Chronic Patellofemoral Pain Syndrome: A Randomised Controlled Trial Based on the International Classification of Functioning, Disability and Health

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Electronic Appendices

Abbreviations

1SD	one standard deviation
®	Registered Trademark
°/C	Degrees Celsius (temperature)
95% CI	95% Confidence intervals
BMI	Body Mass Index
CI	Confidence intervals
cms	centimetres (distance)
CR	Correct Rejection
CU	Computer Units
Deg	Degrees (angles)
Diff	Difference
E	Excitation
EMG	Electromyography
ES	Effect Size
Exc	Excursion
FA	False Affirmative
FIE	Functional Interference Estimate questionnaire
Fig	Figure
GM	Geometric Mean
GSD	Geometric Standard Deviation
I	Inhibition
Lat	Lateral
Lbs	Pounds (mass)
ICC	Intra class correlation coefficient
ICF	International Classification of Functioning, Disability and Health
IQR	Inter Quartile Range
Kgs	Kilograms (mass)
LCL	Lateral collateral ligament
Ltd	Limited company
Max	maximum
MCL	medial collateral ligament
Med	medial
Min	minimum
MFIQ	Modified Functional Index Questionnaire
mms	millimetres (distance)
MRI	Magnetic Resonance Imaging
MVC	Maximum Voluntary Contraction
n	Number of subjects
N.m/Kg	Newton metres per Kilogram (force per body weight)
NHS	National Health Service
NRS-101	Numerical Rating Scale
P(A)	Discriminability
PIP	pain intensity present
PIW	pain intensity previous week
PIM	pain intensity previous month
PUP	pain ‘unpleasantness’ present
PUW	pain ‘unpleasantness’ previous week
PUM	pain ‘unpleasantness’ previous month
PFPS	Patellofemoral pain syndrome
Post	After or following intervention
Pre	Before or prior to intervention
PTA	Patella Tilt Angle
p-value	Probability value
Q-angle	Quadriceps angle
QOL	Quality of life
QST	Quantitative sensory testing
r	Correlation coefficient
ROM	range of motion
ROC	Receiver Operating Characteristics
Secs	seconds

Abbreviations Continued

SD	Standard deviation
SDT	Signal Detection Theory
SF-36	Short Form 36 questionnaire
Temp	Temperature
™	Trademark
UK	United Kingdom
US	United States
USA	United States of America
vs.	Compared with
VAS	Visual Analogue Scale
VL	Vastus lateralis
VM	Vastus medialis
VML	Vastus medialis longus
VMO	Vastus medialis oblique
WHO	World Health Organisation

CONTENTS

ELECTRONIC APPENDIX 1

1.1 SYSTEMATIC REVIEW OF STUDIES IN CHAPTER 3

STUDY	PARTICIPANTS	INTERVENTIONS	OUTCOMES	NOTES	QUALITY RATING (SIGN, 1999)
Abrahams et al (2003)	78 patients 39 female 39 male Mean age= 29 Age range = 16-40 Pain duration= > 8/12 Unilateral and bilateral knee pain? **Source of referral:** Orthopaedic clinics **Incl:** History of patellofemoral joint pain between 8 and 18 months Pain in the retropatellar area/anterior knee pain A positive direct patellofemoral grind test Mal-alignment of the patella as diagnosed via radiographs Age 16-40 years No previous surgery to the knee No history of rheumatic, neurological or intra-articular pathology and signed consent **Excl:** Pregnancy Previous trauma or surgery Previous history of subluxation/dislocation Intra-articular pathology of the knee Below the age of 16 or over the age of 40 years	Quadriceps exercises: 1) Mini squat neutral (n=26) 2) Mini squat with tibial adduction and medial rotation (n=26) 3) Control no treatment (n=26) Home exercises 3x daily for 6 weeks	EMG peak torque MFIQ 'Pain' assessment stated in abstract but not in text. **Assessments at:** 3 and 6 weeks **Results:** Improvement in EMG activity in groups 1 and 2. No significant change in MFIQ in any of the groups	Poor methodological details No details on sample or randomisation procedure **Drop outs:** ? 0 not stated **Power:** not stated	**1^-**
Antich et al (1986)	64 patients ? female ? male Mean age= ?	Quadriceps exercise and 1) Phonophoresis (n=9) 2) Iontophoresis (n=21)	Cybex isometric quadriceps and hamstrings torque at 45^0 flexion	Poor methodological details	**1^-**

	Age range = ? Pain duration= ? Unilateral and bilateral knee? **Source of referral:** Not stated **Incl:** Pain with stair climbing A cracking or grating sensation with active knee motion Pain following prolonged sitting with knees flexed Palpable tenderness of the patella and surrounding structures Pain with quadriceps contraction with compression o f the patella Quadriceps atrophy **Excl:** Unable to attend therapy on a regular basis	3) Ultrasound /ice massage (n=13) 4) Ice (n=16) 4 treatments over 7-8 day period	Subject subjective percentage improvement response **Assessments at:** 7-8 days **Results:** Ultrasound and ice group demonstrated the greatest subjective improvement	No details on sample or randomisation procedure No statistical tests **Drop outs:** 13 **Power:** not stated	
Akarcali et al (2002)	22 patients 16 female 6 male Mean age= 42 Age range = Pain duration= > 2/12 Unilateral and bilateral knee **Source of referral:** Orthopaedic surgeons 22 Healthy subjects 15 female 7 male Mean age = 36 Age range = **Incl:** Onset of pain > 2/12 Age =15-45 Negative findings in clinical examination of knee ligaments, bursae, menisci, synovial plicae,	1) Exercise 2) Exercise and high voltage electrical stimulation Exercise = isometric and eccentric quadriceps ex's	Pain VAS Pain VAS during squatting and step test Lovett's manual muscle strength tests **Assessments at:** 3/52, 6/12 **Results:** Both groups demonstrated improvement in pain reduction and improvement in strength. No additional benefit provided by high voltage muscle stimulation	No details on randomization procedure **Drop outs:** 2 **Power:** Not stated	**1++**

	hamstrings, quadriceps and patella tendons No history or clinical evidence of patellofemoral dislocation subluxation or severe osteoarthritis X-rays putting in evidence lateral displacement of the patella				
Callaghan et al (2001)	16 patients 12 female 4 male Mean age= 30 Age range = Pain duration= > 6/12 Unilateral and bilateral knee? **Source of referral:** Orthopaedic clinics **Incl:** Atraumatic peripatellar pain for greater than 6/12 duration not longer than 3 years Patellofemoral pain provoked by one of combination: prolonged sitting, Deep squatting, kneeling, ascending/descending stairs **Excl:** Epilepsy Cancer Cardiac pacemaker Suspected heart problem Recent surgery (not incl arthroscopy) Abnormal foot and ankle pronation Lumbar spine or hip pain Leg length discrepancy Knee ligament injury Quads tendon injury Meniscal pathology Hoffa's syndrome Medial plica syndrome Femoral ante version Tibial torsion	1) Sequential mixed frequency VM electrical stimulation (n=17) 2) Simultaneous mixed frequency VM electrical stimulation (n=17)	Closed chain isokinetic assessment Surface EMG Quadriceps cross section using ultrasound scanning Kujula patellofemoral pain score VAS Step up test Step down test Squat flexion test **Assessments at:** 6/52, 7/52, 8/52 **Results:** Both groups showed improvement in all outcomes measures except knee flexion angle before pain and fatigue rates. No significant differences between groups	Computer randomization No intention to treat analysis **Drop outs:** 2 **Power:** Not stated – pilot study	**1**[++]

Callaghan and Oldham (2004)	74 patients 43 female 31 male Mean age= 35 Age range = Pain duration= > 6/12 not > 10 years Unilateral and bilateral knee? **Source of referral:** Orthopaedic and rheumatology clinics **Incl:** Atraumatic peripatellar pain for greater than 6/12 duration not longer than 3 years Patellofemoral pain provoked by one of combination: prolonged sitting, Deep squatting, kneeling, ascending/descending stairs **Excl:** Epilepsy Cancer Cardiac pacemaker Suspected heart problem Recent surgery (not incl arthroscopy) Abnormal foot and ankle pronation	1) Bilateral asymmetric biphasic pulse (max amplitude 90mA, duty cycle 10:50, delivering 90 impulses/min, pulse duration 200µs) Frequency components 83, 50 2.5 and 2Hz with a doubles of pulses (125Hz) at the beginning of each pulse train. 2) Asymmetric biphasic rectangular waveform (max amplitude 100mA, duty cycle 10:50, delivery 350 impulses/min, pulse duration 300µs). Fixed frequency 35Hz.	Closed chain isokinetic assessment Surface EMG Quadriceps cross section using ultrasound scanning Kujula patellofemoral pain score VAS Step up test Step down test Squat flexion test **Assessments at:** 6/52 **Results:** Both groups showed improvement in muscle strength, function and reduction in pain. No significant differences between groups	Computer randomization No intention to treat analysis **Drop outs:** 5 **Power:** 85% with alpha of 0.05	**1[++]**
Can et al (2003)	30 patients Females=22 Males = 8 Mean age= 32 Age range=15-56 Pain duration=3/12 Unilateral and bilateral knee pains Source of referral: Not stated **Incl:** Pain underneath or adjacent to patella aggravated by going	Groups I (n=16) TENS Group II (n=14) Diadynamic current Both groups Open closed kinetic chain rehabilitation Stretching Patella mobilisation	Pain VAS Lysholm's Knee Scoring Scale Number of squats in 30 seconds 4 level activity test Assessments at: 6/52 and 12/52 Results Both groups significant reduction in pain and improvement in	Randomisation procedure not stated **Drop outs:** 0 **Power:** not stated	**1[++]**

	up/downstairs Prolonged periods of sitting with knees flexed Tenderness of the peripatellar area and lateral retinaculum Persistence of retropatellar pain>3/12 Unsuccessful physical therapy and rehabilitation program carried out for 6/12 before inclusion Unsuccessful usage of anti-inflammatory **Excl:** Q-angle > 20^0 Sulcus angle > 150^0 Patellar index > 1.20 Increased femoral neck anteversion No foot or subtalar joint hyperpronation No leg length disparities greater than 0.25cm No patient had been using patellar support braces Meniscal or ligament tears Fractures or neuromuscular injuries Osteochondrol injuries Haemarthrosis Systematic inflammatory diseases Severe degenerative joint disease Surgical treatment		function. No difference between groups		
Clark et al (2000)	81 patients 36 female 45 male Mean age= 28 Age range=16-40 Pain duration=>3/12 Unilateral and bilateral painful knees. **Source of referral:** Orthopaedic, rheumatology consultants and GPs **Incl:**	1) General lower limb exercises:- Lower limb strengthening ex's Open chain Closed chain Proprioception Stretching (Hams, Quads, gastrocnemius) Patella taping Education (n=10) 2) Taping and education (n=20)	Satisfaction score Visual analogue pain scales for stairs and gait WOMAC Function Score HAD score **Assessments at** 3/12 and 12/12 **Results:** All groups showed	No additional benefit from standardize taping Therapist contact and advice results in significant improvement in 60% of patients No control No data regarding	**1^{++}**

	Ant knee pain>3/12 **Excl:** True locking Patella dislocation Arthritis Knee radiograph abnormalities Ligamentous laxity Malignancy Infection Previous knee physiotherapy	3) Exercises and education (n=19) 4) Education (n=22)	significant improvement at 3/12 and 12/12. Significantly lower pain scores in ex versus non ex groups. Significant improvement in anxiety and depression scores at 3/12 and in anxiety 12/12. No difference between groups.	compliance with home ex's No evidence of training in McConnell regime Includes 'intention to treat analysis' Computer randomisation **Drop outs:** 3/12 = 11 12/12 = 31 **Power:** 90% power of detecting a 40% difference in disability rate	
Colón et al (1988)	29 patients 10 female 19 male Mean age= Age range=15-24 Pain duration= Unilateral and bilateral painful knees. **Source of referral:** ? recreational athletes **Incl:** Two of the following: Persistent aching knees while at rest Pain in the knees after sitting with knee flexed greater than 10 to 20 minutes Occurrence or exaggeration of pain on walking or down stairs Crepitation in the knees on movement Snapping sensations in the knees upon extension or flexion Locking of the knees Inability to squat Crepitation and positive patellar	Group 1) Conservative isometric quadriceps program (n=13) Group 2) 250 – 700-1000 bounces twice daily on a pogo stick (n=16)	Numerical pain rating scale Muscle strength and endurance using a Cybex isokinetic dynamometer **Assessments at:** 8 weeks **Results:** Both groups showed improvement in pain reduction and improved symptoms e.g. locking and stiffness Muscular strength and power similar for both groups. Greater gains in muscle power in the pogo stick group	Randomisation procedures not stated No intention to treat analysis **Drop outs:** 4 **Power:** Not stated	

	compression sign **Excl:** **?**				
Crossley et al (2002)	71 patients 46 female 25 male Mean age= 29 Age range= 12-40 Pain duration= >1/12 Unilateral and bilateral painful knees. **Source of referral:** Health professionals, advertisements and media **Incl:** Anterior or retropatellar pain from at least two of the following: Prolonged sitting, stair climbing, squatting, running, kneeling, hopping/jumping Insidious onset of symptoms, no trauma Pain on palpation of patella facets, on step down from a 25cm step or during a double-legged squat **Excl:** Meniscal or intraarticular pathology, ligament laxity or tenderness, patella tendon, iliotibial band or pes anserinus tendinopathy, patellar apprehension sign; Osgood-Schlatter's or Sinding-Larsen Johansson syndromes, joint effusion, hip or lumbar referred pain or history of patellar dislocation	1) McConnell regime (n=36) 2) Placebo – sham ultrasound, sham taping (n=35)	VAS FIQ Anterior knee pain score Patient perceived response to treatment SF-36 Functional measure – number of step up, step downs, squats **Assessments at:** 6/52 and 3/12 **Results:-** Significantly greater improvement in McConnell group compared with placebo with respect to VAS and Anterior knee pain score, number of steps up, step-downs and squats. No change in FIQ, SF-36 or patients activity perception in previous week between McConnell and placebo groups	Randomisation by computer and use of opaque envelopes Includes intention to treat analysis **Drop outs:** 6/52 = 4 3/12 = 8 **Power:** 85% in detecting 1.5cm difference in VAS	**1^{++}**
Denton et al (2005)	34 patients 34 female	1) Closed chain exercises	Verbal pain rating score	Randomisation by flip of coin	**1^{-}**

	0 Male Mean age = 32.5 Age range = ? Pain duration = > 1 month Unilateral pain **Source of referral:** Orthopaedic Physicians **Incl:** Diagnosis of PFPS by an orthopaedic physician Pain at least 4 on a 0 to 10 verbal pain scale during at least two activities stairs, squatting, prolonged sitting, waling or running **Excl:** Knee trauma Meniscal lesions Ligamentous pathology	2) Closed chain exercises and Protonics brace	Kujala PFPS score Clinical measures: Hip extension, internal and external rotation ITB flexibility **Assessments at:** 6/52 or at resolution of symptoms **Results:** Significant reduction in pain and increased function in both groups. No difference between groups.	**Drop outs:** ? 0 **Power:** not stated	
Dursun et al (2001**)**	60 patients 12 female 48 male Mean age= 37 Age range=17-50 Pain duration=>10/12 Unilateral pain **Source of referral:** Orthopaedic clinics **Incl:** 5 of the following: a +ve apprehension test patella joint crepitus retropatellar aching on stairs or sitting with knees flexed at 90^0 > 15 minutes Quads atrophy of 0.635cm compared with uninvolved thigh Knee giving way on step down within past 12 months Patella facet sensitivity Retropatellar pain > 10days, but < 48 months **Excl:** No evidence of	1) Exercise with EMG biofeedback 30 min training sessions x3 weekly for 4 weeks (n=30) 2) Exercise without biofeedback 30 min training sessions x3 weekly for 4 weeks (n=30)	Visual analogue pain scale Functional Index Questionnaire Maximum and mean contraction values in (µv) of the vastus medialis and vastus lateralis recorded using biofeedback machine **Assessment at** 1/12, 2/12 and 3/12 **Results** Both groups showed significant improvement in VAS and FIQ. No difference between groups	Randomisation procedure not stated **Drop outs:** **Power:** Not stated	**1**$^{++}$

	intrarticular or extraarticular pathologies by physical examination and radiographic evaluation Normal range of motion values for the knee No history of knee trauma, intrarticular injection therapy or surgery No use of non steroidal anti-inflammatory treatment within past 15 days				
Eburne et al (1996)	75 patients Age= 10-35 Male Female Mean age= Pain duration= Unilateral and bilateral knees? **Source of referral:** GP and consultants **Incl:** ? **Excl:** Previous back and lower extremity surgery Poor general health Pathological or infectious disease Abnormal ligamentous or meniscal tests	1) Isometric quads ex's (n=) 2) McConnell regime (n=)	Visual analogue pain scale during stairs and squatting McConnell 'critical test' **Assessments at** 'until pain free' or 3/12 Results: Significantly fewer patients in McConnell group exhibit pain during critical test 50% of patients with a positive Clarke's test ceased to do so after isometric training compared with 75% in McConnell group	22 patients lost to follow-up 4 patients withdrawn Inclusion criteria not explicitly outlined 'Isometric' group included stepping, walking and running No use of validated tests No data regarding compliance with home ex's No intention to treat analysis No evidence of training in McConnell regime **Drop outs:** 26 **Power:** not stated	**1^{-}**
Eng et al (1993)	20 patients Females=20 Mean age=15 Age range=13-17 Pain duration=>6/52 Bilateral knee pains	1) Exercise group Static isometric quads and SLR 'Placebo' bilateral flat insoles (n=10)	Visual analogue pain scale during walking, running, sitting> 1 hour ascending/descending stairs	Attempted to monitor compliance with exercise program by means of random	**1^{++}**

	Incl: Bilateral retropatellar pain Insidious onset Retropatellar tenderness Pain on patella compression Calcaneal valgus or forefoot varus>6^0 **Source of referral:** Not stated **Excl:** Patella trauma Previous physical therapy or orthotic treatment Leg length discrepancies > 1 cm Pathological or neurological conditions Patients on medication	2) Exercise groups and bilateral corrective soft orthotics with rear and/or hindfoot posting (n=10) Treatment: 8/52	**Assessment at** 2/52, 4/52, 6/52 and 8/52 **Results**: Significantly greater reduction in visual analogue scores for orthotic group for all variables	telephone calls Randomisation procedure not stated **Drop outs:** not stated **Power:** Not stated	
Finestone et al (1993)	395 patients Male=395 Israel Infantry Recruits Mean age=? Age range=? Pain duration=<14/52 Unilateral knee pain=? **Source of referral:** Military personnel **Incl:** Tenderness around patella Swelling Effusion Subjective and objective findings of patellofemoral syndrome **Excl:** Trauma to knee	1) Simple elastic knee sleeve (n=22) 2) Elastic knee sleeve with a silicone patellar ring (n=22) 3) Control group No treatment (n=40)	Clinical examination Pain rating score **Assessment at** 14/52 **Results:** No significant difference between groups	Randomisation process not stated **Drop outs:** not stated **Power:** not stated	**1⁻**
Gaffney et al (1992)	72 patients Males=47 Females=25 Mean age=34 Age range=11-65 Pain duration=>6/12	1) Concentric quadriceps exercises (n=32) 2) McConnell based eccentric exercises	Subjective improvement score VAS Subjective	Randomisation procedure not stated No 'intention to treat'	**1⁺**

	Unilateral and bilateral painful knees **Source of referral:** Newspaper advertisement **Incl:** Based on exclusion criteria Retropatellar pain present on one of the following activities: ascending or descending stairs, squatting, or rising from a squat, or sitting with knees bent at 90^0 **Excl:** No ligamentous damage No meniscal involvement Patellar tendonitis Infrpatellar fat pad tenderness Bursitis Tibial tuberosity pain Knee pain referred from back or hip Rheumatoid arthritis Gout	(n=28)	Improvement in knee function score **Assessments at:** 6/52 **Results:** Significant improvement in pain scores for both groups however no significant difference between groups. Subjective improvement documented in 89.3% eccentric group and in 75% of the concentric group. Improvement in function occurred in 64.3% of the eccentric and 46.7% in the concentric groups	analysis **Drop outs:** 12 **Power:** not stated	
Harrison et al (1999)	113 patients Males=45 Females=68 Mean age=22 Age range=12-35 Pain duration= Unilateral and bilateral painful knees **Source of referral:** Orthopaedic and GPs **Incl:** Patellar pain with manual compression of the patella against the femur Patellar tenderness with palpation of the posteromedial and posterolateral borders of the patella Patellar pain during resisted dynamic knee extension	1) Home exercise programme Open chain ex's Closed chain ex's (n=42) Programme of ex's in a physical therapy clinic (n=34) 2) McConnell regime Taping Biofeedback VMO exercises (n=36) 4/52 treatment each group	Activity level score Physical limitation scale Functional Index Questionnaire Visual analogue pain scale worst, least and usual pain during the day (averaged over 3 days) Patellofemoral Scale Knee pain threshold during a step test **Assessments at** 1/12, 3/12, 6/12 and 12/12 **Results:** Significantly greater functional	54 patients lost to follow-up Random allocation by numbered table method 'Intention to treat analysis' carried out. **Drop outs:** 1/12 = 19 3/12 = 12 6/12 = 13 12/12 = 46 **Power:** 0.8 power using a large effect size	**1**$^{++}$

	Patellar pain with manual compression of the patella against the femur during isometric knee extension contraction **Excl:** Other musculoskeletal conditions of the knee Previous or pending knee surgery Gross knee effusion Knee pain or referred from hip or spine Upper/lower motor neuron lesion Previous steroid injection to the knee Abnormal radiographic finding of the knee		improvement at 1/12 in group 3 compared to group 2 Significant reduction in pain between group 3 and group 2 at one month. Significant improvement in all groups at 12/12 no difference between groups		
Jensen et al (1999)	75 patients Males=31 Females=44 Mean age=31 Age range=18-45 Bilateral and unilateral knee pain Pain duration=? **Source of referral:** Advertisement and orthopaedic and physiotherapy practices **Incl:** Pain on one or both knees during activity, exercise, stairs, during rest, squatting or prolonged sitting Able to participate in activities of daily living No other specific knee disorders **Excl:** Acupuncture in previous 12/12 Steroid treatment in previous 3/12	1) Acupuncture (n=36) 2) Control no treatment (n=34)	Knee Rating System Stairs-hopple test Circumferential quadriceps measurement Visual analogue pain scale – immediately after testing and same evening **Assessments at** 6/52, 5/12 and 12/12 **Results:** Significant improvement at 12/12 in Cincinnati Knee Rating System in acupuncture group.	5 patients lost to follow up No intention to treat analysis Method of randomisation not stated **Drop outs:** 5 **Power:** Not stated	**1**$^{+}$

Kowall et al (1996)	25 patients Males=8 Females=17 Mean age=29 Age range=14-40 Unilateral and bilateral knee pain Pain duration>1/12 **Source of referral:** Not stated **Incl:** Unilateral or bilateral patellofemoral pain>1/12 No history or clinical evidence of patellofemoral dislocation, synovial plicae, or meniscal lesion or ligamentous injury No history of prior knee trauma or knee surgery Patient aged between 14-40 years Ability to complete a 4-week home exercise programme **Excl:** Not specifically stated see incl criteria	1) Physical therapy and home exercise programme Isotonic Isometric Isokinetic ex's Stretching (n=12) 2) Physical therapy and home exercise programme Isotonic Isometric Isokinetic ex's Stretching Including patellar taping (n=13) Treatment 4/52	Visual analogue pain scales:- Severity of pain Effect of pain on athletic activities Effect of pain on adult daily living activities Isokinetic muscle testing Integrated surface EMG Assessments at 4/52 **Results:** Both groups experienced a statistically significant reduction on symptoms, but no difference between groups noted. Both groups demonstrated significant improvement in isokinetic muscle strength and activity, but no difference between groups. No beneficial effect of adding patellar taping to a standard physiotherapy program	Pre-randomisation technique actual process not stated Biofeedback machine used to monitor compliance with exercise **Drop outs:** not stated **Power:** not stated	**1^{++}**
Loudon et al (2004)	29 patients Males=7 Females=22 Mean age=27.2 Age range=21-35 Unilateral knee pain Pain duration>2/12 **Source of referral:** Not stated **Incl:** Unilateral pain>2/12	1) Control group (n=11) 2) Supervised physical therapy exercise program (n=9) 3) Home exercise group N=9)	Visual analogue pain scales:- Patellofemoral pain scale Anteromedial lunge Step down dips Leg press Balance and reach Bilateral squat	Randomised by referral **Drop outs:** 7 **Power:** not stated	

	Pain around or under the patella 3 of the 4 following: pain in the patellofemoral joint during or after activity pain in the patellofemoral joint during or after sitting pain in the patellofemoral joint during stair climbing pain in the patellofemoral joint during squatting **Excl:** History of patella trauma, subluxation, dislocation, Confirmed ligamentous, meniscal, or fat pad damage Evidence of tendonitis, bursitis or chronic effusion (>1 month) Surgery in the lower extremity Osteochondrol or chondrol fractures upper or lower motor neuron lesion radiographic evidence of osteoarthritis in the patellofemoral or tibiofemoral joint Difficulty understanding English Open physeal growth plates Use of intra-articular injection of glycoaminoglycans polysulphate		Assessments at 8/52 **Results:** Home exercise and physical therapy groups experienced greater pain relief and improvement than controls. There was however no difference between the home and clinic based groups.		
Lun et al (2005)	152 patients Males = 53 Females = 76 Mean age=35 Age range= 18 - 60 Bilateral knee pain Pain duration <3/52 **Source of referral:** General population **Incl:** Atraumatic unilateral and/or after activity Inactivity patellofemoral pain	Group 1: Home exercise Group 2: Patellar bracing Group 3: Home exercise program and patellar bracing Group 4: Home exercise program and knee sleeve	Visual analogue pain scales during sport, after sport and following sitting for 30 minutes Modified knee function scale **Assessments at:**12/52 **Results:** All groups demonstrated reduced pain and	Block Randomisation by computer **Drop outs:** 23 **Power:** not stated	**1**$^{++}$

	and / or stiffness, especially with sitting with knee in a flexed position No prior history of any significant knee injury No previous treatment with physiotherapy No or minimal articular or soft tissue periarticular effusion or bursitis No significant joint line tenderness No intrarticular ligamentous instability Peripatellar tenderness and mild inferior patella pole tenderness **Excl:** Patient with any bony abnormalities including bony fracture, osteochondritis dissecans Bipartite patella osteoarthritis		improved function No difference in the 95% confidence intervals between groups		
Miller et al (1997)	59 patients – military personnel Males=48 Females=11 Mean age=? Age range=? Duration of pain=3 weeks Unilateral pain only ? **Source of referral:** Military personnel Incl: Ant knee pain within first 3 weeks of cadet training Excl: Lack of desire to remain in base training at the time of their consent. Any prior knee surgery History of dislocation Other known knee disorders Abnormalities on	Group 1: No treatment (n=20) Group 2: Palumbo knee brace (n=18) Group 3: Cho-pat knee brace (n=13) Treatment 6-8/52	Visual analogue pain scales **Assessments at:** 6-8/52 **Results:** no significance between groups	8 patients loss to follow-up No intention to treat analysis **Drop outs:** 8 **Power:** not stated	**1^-**

	physical examination (Q-angle > 150 in males and > 200 in females, marked apprehension or instability on examination, excessive ligamentous laxity or genu varum/valgum), and Abnormal radiographs (increased patellar tilt, bipartite patella, tendon ossicles, and degenerative changes of the patella)				
Näslund et al (2002)	58 patients Males=24 Females=34 Mean age=34 Age range=20-50 years Pain duration > 6months Unilateral pain **Source of referral:** GP and orthopaedic consultants **Incl:** Age 20-50 Pain > 6/12 in two of the following: stair climbing, squatting, prolonged sitting **Excl:** Ligament or meniscal tears, synovial plicae, tendinopathies, apophysitis, osteoarthritis, osteochondritis dessicans, neuroma, fat pad impingement, radiographic or scintigraphic abnormalities	1) Electroacupuncture (n=30) 2) Minimal superficial acupuncture (n=27)	One leg vertical jump, measured on a Ergo Power machine Tegner's activity score VAS Skin temperature **Assessments at:** 8/52, 3/12 and 6/12 **Results:** No change in ability to jump on one leg, the functional score nor skin temperature between groups. Significant reduction in pain in both groups. No difference between groups.	Randomisation procedure not stated No correlation between decrease in pain and functional outcome measure **Drop outs:** 4 **Power:** not stated	1^{++}
Rogvi-Hansen et al (1991)	40 patients Males=16 Females=20 Mean age=33 Age range=17-56 Duration of pain=? Unilateral pain=? **Source of referral:** Not stated	Group 1: GaAs type pulsed laser wave length 904nm, output 17mW at 1000Hz (n=19) Group 2: Sham laser (n=17)	Visual analogue pain scale Disability score assessing mood, gait, sleep, work sport **Assessments at** 5/52 **Results:**	High incidence of trigger points observed in vastus medialis of examined patients **Drop outs:** 4 **Power:** not	1^{++}

	Incl: Diagnosis of chondromalacia with arthroscopy after normal radiographs **Excl:** Other disease or surgery	Treatment 5/52	No significant differences were found between real and sham low level laser	stated	
Rousch et al (2000)	64 patients Males=36 Females=38 Mean age=26 Age range=? Unilateral pain only Pain duration=? **Source of referral:** Advertisements and GPs **Incl:** Patellar tendonitis Quadriceps tendonitis Patellofemoral syndrome Chondromalacia patella Idiopathic knee pain Osgood-schlatters disease Plicae syndrome **Excl:** Previous treatment for anterior knee pain Internal derangement or pathological damage of the knee Rheumatological disorders Knee infection Abnormal X-rays of the knee	1) Home ex's Stretching (hams, quads, ITB) (n=20) 2) Physical therapy programme x3 weekly 6/52 (McConnell regime) (n=21) 3) Home ex's Modified method of SLR the 'Muncie' method (n=23)	Isokinetic and isometric quads strength testing Journal using 10 point scale used to collect info on: Activity Pain at rest Pain during activity Impairment Compliance **Assessment at** 2/52, 6/52, 12/52 **Results**: . 'Muncie' method resulted in significant improvement in subjective pain and functional impairment rating compared with the other groups. Pain free isometric contractions and maximum voluntary contractions significantly greater in 'Muncie' group compared with other two groups. No change in pain with physical therapy group. Home exercises are more cost effective than formal physical therapy	13 patients lost to follow-up Randomisation procedure not stated No objective functional testing carried out. Compliance with exercises monitored with weekly journal Use of ice applied 3-5 daily – not controlled No intention to treat analysis carried out **Drop outs:** 13 **Power:** not stated.	**1⁺**
Rowland and Brantingham (1999)	30 patients Males=? Females=? Mean age=? Age range=? Duration of symptoms=?	1) Patella passive mobilisation (n=15) 2) Placebo Detuned ultrasound (n=15)	Patients perceived disability McGill Pain Questionnaire Patients perception of	Randomisation method not stated No blinding of assessors	**1⁺**

	Bilateral knee pain=? **Source of referral:** Advertisements **Incl:** Localisation peri or retropatellar pain originating from the peripatella or patellofemoral joint Pain reproducible on 2 of the following Squatting Stair climbing Kneeling Prolonged sitting Isometric quadriceps femoris muscle contraction **Excl:** Traumatic patella dislocation Bursitis, patella tendonitis, fat pad syndrome, systemic arthritides Neurological involvement that influenced gait Undergone knee surgery over past 2 years No medication	Treatment: 4/52	pain intensity using the NRS-101 pain questionnaire Patient-Specific Functional Scale Algometer pressure-pain threshold Algometer pressure-pain tolerance **Assessment at** 4/52 **Results:** No intergroup difference between subjective data. Algometer findings revealed significant improvements in patella mobilisation group	**Drop outs:** not stated **Power:** not stated	
Schneider et al (2001)	40 patients Females=28 Males=12 Mean age=24 Age range=18-36 Pain duration >6/12 Unilateral pain **Source of referral:** amateur athletes **Incl:** Persistent unilateral pain retropatellar pain for more than 6 months Unsuccessful conservative therapy Use of anti-inflammatory and analgesic agents	1) PNF quadriceps exercises (n=20) 2) Protonic brace (n=20)	Isokinetic muscle assessment Surface EMG Bassette and Hunter Score VAS Clinical examination tests Radiographic patellofemoral congruence angle **Assessments at:** 4/52 and 8/52 **Results:**	Randomisation method not stated **Drop outs:** Not stated **Power:** not stated	**1^{++}**

	Electrotherapy physiotherapeutic exercise without PNF Aged between 16 and 40 years **Excl:** Known meniscopathy and damage to cruciate ligaments Chronic inflammatory processed Femoropatellar arthrosis		Significant reduction in PFC angle in Protonic group Increase in quadriceps strength in both groups but no difference between groups Significant improvement in VM/VL ratio to the benefit of VM in Protonic group Improvement in pain reduction in both groups. Significantly greater pain reduction in Protonic group		
Suter et al (2000)	28 patients Females=25 Males=3 Bilateral and unilateral painful knees Duration of pain=? Mean age=34 Age range=? **Source of referral:** Orthopaedic surgeons **Incl:** Anterior knee pain **Excl:**	1) Treatment Lower limb Functional Assessment + sacroiliac manipulation (n=14) 2) Control Lower Limb Functional Assessment (n=14)	Isometric 'Cybex' dynamometer testing and Interpolated twitch technique Electromyographic activity **Assessment at** Before and after x1 'treatment' **Results:** Significant decrease in muscle inhibition observed in the involved legs of the treatment group. No significant change in the knee extensor moment or muscle activation in each group	Randomisation method not stated ? validity of sacroiliac assessment Pts with previous knee surgery (n=5) permitted in study **Drop outs:** 0 **Power:** not stated	**1++**
Taylor and Brantingham (2003)	15 patients Males=8 Females=4 Mean age=30.2 Age range=? 16-60 Duration of symptoms=>1/12 Bilateral knee pain=? **Source of referral:** Advertisements Sports events Private practice University campus	1) Patella passive mobilisation (n=15) 2) Patella passive mobilisation + active general quadriceps regime Treatment: 5/52	McGill Pain Questionnaire Patients perception of pain intensity using the NRS-101 pain questionnaire Patient-Specific Functional Scale Algometer pressure-pain threshold	Randomisation sealed envelopes odd/even numbers Blinding of assessors **Drop outs: 3** **Power:** not stated	**1-**

	Incl: Localisation peri or retropatellar pain originating from the peripatella or patellofemoral joint Pain reproducible on 2 of the following Squatting Stair climbing Kneeling Prolonged sitting Isometric quadriceps femoris muscle contraction **Excl:** Previous surgery in the lower limbs History of traumatic patellar dislocation Any known damage to articular cartilage Any major muscle, ligament or tendon strain Sprain or rupture in the lower extremity Any neurological involvement that influenced their gait		Algometer pressure-pain tolerance **Assessment at** 5/52 **Results:** Both groups demonstrated reduction in pain and improvement in function with a significantly greater improvement in the exercise group		
Thomeé et al (1997)	40 patients Females=40 Mean age=20 Age range=15-28 Unilateral knee pain Pain duration>6/12 **Source of referral:** Orthopaedic surgeons **Incl:** Patellofemoral pain >6/12 3 of the 4 following: Pain in the patellofemoral joint during or after activity Pain from the patellofemoral joint during or after sitting Pain from the patellofemoral joint during stair climbing Pain from the	1) Home ex's using isometric contractions (n=20) 2) Home ex's using eccentric contractions (n=20) Treatment 12/52	Patellofemoral pain questionnaire Visual analogue pain scale during 12 activities Isometric/isokinetic strength measurements EMG activity Vertical jump test Overall knee function rating scale **Assessments at**:3/12 and 12/12 **Results:** A significant reduction in pain and	Randomisation method using odd/even numbers Intention to treat analysis carried out. Compliance recorded by pain diaries **Drop outs:** 0 **Power:** not stated	**1**$^{++}$

	patellofemoral joint squatting **Excl:** History of recurrent patellar subluxation or dislocation History of intermittent or persistent knee joint swelling during the previous year Other injuries to the knee joint such as tears of the menisci, ligaments or joint capsule Overuse symptoms of tendonitis, bursitis, medial plicae or synovitis Any major muscle or tendon rupture in the lower extremity Surgery carried out in the lower extremity		improvement in strength, vertical jumping ability and physical activity levels were seen in both groups after treatment.		
Timm et al (1997)	100 patients Males=60 Females=40 Mean age=30 Age range=24-47 Duration of pain 3/12 Unilateral knee pain **Source of referral:** Orthopaedic surgeons **Incl:** 4 criteria: Pain during ascending/descending stairs Pain when rising from sitting Pain during squatting Pain with prolonged sitting **Excl:** One or more:- Pain with palpation of quads tendon or patellar ligament Snapping sensation or palpable pain in the	1) Protonics knee brace (n=50) 2) Control no treatment (n=50) Treatment 4/52	Radiographs measuring patellofemoral congruence angle Kujala patellofemoral pain score Visual analogue pain score during the four inclusion criteria **Assessment at** 4/52 **Results:** ANOVA test. No difference between pre an post test for the control group, but significant change in patellofemoral congruence angle, Kujala score and visual analogue score in treatment group	Randomisation by odd/even numbers No measure of compliance with brace **Drop outs:** 0 **Power:** not stated	**1**$^{++}$

	area of a medial synovial plica Pain during palpation of the knee joint line or during McMurray's test for meniscus injury, joint effusion when the midpatellar girth was 105% or more than the non involved knee History of patellar dislocation or subluxation History of knee surgery Confirmed or possible pregnancy				
Tunay et al (2003)	80 patients Males= ? Females= ? Mean age= 32 Age range= ? Unilateral pain only Pain duration>1/12 **Source of referral:** Orthopaedic surgeons **Incl:** PFPS diagnosed by clinical and radiological examination **Excl:** History of patella dislocation, meniscal or ligamentous injury, synovial plicae, knee surgery ortrauma	1) Ice, electrical nerve stimulation, medial patellar glide and 'controlled' exercise (n=20) 2) Ice, electrical stimulation, patella taping and 'controlled' exercises (n=20) 3) Ice, patella taping, home exercises (n=20) 4) Ice and home exercise (n=20)	Pain intensity VAS <u>MRI</u> Congruence angle Sulcus angle Patella tilt Q-angle Cincinnati Knee activity rating scale Hamstring and iliotibial flexibility Thigh circumference measurement Leg length discrepancy **Assessments at:** 3/52 **Results:** All groups showed significant t improvement between pre and post treatment results, except sulcus angle. Groups 1 and 2 were significantly better than groups 3 and 4	Randomisation procedures not stated Groups not comparable and hence conclusions drawn ill founded **Drop outs:** not stated **Power:** not stated	**1^-**
Whittingham et al (2004)	30 patients Males=24 Females=6 Mean age=18.7 Age range=17-25 Pain duration= ? acute	1) Patella taping and a standardised exercise program 2) Placebo taping and a standardised exercise	Visual analogue pain scale during previous 24 hours, during a step down activity FIQ	Block Randomisation by sealed envelopes	**1^{++}**

	PFPS ? unilateral pain **Source of referral:** Military personnel **Incl:** 2 of the 4 following:- pain on ascending and/or descending stairs squatting sitting for extended periods of time associated with an increase in physical activity **Excl:** History of patella subluxation or dislocation Anterior or posterior cruciate ligament in sufficiency Previous knee surgery or meniscal damage Any other underlying musculoskeletal problem that would have prevented the subject from performing the exercise regime	program 3) Standardised exercise program only	**Assessments at:** 1/52, 2/52, 3/52 and 4/52 **Results:** Daily patella taping and exercise provided significantly greater improvement in pain and function than with placebo taping and exercise or exercise alone	**Drop outs:** 0 **Power:** 90%	
Witvrouw et al (2000)	60 patients Males=20 Females=40 Mean age=20 Age range=14-33 Bilateral knee pain included, although only most painful assessed Pain duration>6/52 **Source of referral:** Physiotherapy Departments **Incl:** 2 of the following:- Pain on direct compression of the patella against the femoral condyles with the knee in full	1) Open chain knee exercises (n=30) 2) Closed kinetic chain exercises (n=30) Treatment 5/52	Visual analogue pain scale during daily activities and during a jump test Kujala Patellofemoral Score Functional Outcome Tests Unilateral squat test Step test 'Triple' jump test Isokinetic strength tests Muscle length measurements **Assessment at:** 5/52 and 3/12 **Results:**	Randomisation by sealed envelopes **Drop outs:** 0 **Power:** 80%	**1^{++}**

	extension Tenderness on palpation of the posterior surface of the patella Pain on resisted knee extension Pain on isometric quadriceps manual contraction against suprapatellar resistance with the knee in slight flexion **Excl:** Knee problems other than patellofemoral History of knee operation		Both groups experienced a statistically significant decrease in pain and an increase functional performance. No significant difference between groups		
Witvrouw et al (2003)	60 patients Males=20 Females=40 Mean age=20 Age range=14-33 Bilateral knee pain included, although only most painful assessed Pain duration>6/52 **Source of referral:** Physiotherapy Departments **Inlc:** Anterior knee pan>6/52 Exhibit two of the following: Pain on direct compression of patella against femoral condyles with knee in extension Tenderness on palpation of peri-patellar structures Pain on resisted knee extension Pain on isometric quadriceps contraction against suprapatellar resistance with knee in slight flexion Knee problems other	1) Open chain knee exercises (n=30) 2) Closed kinetic chain exercises (n=30) Treatment 5/52	Visual analogue pain scale during daily activities EMG Reflex response timing of vastus medialis and vastus lateralis **Assessments at:** 3/12 **Results:** No alterations in reflex response times in either group. Knee pain decreased significantly in both groups.	Randomisation by sealed envelopes **Drop outs:** 0 **Power:** 80%	**1**$^{++}$

	than anterior knee pain Patients under age 12 years History of knee surgery				
Witvrouw et al (2004)	60 patients Males=20 Females=40 Mean age=20 Age range=14-33 Bilateral knee pain included, although only most painful assessed Pain duration>6/52 **Source of referral:** Physiotherapy Departments **Inlc:** Anterior knee pan>6/52 Exhibit two of the following: Pain on direct compression of patella against femoral condyles with knee in extension Tenderness on palpation of peri-patellar structures Pain on resisted knee extension Pain on isometric quadriceps contraction against suprapatellar resistance with knee in slight flexion Knee problems other than anterior knee pain Patients under age 12 years History of knee surgery	1) Open chain knee exercises (n=30) 2) Closed kinetic chain exercises (n=30) Treatment 5/52	Visual analogue pain scale during daily activities and during a jump test Kujala Patellofemoral Score Functional Outcome Tests Unilateral squat test Step test 'Triple' jump test Isokinetic strength tests Muscle length measurements **Assessment at:** 5/52 and 3/12 **Results:** Both groups experienced a statistically significant decrease in pain and an increase functional performance. No significant difference between groups	Randomisation by sealed envelopes **Drop outs:** 9 **Power:** 80%	**1**$^{++}$

Controlled trials included in review

STUDY	PARTICIPANTS	OUTCOMES	INTERVENTIONS	NOTES	QUALITY
Greenwald et al (1996)	Experiment 1 6 patients Mean age=27 Age range=19-44 6 controls Mean age=29 Age range=25-33 Pain duration = ? **Source of referral:** not stated Experiment 2 15 patients Males=8 Females=7 Mean=22 Age range=14-41 **Incl:** Symptoms of anterior knee pain with no associated ligamentous pathology and with one or more of the following diagnoses:- patellar subluxation, patellar dislocation patellofemoral pain of unknown aetiology. Clinical examination 2 quadrant medial and lateral patella glide and increased patella tilt. History of patella instability and apprehension. **Excl:** Not stated specifically **Incl:** Controls No history of lower limb pain or injury and had normal patellofemoral mechanics on physical examination	Experiment 1 Motion analysis of patients and controls during gait and stair ascent/descent Experiment 2 Patellofemoral patients wore knee brace Treatment 1/12	Experiment 1 Motion analysis Experiment 2 Pain rating scale Instability rating scale **Assessment at** 1/12 **Results**: Significant reduction in pain and perceived instability and in patellofemoral group. Patella brace no effect on knee flexion angle during gait, stair ascent or stair descent for both groups. Significant greater knee extension during stair descent in the patellofemoral group than controls.	**Drop outs:** not stated **Power:** not stated	**2^{++}**

Hazneci et al (2005)	24 healthy control Males = 24 Mean age = 24 24 patients Males = 24 Mean age = 25 Duration of pain= > 1/12 Bilateral knee pain **Source of referral:** ? military personnel **Incl:** Anterior or retropatellar knee pain present during at least two of the following - ascending/ descending stairs, hopping/running, squatting, kneeling, and prolonged sitting, insidious onset of symptoms unrelated to trauma Presence of pain form step down from a 25 cm step or double leg squat Pain on palpation of patellar facet **Excl:** Symptoms present < 1/12 Clinical evident of other knee pathology Undergone previous knee surgery History of patellar subluxation / dislocation Current significant injury affecting other lower limb joints Current use of nonsteroidal inflammatory drugs or corticosteroids Aged 8 30 years	Isokinetic exercise	Passive knee joint position sense on isokinetic dynamometer VAS Isokinetic knee flexion and extension muscle torque **Assessment at:** 6/62 **Results**: Significant improvement in pain, improved torque and position sense in PFPS group	**Drop outs:** not stated **Power:** not stated	**2^+**

McMullen et al (1990)	29 patients Males=16 Females=13 Mean age=28 Duration of pain=4 months Unilateral knee pain only **Source of referral:** Geographical location of therapists and subjects **Incl:** Age 10-40 years A diagnosis of unilateral chondromalacia patella based upon the subject exhibiting at least 5 of the 7 symptoms listed below:- Positive apprehension test Patella crepitus Retropatellar aching on stairs or sitting with knee flexed to 90^0 Quadriceps atrophy of ¼ inch or more when compared to the involved thigh. Giving way of the knee upon stepping down that occurred within 12 months Patella facet sensitivity Retropatella pain < 10 days, but not > 48 months **Excl:** < combined flexion extension range of 135^0 Inability to perform a straight leg raise against gravity Medication within 10 days prior to beginning treatment Pre/infera or pes anserine bursitis, patella tendonitis, iliotibial tract tendonitis or Osgood Schlatter's disease	Group 1: Control no treatment (n=9) Group2: Static progressive resisted exercises (quadriceps setting and straight leg raising) and flexibility exercises 3 sets 10 repetitions (n=11) Group 3: Isokinetic group Cybex isokinetic dynamometer Part 1 (30^0-0^0) 30^0/s, 60^0/s, 90^0/s, 120^0/s 2 sets 15 repetitions Part 2 (90^0-0^0) 180^0/s, 240^0/s, 300^0/s 2 sets 15 repetitions (n=9) Treatment 4/52	Cincinnati Knee Rating System Manual muscle tests Hamstring ROM **Assessments at** 4/52 **Results:** Group 2 and 3 demonstrated significant functional improvements over the control group in walking, stair activity, running, jumping/twisting and overall activity and increased quadriceps strength and hamstring range of motion. No significant difference in knee pain between groups.	**Drop outs:** 0 **Power:** not stated	**2^{++}**

	Patella alta or baja Meniscal tears, ligament instability, or medial plica Abnormal reflexes Vastus lateralis hypertrophy Surgery in previous 12 months Congenital or acquired pathology of back, knee or ankle Abnormal Q-angle> 10^0 and women .> 15^0 Retropatellar pain as a result of external trauma				
Werner and Eriksson (1993)	15 patellofemoral patients Males=9 Females=6 Mean age=28 Age range=17-36 Unilateral and bilateral pain Pain duration=? **Source of referral:** Orthopaedic surgeons **Incl** Intermittent retropatellar and/or anteromedial pain. Pain associated with activities of daily that load the patellofemoral joint and increased during at least 3 of the following activities. Walking, jogging and/or running Going up and down stairs Squatting Prolonged sitting 8 30 min with flexed knees Excl: Not specifically	1) Patellofemoral group – isokinetic training (n=9) 2) Control group (n=6) Treatment 8/52	Borg's pain scale Functional knee brace Improvement rating score Isokinetic dynamometer (Kin Com) **Assessments at** 8/52, 12/12 and 3-4 years. **Results:** Compared with control group patellofemoral group has a significant lower limb knee extensor torque in their painful leg at all velocities measured. The greatest difference during eccentric action. No difference in knee flexor torques	**Drop outs:** not stated **Power:** not stated	**2^{++}**

	stated 9 age gender matched controls **Incl:** No history of lower limb pathology and with a normal range of knee motion				

Non-controlled trials included in review

Alaca et al (2002)	22 patients Males= 5 Females=17 Mean age=27.3 Age range= Duration of symptoms=? **Source of referral:** not stated **Incl:** Positive apprehension test Giving-way Retropatellar crepitation Oversensitivity of patellar surfaces Retropatellar pain after activities that increase patellofemoral reaction force Anterior knee pain Five millimetres of higher quadriceps atrophy compared with opposite limb circumference **Excl:** Elite athletes Patients over the age of 45 and below the age of 14 Meniscal injury Ligamentous injury	Isokinetic rehabilitation Velocities 60^0/s, 180^0/s	Isokinetic evaluation Functional test: 6m hop test 3 step hop test Single leg hop course Lysholm scale VAS **Assessments at:** 6 weeks **Results:** Isokinetic training resulted in significant improvement in functional and isokinetic parameters and reduction in pain	**Drop outs:** 0 **Power:** not stated	
Bennett and Stauber (1986)	41 patients Males=? Females=?	Isokinetic rehabilitation (Cybex dynamometer)	Isokinetic evaluation **Assessments at**:	No specific measure of pain	**2^-**

	Mean age=? Age range=? Duration of pain=? **Source of referral:** Orthopaedic surgeons **Incl:** Anterior knee pain patients 15% deficit in eccentric torque when compared with the limbs concentric equivalent. **Excl:** Not specifically stated	Velocities 30^0s, 60^0/s, 90^0/s Preload=50N 3x weekly 10 repetitions 3 sets (n=27)	Until pain free **Results:** All patients demonstrated an increase in eccentric torque values equal to or exceeding their concentric counterparts	End point arbitrarily decided **Drop outs:** 14 **Power:** not stated	
Doucette and Goble (1992)	28 patients Males=? Females=? Mean age=20 Duration of pain = >6 weeks **Source of referral:** not stated **Incl**: Patellofemoral pain for a duration 6 weeks Evidence of patellar tilt on axial radiographs **Excl:** Secondary knee complications	Pre test-post test design Individualised exercise programs	Pain duration (day) Patellofemoral Index Radiographic congruence angle Q-angle Hamstring flexibility Thigh circumferential measurements Pronation Sulcus angle Activity level **Assessments at**: Completion of treatment ? arbitrarily decided **Results:** 84% of subjects were pain free at the end of treatment. Unable to significantly predict from variables measured which subjects would	**Drop outs:** not stated **Power:** not stated	**2^{++}**

			become pain free.		
Drover et al (2004)	9 patients 5 female 4 male Mean age = Age range = Duration of pain = **Source of referral:** athletes **Incl:** **Excl:**	Active release manipulation technique	Isokinetic knee extensor torque Interpolated twitch technique **Assessment at:** 20 min post treatment **Results:** No significant difference in tests before or after technique applied	**Drop outs:** **Power:** not stated	
Johnston and Gross (2004)	16 patients 13 female 3 male Mean age = 25.4 Age range = 14-50 Duration of pain = >2/12 **Source of referral:** community and physiotherapy outpatient centres **Incl:** Anterior knee pin of at least 2/12 duration Composite score of 200 or greater on WOMAC osteoarthritis Index out of a possible score of 2400 Nontraumatic onset of anterior knee pain Tenderness with palpation on at least one patella facet Ability to walk without assistance for 10m Perform a unilateral unsupported squat to 45^0 of knee flexion Active knee ROM	Foot orthoses	WOMAC score **Assessments at:** Initial assessment and at 2/52 prior to orthotics then 2/52 and 3/12 after supply of orthotics **Results:** All WOMAC subscales significantly improved at 3 months compared with preintervention measurements	Intention to treat analysis used **Drop outs:** 0 **Power:** not stated	

	of 0^0 to 60^0 knee flexion Excessive foot pronation of >9^0 calcaneal rear foot valgus in bilateral weight bearing < than 141^0 longitudinal arch angle in bilateral weight bearing **Excl:** WOMAC score < 200 Inadequate foot pronation Meniscal signs Patella tendonitis Absence of facet tenderness				
Gerrard (1989)	166 patients 80 female 36 male Mean age = ? Age range = ? Duration of pain = >1/12 **Source of referral:** not stated **Incl:** Patellofemoral pain syndrome or chondromalacia patella **Excl:**	McConnell regime	VAS Clinical tests **Assessments at:** 3/12 12/12 after cessation of treatment. Treatments stopped when able to climb stairs or squat without pain, and continued or resumed activities they desired **Results:** 86.2% of patients required 5 treatments sessions or less to be pain free After 7 treatment sessions 90.5% were pain free	**Drop outs:** 3 **Power:** not stated	
O'Neill et al (1992)	30 patients 21 female 9 male Mean age = Age range = 10-53 Duration of pain = ? **Source of referral**: Orthopaedic Department **Incl:**	Isometric quadriceps exercises, hamstring and iliotibial band stretching	Subjective improvement score Patellofemoral congruence angles **Assessment at** 4/52, 6/52, 3/12, 6/12, 9/12 and 12/12 **Results** Subjectively 77% of painful demonstrated subjective	No intention to treat analysis **Drop outs:** 4 **Power:** not stated	

	Anterior peripatellar knee pain despite anatomically normal, non traumatic knees **Excl:** Previous trauma or knee surgery		improvement		
Stiene et al (1996)	33patients 14 female 9 male Mean age = 19 Age range = ? Duration of pain = >1/12 **Source of referral**: not stated **Incl:** Acute exacerbation of patellofemoral pain, but without knee injury Onset no more than 4 weeks prior to physician evaluation **Excl:** Under 11 years old History of prior knee surgery other than arthroscopy for lateral retinaculum release Concomitant ligamentous injury Long bone fracture	Group 1 = isokinetic training x3 weekly for 8 weeks (n=11) Groups 2 = Closed chain rehabilitation programme x3 week for 8 weeks (n=12)	Subjective patellofemoral questionnaire Isokinetic open chain test at 90^0/s, 180^0/s and 360^0/s Number of repeated retro-steps **Assessment at** 8 weeks, 6 months and 1 year **Results** Both groups showed significant increase in peak isokinetic torque, however only the closed kinetic chain group showed significant improvement in closed chain testing and perceived functional status	No intention to treat analysis **Drop outs:** 10 **Power:** not stated	
Werner et al (1993)	30 patients 24 female 6 male Mean age = 33 Age range = 17-52 Duration of pain = > 4/12-132/12 **Source of referral** Orthopaedic surgeons **Incl:**	TENS 20min x2 daily for 10 weeks	Q-angle Functional knee score Isokinetic extensor torques **Assessments at:** 10/52, 52/52 and 182/52. **Results:** 2/3 of patients	**Drop outs:** 1 **Power:** not stated	

	2 of the following hypertrophic vastus medialis muscle confirmed on CT tight lateral retinaculum patella hypermobility **Excl:** ?		demonstrated improvement and this improvement remained at follow-up 3.5 years later		
Yildiz et al (2003)	30 patients 0 female 30 male Mean age = 24 Age range = ? Duration of pain = > ? **Incl:** Male recreational athletes Chondromalacia patellae confirmed by MRI **Excl:** No contralateral lower limb pathologies Neurological problems Other conditions that could be aggravated by testing protocol	Isokinetic training 3x week for 6/52	VAS One leg standing test Single limb hopping course One legged and three legged hop for distance Six metre and cross six metre hop for time Isokinetic muscle torque **Assessments at:** 6/52after cessation of treatment. **Results:** Significant improvement in quadriceps strength and function. Significant t reduction in pain. No correlation between muscle strength and function tests	No intention to treat analysis **Drop outs:** not stated **Power:** not stated	

Studies investigating exercise therapy in patellofemoral pain patients

Study	Intervention(s)	Patient No (N)	Mean Age	Gender(s)	Unilateral or Bilateral Knee Pain	Pain Duration	End point	Main Outcome(s)
Abrahams et al (2003) RCT	Mini squat exercises (neutral) Mini squat exercises (adduction/medial tibial rotation) Control	78	29	M & F	?	>8/12	6/52	Increased EMG activity in treatment groups. No significant difference in subjective function in any of the groups
Alaca et al (2002) NCT	Isokinetic exercise	22	27	M & F	Bilateral	?	1.5/12	Isokinetic exercise significantly improved strength and reduced pain
Clark et al (2000) RCT	McConnell Ex's, taping, education and home ex's	81	28	M & F	Bilateral	3/12	12/12	Ex's reduce pain and increase function No additional benefit of McConnell regime
Colón et al (1988)	Conservative isometric exercises and use of a pogo stick	29	?	M & F	Bilateral	?	2/12	Both groups improved Better improvement in power in pogo stick group with greater long term compliance? as result of novelty factor
Crossley et al (2002) RCT	McConnell ex's, taping and placebo ultrasound	71	28	M & F	Bilateral	>1/12	3/12	McConnell exercises significantly better at reducing pain than placebo ultrasound and sham taping

Dursun et al (2001) RCT	Open and closed exercises with and without EMG biofeedback	60	37	M & F	Unilateral	10/12	3/12	Ex's reduce pain and increase function no additional benefit from EMG biofeedback
Eburne and Bannister (1996) RCT	McConnell ex's and static quadriceps	75	?	?	Bilateral	?	3/12	? additional benefit of McConnell regime
Gaffney et al (1992) RCT	Concentric exercises and McConnell eccentric exercise	72	34	M & F	Bilateral	>6/12	6/52	Both groups demonstrated significant improvement in subjective function and reduction in pain. No difference between groups
Gerrard (1989)	McConnell exercises	116	?	M & F	Unilateral and bilateral	1/12	12/12	Ex's reduced pain in 90.5% of patients after seven treatment sessions
Harrison et al (1999) RCT	Open and closed kinetic chain ex's exercises and McConnell regime	113	22	M & F	Bilateral	?	12/12	Ex's reduce pain and increase function limited additional benefit of McConnell regime
Hazneci et al (2005) CCT	Isokinetic exercise	24	25	M	Bilateral	> 1/12	1.5/12	Isokinetic exercise improved joint position sense, reduced pain and improved knee muscle torque
Kowall et al (1996) RCT	Open and closed chain ex's with and without taping	25	29	M & F	Bilateral	1/12	1/12	Ex's reduce pain and increase function regardless of taping

Loudon et al (2004) CCT/RCT	Supervised home exercise program, home exercise program and control no treatment	29	27	M & F	Unilateral	>2/12	2/12	Both supervised and home exercise better than control. No difference between exercise groups
O'Neill et al (1992) NCT	Isometric quadriceps ex's and ITB and hamstring stretches	30	?	M & F	Bilateral	?	16/12	77% of painful knees examined reported an improvement in symptoms
Rousch et al (2000) RCT	Static quadriceps exercises and 'Muncie' method ex's	64	26	M & F	Unilateral	?	3/12	'Muncie' ex's reduce pain and increase function
Taylor and Brantingham (2003)	Patella passive mobilisation and patella passive mobilisations combined with quadriceps exercises	14	30	M & F	?	>1/12	1.1/12	Both groups demonstrated improvement in pain reduction and increased function. Greater improvement in exercise group.
Thomeé (1997) RCT	Open and closed kinetic chain exercises	40	20	F	Unilateral	1.5/12	12/12	Ex's, education and time reduce pain and increase function
Tunay et al (2003) RCT	'Controlled' exercises and home exercises	80	32	? M & F ('Gender matched')	Unilateral	1/12	3/52	Controlled exercises significantly 'better' than home exercises
Whittingham et al (2004)	Open and closed chain ex's and patella taping	30	19	M & F	?Unilateral	? 'acute'	4/52	All groups showed improvement in pain and function, but greater gains in group with 'McConnell' taping
Witvrouw et	Open and closed	60	20	M & F	Bilateral	1.5/12	3/12	Ex's reduce

al (2000) RCT	kinetic chain ex's							pain and increase function
Witvrouw et al (2003)	Open and closed kinetic chain ex's	60	20	M & F	Bilateral	1.5/12	3/12	Ex's reduce pain. No change in reflex response time of vastus medialis or vastus lateralis
Witvrouw et al (2004) RCT	Open and closed kinetic chain ex's	60	20	M & F	Bilateral	1.5/12	60/12	Ex's reduce pain and increase function no differences between open and closed kinetic chain exercises
Bennett and Stauber (1986) NCT	Isokinetic exercises	?	41	?	Unilateral	?	Until pain free	Isokinetic ex's reduce pain and increase strength
Doucette and Goble (1992) NCT	Exercises open and closed chain, taping	28	20	M & F	Unilateral	1.5/12	Arbitrarily decided	Ex's reduce pain, unable to predict from examination which patients would respond favourably to exercise
McMullen et al (1990) CCT	Isokinetic exercises, static quadriceps exercises and control	28	20	M & F	Unilateral	4/12	1/12	Ex's reduce pain in all groups
Stiene et al (1996) NCT	Isokinetic exercises and closed chain exercises	23	19	M & F	Unilateral?	22/12	1 year	Only closed chain exercises improved perceived functional status
Werner and Eriksson (1992) CCT	Isokinetic exercises and control	15	28	M & F	Bilateral	?	36-48/12	Ex group reduced pain

Yildiz et al (2003)	Isokinetic exercise	30	24	M	Unilateral	?	6/52	Significant improvement in pain, muscle strength and function. No correlation between improvement in muscle strength and function

Studies investigating knee bracing in patellofemoral pain syndrome

Study	Intervention(s)	Patient No (N)	Mean Age	Gender	Unilateral or Bilateral Knee Pain	Pain Duration	End Point	Main Outcome(s)
Denton et al (2005) RCT	Protonic knee brace and closed chain exercise	34	32.5	F	Unilateral	> 3/12	6/52 or resolution	No difference in exercise groups with addition of Protonic brace
Finestone et al (1993) RCT	Knee sleeves and control	395	?	M	?	<3.5/12	3.5/12	No difference with interventions
Greenwald et al (1996) CCT	Knee brace	15	22	M &F	Unilateral?	?	1/12	Reduction in patellofemoral pain with knee brace
Lun et al (2005)	Knee brace	129	35	M & F	Bilateral	> 3/52	3/12	No difference with between PFPS brace, knee sleeve or exercise groups
Miller et al (1997) RCT	Knee sleeves and control	59	?	M & F	?	3/52	1.5-2/12	No difference with interventions
Schneider et al (2001) RCT	PNF quadriceps exercises and 'Protonic' knee brace	40	24	M & F	Unilateral	> 6/12	8/52	'Protonic' brace reduces pain and improved VM/VL fatigue ratio to benefit of VM
Timm (1998) RCT	'Protonic' knee brace	100	30	M & F	Unilateral	3/12	1/12	'Protonic' knee brace reduces pain and increase function

Table 3.8 Studies investigating patella mobilization in patellofemoral pain syndrome

Study	Intervention(s)	Patient No (N)	Mean Age	Gender	Unilateral or Bilateral Knee Pain	Pain Duration	End Point	Main Outcome(s)
Drover et al (2004) NCT	Active release technique	9		M & F	Unilateral		20min	No difference in muscle torque post technique
Rowlands et al (1999) RCT	Patella mobilisation and ‘detuned’ ultrasound	30	?	?	?	?	1/12	Reduced pain on algometry testing in patella mobilisation group

Studies investigating feet orthotics in patellofemoral pain patients

Study	Intervention(s)	Patient No (N)	Mean Age	Gender	Bilateral or Unilateral Knee Pain	Pain Duration	End Point	Main Outcome(s)
Eng et al (1993) RCT	Feet orthoses and ‘placebo’ orthotics	20	15	F	Bilateral	<1.5/12	2/12	Feet orthotics reduce pain
Johnston and Gross (2004) NCT	Feet orthoses	16	25	M & F	Bilateral	>2/12	3/12	Significant improvement in WOMAC score post orthotic intervention

Studies investigating acupuncture in patellofemoral pain syndrome

Study	Intervention(s)	Patient No (N)	Mean Age	Gender	Bilateral or Unilateral Knee Pain	Pain Duration	End Point	Main Outcome(s)
Jensen (1999) RCT	Acupuncture and control	75	31	M & F	Bilateral	?	12/12	Acupuncture reduces pain and increase function
Näslund et al (2002) RCT	Electroacupuncture and superficial acupuncture	48	34	M & F	Unilateral ?	> 6/12	6/12	Both acupuncture groups demonstrated

								significant pain reduction

Studies investigating spinal manipulation in patellofemoral pain syndrome

Study	Intervention(s)	Patient No (N)	Mean Age	Gender	Bilateral or Unilateral Knee Pain	Pain Duration	End Point	Main Outcome(s)
Suter et al (2000) RCT	Sacroiliac manipulation	28	34	M & F	Bilateral	?	One day pre and post test only	Manipulation reduces pain inhibition in quadriceps muscles

Studies investigating electrotherapy in patellofemoral pain syndrome

Study	Intervention (s)	Patient No (N)	Mean Age	Gender	Bilateral or Unilateral Knee Pain	Pain Duration	End Point	Main Outcome(s)
Antich et al (1986) RCT	Phonophoresis Iontophoresis Ultrasound/ice Ice	64	?	?	Bilateral	?	7-8 days	Ultrasound and ice subjectively demonstrated greatest improvement (no statistical tests used)
Akarcali et al (2003 RCT)	Exercise and exercise + high voltage electrical stimulation	22	42	M & F	Bilateral	>2/12	6/52	Both groups demonstrated pain reduction and increased strength. No additional benefit of electrical stimulation
Callaghan et al (2001) RCT	Sequential mixed frequency VM electrical stimulation	16	30	M & F	?	>6/12	2/12	Both groups showed improvement in all outcomes measures

	and simultaneous mixed frequency VM electrical stimulation							except knee flexion angle before pain and fatigue rates. No significant differences between groups
Callaghan and Oldham (2004) RCT	Uniform constant frequency muscle stimulation and simultaneous delivered frequency components muscle stimulation	74	35	M & F	? Unilateral	> 6/12 < 10 years	6/52	Both groups showed improvement in pain and function. No significant difference between groups
Can et al (2003) RCT	TENS and diadynamic currents	30	32	M & F	Bilateral	> 3/12	12/52	Both groups demonstrated significant improvement in reduction in pain and improvement in function. No difference between groups
Rogvi-Hansen et al (1991) RCT	Low intensity laser and 'detuned' laser	40	33	M & F	Unilateral	?	1.1/12	No change in symptoms with laser treatment
Werner et al (1993) NCT	TENS	30	33	M & F	Unilateral	>4/12	42/12	2/3 of patient reported improvement with TENS

? = Information not available from text

ELECTRONIC APPENDIX 2

2.1 PATELLOFEMORAL PAIN REHABILITATION INTERVENTIONS - CURRENT APPROACHES

2.1.1 Rehabilitation and Patellofemoral Pain Syndrome

This section reviews the theory and evidence underpinning current physiotherapy approaches to the conservative management and rehabilitation of PFPS. The two most common rehabilitation rationales observed in the literature (Chapter 3), namely the general quadriceps femoris strengthening approach (Kannus and Nittymäki, 1994; Witvrouw et al, 2000b; 2004a) and the McConnell VMO 'selective activation' approach (McConnell, 1986; Grelsamer and McConnell, 1998), will form the basis of the RCT undertaken in this thesis and hence, these are the focus for this chapter.

A prolonged period of rehabilitation, possibly lasting several months, is thought to be central to the management of PFPS (LaBotz, 2004; Wilk and Reinold, 2001). The term rehabilitation has been defined as "a problem-solving and educational process aimed at restoring a state of health or well-being" (Watson, 1996). To facilitate the clinician in the rehabilitation process, and to help achieve optimum 'health', various theoretical 'rehabilitation models' have been proposed (Figure 2.1).

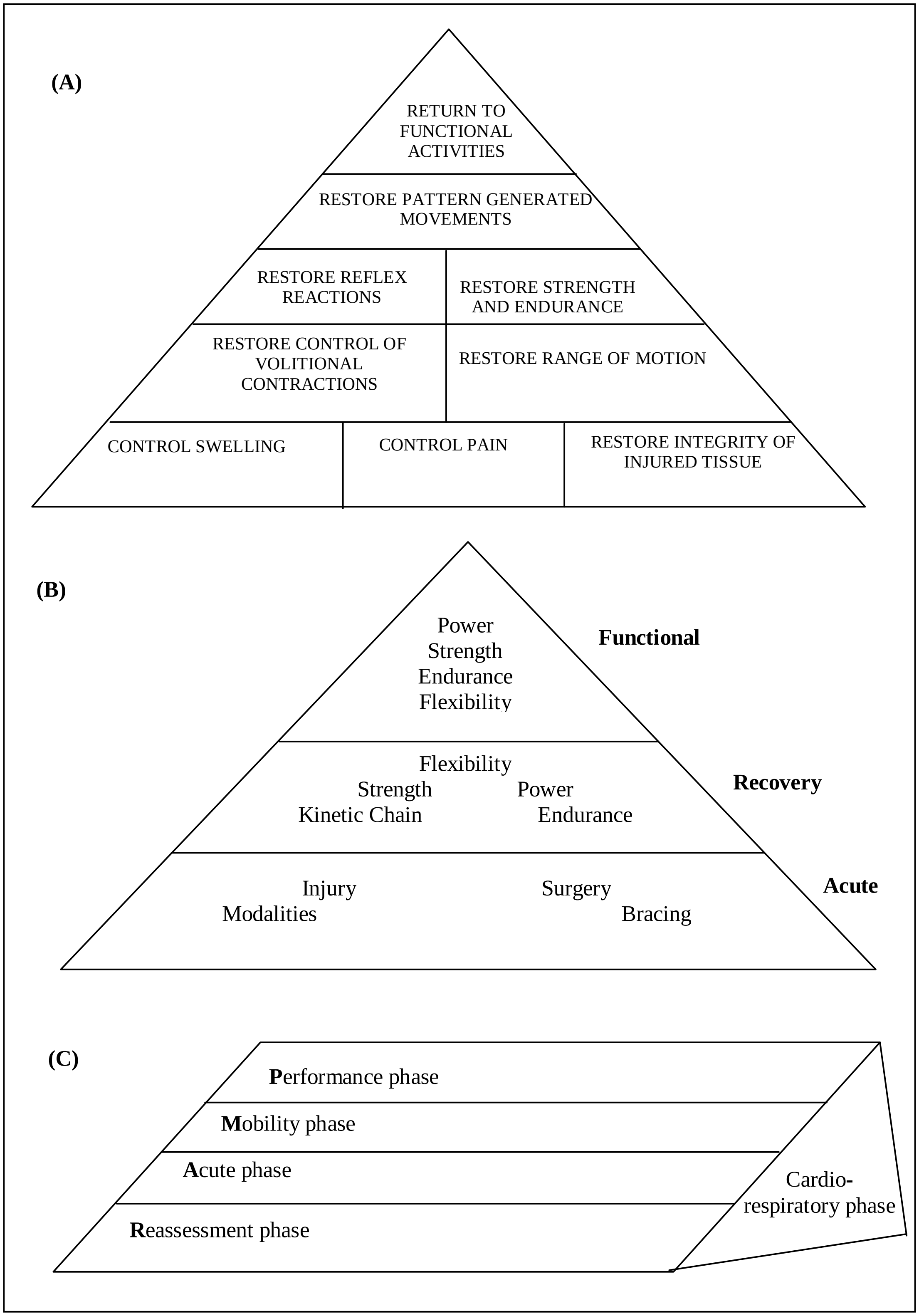


Figure 2.1: Three different models of rehabilitation (A) hierarchy of rehabilitation goals (Hertel and Denegar, 1998, p14); (B) phases of the rehabilitation process (Kibler and Chandler, 2003, p288); and (C) the progressive phases of the RAMP system (Ralston, 2003, p282)

Most of these models provide a logical progression of clinical reasoning and goal setting, culminating in the ultimate goal of optimal performance restoration (Houglum, 2004; Moss, 2000). Given that the pathological basis for PFPS is often obscure (Dye et al, 1999; Witvrouw et al, 1996) and that the rationale for performing any surgical procedure is potentially suspect (Day, 1997; Dye et al, 1999; Dye and Vaupel, 1994; Scapinelli et al, 2002), the importance of optimising effective non-surgical management would seem to be of paramount importance. Indeed it has been considered that surgical intervention should only be contemplated if there is no improvement following a three to six month period of conservative rehabilitation (Arnoldi, 1991; Grubner, 1979).

Rehabilitation programs designed for the patient with a patellofemoral disorder should match the specific disorder and dysfunction(s) identified by the clinical examination (Wilk and Reinold. 2001; Malone et al, 2002). Although theoretically this would seem a relatively simple matter, in clinical practice the situation would seem somewhat more complex (Dye and Vaupel, 1994). At the heart of the confusion lies several factors; the subjectivity of the clinical examination surrounding PFPS (Dye and Vaupel, 1994; Post et al, 2002), lack of universally accepted PFPS outcome measures (Bennell et al, 2000; Crossley et al, 2004b) and little consensus as to what constitutes the most appropriate conservative management (Dye and Vaupel, 1994; Natri et al, 1998; Wilk and Reinold, 2001; Witvrouw et al, 2005; Thomeé et al, 1996).

The systematic review presented in Chapter 3 demonstrated the widespread use and effectiveness of rehabilitation of the quadriceps femoris musculature in the management of PFPS. There therefore appears to be agreement that optimal quadriceps function is necessary for a good functional outcome (Fulkerson, 1983; Kannus et al, 1999; Natri et al, 1998; Powers et al, 1997a; Thomeé, 1997). There is also consensus that the most successful rehabilitation programs should emphasise functional progression without exacerbating the symptoms (Bizzini et al, 2004; Dye et al 1999; McConnell, 2002; Thomeé et al, 1996; Wilk et al, 1998).

On reviewing the literature regarding the conservative management of PFPS there would seem to be two different approaches, with a certain degree of overlap. One approach appears to place greater emphasis on generally strengthening the quadriceps musculature as a group, using both ‘open’ and ‘closed’ kinetic chain exercises, in addition to stretching the extensor mechanism and surrounding musculature (McGinty et al, 2000; Powers, 1998; Wilk and Reinold, 2001; Witvrouw et al, 2004a). The second approach includes stretches of the extensor mechanism and surrounding musculature, but places greater emphasis on ‘closed’ chain exercises with the ‘selective activation’ and re-education of the vastus medialis oblique (VMO) component of the quadriceps femoris muscles (McConnell, 1986). The theory at the centre of the selective activation approach is that an abnormal muscular imbalance balance between the VMO and vastus lateralis (VL) muscles can predispose to maltracking of the patella, abnormal loading of the patella mechanism and predispose to pain generation (Cowan et al, 2001a; Cowan et al, 2002a; Neptune et al, 2000; Voight and Weider, 1991). The goal of rehabilitation has been stated as the need to “enhance the coordination and skill of the movement not just the strength of the muscle” (Grelsamer and McConnell, 1998, p125), “Coordinated movement requires not maximum but optimal activity so that the appropriate muscles are selected (spatial pattern) and stimulated at the right time (temporal pattern)” (Brooks, 1983 cited by Grelsamer and McConnell, 1998, p125). Considerable debate, however, exists as to whether exercises should be based on strengthening the quadriceps femoris muscle group as a whole or should specifically target the VMO or VL muscles in isolation (Callaghan and Oldham, 1996).

In this section both approaches will be examined in a systematic manner.

2.2 GENERAL QUADRICEPS FEMORIS STRENGTHENING APPROACH

2.2.1 Introduction

The early treatment of PFPS was largely based on strengthening exercises comprising of terminal extension exercises, which were thought to selectively isolate and activate the VMO muscle in the last 10° to 15° of knee extension (Powers 1998; Malone et al, 2002). This has now been shown to be incorrect with the quadriceps muscles showing a stable and consistent pattern of recruitment throughout the range of motion (Lieb and Perry, 1971; Reynolds et al, 1983; Salzman et al, 1993). Despite evidence to the contrary there remains widespread clinical support for terminal extension exercises (Blazer, 2003; Cerny, 1995; Gryzlo et al, 1994). Advocates of terminal extension exercises claim that as the patella is above the patellofemoral articulation in terminal extension, there is therefore no patellofemoral contact, potentially reducing pain during rehabilitation (Knight, 1979; Kramer, 1986). Furthermore, the knee range 0° to 40° is where most functional activities are performed and it is also where the patella is least stable prior to engaging in the trochlea, hence exercise training in this range of motion would seem important (Doucette and Child, 1996). Finally, terminal knee extension exercises have been shown to be effective in reducing symptoms (McMullen et al, 1990). That said, the use of terminal knee extension exercises to selectively recruit the VMO remains unsubstantiated (Grabiner et al, 1991a; Reynolds et al, 1983) and some argue that terminal knee extension exercises potentially increase the risk of pain exacerbation, owing to the lateral displacement of the patella and increased patellofemoral contact stress (Powers et al, 1998).

Besides the lack of evidence against selective activation of the VMO during terminal knee extension, a further claim made against these exercises is that they do not replicate functional movements (Rivera, 1994). It is proposed that these, usually non-weight bearing terminal extension exercises, do not maximise coordination, biarticular muscle work, eccentric muscle work and proprioception associated with more functionally orientated weight bearing activities (Rivera, 1994). It has been stated that these training regimes primarily strengthen within the limited knee angle used with minimal ‘carry over’ to functional activities (Grelsamer and McConnell, 1998 p126), although some evidence exists to the contrary (Barak et al, 2004).

The relationship between the decreases in symptoms with increased quadriceps strength is difficult to explain biomechanically or physiologically, but clinically, improvement in quadriceps strength appears to be related to a reduction in symptoms (Arnoldi, 1991; Insall et al, 1976; Kramer, 1986; Powers, 1998; Radin, 1979). The biomechanical and physiological rationales proposed to explain the possible links between strength improvements and pain reduction are examined in this section.

2.2.2 Biomechanical Theory

Currently rehabilitation exercises for the knee are described as occurring in either an open kinetic chain or closed kinetic chain manner (McGinty et al, 2000). The phrase 'lower extremity kinetic chain' refers to the hip, knee and ankle joints when taken together (Irrgang, 1993). Many authors have sought to apply the principles of strength training underpinned by an understanding of kinetic chain biomechanics to PFPS rehabilitation (Doucette and Child, 1996; McGinty et al, 2000; Powers, 1998).

In rehabilitation terms, a closed kinetic chain is said to exist when the terminal segment meets some considerable resistance, for example during a squat activity when the feet are on the floor (Palmitier et al, 1991). An open kinetic chain activity is where, in successively arranged joints, the terminal segment is free to move, for example, during a seated knee extension exercise (Palmitier et al, 1991).

The biomechanics of the patellofemoral joint in an open kinetic chain configuration are well described (Heegaard et al, 1994; Hungerford and Barry, 1979; van Kampen and Huiskes, 1990; McGinty et al, 2000; Seedhom et al, 1979; Woodhall and Welsh, 1990). In summary, from approximately 0° to 10° the patella tendon contacts the femur and the patella contacts the supratrochlear fat pad. Patellofemoral contact is made between 10° and 20° of knee flexion along the inferior border of the patella, across both medial and lateral facets. As flexion increases the contact area on the patella moves proximally. The contact area increases with increased knee flexion to 90°. With knee flexion to 80°, only the articular surface of the patella makes contact with the trochlea and after 90° of knee flexion the tendinous band of the quadriceps begins to share the load of transmission. After flexion to 90° the patellar contact area decreases and the medial facet begins to come into contact the intecondylar notch while the odd facet makes contact with the lateral margin of the medial femoral condyle at extreme knee flexion (Woodhall and Welsh, 1990; McGinty et al, 2000).

During closed kinetic chain activity, the patella comes in contact with the femur between 10° and 20° of knee flexion. Contact on the patella initially occurs at the inferior pole and continues to move superiorly with progressive knee flexion to 90°. At 135° of knee flexion the patella has a small area of contact medially on the odd facet and also on the lateral patella facet (Goodfellow et al, 1979b; Grood et al, 1984). Patellofemoral joint compressive force increases with knee flexion (Grood et al, 1984; Koh et al, 1992), however, the increased contact on the patella during greater knee flexion helps to distribute this force over a greater surface area (Hungerford and Barry, 1979).

The uses of the terms open and closed kinetic chain in rehabilitation is controversial and the current trend would appear to discourage the use of kinetic chain terminology (DiFabio, 1999; Mayer et al, 2003; Wilk et al, 1997). The main arguments against kinetic chain terminology being that many functional activities are a combination of open and closed chain activities and that without an understanding of the underlying biomechanics the application of exercise based purely on descriptive terms may be detrimental to the rehabilitation process (DiFabio, 1999; Mayer et al, 2003). There is evidence, however, that traditional open chain exercises do have some functional overflow (Cohen et al, 1994; Wilk et al, 1994; Pincivero et al 1997; Siff, 2002). Moreover, open chain exercises are often desired for isolated muscle strengthening when specific muscle weakness is present (Wilk and Reinold, 2001). Nevertheless given the widespread use of the terms 'open and closed kinetic chain' exercise in the literature the traditional kinetic chain terminologies as defined by Palmitier et al (1991) were used in this thesis.

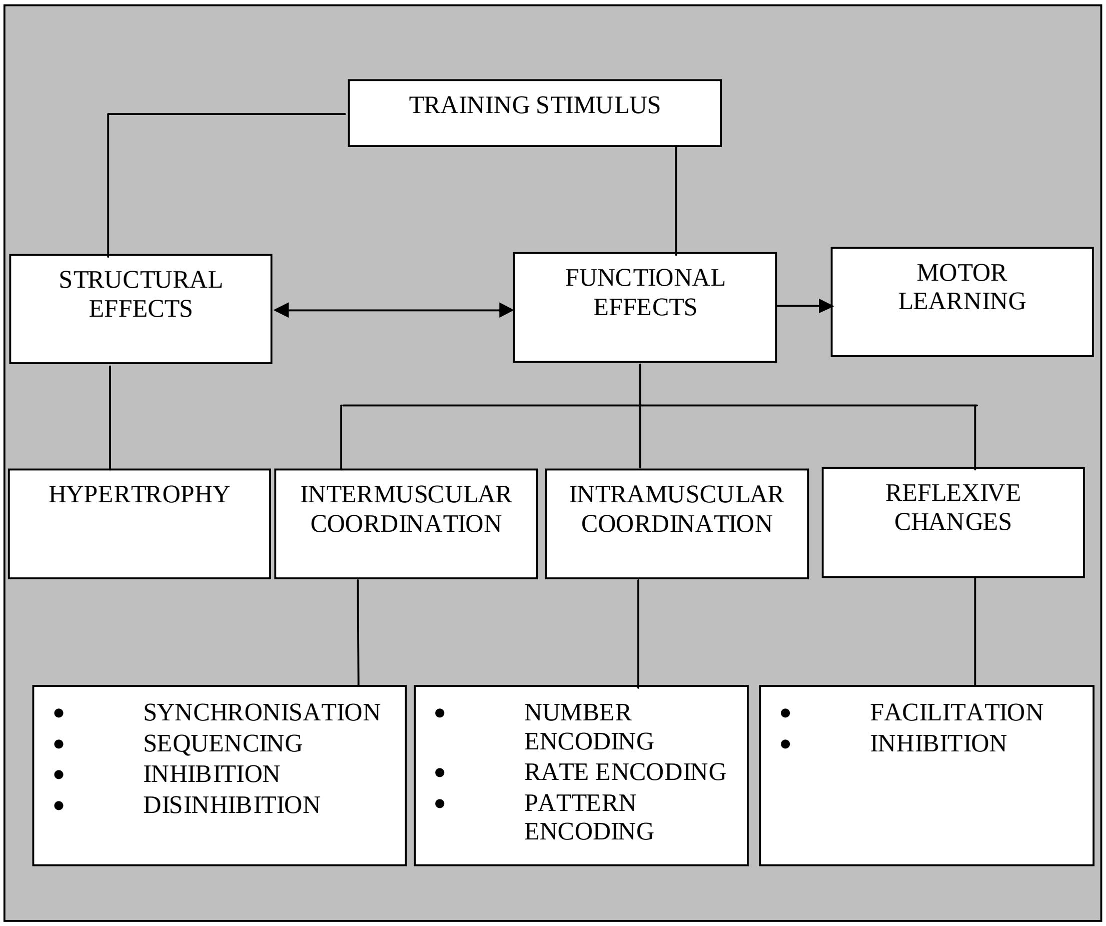
Both open and closed kinetic chain rehabilitation have been shown to reduce pain and improve function in PFPS (Gaffney et al, 1992; Thomeé, 1997; Witvrouw et al 2000b; Witvrouw et al, 2004a). In a five-year follow-up study Witvrouw et al (2004a) noted improvement and maintenance of subjective and functional outcomes in groups of PFPS patients who had been previously randomly assigned to either a five week open or closed chain quadriceps femoris training program. However, with the lack of a control group in this study the long-term improvement may merely represent an improvement in the natural history of the condition (Witvrouw et al, 2004a). A Cochrane review concluded there was strong evidence that both open and closed kinetic chain exercises were equally effective in the management of PFPS (Heintjes et al, 2003).

It has been suggested that diminished quadriceps strength may lead to altered biomechanical properties of the patellofemoral and tibiofemoral joints (Dehaven et al, 1979; Kannus and Nittymäki, 1994; Kannus et al, 1999; Powers, 1998). Thus any change in quadriceps force on the patella may modify the resultant force vector produced by the synergistic pull of the quadriceps femoris and patellar tendons, altering contact location and pressure distribution of joint force, and hence possibly irritating a pain sensitive area (Powers, 1998). Conversely, quadriceps femoris strength training may improve the synergistic pull of the quadriceps femoris, improve patella tracking and reduce patellofemoral contact stress on a pain sensitive area.

2.2.3 Physiological Theory

In terms of muscle physiology, it had been demonstrated that patients with PFPS exhibit reduced neural drive to the VMO and VL muscles compared to healthy controls (Grabiner et al, 1991b; Grabiner et al, 1992b), to the vasti as a muscle group (Powers et al, 1996) and to the VMO muscle (Thomeé et al, 1995c; Thomeé et al, 1996). The reduction in neural activity may be related to pain inhibition and/or related to an inability to recruit high threshold motor units, as a consequence of reduced lifestyle activity, commonly seen in PFPS patients (Grabiner et al, 1992b). One theory, therefore, is that if the force generated by the VMO is essential to proper patella tracking, general quadriceps femoris strengthening might simply bring the VMO up to a 'threshold' necessary for optimal tracking (Grabiner et al, 1994).

While the common perception of strength training is associated with bodybuilding and weight training, many of the principles involved in these disciplines have been extrapolated to the rehabilitation field (Siff, 2003a). While structural resistance training is aimed primarily at producing muscle hypertrophy (and some aspects of flexibility), functional strength training is associated with many different performance goals, including improvement in static strength, speed-strength, muscle endurance and reactive ability (Siff, 2003a). In other words the former produces increases in diameter and/or strength of individual muscle fibres, whereas the latter implicates the contractions of numerous muscle fibres to produce the appropriate performance effect (Siff, 2003a). Traditionally strength has been defined as “the ability to generate maximal force”, however more correctly “it is the ability to generate force, muscle tension or torque in a given context” (Siff, 2003b, p140). Some of the physiological processes underpinning strength training, besides muscle hypertrophy, are outlined in Figure 2.2. Indeed, empirical evidence exists that strength training can alter motor unit behaviour (Francis and Tipton, 1969; Moritani and DeVries, 1979) and sensorimotor coordination (Carroll et al, 2001).



Intermuscular coordination - the synchronisation or sequencing of actions between different muscle groups

Intramuscular coordination - implicates one or more of the following mechanisms: -

- Number encoding (control of muscle tension by activating or deactivating certain numbers of fibres)
- Rate (frequency) encoding (the control of tension by modifying the firing rate of active muscle fibres)
- Pattern encoding (the control of tension by modifying the firing rate of active fibres)

Facilitatory and inhibitory reflex processes - may be modified at various levels of the nervous system to optimise the development of strength either by improving intra and inter muscular coordination or by promoting adaptive changes in the various reflex systems of the body

Motor learning - the process of programming the brain/central nervous system to be able to carry out specific movement tasks

Figure 2.2: The structural and functional effects of strength training (Siff, 2003a, p8)

Hence, the benefits of strength training in rehabilitation may be more related to the changes in neural activity and improvement in muscle coordination than improvements in force production or muscle hypertrophy (Freiwald, 1993). Furthermore, rehabilitation must consider the confounding neural mechanisms of reflex inhibition and reduced neural activation (Grimby, 1992) in the treatment of PFPS. The clinical conditions or neural 'threshold' at which strengthening exercises become beneficial or detrimental to the rehabilitation process remain to be investigated.

2.2.4 A Review and Critique of Scientific Research Surrounding the 'General Strengthening' Approach

The databases of Medline, CINAHL, Sports Discus and Web of Science were searched using combinations of the following key words and phrases; quadriceps(s), quadriceps femoris, strengthening, open kinetic chain, closed kinetic chain, timing, non-weight bearing, weight bearing, terminal knee extension, short arc quadriceps, static quadriceps, isometric quadriceps, electromyographic, electromyography, neural drive and EMG.

Most papers to date appear to have concentrated on the issue as to whether the VMO can or cannot be selectively activated (Davies et al, 2001); as opposed to the effects general strength training has on mechanical or neuromuscular activity in patients with PFPS. The evidence, however, of a direct empirical correlation between pain and quadriceps strength does appear to be lacking (Power et al, 1997a; Yildez et al, 2003b). There is considerable circumstantial evidence linking the importance of quadriceps femoris strength with pain reduction when PFPS patients participate in clinical trials using strengthening exercises. For example, most investigators report an improvement in general quadriceps strength using isometric testing (Antich et al, 1986b), isokinetic concentric/concentric knee flexion/extension protocols (Rousch et al, 2000; Stiene et al, 1996; Witvrouw et al, 2000b; Yildez et al, 2003), isokinetic concentric/eccentric knee extension protocols (Bennett and Stauber, 1986; Werner and Eriksson, 1993) and isometric strain gauge testing (Clark et al, 2000a, Thomeé et al, 1996), when PFPS patients participate in clinical trials using strengthening exercises. Furthermore, in comparison with healthy controls, a reduction in quadriceps strength has been noted in PFPS patients (Duffey et al, 2000; Dvir et al; 1990, Powers et al, 1997; Väätäinen et al, 1995; Werner and Eriksson, 1993). Interestingly, Duffey et al (2000) found reduced peak extension torque as a significant predictor of the development of PFPS in previously healthy distance runners (n=70).

Evidence from Dvir et al (1990) and Anderson and Herrington (2003) suggested that muscle strength deficits might be more evident in the PFPS population if eccentric muscle testing protocols were used, however, such testing protocols can potentially increase pain in PFPS patients (Dvir, 1995, p120). This is supported by the work of Owings and Grabiner (2002), which highlighted that in comparison with healthy controls, PFPS patients showed VMO activity was impaired during eccentric, but not concentric muscle activities. These findings raise the possibility that eccentric contraction conditions increase lateralisation of the patella, increase patellofemoral stress and ultimately pain predisposition (Owings and Grabiner, 2002), hence the greater reduction in strength production.

The general effects of strength training have been investigated extensively in the healthy population and athletes, including neuromuscular, biomechanical and biochemical mechanisms (Deschenes and Kraemer, 2002; Komi, 1992). The effect of general strengthening on these parameters, however, has not been fully investigated in patients with PFPS. Some limited evidence related to these areas does exist and is now discussed.

Neuromuscular mechanisms

In a comparative study of concentric and eccentric strengthening programs Thomeé (1997) found no difference in average EMG activity of the VMO or rectus femoris muscles before or after, either concentric or eccentric, quadriceps training regimes, however there was a significant reduction in pain in both groups. Moreover, when the difference in VMO activity was compared between the ranges 50° to 75° and 25° to 50° the difference was greater in PFPS subjects than for healthy controls, even after the 12-week strength-training program. Hence, although neural activity did not improve there was a reduction in pain suggesting that the neural effects of strength training and pain reduction were not directly linked. Similarly, Witvrouw et al (2003) found no alteration in VMO and VL reflex response times after five weeks of open and closed chain strengthening exercises, although there was a statistically significant reduction in pain. Whether the results of reflex response times have any relevance to more voluntary movements is debatable. Natri et al (1998) noted that the smaller the knee extension strength difference between the affected and unaffected knee in patients with unilateral PFPS the better the long-term outcome with strength training, perhaps suggesting that there is a ‘threshold’ below which the benefits of strength training diminish.

Biomechanical Mechanisms

Ingersoll and Knight (1991) demonstrated that general quadriceps strength training did not improve patellofemoral alignment in comparison to biofeedback VMO training, which did improve patellofemoral alignment. This study, however, examined only 30 healthy females thereby making it difficult to extrapolate the findings to the PFPS population.

Evidence from studies of osteoarthritic knees (Radin et al 1991) suggest, that during eccentric activities, the quadriceps femoris musculature serves as a shock absorber during weight bearing and joint compression, (Radin et al 1991; Trudell-Jackson et al, 1989) and that neuromuscular disturbances in the quadriceps muscles may result in impulsive loading and increased heel strike force (Radin et al, 1991). Hence, during activity muscle contractions and protective reflexes are applied to shield the knee joint tissues from injury (Solomonow and D’Ambrosia, 1994). Any abnormal deviations in quadriceps strength may result in additional strain on the patellofemoral or tibiofemoral joints (Anderson and Herrington, 2003; Hurley, 1997; Wilk and Reinold, 2001). Furthermore, if the speed of muscle contraction is delayed then it will take longer for these protective mechanisms to be initiated (Marks et al 1995; 2000). Strengthening exercises may improve the speed of force generation (Reeves et al, 2003), and thus may improve knee joint protection (Hurley, 2003; Marks et al, 2000). Strength training may also increase the rate of voluntary force development (Häkkinen et al, 1985; Kubo et al, 2001) and reduce the time to peak force (Narici et al, 1996). A possible mechanism through which this could occur is via an increase in tendon stiffness that is associated with strength training (Reeves et al, 2003).

Alternatively, alterations in gait biomechanics as a result of reduced quadriceps strength may serve as a protective mechanism in PFPS. Powers et al (1997a) reported a correlation between reduced quadriceps strength and both reduced walking speed and stride length in PFPS patients. Levinger and Gilleard (2005), however, noted alterations in the heel strike force, but no difference in walking speed in a sample of PFPS patients. The question is whether muscle strengthening could reverse these gait alterations?

Arnoldi (1991) suggested that the repetitive mechanical mechanism of quadriceps exercises might cause a venous pump effect draining the proximal and marginal veins associated with the patella and thus reducing patella osseous pressure. This presumably could potentially reduce pain by reducing osseous mechonoreceptor excitation.

Evidence from mechanical modelling of human cadavers on the effects of quadriceps strengthening on the patellofemoral joint has also been inconclusive. Lee et al (2002) revealed that patellofemoral kinematics and contact pressures were not significantly influenced by VMO strength except at extreme conditions (0% of VMO strength or 150% of VMO strength). In contrast, Powers et al (1998) demonstrated subtle yet significant changes in patellofemoral contact joint mechanics with alterations in isolated vasti strength. The difference in results may be explained given that Powers et al (1998) used a multi-plane loading system, to replicate the three-dimensional orientation of the individual components of the quadriceps, compared with the two-dimensional axial loading technique of Lee et al (2002). It should be noted that such cadaver modelling, although providing useful gross information about patella kinematics, fails to reproduce the proprioceptive and coordinated muscle activity created in vivo (Lee et al, 2002).

Biochemical Mechanisms

Other benefits of general muscle strengthening are that it promotes cartilage health and stabilises the joint (Sharma et al, 2003; Thomeé, 1997), thereby potentially improving the load bearing properties of the patellofemoral joint. It has also been noted that in patients with knee osteoarthritis that isometric quadriceps femoris exercise can bring about significant changes in joint fluid biochemical parameters, which may explain the ameliorative effect of quadriceps femoris exercises in this group (Miyaguchi et al, 2003). The question then arises whether similar mechanisms and benefits could be derived from general quadriceps femoris strengthening exercises in PFPS patients.

It has also been postulated that in a large percentage of patients with PFPS the pain originates from the surrounding soft tissues and not from the osseous or articular cartilage structures (Wilk and Reinold, 2001). In light of this there is increasing evidence that strengthening exercises, more specifically eccentric strengthening exercises, may have a role in modifying pain associated with chronic soft tissue disorders (Alfredson, et al, 1998; Cannell et al, 2001; Khan and Maffulli, 1998; Sandrey, 2003). It is hypothesised that the mechanism of action relates to the mechanical effect of the exercise modifying cellular activity and expression through a mechano-electrochemical sensory system (Banes et al, 1995).

Finally, physical activity in general can enhance self-esteem (Fulkerson and Hungerford, 1990) and help patients to improve their function, through the release of endorphin chemicals (Thorén et al, 1990).

2.2.5 Methodological Considerations

Despite the known benefits of strengthening, the methods of strength development are far from being fully understood even for healthy subjects (Siff, 2003a). Some of the more common practical approaches to strength development in healthy individuals are shown in Table 2.1.

Table 2.1: Strength training protocols for healthy individuals

Author(s)	Method	Protocol
DeLorme (1945)	Progressive Resistance Method	3 sets x 10 repetitions x 3 week Set - 1 50% 10RM Set - 2 75% 10RM Set - 3 100% 10RM
McCloy (1954)	McCloy Method	3 sets x 10 repetitions x 3 week Set - 1 50% 10RM Set - 2 100% 10RM Set - 3 75% 10RM
Zinovieff (1951)	Zinovieff Method	3 sets x 10 repetitions x 3 week with increasing repetitions Set - 1 100% e.g. 10RM Set - 2 75% e.g. 15RM Set - 3 50% e.g. 20RM
Berger (1965)	Berger	3 sets x 6 repetitions x 2-3 week 100% 6RM
Knight (1979)	DAPRE (Daily Adjustable Progressive Resistance Exercise Method)	4 sets Set 1 - 10 reps 50% of anticipated 6RM Set 2 - 6 reps anticipated 75% 6RM Set 3 - anticipated 6RM to failure Set 4 - The number of strict full repetitions with weight in set 3 is used to determine the appropriate load for set 4 according to an adjustment table. Number of reps completed in this set is used as the starting point for next workout
Hettinger (1961)	Isometric Method	1-5 repetitions x 3-4 week maximal contraction 2-5 second holds practised at different joint angle
Davies et al (1986)	Isokinetic Conditioning	3 sets x 10 to 20 repetitions x 6 weeks
Dvir (1995)		Effort > 50% MVC
Perrin (1993)		30 seconds worth of exercise per velocity Peak moment reduced by 50% from initial peak moment

RM = Repetition Maximum
MVC = maximal voluntary contraction

A frequently cited guide is that muscular effort needs to be at least 60% maximal voluntary contraction to achieve an adequate strengthening stimulus (Siff, 2003a). A review of the strengthening methods used in PFPS studies reveals a range of different strengthening protocols Table 2.2, with some using training principles underpinned with a sound scientific prescription, while others appear to lack a clear rationale. The question is whether some of these protocols ever achieve loading to approximate a 60% maximum voluntary contraction to achieve a quadriceps femoris 'strengthening effect', especially in the presence of pain. Motor unit and neural stimulation, although not optimal, still occurs at non maximal loads (Zatsiorsky, 1995) and hence may still be clinically beneficial in stimulating neural activation.

Table 2.2: Strengthening protocols used in PFPS studies

Study	Exercise used	Strengthening Protocol
Alaca et al (2002)	Isokinetic knee extension	3 sets x 10 reps 60°/s and 180°/s concentric/concentric 3 x weekly.
Anitch et al (1986b)	ISQ, SLR, SAQ, HADD	2 sets x 10 reps x 10sec hold daily.
Bennett and Stauber (1996)	Isokinetic knee extension	3 sets x 10 reps 30°/s, 600/s, 90°/s 3x week.
Clark et al (2000a)	ISQ, Static double knee squats Isotonic exercises Sit to stand Trampette work Gluteus maximus and medius	10 reps x 10 sec holds daily.
Eng and Pierrynowski (1993)	ISQ, SLR	1 set x 10 reps Small weight added for progression.
Gaffney et al (1992)	Concentric SLR, IRQ Eccentric Isometric self resisted quads Squats Step up/down	3-6 x 10 reps 3-5 sec holds daily Progressive weight increments 3 sets 10 with increasing weight daily.
Harrison et al (1999)	SAQ, SLR, HADD Step downs	3 sets 10 x 3 week When 3 sets of 10 performed pain free progressive weight added.
McMullen et al (1990)	ISQ, SLR	ISQ - 30 reps x 3 sec hold SLR with weights 'DeLorme protocol' x 3 week.
Rousch et al (2000)	SLR, HADD Modified SLR	2 x 10 reps 5 sec holds daily.
Steiner et al (1998)	Isokinetics knee ext Double squats Lateral/retro step up	180°/s to 360°/s in 30°/s increments Progression after 30 reps pain free 2lbs weight increments added to max 10lbs.
Thomeé (1997)	Isometric: SLR, HADD, HABB, Leg pulls with elastic cord Eccentric: SLR, Sit to stand, Step up/down, squats	'Authors own progression plan'.
Werner and Eriksson (1993)	Isokinetic knee extension	120°/s 5 sets x 10 reps sub-MVC 120°/s 10 sets x 10 reps MVC 90°/s 15 sets x 10 reps.
Witvrouw et al (2000b; 2004a)	Open kinetic chain exercises including: ISQ, SLR, SAQ, HADD Closed kinetic chain exercises including: Single leg press Stationary Bike Rowing machine Step up/down exercise Jumping trampette	3 x 10 (sec hold) x 3 weekly 3 x 10 60%RM x 3 weekly.

ISQ=isometric static quadriceps; SAQ=short arc quadriceps; SLR= straight leg raising; HADD/HABB= Hip adduction/abduction; Reps =repetitions; Ext = extension, Secs=seconds, MVC = maximal voluntary contraction

2.7.6 Summary

In summary, there appears to be evidence that general quadriceps femoris strengthening can be helpful in reducing pain and improving function in PFPS patients. Various parameters including alterations in biomechanical patella alignment, motor control shock absorbency, motor unit coordination, psychological well-being, soft tissue integrity and joint biochemical constituents could all be implicated in explaining any beneficial effect of quadriceps femoris strengthening in patients with PFPS. The search for the exact mechanism(s) of action, however, continues.

2.3 'SELECTIVE ACTIVATION' APPROACH

2.3.1 Introduction

Despite the apparent lack of sophistication of the general quadriceps femoris strengthening approaches some patients improve; however, others do not (Lee et al, 2002; Simoneau, 2003). In 1986, Jenny McConnell, an Australian private physiotherapist, published a pioneering paper on the management and rehabilitation of PFPS (McConnell, 1986). This multifaceted approach was based predominately on biomechanical closed kinetic chain principles (McConnell, 1986). Specific emphasis, however, was placed on identifying and improving patella tracking (McConnell, 1986). The key components of McConnell's philosophy included VMO training, soft tissue stretching, foot orthoses and patella taping (McConnell, 1986; McConnell, 1995; Grelsamer and McConnell, 1998). The widespread interest amongst the UK physiotherapy community regarding the McConnell (1986) approach, and focus on selective activation of the VMO (Brown, 2000), is perhaps surprising as there appears to be few high quality research studies supporting the use of this approach (Wilson, 1990; Wilson et al, 2003). The original report on the McConnell regime claimed success rates of 96% (McConnell, 1986). However, it is known that high rates of healing can be expected with conservative management alone (maintaining activity and avoiding pain exacerbating activity), making it difficult to assess the benefit of the additional therapy without a control group (Finestone et al, 1993). The validity of McConnell's (1995) diagnostic classification system for identifying patella malalignment has also been questioned (Fitzgerald and McClure, 1995; Watson et al, 1999; Powers et al, 1999b; Watson et al, 2001), although there is some evidence to the contrary (Herrington, 2002).

Clinicians, however, appear to use the McConnell philosophy mainly on the grounds that it "works clinically" by reducing patients' pain (Watson et al, 1999). Gerrard (1989) claimed that 86% of patellofemoral patients had a 'good' to 'excellent' outcome when treated with the McConnell approach. This, however, was an uncontrolled trial with almost 50% of patients lost to follow-up. More recently Crossley et al (2002) conducted a randomised controlled trial of the McConnell approach in direct comparison with placebo ultrasound therapy. Statistically significant improvements in the 'McConnell' treatment group with regards to a reduction in pain and improved function were noted at three month follow-up. The Crossley et al (2002) paper was undertaken in various centres in Australia, using patients self referred from poster advertisements. The result of this study are interesting, however, caution must be exercised in extrapolating such evidence to the UK NHS where patients are usually referred from General Practitioners and Orthopaedic Consultants.

The following section reviews the biomechanical and physiological theory associated with selective activation of the VMO.

2.3.2 Biomechanical Theory

For many years clinicians apparently believed that the VMO had a selective action during extension of the knee joint (Smillie, 1973; Malone et al, 2002). This was thought to produce the last 15° of knee extension (Speakman and Weisberg, 1977). A premise that was subsequently disproved (Lieb and Perry, 1968, Lieb and Perry, 1971).

Lieb and Perry (1968) in their classic cadaver and biomechanical study described the vastus medialis as being subdivided into two components: a proximal portion referred to as the vastus medialis longus (VML) and a distal portion the VMO. Cadaver dissections demonstrated that the proximal vastus medialis muscle fibres deviated 12° to 15° to the long axis of the femur, while the distal vastus medialis fibres deviated 50° to 55° from this axis. Owing to this difference in fibre alignment between the two portions, it was considered that the vastus medialis was composed of two parts, the VML and the VMO (Lieb and Perry, 1968). Lieb and Perry (1968) further demonstrated that the VMO did work throughout the range of knee extension and owing to its unique orientation and alignment had a key role in maintaining patella alignment within the trochlea.

Bose et al (1980) added further weight to the argument for the unique role of the VMO in an analysis of thirty-four cadaver knees. These investigators highlighted that the VMO was seen to originate from the adductor longus and adductor magnus tendons as well as from the medial inter muscular septum, and inserted almost horizontally to the medial margin of the patella. Furthermore when human specimens were compared to other mammals this VMO/adductor link was found to be unique to humans. Bose et al (1980) concluded that VMO might have a specific role, in comparison to the other quadriceps femoris muscle components, in medially stabilising the patella. It is therefore now widely accepted that the VMO acts throughout knee extension (Basmajian and DeLuca, 1985) and is one of the key muscles primarily responsible for controlling the function of the patella (Basmajian and DeLuca, 1985; Hodges and Richardson, 1993).

2.3.3 Physiological Theory

With the function of the VMO more clearly defined, the concept of VMO rehabilitation appeared to gain increasing acceptance as a specific muscle entity (Grelsamer and McConnell, 1998; Hanten and Schulthies, 1990; McConnell, 1986). It is also a common clinical opinion that in the presence of knee trauma, injury or patellofemoral pain the VMO is the first to atrophy and the last to rehabilitate (Boucher et al, 1992; Fox, 1975; Grana and Kriegshauser, 1985). Hence, the need to selectively rehabilitate the VMO may also be related to the belief that the VMO selectively atrophies in PFPS.

Contrary to this, it has been suggested that quadriceps atrophy is not as common in PFPS as in other knee pathologies (Callaghan and Oldham, 2001; Insall, 1982). Lieb and Perry (1968) attributed the notion of selective VMO atrophy to the thin fascial covering of the VMO relative to the other quadriceps muscles and concluded that the early atrophy of the VMO merely indicated general quadriceps femoris wasting, rather than specific local VMO deficiency. Nevertheless, selective retraining of the VMO is thought to improve an assumed disruption of the mechanical balance of the medially and laterally directed forces exerted on the patella that influences patella tracking patterns, patellofemoral contact forces and pressures (Grabiner et al, 1994). Thus, restoration of the balance of this force system is thought to result in an 'appropriately' positioned patella within the trochlea groove, decreased patellofemoral forces, decreased patellofemoral pressures and improved quadriceps femoris efficiency (Grabiner et al, 1994).

2.3.4 A Review and Critique of Scientific Research Surrounding the 'Selective Activation' Approach

The databases of Medline, CINAHL, Sports Discus and Web of Science were searched using combinations of the following key words and phrases; vastus medialis, VMO, vastus medialis obliquus, vastus medialis longus, vastus medialis oblique, vastus medialis, vastus lateralis, vastus lateralis longus, exercise(s), kinetic chain, quadriceps(s), vastii, timing, imbalance, firing, hip adduction, knee extension, ratio(s), hip position, hip rotation, endurance, non-weight bearing and weight bearing. The outcome revealed both numerous and diverse studies investigating the relationship of the VMO muscle to the VL muscle. The results are presented in full in Electronic Appendix 4; however a discussion of some of the key papers and methodological issues regarding selective activation of the VMO follows. For clarity these are grouped under studies investigating 1) the mean VMO/VL electromyography activity ratio 2) the effect of endurance work on the VMO/VL electromyography activity and 3) investigations of the timing of VMO and VL activation.

Mean Electromyography Activity Ratio between Vastus Medialis Oblique/Vastus Lateralis

Unfortunately isolated muscle strength of the VMO cannot be measured directly (Grabiner et al, 1992a; 1992b). Many authors have therefore addressed whether selective activation can occur using electromyography (EMG), and if identified, to extrapolate this information to assume that selective strengthening can also occur (LeVeau and Rodgers, 1980; Soderberg and Cook, 1984; King et al, 1984; Hanten and Schulthies, 1990).

The literature review identified a large number of studies investigating VMO/VL EMG ratios, both in healthy subjects and in PFPS patients (for example, Cerny, 1995; Earl et al, 2001; Hodges and Richardson, 1993, Karst and Jewett, 1993; Souza and Gross, 1991; Tang et al, 2001). These studies used a range of different experimental conditions, for example using concurrent hip adduction with knee extension, different positions of the hip, weight bearing and non weight bearing exercise positions and exercises that fatigue the quadriceps muscles to ascertain whether VMO/VL EMG ratios could be altered under different conditions. Moreover these studies used a range of different EMG methodologies to investigate VMO/VL ratios. A list of studies and methodologies used to investigate VMO/VL ratios are shown in Table 2.4, in conjunction with the codes outlined in Tables 2.5 and 2.6. Additionally, the literature review highlighted that investigators have used a wide range of different exercise modes, including isometric, isotonic and isokinetic muscle work, both in weight bearing and non-weight bearing positions to explore VMO/VL ratios, both in healthy controls and PFPS patients (Table 2.7). Table 2.7 also highlights those studies, which demonstrated a difference in VMO/VL ratios with different exercise conditions.

Table 2.4: Methodologies used in studies investigating vastus medialis/vastus lateralis muscle activation

Study	Gender	Normalisation procedures (See Table 2.5 for codes)	Electrode method	Electrode placement (See Table 2.6 for codes)	Exercise position
Hip adduction					
Andriacchi et al (1984)	M	23	Fine Wire	2	Open chain knee extension supine with abduction moment
Cerny (1995)	M & F	6	Fine wire	3	Wall slides with pillow between knees
Coqueiro et al (2005)	?	1	Surface	30	Weight bearing isometric squat with hip adduction
Earl et al (2001)	M & F	4 and 20	Surface	4	Mini squat with concurrent hip adduction
Grabiner et al (1992a)	M	7	Surface	1	Seated extension with 50% maximum adduction
Hanten and Schulthies (1990)	M & F	3	Fine wire	5	Hip adduction in supine
Hertel et al (2004)	M & F	19	Surface	26	Weight bearing uniplanar isometric knee ext neutral, with abduction, with adduction
Hodges and Richardson (1993)	F	19	Surface	1	Weight bearing squat with 100%, 50% and 15% adduction MVC
Karst and Jewett (1993)	M & F	17	Surface	6	Straight leg raising with adduction
Laprade et al (1998)	F	13	Surface	1	Seated knee extension with hip adduction
Rice et al (1995)	M & F	19	Surface	7	Seated isokinetic knee extension with hip adduction
Wheately and Jahanke (1951)	M	19	Surface	8	Standing bilateral hip adduction
Zakaria et al (1997)	?	10	Surface	9	Bilateral hip adduction in supine
Hip rotation					
Herrington et al (2006)	M & F	4	Surface	32	Open and closed chain exercise with hip neutral, int and ext rot
Lam and Ng (2001)	M & F	20	Surface	12	Submaximal seated knee extension with foot neutral, int and ext rot
Liaw (2000)	M & F	1	Surface	29	Step up with foot externally rotated 0°, 30° and 60°
Livecchi et al (2002)	M	21	Surface	6	SLR and seated knee extension with foot neutral and ext rot
Miller et al (1997)	F	4	Surface	22	Step down with limb 45° int and ext rot
Mirzabeigi et al (1999)	?	22	Fine Wire	1	Knee extension at 15° with hip neutral and 30° ext rot
Ng and Man (1996)	M & F	14	Surface	7	Half lying knee extension with hip int and ext rot and ankle df/pf
Ninos et al (1997)	M & F	12	Surface	1	Squat in neutral and with lower limb in 30° ext rot
Signorile et al (1995)	M & F	17	Surface	1	Knee extension with foot neutral and ext rot
Sykes and Wong (2003)	M	19	Surface	13*	? SLR with hip 45° ext rot, neutral and 30° internal rot
Willet et al (1998)	M & F	12	Surface	31	Weight bearing knee extension against elastic with 30° hip ext/int rot

M = male F = female SLR= Straight leg raising MVC = Maximum voluntary contraction d/f = dorsiflexion p/f = plantarflexion
Int = internal Ext = external *VMO electrode only rot = rotation

Table 2.4 Continued: Methodologies used in studies investigating vastus medialis/vastus lateralis muscle activation

Study	Gender	Normalisation procedures (See Table 2.5 for codes)	Electrode method	Electrode placement (See Table 2.6 for codes)	Exercise position
Endurance					
Callaghan et al (2001a)	?M & F	20	Surface	14	Closed chain isokinetic knee extension with 60% MVC?
Grabiner et al (1991a)	M	7	Surface	1	Isometric seated knee extension
Grabiner et al (1992a)	M & F	7	Surface	1	Isotonic seated knee extension
Kaljumäe et al (1994)	M	2	Surface	1	Cycling
Ng (2002)	M & F	2	Surface	15	Cycling
Vääatäinen et al (1995)	M & F	2	Surface	15	Isokinetic knee ext 40% maximal effort
Weight bearing					
Anderson et al (1998)	?M&F	10	Surface	23	Narrow and wide stance squats at 30°, 60° and 90°
Cuddeford et al (1996)	M & F	2	Surface	24	Quadriceps setting standing
Gryzlo et al (1994)	M & F	22	Fine wire	27	Squat, SLR, short arc quads, short arc quads/hamstring co contraction, isometric quads
Hung and Gross (1999)	M & F	12	Surface	17	Squat on level surface, with 10° medial 10° lateral foot wedge
Miller et al (1997)	M & F	4	Surface	22	Static lunges, wall slides and step downs
Reynolds et al (1983)	F	2	Fine wire	18	Squat
Schaub and Worrell (1995)	M & F	2	Surface	6	Squat
Partial weight bearing					
Willis et al (2005)	?M & F	25	Surface	1	Cycling with foot in neutral and open stance ‘turned out’ position
Non-weight bearing					
Boucher et al (1992)	F	1, 6 and 8	Surface	8	Seated knee extension
Doxey and Eisenman (1987)	M & F	5 and 10	Surface	21	Submaximal knee extension with ankle weights
Mariani and Caruso (1979)	M & F	19	Surface and Fine wire		Seated knee extension
Matheson et al (2001)	M & F	2	Surface	5	Knee extension with isokinetics, elastic tubing and inertial trainer
Morrish and Woledge (1997)	M & F	7	Surface	20	Seated knee extension at 20° flexion
Richardson and Bullock (1986)	F	15	Surface	8	Prone knee flexion and extension against spring resistance
Serrão et al (2005)	M & F	24	Surface	30	Leg press with tibia in neutral, lateral and media rotation
Souza and Gross (1991)	M & F	9	Surface	8	?
Sczepanski et al (1991)	M & F	19	Surface	7	Isokinetic knee extension concentric/eccentric at 60°/s
Tang et al (2001)	M & F	11	Surface	1	Isokinetic knee extension concentric/eccentric at 120°/s, also squats
Wild et al (1982)	M & F	19	Surface	25	SLR with varying positions of hip rotation

SLR= Straight leg raising   MVC = Maximum voluntary contraction   ? = not stated or unclear
Int = internal   Ext = external

Table 2.5: Codes used in Table 2.4 for normalisation method

Code	Position
1	Seated isometric knee extension at 90° knee flexion
2	Seated isometric knee extension at 60° knee flexion
3	Seated isometric knee extension at 50° knee flexion
4	Seated isometric knee extension at 45° knee flexion
5	Seated isometric knee extension at 40° knee flexion
6	Seated isometric knee extension at 30° knee flexion
7	Seated isometric knee extension at 20° knee flexion
8	Seated isometric knee extension at 15° knee flexion
9	Seated isometric knee extension at 10° knee flexion
10	Seated isometric knee extension at 0° knee flexion
11	Seated isometric knee extension at 90° to 0° knee flexion in 15° intervals
12	Standing isometric knee extension at 0° knee flexion
13	Seated isometric knee extension at 60° knee flexion with 50% MVC
14	Half lying isometric knee extension at 20° knee flexion
15	Prone maximum isometric knee flexion and extension
16	% maximum torque during isokinetic knee extension 0° to 90° at 90°/s
17	% activity of isometric knee extension at 0° knee flexion
18	Maximum value relative to maximum obtained during any exercise/test position
19	No normalisation procedure
20	Closed kinetic chain knee extension at 45° knee flexion
21	Peak muscle activity for test
22	Peak muscle activity during manual muscle test
23	Mean maximum EMG activity
24	Leg press 90° knee flexion isometric contraction
24	Maximum EMG during traditional cycling

Table 2.5: Codes used in Table 2.4 for electromyography electrode placement sites

Code	Vastus medialis position	Vastus lateralis position
1	muscle belly	muscle belly
2	23cm above joint space	10cm above joint space
3	muscle belly	1/3 distance between patella and anterior superior iliac spine
4	half way between muscle belly and tendinous insertion	half way between muscle belly and tendinous insertion
5	4cm superior and medial to superomedial border of patella	10 cm superior to lateral epicondyle of femur
6	skin over muscle	skin over muscle
7	largest area of muscle mass	largest area of muscle mass
8	muscle motor point	muscle motor point
9	straddling motor point	straddling motor point
10	4cm proximal to the superior border of patella and slightly medial to medial border	muscle belly
11	4cm superior and 3cm medial to superomedial patella border	muscle belly 10cm superior and 6-8cm lateral to superior border of patella
12	midpoint of muscle	midpoint of muscle
13	oblique angle 55° and 2cm from superomedial edge of patella	not assessed
14	distal muscle	distal muscle
15	50° from long axis of the femur and 5cm from the superomedial border of patella	12°-15° from the long axis of the femur and 15cm from the superior medial border of the patella
16	midpoint of muscle 6cm and 3cm medial to superomedial border of patella	10cm superior and 7cm lateral to the superior border of patella
17	most prominent part of muscle	most prominent part of muscle
18	muscle belly	distance between 40% lateral joint line to greater trochanter
19	muscle belly	middle 1/3 muscle belly
20	muscle belly 4cm proximal to superior medial angle of patella	muscle belly 8cm proximal to lateral knee joint line
21	distal edge 1.5cm from medial edge of base of patella	taken from line from ITB to the lateral edge of base of patella as far down the muscle belly as possible
22	bulk of vastus medialis	20% distance between lateral knee joint line and greater trochanter
23	motor end plate	motor end plate
24	2cm medial and proximal from superior patella	1/3 from greater trochanter to superior pole of patella
25	adjacent to motor point	1/2 distance from motor point to distal tendon
26	55° to long axis of femur over the muscle belly when knee flexed to 60° flexion	proximal to the distal tendon over area of greatest muscle bulk
27	confirmed by manual muscle test	confirmed by manual muscle test
28	4 cm from superopatella border and 55° to long axis of femur	8 cm from superopatella border and 20° to long axis of femur
29	muscle bulk of vastus medialis oblique	distal 1/3 distance from ASIS to patella
30	4 cm from superomedial border of the patella at inclination of 50-55°	15 cm from superolateral border of patella at inclination of 13.6°
31	Most distal palpable portion of muscle 50° to femoral shaft	Most distal palpable portion of muscle 15° to femoral shaft
32	2 cm superior and medial to superiomedial patella border, angled at 50° to femoral axis	10 cm superior and 6 cm lateral to superiolateral patella border angled at 15° to the femoral axis

Table 2.7: Differences in exercise types and weight bearing status to investigate vastus medialis oblique/vastus lateralis muscle imbalance

Study	Exercise Type(s) Isometric = ISM Isotonic = IST Isokinetic = ISK	Weight bearing = WB Non weight bearing = NWB	Difference in VMO:VL ratio Yes = Difference found No = Difference not found
Healthy subjects			
Anderson et al (1998)	**ISM**	**WB**	**No**
Cuddeford et al (1996)	**ISM, IST**	**WB, NWB**	**Yes**
Davlin et al (1999)	**ISM**	**NWB**	**Yes (biofeedback) No (hip position)**
Earl et al (2001)	**IST**	**WB**	**Yes**
Grabiner et al (1992b)	**ISM**	**NWB**	**No**
Gryzlo et al (1994)	**ISM**	**NWB**	**No**
Hanten and Schulthies (1990)	**ISM**	**NWB**	**Yes**
Hertel et al (2004)	**ISM**	**WB**	**N**
Hodges and Richardson (1993)	**ISM**	**WB, NWB**	**Yes**
Hung and Gross (1999)	**IST**	**WB, NWB**	**Yes**
Karst and Jewett (1993)	**ISM**	**NWB**	**No**
Livecchi et al (2002)	**ISM**	**NWB**	**No**
Matheson et al (2001)	**ISM, IST, ISK**	**NWB**	**No**
Mirzabeigi et al (1999)	**ISM, IST, ISK**	**NWB**	**No**
Ng and Man (1996)	**ISM**	**NWB**	**Yes**
Ninos et al (1997)	**IST**	**WB**	**No**
Reynolds et al (1983)	**IST**	**WB**	**No**
Rice et al (1995)	**ISK**	**NWB**	**Yes**
Schaub and Worrell (1995)	**ISM**	**WB**	**No**
Serrão et al (2005)	**ISM**	**NWB**	**No**
Sykes and Wong (2003)	**ISM**	**NWB**	**No**
Sczepanski et al (1991)	**ISK**	**NWB**	**Yes**
Willet et al (1998)	**ISM**	**WB**	**No**
Zakaria et al (1997)	**ISM**	**NWB**	**No**
PFPS patients			
Boucher et al (1992)	**ISM**	**NWB**	**No**
Cerny (1995)	**ISM, IST**	**WB, NWB**	**No**
Lam and Ng (2001)	**ISM**	**NWB**	**Yes**
Laprade et al (1998)	**ISM**	**NWB**	**No**
MacIntyre and Robertson (1992)	**Running**	**WB**	**No** **No**
Miller et al, (1997a)	**ISM, IST**	**WB**	**Yes = healthy, No = PFPS subjects**
Miller et al (1997b)	**ISM, IST**	**WB**	**No**
Sheehy et al (1998)	**Stair ambulation**	**WB**	**No**
Souza and Gross (1991)	**ISM, IST**	**WB, NWB**	**No**
Tang et al (2001)	**IST, ISK**	**WB, NWB**	**No**
Wild et al (1982)	**ISM**	**NWB**	**No**

The results appear contradictory, with some studies reporting that VMO/VL ratios can be altered with selective activation of the VMO, while others have shown no change. The VMO/VL ratio has been a source of debate for some time with many studies using root mean square or integrated amplitude EMGs to generate a mathematical ratio (Callaghan et al, 2001a). Despite a variety of methodologies and analyses, the amplitude values seem to generate a VMO/VL EMG ratio in healthy subjects of approximately 1.0 (Callaghan et al, 2001a). A ratio of less than or greater than 1.0 would therefore indicate VMO VL muscle imbalance. However, a ratio of 1.0 may not necessarily exclude quadriceps dysfunction (Kasman et al, 1998b). Large inter-subject variations have been shown in the context of EMG and VMO/VL ratios (Callaghan et al, 2001a; Cerny 1995).

Electromyography can be used as a crude predictor of muscle tension during static isometric work, however during concentric or eccentric contractions the relationship is more variable (Winter, 1990). As previously stated it is generally accepted that a 60% maximal force is required to achieve strength gains (Rutherford, 1997). Whether the activation generated in these studies is sufficient to achieve the threshold required for an isolated strengthening effect is questionable. For example, in the paper by Hanten and Schulthies (1990), the investigators reported that hip adduction exercise was associated with VMO activation significantly greater than that of the VL. In Hanten and Schulthies' experiment, however maximum effort hip adduction conditions activated the VMO and VL to approximately 62% and 46%, respectively, of the EMG values observed, during maximum knee extension. Furthermore the large variability of their data, which for the VMO and VL was approximately 75% and 66% respectively (Grabiner et al, 1992a), threatens the validity of Hanten and Schulthies' experiment and the deduction that the proposed exercise protocol could achieve a strengthening effect. Interestingly, Grabiner et al (1992a) in an attempt to reproduce Hanten and Schulthies' (1990) findings were unable to demonstrate selective activation of VMO with hip adduction during open chain knee extension.

Believers in selective activation of the VMO have criticised many of these studies for being non weight bearing and 'non-functional' (Grelsamer and McConnell, 1998, p 150-152). Hodges and Richardson (1993), for example, demonstrated that the addition of isometric adduction of 5% of body weight (about 30% of a maximum voluntary contraction) had no differential effect on the activation of the VMO in a non-weight bearing situation. Hodges and Richardson (1993) found that a maximal contraction was required before increase in activity in the VMO relative to the VL could be demonstrated. Yet in weight bearing, only 20% of a maximal contraction of the adductors was required to differentially increase VMO activity relative to the VL. This suggested that the functional position of the limb in weight bearing was essential if preferential activation of the VMO was desired. Again the question of whether this 'selective activation' is of sufficient intensity to alter patella tracking and alignment remains. Hence, while there is evidence that selective muscle activation and motor unit recruitment can occur, the topic of selective VMO strengthening remains controversial (Grabiner et al, 1992a).

It is, however, the specific role of the VMO in controlling patella tracking and the ability to selectively train this muscle that underpins the concept validity of McConnell based exercises. The relationship between the in vivo balance between the forces generated by the VMO and VL is not just a simple biomechanical one, but a dynamic function of: (a) the angle of pull of each muscle relative to the patella, (b) the contraction force potential of each muscle which is a function of the cross sectional area, (c) the maximum rate of muscular tension developed which is an action of fibre type composition and (d) the neural excitation (Grabiner et al, 1992a). Furthermore, the effects of muscle inhibition (Hurley, 1997), motivation (Werner and Eriksson, 1993) and an individual's ability to retrain motor control (Comerford and Mottram, 2001), may complicate the PFPS patient's ability to selectively isolate and train the VMO muscle.

In conclusion, the theoretical arguments for selective activation and for altering VMO/VL amplitude ratios are appealing, and evidence can be found to support the theory. Equally, evidence to the contrary can also be referenced demonstrating no selective activation of the VMO relative to the VL and in practice other physiological and psychological parameters may be of greater significance in PFPS.

Endurance Electromyography Activity in Vastus Medialis Oblique/Vastus Lateralis

Grabiner et al (1991a) hypothesised that selective fatigue of the VMO relative to the VL could be used to indirectly measure potential muscle strengthening effects. This premise was based on two facts 1) that the VL has a larger cross sectional area than the VMO and 2) the VL has a greater proportion of type II muscle fibres relative to the VMO (Grabiner et al, 1991a). Consequently, the VL can generate a larger maximum force relative to the VMO. Hence, as muscle force increases, concomitant increases in intramuscular pressure results in diminution of blood flow within the VL, which would be expected to be greater than that of the VMO (Grabiner et al, 1991a). With reference to fibre type, it has been reported that the VMO contains approximately 64% of type I fibres (Erzen et al, 1995), whereas the VL comprises approximately about 43% of type I fibres (Wretling et al, 1997). Type I fibres have slower contraction velocities and produce less force than type II fibres, but they are more fatigue resistant (Noth, 1992 p23). With a higher percentage of type I fibres, the VMO may have greater endurance than the VL. The larger proportion of type II muscle fibres in VL suggests that at larger forces the accumulation of glycolytic metabolites in the VL should be greater than the VMO contributing to a greater rate of fatigue (Ng, 2002). Considering the physiological and morphological differences between VMO and the VL, the VL should demonstrate greater fatigability in comparison with the VMO during a general quadriceps strengthening exercise (Grabiner et al, 1992a). Based, however, upon the clinical goal to selectively strengthen the VMO, isolated VMO activation should result in fatigue of the VMO relative to the VL and indirectly give an indication of a potentially isolated strengthening effect (Grabiner et al, 1992a).

Few studies (Callaghan et al 2001a; Grabiner et al, 1991a; Kaljumäe et al, 1994; Ng 2002; Väätäinen et al, 1995a; Yeung et al, 1999) have investigated the fatigue characteristics of the VMO and VL, with even fewer investigating endurance properties in PFPS (Callaghan et al 2001a; Väätäinen et al, 1995). Investigators have used a range of exercise modes to explore vastii endurance including, cycling (Kaljumäe et al, 1994; Ng 2002), open chain isometric contractions (Grabiner et al, 1991a; Yeung et al, 1999), isotonic contractions (Grabiner et al, 1991a), isokinetic tests (Väätäinen et al, 1995a) and closed chain isometric contractions (Callaghan et al 2001a). Endurance training protocols have ranged from one minute (Väätäinen et al, 1995a) to 30 minutes (Kaljumäe et al, 1994) in duration.

Grabiner et al (1991a) were unable to support the hypothesis that owing to the physiological and morphological differences between VMO and the VL, that the VL or VMO could be selectively isolated and fatigued using isometric or isotonic test set-ups. In contrast, Ng (2002) was able to demonstrate selective fatigue of the VL using a cycling protocol of approximately 20 minutes. Interestingly, Ng (2002) noted a faster rate of recovery over seven hours in the VL compared to the VMO muscle. This potentially gives rise to another mechanism of vastii imbalance in PFPS patients, namely an inability for the VMO to recover relative to the VL after endurance activity, possibly causing vastii imbalance and patella maltracking.

Väätäinen et al (1995a) noted no change in VMO/VL ratios in PFPS patients, however, they used only a one-minute isokinetic ‘endurance’ test. It is debatable whether this was of sufficient duration to induce selective muscular fatigue. Callaghan et al (2001a) reported no significant changes in VMO/VL ratios when patients with PFPS were compared to healthy controls. However, PFPS patients did demonstrate greater variability in median frequency EMG activity, with greater fatigability in both the VL and VMO compared with healthy controls (Callaghan et al, 2001a). This evidence highlights the dangers of extrapolating findings from healthy subjects to PFPS patients, and that patients may have greater potential for improvement in muscular performance (Grabiner et al, 1991a).

In conclusion, the evidence that either the VMO or VL can be selectively fatigued and hence selectively strengthened remains inconclusive.

Vastus Medialis Oblique/Vastus Lateralis Timing

With a lack of agreement on the selective activation and strengthening of the VMO, others have looked to alterations in the activation timing of the VMO using both weight bearing (Adler et al, 1983; Cowan et al 2000a; Cowan et al, 2001a; Cowan et al, 2001b; Cowan et al, 2002a; Cowan et al, 2002b; Cowan et al, 2002c; Cowan et al 2003; Powers et al 1996; Sheehy et al, 1998) and non weight bearing protocols (Cesarelli et al, 2000; Karst and Willet, 1995; Stensdotter et al, 2003; Voight and Wieder; 1991; Witvrouw et al, 1996; Witvrouw et al, 2003). Furthermore, investigators have explored involuntary reflex quadriceps contraction (Karst and Willet, 1995; Voight and Wieder; 1991; Witvrouw et al, 1996; Witvrouw et al, 2003), quadriceps femoris reaction times during voluntary reaction protocols (Cowan et al, 2001a; Cowan et al, 2002a; Cowan et al, 2003; Stensdotter et al; 2003), during isokinetic exercise (Cesarelli et al, 2000); and during functional activities (Adler et al, 1983; Cowan et al 2000a; Cowan et al, 2001a; Powers et al 1996; Sheehy et al, 1998)

Beyond 30° knee flexion the joint surface congruence is thought to be the major factor in patella tracking (Heegaard et al, 1994). Hence the idea of a temporal 'feed forward' mechanism (with larger relative initiation of VMO activation compared to the VL muscle) to position the patella in the trochlea during the *early* stages of flexion seems plausible. Voight and Wieder (1991) were some of the first investigators to examine reflex EMG activity elicited by a patellar tap in asymptomatic subjects and PFPS patients. These authors concluded that the reflex response of the VMO occurred earlier than that of the VL in asymptomatic subjects, whereas the reverse was true in patients with patellofemoral pain (Voight and Wieder, 1991). The change in the VMO/VL timing difference was related to a faster response time of the VL (not a delay on the VMO) in the patient group compared with the asymptomatic group. Voight and Wieder (1991) did not report the actual magnitude of the reflex latency difference between VMO and VL onset of activity making it difficult to accept, even in the presence of a 'feed forward', mechanism that the VMO could generate sufficient force to control patellar tracking. The functional relevance of Voight and Wieder's findings is based on the assumption that changes in reflex latencies are associated with similar changes during voluntary activation of the knee extensors, an assumption that may not necessarily be correct.

Karst and Willett (1995) could not support the findings of Voight and Wieder (1991) and furthermore could not identify a significant timing difference during voluntary contractions. Karst and Willett (1995) highlighted statistical and methodological flaws in Voight and Wieder's paper accounting for the disparity between the studies. A major problem highlighted with Voight and Wieder's work was the lack of uniformity of subjects' height. Most of the reflex latency is due to time required for nerve conduction in the afferent and efferent components of the reflex loop, thus absolute reflex response times are strongly related to subject height (Ryushi et al, 1990). If the groups differed in height, as seemed likely given variations in gender, then this would directly affect reflex response time. Knee extensor velocity was not tightly controlled in the weight bearing and non-weight bearing conditions employed in Karst and Willet's experiment. Motor recruitment patterns, however, may be related to the task performed and speed of initiation of the task (Barnes, 1980; Grabiner et al, 1992b).

Witvrouw et al (1996, 2003), similarly, demonstrated a reversal of the firing pattern of the VMO and VL muscles in patellofemoral pain patients, with an increase in VL reflex response time rather than in a decrease in VMO reflex response. Interestingly, Witvrouw et al (2003) observed no change in vastii timing after exercise-based rehabilitation in PFPS patients, despite pain reduction and improvements in function. The result of the study perhaps indicating that vastii timing is not clinically relevant to outcome (Witvrouw et al, 2003).

Grabiner et al (1992b) investigated the effect of different muscle activation strategies on VMO/VL activation patterns in patients with and without PFPS patients. The results revealed that the VMO did not receive statistically significantly larger initial excitation than the VL in control subjects during constant force and slow onset force conditions. However, patellofemoral pain subjects demonstrated significantly lower VMO and VL excitation than the control group during the rapid force conditions (Grabiner et al, 1992b). Based upon expected motor unit recruitment patterns, the findings were interpreted as possibly reflecting disuse atrophy of high threshold motor units of the knee joint musculature and/or reduced ability to recruit fast twitch motor units (Grabiner et al, 1992b). Thus, the clinical relevance of inferences made from studies employing non-functional, slow isometric contractions should be taken with caution (Grabiner et al, 1992b). Similarly, Powers et al (1996) noted that all the vastii muscles had decreased mean EMG intensities during gait in patellofemoral pain patients compared with healthy subjects, but found no temporal difference in VMO/VL ratios.

In contrast Cowan et al (2001a; 2002a; 2003) demonstrated significant statistical differences in VMO and VL onset times between PFPS patients and healthy controls. Furthermore, these vastii timing differences were reduced following a course of ‘McConnell based’ rehabilitation, including EMG dual channel biofeedback, to enhance selective VMO activation Cowan et al (2002c; 2003). The mean differences in VMO and VL EMG onset times during a concentric step up and eccentric step down were 12.20ms and 11.56ms respectively in healthy controls (Cowan et al, 2000a) and 15.80ms and 19.39ms respectively in PFPS patients (Cowan et al, 2001a) (with the VMO generally firing earlier than the VL muscle). The work of Cowan et al (2001a; 2002a; 2003) would therefore appear to support the argument that a temporal imbalance between the VMO and VL muscles in patients with PFPS does exist. Even if a compromised VMO and VL timing dysfunction does exist, there is only limited evidence to date suggesting that decreased VMO recruitment translates to patellar instability and altered patellar function. Neptune et al (2000), however, did provide some evidence that a 5ms VMO timing delay was associated with a significant increase in lateral patellofemoral joint loading.

Furthermore, the ‘McConnell’ based physiotherapy program used in Cowan’s work included patella taping, gluteal strengthening and manual patella mobilisation therapy (Cowan et al, 2002c; 2003), making it difficult to ascertain if these improvements were directly associated with selective VMO training. Other central neural mechanisms may also be implicated in musculoskeletal physiotherapy interventions (Zusman, 2004).

In conclusion, the literature does not conclusively support a difference in the timing of the VMO and VL activation patterns in those with and without patellofemoral pain. The theoretical rationale and empirical evidence to date suggests that abnormal timing of the VMO relative to the VL may be of clinical significance and offers a possible mechanism whereby selective VMO retraining could influence patella tracking and reduce pain.

2.3.5 Methodological Considerations

The difficulty in reviewing the literature on selective VMO activation is that most of the published work consists of numerous individuals and teams, applying a wide variety of methodologies and analytical procedures (Grabiner et al, 1994). The widespread variation in results, even from studies investigating similar parameters, can be explained (in part) by the variations in sample gender, normalisation procedures, electromyography electrode method and electrode placement, absence of standardised measurement positions even for similar exercises, varied methods used to investigate the VMO/VL relationship, anatomical diversity and statistical variations regarding measuring VMO/VL timing differences (Electronic Appendix 4).

2.3.6 Summary

The evidence as to whether the VMO muscle can be selectively retrained remains equivocal. Evidence for the retraining of the timing between the VMO and VL muscles in PFPS appears the most substantiated mechanism of selective activation at the present time.

2.4 CONCLUSIONS

Quadriceps femoris muscle retraining appears to be an essential component in the management of PFPS. Two basic schools of thought propose methods to achieve optimal quadriceps femoris function. The first, more traditional approach, involves a general strengthening of the quadriceps femoris muscles as a whole group. It is surmised that the general strengthening approach may bring the quadriceps femoris muscles up to a satisfactory physiological ‘threshold’ for optimum patella tracking. The second approach, originally advocated by McConnell (1986), involves methods predominately aimed at improving the timing or activation of the VMO muscle relative to the VL muscle, thus improving patella tracking and alignment. To achieve this ‘selective activation’ McConnell (1986) also advocated a more integrated approach to the management of PFPS, encompassing the use of patella taping, lower limb stretching and the use of foot orthoses.

Some of the integral components of McConnell philosophy, for example VMO selective activation and patella taping, have attracted much interest in the literature. However, the evidence supporting the 'selective activation' approach, as proposed by McConnell (1986), appears imprecise, equivocal and conflicting. There is also a lack of independent RCTs investigating McConnell's 'selective activation' approach, as described in its entirety, especially within the NHS. Two pressing questions for clinicians are 1) is it worth investing financial resources on purchasing EMG units, specific patella taping materials and foot orthoses? and, 2) is it worth undertaking advanced clinical reasoning and hypotheses generation when a simpler, more generic rehabilitation process, involving quadriceps femoris strengthening (Witvrouw et al, 2000b; 2004a) or even a simple education approach (Clark et al, 2000a; LaBotz, 2004; Thomeé, 1997; Thomeé et al, 1999) would suffice.

No high quality study within the UK NHS has compared the 'general quadriceps strengthening' and VMO 'selective activation' approaches to PFPS rehabilitation, against an adequate control group. A study was therefore required that aimed to address these issues.

ELECTRONIC APPENDIX 3

3.1 METHODOLOGIES USED IN VASTUS MEDIALIS STUDIES

The following Electronic Appendix explores some of the methodological that need to be considered when investigating vastus medialis / vastus lateralis muscle imbalance in relation to PFPS. The issues explored are variations in sample gender, electromyographic (EMG) normalisation procedures, electromyography electrode position and methods, standardised testing positions, anatomical variations and EMG statistical considerations.

3.2 VARIATIONS IN SAMPLE GENDER

Differences in patellofemoral biomechanics between males and females have been noted with females demonstrating a tendency toward wider pelvis widths (Horton and Hall, 1989, Cox, 1990), increased femoral anteversion, excessive Q-angle, external tibial torsion and foot pronation (Ireland, 2000, p292 to 293). These differences may in part explain neuromuscular coordination differences between males and females (Ireland, 2000, p292), which potentially could affect the relationship between the vastus medialis oblique and vastus lateralis muscle activity.

3.3 NORMALISATION PROCEDURES

Some studies have used non-normalised ratios to compare overall electromyography activity in the vastus medialis oblique compared to the vastus lateralis muscle (Hodges and Richardson, 1993; Souza and Gross, 1991). The use of non-normalised EMG data is however not acceptable when constructing ratios that relate one muscle activity to another (Minor, 1991). The basis for rejecting comparisons using non-normalised EMG data is that the amplitude of the surface EMG signal may be affected by variables not related to actual muscle contractile activity or effective force output. Such unrelated variables may include (1) the inability to standardise electrode placement, (2) differences in muscle bulk within the pickup range of the electrode (3) differences in the amount of subcutaneous tissue between the electrode and the muscle (Minor, 1991). This is true of different muscles within the same limb of the same subject, for the same muscle in contra lateral limbs within the same subject and for comparison among subjects (Minor, 1991).

3.4 ELECTROMYOGRAPHY ELECTRODE PLACEMENT AND METHOD

Electrode placement either using fine wire or surface electrodes has involved varying methods for detecting both vastus medialis oblique and vastus lateralis activity, potentially introducing variability to the results. For example, some studies have placed the electrodes within or over the muscle bellies (Voight and Wieder, 1991; Grabiner et al, 1992b; Karst and Willet, 1995; Powers et al, 1996; Sheehy et al, 1998; Witvrouw et al, 1996; Laprade et al, 1998, Cesarelli et al, 2000), while others have placed them relative to the knee joint lines (Andriacchi et al, 1984), over the largest area of muscle mass (Rice et al, 1995, Ng and Mann, 1996), in relation to motor points (Wheately and Jahnke 1951; MacIntyre and Robertson, 1992; Zakaria et al, 1997), at a set distance from the patella (Adler et al, 1983; Callaghan et al, 2001b; Cowan et al, 2000, 2003), at the midpoint of muscle (Lam and Ng, 2001), on the most prominent part of muscle (Väätäinin et al, 1995a) or on the skin overlying the muscle (Schaub and Worrell, 1995).

Both surface (Cesarelli et al 2000; Cowan et al, 2000; 2003; Karst and Willet, 1995; Voight and Wieder, 1991; Witvrouw et al, 1996) and fine wire electrodes (Cerny, 1995; Powers et al, 1996) have been used to the evaluate vastus medialis oblique / vastus lateralis relationships in PFPS patients. The advantage of surface EMG is the relative ease of use both in terms of application and subject comfort (Basmajian and De Luca, 1985). A limitation of surface EMG is the reduced specificity of the technique and the confounding problems induced by cross talk noise from adjacent muscles under examination (Basmajian and De Luca, 1985). This is potentially problematic in studies assessing dynamic muscle work where impedance may be altered as heterogeneous connective tissue passes beneath the recording electrodes or over motor points (Basmajian and De Luca, 1985; Sczepanski et al, 1991).

Despite these concerns, moderate reliability (Powers, 1996) and high reliability (Ng, 2002) has been reported for studying vastus medialis oblique / vastus lateralis muscle balance ratios. However, the question of validity might be more concerning with Haig et al (2003) in a cadaver experiment demonstrating that expert anatomists could identify the vastus medialis muscle with wire electrodes with a success rate of 100%, however the vastus lateralis could only be identified with a success rate of 70%. Thus, the question arises if investigators are actually assessing what they think they are assessing.

Thus the widespread variations in EMG methodologies and doubts about validity make it difficult to compare and contrast evidence from different investigators, and reach an overall consensus on the topic of vastus medialis oblique selective activation.

3.5 STANDARDISED MEASUREMENT POSITIONS

Controversy exists as to the optimal position(s) to selectively activate and train the vastus medialis oblique. Goh (2000) commented "Can the vastus medialis oblique be targeted with selective exercises preformed by patients who are not contortionists?"

Brownstein et al (1985) and McConnell (1986) utilised the information of Bose et al (1980) to suggest that hip adduction exercises could provide a mechanism whereby the vastus medialis oblique could be isolated. Investigations into the effect of hip adduction to enhance vastus medialis oblique activation have been tested both in weight bearing (Hodges and Richardson, 1993) and non weight bearing positions (Cerny, 1995; Hanten and Schulthies, 1990, Grabiner et al, 1992a; Laprade et al, 1998). Subsequently, some studies have shown selective activation of the vastus medialis oblique (Hanten and Schulthies, 1990; Hodges and Richardson, 1993), while others have not (Cerny 1995; Karst and Jewett, 1993; Laprade et al, 1998).

Methodological variations in test positioning also make for difficulty in interpretation. For example, Hanten and Schulthies (1990) used different knee joint angles when normalising the knee extension and hip adduction measurement (knee extension was measured at 60^0 flexion and hip adduction with the knee extended), thereby adding experimental variation of different muscle lengths, and the effect of changing muscle length on intramuscular placement of the fine wire indwelling electrodes.

It should be noted that the anatomical rationale for a supposed functional link between the adductors and vastus medialis oblique remains contentious (Karst and Jewett, 1993). An alternative rationale for hypothesising an increase in vastus medialis oblique activity ratio during hip adduction exercises is that muscle groups crossing the medial aspect of the knee joint, the vastus medialis oblique and medial hamstrings, might be activated in response to stress of the medial structures, such as joint capsule and medial collateral ligament, in order to augment and protect those passive structures by providing dynamic support (Kim et al, 1995). The presence of sensory receptors in ligaments and identification of ligamentous muscular reflexes support this hypothesis (Brand, 1986; 1989). Therefore if this factor is important the position of the abductor moment to cause adduction muscular stimulation needs to be distal to the knee joint line, this is the case in some studies (Hanten and Schulthies 1990; Grabiner et al, 1992a; Zakaria et al, 1997), but not in others (Earl et al 2001; Hertel et al, 2004; Laprade et al, 1998; Miller et al, 1997b; Rice et al, 1995).

It has been shown that when closed chain activities are compared with open chain activities in healthy subjects the vastus medialis oblique muscle fires earlier than the vastus lateralis and that the overall EMG amplitude was greater during non-weight bearing closed chain testing compared to non-weight bearing open chain testing (Stensdotter et al, 2003). Hence the contradictory results from investigations into vastii onset timing (Cowan et al, 2001a; 2002a; 2003; Grabiner et al, 1992a; Karst and Willett; 1995), may be related to the weight bearing status of the individual during testing.

Similarly, varying degrees of hip position have been investigated in weight bearing (Cerny, 1995; Miller et al, 1997a; Ninos et al, 1997; Willet et al, 1998) and non-weight bearing positions (Cerny, 1995; Mirzabeigi et al, 1999; Ng and Man, 1996; Signorile et al, 1995; Sykes and Wong, 2003; Wheately and Janke, 1951). Again the results are contradictory, for example, some investigators report selective vastus medialis activation with external hip rotation (Wheately and Janke, 1951; Sykes and Wong, 2003), while others not (Cerny, 1995; Lam and Ng, 2001; Livecchi et al, 2002; Miller et al, 1997a). Given the number of potential variables in these studies it is difficult to derive any definitive conclusions.

In conclusion the contradictory results on selective vastus medialis oblique activation may be related to the different positions used to test for selective vastus medialis oblique activation, which involves different degrees of weight bearing, varying angles of lower limb rotation, multi joint versus single joint configuration testing and varying positions of applied resistance relative to the knee joint line. All these variables may cloud the issue over whether the vastus medialis oblique can be selectively activated.

3.6 ANATOMICAL VARIATIONS

Willan et al (1990) proposed that anatomical variations could account in part for some of the inter subject variability found in comprehending the EMG recordings of the vasti muscles. In a study on the morphology of the vastus lateralis Willan et al (1990) described two heads for the vastus lateralis muscle in some cadavers, but not others, with variations in the interface between the vastus intermedius and vastus lateralis. There were also differences in quadriceps topography between the right and left sides (Willan et al, 1990). Additionally, the vastus lateralis has been described has having two components, namely a vastus lateralis and vastus lateralis obliquus (Hallisey et al, 1987; Weinstabl et al, 1989), which may be separated by a fascial plane (Farahmand et al, 1998). Indeed, variations in the fibre direction and anatomical attachment of the vastus lateralis obliquus may be a contributory factor in some patients with PFPS (Hallisey et al, 1987).

Similar anatomical variations in the vastus medialis oblique muscle have been documented (Bose et al, 1980). Bose et al (1980) noted that the direction of the vastus medialis oblique muscle fibres could be variable on both sides in any one individual. Variations in the reported orientation of the proximal vastus medialis longus and the distal vastus medialis oblique fibres have also been reported in the literature (Farahmand et al, 1998; Hubbard et al, 1998; Jacobson and Flandry, 1989; Lieb and Perry, 1968; Nozic et a1, 1997; Peeler et al, 2005; Raimondo et a1, 1998; Reider et al, 1981b; Terry, 1989; Weinstabl et al, 1989) and appear in part to be related to the reference axis used to measure fibre orientation (Table 3.1). Furthermore evidence for an 'areolar fascial plane' or 'fascial investment' has been described separating the distinct fibres of the vastus medialis longus and vastus medialis oblique supporting the idea of a two component muscle in some specimens (Lieb and Perry, 1968; Weinstabl et al, 1989). However, in a review of fifty cadavers Nozic et al (1997) could only identify a fascial plane in one specimen.

The widespread variability in the anatomy of the vastus medialis oblique and vastus lateralis muscles may threaten the validity of information gathered from EMG measurements and obtained from different subjects.

Table 3.1: Reported orientations of proximal (VML) and distal (VMO) fibres of the vastus medialis muscle

Author(s)	Year	N	VML (degrees)	VMO (degrees)	Axis
Lieb and Perry	1968	6	15-18	50-55	Femoral Shaft
Reider et al	1981b	48	-	55-70	Rectus femoris tendon
Jacobsen and Flandry	1989	-	-	65	-
Terry	1989	-	15-18	50-55	Sagittal plane
Weinstabl et al	1989	115	15-18	46-52	Femoral Shaft
Nozic et al	1997	50	mean 11.5	mean 52.2	Femoral axis
Hubbard et al	1998	229	6-28	28-70	Femoral shaft
Farahmand et al	1998	12	13-19	41-59	Femoral axis
Raimondo et al	1998	21	13-26	33-60	Femoral Shaft
Peeler et al	2005	24	22	57	Femoral Axis

3.7 STATISTICAL CONSIDERATIONS IN THE MEASUREMENT OF VASTUS MEDIALIS OBLIQUE/VASTUS LATERALIS TIMING

One of the major problems in the assessment of muscle timings is how to determine the onset of muscle activity from the electromyographic trace. Methods have included; the point in time at which the EMG amplitude increases beyond the baseline (Voight and Wieder, 1991; Witvrouw et al, 1996), increases in amplitude one standard deviation (Karst and Willet, 1995), increases in amplitude by three standard deviations (Gilleard et al, 1998), increases in amplitude for three standard deviations, for a minimum of 25ms (Cowan et al, 2000; 2001a; 2003), the onset of peak VMO and VL activity (Sheehy et al, 1998), activity exceeding 5% of that obtained during a maximum isometric contraction (Powers et al, 1996) and enveloped EMG start and end points related to a knee position trace (Cesarelli et al, 1999). The conflicting results on vastii timing (Cowan et al, 2000; 2001a; 2003; Voight and Wieder, 1991; Witvrouw et al, 1996) may in part be related to variations in statistical analysis.

3.8 SUMMARY

The contradictory results obtained from studies investigating vastus medialis oblique / vastus lateralis activation could be due to different methods of EMG, different electrode placements and techniques, inter subject anatomical differences, statistical differences and the performance of similar, but not identical exercises in different weight bearing positions. These confounding variables make it almost impossible to derive any uniform conclusions regarding the evidence underpinning the rationale for prescribing various knee exercises to selectively target the vastus medialis oblique muscle. It is therefore not surprising that clinicians are rather confused about whether the vastus medialis oblique muscle can be selectively activated during the rehabilitation of PFPS, and if possible how best to achieve this goal (Goh, 2000).

ELECTRONIC APPENDIX 4

4.1 INTRODUCTION - PATELLA TAPING, STRETCHING AND ORTHOTICS

The following Electronic Appendix investigates the role of patella taping, soft tissue stretching and feet orthoses in the management of PFPS.

4.2 PATELLA TAPING IN THE MANAGEMENT OF PFPS

The purpose of the McConnell taping procedure was originally to correct abnormal patellar tracking to allow the patient to engage in physical therapy exercise pain free (McConnell, 1986). There are several variations of the taping procedure recommended, depending on the assessed orientations of the patient's patella (e.g. patella glide in the coronal plane, tilt in the sagittal and frontal planes and/or rotation in the coronal plane) (Grelsamer and McConnell, 1998). It has been stated that nearly all patients require a medial glide of the patella (McConnell, 1986). Correction is accomplished by way of application of specialised adhesive tape applied across the anterior aspect of the patella (Pfeiffer et al, 2004). Taping is deemed to be successful if during the assessment procedure a 50% reduction in pain can be achieved, with a symptom provocation test (Grelsamer and McConnell, 1998, p123).

Alternative taping procedures for the patellofemoral joint and surrounding structures have been described (Crozier, 1989; Macdonald, 1991), but on reviewing the literature these alternative techniques have not stimulated as much interest in physiotherapy research in contrast to McConnell's' taping procedures. Furthermore taping procedures involving the gluteal muscles and the feet have also been described (Grelsamer and McConnell, 1998; McConnell, 2002), however these techniques remain to be investigated. Each of these theories are now examined in turn.

4.2.1 Patella Taping Theory

Many theories have been postulated to explain the benefits of patella taping, including 1) mechanical repositioning of the patella within the femoral trochlea to improve patella tracking 2) mechanical repositioning of the patella to improve the patella lever arm 3) reduction in pain through neural modulation 4) reduction in pain by off-loading pain sensitive soft tissues 4) improvement in vastus medial oblique / vastus lateralis muscle imbalance 5) improvement in proprioception 6) changes in patella osseous or intra articular pressure.

4.2.2 Mechanical Repositioning of the Patella within the Trochlea

Taping techniques were originally based on the concept that proper alignment of the patella in the patellofemoral groove will decrease pain with activity, allowing facilitation of the vastus medialis oblique muscle (Bockrath et al, 1993). The basis of this philosophy was that passive correction of patella subluxation; tilt and/or rotation would decrease pain during quadriceps femoris muscle rehabilitation (Kowall et al, 1996). Accepting, however, that identification of patella position is unreliable (Fitzgerald and McClure, 1995; Watson et al, 1999; 2001; Powers et al, 1999b), the benefit of identifying and passively correcting ‘patella position’ is questionable.

4.2.3 Mechanical Repositioning of the Patella to improve the Patella Lever Arm

Another possible mechanical mechanism proposed to explain the beneficial effects of patella taping suggested is that the taping limits the distal displacement of the patella during knee flexion, anchoring the patella to the medial aspect to the femur (Conway et al, 1992). This would position the knee extensor moment arm in a more advantageous position, thereby accounting for an improvement in strength and quadriceps function (Conway et al, 1992; Ernst, et al, 1999). This would presumably improve perceived stability on the knee.

4.2.4 Pain modulation

Pain can directly inhibit quadriceps activation and force production (Stokes and Young, 1984). Bockrath et al (1993) believed that taping provided a strong inhibitory stimulus via the large fibre afferents at the dorsal horn of the spinal cord to block the small diameter input through the pain gate mechanism. It has also been postulated that taping might increase mechanical pain thresholds by generating hypoalgesia due to the stimulation of the periaqueductal grey area of the medulla, creating descending noradrenergic system inhibition at the dorsal horn (Wilson, 1995; Wright, 1995; Herrington and Payton, 1997).

4.2.5 Off-Loading Of Pain Sensitive Soft Tissues

Dye et al (1999) proposed that the sudden decrease in pain associated with taping was probably attributed to the unloading of regions of mechanically irritated and swollen peripatellar soft tissues such as synovium rather than correcting malalignment.

4.2.6 Vastus Medialis Oblique/Vastus Lateralis Muscle Imbalance

Westfall and Worrell (1992) proposed that patella taping would increase the vastus medialis oblique/vastus lateralis amplitude ratio, which in turn could improve patella tracking. Cowan et al (2006), however, was unable to support the premise that the amplitude of vasti activity was altered by patella taping. However, in keeping with more recent evidence on vastus medialis oblique/vastus lateralis muscle temporal ratios (Cowan et al, 2002a; 2002b; 2003), both Gilleard et al (1998) and Cowan et al (2002b) suggested that taping was more likely to work by altering the onset timing of the vastus medialis oblique activity relative to the vastus lateralis muscle, thus potentially improving patella tracking. The mechanism of vastii onset timing changes may be related to taping altering the length/tension muscle relationships (Parsons and Gilleard, 1999), for example as a result of increased knee flexion angles during the stance phase of gait (Salsich et al, 2002).

4.2.7 Proprioception

Callaghan et al (2002) suggested patellar taping could enhance proprioceptive sensory function through afferent input from articular, muscular and cutaneous stimuli. These neural inputs might play a role in mediating pain at a central level (Callaghan et al, 2002). Stretch sensitive mechanoreceptors in the skin of the knee and thigh may convey information about knee joint proprioception (Edin, 2001; Garnett and Stephens, 1981) and cutaneous stimulation may alter both the recruitment threshold and the recruitment order of motor units (Garnett and Stephens, 1981; Jenner and Stephens, 1982), altering neural motor output.

4.2.8 Changes in Intrarticular Pressure

Small changes in patellofemoral joint mechanics may alter the location of the contact surface area (Powers et al, 1997a; Gilleard et al, 1998). The change in contact area may serve to reduce contact stress over a sensitive area thus facilitating pain free function (Powers, 1998). Thus pain reduction may be associated with subtle changes in intraarticular or intraosseous pressure so relieving symptoms of pain (McConnell, 1986).

4.3 A SYSTEMATIC REVIEW AND CRITIQUE OF SCIENTIFIC RESEARCH SURROUNDING PATELLA TAPING

The data bases of Medline, CINAHL, Sports Discus and Web of Science were searched using combinations of the following key words and phrases; patella, taping, vastus medialis oblique, vastus medialis, vastus lateralis, patellofemoral, anterior knee pain, pain, strapping(s), proprioception. The results revealed a wide variation in study methodology, with marked differences in the standardisation of taping force, taping techniques such as whether multiple patella malalignment were assessed and corrected and the degree of taped skin coverage (Table 4.1).

Electronic Appendix 4

Table 4.1: Studies investigating patella taping

Study	**N**	**Type**	**Taping force** NS= not stated	**Skin coverage** NS= not stated	**50% pain reduction** NA= not applicable	**Outcomes**
Bockrath et al (1993)	PFPS=12	McConnell	NS	NS	Yes	VAS, radiographs
Callaghan et al (2002)	Healthy=52	Unidirectional	Inter applier standardisation	50% total knee circumference	NA	Angle reproduction, threshold to movement
Cerny (1995)	PFPS=10 Healthy=21	McConnell	NS	NS	Yes	VAS, EMG
Cowan et al (2002c)	PFPS=10 Healthy=12	McConnell	NS	NS	Yes	VAS, EMG, Motion analysis
Cowan et al (2006)	PFPS=10 Healthy=12	McConnell	NS	NS	Yes	VAS, EMG
Cushnaghan et al (1994)	PFPS=14	Unidirectional	NS	NS	No	Pain diary
Ernst et al (1999)	PFPS=14	McConnell	NS	NS	No	Motion analysis
Gigante et al (2001)	PFPS=16	McConnell	NS	NS	No	CT scan
Gilleard et al (1998)	PFPS=14	McConnell	NS	NS	Yes	Motion analysis
Handfield and Kramer (2000)	PFPS=36	McConnell	NS	NS	Yes	Isokinetic tests
Hinman et al (2003a)	OA=18	McConnell	NS	NS	No	VAS, gait velocity
Hinman et al (2003b)	OA=20	McConnell	NS	NS	No	VAS, WOMAC, SF-36
Herrington and Payton (1997)	PFPS=20	McConnell	NS	NS	No	EMG, VAS
Herrington (2001)	PFPS=14	McConnell	NS	NS	No	Isokinetic tests, VAS
Herrington (2004)	Healthy=40	? Unidirectional	NS	NS	NA	Hop test
Herrington et al (2005)	Healthy=10	?Unidirectional	NS	NS	NA	EMG, Motion analysis
Kowall et al (1996)	PFPS=25	McConnell	NS	NS	No	Radiographs, isokinetic tests, radiographs
Larsen et al (1996)	PFPS=25	Unidirectional	NS	NS	No	Radiographs
Mungoven et al (1991)	Healthy=10	McConnell	NS	NS	No	EMG, video
Ng and Cheng (2002)	PFPS=15	McConnell	Standardised	NS	No	VAS, EMG
Ng (2005)	Healthy=29	McConnell	Standardised	NS	NA	EMG
Pfeiffer et al (2004)	Healthy=18	Unidirectional	NS	NS	No	Kinematic MRI
Parsons and Gilleard (1999)	Healthy=13	Unidirectional	NS	NS	No	Motion analysis, EMG
Powers et al (1997b)	PFPS=15	McConnell	NS	NS	Yes	Motion analysis
Salsich et al (2002)	PFPS=10	McConnell	NS	NS	Yes	Motion analysis, EMG
Somes et al (1997)	PFPS=9	McConnell	NS	NS	Yes	Radiographs, VAS
Tobin and Robinson (2000)	Healthy=18	McConnell	NS	NS	NA	EMG
Werner et al (1993a)	PFPS=48	McConnell	NS	NS	NS	EMG, isokinetic tests
Wilson et al (2003)	PFPS=71	McConnell	NS	NS	NS	VAS
Worrell et al (1998)	PFPS=12	McConnell	NS	NS	NS	MRI

MRI = Magnetic Resonance Imaging CT = Computer Tomography VAS = Visual Analogue Scale PFPS = Patellofemoral Pain Syndrome
EMG = Electromyography SF-36 = Short From 36 Questionnaire WOMAC = Western Ontario and McMaster universities osteoarthritis index

4.3.1 Mechanical Repositioning of the Patella within the Trochlea

McConnell (1986) and Gerrard (1989) in uncontrolled studies reported a high success rates with PFPS treatment regimes in which patella taping was used to correct perceived patella malalignment. In contrast, Kowall et al (1996) investigated the effects of adding patellar taping to standard physiotherapy interventions and reported similar improvements in both taped and 'untaped' groups as regards improved pain, radiographic findings and EMG activity. Similarly Clark et al (2000) found no additional benefit of taping to standard physiotherapy regimes without tape. It should be noted that in Kowall's, study the tape was applied only for the duration of the exercise. Clinically, it has been suggested that taping needs to be continually applied for at least two weeks for optimum benefit (Herrington and Payton, 1997). Inherent problems with patella taping, however, have been documented including, poor patient reproduction of taping procedures, loss of effect with activity and skin breakdown (Grace, 1997), hence the long term value of taping may be limited. Furthermore approximately 5% of patients who require patella taping are allergic to the zinc oxide tape commonly used for patella taping (Grelsamer and McConnell, 1998).

Bockrath et al (1983) studied the effect of patellar taping in twelve patients using Merchant radiograph views and visual analogue scales. These authors demonstrated a reduction in perceived pain, but there was no significant change in patella position. This study only measured patellofemoral congruency at 45^0-knee flexion. Therefore it cannot be excluded that changes in patella position are possible at other angles of motion. Indeed, this result was perhaps not surprising as patella position is determined by the bony configuration of the femoral groove beyond 30^0 flexion (Hehne, 1990). In the 0^0 to 30^0 knee flexion patella orientation is determined by the soft tissues (Hehne, 1990), hence in this range the patella may be more susceptible to alteration by taping.

Larsen et al (1995) and Pfeiffer et al (2004) using radiographs and MRI respectively were able to demonstrate a change in patella position with medial patella glide taping. This position, however, was not maintained after approximately fifteen minutes intensive exercise (Larsen et al, 1995). Interestingly, in the Larsen et al (1995) study the increase in lateral patella shift in the taped group post exercise was less than that of the non-taped group. Larsen et al (1995) postulated that lateral displacement of the patella might be due to; 1) vastus medialis fatigue increasing the relative lateral vector force pull, 2) iliotibial band tightness as a result of enlargement of the tensor fascia lata and quadriceps muscle secondary to fluid and blood shifts that occur during exercise and 3) the medial retinacular structures might have increased elasticity during exercise. Whether these findings in healthy subjects are relevant to patellofemoral pain patients is debatable. Furthermore, both Larsen et al (1995) and Pfieffer et al (2004) only examined medial glide techniques, which is only one component of the McConnell taping procedure, which may limit the generalisability of the results.

4.3.2 Mechanical Repositioning of the Patella to Improve the Patella Lever Arm

Increased quadriceps power with patella taping has been noted (Ernst et al, 1999; Handfield and Kramer, 2000) and associated with significant reductions in pain (Handfield and Kramer, 2000). Conway et al (1992), however, reported that despite an improvement in torque generation with the taped condition, there was a poor correlation (r = -0.14) between perceived pain and isokinetic strength, which did not support the argument that a reduction in pain necessarily resulted in greater quadriceps force production. Interestingly, the effect of medial taping in asymptomatic pain free subjects actually impaired functional performance (hop distance) (Herrington, 2004), reduced peak stance flexion angle and angular velocity during stair descent (Herrington et al, 2005), supporting the premise that pain mechanisms are not solely responsible for altered knee function with patella taping (Herrington, 2004; Herrington et al, 2005), perhaps providing further evidence of a mechanical effect.

4.3.3 Pain Modulation

Cowan et al (2002a), reported that patella taping as described by McConnell (McConnell, 1986) was superior to placebo tape. Reports on the mean reduction of pain using visual analogue scales range from 13% (Herrington and Payton, 1997), 25% (Cushnaghan et al, 1994), 50% Bockrath et al (1993), 67% (Cowan et al, 2002a), 78% (Powers et al, 1997b), 93% (Salsich et al, 2002), 94% (Cerny, 1995). Interestingly, in a study of knee osteoarthritis patients, patella taping reduced pain by 38% to 48% and was maintained 3 weeks after the cessation of tape usage (Hinman et al, 2003a), suggesting the effect of patella taping does not immediately diminish and may have longer acting pain modulation effects.

Wilson et al (2003), however, in a single blind study of medial, neutral and lateral glide taping procedures in a cohort of 71 NHS PFPS patients (mean age 34) found that the mean reduction in pain was only 16%, 35% and 33% for the medial, neural and lateral glide patella taping techniques respectively. Hence the medial glide technique commonly advocated by McConnell (McConnell, 1986) actually produced the least pain reduction.

4.3.4 Off-Loading Of Pain Sensitive Soft Tissues

Cushnaghan et al (1994) studied fourteen patients (mean age 70.4 years) with patellofemoral osteoarthritis. These authors used a randomised single blind cross over trial of three different forms of taping. Each tape (medial, lateral or neutral) was applied for four days with three days of no treatment between tape positions. Results demonstrated that medial taping was significantly better than neutral or lateral taping for pain scores, symptoms change and patient preference. Thus the direction of taping appeared related to the magnitude of pain reduction. It was proposed that the direction of taping could potentially alter patella tracking or ‘off load’ pain sensitive soft tissue structures (Cushnaghan et al, 1994). The high mean age of the participants may not be applicable to the younger patient with PFPS. The results of Cushnaghan et al (1994) appear to conflict with the larger study (n=71) of Wilson et al (2003) who found no additional benefit with medial taping in a study of PFPS patients.

4.3.5 Vastus Medialis Oblique/Vastus Lateralis Muscle Imbalance

Gilleard et al (1998) in a study of fourteen female subjects with patellofemoral pain demonstrated that taping caused earlier activation of the vastus medialis oblique and postulated that this may improve patella tracking. Similarly, Cowan et al (2002a) reported an improvement in the temporal activation of the vastus medialis oblique relative to the vastus lateralis in PFPS patients, with an associated reduction in pain (Cowan et al, 2002a). Tobin and Robinson (2000) noted a decrease in vastus lateralis EMG amplitude activity relative to the vastus medialis oblique with vastus lateralis inhibitory strapping. Certainly, the raw enveloped data appeared to show a generally trend for reduced vastus lateralis activity. The EMG data, however, was not normalised. Whether such changes facilitate patella tracking that occur in PFPS remains to be seen. No difference in vastus medialis oblique onset timing relative to the vastus lateralis could be demonstrated in healthy subjects (Ng, 2005). Indeed, it was noted that in healthy subjects vastus medialis oblique had a mean later onset time relative to the vastus lateralis muscle. Again the study of Ng (2005) demonstrates the problem of extrapolating evidence from healthy subjects to PFPS patients.

Westfall and Worrell (1992) also reported that patella taping increased the vastus medialis oblique/vastus lateralis amplitude ratio. Conversely, Cerny (1995) and Herrington and Payton (1997), however, reported taping not to have any overall effect on vastus medialis oblique/vastus lateralis amplitude activity during isometric quadriceps contractions or during a stair descent activity (Herrington et al, 2005). Hence once again the evidence is conflicting.

4.3.6 Proprioception and Joint Sense

Callaghan et al (2002) demonstrated patella taping improved joint reposition sense in healthy individuals with poor proprioception. Salsich et al (2002) reported increased knee flexion angles and increased knee extensors moments with patella taping, but no increase in concurrent quadriceps femoris EMG activity. The lack of increased EMG activity would suggest that other muscles and joint kinematics, which contribute to knee extensor moment, besides those acting directly at the knee, were responsible for the increased knee extensor moment. Both Ernst et al (1999) and Salsich et al (2002) postulated that, by decreasing pain and promoting a sense of knee joint stability patella taping could indirectly bring about a change in body position, which would allow a greater knee extensor moment.

Compensatory increases in trunk flexion in patients ascending stairs after total knee arthroplasty have been noted (Berger et al, 1990). The change of the centre of mass position with respect to the knee and hip joint transfer the demand from the knee extensors to the hip extensors to overcome the tendency of the body weight to flex the hip and knee. The reduced work of the quadriceps in the forward lean position results in a smaller patellofemoral joint reaction force (Berger et al, 1990). Ernst et al (1999) postulated that a similar situation may exist with patellofemoral pain patients and that by increasing confidence in the affected knee through taping may result in reduced trunk flexion and re-establish normal quadriceps work. Hérbert et al (1994) demonstrated that patellofemoral pain patients have altered kinesiology. However, unexpectedly these authors found, during a sit to stand task that PFPS patients demonstrated reduced trunk flexion not increased trunk flexion causing increased patellofemoral stress. Hence PFPS patients did not demonstrate a strategy to decrease the knee extensor moment (Hérbert et al, 1994). The resulting increased loads potentially increase pain, which may in turn cause reflex inhibition of the quadriceps (Powers et al, 1997b). Whether taping would reduce pain, restore normal trunk kinesiology and reduce patellofemoral joint stress remains to be tested.

Patella taping effects on ambulation during gait and stair activities have also been studied (Powers et al, 1997b). In this study a small, but significant increase in loading response during knee flexion was observed. It was suggested that the increased knee flexion angle during midstance phase might indicate an increased willingness to load the knee, thus permitting increased loading response, improving shock absorption, quadriceps activity and tolerance of increased patellofemoral joint reaction force (Powers et al, 1997b).

4.3.7 Changes in Intrarticular Pressure

No evidence for changes in intrarticular or osseous patella pressure with patella taping could be found.

4.4 PATELLA TAPING METHODOLOGICAL CONSIDERATIONS

If taping has a mechanical effect on the patella then the taping force or tension applied through the tape should be carefully controlled in any study. A review of the studies identified (Tables 43.2 and 43.3), demonstrated that only three studies (Callaghan et al, 2002; Ng and Cheng, 2002; Wilson et al, 2003) make any reference to taping force. Similarly, if through the activation of skin mechanoreceptors is how patella tape predominately works, then the area of skin covered by the tape should be carefully controlled; again skin coverage was only reported in one study (Callaghan et al, 2002).

Table 4.2: Patella taping journal articles

Multidirectional taping = taping with correction for glide, tilt and rotation
Unidirectional taping = taping with correction for one component only, usually medial glide
Strapping force = force used to apply tape to the skin NS (Not stated) or yes as described
Skin coverage = cross-sectional area of skin covered by tape = NS not stated or 'yes' as described
Pain ¯ 50% = pain reduction in pain by 50% on pain scale on tape application or NS = not stated

Study	No of Subjects	Testing activity(s)	Outcome measures	Conclusions
Bockrath et al (1993)	PFPS patients = 12 5 male 5 female Mean age = 29	Step down with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Merchant view with isometric quadriceps contraction VAS	No significant change in patella position with patella taping Significant 50% reduction in pain with patella taping
Callaghan et al (2002)	Healthy subjects = 52 25 male 27 female Mean age = 23	Seated knee extension **Unidirectional taping** **Strapping force** inter applier standardisation **Skin coverage** 50% total circumference knee **Pain ¯ 50%** NS	1. passive angle reproduction 2. active angle reproduction 3. threshold to detection of passive movement Proprioception tests	In healthy subjects with poor proprioception ($>5^0$) ability as measured by active and passive knee reproduction patella taping provided proprioceptive enhancement
Cerny (1995)	PFPS patients = 10 1 male 9 female Mean age = 27 Healthy subjects = 21 11 male 10 female Mean age = 27	Open and closed kinetic chain exercises with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** Yes	Fine wire EMG VAS	No significant difference in VMO:VL ratios in any group. 94% reduction in PFPS pain.

Table 4.2 Continued: Patella taping journal articles

Study	No of Subjects	Testing activity(s)	Outcome measures	Conclusions
Cowan et al (2002a)	PFPS patients = 10 3 male 7 female Mean age = 23 Healthy subjects = 12 4 male 8 female Mean age = 20	Stair stepping task before and after no tape, placebo taping and McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** Yes	Pain VAS Surface EMG and motion analysis	No change in the EMG onset of VMO VL activation relationship with the application of placebo or therapeutic taping conditions in the asymptomatic group. In PFPS group therapeutic tape significantly altered the temporal characteristic of VMO and VL activation in favour of VMO occurring before VL activation
Cushnaghan et al (1994)	PFPS patients = 14 4 males 10 females Mean age = 70	Medial, lateral and neutral patella taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	4 day pain diary	Medial patella taping resulted in a 25% reduction in pain
Ernst et al (1999)	PFPS patients = 14 14 females Mean age = 25	Vertical jump Lateral step up with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Motion analysis system and force plates	Significant increase in knee extensor power and moment during vertical jump and lateral step up with patella taping
Gigante et al (2001)	PFPS patients = 16 Median age = 21	Quadriceps relaxed and contracted between 0^0 and 15^0 knee flexion with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	CT scan with knees flexed 0^0 - 15^0	No significant difference in patella lateralisation or tilt with patella taping
Gilleard et al (1998)	PFPS patients = 14 female Mean age = 23	Stairs ascent/descent with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** Yes	Surface EMG Motion analysis	With taping the VMO muscle was activated earlier than the VL
Handfield and Kramer (2000)	PFPS patients = 36 10 males 26 females	Isokinetic exercise with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** Yes	Isokinetic testing	Significant increase in quadriceps torque with patella taping
Hinman et al (2003a)	Knee osteoarthritis patients = 18 6 male 18 females Mean age=67	Step test Timed up and go with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** No	VAS Gait velocity	No difference in walking speed or timed up and go, but significant improvement in stepping task Significant reduction in pain up to 50% with taping

Table 4.2 Continued: Patella taping journal articles

Study	No of Subjects	Testing activity(s)	Outcome measures	Conclusions
Hinman et al (2003b)	Osteoarthritis patients = 87 30 males 57 females	Nominated aggravating activity No tape, control tape and therapeutic tape Tape worn for 3 weeks and follow-up assessment at a further 3 weeks **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** No	VAS 5 point change in pain Likert scale WOMAC index SF-36	Significant reduction in pain (38-40%) in therapeutic taped group. Improvements maintained at 3 weeks follow-up from ceasing to use tape
Herrington and Payton (1997)	PFPS patients = 20 10 males 10 females	Isometric knee extension contractions at 120^0, 90^0, 60^0, 30^0 and 0^0 with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Surface EMG VAS	No difference in VM0:VL ratio activity. 13% reduction in pain scores.
Herrington (2001)	PFPS patients = 14 females Mean age = 23	Isokinetic testing with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Isokinetic testing at 60^0/s and 180^0/s VAS	Pain sores reduced by 69.5% and 76.9% at 60^0/s and 180^0/s respectively Significant increase on peak torque with taping
Herrington (2004)	Healthy subjects = 40 40 females Mean age = 20	Isokinetic testing and hop test with McConnell taping **? Unidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NA	Isokinetic testing at 180^0/s Single hop test	No significant difference in muscle torque between tape and no tape conditions Hop distance significantly reduced with tape compared to no tape
Herrington et al (2005)	Healthy subjects = 10 10 females Mean age = 21	Stair descent activity with McConnell medial taping **? Unidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NA	Motion analysis during stair descent and EMG	No significant difference in VMO/VL activity Significant reduction in peak flexion angle and angular velocity in taping condition
Janwantanakul and Gaogastigam (2005)	Healthy subjects = 30 30 females Mean age = 21	Repeated measures with McConnell vastus lateralis taping 1) inhibition taping 2) facilitation taping 3) no taping **Strapping force =** maximum stretch of tape **Skin coverage** NS **Pain ¯ 50%** NA	Stair descent Surface EMG	No significant difference between any of the taping groups in increasing vasti activity
Kowall et al (1996)	PFPS patients = 25 8 male 17 female Mean age = 29	Two exercise groups with and without tape with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Merchant and Laurin non weight bearing radiographic views VAS Surface EMG Isokinetic muscle testing	No difference in any of the variables between the groups
Larsen et al (1995)	Healthy subjects = 20 Mean age = 25	Patella taping before and after 15 minute exercise circuit with McConnell taping **Unidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Radiographs (modified Merchant's view PWB)	Taping did move the patella medially, but effect lost after 15 minutes of exercise

Table 4.2 Continued: Patella taping journal articles

Study	No of Subjects	Testing activity(s)	Outcome measures	Conclusions
Mungoven et al (1991)	Healthy subjects = 10 10 female Mean age = Age range = 20 –22	Sit to stand tasks with and without McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Surface EMG, videotape and force plate data	No difference in motion analysis time for completion of movement tasks. Significant reduction in VMO and VL EMG activity during sit to stand in the taping group
Ng and Cheng (2002)	PFPS patients = 15 8 male 7 female Mean age = 32	Single leg squat test before and after McConnell taping **Multidirectional taping** **Strapping force** standardised force **Skin coverage** NS **Pain ¯ 50%** NS	Knee pain VAS Surface EMG	Significant reduction in pain (48%) with patella taping Significant reduction in VM to VL EMG activity after taping
Ng (2005)	Healthy subjects = 29 15 male 14 female Mean age = 22	Single leg stand with posteroanterior perturbation McConnell taping **Unidirectional taping** **Strapping force** standardised force **Skin coverage** NS **Pain ¯ 50%** NA	Surface EMG	No significant difference in temporal activation of VMO relative to VL muscle
Pfeiffer et al (2004)	Healthy subjects = 18 18 female Mean age = 22	Patella taping before and after exercise circuit with McConnell taping **Unidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Kinematic MRI	Taping did move the patella medially, but effect lost after exercise
Parsons and Gilleard (1999)	Healthy subjects = 13 13 female Mean age = 22	Patella taping McConnell taping during stair ascent /descent **Unidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Motion analysis and EMG	Taping significantly delayed the muscle activation of VMO and VL during stair ascent, but not descent
Powers et al (1997b)	PFPS patients = 15 female Mean age = 27	Gait, ascending/descending ramps/stairs with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** Yes	Motion analysis	Small but significant increase in loading response during knee flexion across all conditions
Salsich et al (2002)	PFPS patients = 10 5 males 5 females	Stair ascent/descent with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** Yes	Motion analysis Force platforms Surface EMG on VL	Taping resulted in significant increase knee extensor moments, cadence, knee flexion angles and cadence
Somes et al (1997)	PFPS patients= 9 2 males 7 females Mean age = 34	Step down with McConnell taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Merchant view radiographs 45^0 open chain and 45^0 knee flexion closed chain VAS	Significant increase in lateral patellofemoral angle with patella taping in the closed chain position. No change in patellofemoral congruence angle. Pain reduced 45% with patella taping.

Table 4.2 Continued: Patella taping journal articles

Study	No of Subjects	Testing activity(s)	Outcome measures	Conclusions
Tobin and Robinson (2000)	Healthy subjects = 18 7 males 11 females	Stairs descent with and without vastus lateralis strapping with McConnell ITB taping **Unidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NA	Surface EMG	Strapping significantly reduced vastus lateralis activity
Whittingham et al (2004)	PFPS patients = 30 24 males 6 females Mean age = 19	Group 1) McConnell taping and exercise Group 2) Placebo taping and exercise Group 3) Exercise only 4 week programme **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	VAS score for pain in previous 24 hours Pain during step down activity	McConnell taping and exercise significantly better than placebo taping and exercise or exercise only in reducing pain
Wilson et al (2003)	PFPS patients = 71 39 males 32 females Mean age= 34	Step down tests with medial, neutral and lateral patella taping **Unidirectional taping** medial, lateral , neutral **Strapping force** light to moderate **Skin coverage** NS **Pain ¯ 50%** NS	Knee pain VAS scores	Reduction in pain for medial, neutral and lateral taping was 15.9%, 34.9% and 33.2% respectively.
Werner et al (1993a)	PFPS patients = 48 20 males 28 females	Isokinetic concentric and eccentric exercise with patella taping **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	Isokinetic testing Surface EMG	Only patients with clinical evidence of medial or lateral hyper mobility demonstrated increased muscle torque with lateral and medial patella taping respectively. No difference in EMG activity with or without taping
Worrell et al (1998)	PFPS patients = 12 2 males 10 females Mean age = 27	Supine with quadriceps relaxed with no taping, McConnell taping or Palumbo knee brace **Multidirectional taping** **Strapping force** NS **Skin coverage** NS **Pain ¯ 50%** NS	MRI images at 8 angles of knee flexion (10^0, 16^0, 25^0, 30^0, 34^0, 39^0, 41^0, and 45^0)	Patella taping and bracing influenced patella position (patellofemoral congruence angle and lateral patella displacement) at 10^0 knee flexion

Table 4.3: Patella taping (abstracts)

Study	No of Subjects	Testing activity(s)	Outcome measures	Conclusions
Arcand et al (1998)	PFPS patients = 20 8 male 12 female	Step down with McConnell taping and sham taping **Multidirectional taping** **Strapping force** NS **Skin coverage** with stockinette **Pain ¯ 50%** NS	VAS	Pain reduction noted in a greater number of McConnell taping group
Davies (1998)	PFPS patients = 8 3 male 5 female	'Specific activities' with McConnell taping	MRI imaging at 0^0, 10^0 and 20^0 knee flexion VAS	Significant reduction in pain and lateral patella displacement with taping
Millar et al (1999)	PFPS patients = 13 6 males 7 females	One leg squat No tape, placebo tape and McConnell taping	Surface EMG	No significant difference between groups No significant difference in pain, though trend to pain reduction in McConnell tape group
Nicholas et al (1996)	PFPS patients = 20	Weight bearing and non-weight bearing quadriceps exercises with McConnell taping	Surface EMG	One open chain and four closed chain exercises enhanced VMO activity over VL activity

Some investigators (Cerny, 1995; Cowan et al, 2002a; Gilleard et al, 1998; Handfield and Kramer, 2000; Powers et al, 1997b; Salsich et al, 2002) ensured a 50% immediate pain reduction on the application of the patella tape, while other investigators (Bockrath et al, 1993; Cushnaghan et al, 1994; Ernst et al, 1999; Gigante et al, 2001; Herrington and Payton, 1997; Herrington, 2001; Kowall et al, 1996; Ng and Cheng, 2002; Somes et al, 1997; Wilson et al, 2003; Werner et al, 1993a; Worrell, et al, 1998) did not ascertain a 50% immediate reduction in pain. Wilson et al (2003) commented that the 50% reduction 'rule' had no scientific basis and the question arose about how patients who did not achieve an immediate 50% in pain should be managed. Furthermore some investigators (Cushnaghan, et al, 1994; Wilson et al, 2003) did not apply the tape, with the multidirectional correction of patella glide, tilt and rotation, as proposed by McConnell (McConnell, 1986). Thus, it could be claimed that these studies did not investigate the taping technique advocated by McConnell.

4.5 PATELLA TAPING SUMMARY

Overall the evidence suggests that patella taping does appear to reduce pain in PFPS. The mechanism of action, however, remains unclear. Contradictory and conflicting results from patella taping studies can be attributed to different methods of assessment, the different biomechanical and physiological mechanisms explored and the different taping techniques used, despite using a similar taping philosophy.

4.6 SOFT TISSUE STRETCHING AND FLEXIBILITY IN THE MANAGEMENT OF PFPS

4.6.1 Introduction

The use of stretching techniques as a means of treating soft tissue hypomobility is widely advocated as a means of preventing injury as a well as forming an important component of a rehabilitation programme following injury or surgery (Schwellnus et al, 2003). Soft tissue 'tightness' of the hamstrings, quadriceps femoris, gastrocnemius/soleus musculature, patellar retinaculum and iliotibial band have all been inculpated as a possible cause(s) of patellofemoral pain (McConnell, 1986; 1995, 2002).

4.6.2 Theory of Soft Tissue Stretching and Flexibility

Stretching protocols

The proposed benefits of stretching have been attributed to 1) a direct decrease in muscle stiffness (defined as the force required to produce a given change in length) via passive viscoelastic changes) and 2) an indirect decrease due to reflex inhibition and consequent viscoelastic changes from decreased actin-myosin cross-bridging (Shrier and Gossal, 2000). It has been proposed, however, that an increase in stretch 'tolerance' is more important than a decrease in stiffness (Magnusson et al, 1996). Current recommendations advocate that one to four stretches daily be performed for 30 seconds holds and is sufficient in most patients to increase joint range of motion (some patients may require longer) (Shrier and Gossal, 2000).

4.6.3 Hamstrings

Hamstring 'tightness' has been considered as a contributory cause of PFPS (Swenson et al, 1987). Sound biomechanical rationale for hamstring shortening involvement in the aetiology of PFPS does exist. For example, Hsu et al (1993) demonstrated the increasing stabilising demands on the quadriceps femoris during stance phase, with increasing knee flexion angles. Thus if hamstring shortening contributes to increased knee flexion then this could potentially increase the load on the patellofemoral joint. Similarly, Winter (1983) demonstrated during running that 'hamstring tightness' caused increased flexion of the knee, thereby causing an in increased patellofemoral joint reaction forces. It has also been postulated that hamstring 'tightness' could alter patellofemoral tracking by externally rotating the lower leg and moving the tibial tuberosity laterally resulting in an increased Q-angle and altered patella tracking (Christou, 2004). Whether reduced hamstring length is a primary cause of PFPS is debatable as nociceptor withdrawal response and knee flexion facilitation is an accepted reaction to knee joint pain (Young and Stokes, 1987), hence it is difficult to delineate if muscle 'tightness' relates to structural length changes or as a result of altered neural mediated muscle tone changes.

4.6.4 Quadriceps Femoris

'Tightness' of the rectus femoris muscle might also affect patellar movement during knee flexion (McConnell, 1986). The complex patellofemoral joint kinematics (Reider et al, 1981a, van Kampen and Huiskes, 1990; Veress et al, 1979), and the apparent importance of vastus medialis oblique muscle in relation to optimal patella tracking (Cowan et al, 2001a; 2001b; Neptune et al, 2000), predetermines that a 'tight' quadriceps femoris mechanism may alter the timing of the patella as it enters the trochlea during knee flexion, resulting in abnormal tracking and abnormal patellofemoral contact stress.

4.6.5 Gastrocnemius/Soleus

Root et al (1977) claimed that gastrocnemius 'tightness' could result in compensatory pronation because dorsiflexion of the talocrural joint cannot occur and the movement is transmitted to the subtalar joint, which in turn could potentially alter tibial rotation and consequently patellofemoral joint mechanics (Tiberio, 1987).

4.6.6 Iliotibial Band and Patella Lateral Retinaculum

On the lateral side of the knee joint the lateral patella retinaculum, iliotibial tract and its associated attachments have also received much attention based on the premise that shortening of these structures might also contribute to lateral patella displacement (Doucette and Goble, 1992; McConnell, 1986; Puniello, 1993; Winslow and Yoder, 1995), causing abnormal patella tracking and possible patellofemoral pain (McNichol, 1981; Noble, 1980; Percy and Strother; 1985). Electrical stimulation of the iliotibial tract under general anaesthesia has however been reported to have no effect on the knee or patellofemoral joint motion (Kaplan, 1958) and as yet no consistent method of describing this structure had been described (Rouse, 1996). Kwak et al (2000), using cadavers did demonstrate a small, but subtle effect of the iliotibial band in altering patellofemoral contact stress. Mercer et al (1998) in a review of the iliotibial band dismissed the idea of it being a mobile band of connective tissue representing the insertion of tensor fascia latae and gluteus maximus running down the lateral aspect of the hip joint, thigh and knee joint to insert into the patella and tibia as often depicted in many anatomy text books. Due to the strong attachment of the iliotibial band to the linea aspera via the lateral intermuscular septum, the iliotibial band is effectively attached to the femur (Mercer et al, 1998). Hence many of the commonly advocated stretching techniques for the iliotibial band might be founded on a faulty conceptual understanding of the structure.

4.7 A SYSTEMATIC REVIEW AND CRITIQUE OF SCIENTIFIC RESEARCH SURROUNDING SOFT STRETCHING AND FLEXIBILITY

The data bases of Medline, CINAHL, Sports Discus and Web of Science were searched using combinations of the following key words and phrases; patella, patellofemoral, patellofemoral pain, anterior knee pain, McConnell, quadriceps, gastrocnemius, gastrocsoleus, soleus, tensor fascia lata(e), iliotibial band, ITB, hamstrings, flexibility, flexibility training, stretching, stretches. A review of the results revealed a large volume of studies covering disciplines from sport injury prevention, sports performance enhancement, rehabilitation and occupational health. Hence only some of the more pertinent studies relevant to PFPS rehabilitation are reviewed.

4.7.1 Hamstrings

Witvrouw et al, 2000a measured hamstring length and found no empirical evidence of a correlation between the development of PFPS and hamstring shortening. Piva et al (2005) (PFPS patients n = 30 and healthy controls n= 30) noted that PFPS patients did demonstrate significantly less flexibility of the hamstrings compared to healthy controls.

4.7.2 Quadriceps Femoris

Witvrouw et al (2000a) reported decreased quadriceps muscle flexibility as a significant predictor of PFPS development in previously healthy subjects. Similarly, Piva et al (2005) (PFPS patients n = 30 and healthy controls n= 30) noted that PFPS patients did demonstrate significantly less flexibility of the quadriceps compared to healthy controls.

4.7.3 Gastrocnemius/Soleus

Witvrouw et al (2000a) reported significant correlation between PFPS and gastrocnemius tightness. Again, Piva et al (2005) (PFPS patients n = 30 and healthy controls n= 30) noted that PFPS patients did demonstrate significantly less flexibility of the gastrocnemius/soleus muscles compared to healthy controls. It should be noted that one study, however, has failed to support the hypothesised link between excessive foot pronation altering tibial internal rotation in PFPS patients and hence altering patellofemoral tracking (Powers et al, 2002). Thus, the correlation between PFPS and gastrocnemius tightness might not be linked through the mechanism of increased foot pronation.

4.7.4 Iliotibial Band and Lateral Patella Retinaculum

Puniello (1993) claimed to demonstrate that iliotibial band tightness was a cause of reduced medial patellar glide in patients with patellofemoral dysfunction, however, this study was not blind, had no control and relied on subjective tester palpation skills therefore the conclusions of the study are questionable. Hilyard (1990) advocated the use of Maitland mobilisation techniques to stretch the distal portion of the iliotibial band. There appears to be no sound scientific evidence at present to support peripheral manual therapy techniques (Davies, 1995). Indeed, the test often used to test for iliotibial band tightness called Obers' test was actually initially devised to define a hip abduction contracture as a cause of low back pain and sciatica (Ober, 1936). Doucette and Goble (1992) demonstrated a statistically significant improvement in Ober's test between PFPS patients who improved with rehabilitation and those who did not improve. Similarly, Tunay et al (2003) also noted improvements in iliotibial band flexibility measured using Ober's test with rehabilitation.

Only limited indirect evidence exists describing exercises to conclusively lengthen the iliotibial tract (Fredericson et al, 2002), and no clear evidence of a direct correlation with patellofemoral pain exists to date. McConnell (2002) and Crossley et al (2002) have advocated the use of local mobilisation and massaging the lateral retinaculum and iliotibial band. Support for cellular, morphologic and functional changes in response to local soft tissue mobilisation and massage has been documented (Davidson et al, 1997; Gehlsen et al, 1999; Gregory et al, 2003), but has yet to be substantiated in PFPS.

4.8 FLEXIBILITY METHODOLOGICAL CONSIDERATIONS

The literature review on patellofemoral stretching confirmed that the most commonly prescribed stretches for 'tight' anatomical structures thought to contribute PFPS are hamstrings, quadriceps, gastrocnemius / soleus, and iliotibial band (Table 4.4).

Table 4.4: Commonly stretched anatomical structures in PFPS

Structure	Authors
Hamstrings	(Akarcali et al, 2002; Alaca et al, 2002; Clark et al, 2000; Colón et al, 1988; Crossley et al, 2002; Dursun et al, 2001; Eng and Pierrynowski, 1993; Gaffney et al, 1992; Harrison et al, 1999; McConnell, 1986; McMullen et al, 1990; Taylor and Brantingham, 2003; Thomeé, 1997, Witvrouw et al, 2000b; 2004a)
Quadriceps	(Akarcali et al, 2002; Alaca et al, 2002; Clark et al, 2000; Crossley et al, 2002; Dursun et al, 2001; Eburne and Bannister, 1996; Eng and Pierrynowski, 1993; Gaffney et al, 1992; Harrison et al, 1999; Taylor and Brantingham, 2003; Thomeé, 1997, Witvrouw et al, 2000b; 2004a)
Iliotibial band	(Akarcali et al, 2002; Alaca et al, 2002; Clark et al, 2000; Colon et al, 1988; Dursun et al, 2001; Gaffney et al, 1992; McConnell, 1986)
Tensor fascia latae	(Eburne and Bannister, 1996; Harrison et al, 1999)
Lateral retinaculum	(Eburne and Bannister, 1996; Crossley et al, 2002; Gaffney et al, 1992; Harrison et al, 1999)
Gastrocnemius/soleus	(Akarcali et al, 2002; Alaca et al, 2002; Clark et al, 2000; Colón et al, 1988; Dursun et al, 2001; Eburne and Bannister, 1996; Gaffney et al, 1992; Harrison et al, 1999; McConnell, 1986; Thomeé, 1997, Witvrouw et al, 2000b; 2004a)
Anterior hip capsule	(Crossley et al, 2002)
Hip adductors	(Alaca et al, 2002; Colón et al, 1988)

Only six studies shown in Table 3.4 (Clark et al, 2000; Gaffney et al, 1992; McMullen et al, 1990; Taylor and Brantingham, 2003; Witvrouw et al, 2000b; 2004a) documented the actual stretching protocol used in the study. Moreover, when comparing the studies that clearly stated the stretching protocol there were marked differences in the number of repetitions and hold time for the specific stretches, for example Clark et al (2000) used 10 repetitions stretches held for ten seconds each, Gaffney et al (1992) used three repetitions stretches held for twenty seconds each, McMullen et al (1990) used 30 repetitions held for 3 seconds each, Crossley et al (2002) and Witvrouw et al (2000b; 2004a) used three repetitions stretches held for thirty seconds each.

No study was found examining the effects of isolated flexibility training in PFPS sufferers, a conclusion supported by Hunt (2003).

4.9 FLEXIBILITY SUMMARY

The use and benefits of soft tissue stretching in the management of PFPS is well documented. There is, however, limited research documenting either the effects of stretching on specific anatomical structures in PFPS or investigating the optimum protocol to maximise treatment outcomes.

4.10 FOOT ORTHOSES IN THE MANAGEMENT OF PFPS

The use of foot orthoses (devices inserted between the foot and shoe to modify foot biomechanics) has been advocated as a useful adjunct to the management of PFPS in the clinical setting (Eng and Pierrynowski, 1993; Klingman et al, 1997; McConnell, 1995; McConnell and Greslamer, 1998; Saxena and Haddad, 2003). It is postulated that suboptimal biomechanics at the distal end of the kinetic chain could cause abnormal joint forces at the tibiofemoral and patellofemoral joints (McConnell, 1986; Powers, 2003a; Tiberio, 1987). The addition of foot orthoses in the management of patients may help to modify abnormal patellofemoral joint forces (McConnell and Grelsamer, 1998; Neptune et al, 2000) and ultimately reduce pain.

4.10.1 Theory of Foot Orthoses

There is considerable debate about the scientific rationale and benefits of orthotic prescription in the management of patients with lower limb musculoskeletal problems (Landorf and Keenan, 2000; Nawoczenski and Janisse, 2004). The mode of action remains contentious with potential beneficial mechanisms postulated to be biomechanical, physiological and/or psychological in origin (Table 4.5).

Table 4.5: Possible factors that foot orthoses influence

Biomechanical

Range of pronation (Eng and Pierrynowski et al; 1994; McClay and Manal, 1998; McCullouch et al, 1993)
Range of eversion (Novick and Kelley, 1990; Novick et al, 1992)
Pronation velocity (Novick and Kelley, 1990)
Range of internal tibial rotation (Nawoczenski et al, 1995; Stacoff et al, 2000)
Lower extremity impact load (Mündermann et al, 2003)
Loading rate of vertical ground reaction force (Mündermann et al, 2003)
Ankle inversion moments (Nigg et al, 2003)
Knee abduction and external rotation moments (Nigg et al, 2003
Modifications in the maximal vertical loading rate (Hreljac et al, 2000)
Modifications vertical force impact peak (Hreljac et al, 2000)

Physiological

Lower limb muscle electromyography modification (Hung and Gross, 1999; Tomaro and Burdett, 1993)
Alteration in proprioception (Stacoff et al, 2000)
Alterations in sensory feed back (Nigg et al, 1999)

Psychological

Comfort (Mündermann et al, 2001)

Discrepancies among studies investigating foot orthoses can be explained in part by anatomical variability in subjects' foot structure, difference in orthotic fabrication, differences in foot posting locations, variations in footwear, lack of statistical power (Nawoczenski and Janisse, 2004), inadequate information about subject characteristics, the specific aspects of function or physical symptoms that were affected by the intervention (Gross and Foxworth, 2003), the test surface and speed of ambulation (Nawoczenski et al, 1995).

An area of focus from a clinical standpoint has been the influence of foot pronation on lower extremity rotation and patellofemoral joint mechanics (McPoil and Cornwall, 2000; Powers et al, 2002). Structural abnormalities of the foot are believed to be one of the primary causes of excessive subtalar pronation (Tiberio, 1987). Certain bony deformities require compensatory subtalar motion in order to achieve normal lower extremity function during gait. Forefoot varus, plantarflexed fifth ray and rear foot varus fall into this category (Root et al, 1977). Limb length differences might also result in biomechanical compensatory pronation, affecting the side with the longer limb (Blustein and D'Amico, 1985), although not supported empirically (Bloedel and Hauger, 1995).

It is a common clinical assumption that excessive foot pronation results in excessive tibial internal rotation and that this in turn results in rotatory strain on the soft tissues of the lower extremity (Powers, 2003a). This assumption is based on the premise that there is direct correlation between the ranges of foot pronation and tibial rotation (McPoil and Cornwall, 2000). While theoretically the link between foot pronation and tibial internal rotation appears highly plausible (Tiberio, 1987), the evidence is somewhat contradictory, with some investigators reporting a clear link (Cornwall and McPoil, 1995) and other not (Reischl et al, 1999). At the heart of the argument supporting a link is that rear foot subtalar motion is directly related to movement of the tibia (Gross and Foxworth, 2003). There is, however, evidence, that the morphology of the tibiocrural joint might play a significant role in modifying talocrural joint forces (Morris, 1977), causing variability in the movement of the proximal lower limb.

Furthermore excessive tibial internal rotation caused by abnormal subtalar joint pronation would actually decrease the Q-angle and the lateral forces acting on the patella (Powers, 2003a). This is supported by the work of Huberti and Hayes (1984) and Cerny (1995) who demonstrated that when subjects were in a weight bearing position with the foot pronated the tibial tubercle would shift more medially and thus pulled the patella medially. These authors proposed that the smaller valgus vector and a smaller Q-angle might decrease the lateral patella tracking force. Given that lateral tracking of the patella has been postulated to contribute to the pathomechanics of PFPS (Insall, 1979), potential reductions in the Q-angle clinically may be beneficial, hence attempting to reduce the effects of pronation through the se of an orthotic device would be counter productive.

On the opposite side of the argument others describe a mechanism whereby to compensate for the lack of tibial external rotation caused by the failure of the foot to resupinate, the femur will have to internally rotate on the tibia such that the tibia is in relative external rotation (D'Amico and Rubin, 1986; Tiberio 1987; Powers et al, 1995). In turn excessive internal rotation of the femur would move the patella medially with respect to the anterior superior iliac spine and the tibial tuberosity thereby increasing the Q-angle and the lateral component of the quadriceps vector (Powers, 2003a). Lafortune et al (1994) analysed lower limb joint kinematics in subjects walking with different foot positions pronated, neutral and supinated. It was noted that increased internal or external tibial rotation caused by different foot positions was resolved at the hip joint in healthy individuals suggesting the impact of pronation was greater on the femur than on the tibia. The magnitude of the foot pronation, however, has been shown not to predict the degree of either tibial or femoral rotation (Reischl et al, 1999). The methodological limitations in the placement of the foot markers used in the Reischl et al (1999) study may limit the conclusion of this work (Gross and Foxworth, 2003).

Perhaps the wide variety of reports on pronation and its effects at the knee stem from the controversy regarding the measurement of the 'so called subtalar neutral' position (Elveru et al, 1988a; 1988b), often used to underpin orthotic prescription (Astrom and Arvidson, 1995; Ball and Afheldt, 2002). A reliability study of subtalar neutral and the various ankle measurements undertaken found the interclass reliability of determining subtalar neutral to be universally poor even for experienced therapists (Elveru et al, 1988a). Furthermore a review of the literature reveals the classic orthotic paradigm proposed by Merton Root to lack reliability, validity and is seldom strictly followed (Ball and Afheldt, 2002).

4.11 A SYSTEMATIC REVIEW AND CRITIQUE OF SCIENTIFIC RESEARCH SURROUNDING FOOT ORTHOSES

The data bases of Medline, CINAHL, Sports Discus and Web of Science were searched using combinations of the following key words and phrases; patella, patellofemoral, patellofemoral pain, anterior knee pain, knee, McConnell, orthotics, orthoses, shoe inserts and insoles, pronation, internal tibial rotation. Despite the apparent importance given to the use of orthotic in the management of patellofemoral pain (McConnell and Grelsamer, 1998), only one RCT incorporated foot orthoses use in the treatment program (Eng and Pierrynowski, 1993). A further three studies (Amell et al; 2000; Pitman and Jack, 1998; Saxena and Haddad, 1998) and one case study (Way, 1999) were identified investigating qualitative aspects of orthotic use in PFPS.

Eng and Pierrynowski (1993) reported that an eight week regime of soft foot orthoses in conjunction with a lower extremity stretching a strengthening program effected significantly greater reductions in pain during running, stair ambulation and squatting compared with pain reduction for a matched control group that preformed only stretching and strengthening. Way (1999) reported an A-B-A-B case study in which a thermoplastic device significantly improved functional and sporting activities for a college athlete with unilateral PFPS. In a retrospective study Pitman and Jack (1998) questioned 57 patients with PFPS six months after the supply and fitting of foot orthoses. The authors reported an average pain reduction of 67%, using pain rating methods based on qualitative responses (Pitman and Jack, 1998). Saxena and Haddad (1998) reported that foot orthoses significantly reduced symptoms associated with PFPS, however, the authors did not control for use of other modalities, such as exercise. Amell et al (2000) retrospectively questioned 21 PFPS patients nine months after the supply and fitting of foot orthoses. These authors reported that 85.7% of subjects reported subjective improvement in their symptoms. The studies of Amell et al (2000); Pitman and Jack, (1998), Saxena and Haddad (1998) did not have control groups, hence it is difficult to ascertain if any reported improvement merely represented a natural improvement in the condition with time.

Laboratory-based observational investigations into orthotic use in PFPS have reported benefits in reducing lateral patella glide (Klingman et al, 1997) and reducing Q-angle measurement (D'Amico and Rubin, 1986; Rose et al, 2002). Caution must be exercised in linking foot pronation, Q-angle measurements and PFPS. In a study on adolescent males subtalar pronation, not Q-angle was found to be the single most significant predictor of patellofemoral pain (McConnell, 1984 cited by McConnell, 1986). Powers et al, (1995) demonstrated a functional relationship between the degree of rear foot position and patellofemoral pain. However, although the patellofemoral group demonstrated a 30% greater amount of rear foot varus on average in comparison with the normal controls the clinical significance of a 2^0 difference can be debated despite statistical significance (Powers et al, 1995).

Hung and Gross (1999) studied the effect of foot position on vastus medialis oblique/vastus lateralis EMG amplitude activation ratios. These investigators could find no evidence to support the theory that altering the foot position could improve vastus medialis oblique/vastus lateralis activation, which is often a primary goal in the management of patellofemoral pain management (McConnell, 1986). Similarly, Nawoczenski and Ludewig (1999) and Rose et al (2002) reported no change in medial or lateral quadriceps femoris EMG activity with the application of foot orthoses.

4.12 FOOT ORTHOSES METHODOLOGICAL CONSIDERATIONS

Most of the evidence based on the use of orthotics in PFPS is based on patient satisfaction questionnaires (Amell et al, 2000; Pitman and Jack, 1998; Saxena and Haddad, 1998) or laboratory based observational studies (D'Amico and Rubin, 1986; Hung and Gross, 1999; Klingman et al, 1997). Only one RCT (Eng and Pierrynowski, 1993) has specifically studied the use of foot orthoses in PFPS. Although foot orthoses are advocated as a key component in the 'McConnell' approach to the management of patellofemoral pain (Grelsamer and McConnell, 1998), the use of foot orthoses does not seem to have been used in any RCT investigating the McConnell approach in its entirety.

4.13 FOOT ORTHOSES SUMMARY

In summary, there appears limited scientific evidence for the use of foot orthotics in PFPS, however this may merely reflect the controversy in the underlying scientific principles of current podiatric ideology. Despite concerns, however, regarding the mode of action, there appears to be limited subjective evidence that PFPS patients benefit with a reduction in symptoms from wearing orthotics (Amell et al, 2000; Gross and Foxworth, 2003; Pitman and Jack, 1998; Saxena and Haddad, 1998).

ELECTRONIC APPENDIX 5

5.1 STUDIES INVESTIGATING VASTUS MEDIALIS ACTIVATION

Effect of hip adduction on VMO:VL ratios

Study	Participants	EMG procedures	Exercises Examined	Main Conclusions
Andriacchi et al (1984**)**	Healthy subjects = 4 Female = 0 Male = 4 Mean age = 26 Age range=21-35	Fine wire EMG **Normalisation** = mean maximum myoelectric activity used to normalise data Electrode placement VM = 23cm above joint space VL = 10cm above joint space	Open chain knee extension in supine	Highest VM values occurred at 10^0 flexion At 40^0 flexion with an abduction moment applied to the lower leg caused an increase in VM activity compared with pure knee extension
Cerny (1995)	Healthy subjects = 21 Female = 10 Males = 11 Mean age = 27 Age range = 19-43 PFPS patients = 10 Female = 9 Male = 27 Age range = 21-38 Pain duration = < 6 years Inc: Retropatellar pain on at least two of the following:- Squatting Ascending/descending stairs Prolonged sitting 50% reduction in pain with patella taping	Fine wire EMG Normalisation = Seated isometric knee extension at 30^0 knee flexion Electrode placement VM = muscle belly VL = 1/3 distance between patella and anterior superior iliac spine	Quadriceps muscle setting Knee extension Isometric knee extension Walk stance -step down (a) alteration foot position (b) patella taped Step downs Wall slides (a) straight (b) squeezing pillow between knees	No difference in VMO:VL ratios within or between groups
Earl et al (2001)	Healthy subjects = 2- Females = 10 Male = 10 Mean age = 28	Surface EMG **Normalisation =** Seated knee extension at 45^0 flexion Adduction in standing 30^0 flexion **Electrode placement** VM = half way	Mini squat Mini squat with concurrent hip adduction	Significant increase in VMO activity with concurrent hip adduction

		between muscle belly and tendinous insertion VL = half way between muscle belly and tendinous insertion		
Grabiner et al (1992)	Healthy subjects = 10 Female = 0 Male = 10 Mean age = 28 Age range =	Surface EMG Normalisation = Seated knee extension at 20^0 knee flexion Electrode placement VM = muscle belly VL = muscle belly	Seated knee extension with 50% maximum hip adduction	No significant change in VM:VL ratio with hip adduction
Hanten and Schulthies (1990)	Healthy subjects = 16 Female = 7 Male = 9 Mean age = 27 Age range = 23-41	Fine wire EMG **Normalisation =** Seated knee extension in 50^0 flexion Electrode placement VM = 4cm superior and medial to superomedial border of patella VL =10cm superior to lateral epicondyle of femur	Maximum hip adduction in supine Seated medial rotation in 30^0 knee flexion	Greater VMO activity relative to VL with hip adduction
Hertel et al (2004)	Healthy subjects = Female = 3 Males = 8 Mean age = 24 Age range =	Surface EMG Normalisation = **not done** Electrode placement VM = 550 to long axis of the femur over the muscle belly when knee in 60^0 flexion VL = proximal to the distal tendon over are of greatest muscle bulk	Weight bearing uniplanar isometric knee extension 60^0 flexion in neutral, with hip adduction and with hip abduction	Hip abduction or adduction did not increase VMO activity
Hodges and Richardson (1993)	Healthy subjects = 20 Female = 20 Males = 0 Mean age = 20 Age range = ?	Surface EMG Normalisation = **not done** Electrode		Significant increase in VMO activity relative to VL activity with weight bearing

		placement VM = muscle belly VL = muscle belly		and all levels of concomitant adduction effort
Karst and Jewett (1993)	Healthy subjects = 12 Female = 6 Male = 6 Man age = 25 Age range 20-36	Surface EMG **Normalisation =** maximum value relative to the maximum value obtained for that muscle during any of the exercises Electrode placement VM = Skin over muscle VL = skin over muscle	Straight leg raising Straight leg raising with adduction Straight leg raising with lower limb lateral rotation	No preferential activation of VMO with hip adduction
Laprade et al (1998)	Healthy subjects = 19 Female = 19 Male = 0 Mean age = 24 Age range = PFPS patients = 8 Female = 8 Male = Mean age = 24 Age range = Pain duration Incl: No neurological deficit No history of recurrent patella subluxation No meniscal involvement or ligamentous damage No gross knee effusion Positive responses in at least two of the following:- Clarke's sign Patellar grind Palpation of patellar surface	Surface EMG **Normalisation =** Seated knee extension 60^0 knee flexion with 50% MVC Electrode placement VM = muscle belly VL = muscle belly	Knee extension Hip adduction Hip adduction with knee extension Medial tibial rotation with knee 70^0 flexion Medial tibial rotation with knee in extension	No significant difference between PFPS group and control No preferential recruitment of the VMO compared with VL
Miller et al (1997)	Healthy subjects = 9 Female = 9 Male = 0 Mean age = 20 Age range = 18-26 PFPS subjects = 6 Female = 9 Male = 0 Mean age = 21 Age range = 18-26	Surface EMG **Normalisation =** Seated knee extension at 45^0 knee flexion Electrode placement VM = estimated motor end plates VL = estimated	Static lunge with 30^0 knee flexion Static lunge at 70^0 knee flexion Modified wall slides – squat with adduction Step/step downs	Lower VMO:VL ratios in individuals with PFPS compared to healthy controls Closed kinetic chain exercises examined in

	Incl: Theatre sign Anterior knee pain while ascending/descending stairs Anterior knee pain on testing by 'critical test'	motor end plates		this study did not preferentially recruit the VMO
Rice et al (1995)	Healthy subjects = 10 Female = 5 Male = 5 Mean age = 34 Age range = 24-44	Surface EMG **Normalisation** = not done Electrode placement VM = largest are of muscle mass VL = largest are of muscle mass	Isokinetic exercise 10^0-90^0 concentric and eccentric at 30^0/s Isokinetic knee extension with hip adduction	Significant reduction in VL activity compared with VMO in both concentric and eccentric phases with hip adduction
Wheately and Jahnke (1956)	Healthy subjects = 11 Female = 0 Male = 11 Mean age = Age range =	**Surface EMG** **Normalisation** = not done Electrode placement VM = Muscle motor point VL = Muscle motor point	Standing hip adduction and abduction SLR in standing with hip in external rotation and internal rotation	Increase activity noted with hip adduction and with hip flexion and hip externally rotated
Zakaria et al (1997)	Healthy subjects = 20 Female = 20 Male = 0 Mean age = 24 Age range =	Surface EMG **Normalisation =** % of activity measured in knee muscle during quadriceps setting Electrode placement VM = straddling motor points VL = straddling motor points	Quadriceps setting in neutral Quadriceps setting with foot in dorsiflexion Bilateral hip adduction	No significant activation of the VMO over VL with quadriceps setting or bilateral hip adduction

Effect of hip position on VMO:VL ratios

Study	Participants	EMG procedures	Exercises Examined	Main Conclusions
Lam and Ng (2001)	PFPS patients = 16 Females = 11 Male = 5 Mean age = 34 Age range = Pain duration = > 6/12	Surface EMG **Normalisation =** Knee extension at 20^0 and 40^0 knee flexion in standing Electrode placement VM= mid point of muscle VL = midpoint of muscle	Sub maximal knee extension at 20^0 and 40^0 flexion with foot 30^0 internal rotation, neutral and 45^0 external rotation.	Sub maximal knee extension in 40^0 flexion with medial rotation of the hip resulted in higher VMO activity than VL activity than lateral rotation
Liaw (2000)	Healthy subjects = 28 Females= 14 Males = 14 Mean age = 25 Age range = 21-30 Incl: 18-40 yeas age No history of anterior knee pain No lower limb fractures No lower limb pathologies and surgery No back pain within the last 5 years Right lower limb dominance	Surface EMG **Normalisation** = maximum knee extension torque at 90^0 knee flexion Electrode placement VM = bulk of muscle VL = 1/3 distal from ASIS to patella muscle	Step up with hip in neutral, 30^0 and 60^0 external rotation	No significant change in VMO or VL electrical activity with change in hip position
Livecchi et al (2002)	Healthy subjects = 13 Females= 0 Males = 13 Mean age = 25 Age range = **Incl**: No history of significant knee or quadriceps injury	Surface EMG **Normalisation** = Against peak muscle activity for tested activity Electrode placement VM = overlying skin VL = overlying skin	SLR with hip in neutral, SLR with lateral hip rotation, knee extension with the hip in neutral position and knee extension with lateral hip rotation	No significant change in VMO or VL electrical activity with change in hip position or exercise
MacIntyre and Robertson (1997)	Healthy subjects = 12 Female = 12 Male = 0 Mean age = Age range = 20-32	Surface EMG **Normalisation =** by linear interpretation Electrode placement	Running	No significant difference in quadriceps activity between healthy and PFPS groups

	PFPS patients = 8 Female = 8 Male = 0 Mean age = Age range = 15-36 Pain duration = ?	VM = motor point VL = motor point		
Miller et al (1997)	Healthy subjects = 9 Female = 9 Male = 0 Mean age = 20 Age range = PFPS patients = 6 Female = 6 Male = 0 Mean age = 21 Pain duration = 'missed practice session' within past 2 months	Surface EMG Normalisation = Seated knee extension at 45^0 flexion Electrode placement VM = estimated motor end plates VL = estimated motor end plates	Step ups/step downs 45^0 lower limb internal rotation 45^0 lower limb internal rotation Modified wall slides	No significant difference in VM:VL ratio with leg rotation in any group
Mirzabeigi et al (1999)	Healthy subjects = 8 Female = Male = Mean age = 27 Age range =	Fine wire EMG **Normalisation =** manual muscle tests **Electrode placement** VM = muscle belly VL = muscle belly	Isometric knee extension in 155 knee flexion hip neutral Isometric knee extension in 15^0 knee flexion hip 30^0 internally rotated Isometric knee extension in 15^0 knee flexion hip externally rotated Isokinetic knee extension 90^0-0^0 at 60^0/s Isokinetic knee extension 30^0-0^0 at 60^0/s Full flexion to full extension while lying on ipsilateral side with 10Ibs weight Full flexion to full extension while lying on side contralateral side with 10Ibs weight Full squat Jump squat	No significant specific isolation of VMO identified
Ng and Man	Healthy subjects =	Surface EMG	Half lying knee	Hip internal

(1996)	30 Females = 21 Males = 9 Mean age = 28 Age range =	**Normalisation =** Knee extension half lying 20^0 knee flexion Electrode placement VM = largest area of muscle mass VL = largest area of muscle mass	extension hip internally rotated and externally rotated with ankle neutral, dorsiflexed and plantarflexed	rotation with foot dorsiflexed produced significantly greater VMO:VL ratios than hip neutral and ankle neutral
Ninos et al (1997)	Healthy subjects = 25 Female = 11 Male = 14 Mean age = Age range = 18-35	Surface EMG **Normalisation =** knee extension in 0^0 flexion Electrode placement VM = muscle belly VL = muscle belly	25% MVIC squat neutral and in 30^0 lower limb external rotation in 10^0 increments 60^0-10^0.	No change in muscle activity patterns with lower limb external rotation
Signorile et al (1995)	Healthy subjects = 23 Female = 18 Male = 5 Mean age = 25 Age range = 18-35	Surface EMG **Normalisation =** highest recorded value within each individual muscle across all knee angle and foot position Electrode placement VM = muscle belly VL = muscle belly	Isometric knee extension at 90^0, 30^0 and 5^0 with internal, neutral and external rotation of foot	Quadriceps setting demonstrated the highest values of EMG vastus medialis and vastus lateralis activity
Sykes and Wong (2003)	Healthy subjects = 30 Females = 0 Males = 30 Mean age = 29 Age range = 19-42	Surface EMG Normalisation = N/A Electrode placement VM= Oblique angle 550 2cm from superomedial; edge of patella	45^0 external hip rotation Neutral hip position 30^0 internal rotation with and without 1.125kg ankle weight	VM examined only. External hip rotation at 45^0 elicited a significant increase in VM activity compared with the other hip positions
Willet et al (1998)	Healthy subjects = 16 Female = 7 Male = 9 Mean age = 27 Age range = 23-41	Surface EMG **Normalisation =** Seated in extension in full extension Electrode placement VM = distal muscle VL = distal muscle	Weight bearing knee extension Weight bearing knee extension against elastic resistance Weight bearing knee extension against elastic resistance with 30^0 hip internal rotation	No significant difference in VMO:VL ratios

			Weight bearing knee extension against elastic resistance with 30^0 external rotation	

Effect of PFPS on endurance properties of quadriceps

Study	Participants	EMG procedures	Exercises Examined	Main Conclusions
Callaghan et al (2001)	Healthy subjects = 10 Female = Males = Mean age = 28 Age range = PFP patients = 10 Female = Males Mean age = 31 Age range = Pain duration = mean 2.5 years **Incl**: Atraumatic peripatellar pain > 6 months and not longer than 3 years Peripatellar pain provoked by one of the following:- Prolonged sitting Deep squatting Ascending/descending stairs Excl: Epilepsey Ca Cardiac pacemaker Recent surgery Hoffa's syndrome Medial plica syndrome Femoral anteversion Tibial torsion Lumbar and hip joint pain Sever leg length discrepancy Knee ligament injury Quadriceps tendon injury Muscle pathology	Surface EMG **Normalisation =** Closed kinetic chain knee extension 45^0 knee flexion Electrode placement VM 50^0 from long axis of the femur and 5cm from the superomedial border of the patella VL 12^0-15^0 from the long axis of the femur 15 cm from the superior medial border of the patella	Closed kinetic chain attachment on isokinetic dynamometer 60% MVIC 60 second hold	No significant difference in VMO:VL fatigue ratios between PFPS patients and healthy controls
Grabiner et al (1991)	Healthy subjects = 9 Females = 0 Males = 9 Mean age = 28 Age range =	Surface EMG **Normalisation =** Seated knee extension at 20^0 knee flexion	Static endurance knee extension Dynamic endurance knee extension	VMO or VL not selectively fatigued by short arc knee extension exercises

		Electrode placement VM = muscle belly VL = muscle belly		
Grabiner et al (1992)	Healthy subjects = 15 Female = 3 Male = 12 Mean age = 26 Age range = PFPS patients = 8 Female = 5 Male = 3 Mean age = 19 Age range = Pain duration = 4 days – 6 years	Surface EMG **Normalisation =** Seated knee extension at 20^0 knee flexion Electrode placement VM = muscle belly VL = muscle belly	Seated knee extension (a) fast rate (b) slow rate (c) constant	No difference in VM:VL ratio in control group PFPS significant decrease in both VM and VL activity than controls
Kaljumäe et al (1994)	Healthy subjects = 7 Female = 0 Male = 7 Mean age = 21 Age range = ?	Surface EMG **Normalisation** = Seated knee extension at 60^0 knee flexion Electrode placement = VM = muscle belly VL = muscle belly	Cycling	After 10 week training program fatigability reduced to a greater extent in vastus medialis than vastus lateralis
Ng (2002)	Healthy subjects = 20 Female = 10 Male = 10 Mean age = 20.3 Age range = ? Incl: No history of lower limb injuries requiring medial attention or complaints of knee pain during activities or rest at the time of study	Surface EMG **Normalisation =** Seated knee extension at 60^0 knee flexion VM = midpoint of muscle 6cm and 3cm medial to superomedial border of patella VL = 10cm superior and 7 cm lateral to the superior border of patella	Cycling	VL fatigued relatively more than VMO during cycling exercise. Both muscles recovered from fatigue after exercise, but the rate of recovery was faster in VL than VMO
Väätäinen et al (1995)	Healthy subjects = 31 Female = 15 Male = 16 Mean age = 30 Age range 21-48 PFPS patients = 41 Female = 25 Male = 16	Surface EMG **Normalisation =** Seated knee extension at 60^0 knee flexion Electrode placement	Isokinetic endurance test 40% maximal effort	Peak torque and force output in the symptomatic group lower than control group No significant

	Mean age = 30 Age range = 18-48 Pain duration = 9 months – 5 years Incl: Anterior knee pain Confirmed chondromalacia on arthroscopy	VM = most prominent part of muscle VL = most prominent part of muscle		difference in VMO:VL ratio

Effect of weight bearing exercise on VM:VL ratio

Study	**Participants**	**EMG procedures**	**Exercises Examined**	**Main Conclusions**
Anderson et al (1998)	Healthy subjects = 15 Female = ? Male = ? Mean age = 29	Surface EMG **Normalisation =** Seated isometric knee extension Electrode placement VM= 2cm medial and proximal from superior patella VL = 1/3 distance from greater trochanter to superior portion of patella	Narrow stance squats Wide stance squats at 30^0, 60^0 and 90^0 flexion	Greater VMO activity noted compared with VL activity at greater knee flexion angles
Cuddeford et al (1996)	Healthy subjects = 54 Female = 30 Male = 24 Mean age = 28 Age range = 15-49	Surface EMG **Normalisation =** Seated knee extension 60^0 flexion Electrode placement VM = adjacent to motor point VL = Half distance from motor point to distal tendon	Stationary bicycle ¼ single leg squat Bench step Quadriceps setting – standing Short arc quadriceps Straight leg raising	Stationary bicycle, single squat and bench step demonstrated significantly greater VMO:VL ratio than the other exercises
Gryzlo et al (1994)	Healthy subjects = 12 Female = 3 Male = 9 Mean age = 29 Age range =	Fine wire EMG Normalisation = maximal manual muscle test for each muscle Electrode placement VM = confirmed by manual muscle	Squat SLR Short arc knee extension Short arc knee extension with hamstring cocontraction Isometric knee cocontraction	Short arc quads recruited more activity in vastus medialis and vastus lateralis than squat, SLR or isometric contractions. No significant difference between vastus medialis and

		test VL = confirmed by manual muscle test		vastus lateralis activity noted
Hung and Gross (1999)	Healthy subjects = 20 Female = 10 Male = 10 Mean age = 29.4 Age range = 25-36	Surface EMG Normalisation = Isometric knee extension in standing Electrode placement VM = muscle belly VL = distance between 40% lateral knee joint line to greater trochanter	Weight bearing squat (a) level surface (b) With 10^0 medial foot wedge (c) With 10^0 lateral foot wedge	VMO:VL ratio greater during the squat activity than the maximum voluntary contraction No significant difference identified across the three different foot positions
Reynolds et al (1983)	Healthy subjects = 20 Female = 20 Males = 0 Mean age = 24 Age range = 20-32	Fine wire EMG **Normalisation =** Seated isometric knee extension in 60^0 flexion **Electrode placement** VM= muscle belly VL= middle 1/3 muscle belly	Controlled squat exercise	No difference in VMO:VL ratio
Schaub and Worrell (1995)	Healthy subjects = 23 Female = 14 Male = 9 Mean age 26 Age range =	Surface EMG **Normalisation =** Seated knee extension at 60^0 knee flexion Electrode placement VM = overlying skin VL = overlying skin	Squat exercise	No significant difference between VMO:VL ratios during MVIC or squat testing

Effect of non-weight bearing exercises on VM:VL ratios

Study	Participants	EMG procedures	Exercises Examined	Main Conclusions
Boucher et al (1992)	PFPS Patients = 18 Female = 9 Male = 0 Pain duration = ? Healthy subjects = 9 Female = 9 Male = 9 Mean age = 19 Inc: Traditional diagnosis of patellofemoral pain	Surface EMG Normalisation = **Seated isometric knee extension at 90^0, 30^0 and 15^0** Electrode placement = VM = muscle	Seated knee extension	No difference in VMO:VL ratio between groups at angles tested

	Abnormal Q-angle **Excl:**	belly estimated motor point VL = muscle bell estimated motor point		
Davlin et al (1999)	Healthy subjects = 36 Females = 36 Males = 0 Mean age = 20 Age range = ?	Surface EMG Normalisation **= ?** Electrode placement = VM = muscle belly estimated motor point VL = muscle bell estimated motor point	Long sitting isometric quadriceps contraction in neutral, with maximum internal and maximum external hip rotation	Significant increase in VMO:VL activity in 5 days with biofeedback training. No significant difference between groups with different hip positions
Doxey and Eisenman (1987)	PFPS Patients = 37 Female = 16 Male = 21 Mean age = 28 Age range = 15-31 Pain duration = 'Majority' > 1 year **Inc:** Unilateral patellofemoral pain Excl: Previous knee surgery Rheumatic diseases Knee flexion contracture	Surface EMG **Normalisation =** Seated isometric knee extension knee 40^0 and 0^0 flexion Electrode placement VM = bulk of vastus medialis muscle VL= 20% distance between lateral knee joint line and greater trochanter	Sub maximal knee extension with ankle weights	Significant reduction in EMG activity in painful limb compared with pain free limb. Did not examine VMO:VL ratios
Mariani and Caruso (1979)	Healthy subjects = 4 Females = 3 Males = 2 Mean age = Age range = 20-30 PFPS patients = 8 Female = 7 Male = 1 Mean age = Age range = 20-30 Pain duration = ? Inc: Patients with patella subluxation or dislocation requiring surgery	EMG ?	Seated knee extension 90^0-60^0, 60^0-30^0, 30^0-0^0.	Reduced raw VMO activity in patients with patella dysfunction. Improved with surgery
Matheson et al (2001)	Healthy subjects = 52 Female = 35 Male = 17 Mean age = 23 Age range =	Surface EMG **Normalisation** = Seated knee extension at 60^0 flexion Electrode placement	Knee extension with:- Isokinetic exercise Elastic tubing Inertial Exercise Trainer	No specific isolation of vastus medialis with any of the exercise regimes

		VM = muscle belly approximately 4cm proximal to the superior medial angle of patella VL = muscle belly approximately 8cm proximal to lateral knee joint line		
Richardson and Bullock (1986)	Healthy subjects = 20 Female = 20 Male = 0 Mean age = 29 Age range = 20-35	Surface EMG **Normalisation =** prone maximum isometric knee flexion and extension Electrode placement VM = motor point VL = motor point	Knee flexion extension against inertia balanced spring resistance at slow and fast speeds	With increasing speed there was an increase in activity of the rectus femoris and hamstrings relative to the vasti which demonstrated tonic activity
Souza and Gross (1991)	Healthy subjects = 7 Female = 2 Male = 5 Mean age = 29 Age range = 21-36 PFPS patients = 9 Female = 8 Male = 1 Mean age 27 Age range = 18-35 Pain duration = Incl: Anterior knee pain Excl: Pain on palpation of quadriceps tendon or patella ligament Plica Pain on palpation of knee joint line or +ve McMurray's No joint effusion No trauma or surgical procedures to the affected knee in past 2 years prior to testing	Surface EMG **Normalisation =** Seated knee extension 10^0 knee flexion Electrode placement VM = distal potion muscle VL	Maximal isometric contraction Sub maximal isometric contraction Concentric Eccentric	No difference in VMO:VL ratios for normalised data between PFP patients and healthy subjects
Tang et al (2001)	Healthy subjects = 10 Female = 5 Male = 5 Mean age = 26 Age range = 21-32	Surface EMG Normalisation = Isometric contractions 90^0-	Isokinetic exercise non-weight bearing concentric/eccentric 0^0-90^0 120^0/s	Closed kinetic chain can induced greater VMO firing at 60^0 knee flexion.

	PFPS patients = 10 Female = 6 Male = 4 Mean age = 28 Age range = 19-48 Inc: **Bilateral anterior knee pain >6/12** **Pain on squatting, kneeling, stair climbing and prolonged sitting** Excl: **Trauma to patellofemoral joint** **Ligamentous injury**	0^0 in 15^0 intervals Electrode placement **VM =** muscle belly **VL =** muscle belly	squat to stand stand to squat	No significant difference in VMO:VL ratios between PFPS patients and healthy controls during closed kinetic chain exercises
Wild et al (1982)	Healthy subjects = Female Male = Mean age = Age range = PFPS patients = 18 Female = 14 Male = 4 Mean age = Age range 11-42 Inc: Patella compression syndrome Patella subluxation/dislocation Chondromalacia 10/26 knees had had previous surgical procedure	Surface EMG **Normalisation =** Electrode placement VM = central muscle mass VL = central muscle mass	Straight leg raise in 10^0-20^0 flexion Straight leg raise in full extension +/- 5lbs weight Quadriceps setting and straight leg raise in sitting Exercises above with variable hip position	No consistent difference in EMG activity observed between tests or when altering position of hip

Effect of isokinetic exercise on VM:VL ratios

Study	Participants	EMG procedures	Exercises Examined	Main Conclusions
Sczepanski et al (1991)	Healthy subjects = 30 Female= 15 Male = 15 Mean age = 28 Age range = 19-35	Surface EMG **Normalisation =** not done Electrode placement VM = Largest are of muscle mass VL = largest area of muscle mass	Isokinetic knee extension at 60^0/s Concentric 95^0-5^0 flexion Eccentric 5^0–95^0 flexion	VMO:VL ratio significantly greater at concentric contraction at 120^0/s than the ratio 60^0/s

Effect of PFPS on timing of VMO:VL ratios

Study	Participants	EMG procedures	Exercises Examined	Main Conclusions
Adler et al	Healthy subjects =	Fine wire EMG	Gait	During gait the

(1983)	Female = 7 Male = 10 Mean age = Age range = 21-40	**Normalisation** = Electrode placement VM = 4cm proximal to the superior border of the patella and slightly medial to the medial border VL = muscle belly		VMO and VL fire almost simultaneously. With wide variation in timing of the VMO between individuals
Cesarelli et al (2000)	Healthy subjects = 30 Female = 30 Male = Mean age = 30 Age range = 18-38 PFPS patients = 12 Female = Male = Mean age = 29 Age range 20-36 Pain duration = ?	Surface EMG **Normalisation =** isokinetic 0^0-90^0 at 90^0/s Electrode placement VM = muscle belly VL = muscle belly	15 repetitions isokinetic knee extension 0^0-90^0 at 90^0/s	Significant delay in excitation of VMO in PFPS patients
Cowan et al (2000)	Healthy subjects = 10 Female = 6 Male = 4 Mean age = 20 Age range =	Surface EMG Normalisation = Electrode placement VM = muscle belly 4cm superior and 3cm medial to superomedial patella border VL = muscle belly 10cm superior and 6-8cm lateral to superior border of patella	Stair climbing	Timing differences of greater than 12.20seconds during concentric and 11.56 seconds during eccentric muscle work during stair climbing would be required to demonstrate a significant difference in VMO: VL EMG timing in pathological groups
Cowan et al (2001)	Healthy subjects = 33 Female = 20 Male = 15 Mean age = 27 Age range = PFPS patients = 33 Female = 22 Male = 11 Mean age = 23 Age range = Pain duration = 1month – 12 years **Incl**: Patellofemoral pain on any two of the following:- Prolonged sitting Ascending/descending stairs Squatting Running	Surface EMG Normalisation = Electrode placement VM= muscle belly 4cm superior and 3cm medial to superomedial patella border VL = muscle belly 10cm superior and 6-8cm lateral to superior border of patella	Stair climbing	VL EMG activity occurred significantly before VMO activity

	Kneeling Hopping/jumping Pain patella palpation Excl: Coexisting pathologies Previous history of knee surgery (past 3 months) Patella dislocation or subluxation Meniscal lesion Ligamentous instability Traction apophystis Patella tendon pathology Chondrol damage Osteochondritis Spine referred pain			
Cowan et al (2001b)	Healthy subjects = 9 Female = 4 Male = 5 Mean age = 27.3 Excl: Any lower limb pathology or neuropathology	Surface EMG Normalisation = Electrode placement VM= muscle belly 4cm superior and 3cm medial to superomedial patella border VL = muscle belly 10cm superior and 6-8cm lateral to superior border	Heel toe and toe raise rock tasks	VMO and VL activity occurred simultaneously in both tasks
Cowan et al (2002b)	PFPS = 37 Female = 23 Male = 14 Mean age = 28.5 Healthy subjects = 37 Female = 37 Male = 14 Mean age = 24.4 **Incl**: Patellofemoral pain in at least two of the following:- Prolonged sitting Ascending/descending stairs Squatting Running Kneeling Hopping/jumping In addition pain on patella palpation, symptoms>1/12, average of level 3cm on a 10cm VAS, symptoms unrelated to traumatic incident	Surface EMG Normalisation = Electrode placement VM= muscle belly 4cm superior and 3cm medial to superomedial patella border VL = muscle belly 10cm superior and 6-8cm lateral to superior border of patella	Heel toe and toe raise rock tasks	In asymptomatic subjects the VMO contracted simultaneously with VL. In PFPS the VL contracted before that of VMO

	Age 40 years or less Excl: Coexisting pathologies Previous history of knee surgery (past 3 months) Patella dislocation or subluxation Meniscal lesion Ligamentous instability Traction apophystis Patella tendon pathology Chondrol damage Osteochondrtis Spine referred pain			
Cowan et al (2002c)	PFPS patients = 65 Female = 42 Male =23 Mean age = **Incl**: Patellofemoral pain in at least two of the following:- Prolonged sitting Ascending/descending stairs Squatting Running Kneeling Hopping/jumping In addition pain on patella palpation, symptoms>1/12, average of level 3cm on a 10cm VAS, symptoms unrelated to traumatic incident Age 40 years or less Excl: Coexisting pathologies Previous history of knee surgery (past 3 months) Patella dislocation or subluxation Meniscal lesion Ligamentous instability Traction apophystis Patella tendon pathology Chondrol damage Osteochondritis Spine referred pain	Surface EMG Normalisation = Electrode placement VM= muscle belly 4cm superior and 3cm medial to superomedial patella border VL = muscle belly 10cm superior and 6-8cm lateral to superior border of patella	Stair stepping tasks Group 1 (n=35) given McConnell physical therapy regime Group 2 (n=30) given placebo ultrasound and sham taping	At baseline in both groups the VL EMG activity occurred before VMO in both concentric and eccentric stair stepping tasks. Significant change in latency between the onsets of VMO and VL EMG activity in the physical therapy group. In the physical therapy group VMO activity EMG occurred before VL these changes were not seen not in the placebo group.
Cowan et al (2003)	PFPS patients = 40 Female = 25 Male =15 Mean age = 27.2 Age range = < 40 years **Incl**: Patellofemoral pain in at	Surface EMG Normalisation = Electrode placement VM= muscle belly 4cm superior and 3cm	Heel raise rock task Group 1 (n=22) given McConnell physical therapy regime	At baseline in both groups the VL EMG activity occurred before VMO in both heel raise and rock tasks. Significant change

	least two of the following:- Prolonged sitting Ascending/descending stairs Squatting Running Kneeling Hopping/jumping In addition pain on patella palpation, symptoms>1/12, average of level 3cm on a 10cm VAS, symptoms unrelated to traumatic incident Age 40 years or less Excl: Coexisting pathologies History of patella taping Inability to attend physical therapy clinic for 6 weeks of the trial Allergic reaction to patella tape Lack of understanding of written or spoken English	medial to superomedial patella border VL = muscle belly 10cm superior and 6-8cm lateral to superior border of patella	Group 2 (n=18) given placebo ultrasound and sham taping	in latency between the onsets of VMO and VL EMG activity in the physical therapy group. In the physical therapy group VMO activity EMG occurred simultaneously with VL, these changes were not seen not in the placebo group.
Karst and Willet (1995)	Healthy subjects = 24 Females =16 Males = 8 Mean age = 29 Age range =15-46 PFPS patients = 24 Females = 18 Males = 6 Mean age = 28 Age range = 21-46 Pain duration = > 1 year Incl: Age > 12 years No history of knee injury requiring medical treatment No present knee pain A diagnosis of patellofemoral dysfunction Anterior knee pain with sitting No history surgery in past 1 year	Surface EMG Normalisation = Electrode placement VM = muscle belly VL = muscle belly	Reflex knee extension activity with patella tap Active knee extension while non weight bearing Active knee extension while weight bearing	No difference in timing between groups
Morrish and Woledge (1997)	Healthy subjects = 20 Female = 13 Male = 7 Median age = 25 Age range = 20-33 PFPS patients = 49 Female = 33	Surface EMG **Normalisation =** Seated knee extension at 20^0 Electrode placement	Seated knee extension at 20^0 knee flexion	In PFPS patients VM/VL activity lagged behind force rise of the bulk of the rest of the quadriceps

	Male = 16 Median age = 26 Age range = 20-37 Duration of symptoms = 6/12 to 10 years Incl: Pain exacerbated by:- Climbing or descending stairs Undertaking sports or activities involving running and or deep flexion of the knee Retropatellar tenderness Insidious rather than traumatic onset Excl: Bipartite patella Femoral trochlea fracture Osteochondritis dessicans Osgood Schlatter's disease Sinding-Larsen Johansson syndrome Patella tendonitis Prepatellar bursa Muscle tear Meniscal pathology Ligamentous pathology Reflex sympathetic dystrophy Scarred or inflamed plica Gross effusion Recent knee operation	VM = distal edge was 1.5cm from medial edge of base of patella VL = taken from line from ITB to the lateral edge of the base of patella as far down the muscle belly as possible		
Powers et al (1996)	Healthy subjects = 19 Females = 19 Males = 0 Mean age = 27 Age range = 23-38 PFPS patients = 26 Females = 26 Males = 0 Mean age = 26 Age range = 14-46 Incl: Reproducible patellofemoral pain on at least two of the following:- Squatting Stair climbing Kneeling Prolonged sitting Isometric quadriceps femoris muscle contraction Excl:	Fine wire EMG **Normalisation =** Seated knee extension at 60^0 knee flexion Electrode placement VM = muscle belly VL = muscle belly	Level walking Ramp walking Stairs	No difference in timing of vasti between PFPS patients and controls (measured mean VMO and VL) activity

	Any previous knee surgery A history of traumatic patellar dislocation Any neurological involvement that would influence gait			
Sheehy et al (1998)	Healthy subjects = 15 Females = 8 Males = 7 Mean age = 20 Age range = 10-49 PFPS patients = 13 Female = 6 Male = 7 Mean age = 27 Age range = 15-45 Pain duration = ? **Incl**: Patellofemoral joint pain while ascending/descending stairs or sloped surfaces During prolonged sitting with knees bent	Surface EMG **Normalisation =** Seated knee extension at 0^0 flexion Electrode placement VM = muscle belly VL = muscle belly	Stair ascent / descent	VMO:VL ratio less during stair descent than ascent No significant difference between the onset time of peak VMO and peak VL
Stensdotter et al (2003)	Healthy subjects = 10 Female = 7 Male = 3 Mean age = 29 Age range = ?	Surface EMG Normalisation = **MVC manual muscle tests** Electrode placement VMO = 4cm from suprapatella border at angle of 55^0 VL = 8cm from suprapatella border at angle of 20^0	Long sitting knee isometric knee extension at 30^0 knee flexion, closed chain knee extension at 30^0 knee flexion	Significant t difference in EMG onset timing between open and closed chain positions with knee vastus medialis onset occurring later in open chain conditions
Voight and Wieder (1991)	Healthy subjects = 41 Female = 24 Male = 17 Mean age = 25 Age range = 18-45 PFPS patients = 16 Female = 6 Male = 10 Mean age = 26 Age range = 19-31 Pain duration =	Surface EMG Normalisation = Electrode placement VM = muscle belly VL = muscle belly	Knee extension with patella tap	Significantly faster vastus lateralis response times in PFPS patients compared with healthy subjects
Witvrouw et al (1996)	Healthy subjects = 80 Female = 37 Male = 43 Mean age = 18 Age range = 17-22 PFPS patients = 19 Female = 11	Surface EMG Normalisation = Electrode placement VM = muscle	Knee extension patella tap	Significant earlier firing of vastus lateralis compared with VMO in PFPS group

	Male = 8 Mean age = 21 Age range = 17-26 Pain duration = > 6/52 Incl: At least two of the following:- Tenderness on palpation of the posterior surface of the patella Pain on resisted knee extension Pain with isometric quadriceps contraction against suprapatella resistance with the knee in slight flexion	belly VL = muscle belly		
Witvrouw et al (2003)	PFPS patients = 60 Female = 40 Male = 20 Mean age = 20 Age range = 14-33 Pain duration = > 6/52 Incl: At least two of the following:- Tenderness on palpation of the posterior surface of the patella Pain on resisted knee extension Pain with isometric quadriceps contraction against suprapatella resistance with the knee in slight flexion	Surface EMG Normalisation = Electrode placement VM = muscle belly VL = muscle belly	Knee extension patella tap Group 1 open kinetic chain exercises Group 2 closed kinetic chain exercises	No significant t change in reflex response times between groups

ELECTRONIC APPENDIX 6

6.1 PATELLOFEMORAL OUTCOME MEASURES

6.1.1 Introduction

The following chapter examines the outcome measures reported in previous PFPS studies under the key ICF domains (WHO, 2001), namely Part A Impairments of 1) Body Functions and Structures and 2) Activities and Participation, and Part B problems related to Contextual Factors consisting of 1) Environmental and 2) Personal Factors. To date the main outcome measures used in the rehabilitation of patellofemoral pain patients are reported to be those of pain and disability (Bennell et al, 2000; Harrison et al, 1996). Pain can be viewed as an impairment of the body structure and functions, and disability is the negative descriptor for limitations in activities and participation (WHO 2001). The following chapter explores these parameters under the components of the ICF, namely 1) Body Functions and Structures, 2) Activities and Participation and 3) Contextual Factors.

6.2 BODY STRUCTURE AND FUNCTION IMPAIRMENT MEASURES

6.2.1 Introduction

In the context of health 'body functions' are the physiological functions of body systems (including psychological functions). 'Body structures' refers to the anatomical parts of the body such as organs, limbs and their components. Impairments are problems related to the body function or structure, such as significant deviation or loss (WHO ICF, 2001). Accepting that the exact cause(s) of PFPS are unknown the outcome measures used to investigate PFPS reflect the search for impairments in both the physiological and anatomical domains. The strengths and weaknesses of the common impairment outcome measures routinely available in standard medical or physiotherapy practice are discussed, including pain assessment measures, quadriceps muscle performance measures (strength, muscular endurance, neuromuscular activity, muscle atrophy, neural inhibition and muscle lengths), knee range of motion, joint swelling, general joint laxity, leg lengths, quadriceps angle, patella mobility, foot position, and imaging. Other impairment measures, less commonly used in routine clinical practice, including psychological (Carlsson et al, 1993; Thomeé et al, 2002; Witoński et al, 1998; Witvrouw et al, 2000a), bone densitometry (Kannus et al, 1999; Leppälä et al, 1998), bone metabolism (Dye and Boll, 1986; Dye and Chew, 1993; Lorberboym et al, 2003) and patella pressure monitoring (Miltner et al, 2003; Schneider et al, 2000) are discussed in Chapter 8.

6.2.2 Pain Impairment Measures

One of the most frequently used methods of assessing pain in the clinical environment is the Visual Analogue Scale (VAS) (Carlsson, 1983). The VAS has been advocated for use in studies of patellofemoral treatment (Flandry et al, 1991; Eng and Pierrynowski, 1993; Harrison et al, 1995), presumably for its ease of use and speed of application (Chapman et al, 1985). Moderate reliability and validity of the VAS for PFPS patients has been reported (Chesworth et al, 1989; Bennell et al, 2000).

The VAS, despite its ease of use, does have some inherent problems as it only estimates with a one-dimensional character, usually pain intensity (Carlsson, 1983). Kremer et al (1981) claimed that visual analogue scales are difficult for many patients to understand which may diminish the validity of the instrument. Subsequently, patients may also 'reset the scale' to convey psychological meanings not immediately transparent to the clinician (Williams et al, 2000). Attempts have been made to capture the pain experience, beyond simply pain intensity, by having a scale designated for 'pain affect' by asking the subject to grade the degree of 'pleasantness or unpleasantness' of the pain experience (Price et al, 1987). A further problem with the VAS relates to statistical analysis, and the fact that VAS scores should be viewed as data on an ordinal scale (Carlsson, 1983). Subsequently, it has been argued that VAS 'scores' should be converted to an interval scale by using Rasch analysis for the purposes of statistical analysis (Thomeé et al, 1995a). There remains much debate as to how best VASs should be analysed and how best to interpret them (Williams et al, 2000).

Alternative pain measures such as the McGill pain questionnaire were developed to incorporate the different aspects of the pain experience (Melzack and Torgerson, 1971). Despite the McGill pain questionnaire being shown to be valid and reliable method of pain in PFPS patients (MacIntyre et al, 1995), it has been used only sparingly in patellofemoral pain research (Rowlands and Brantingham, 1999; Taylor and Brantingham, 2003). A potential problem with the McGill pain questionnaire is that if not carefully administered, pain in a specific joint can be confounded by pain from other areas (O'Malley et al, 2003). It has also been argued that it is time consuming to complete (MacIntyre et al, 1995).

Post and Fulkerson (1994) offered the possibility of using knee pain diagrams to correlate palpation findings during the physical examination with patient drawings of the location of their discomfort. These authors concluded that a clinician could be confident that findings of tenderness will likely be within zones marked by the patient on a standard diagram of the knee. From the description of the study design it is difficult to comprehend that patients did not bias the results by reporting areas of tenderness that they could recall documenting on their pain diagrams (Post and Fulkerson, 1994). Furthermore, the unreliability of palpation in chronic pain states has been reported (Gifford, 1998).

In conclusion, pain measures, especially pain rating scales, appear to be commonly used in clinical investigations to assess PFPS despite their inherent limitations.

6.2.3 Muscle Impairment Measures

Quadriceps Muscle Strength

The evaluation of quadriceps muscle strength in patients with PFPS is common (Akarcali et al, 2002; Alaca et al, 2002; Antich et al, 1986b; Bennett and Stauber, 1986; Callaghan et al, 2001b; Clark et al, 2000; Duffey et al, 2000; Kannus et al, 1992; Kannus et al, 1999; Milgrom et al, 1991; Rousch et al, 2000; Schneider et al, 2001; Stiene et al, 1996; Suter et al, 2000; Thomeé 1997; Werner and Eriksson

1993; Witvrouw; 2000a; 2002; 2004a). Quadriceps femoris strengthening is central to the management of patellofemoral pain and hence many researchers undertake strength assessment (Callaghan and Oldham, 1996; Thomeé et al, 1999). Impaired muscle function has also been related to impaired function (Powers et al, 1997a). There would appear to be no consensus in the literature as to the optimum method to assess muscle strength. A range of different methods have been employed involving different patient positioning, for example open kinetic chain (Anderson and Herrington, 2003; Bennett and Stauber 1986; Dvir, 1990, Werner and Eriksson, 1993) and closed kinetic chain (Callaghan et al, 2000) set-ups, different muscle contraction types for example isometric (Antich et al, 1986b; Kannus et al 1992; Thomeé, 1997) and isokinetic contractions (Anderson and Herrington, 2003; Bennett and Stauber 1986; Dvir et al, 1990, Werner and Eriksson, 1993), involving both concentric (Alaca et al, 2002; Stiene et al, 1996) and eccentric contractions (Anderson and Herrington, 2003; Bennett and Stauber 1986; Dvir et al, 1990, Werner and Eriksson, 1993) and different testing equipment, for example isokinetic dynamometry (Bennett and Stauber, 1986; Duffey et al, 2000), strain gauges (Clark et al, 2000) or manual muscle testing (Akarcali et al, 2002). Despite the range of techniques used there does appear to be sufficient evidence to suggest that muscle strength is impaired in PFPS patients when compared with healthy controls (Anderson and Herrington, 2003; Callaghan et al, 2000; Dvir et al, 1990, Thomeé et al, 1995c; Werner and Eriksson, 1993) and should be assessed clinically.

Quadriceps Muscle Endurance

Callaghan et al (2001a) using a closed chain isokinetic protocol, investigated the fatigue characteristics of the vastus medialis oblique and vastus lateralis muscles in subjects with and without PFPS. Although not statistically significant Callaghan et al (2001a) noted that the vastus medialis muscle demonstrated reduced fatigue compared to the vastus lateralis in patients with PFPS, but not in healthy controls. In healthy controls the vastus lateralis should fatigue before the vastus medialis (Ng, 2002). The role of quadriceps muscle fatigue in PFPS remains to be further explored.

Neuromuscular Activity

The concept of a neuromuscular ‘imbalance between’ the vastus medialis oblique and vastus lateralis muscle and its involvement in altering patella tracking has been of interest to PFPS research for a number of years (Callaghan et al, 2001a; Thomeé et al, 1999). Various methods have been used to explore this premise, including vastus medialis oblique vastus lateralis EMG amplitude ratios, endurance ratios and timing patterns (Chapter 5). Although the evidence of a temporal deficit is gradually gaining some momentum (Cowan et al 2000; 2001a; 2001b; 2002a; 2002b; 2003) the question really is to what extent these techniques are clinically useful, given the time and effort required to obtain reliable and valid information (Powers, 1996; Haig et al, 2003). It has been proposed that EMG biofeedback can improve the timing of the vastus medialis oblique relative to the vastus lateralis muscle (Felder and Leeson, 1990). The difference between vastus medialis oblique and vastus lateralis contraction has been reported to be in the order of less than 5 milliseconds (Karst and Willet, 1995) or 16 milliseconds and 19 milliseconds, during concentric and eccentric muscle work respectively, in PFPS patients (Cowan et al, 2001a). The reaction time to discriminate the relative onset of two closely timed sensory cues in normal subjects is 69 milliseconds (Artiedo et al, 1992) and this is beyond the technical capability of most biofeedback units (Karst and Willet, 1995). Hence it is difficult to ascertain how subjects can consciously improve vastus medialis oblique/vastus lateralis muscle timing (Karst and Willet, 1995). Thus, the common clinical use of EMG biofeedback as indicative of muscular imbalance and patellofemoral joint kinematics is probably ill founded (Powers, 2000b).

Quadriceps Muscle Atrophy

Muscle atrophy of the quadriceps muscles (Fisher, 1986) or the vastus medialis oblique in particular (Bourne, 1988; Wilk et al, 1998) has been reported as a clinical feature of PFPS. The reduction in muscle mass has been used as an indirect measurement of impaired muscle performance (Doxey, 1987). Several studies (Doucette and Goble, 1992; Gaffney et al, 1992; Jensen et al, 1999; Milgrom et al, 1991; Tunay et al, 2003) have used a standard tape measure to measure the circumferential measurements around the thigh at various distances from the patella (no standardised method was found). This method, however, encompasses the posterior, lateral and medial thigh muscles, bone and subcutaneous fat (Callaghan and Oldham, 2004a). Moreover, the tape measure technique has been found to exhibit poor inter and intra tester reliability (Harrelson et al, 1998; Middleton-Duff et al, 2000; Stokes, 1985). Doxy (1987) did report statistically significant differences in quadriceps cross sectional area in patients with unilateral PFPS, measured using ultrasound scanning, when comparing the quadriceps thickness in the painful limb to the asymptomatic limb. Callaghan and Oldham (2004a) similarly used ultrasound scanning, to investigate quadriceps atrophy in patients with unilateral PFPS and healthy controls. A significant difference in muscle strength was noted between the symptomatic and asymptomatic limbs of the PFPS groups and between the PFPS group and healthy controls, however, there was no statistical significant difference in quadriceps cross sectional area within or between groups (Callaghan and Oldham, 2004a). The difference between the results of Doxy (1987) and Callaghan and Oldham (2004a) has been attributed to differences in study inclusion criteria, with Doxey (1987) including patients with both traumatic and atraumatic PFPS, and Callaghan et al (2004) including only those with atraumatic PFPS. Clinical experience would indicate that ultrasound scanning is not yet used routinely within NHS physiotherapy departments for reasons such as cost, availability and lack of training. Conversely the cheaper and more available alternative, the standard tape measure, lacks reliability and validity, especially in detecting small and subtle reduction in muscle mass. If the detection of small changes in muscle mass are relevant in the assessment of PFPS patients then the benefits of the tape measure are questionable.

Muscle inhibition

Reflex muscle inhibition can occur as a result of effusion (de Andrade et al, 1965; Stokes and Young, 1984; Spencer et al, 1984), ligament stretch (Ekholm et al, 1960), pain (Solem-Bertroft et al, 1996) and abnormal afferent input (Hurley, 1997). The interpolated twitch technique has been proposed as a means of inferring the amount of neural inhibition present during a maximum muscular contraction in patients with PFPS (Suter et al, 1998b). Interestingly, Suter et al (1998a) demonstrated that patients with PFPS still had significant muscle inhibition, both in the affected and contralateral limbs even at 6 months following knee arthroscopy, demonstrating that arthroscopy is not without complications. The study of Suter et al (2000) investigated the immediate response of PFPS to spinal manipulation and measured muscle inhibition using the interpolated twitch technique. The authors reported a significant reduction in muscle inhibition immediately post manipulation. It is difficult to ascertain from the study if these patients had only PFPS or a concurrent back problem, which might have influenced the results, or how long the reduced muscle inhibition lasted for (Suter et al, 2000). This interpolated twitch technique is, however, not routinely available in clinical practice.

Muscle lengths

Reduced flexibility in the hamstring, quadriceps, iliotibial band and gastrocnemius/soleus muscles have been given as causes of PFPS (Clark et al, 2000; Gaffney et al, 1992; McMullen et al, 1990; Taylor and Brantingham, 2003; Witvrouw et al, 2000b; 2004a). Hamstring muscle length cannot be measured directly, but only inferred by angular measurements of unilateral hip flexion with the knee extended or unilateral knee extension with the hip flexed at 90° (Gajdosik et al, 1993). Methods employed to measure hamstring flexibility in PFPS populations have included the straight leg raising technique (Gaffney et al, 1992; Witvrouw, 2000b; 2004a) and hip flexed to 90° with the deficit in terminal knee extension recorded (Doucette and Goble, 1992; Tunay et al, 2003). No study was found comparing hamstring flexibility in subjects with and without patellofemoral pain.

Surprisingly very few studies were found evaluating quadriceps muscle length, or more specifically the rectus femoris muscle, in PFPS. Witvrouw et al (2000b) used a method proposed by Evjenth and Hamberg (1988) (with the subject in a prone position, the knee to be tested is maximally flexed with the foot of the non-involved side placed on the floor in a 90° hip flexion position). Hamberg et al (1993), using baseline knee flexion angles and standardised pelvic tilt positions using radiographs, demonstrated that the Evjenth and Hamberg (1988) method was a valid method of measuring rectus femoris length. Additionally, Hamberg et al (1993) reported excellent intratester reliability values for the Evjenth and Hamberg (1988) method (Pearson's correlation coefficients $r = 0.96$). However, it should be noted that the use of Pearson's correlations for establishing reliability is questionable and the statistic cannot, on its own, assess systematic bias and it depends greatly on the range of values in the sample (Atkinson and Nevill, 1998). The reliability results therefore of Hamberg et al's (1993) investigation must be viewed with caution.

Gastrocnemius/soleus flexibility has been indirectly inferred from measuring ankle dorsiflexion. A literature review by Rome (1996), however, concluded that there was no widely accepted method of clinically measuring ankle joint dorsiflexion. Witvrouw et al (2000b) measured ankle dorsiflexion range of movement in standing by leaning against a wall while keeping the foot in contact with the floor. Witvrouw et al (2000a) concluded that reduced gastrocnemius flexibility was a predictor of PFPS in previously healthy subjects.

Iliotibial band flexibility has been assessed in PFPS subjects using Ober's test (Doucette and Goble, 1992; Tunay et al, 2003) and inferred from external tibial hip rotation (Winslow and Yoder, 1995). The reliability and validity of these methods have not been established. This is perhaps not surprising given the debate over the morphology and role of the ITB (Mercer et al, 1998).

Reduced flexibility of the hamstrings, quadriceps and gastrocnemius /soleus complex may possibly contribute to PFPS. A reliable and valid method of clinically assessing iliotibial band flexibility remains to be developed.

6.2.4 Knee Range of Motion

Three studies (Duffey et al, 2000; Gaffney et al, 1992; Kannus and Nittymäki, 1994) were identified that assessed knee flexion extension range of motion. Each of these studies used a standard manual goniometer to measure range of motion. Impairments in range of motion were deemed not to be clinically significant in PFPS. The studies of both Duffey et al (2000) and Kannus and Nittymäki (1994) involved athletic populations and the study of Gaffney et al (1992) recruited from newspaper advertisements. Whether such study populations are reflective of an average NHS population remains to be investigated.

6.2.5 Knee Joint Swelling

Knee joint swelling is thought to be rare in PFPS patients and when present, mild and intermittent (Bentley, 1989; Thomeé et al, 1999; Tria et al 1992). More commonly patients complain of a feeling of infrapatellar swelling (Reid, 1993). No empirical studies were found investigating knee swelling in a group of PFPS patients, although potentially the presence of an effusion may be relevant in excluding other pathologies.

6.2.6 General Joint Laxity

Hypermobility has been considered a contributory factor in the pathogenesis of patellofemoral pain (Al-rawi and Nassan, 1997). The 9-point Beighton scoring system to evaluate hypermobility (Beighton et al, 1973) has been used (Kannus and Nittymäki, 1994) and a modified version (Witvrouw et al, 2000a) to evaluate PFPS patients. The main disadvantage of the Beighton score is that it is an 'all or nothing' test, giving a reasonable estimate of joint mobility, but no indication of its degree (Grahame, 1993). A score of four or more is said to indicate generalised hypermobility (Child, 1986). The Beighton score has been shown to be reliable in an athletic population of females (aged 15 to 45 years) (Boyle et al, 2003). Witvrouw et al (2000a) reported that only thumb-forearm mobility in PFPS patients showed a statistically greater range of motion compared with healthy controls. No study has examined joint hypermobility in a PFPS population within the NHS.

6.2.7 Leg Lengths

Leg length discrepancies have been implicated as a possible cause of PFPS (Reid, 1993), possibly related to the fact that limb differences might result in biomechanical compensatory pronation (Blustein and D'Amico, 1985), which in turn could potentially alter patella tracking. A video motion analysis experiment conducted by Bloedel and Hauger (1995), found no relationship between leg length differences and pronation. Methods used to measure leg length differences in PFPS subjects include measures of absolute leg length, for example tape measured distance from anterior superior iliac spine to medial malleolus (Duffey et al, 2000; Tunay et al, 2003) or distance from greater trochanter to lateral malleolus (Gaffney et al, 1992) and relative leg length for example the tape measured distance from umbilicus to medial malleolus (Duffey et al, 2000). Tunay et al (2003) reported no evidence of leg length discrepancies in PFPS and both Duffey et al (2000) and Witvrouw et al (2000a) reported that there was no evidence that leg length discrepancies were predictive of the development of PFPS in previously healthy individuals. No study has investigated leg lengths in NHS PFPS patients.

6.2.8 Quadriceps-angle (Q-angle) and A-Angle Measurements

Abnormal quadriceps (angle) Q-angle is arguably one of the most commonly quoted contributory causes of PFPS (Ando et al, 1993; Hahn and Foldspang, 1997; Huberti and Hayes. 1984, Insall et al, 1976; Kernozek and Greer, 1993; McConnell, 1986; Olerud and Berg, 1984; Schulthies et al, 1995; Woodland and Francis 1992). Insall et al (1976) defined the measurement of the Q-angle as the angle formed by the lines drawn from the anterior superior iliac spine to the centre of the patella and from the centre of the patella to the tibial tubercle. It is surmised that the Q-angle provides an indication of patella tracking impairments and has been associated with PFPS (Aglietti et al, 1983; Caylor et al, 1993). A Q-angle in excess of 15°-20° has often been suggested as a causative factor in the aetiology of the patellofemoral problems (Aglietti et al, 1983; Goldberg, 1997; Hvid et al, 1981; Insall et al, 1979; Jernick and Heifitz, 1979; Pagagelopoulos and Sim, 1997; Paulos et al, 1980).

Woodland and Francis (1992) have demonstrated that patients position either standing or supine does in fact significantly alter the value of the Q-angle. Wendell-Holmes and Clancy (1998) coined the phrase the 'functional Q-angle' when this angle was measured in the weight bearing position. Further variables such as quadriceps activity (Hahne and Foldspang, 1997; Woodland and Francis, 1992), knee joint position (Ando et al, 1993; Dzioba, 1990) and foot position (Livingston and Spaulding, 2002; Olerud and Berg, 1984) have all been reported to alter the Q-angle. There are also a variety of methods used to measure the Q-angle, such as goniometry (Aglietti et al, 1983, Horton and Hall; 1989), vectographs (Fairbank et al, 1984), X-ray absoptiometry (Fehling et al, 2003), OPTOTAK motion analysis systems (Livingston and Spaulding, 2002), Peak-5 motion analysis systems (Wilson and Kitsell, 2002) and computerised tomography (CT) scanning (Ando et al, 1993). The confusion as to what constitutes 'normal' Q-angle measurements in both sexes is probably a consequence of the lack standardised valid and reliable measurement methodologies.

A hand held goniometer is clinically the most common method used for measuring the Q-angle. The technique involves drawing two lines manually on the skin, with one line extending from the midpoint of the patella to the anterior superior iliac spine and the other extending from the midpoint of the patella to the tibial tubercle (Insall et al, 1976: Messier et al, 1991). Others (Caylor et al, 1993; Horton and Hall, 1989) have attempted to improve upon the accuracy of the method by using string stretched between the anterior superior iliac spine and the patella midpoint to ensure a 'more accurate' alignment of the proximal arm of the goniometer. However one of the main problems in Q-angle measures is actually identifying the anatomical landmarks of the patella centre and tibial tuberosity, with a defined accuracy of less than 2mm required to ensure errors in quadriceps angle remain below 5° (France and Nester, 2001). Furthermore (Wilson and Kitsell, 2002) have demonstrated the when the Q-angle is measured in standing the Q-angle value varied by on average 3° over a one minute period.

There remains, however, doubt in the literature as to whether excessive or reduced Q-angles are correlated with the incidence of patellofemoral pain syndrome (Aglietti et al, 1983; Caylor et al, 1993; Fairbank et al 1984; Livingston and Mandigo, 1999; Messier et al, 1988). The increased incidence of patellofemoral pain in females (Outerbridge 1964; Yates and Grana, 1986) and the fact that women have been noted to have having greater Q-angles has led some to try and establish a link between these two variables (Aglietti et al 1983; Percy and Strother, 1985). These greater Q-angles have been considered a result of gender differences such as greater pelvic width in women (Outerbridge, 1964; Pevsner et al, 1979). However, Horton, and Hall (1989) and Kernozek and Greer (1993), measuring hip width between the greater trochanters and the anterior superior iliac spines respectively, could not substantiate the theory that Q-angles were greater in females owing to greater pelvic widths.

It has also been proposed that bilateral asymmetry within individuals in Q-angles is implicated in the aetiology of knee pathologies (Bloedel and Hauger, 1995; Kujala et al, 1987; Shambaugh et al, 1991). In a comprehensive study Livingston and Mandigo (1999) found significant right versus left lower limb differences in Q-angle. These authors found only a weak, but significant correlation between right and left Q-angle measurements (Livingston and Mandigo, 1999). There was no correlation between Q-angles and the magnitude of discomfort experienced in unilateral knee pain sufferers. However, these relationships were weak yet statistically significant in bilateral knee pain sufferers (Livingston and Mandigo, 1999). Anatomical differences in skeletal geometry and muscle tone have also been suggested as contributory cause to intra subject variations in Q-angle asymmetry (Byl et al, 2000; Livingston and Mandigo, 1999).

Arno (1990) proposed an alternative measurement to the Q-angle, the A-angle. The A-angle is the angle formed by lines drawn through the centre of the patella to the pole of the patella and in a line drawn from the tibial tubercle through the inferior pole of the patella. DiVeta and Vogelbach (1992) demonstrated significantly higher A-angles in patients with patellofemoral pain compared with a control group. They demonstrated good intra-tester reliability, but poor inter-tester reliability with A-angle measurements in their study. Ehrat et al (1994), however, reported both intra and inter tester reliability of A-angle measurements as poor. This was supported by the work of Selfe et al (1996) who also found low A-angle reliability with manual goniometry testing.

Both Q-angle and A-angle measurements appear to suffer from both inter and intra rater variability, depending on a range of factors, such as the method of measurement, position of the subject and lower limb anatomical variations. The correlation between patellofemoral pain and Q-angle measures must be questioned at the current time. However, the fact that no direct correlation between Q-angle and the incidence of patellofemoral pain has yet been established, may reflect differences in measurement technique rather than a variability of patient pathology (Wendell-Holmes and Clancy, 1998).

With a consistent trend towards higher Q-angle measurements in PFPS patients compared to healthy controls across studies, using simple goniometric techniques, the clinical measurement of a basic Q-angle is perhaps endorsed in the assessment of PFPS patients (Duffey et al, 2000).

6.2.9 Patella Position and Mobility

An abnormal position of the patella within the trochlea has been postulated as a potential cause of PFPS (Kowall et al, 1996). Hence some investigators have tried to document the position of the patella, especially with regard to the mediolateral orientation relative to the underlying femur. Methods used have been subjective observation (Gaffney et al, 1992), patella movement relative to the femur, by displacing the patella manually, and estimating the degree of displacement relative to width of the patella (Kannus and Nittymäki, 1994) and patella movement relative to the femur, but measured with a ruler (Witvrouw et al, 2000a; 2002). The reliability (Fitzgerald and McClure, 1995; Powers et al, 1999b; Watson et al, 1999; 2001) and validity (Powers et al, 1999b) of clinically defining patella position does appear to be suspect, although there are limited claims to the contrary (Herrington, 2002).

6.2.10 Knee Alignment

Investigators have attempted to extrapolate information about patella alignment from the alignment of the knee joint and specifically the knee valgus/varus angles by measuring the intercondylar or intermalleolus distance (Milgrom et al, 1991; Witvrouw et al, 2000a). Witvrouw et al (2000a) reported no difference between PFPS patients and healthy controls for varus valgus measures; however Milgrom et al (1991) did report a statistical difference in a prospective study of 390 infantry recruits. The difference may reflect the different aetiologies; Witvrouw et al (2000) only included patients with insidious onset of pain. In comparison Milgrom et al (1991) only included patients with overuse PFPS. A clinical reliable and valid method of assessing patella position relative to the femur remains to be developed.

6.2.11 Foot Position

The presence of abnormal foot pronation has been associated with PFPS (Bennett, 1988; Eng and Pierrynowski, 1993). There exists a multitude of techniques for measuring foot pronation clinically, with no universally agreed accepted method available. Static foot measures range from footprints, navicular position, and subtalar neutral based methods (Menz, 1998) with many variations of these static measurements used in studies of PFPS patients (Doucette and Goble, 1992; Duffey et al, 2000; Eng and Pierrynowski, 1993; Kannus and Nittymaki, 1994; Milgrom et al, 1991; Witvrouw et al 2000a). One of the main problems is that static foot position data cannot always be extrapolated to the dynamic situation (Hamill et al, 1989). Powers et al (2002) investigated foot pronation using three-dimensional motion analysis and found no statistically significant differences with respect to either the magnitude or timing of peak foot pronation in PFPS patients compared with healthy controls. The contribution of foot pronation to PFPS remains controversial

6.2.12 Proprioception

The classic methods of testing proprioception involve; 1) using methods to determine the lowest threshold for detecting joint rotation and 2) detecting joint position sense from the accuracy with which the contralateral joint angles can be matched or a limb segment repositioned in three-dimensional space, without the aid of vision (Ashton-Miller et al, 2001). Baker et al (2002) used the repositioning technique to investigate knee joint proprioception, both in non-weight bearing and unilateral weight bearing. These investigators concluded that knee joint proprioception was impaired in PFPS patients. Conversely, Kramer et al (1997), using a similar repositioning method, found no statistical difference in knee joint proprioception between PFPS and healthy controls. No studies were found examining the lowest thresholds for detecting knee joint rotation in PFPS patients.

6.2.13 Imaging

Radiology and imaging techniques have been used extensively to investigate possible impairments of patellofemoral joint anatomy and kinematics (Elias and White, 2004). Imaging techniques, including radiography (Aglietti et al, 1983, Insall et al, 1983; Murray et al, 1999; Davies et al, 2000), computer tomography (CT) (Delgado-Martins, 1979, static MRI (Pookarnjanamorakot et al, 1998; Joensen et al, 2001) and MR arthrotomography (Staübli et al, 1999). Dynamic imaging approaches include x-ray imaging, cine computer tomography (Stanford et al, 1988), motion-triggered cine MR imaging (Brossmann et al, 1993) and kinematic MRI (Shellock et al, 1999; Witoński and Góraj, 1999).

Static imaging techniques investigating the position and orientation of the patella relative to the femoral patella groove have been performed. Measurements frequently used include the congruence angle (CA), the lateral patellofemoral angle (LPA) (Möller et al, 1987), the patellar tilt angle (PTA) (Schutzer et al, 1986) and the bisect off-set angle (BSO) (Brossmann et al, 1993). The CA is a measure of media/lateral position of the patella within the trochlea groove, and the LPA and PTA are measures of the medial/lateral tilt of the plane of the patella relative to the femur (Möller et al, 1987; Brossmann et al, 1993). Subsequently, some investigators (Aglietti et al, 1983; Laurin et al, 1978; Merchant et al, 1974) report an association between radiographic patella malalignment and PFPS, while others (Kannus and Nittymäki et al, 1994; Reid, 1993; Thomeé et al, 1995a) report no such correlation. The results of MRI imaging in patients with and without PFPS appear to support the idea of patellofemoral joint incongruence and malalignment (Pookarnjanamorakot et al, 1998; Powers et al, 1998; Shellock et al, 1999; Witoński and Góraj, 1999).

The contradictory results of imaging studies can be partly related to variations in imaging technique, patient positioning, state of quadriceps activation, patient selection and diagnosis and definition of angles measured. Furthermore disparity between estimation of the patellofemoral contacts between the bony outline seen by radiography and the articular chondrol contact demonstrated by MRI have been noted (Stäubli et al, 1999). Hehne (1990) similarly highlighted that cartilage geometry compensates for apparent osseous incongruence. Hence, information regarding patellofemoral joint position derived from radiological bone imaging techniques alone should be treated with caution.

The effect of exercise on radiological measurements has also been investigated (Doucette and Goble, 1992; Ingersoll and Knight, 1991; Kannus and Nittymäki, 1994; 1999; Schneider, et al, 2001; Tunay et al, 2003). Radiological results of some studies (Doucette and Goble, 1992; Ingersoll and Knight, 1991; Schneider, et al, 2001; Tunay et al, 2003) indicate that physiotherapy can improve patella tracking, while others studies reports no change (Kannus and Nittymäki, 1994; Kannus et al, 1999). The difference in results may be related to the patellofemoral joint angles measured, varying treatment protocols or different study inclusion/exclusion criteria.

Although imaging can provide useful information and exclude other pathologies, the widespread use of patellofemoral imaging within the NHS is not indicated at the current time given the cost, availability and ethical considerations involved.

6.2.14 Reliability and Validity of Impairment Measures

In order for a measurement tool to be scientifically useful it must be reliable, valid and be sufficiently responsive to change (Dvir 1995; Liang and Jette, 1981; Liang et al 1985). Test results are described as reproducible if under the same experimental conditions the measured entities are the same (Dvir, 1995). Content validity has been described as the extent to which measures represent functions or items of relevance given the purpose and matter at issue (Johnston et al, 1992). Sensitivity or responsiveness is an instruments ability to detect real changes in the construct that it is intended to measure (Irrgang et al, 1998). Thus, a suitable measurement scoring system for any study on patellofemoral pain must have these components.

The randomised controlled trials and controlled trials reviewed in the systematic review (Chapter 3) were re-examined. An effort was made to ascertain if the impairment measures used had validity, beyond face validity (George et al, 2000; Rothstein, 1985), and reliability (established by the authors, referenced from an external source for patellofemoral pain or general pain condition, or not stated/documented). The studies were grouped under the headings; muscle strength, neuromuscular activation, muscle lengths; range of knee joint movement, range of patella mobility, Q-angle, proprioception, radiological investigations, and pain variables (Electronic Appendix 6).

Of the measurements reviewed only six studies (Callaghan et al, 2001a; Cowan et al, 2003; Doucette and Child, 1996; Eng and Pierrynowski, 1993; Thomeé, 1997; Witvrouw et al, 2002) appear to have established validity and or reliability of the impairment measures used. For example, a clinical measure such as the measurement of thigh muscle bulk was described in at least six different ways (Callaghan et al, 2001a; Doucette and Goble, 1992; Gaffney et al, 1992; Milgrom et al 1991; Tunay et al 2003) and isokinetic muscle assessment used six different velocities over a range of studies (Bennett and Stauber, 1986; Stiene et al, 1996; Werner and Eriksson, 1993; Witvrouw et al, 2000b; 2002). Visual analogue scales have been widely used in PFPS studies, but again a wide range of methods have been used some using temporal, or functional dimensions to operationalise the construct (Eng and Pierrynowski, 1993; Harrison et al, 1999; Thomeé, 1997), and with variations in the labels used to anchor the line (Näslund, et al, 2002; Schneider et al, 2001; Thomeé, 1997). It has been shown that labels assigned to scale endpoints affect the use and outcome of visual analogue pain scales (Williams et al, 2000). Hence, any attempt to truly combine these outcomes for meta-analysis is conceptually flawed.

In conclusion a range of different impairment measurements have been used to investigate PFPS. The wide variety of measurements and techniques reflects the confusion over the aetiology of the condition. There does appear to be some agreement that pain is a significant impairment in PFPS patients. To date pain impairment measurements (such as the pain VAS) have featured in many PFPS studies. Epistemological arguments are acknowledged as to whether the subjective pain experience can be regarded as an impairment (Millard et al, 1991), which can ultimately be measured (Williams et al, 2000). Pain was regarded as 'an impairment' (Millard et al, 1991) for the purposes of this thesis. Few of the impairment measures used have been assessed for reliability and validity in the PFPS population.

6.3 ACTIVITIES AND PARTICIPATION MEASURES

6.3.1 Introduction

Measures of knee functional limitations and disability include performance-based clinical assessments; such as the one leg-leg hop test and patient-reported assessment (Bolgla and Keskula, 1997). There are, however, difficulties with the use of performance-based measures of function, especially in the early stages of rehabilitation when issues such as pain, reduced range of movement, adequate muscle strength to perform the test (Fitzgerald et al, 2001), motivation, motor learning and space required for testing (Risberg and Ekeland, 1994) may all contribute to the outcome. Furthermore a dearth of normative data on functional tests for interpretation has led practitioners to consider alternatives such as patient-reported measures of function (Irrgang et al, 1998; Sgaglione et al, 1995). A review of functional outcomes used in PFPS studies (Electronic Appendix 6) reflected these difficulties with the identification a diverse range of functional activity measurement tools. These can be grouped under the headings; performance based measures of function (for example hop/jump tests, step up/down tests, squat tests and general fitness tests), subjective functional questionnaires, and motion analysis. Only Thomeé, (1997) and Selfe et al, (2001a, 2001b) seem to have undertaken extensive independent studies on the reliability and/or validity of functional measures used in their PFPS investigations.

6.3.2 Performance Based Measures of Function

Functional performance testing is an attempt to evaluate the functional stability of the knee joint and may also contribute to finding a better relationship between the results of the clinical examination and the patients' knee function (Risberg and Eckland, 1994). Functional performance tests cannot detect specific impairments, but are useful in assessing general lower limb function (Bolga and Keskula, 1997). Barber et al (1990) reported that the importance of functional performance tests for the lower limb encompassed many variables such as pain, swelling, crepitus, neuromuscular coordination, muscle strength and joint stability and therefore it is difficult to related functional outcomes to cause.

Several functional performance tests have been described in the literature and include the one-legged and two-legged vertical jump tests (Petschnig et al, 1998; Risberg and Ekeland, 1994; Thomeé et al, 1995b), single hop for distance, triple hop for distance, cross over hop for distance, timed hop (Noyes et al, 1991), figure of eight tests and Stairs-Hopple tests (Risberg and Ekeland, 1994); shuttle run test (Anderson et al, 1991); step down tests (Loudon et al, 2002; Selfe et al, 2001a), squat tests, lunge tests, single leg stand and reach tests (Loudon et al, 2002). With the exception of the work of Loudon et al (2002), Selfe et al (2001) and Thomeé et al (1995a), most functional tests seem to have been targeted at anterior cruciate ligament injury patients (Loudon, 2000; Loudon et al, 2002).

Hop/jump tests

Hop tests (triple hop for distance and Stairs-Hopple tests) have been shown to be reliable measures in a normal athletic population (Risberg et al, 1995). There is, however, only a poor to moderate correlation between hop tests and isokinetic quadriceps strength measures (Petchnig et al, 1998). Alaca et al (2002) measured a timed six-metre hop, triple hop for distance and a timed single hop course in PFPS patients before and after physiotherapy treatment. The results showed that the hop measures were sensitive to change and improved significantly post treatment. There were, however, no correlations either with isokinetic quadriceps strength or pain (Alaca et al, 2002).

Step up/step down tests

Step tests, usually used in conjunction with pain measures, have been used as outcome measures in patellofemoral pain studies (Callaghan et al, 2001b; Callaghan and Oldham, 2004b; Crossley et al, 2002; Harrison et al, 1999; Selfe et al, 2001a; Stiene et al, 1996; Thomeé et al, 1997 Witvrouw et al, 2000; 2004) and appear sensitive to change when used to assess PFPS patients (Callaghan et al, 2001b; Callaghan and Oldham, 2004b; Crossley et al, 2002; Harrison et al, 1999; Stiene et al, 1996; Thomeé, 1997; Witvrouw et al, 2000b; 2004a). Presumably step tests are used because they increase patellofemoral joint stress (Loudon et al, 2002). Loudon et al (2002), however reported only moderate reliability for the step down test in PFPS patients, and although reporting a significant correlation with pain ($p<0.01$), the correlation coefficient was only moderate $r = 0.570$). Similarly, Selfe et al (2001a) found that 'critical angle' and angular velocity during as step down test were poor and weak predictors respectively of change in the patient's reported functional score.

Squat tests

Squat tests including the number of squats in a certain time (Can et al, 2003), number of squats before increase in pain (Crossley et al, 2002), squat repetitions with functional grading scale (Kannus et al, 1992) and unilateral squat maximum knee flexion angle before pain onset (Witvrouw et al, 2002) have all been used to assess pain and functional outcome in PFPS studies. All these squat tests appeared responsive to change.

General fitness tests

Milgrom et al (1991) in a study of military recruits measured the number of sit-ups, time for a two kilometre run and numbers of push-ups were used as possible predictive measures for the development of PFPS in healthy recruits. Only the number of push-ups was associated with the development of PFPS. Witvrouw et al (2000a) in a prospective study of healthy subjects used the 'Eurofit' test (which comprises a battery of fitness variables, including shuttle runs, jump tests, muscle strength, balance, flexibility measures), and also cardiovascular evaluation to ascertain possible predictive factors for the development of PFPS. The only 'physical fitness' predictive variable for the development of PFPS identified was reduced vertical jump performance in PFPS patients compared with controls (Witvrouw et al, 2000a).

In conclusion functional performance tests, such as the triple hop for distance and step up tests do appear to be reliable and sensitive to change in patients with PFPS, however there appears to be poor correlation between pain and functional performance measures. The question of validity is difficult to assess, as these tests comprise many different factors such as strength, balance, motor coordination and pain. Hence there is no 'gold standard' against which to compare the functional performance measures.

6.3.3 Patient Reported Measures of Functional Activity

Patient reported measures of function include general and specific measures of health status. General measures of health that have been used for patients who have musculoskeletal conditions include the Medical Outcomes Study Short Form-36 (SF-36) (McHorney et al, 1993) and the Sickness Impact Profile (SIP) (Ware and Sherbourne, 1992). Specific patient reported measures of knee function include the Lysholm Knee Scale (Lysholm and Gillquist, 1987), the Tegner Scale (Tegner and Lysholm, 1985), the Cincinnati Knee Scale (Noyes et al, 1984), the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (Bellamy et al, 1988), the Functional Index Questionnaire (FIQ) (Chesworth et al, 1989; Roos et al, 1998) Modified Functional Index Questionnaire (MIFQ) (Selfe et al, 2001a). Several instruments have combined patient reported measures of function with physical examination measures. These include those established by the International Knee Documentation Committee (IKDC) (Hefti et al,

1993) for the evaluation of knee ligament injuries, the Hospital for Special Surgery Knee Rating Scale (Windsor et al, 1988) and those developed by the Knee Society (Insall et al, 1989).

Demirdjian et al (1998) argued that the use of knee rating systems are of limited value as at present there is a lack of data on knee scores for 'normal' knees. In a comparison of the Cincinnati and Lysholm knee scoring questionnaires the 95% confidence intervals in both groups of normal subjects did not contain the maximal (normal) value of 100 (Demirdjian et al, 1998). Moreover, variations between genders were noted suggesting differences in perceived knee pain abnormalities between the sexes (Demirdjian et al, 1998). Demirdjian et al (1998) proposed that future knee score values should be compared to normative reference values based on subject's age, gender and activity levels, in a similar approach to the evaluation of lung function tests.

A review of these knee rating scales revealed that they have predominantly been designed to assess outcome following anterior cruciate ligament reconstruction, knee arthroplasty or post arthroscopy (Katz et al, 1992; Noyes et al, 1984; Tegner and Lysholm, 1985; Insall et al, 1989). Karlsson et al (1996) used the Tegner scale in an eleven-year follow-up of PFPS patients. No evidence for its reliability was given. Similarly, Natri et al (1998) used both the Tegner and Lysholm questionnaires in a patellofemoral longitudinal study. Natri et al (1998) quoted the intra tester reliability of these instruments to be good from the original authors. The measurements tested for reliability in the original studies (Lysholm and Gillquist, 1982; Tegner et al, 1988) were for ligamentous problems, not patellofemoral pain. Sources of error in patient-reported measures may be introduced by disproportionate combination of unrelated scores or by overrating low-activity individuals who avoid stressing their knees (Sgaglione et al, 1995).

Patient reported rating scales, examining the patients self reported ability to undertake such tasks as kneeling, squatting and stairs have been used in the assessment of PFPS (Chesworth et al, 1989; Flandry et al, 1991; Selfe et al, 2001a, 2001b). Some of these rating scales appear to be adapted from existing scales, for example Chesworth et al (1989) adapted a previously used Functional Index Questionnaire (Stratford, 1982 cited by Chesworth et al, 1989) and did not establish any concurrent validity. Flandry et al (1991) did establish concurrent validity of a 'VAS functional questionnaire' against the Lysholm (Lysholm and Gillquist, 1982), Noyes (Noyes and McGinniss, 1985) and Larson knee outcome questionnaires (cited by Flandry et al, 1991). Caution, however, needs to be exercised when establishing concurrent validity, for example the original Lysholm and Gillquist (1982) questionnaire included patient's with knee ligament damage, meniscal injury and chondromalacia patellae. They concluded, however that although their scoring system was reproducible, different scoring systems for different pathologies were warranted (Lysholm and Gillquist, 1982). Selfe et al (2001a) combined both the Functional Index Questionnaire and Kujala questionnaire (Kujala et al, 1993) et ;al has shown the MIFQ to be a clinically valid and reliable in PFPS patients, with a change in score of ten points probably indicating a clinically significant change in the patients' condition. With high Cronbach's alpha values (0.80 to 0.89), the MFIQ is internally consistent, hence suggesting that it is also a valid measure of PFPS (Selfe et al, 2001a).

In conclusion, given that pain is a key feature of PFPS then capturing the patients' self-reported measure of the effect of pain on functional performance would seem desirable. To date a large number of self-reported knee questionnaires reported in the literature have focused on anterior cruciate ligament patients. Selfe et al (2001a, 2001b) has demonstrated the MFIQ to be a reliable and valid measure in PFPS.

6.3.4 Motion Analysis Systems

Motion analysis systems are capable of measuring a whole array of different variables for part or for the whole of the body (Dolan, 1995) and have been used mainly in laboratory-based investigations of PFPS (Powers et al, 1997a, 1999a). Typically, data acquired during analysis include relative positions and orientations of body segments, foot-floor reaction forces, temporal-distance parameters, and phasic activity of the muscles (Kadaba et al, 1990).

Comprehensive overviews of motion analysis systems are available (Allard et al, 1995; Dolan, 1995; Rowe, 1999). In the past these systems were based on photographic techniques, but nowadays they are generally based on optoelectronic technology such as video. There have been several motion analysis studies undertaken investigating patellofemoral pain patients. Dillon et al (1983) used cinematography on a small group of patellofemoral pain patients (n=8). They used cinematography at a speed of 64Hz to analyse gait during flat and 15° downhill walking. Patellofemoral pain patients in this study exhibited more external rotation of the femur during swing phase and reduced knee flexion during single support phase. It was not apparent from this study if subjects were experiencing pain during testing. Nadeau et al (1997) compared PFPS patients (n=5) and healthy controls (n=5) and noted significantly decreased knee flexion angles up to 8.4° in the PFPS group during level walking. Similarly, Greenwald et al (1996) used video analysis to study PFPS (n=12) patients and healthy controls (n=6) performing level walking, stair ascent and stair descent. The results revealed a general tendency of the patellofemoral group to use a more extended knee than the control group. The only activity in which a significant difference between groups was noted was during stair descent. When looking at anterior cruciate ligament deficient knees Berchuck et al (1990) coined the phrase "quadriceps avoidance pattern" to describe a gait pattern that minimises the knee flexion moment during the loading response and therefore the demand of the knee extensors. Powers et al (1997a), sought to confirm the findings of Dillon et al (1983) and Nadeau et al (1997) and a "quadriceps avoidance pattern" for PFPS patients during free level walking. In a study of female subjects (n=19) Powers et al (1997a) investigated patellofemoral pain patients during level walking, stair ascent/descent, ascending and descending ramps. A Footswitch Stride Analyser System, consisting of compression-closing foot-switches, a Vicon motion analysis system and isometric dynamometer testing were used in this study. The primary gait compensation observed was a reduced walking speed, which was a function of both reduced stride length and cadence. Knee extensor torque was the only predictor of gait function, with increased torque correlating with improved stride characteristics. No significant difference in peak midstance knee flexion angles between the PFPS and controls was noted (Powers et al, 1997a) during free walking.

Chesworth et al (1989) investigated both males and females with patellofemoral pain (n=18) during level walking, stair ascent and a 12° downhill treadmill walking. They used a Clinical Stride Analyser, electrogoniometry and surface electromyography. No calibration details of the equipment were included. They concluded that there were no differences in the gait variables observed and that gait analysis may not be sensitive enough to detect changes in pain and function in patellofemoral pain patients. The role and presence of pain may be crucial to the outcome of these studies. McClay (1997) argued that future studies should incorporate specific tests that cause compensatory mechanisms to be exhibited. Powers et al (1997a) argued that because an individual does not experience pain during a particular activity does not imply that a gait compensation mechanism could still not be evident. They quoted the work of Andriacchi (1990) who proposed that the 'quadriceps avoidance' gait pattern in persons with anterior cruciate ligament insufficiency is the result of locomotor reprogramming, which occurs following the early experiences after loss of the anterior cruciate ligament. Powers et al (1997a) proposed that patients with patellofemoral pain may adopt a particular gait pattern following an acute episode of symptoms and continue to use this strategy in an attempt to 'protect' the joint from additional forces. There remains, however, controversy as to whether 'quadriceps avoidance' is a phenomenon present even in anterior cruciate ligament deficient injured patients (Roberts et al, 1999), thus to link such findings to patellofemoral pain patients is a tenuous one at present.

Powers et al (1999a) further investigated the influence of patellofemoral pain on lower limb loading during gait. In a study of PFPS subjects (n=15) they used piezoelectric force plates, Vicon Motion Analysis system and a stride analyser to examine the peak loading response and peak vertical ground reaction force compared with controls during free and fast walking. During free walking there were no significant differences in knee kinematics between PFPS patients and healthy controls. However, both the peak loading response and peak vertical ground reaction force parameters were reduced by 91% and 58% respectively. The results suggested that PFPS subjects had altered their gait pattern to reduce any potential effect of any abnormal lower limb loading during free walking gait. The decrease in lower limb loading in PFPS patients compared with controls correlated with a reduced gait velocity during free walking, as opposed to differences in knee kinematics. At faster speeds, however, PFPS patients did demonstrate altered knee kinematics with a significantly greater knee flexion angle during early stance phase. These variations in gait behaviour were thought to be an attempt by the PFPS patients to reduce the patellofemoral reaction force, which has been shown to be a function of both quadriceps force and knee angle (Buff et al, 1988). Thus the manifestation of the 'quadriceps avoidance' gait pattern may in part be gait velocity dependent (Powers et al, 1999a).

In a study by Radin et al (1991) subjects with intermittent tibiofemoral pain demonstrated diminished active shock absorption through diminished quadriceps muscle contraction and greater passive shock absorption through the viscoelastic properties of both bone and cartilage. This has led some to suggest that instead of patellofemoral structural abnormalities influencing gait, alteration in gait itself may actually be the cause of the degenerating patellar surface (Dillon et al, 1983).

Stair climbing has been used in patellofemoral motion analysis studies (Chesworth et al, 1989; Dillon et al, 1983; Greenwald et al, 1996; Powers et al, 1997a). This activity is frequently quoted as being an aggravating factor in patellofemoral pain patients (Crossley et al, 2002; Crossley et al 2004; McConnell, 1986; Powers, 1998; Vo, 2002). Furthermore, stairs are frequently encountered obstacles in daily living and require greater knee moments and ranges of motion than those required in level walking (Andriacchi et al, 1982). Selfe (1998; 2000a) studied the eccentric control during the step down task. This investigation has focused on the use of the Peak 5 motion analysis system. Selfe (2000a) studied the knee joint angle (or critical angle) and angular velocity at which healthy subjects (n=100) lost control of the knee during step down motion when the contra-lateral heel touched the floor. When considering healthy subjects the mean critical angle was 61° and the mean knee joint velocity, at contra lateral heel strike was 55°/s. From the original validity and reliability data, Selfe (1998) demonstrated that the 95% confidence intervals for intra subject variation of critical angle are +/-11° and for angular velocity +/-17°/s. The author proposed that this data could be used to measure clinical outcome. If patients' critical angles changed by more than 11° or velocity changes by more than 17°/s, the difference could be attributable to response to treatment rather than day-to-day change in the condition or measurement error. The use of such optoelectronic motion analysis systems, however, in the clinical setting remains prohibitively expensive at the present time.

Hérbert et al (1994) hypothesised that patellofemoral pain patients reduce the stress on their painful patellofemoral joint by decreasing the use of the extensor muscle during functional activities and examined specifically squatting. They compared PFPS subjects (n=11) with pain free controls (n=11) using photographic techniques, electrogoniometry and force plates. Contrary to the expected hypothesis, the patellofemoral pain subjects did not show a strategy tending to decrease the knee extensor moments. In fact during a squat test on tiptoes, the subjects affected by patellofemoral pain syndrome showed increase use of the knee extensor muscles. This would appear to conflict with the evidence of Powers et al (1999a) who suggested PFPS patients reduced gait velocity in an attempt to reduce the knee extensor moment. Heino Brechter and Powers (2002) added to the debate in a comparison of PFPS subjects (n=10) and healthy controls (n=10). Using a combination of MRI modelled contact areas; gait analysis and force plates they reported increased patellofemoral joint stress-time integrals in PFPS subjects. There was, however, no difference in peak knee flexion angles during the loading phase of gait or in walking velocity. Again, it was proposed that a subtle forward lean angle between the hips and lower limbs may be used by PFPS subjects to reduce the knee extension moment. Salsich et al (2001) supported the premise of 'quadriceps avoidance' during stair ambulation. These investigators noted reduced peak extensor moments in PFPS subjects (n=10) compared with healthy control (n=10) and contributed a proportion of the reduction in peak extensor moment to a decrease in cadence. Again a tendency towards an anterior trunk lean position was noted in the PFPS group (Salsich et al, 2001). Similarly, Crossley et al (2004a) noted reduced stance-phase knee flexion during stair ambulation in PFPS subjects (n=48) compared to healthy controls (n=18).

The variability in the data supporting the 'quadriceps avoidance pattern' may reflect the range of factors thought to contribute to patellofemoral contact stress (Figure 6.1), but also the different methods (Electronic Appendix 8) used to model these components.

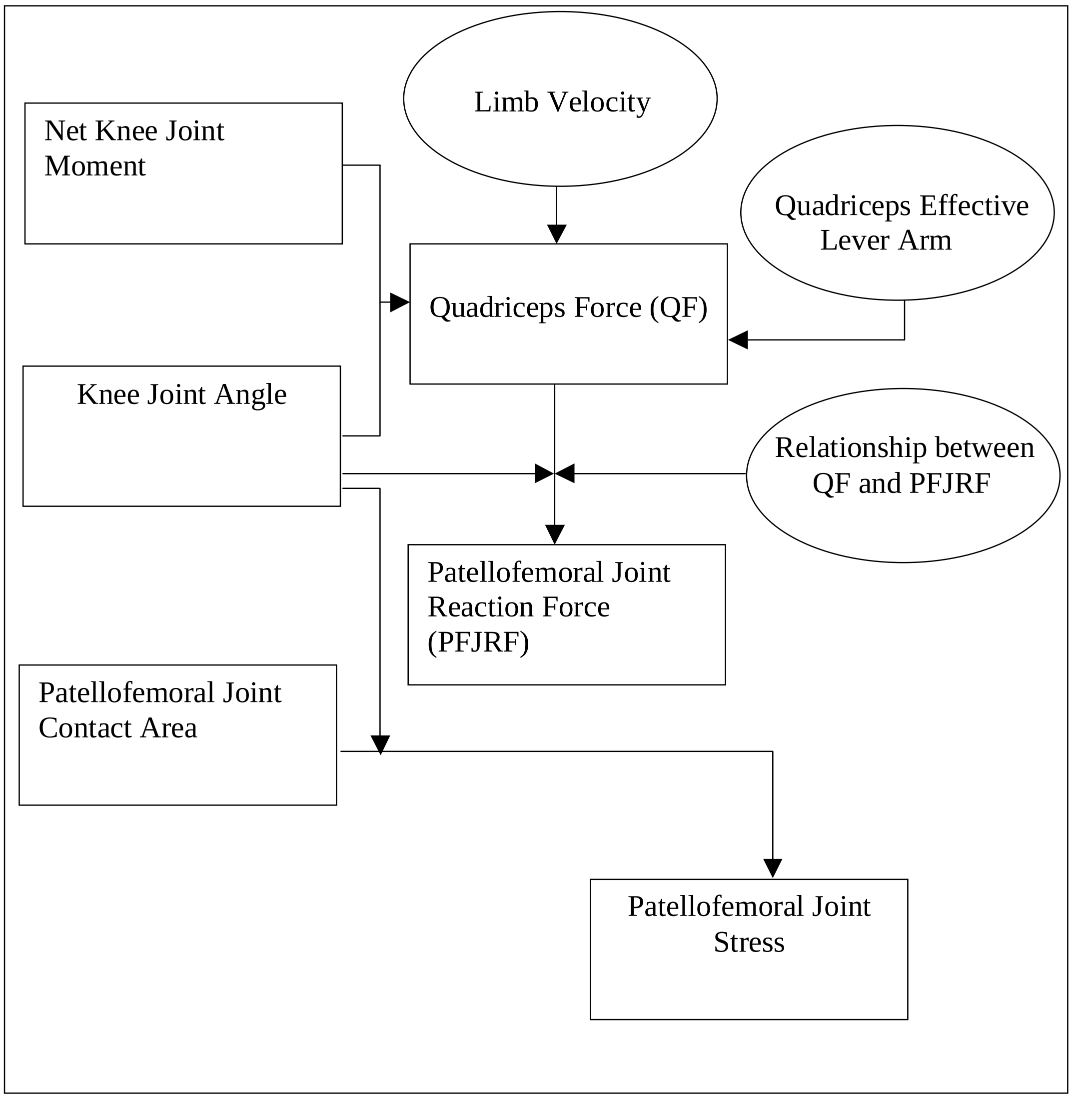


Figure 6.1: Factors involved in the determination of patellofemoral joint stress (Adapted from Winter, 1984; van Eijden et al, 1986; Brechter and Powers, 2002)

Furthermore variations in pain intensities and the level of demand placed upon the patellofemoral joint, during a wide spectrum of functional activities, may also in part explain the diversity of results between different investigators (Nadeau et al, 1997; Powers et al, 1997a).

In conclusion, motion analysis has been used in PFPS studies and does appear to demonstrate abnormal functional activity. Most of the systems to date have used expensive optoelectronic laboratory based systems, which are either impractical or too expensive for routine clinical use. Perhaps these limitations are reflected in the low number of subjects tested in many motion analysis studies investigating PFPS. A more financially viable and practical solution, the use of flexible electrogoniometry (Rowe et al, 2001), has not been used to assess the outcome of treatment in a clinical PFPS population.

6.4 PARTICIPATION METHODS

No PFPS study could be found investigating 'Participation' in isolation, with many of the studies outlined in section 6.3 combining the domains of 'Activities' and 'Participation'. Whether these two domains are separate phenomena remains a debatable issue not clarified by the ICF (Jette et al, 2003; Perenboom and Chorus, 2003). Crossley et al (2002) used the SF-36 questionnaire in a PFPS RCT, however, the results were only briefly reported as showing no change pre-post intervention, hence the domains of 'Activities and 'Participation' were not fully explored leaving scope for further investigation with the SF-36 tool in this patient group.

6.5 CONTEXTUAL FACTOR MEASURES

While most previous PFPS studies have reported Personal Factors, such as age and gender of patients (see Chapter 3), very few, if any, have reported on social status, ethnic origin, education or life experiences. Environmental Factors, such as relationships and roles, attitudes and values, social system and services, and policies, rules and laws (WHO, 2001), have not been explored. It should be noted that although Personal Factors are extremely important in the rehabilitation process, they are not classified in the ICF because of the large social and cultural variance associated with them (WHO, 2001). Thus although this study explored some basic Personal Factors, such as social status and deprivation, the majority of the study concentrated on impairments of 'Body Structures and Functions' and limitations of 'Activities and Participation'.

6.6 SUMMARY AND CONCLUSIONS

There has been a plethora of outcome measures proposed to evaluate PFPS. These outcome tools have included both subjective and objective methods, mainly examining the areas of pain, structural impairments and functional activity deficits. The reliability and validity of the methods used are often not reported, not tested for PFPS patients or simply have not been carried out. Measuring clinical outcome has many dimensions and treatment can affect one specific aspect of outcome without having a corresponding effect on other outcome dimensions (Duckworth, 1999). The categories of impairment, activity limitation and restricted participation are dependent. It is, however, possible to have impairment without activity limitation, and to have activity limitation without restriction in participation (Abenhaim et al, 2000). Thus, the argument for a study of PFPS encompassing the many facets of this condition, beyond those of simple impairment and functional boundaries, has been made (Harrison and Magee, 2001). To date no NHS based study has used electrogoniometry to investigate lower limb function in PFPS patients or examined PFPS within a more encompassing health framework such as the WHO ICF model.

ELECTRONIC APPENDIX 7

7.1 VALIDITY AND RELIABILITY OF PATELLOFEMORAL PAIN SYNDROME OUTCOME MEASURES USED IN PREVIOUS STUDIES

Codes: X = No - not tested Ö **= Yes - tested**

Muscle strength tests									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Akarcali et al (2002)	Lovett's manual muscle tests	X	X	√	X	X	X	X	√
Alaca et al (2002)	Cybex isokinetic concentric knee extension 60^0/s and 180^0/s	X	X	X	√	X	X	X	√
Antich et al (1996)	Cybex isometric quadriceps and hamstrings at 45^0 knee flexion	X	X	X	√	X	X	X	√
Bennet and Stauber (1986)	Kin Com concentric/eccentric knee extensor torque at 30^0/s	X	X	X	√	X	X	X	√
Callaghan et al (2001)	Biodex 2 extensor torque closed chain isometric at 45^0 and concentric isokinetics at 90^0/s	√	X	X	X	√	X	X	X
Duffey et al (2000)	Isokinetic muscle torque concentric knee extension and flexion (60^0/s and 240^0/s) 32 repetitions at 240^0/s to calculate endurance	X	X	X	√	X	X	X	√
Kannus et al (1992)	Standardised isometric dynamometer (Knee extension at 60^0 knee flexion	X	X	√	X	X	X	X	√
Kannus et al (1999)	Standardised isometric dynamometer (Knee extension at 60^0 knee flexion)	X	X	√	X	X	X	X	√
Milgrom et al (1991)	Maximum isometric quadriceps strength at 85 degrees flexion using a modified Dan Lurie knee machine	X	X	X	X	X	X	X	√
Rousch et al (2000)	Cybex isokinetic concentric flexion/extension at 60^0/s and 180^0/s Isometric contraction at 45^0 knee flexion	X	X	X	X	X	X	X	√
Schneider et al (2001)	Cybex isokinetic concentric knee extensor and flexor	X	X	X	√	X	X	X	√

	peak torque at 60^0/s								
Stiene et al (1996)	Cybex concentric knee extension peak torque 90^0/s, 180^0/s, 360^0/s	X	X	X	√	X	X	X	√
Suter et al (2000)	Icybes isometric dynamometer knee extension at 30^0 flexion	X	X	X	√	X	X	X	√
Thomeé (1997)	Isometric knee extension torque at 60^0 knee flexion	X	X	X	√	X	X	X	√
Thomeé (1997)	Cybex isokinetic knee extension concentric/eccentric torque at 30^0/s	X	X	X	√	X	X	X	√
Werner and Eriksson (1993)	Kin Com isokinetic concentric and eccentric extension and flexion contraction. Extension at 60^0/s, 90^0/s, 120^0/s, 180^0/s and flexion at 60^0/s and 180^0/s	X	X	X	√	X	X	X	√
Witvrouw et al (2000)	Cybex Isokinetic muscle torque. Concentric knee extension and flexion (60^0/s, 180^0/s and 240^0/s)	X	X	X	√	X	X	√	X
Witvrouw et al (2000)	Cybex Isokinetic muscle torque. Concentric knee extension and flexion (60^0/s, 180^0/s and 300^0/s)	X	X	X	√	X	X	X	X
Witvrouw et al (2002)	Cybex Isokinetic muscle torque. Concentric knee extension and flexion (60^0/s, 180^0/s and 300^0/s)	X	X	X	√	X	X	√	X

Pain									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Akarcali et al (2002)	VAS 0=no pain 100 unbearable pain during step up and down 3 steps and squatting	X	X	√	X	X	X	X	√
Alaca et al (2002)	VAS 0	X	X	X	X	X	X	X	√
Callaghan et al (2001)	VAS 0=no pain 10= worst pain ever on day of assessment	X	√	√	X	X	X	X	√
Can et al (2002)	VAS 0=no pain 10=extremely intense pain	X	√	√	X	X	X	X	X
Clark et al (2000)	VAS pain during stair climbing and walking on flat with 0=no pain and 100=extreme pain	X	X	X	√	X	X	X	√
Crossley et al (2002)	VAS 10cm line Worst and usual pain in previous week	X	√	X	X	X	√	X	X
Crossley et al (2002)	Anterior knee pain score	X	√	X	X	X	X	X	X
Dursun et al (2001)	VAS Greatest level of knee discomfort during the last week	X	X	X	√	X	X	X	√
Eng and Pierrynowski (1993)	VAS 0=no pain 10 = pain as bad as could be in last week during walking, running , ascending/descending stairs	X	√	X	X	X	√	X	X
Finestone et al (1993)	Pain 4-point rating scale	X	X	X	√	X	X	X	√
Gaffney et al (1992)	VAS Maximum pain intensity 0-10	X	X	X	√	X	X	X	√
Greenwald et al (1996)	Pain 0 to 10 scale	X	X	X	√	X	X	X	√
Harrison et al (1999)	VAS 0=no pain 10=pain as severe as it could be Worst, lest and average pain over previous 3 days	X	X	X	√	X	X	X	√
Harrison et al (1999)	PFPS score	X	√	X	X	X	X	X	√
Jensen et al (1999)	VAS	X	X	X	√	X	X	X	√
Kannus and Niittymäki (1994)	VAS 0=no pain 100=extremely intensive pain	X	X	X	√	X	X	X	√
Kannus et al (1992)	VAS 0=no pain 100=extremely intense pain	X	X	X	√	X	X	X	√
Kannus et al (1999)	VAS during activities 0=no pain 100=extremely intense pain	X	√	√	X	X	√	X	X
Milgrom et al (1996)	4-point pain rating scale	X	X	X	√	X	X	X	√
Miller et al	VAS no pain and	X	X	X	√	X	X	X	√

(1996)	worst pain in life								
Näslund et al (2002)	VAS 0 = no pain 100 = unbearable pain Highest level of pain during the day	X	X	X	√	X	X	X	√
Rogvi-Hansen et al (1991)	VAS	X	X	X	√	X	X	X	√
Rowlands and Brantingham (1999)	McGill pain questionnaire	X	X	X	√	X	X	X	√
Rowlands and Brantingham (1999)	NRS-101	X	X	√	X	X	X		X
Rowlands and Brantingham (1999)	Algometer	X	X	X	√	X	X	X	√
Schneider et al (2001)	VAS 0=no pain 100=greatest imaginable pain	X	X	√	X	X	X	X	√
Stiene et al (1996)	Patellofemoral pain questionnaire	X	X	X		X	X	X	√
Thomeé (1997)	Pain questionnaire	X	√	X	X	X	X	X	√
Thomeé (1997)	VAS 0=no pain 10 = pain as bad as it could be Maximum pain, minimum pain and average pain in past 3/52	√	X	X	X	√	X	X	X
Timm (1998)	VAS no sensation of soreness to worst sensation of soreness imaginable while ascending/descending stairs, rising from sitting, squatting and prolonged sitting	X	X	√	X	X	X	√	X
Tunay et al (2003)	VAS 0=no pain 10 =maximum pain	X	√	X	X	X	X	√	X
Werner and Eriksson (1993)	Borg's pain score	X	X	X	X	X	X	X	√
Witvrouw et al (2000)	VAS 0=no pain 100 =extremely intense pain in 18 functional tests	X	X	X	X	X	X	X	√
Witvrouw et al (2002)	VAS during rest and activities 0=no pain 100= extremely intense pain	X	√	X	X	X	√	X	X
Witvrouw et al (2003)	VAS during daily activities 0=no pain 100= intense pain	X	√	X	X	X	√	X	X

Range of knee joint movement									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Duffey et al (2000)	Manual goniometer with axis inline with greater trochanter and lateral malleolus	X	X	X	√	X	X	X	√
Gaffney et al (1992)	Knee ROM ? method	X	X	X	√	X	X	X	√
Kannus and Nittymäki (1994)	Goniometer from knee flexion to extension	X	X	X	√	X	X	X	√

Iliotibial band length									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Doucette and Goble (1992)	Ober's position and defined as the distance between medial patella and the table	X	X	X	√	X	X	X	√
Tunay et al (2003)	Ober's test	X	X	√	X	X	X	X	√

Q-angle									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Doucette and Goble (1992)	Manual goniometer in supine with quadriceps relaxed and in standing	X	X	X	√	X	X	X	√
Duffey et al (2000)	Manual goniometer	X	X	√	X	X	X	X	√
Eburne and Bannister (1996)	Q-angle ? method	X	X	X	√	X	X	X	√
Eng and Pierrynowski (1993)	Q- angle? method	√	X	X	X	√	X	X	X
Gaffney et al (1992)	Q-angle ? method	X	X	X	√	X	X	X	√
Kannus and Niittymäki (1994	Manual goniometer	X	X	X	√	X	X	X	√
Witvrouw et al (2000)	Manual goniometer supine with relaxed quadriceps	X	√	X	X	X	X	X	√
Witvrouw et al (2002)	Manual goniometer supine with relaxed quadriceps	X	√	X	X	X	√	X	X

Thigh muscle bulk									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Callaghan et al (2001)	Quadriceps cross sectional area using ultrasound scanning	X	X	X	√	X	X	X	√
Doucette and Goble (1992)	Thigh measurement taken bilaterally at 20N and 50N of the distance from the lateral joint line to greater trochanter	X	X	X	√	X	X	X	√
Gaffney et al (1992)	Quadriceps circumference 5 and 10cm above upper border of patella	X	X	X	√	X	X	X	√
Jensen et al (1999)	Thigh muscle atrophy 5cm to superior margin of patella	X	X	X	√	X	X	X	√
Milgrom et al (1991)	Circumference of thigh and calf	X	X	X	√	X	X	X	√
Tunay et al (2003)	Thigh circumference 15 and 20cm from medial tibial plateau	X	X	√	X	X	X	X	√

Hamstring length									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Doucette and Goble (1992)	Goniometer measurements with subject supine and hips flexed to 90^0	X	X	X	√	X	X	X	√
Gaffney et al (1992)	SLR degree of elevation at hip	X	X	X	√	X	X	X	√
Tunay et al (2003)	In supine knees and hips flexed to 90^0 complete extension deficit recorded	X	X	√	X	X	X	X	√
Witvrouw et al (2000)	Hip angle during SLR	X	X	√	X	X	X	X	√
Witvrouw et al (2002)	Straight leg raise in supine. Hip angle measured with goniometer	X	X	√	X	X	X	X	X
Witvrouw et al (2002)	Straight leg raise in supine. Hip angle measured with goniometer	X	X	√	X	X	X	X	√

Quadriceps muscle length									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Witvrouw et al (2000)	Patient prone, knee maximally flexed while the foot of the non involved side was placed on the floor	X	X	√	X	X	X	X	√
Witvrouw et al (2002)	Patient prone, knee maximally flexed while the foot of the non involved side was placed on the floor	X	X	√	X	X	X	X	√
Witvrouw et al (2002)	Patient prone, knee maximally flexed while the foot of the non involved side was placed on the floor	X	X	√	X	X	X	X	√

Ankle dorsiflexion range of motion									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Witvrouw et al (2000)	In standing leaning against solid support, maximal flex of ankle while keeping tested ankle on floor	X	X	X	√	X	X	X	√
Witvrouw et al (2000)	In standing leaning against solid support, maximal flex of ankle while keeping tested ankle on floor	X	X	X	√	X	X	X	√
Witvrouw et al (2002)	In standing leaning against solid support, maximal flex of ankle while keeping tested ankle on floor	X	X	X	√	X	X	X	

Leg lengths									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Doucette and Goble (1992)	In supine distance from anterior superior iliac spine to medial malleolus	X	X	X	√	X	X	X	√
Duffey et al (2000)	Relative leg length measured from umbilicus to medial malleolus. Absolute	X	X	√	X	X	X	X	√

	leg length measured from anterior superior iliac spine to medial malleolus								
Gaffney et al (1992)	In supine distance from greater trochanter to lateral malleolus in supine	X	X	X	√	X	X	X	√
Kannus and Niittymäki (1994)	Distance between anterior superior iliac spine and medial malleoli, confirmed by lifting block under foot	X	X	X	√	X	X	X	√
Tunay et al (2003)	In supine anterior superior iliac spine to medial malleolus	X	X	√	X	X	X	X	√
Witvroux et al (2000)	Distance between n anterior superior iliac spine and medial malleolus	X	X	√	X	X	X	X	√

Muscle electrical activity									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Callaghan et al (2001)	Muscle fatigue rates of VMO, Vl and rectus femoris using surface EMG	X	X	√	X	X	X	X	√
Cowan et al (2000, 2001, 2001, 2002,2003)	VMO to VL timing differences using surface EMG	√	X	X	X	√	X	X	X
Schneider et al (2001)	Isometric surface EMG activity of vastus medialis and vastus lateralis	X	X	X	√	X	X	X	√
Suter et al (2000)	Surface EMG vastus medialis and vastus lateralis Root mean square values	X	X	X	√	X	X	X	√
Thomeé (1997)	Surface VMO/VL activity during isometric, isokinetic and vertical jump tests	√	X	X	X	√	X	X	X
Witvrouw et al (2000)	Reflex response time from VMO and VL using a patella tendon jerk reflex input	X	X	X	√	X	X	X	√
Witvrouw et al (2002)	Reflex response time from VMO and VL using a patella tendon jerk reflex input	X	√	X	X	√	X	X	X
Witvrouw et al (2003)	Reflex response time from VMO and VL using a patella tendon jerk reflex input	X	√	X	X	√	X	X	X

Patella mobility										
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Rowlands and Brantingham (1999)	Patella mobility – chiropractic technique	X	√	X	X	X	X	X	√
Gaffney et al (1992)	Patella movement with quadriceps contraction	X	X	X	√	X	X	X	√
Gaffney et al (1992)	Transverse mobility of patella	X	X	X	√	X	X	X	√
Kannus and Niittymäki (1994)	Mild laxity = mediolateral movement over half the knee in full extension and less but obvious movement in 30^0 flexion. Clear laxity the examiner could easily sublux patella laterally	X	X	X	√	X	X	X	√
Witvrouw et al (2000)	Medio-lateral patellar displacement Manual passive patella glide using a ruler	X	√	X	X	X	X	√	X
Witvrouw et al (2002)	Medio-lateral patellar displacement Manual passive patella glide using a ruler	X	√	X	X	X	X	√	X

General joint laxity									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Kannus and Niittymäki (1994)	Beighton's score	X	√	√	X	X	X	X	√
Witvrouw et al (2000)	Measuring apposition of the thumb to forearm, elbow, knee, shoulder and little finer hyperextension and mediolateral mobility of patella	X	√	√	X	X	X	√	X

Foot position									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Doucette and Goble (1992)	Subjects in standing and dynamically rating scale normal, mild, moderate or severe	X	X	X	√	X	X	X	√
Duffey et al (200)	Arch index from ink foot prints	X	X	√	X	X	X	X	√
Eng and Pierrynowski (1993)	Forefoot varus	X	X	√	X	X	X	X	√
Eng and Pierrynowski (1993)	Calcaneal varus	X	X	√	X	√	X	X	X
Kannus and Niittymäki (1994)	Ankle hyperpronation angle between axes of Achilles tendon and calcaneus measured with 'special' goniometer during a squat test	X	X	X	√	X	X	X	√
Milgrom et al (1991)	Height of arch of foot, Inclination of hindfoot, range of subtalar neutral	X	X	X	√	X	X	X	√
Milgrom et al (1991)	Length and width of foot	X	X	√	√	X	X	X	√
Witvrouw et al (2000)	Podograph	X	X	√	√	X	X	X	√
Witvrouw et al (2000)	Lower leg-heel and heel-forefoot alignment	X	X	√	X	X	X	√	X

Skin temperature									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	For knees general			For PFPS	For knees general	
Näslund et al (2002)	Skin temperature Distal end of rectus femoris, the patella and anterior tibial muscle	X	X	X	√	X	X	X	√

Valgus /varus position									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Milgrom et al (1991)	Medial tibial intercondylar distance	X	X	X	√	X	X	X	√
Witvrouw et al (2000)	Distance between knee or malleolli depending on knee orientation using a ruler	X	X	X	√	X	X	X	√

Psychological variables									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Clark et al (2000)	HAD score	X	X	X	√	X	X	X	√
Witvrouw et al (2000)	Utrecht Coping List and Amsterdam Biographic Questionnaire	X	X	√	X	X	X	√	X

Radiological variables									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Doucette and Child (1996)	Merchant's congruence angle	X	√	X	X	√	X	X	X
Doucette and Goble (1992)	Condition of subchondral bone and sulcus angle measurement	X	X	X	√	X	X	X	√
Ingersoll and Knight (1996)	Patellofemoral congruence angle, sulcus angel and patella rotation	X	√	X	X	X	X	X	√
Kannus and Niittymäki (1994)	Insall-Salvati index Sulcus angle Lateral patellofemoral angle Lateral patellar displacement Patellofemoral index	X	√	X	X	X	X	X	√
Kannus et al (1999)	MRI and plain radiographs Patella cartilage thickness Subchondrol bone changes	X	√	X	X	X	X	X	√
Schneider et al (2001)	Patellofemoral congruence angle	X	√	X	X	X	X	X	√
Timm (1998)	Patellofemoral congruence angle	X	√	X	X	X	X	X	√
Tunay et al (2003)	Congruence, sulcus and patella tilt angles	X	√	X	X	X	X	X	√

Clinical tests										
Study	**Method**	**Validation**				**Reliability**				
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Eburne and Bannister (1996)	McConnell critical test	X	X	X	√	X	X	X	√
Eburne and Bannister (1996)	Clarke's test	X	X	X	√	X	X	X	√
Gaffney et al (1992)	Tenderness on medial and lateral articular patella surface	X	X	X	√	X	X	X	√
Gaffney et al (1992)	Clarke's test	X	X	X	√	X	X	X	√
Gaffney et al (1992)	Patella length to patella tendon length ratio	X	X	X	√	X	X	X	√
Kannus et al (1992)	4-point rating scale during clinical tests: compression and grinding patella against femur, pain during apprehension test and crepitation during the compression test	X	X	X	√	X	X	X	√
Kannus et al (1999)	4-point rating pain scale for patellar compression test, pain during apprehension test and crepitation during compression test	X	√	X	X	X	X	X	√
Milgrom et al (1991)	Length of tibia ? method	X	X	X	√	X	X	X	√
Milgrom et al (1991)	Hip internal and external rotation ? method	X	X	X	√	X	X	X	√
Raatikainen et al (1990)	4-point rating scale: pain during palpation, pain on patella compression, pain during apprehension test, pain descending stairs, pain squatting,, hindrance o normal life and sports activities	X	X	X	√	X	X	X	√
Thomeé (1997)	Palpation of patella using a force gauge to aid reliability of test	X	√	X	X	X	X	X	√
Yates and Grana (1986)	5-point rating scale for pain during activities	X	X	X	√	X	X	X	√

Bone density									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Kannus et al (1999)	Bone densitometry	X	X	√	X	X	X	X	√

Muscle inhibition									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Suter et al (2000)	Interpolated twitch technique	X	X	√	X	X	X	X	√
Callaghan et al (2001)	Interpolated twitch technique	X	X	√	X	X	X	√	X

Arthroscopic investigations									
Study	**Method**	**Validation**				**Reliability**			
		By authors	External reference		Not referenced or mentioned	By authors	External reference		Not referenced or mentioned
			For PFPS	General			For PFPS	General	
Raatikainen et al (1990)	Arthroscopic investigation of patella cartilage using rating scale	X	X	X	√	X	X	X	√

ELECTRONIC APPENDIX 8

8.1 FUNCTIONAL MOVEMENT STUDIES

Table 8.1: Patellofemoral pain syndrome functional gait studies

Study	Subjects	Functional Movement(s)	Method	Conclusions
Callaghan and Baltzopoulas (1994)	15 healthy subjects 15 females 0 males Mean age = 23 15 PFPS subjects 15 females 0 males Mean age = 27	Gait analysis of rear foot motion	Video motion analysis Level walkway Barefoot	PFPS subjects demonstrated prolonged but not excessive mediolateral force in the lateral direction
Heino Brechter et al (2002)	10 healthy subjects 5 females 0 males Mean age = 38 5 PFPS subjects 5 females 5 males Mean age = 36	Gait	Vicon motion analysis system Level walkway Barefoot	Patellofemoral stress was significantly greater in PFPS subjects compared with control. This was attributed to a significant reduction in PFJ contact area as the PFJ reaction force were similar between groups
Crossley et al (2002) abstract	22 PFPS	Stair ambulation	?	PFPS subjects demonstrated significantly reduced knee flexion at heel strike and peak stance phase knee flexion
Dillon et al (1983)	11 healthy subjects 8 PFPS subjects College age	Gait	High speed cinematography Treadmill Level walking 15^0 down slope Footwear?	PFPS subjects demonstrated significantly less knee flexion during single support phase on both surfaces PFPS demonstrated significantly greater external rotation while the leg was swinging through
Heiderscheit et al (2002)	PFPS subjects 8 females Mean age = 24	Running	Qualisys ProReflex motion analysis system Treadmill level Free speed Fixed speed Shod foot	PFP displayed greater stride length variability during running at free speed. Significant reduction in joint co-ordination variability for the thigh rotation/leg rotation coupling of the PFPS subjects.

Table 8.1 Continued: Patellofemoral Pain Syndrome Dynamic Functional Studies

Study	Subjects	Functional Movement(s)	Method	Conclusions
Heino Brechter and Powers (2002)	10 healthy subjects 5 females 0 males Mean age = 38 5 PFPS subjects 5 females 5 males Mean age = 36	Stair ambulation	Vicon motion analysis system	No difference in patellofemoral joint stress between control and PFPS subjects. However PFPS demonstrated significantly reduced cadence and reduced knee extensor moment
Nadeau et al (1997)	5 healthy subjects 2 male 3 female Mean age = 26 5 PFPS subjects 2 male 3 female Mean age = 28	Gait	Peak Performance Motion analysis system Level walkway Shod foot	Significant reduction in knee flexion at the beginning of stance phase during gait
Powers et al (1999)	15 healthy subjects 15 female 0 male Mean age = 27 15 PFPS subjects 15 female 0 male Mean age = 31	Gait	Vicon motion analysis system Level walkway Free Fast Barefoot	No significant difference in knee flexion during stance phase, during free walking. Significant difference in knee flexion during stance phase during fast walking
Powers et al (1997)	19 healthy subjects 19 female 0 male Mean age = 25 19 PFPS subjects 19 female 0 male Mean age = 25	Gait Stair ambulation Ramp walking	Vicon motion analysis system Level walkway Free Fast Four step staircase Ramp walking 12^0 incline Barefoot	No significant difference in knee flexion during stance phase for any of the conditions Significant reduction in walking speed in PFPS subjects which was a function of reduced stride length and cadence
Salsich et al (2001)	10 PFPS subjects 5 female 5 male Mean age = 37 10 healthy subjects 5 female 5 male Mean age = 32	Stair ambulation	Vicon motion analysis system 2 step staircase Footwear?	PFPS subjects demonstrated a significant decreased peak knee extensor moments during stair ascent and descent. Significant reduction in cadence during stair descent

ELECTRONIC APPENDIX 9

9.1 FIBREOPTIC ELECTROGONIOMETER VERSION 1

This appendix outlines the experimental procedures used to evaluate the precision, accuracy, reliability and validity of the original 1999 version of the fibreoptic electrogoniometer (Measurand Inc, 1999) referred to in Chapter 7.

9.2 FIBREOPTIC ELECTROGONIOMETER / COMPUTER INTERFACE

The S700 Shape Sensor™ was connected to a computer via a connection lead (C1500 interconnect lead) to an amplification box and integral power supply. An IBM personal computer with a 486MHz clock speed, 16Mb RAM and 2Gb hard drive was used. It was fitted with an Amplicon PC26AT 12 bit Analogue to Digital computer board with an interference box for wiring connections to the board allowing the signal to be quantified to 4096 discrete levels (0 to 4095), equivalent to a voltage of 6.33 volts.

9.3 SOFTWARE

Two software programs developed within the Department of Physiotherapy, Queen Margaret University College, Edinburgh and written in Borland Turbo Pascal were used in this study. These operated in MS-DOS and were designed to collect data from many types of measuring equipment. The first was a 'data collection program', which performed a number of functions during calibration and recording of data as listed below:

- Sampling frequency - could be adjusted between 5Hz and 200Hz depending on the rate of change of the stimulus being recorded.
- Average - for calibration purposes this function calculated the average of 100 consecutive

values. The second was a 'general program' this recorded the angular displacement and could record 4000 samples per fibreoptic electrogoniometer. At a sample frequency of 50Hz it gave a recording time of 80 seconds.

9.4 CALIBRATION TESTS

The manufacturers specifications revealed that the sensing area of the fibreoptic electrogoniometer was positioned 40mm from the optoelectronic end box. Thus, it was essential to ascertain how the output of the device was affected by changes in angular displacement when the axis of movement of the input movement altered in relation to the sensing zone.

A testing set-up was prepared this consisted of a bisecting line drawn along the long axis of a 0.91 x 0.61 x 0.02 metres piece of medium density fibre wood (MDF). The fibreoptic end box was placed on its broad side centrally at one end of the MDF. The proximal end of the fibreoptic measuring element or cantilever was extended parallel along the length of the central line marked on MDF. The fibreoptic end box was then held in place by interference fit by two pieces of 0.08 x 0.03 x 0.02 metres blocks of pinewood glued to the MDF. An angle grid system was constructed on a piece of A3 paper, which consisted of consecutive semicircles with radii ranging from 1 cm to 23 cm in 1 cm increments. A central line was drawn between the centre of the semicircle and the outer semicircle. Another two lines denoting arbitrary angles of $+30^0$ and -30^0 were marked on either side of the central line, using trigonometry, and lines extended between the centre to the outer semicircle shown in Figure 9.1.

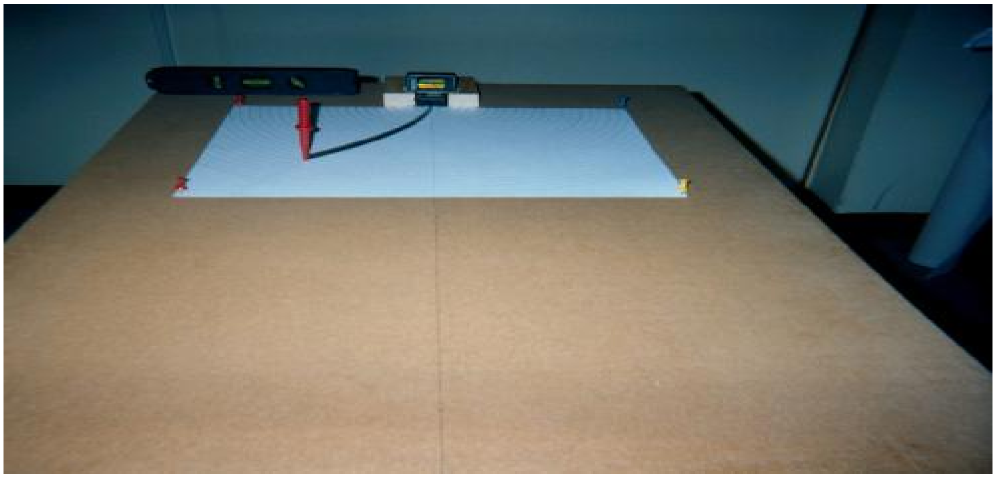


Figure 9.1 Basic experimental set-up for testing the fibre-optic electrogoniometer

9.5 EFFECT OF CHANGING THE LOCATION OF MOVEMENT ALONG FIBREOPTIC GONIOMETER RELATIVE TO THE SENSING ZONE

9.5.1 Experiment Aim

The aim of this experiment was to assess the effect of changing the location of movement along the length of the fibreoptic.

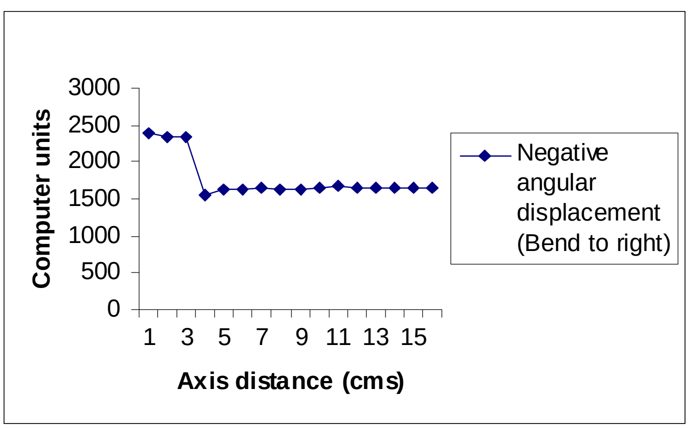
9.5.2 Method

Blocks of wood were prepared 0.02 x 0.03 metres with varying lengths ranging from 0.01 metres to 0.18 metres in 0.01 metres increments. A bisecting saw cut 0.001 metres wide and 0.01 metres deep were made along the long axis of the underside of each piece of pinewood to accommodate the cantilever. Each piece of wood was sequentially placed over the cantilever, with the cantilever placed within the saw cut. The proximal end of the 'restraining' wood was placed in contact with the fibreoptic end box. Each piece of wood was held in place with a wooden cross baton, secured with clamps. The fibreoptic was moved through 30^0 to the perpendicular in both positive (bends to the left) and negative (bends to the right) directions for each change in wood length, as indicated by the constructed angle grid. The metal pin was situated an arbitrary distance of 0.05m from the distal end of the 'restraining' wood, thus allowing sufficient bend in the cantilever without damaging it. This ensured accurate identification of the grid position. 100 consecutive values were then recorded at each distance for both the negative and positive 30^0 directions. The procedure was repeated by replacing each piece of wood with increasing increments, hence changing the location along the cantilever at which bending was possible. The set up is shown in Figure 9.2.

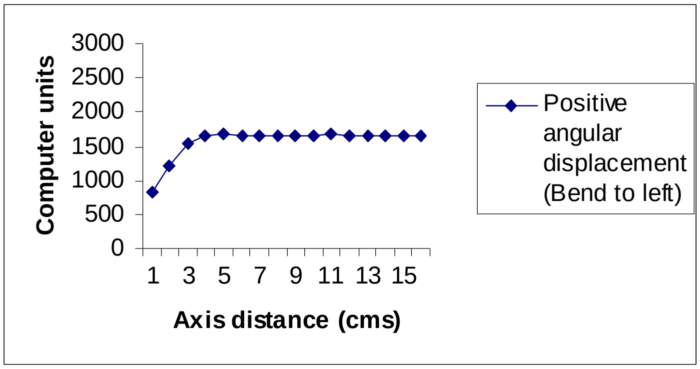
Figure 9.2: Experimental set-up varying the axis of movement along fibreoptic goniometer

9.5.3 Results

The change in computer output with a 30^0 angular displacement whilst changing the distance along the cantilever at which it could bend is shown in Graphs 9.1 and 9.2.



Graph 9.1: Effect of altering the location of maximum movement along the cantilever relative to the sensing zone in the negative direction



Graph 9.2: Effect of altering the location of maximum movement along the cantilever relative to the sensing zone in the positive direction

Results confirm that if movement did not occur at the area of the sensing zone, then no change in output was recorded.

9.5.4 Conclusion

The goniometer was sensitive to altering the location of movement along the cantilever relative to the sensing zone.

9.6 CHANGE IN ATTACHMENT DISTANCE

9.6.1 Experiment Aim

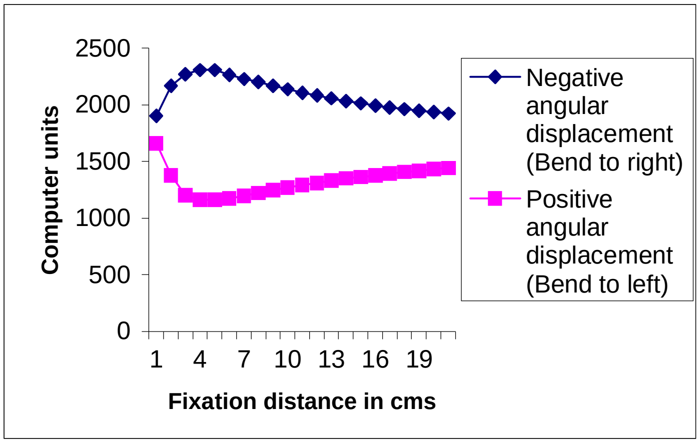
The manufacturers provided no guidance as to the optimal position along the cantilever to place any distal attachment mechanism. This experiment set out to assess the effect of changing the distance between proximal and distal attachments

9.6.2 Method

A similar set up was adopted as in the previous experiment. On this occasion the free cantilever was moved through an arbitrary distance of 30^0 in both a positive (bend to the left) and negative (bend to the right) direction. The fixation distance from the centre of proximal end of the cantilever was increased in one-centimetre intervals and held in place with a plastic marker and pin. One hundred samples were taken individually at each attachment length.

9.6.3 Results

The effect of changing the distal attachment distance is shown in Graphs 9.3. The results demonstrated a non-linear response to changing the distal attachment.



Graph 9.3: Effect of changing the distal attachment distance

9.6.1 Conclusions

The electrogoniometer output was sensitive to changes in location of the distal attachment mechanism.

9.7 ACCURACY

9.7.1 Experiment Aim

The aim of this experiment was to establish the degree of accuracy of the electrogoniometer output, through a simulated functional range of excursion. The 'normal' range of sagittal motion at the knee joint is reported to be in the region of 140^0 (Roaas and Andersson, 1982; Miller, 1985), with 135^0 of knee joint mobility required to undertake a wide range of basic functional activities of daily living (Rowe et al, 2000).

8.7.2 Method

The fibreoptic electrogoniometer was attached to a 360^0 hand held plastic universal goniometer (BASELINE™ Physio-Med Services Ltd, Glossop, Derbyshire) calibrated in one-degree increments. The axial mechanism of the universal goniometer was counter sunk into MDF wood used in the previous experiments. Pilot studies revealed that if the distal end of the cantilever was completely fixed the cantilever and contained fibreoptic tended to undergo acute angulations as it approached 90^0 excursions, this had the potential to damage the fibreoptic. To overcome this a mounting with rotating bushings was constructed to contain the cantilever, but allow it to slide through the mounting as angle excursion increased. The mounting was constructed from Perspex and "Meccano toy" components (Figures 9.3 and 9.4).

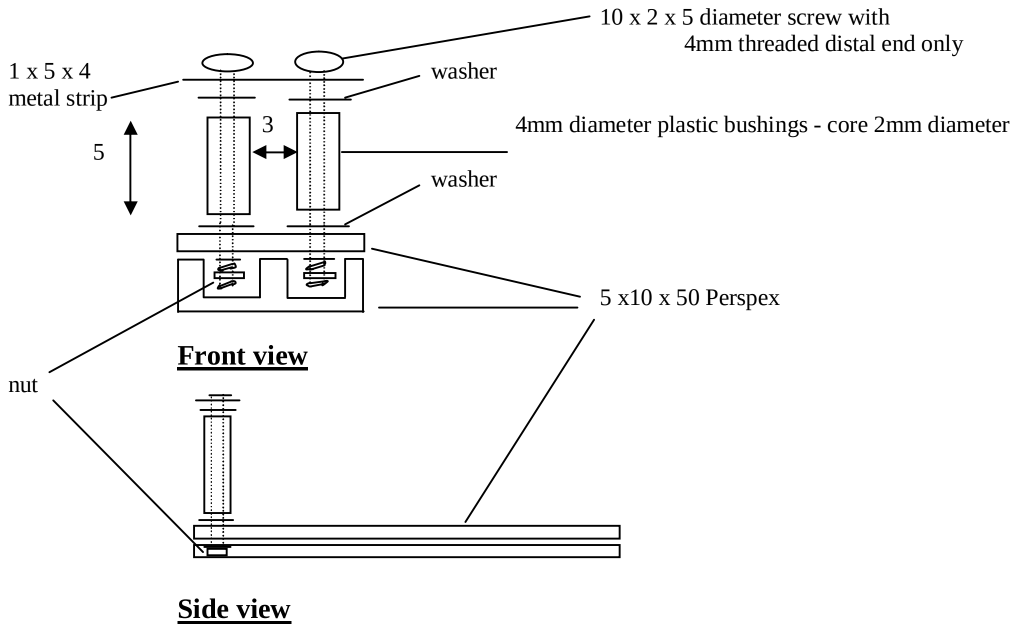


Figure 9.3: Schematic of distal end mechanism (dimensions in mm)

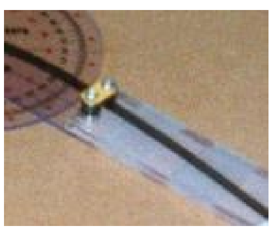
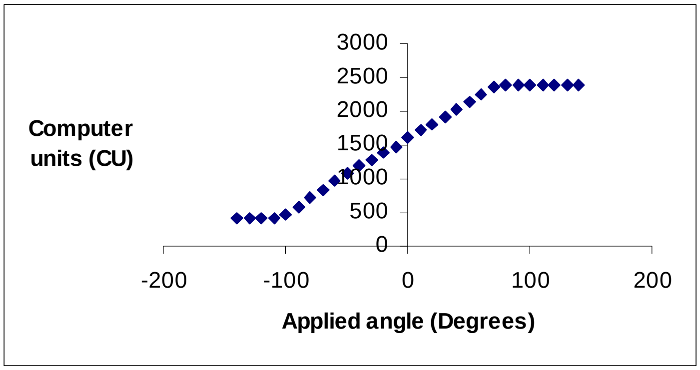


Figure 9.4: Distal end mechanism

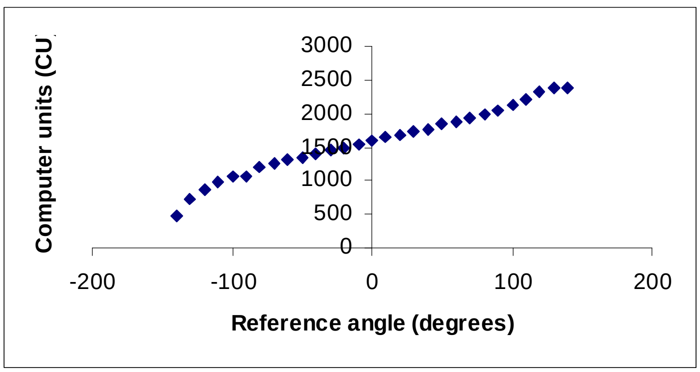
The centre of this distal mounting was fixated using Velcro and single sided adhesive tape around the distal arm of the plastic goniometer at an arbitrary distance of 3cm in line with the plastic goniometer axis centre. The cantilever was then aligned along the long axis of the plastic goniometer and the proximal optoelectronic end box fixated initially at 3cm from the plastic universal centre, using Velcro and adhesive tape. The electrogoniometer was manipulated through a range of angular displacements using the plastic goniometer from 0^0 to 140^0 back through 0^0 to -140^0 in ten-degree increments. This process was repeated 10 times but on each new occasion the proximal end of the cantilever and optoelectronic end box was moved in 1cm increments from the 3cm position to 12cm in line with the long axis of the plastic goniometer. The manufacturer's recommendation was that the cantilever should not be deflected through an arc less than a radius of less than 3cm, which could potentially damage the fibreoptic.

9.7.3 Results

A graph was plotted of the input from the plastic goniometer (reference angles) against the fibreoptic electrogoniometer output (computer units), regression lines were inserted and the equations of these regression lines determined. Examples of the graphs obtained for 6cm and 12cm attachment lengths are shown in Graphs 9.4 and 9.5.

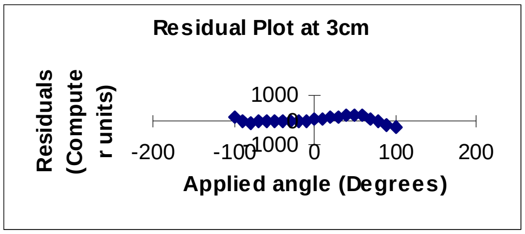


Graph 9.4: Attachment length 6 cm from optoelectronic and box to goniometer axis of rotation

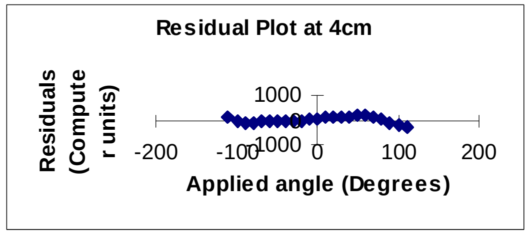


Graph 9.5: Attachment length 12 cm from optoelectronic end box to goniometer axis of rotation

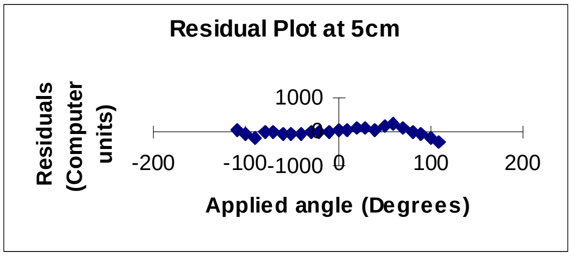
Evidently the electrogoniometer output was variable in relation to the axis of rotation of the reference input, with linearity being more evident when movement occurred in the proximity of the sensing zone. The device demonstrated greater inaccuracies with increasing angular displacement, beyond the ranges $+70^0$ and -70^0, which was highlighted from the residual values (Graphs 9.6 to 9.15).



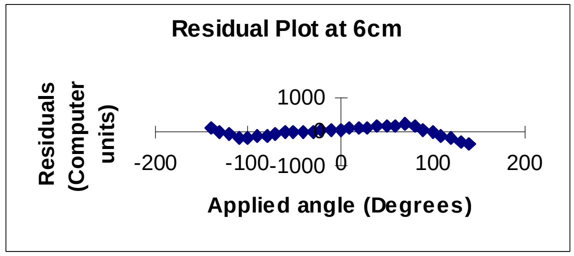
Graph 9.6



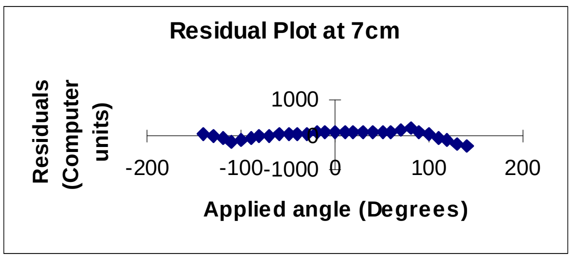
Graph 9.7



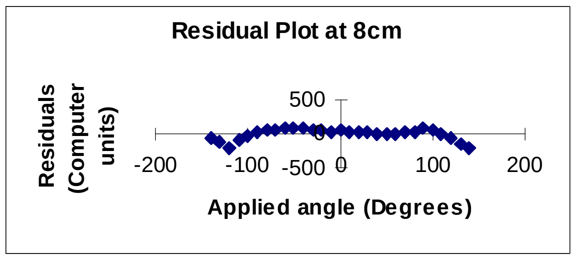
Graph 9.8



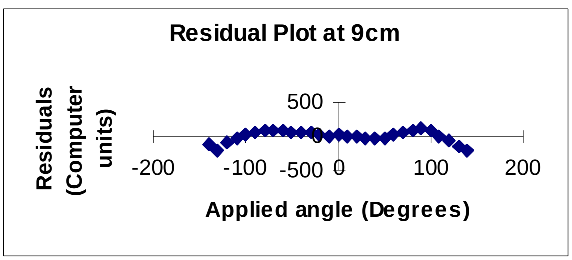
Graph 9.9



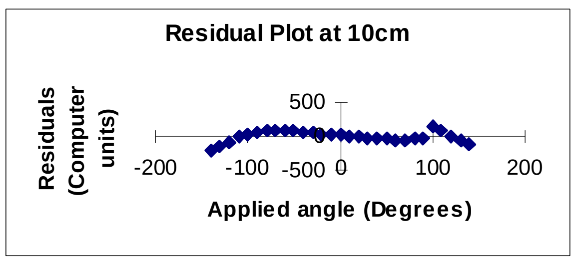
Graph 9.10



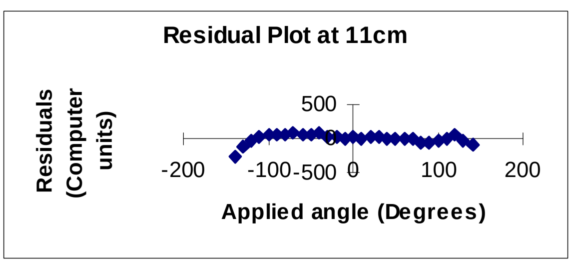
Graph 9.11



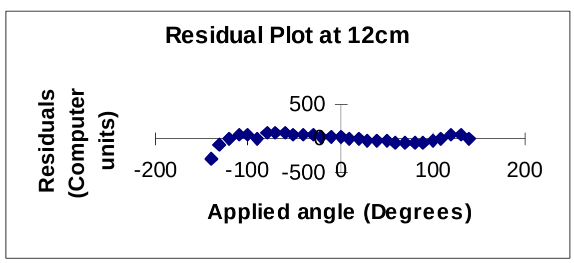
Graph 9.12



Graph 9.13



Graph 9.14



Graph 9.15

The manufacturer's specification (Table 9.1) detailed that the device was accurate to within 1.5% +/- 90^0.

Table 9.1: Manufacturers specification of fibreoptic electrogoniometer version 1 (Measurand Inc, 1999)

- Full scale (FS) range: +/- 1.0V for 90 joint angles.
- Output voltage for straight sensor: 2.5V, =/-0.2V.
- Accuracy: +/-1.5% of FS
- Resolution: +/-0.03% of FS
- Noise floor: 0.07 mVrms/$Hz^{-1/2}$.
- 3dB Bandwidth: 1.0KHz.
- Temperature sensitivity, offset: +/-2% of FS, -40^0C to 70^0C.
- Environmental: -40^0C to 70^0C.
- Excitation: 5 to 15 VDC (Supply current at 5VDC, 15^0C: 5mA)
- Electrical Connections: Red; Power supply (5 to 15 volts regulated); Black: Ground (Power supply and signal); Clear: Sensor output

In light of this information the accuracy was determined within this $+90^0$ to -90^0 ranges for the device. The regression equations were observed to vary markedly depending on the position of the cantilever attachments in relation to the reference axis of rotation (Table 9.2).

Table 9.2: Change in regression equations, gradient and intercept with changes in attachment distance relative to the axis of rotation

Distance between optoelectronic end box and goniometer axis of rotation	Gradient (Computer units)	Intercept (Computer units)
3cm	12.7	1520
4cm	12.0	1527
5cm	11.6	1535
6cm	10.4	1585
7cm	9.3	1584
8cm	7.5	1573
9cm	7.2	1603
10cm	6.0	1572
11cm	5.7	1596
12cm	5.2	1602

Based on these individual regression equations the maximum residual, mean residual, percentage linearity, coefficient of determination and standard error of the estimate were calculated (Table 9.3).

Table 9.3: Maximum absolute residuals; mean absolute residuals and percentage linearity for changes in distance between axis of rotation and optoelectronic end box based on the regression equations $+90^0$ to -90^0 for each distance.

	3cms	4cms	5cms	6cms	7cms	8cms	9cms	10cms	11cm	12cm
Maximum absolute residual in computer units	21.8	19.3	16.7	13.0	6.5	7.9	12.6	6.67	8.1	18.7
Mean absolute residual	5.6	9.9	7.5	2.3	2.4	2.6	4.6	2.3	2.8	5.5
Percentage linearity (180^0 range)	12.1%	10.7%	9.3%	7.2%	3.6%	4.4%	7.0%	3.7%	4.5%	10.4%
Coefficient of determination	<0.99	>0.99	<0.98	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	<0.99
Standard error of estimate in computer units	107	78	90	42	29	25	43	18	21	41
2 standard error of estimate in computer units	214	156	180	84	58	50	86	36	42	84

Again these values highlighted the variations in output with alteration in distance between the proximal and distal end attachments. The results indicated that output from the device was variable depending on its relation to the axis of rotation. At best it had a mean residual of 2.4^0 and maximum residual of 6.5^0, which was beyond the tolerance required for this project (accuracy to within 5^0). In relation to attaching the electrogoniometer for the purposes of measuring human joint motion this would necessitate guaranteeing that the end attachments would maintain a constant relationship and that movement would remain constant about the sensing zone, which in practical terms would be almost impossible owing to soft tissue movement. A further factor contributing to this inaccuracy may have been caused by the fact that the sprung steel within the cantilever tended to recoil with increasing angular displacements and at different locations relative to the sensing zone. Given the unpredictability of the device it was deemed that this particular fibreoptic electrogoniometer would not be suitable for this study.

9.7.1 Conclusions

The device demonstrated unacceptable levels of accuracy required for this study.

9.8 PRECISION AND NOISE

9.8.1 Experiment Aim

Signal stability is an important aspect of system performance (Rowe et al, 2001). In measuring devices, which employ electrical circuits there is some fluctuation or noise in the signal due to interference of electromagnetic currents, so affecting precision (Basmajian and De Luca, 1985). Therefore, in determining the precision of the electrogoniometer the electrical noise of the system was recorded and analysed.

9.8.2 Method

The output from the electrogoniometer was recorded for two seconds at 50Hz (100 readings) as the device was manipulated through 0^0 to $+140^0$ and back trough 0^0 to -140^0 in 10-degree increments. This was repeated for each of the 10 different distal attachment distances. Note at the shorter attachment distances 3cm to 5cm the full angular excursion could not be undertaken as the cantilever tended to spring out of the attachment.

9.8.3 Results

The device appeared precise with coefficients of variations between 0.1 to 0.4% between. -140^0 to $+140^0$ (Table 9.4). There did however appear to be a reduction in precision towards greater angular displacements, greater than 90^0, when the device was moved in a negative direction (bent to the right).

Table 9.4: Precision of 100 values at 10^0 increment angles (sampled at 50Hz)

Angle	Standard deviation of 100 samples in computer units (Coefficient of variation % in brackets)									
(degrees)	3cm	4cm	5cm	6cm	7cm	8cm	9cm	10cm	11cm	12cm
0	1.7(0.1)	1.9(0.1)	1.9(0.1)	1.7(0.1)	1.8(0.1)	1.8(0.1)	1.6(0.1)	1.6(0.1)	1.7(0.1)	1.8(0.1)
10	1.9(0.1)	1.6(0.1)	1.6(0.1)	1.7(0.1)	2.0(0.1)	1.8(0.1)	1.6(0.1)	1.7(0.1)	1.8(0.1)	2.0(0.1)
20	1.6(0.1)	1.4(0.1)	1.4(0.1)	1.5(0.1)	2.0(0.1)	1.6(0.1)	1.7(0.1)	1.8(0.1)	1.7(0.1)	1.4(0.1)
30	1.8(0.1)	1.9(0.1)	1.9(0.1)	1.6(0.1)	1.9(0.1)	1.8(0.1)	1.7(0.1)	1.7(0.1)	1.6(0.1)	1.4(0.1)
40	2.1(0.1)	2.2(0.1)	1.9(0.1)	1.5(0.1)	1.9(0.1)	1.6(0.1)	1.8(0.1)	1.8(0.1)	1.6(0.1)	2.0(0.1)
50	2.2(0.1)	2.3(0.1)	2.3(0.1)	2.3(0.1)	1.6(0.1)	1.8(0.1)	2.0(0.1)	1.8(0.1)	1.6(0.1)	1.6(0.1)
60	2.2(0.1)	2.4(0.1)	2.4(0.1)	2.0(0.1)	2.3(0.1)	1.4(0.1)	2.0(0.1)	1.8(0.1)	1.6(0.1)	1.6(0.1)
70	2.5(0.1)	2.3(0.1)	2.3(0.1)	2.0(0.1)	2.3(0.1)	2.0(0.1)	2.2(0.1)	1.5(0.1)	1.6(0.1)	1.6(0.1)
80	2.3(0.1)	3.3(0.1)	2.3(0.1)	2.5(0.1)	2.4(0.1)	2.0(0.1)	1.9(0.1)	2.1(0.1)	1.6(0.1)	1.8(0.2)
90	2.2(0.1)	2.2(0.1)	2.1(0.1)	2.1(0.1)	2.3(0.1)	1.9(0.1)	2.0(0.1)	2.1(0.1)	2.1(0.1)	2.0(0.1)
100	2.3(0.1)	1.6(0.1)	2.3(0.1)	2.0(0.1)	2.4(0.2)	2.2(0.2)	1.9(0.1)	2.4(0.2)	2.3(0.2)	2.4(0.1)
110	-	2.4(0.1)	2.4(0.1)	2.2(0.1)	2.4(0.1)	2.2(0.2)	2.1(0.1)	2.0(0.1)	1.8(0.1)	1.9(0.1)
120	-	-	-	2.0(0.1)	1.4(0.1)	2.4(0.1)	1.9(0.1)	1.9(0.2)	2.1(0.1)	1.9(0.1)
130	-	-	-	2.5(0.1)	1.7(0.1)	1.5(0.1)	2.2(0.1)	1.8(0.1)	1.8(0.1)	2.3(0.1)
140	-	-	-	2.1(0.1)	1.6(0.1)	1.7(0.1)	2.1(0.1)	2.4(0.1)	2.5(0.1)	2.4(0.1)
-10	2.0(0.1)	1.7(0.1)	1.7(0.1)	1.7(0.1)	1.8(0.1)	2.1(0.1)	2.0(0.1)	1.8(0.1)	1.9(0.1)	1.7(0.1)
-20	1.8(0.2)	1.9(0.1)	1.9(0.1)	1.6(0.1)	2.0(0.1)	1.7(0.1)	1.6(0.1)	1.9(0.1)	2.4(0.1)	1.8(0.1)
-30	2.0(0.2)	2.1(0.1)	2.1(0.2)	1.7(0.1)	1.6(0.1)	1.7(0.1)	1.8(0.1)	1.4(0.1)	1.5(0.1)	1.9(0.1)
-40	2.0(0.2)	2(0.1)	2.0(0.2)	2.0(0.2)	1.7(0.1)	1.8(0.1)	1.8(0.2)	1.6(0.1)	1.5(0.1)	1.6(0.1)
-50	2.1(0.2)	2.2(0.1)	2.1(0.2)	2.0(0.2)	1.9(0.2)	1.9(0.1)	2.1(0.1)	1.8(0.1)	1.8(0.1)	2.0(0.1)
-60	2.0(0.3)	2.1(0.1)	2.1(0.3)	2.0(0.2)	1.8(0.2)	1.8(0.1)	2.0(0.2)	1.9(0.1)	2.1(0.2)	1.6(0.1)
-70	2.3(0.4)	2.7(0.1)	2.7(0.4)	1.8(0.2)	2.3(0.2)	1.5(0.1)	2.0(0.2)	1.9(0.2)	1.8(0.1)	1.9(0.1)
-80	1.8(0.4)	1.7(0.1)	2.1(0.3)	1.9(0.3)	2.0(0.2)	1.9(0.2)	2.0(0.2)	1.9(0.2)	1.9(0.2)	1.8(0.1)
-90	1.4(0.3)	1.4(0.1)	1.4(0.3)	2.0(0.3)	2.4(0.3)	1.9(0.2)	1.9(0.2)	1.9(0.2)	2.1(0.2)	1.9(0.2)
-100	1.4(0.3)	1.4(0.3)	1.6(0.4)	1.8(0.4)	1.4(0.2)	2.4(0.3)	2.0(0.2)	2.0(0.2)	1.8(0.2)	1.9(0.2)
-110	-	1.5(0.4)	1.5(0.4)	1.6(0.4)	2.0(0.5)	2.4(0.4)	1.8(0.2)	1.9(0.2)	1.9(0.2)	1.8(0.2)
-120	-	-	-	1.7(0.4)	2.3(0.6)	2.2(0.5)	2.7(0.5)	1.8(0.3)	2.0(0.3)	1.9(0.2)
-130	-	-	-	1.3(0.3)	2.4(0.6)	2.3(0.6)	2.0(0.5)	2.4(0.4)	2.0(0.3)	2.1(0.3)
-140	-	-	-	2.1(0.5)	1.6(0.4)	1.7(0.4)	1.5(0.4)	2.0(0.5)	2.3(0.6)	1.7(0.3)

9.8.2 Conclusions

The device appeared precise within the range -140^0 to $+140^0$.

9.8 SUMMARY

The fibreoptic electrogoniometer appeared precise, but prone to inaccuracy. On challenging the manufacturers on the accuracy of the device Measurand Inc stated that they had improved their product since 1999 and offered to send a newer version of their fibreoptic electrogoniometer at no extra cost.

ELECTRONIC APPENDIX 10

10.1 FIBREOPTIC ELECTROGONIOMETER VERSION 2

The following appendix gives an overview of the fibreoptic electrogoniometer (version 2) trialled for use in this study.

10.2 PRECISION AND SYSTEM NOISE

10.2.1 Signal Stability

Signal stability is an important aspect of system performance (Rowe et al, 2001). In measuring devices, which employ electrical circuits there is some fluctuation or noise in the signal due to interference of electromagnetic currents, so affecting precision (Basmajian and De Luca, 1985). Therefore, in determining the precision of the electrogoniometer the electrical noise of the system was recorded and analysed. The aim of this experiment was to confirm the precision of the fibreoptic electrogoniometer.

10.2.2 Method

Fibreoptic Electrogoniometer / Computer Interface

The following interface configuration between the fibreoptic electrogoniometer and computer was used for all fibreoptic electrogoniometer experiments. The S700 Shape Sensor^{TM} was connected to a computer via a connection lead (C1500 interconnect lead) to an amplification box and integral power supply. An IBM personal computer with a 486MHz clock speed, 16Mb RAM and 2Gb hard drive was used. It was fitted with an Amplicon PC26AT 12 bit Analogue to Digital computer board with an interference box for wiring connections to the board allowing the signal to be quantified to 4096 discrete levels (0 to 4095), equivalent to a voltage of 6.33 volts.

Software

Two software programs developed within the Department of Physiotherapy, Queen Margaret University College, Edinburgh and written in Borland Turbo Pascal were used in this study. These operated in MS-DOS and were designed to collect data from many types of measuring equipment. The first was a 'data collection program', which performed a number of functions during calibration and recording of data as listed below:

- Sampling frequency - could be adjusted between 5Hz and 200Hz depending on the rate of change of the stimulus being recorded.
- Average - for calibration purposes this function calculated the average of 100 consecutive values.

The second was a 'general program' this recorded the angular displacement and could record 4000 samples per fibreoptic electrogoniometer. At a sample frequency of 50Hz it gave a recording time of 80 seconds.

Fibreoptic Electrogoniometer Precision Test Method

The fibreoptic electrogoniometer was attached to the arms of a plastic universal hand held goniometer (BASELINE™ Physio-Med Services Ltd, Glossop, Derbyshire) using plastic mushroom-head Velcro. These were further secured by applying single-sided adhesive tape around the end boxes and universal goniometer arms. The fibreoptic electrogoniometer was manipulated through a range of angular displacements, using the universal plastic goniometer, from 0° to 140° back through 0° to -140° and back to 0° in ten degree increments. One hundred samples were recorded at each increment and the mean of thee 100 samples calculated.

9.2.3 Results and Conclusions

The results of recording 100 samples at each 10° angle are shown in Table 10.1. The standard deviation of each reading from the mean value for that position was also calculated for all 100 readings at each 10° increment. The deviation of each reading from the mean for that position indicated that none of the readings varied from the mean value more than 0.2% of the measured range (equivalent to 0.56°). The output of the fibreoptic electrogoniometer (version 2) appeared precise.

Table 10.1: Precision of 100 values at 10° increment angles (sampled at 50Hz)

Angle (degrees)	Standard deviation of 100 samples in computer units (Coefficient of variation % in brackets)
-140	1.9 (0.1)
-130	1.8 (0.1)
-120	2.0 (0.1)
-110	1.8 (0.1)
-100	1.9 (0.1)
-90	1.8 (0.1)
-80	1.8 (0.1)
-70	1.7 (0.1)
-60	1.9 (0.1)
-50	1.7 (0.1)
-40	1.5 (0.1)
-30	1.6 (0.1)
-20	1.6 (0.1)
-10	1.7 (0.1)
0	1.7 (0.1)
10	1.7 (0.1)
20	1.8 (0.1)
30	2.0 (0.1)
40	2.2 (0.2)
50	1.7 (0.1)
60	2.0 (0.2)
70	1.5 (0.1)
80	2.0 (0.2)
90	1.9 (0.2)
100	1.8 (0.2)
110	1.8 (0.2)
120	1.8 (0.2)
130	1.6 (0.1)
140	1.7 (0.2)

10.3 SIGNAL STABILITY

10.3.1 Experimental Aim

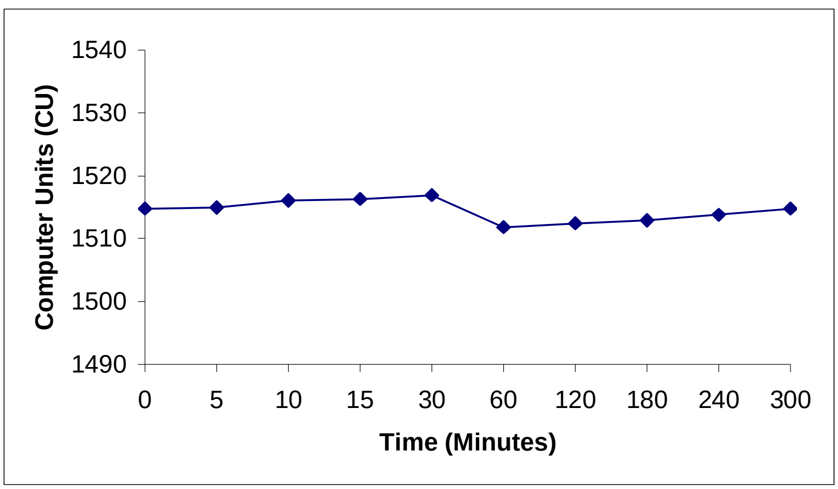
To investigate the stability of the electrogoniometer during continuous data collection, data were recorded from the device over a five hour time period.

10.3.2 Method

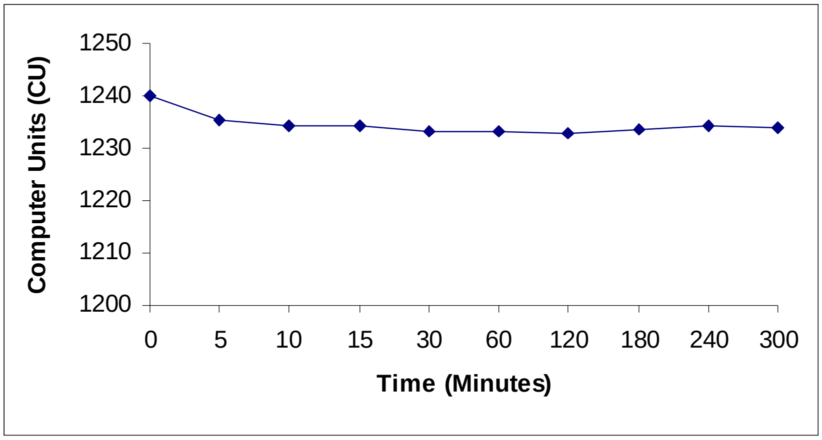
100 readings were recorded from the electrogoniometer attached to a plastic goniometer. Time intervals of 0, 5, 10, 15, 30, 60, 120, 180, 240 and 300 minutes from switch-on of the device were recorded at an angle of 0°. The procedure was also repeated at an angular displacement of 60°.

10.3.3 Results and Conclusions

Standard deviation for drift over the recorded 5 hour time period was 1.7 computer units, (equivalent to 0.37°) at 0° and 2.1 computer units (equivalent to 0.45°) at 60° (Graphs 10.1 and 10.2). These tests confirmed that the static output of the electrogoniometer was stable over a five-hour period.



Graph 10.1: Drift with start-up at 0° angle



Graph 10.2: **Drift with start-up at 60° angle**

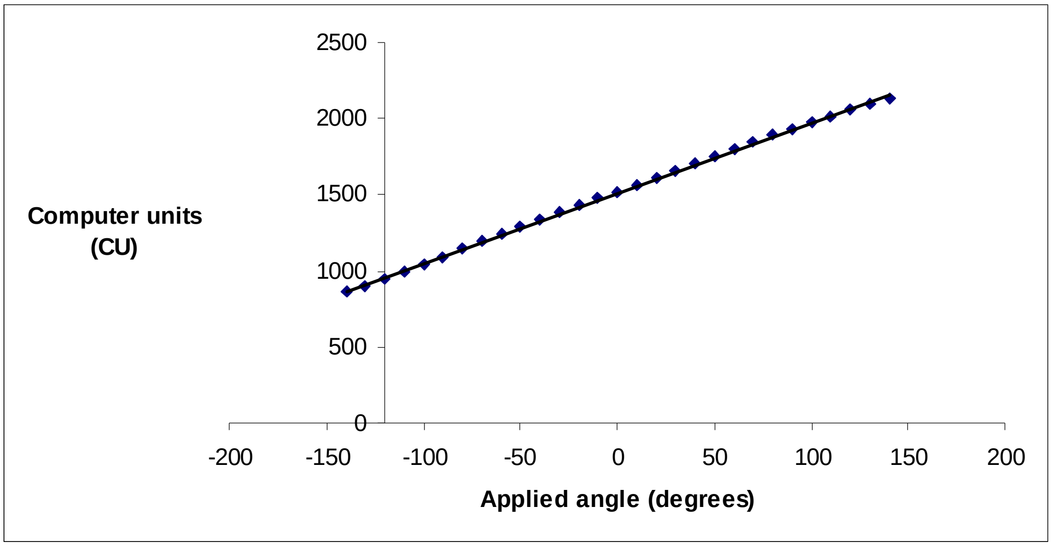
10.4 ACCURACY

10.4.1 Experiment Aim

The aim of this experiment was to establish the accuracy and calibration coefficients of the fibreoptic electrogoniometer 1. For the fibreoptic electrogoniometer to be clinically useful it must demonstrate a stable linear relationship between the angles applied to the device as measured by a reference system (Rowe, 1999). In this case a standard universal plastic goniometer acted as the reference system ('true' input angles), and the computer recorded the output from the fibreoptic electrogoniometer in computer units.

10.4.2 Method

The electrogoniometer was manipulated through a range of angular displacements, using the universal plastic goniometer, from 0° to 140° back through 0° to -140° and back to 0° in ten degree increments. One hundred samples were recorded at each increment and the mean of these 100 samples calculated. Regression analysis was used to produce the best-fit line through the data relating to the applied input angle in degrees (x) to the recorded output in computer units (y) (Graph 10.3). Based on these individual regression equations the maximum residual, mean residual, percentage linearity, coefficient of determination and standard error of the estimate were calculated (Table 10.2).



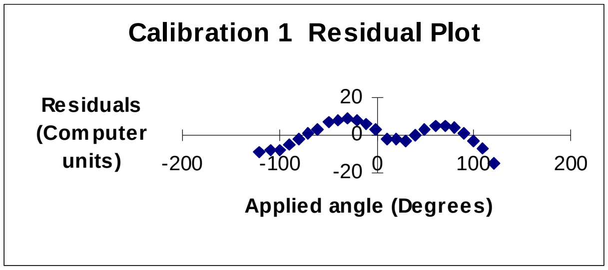
Graph 10.3: The relationship between the applied angle (true angle) and the measured output (in computer units) when the electrogoniometer is manipulated through a range of angles from –140° to +140°.

Table 10.2: Regression analysis calculations

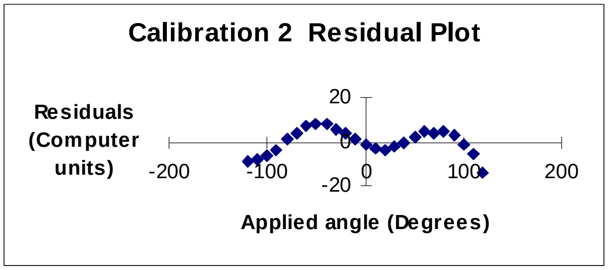
	Computer units (CU) (degrees in brackets)				
	Calibration 1	**Calibration 2**	**Calibration 3**	**Calibration 4**	**Calibration 5**
Maximum absolute residual (degrees)	23.5 (5.1)	23.0 (5.0)	25.2 (5.5)	24.9 (5.4)	22.4 (4.9)
Mean absolute residual	6.93 (1.5)	6.56 (1.4)	7.2 (1.6)	6.98 (1.5)	6.80 (1.5)
Percentage linearity(280° range)	8.4%	8.2%	9%	8.9%	8%
Coefficient of determination	>0.99	>0.99	>0.99	>0.99	>0.99
Standard error of estimate	8.8 (1.9)	8.4 (1.8)	9.2 (2.0)	8.8 (1.9)	8.6 (1.9)
2 standard errors of estimate	17.6 (3.8)	16.8 (3.6)	18.4 (4.0)	17.6 (3.8)	17.2 (3.7)

The equation of this line calibration was $y = 4.61x + 1514$ indicating that there were 4.61 computer units generated per degree (95% CI 4.58 to 4.66) and that at 0° the computer would obtain a reading of 1514 units (95% CI 1511 to 1518). The R squared value for the line was > 0.99, indicating a highly significant and linear correlation between the applied angles and output with less than 1% of the variation in the output data remaining unexplained by the regression. The maximum standard error of the estimate was 9.2 computer units equivalent to 2° (9.2 / 4.61) with 95% of the systematic errors following within two standard deviations equivalent to 18.4 computer units equivalent to 4°. The experiment was repeated a further five times with variation in the slope of the line 4.59 to 4.60 or intercept 1512 to 1518 computer units.

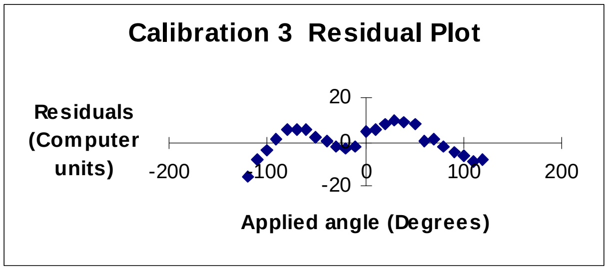
Closer analysis of Graph 10.3 revealed that the linear relationship of the true input angle to the output in computer units appeared to diminish beyond 100° with a maximal residual recorded of 25.2 computer units at 140° equivalent to 5.5° (25.2 / 4.61). This is reflected in the residual values obtained, which appeared to demonstrate a systematic response with increasing residual errors beyond 90° (Graphs 10.4 to 10.8).



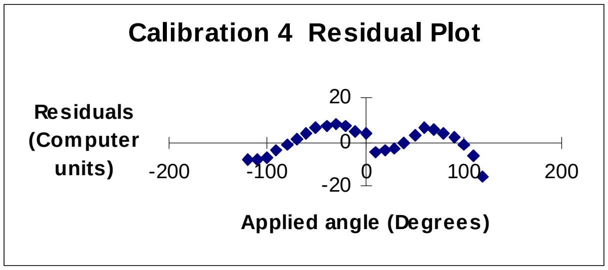
Graph 10.4: **Residual plots during calibration 1**



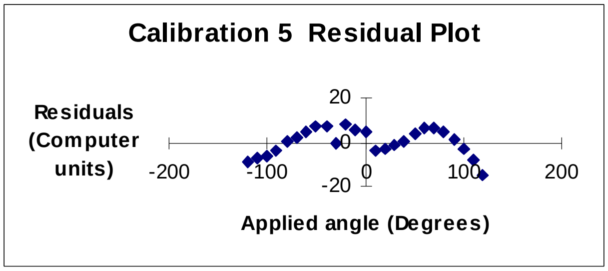
Graph 10.5: **Residual plots during calibration 2**



Graph 10.6: **Residual plots during calibration 3**



Graph 10.7: **Residual plots during calibration 4**



Graph 10.8: **Residual plots during calibration 5**

The manufacturer's specifications (Table 10.3) reflect this with linearity stated up to at least + / - 90° ranges of movement. Errors greater than 5° were beyond the tolerance required for this study.

Table 10.3: Manufacturer's specification of S700™ Shape Sensor (2001 model)

Full scale (FS) range: +/- 1.0 V for +/- 90° joint angles
Output voltage for straight sensor: 2.5 V, +/- 0.2V
Accuracy: +/-2% of FS
Resolution: 0.05
Noise floor: 0.07 mVrms/Hz1/2
3dB Bandwidth: 1.0 kHz
Environmental: -40°C to +70°C
Temperature sensitivity offset +/- 2% of FS. –40°C to +70°C
Weight: 45g
Excitation: 5 to 15 VDC (Supply current at 5VDC, 15 C: 5mA)
Electrical connections: Red: power supply (5 to 15 volts regulated); Black: ground (power supply and signal); Clear; sensor output

It was therefore decided to compromise and calibrate the device through + / - 120° ranges since the functional activities involved in this study walking, stairs, sitting to standing involved joint excursions with ranges of less than 120°. Based on these individual regression equations the maximum absolute residual, mean residual, percentage linearity, coefficient of determination and standard error of the estimate were calculated and are shown in Table 9.4 for regression analysis between +120° to -120°.

Table 10.4 Regression analysis calculations

	Computer units (CU) (Degrees in brackets)				
	Calibration 1	**Calibration 2**	**Calibration 3**	**Calibration 4**	**Calibration 5**
Maximum absolute residual (degrees)	14.60 (3.1)	13.84 (3.0)	15.71 (3.4)	15.40 (3.3)	15.19 (3.3)
Mean absolute residual	5.05 (1.1)	4.60 (1.0)	5.20 (1.1)	5.02 (1.1)	4.99 (1.1)
Percentage linearity(240° range)	6.1%	5.8%	6.5%	6.4%	6.3%
Coefficient of determination	>0.99	>0.99	>0.99	>0.99	>0.99
Standard error of estimate in computer units (degrees in brackets)	6.25 (1.3)	5.77 (1.2)	6.54 (1.4)	6.14 (1.3)	6.26 (1.3)
2 standard errors of estimate in computer units (degrees in brackets)	12.50 (2.7)	11.54 (2.5)	13.08 (2.8)	12.28 (2.7)	12.52 (2.7)

The equation of this line was $y = 4.64x + 1516$ indicating that there were 4.64 computer units generated per degree (95% CI 4.60 to 4.67) and that at 0° the computer would obtain a reading of 1516 units (95% CI 1513 to 1519). The R squared value for the line was > 0.99, indicating a highly significant and linear correlation between the applied angles and output, with less than 1% of the variation in the output data remaining unexplained by the regression. The maximum standard error of the estimate was 6.5 computer units equivalent to 1.4° (6.5 / 4.64) with 95% of the systematic errors following within two standard deviations equivalent to 13.0 computer units equivalent to 2.8°.

10.4.3 Results and Conclusions

The results indicated that the electrogoniometer and amplifier had an accurate linear response. When attached to a 12-bit analogue-to digital converter the system is able to quantify angular displacement to the nearest 0.2° (1 / 4.64) with an accuracy of on average 1.1° and at worse 3.4 °. The experiment was repeated a further five times with variation in the slope of the line (4.56 to 4.67) 1507 to 1518. The mean values for the slope 4.62 and the intercept 1514. These mean values were used as the calibration coefficients for subsequent evaluations.

10.5 HYSTERESIS

10.5.1 Experiment Aim

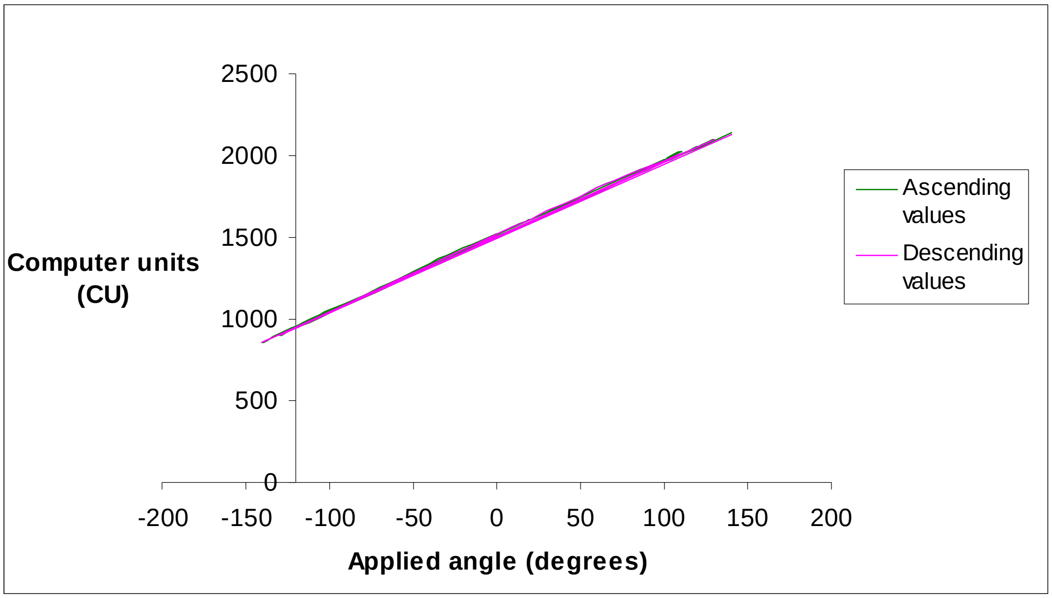
The following experiment set out to investigate if the fibreoptic electrogoniometer 1 exhibited hysteretic features. Hysteresis can be present in both mechanical and electrical systems, owing to the storage of mechanical and electrical energy during the ascending phase and its release during the descending phase. It therefore represents a systematic error dependent upon the direction in which the recording device is moving through the measuring range. Small hysteretic effects may be allowable, but large effects may render a measuring useless unless the direction in which the data are changing is known (Rowe, 1999).

10.5.2 Method

The fibreoptic electrogoniometer was attached to the plastic goniometer as before (section 10.2.2). The device was manipulated through -120° to +120° in ten-degree increments using the plastic goniometer in both an ascending and descending directions.

9.5.3 Results and Conclusions

The result of both ascending and descending computer values were plotted simultaneously on a graph (Graph 10.9). Furthermore regression equations for the joint angles between directions in both ascending and descending direction were calculated separately and the mean and maximum difference for each increment was noted (Table 10.5).



Graph 10.9: Graph of hysteretic effects. Relationship between the applied angle (true angle) and the measured output (in computer units) when the electrogoniometer is manipulated through a range from –120° to +120° in both ascending and descending directions.

Table 10.5: Regression equations, mean and maximum differences in computer units

	Ascending range (regression equations	Descending range (regression equations)	Mean difference in computer units (Degrees in brackets)	Maximum difference in computer units (Degrees in brackets)
Calibration 1	y = 4.64x + 1516	y = 4.65x + 1513	5.3 (1.1)	10.2 (2.2)
Calibration 2	y = 4.61x + 1514	y = 4.63x + 1512	5.1 (1.2)	7.7 (1.7)
Calibration 3	y = 4.61x + 1518	y = 4.61x + 1516	5.6 (1.2)	11.3 (2.4)
Calibration 4	y = 4.62x + 1518	y = 4.63x + 1514	6.6 (1.4)	10.5 (2.3)
Calibration 5	y = 4.61x + 1520	y = 4.63x + 1517	6.2 (1.3)	10.3 (2.2)

Regression equations remained relatively similar with a maximum difference of 11.3 computer units, equivalent to 2.4° and a maximum mean difference of 6.6 computer units, equivalent to 1.4°. Given the limitations of the plastic universal goniometer and Velcro and tape fixation methods these results would appear to indicate that device was not subject to large hysteretic effects.

10.6 WITHIN-DAY RELIABILITY

10.6.1 Experiment Aim

The aim of this experiment was to investigate the within-day reliability of the electrogoniometer.

10.6.2 Method

The procedure of investigating the accuracy of the device was repeated twice on the same day to investigate the within day reliability of the fibreoptic electrogoniometer. All the equipment was dismantled and stored between tests. Test 1 was performed in the morning and Test 2 performed in the afternoon. The output from the fibreoptic was recorded while it was moved through a range of -120° to +120° using the plastic goniometer. These values were plotted, a linear regression line inserted and the equation determined.

10.6.3 Results and Conclusions

A within day difference of 0.04 computer units and 6 computer units were recorded for the slope and intercept respectively Table (9.6). The device was consistent when used on the same day.

Table 10.6: Within day stability reliability

Gradient (Computer units)			Intercept (Computer units)		
Test 1	**Test 2**	**Difference**	**Test 1**	**Test 2**	**Difference**
4.63	4.67	0.04	1511	1517	6

10.7 DAY-TO-DAY RELIABILITY

10.7.1 Experiment Aim

The aim of this experiment was to investigate the day-to-day reliability of the electrogoniometer.

10.7.2 Method

The procedure of investigating the accuracy of the device was repeated on two separate days to investigate the between day reliability of the fibreoptic electrogoniometer. All the equipment was dismantled and stored between tests. Test 1 was preformed in the morning of the first day and Test 3 performed in the morning of the second day. The output from the fibreoptic was recorded while it was moved through a range of -120° to +120° as previously described. These values were plotted, a linear regression line inserted and the equation determined.

10.7.3 Results and Conclusions

Day-to day differences of 0.03 computer units and 2 computer units were recorded for the slope and intercept respectively (Table 10.7). The device was therefore unaffected by environmental differences between days, and the process of dismantling and reassembling for use allows reproducible results.

Table 10.7: Day to day stability reliability

Gradient (Computer units)			Intercept (Computer units)		
Test 1	**Test 3**	**Difference**	**Test 1**	**Test 3**	**Difference**
4.63	4.60	0.03	1511	1514	2

10.7.4 Reliability Comment

However, on beginning subsequent experiments it became evident that the offset appeared to occasionally randomly change, especially when repeatedly attached and reattached to a fixation device. The experiments for both internal consistency reliability and day-to-day stability were therefore repeated. The offset intercept was recorded between values of 1509 to 1533 with the gradients observed between 4.52 and 4.67 (Tables 10.8 and 10.9).

Table 10.8: Within day stability reliability

	Gradient			Intercept (CU)	
Test 1	**Test 2**	**Difference**	**Test 1**	**Test 2**	**Difference**
4.67	4.60	0.07	1528	1533	5

Table 10.9: Day to day stability reliability

	Gradient			Intercept (CU)	
Test 1	**Test 3**	**Difference**	**Test 1**	**Test 3**	**Difference**
4.67	4.52	0.65	1528	1509	1526

On closer inspection of the device it was apparent that the output was sensitive and vulnerable to random alteration with movement on removal from test set ups or with strong direct pressure over the offset and gain potentiometer controls. Subsequently the calibration of the device had to be continually monitored before and after each experimental set-up and the end boxes handled with extreme care. The gain potentiometer appeared more stable to such handling than the offset control. When handled with care the results of the device appeared reliable on subsequent testing. When the manufacturer's were contacted regarding this latest anomaly the researcher was informed that the manufacture's were in the process of changing the design of the fibreoptic electrogoniometer from one turn gain and off-set potentiometers to twelve turn potentiometers.

10.8 EFFECT OF CROSS TALK

Motion of the knee joint occurs not only in the sagittal plane, but also in the coronal (abduction and adduction) and transverse (internal and external rotation). Measurements of joint angles during motion analysis are subject to error caused by kinematic cross talk, that is, one joint rotation being interpreted as another (Piazza and Cavanagh, 2000). The following experiments explored the potential effects of abduction adduction moments, internal external rotation, anterior posterior, medial lateral and proximal distal displacement translations on the recorded flexion/extension angle.

10.8.1 Experiment Aim - Effect of Abduction Adduction Moments

The measured angle between the femoral and tibial shafts is not a straight line and usually the femur and tibia form an angle, with individual differences ranging from 5° to 10° in either a varus or valgus direction (Kapanji, 1987). Furthermore Lafortune et al (1992) documented that the mean pattern of abduction / adduction of the tibia with respect to the femur to be uniphasic towards abduction and limited to 5° during the swing phase of gait. Reinschmidt et al (1997) reported no general patterns across subjects, however greater abduction-adduction ranges of motion were found, varying between 5° and 10° for each direction. Thus the aim of this experiment was to evaluate the effect of coronal movement in a range of at least 10° on sagittal measurements in a coronal direction.

10.8.2 Method

The electrogoniometer was attached to a modified standard plastic goniometer. Two pieces of Perspex plastic (12 x 3 x 0.2 cm) were attached at one end by a 3cm wide hinge. The hinge brackets were counter sunk into the Perspex. The lower piece of Perspex was then glued to the plastic goniometer with the long axis of the hinge positioned directly over the centre of the universal goniometer (Figure 10.5 and 10.6). Perspex sheets (12 x 3 x 0.2cm) were used to build up the universal goniometer to ensure that the two fibreoptic end boxes were level to the plane of the supporting table with the universal goniometer in the 0° neutral position i.e. in neither abducted or adducted. A spirit level was used to confirm this.

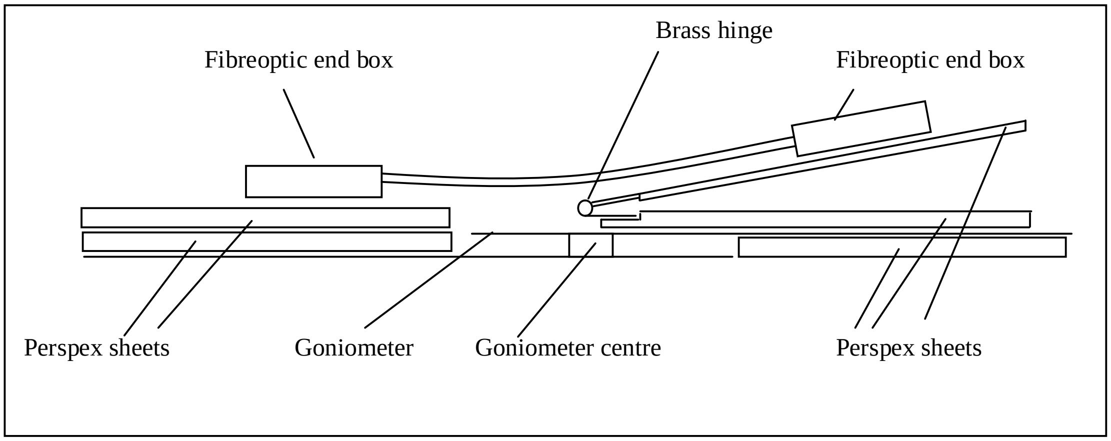


Figure 10.5: Schematic side view of abduction/adduction set-up

For abduction the fibreoptic end boxes were positioned with the gain and offset controls upper most and for adduction the boxes were reversed and the controls lower most. Calibration of the test set-up was checked by manipulating the device at 0° abduction / adduction through a range $+120^{\circ}$ to -120° of sagittal motion. These values were plotted, a linear regression line inserted and the equations determined. The regression equation were y = 4.61x + 1510 for abduction and y = 4.62x + 1511 for adduction respectively.

Wedge shaped wooden blocks comprising of 5°, 10°, 15° and 20° angles were manufactured (using trigonometry to calculate the block dimensions). These were individually placed between the hinged Perspex with the end of the designated angle directly at the hinge axis (Figure 10.6). The fibreoptic electrogoniometer was moved through $+120^{\circ}$ and -120° as previously described.

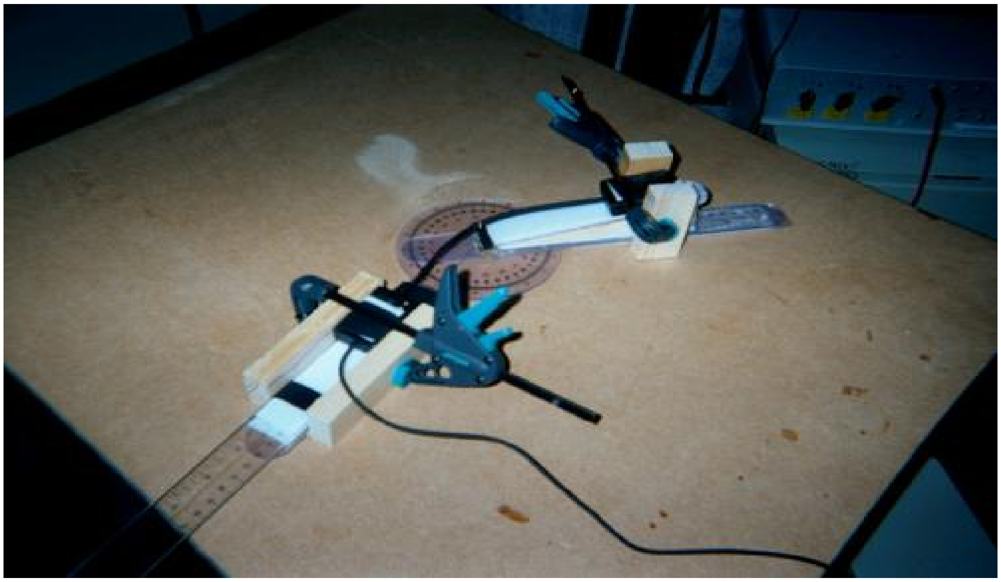


Figure 10.6: Abduction/adduction experimental set-up

10.8.3 Results and Conclusions

The effect of abduction and adduction on the output of the fibreoptic electrogoniometer is shown in Tables 10.10 and 10.11. The mean errors induced for both abduction and adduction were under 5°. The effect of 5° and 10° abduction and 5° and 10° adduction movements caused maximum errors below 5°, except at the extremes of the recorded range, 110° to 120°. Maximum errors greater than 5° were recorded throughout the available range for both 15° and 20° abduction and 15° and 20° adduction respectively. It was visibly evident that the inflexible rectangular design of the steel sprung fibreoptic electrogoniometer cantilever limited abduction and adduction excursion at angles greater than 15° and 20° abduction.

Table 10.10: Effect of abduction and adduction at 0°

5° Abduction	0.0°	5° Adduction	0.9°
10° Abduction	1.7°	10° Adduction	0.6°
15° Abduction	5.7	15° Adduction	0.1°
20° Abduction	7.0°	20° Adduction	4.4°

Table 10.11: Effect of abduction and adduction movements through range 0° to +/- 120°

	Mean error	Maximum error		Mean error	Maximum error
5° Abduction	1.4°	6.6° at 120°	5° Adduction	1.7°	7.2 at 120°
10° Abduction	2.2°	6.4°	10° Adduction	1.5°	7.9°
15° Abduction	4.2°	9.3	15° Adduction	4.1°	11.2
20° Abduction	4.4°	7.4°	20° Adduction	3.5°	10.3°

The device is able to accurately record sagittal motion to within 5° between +100° to –100° while tolerating abduction and adduction movements in the range 0° to 10°. Owing to the physiological valgus angle, which could be beyond 10° in some knees, it is important to eliminate the angle between the surface of the skin lateral to the femur and tibia when applying the device to the knee joint.

10.8.4 Experiment Aims -Effect of Internal and External Rotation

The range of transverse motion (internal and external rotation) of the tibia with respect to the femur has been reported to be in the region of 5° to 15.2° (Kettelkamp et al, 1970; Lafortune et al, 1992; Reinschmidt et al, 1997). During stair climbing internal and external rotation may reach values up to 20°. (Kowalk et al, 1996). The aim of this experiment was to investigate the effect of 20° of internal and external rotation during sagittal motion of the fibreoptic electrogoniometer.

10.8.5 Method

The sensitivity to rotational cross talk was investigated by constructing a calibration jig, which allowed sagittal motion in a flexion and extension range, but also concomitant 'internal' and 'external' rotation in both positive and negative directions. A three sided box structure (open at the front) was constructed (60cm x 31cm x 31cm) from MDF wood. Two universal goniometers were aligned in parallel and secured to each side of the box and the distal goniometer arms joined by a wooden cross beam. The proximal arms of the universal goniometers rested on a proximal wooden platform. The proximal electrogoniometer end box was secured in the centre of the platform with a clamp. The distal end box of the electrogoniometer was fixed to a modified plastic goniometer with a rotating centre platform, thus allowing 30° internal and 30° external rotations in relation to the long axis of the cantilever. The top of the distal electrogoniometer end box was secured with metal crossbars taking care to avoid contact with the electrogoniometer cantilever. These metal cross bars were attached to wooden blocks held in place by lightweight clamps. The distal electrogoniometer end box was flexed and extended through a range of motion 0° to 120° using a draw cord attached to a distal metal beam adjoining both universal goniometers. The centre of the cantilever was aligned with the axis of rotation of both universal goniometers by projecting a laser beam through the centre holes of both universal goniometers and matching holes drilled in the MDF box (Figures 10.7 and 10.8)

Figure 10.7: Experimental set-up for internal and external rotation

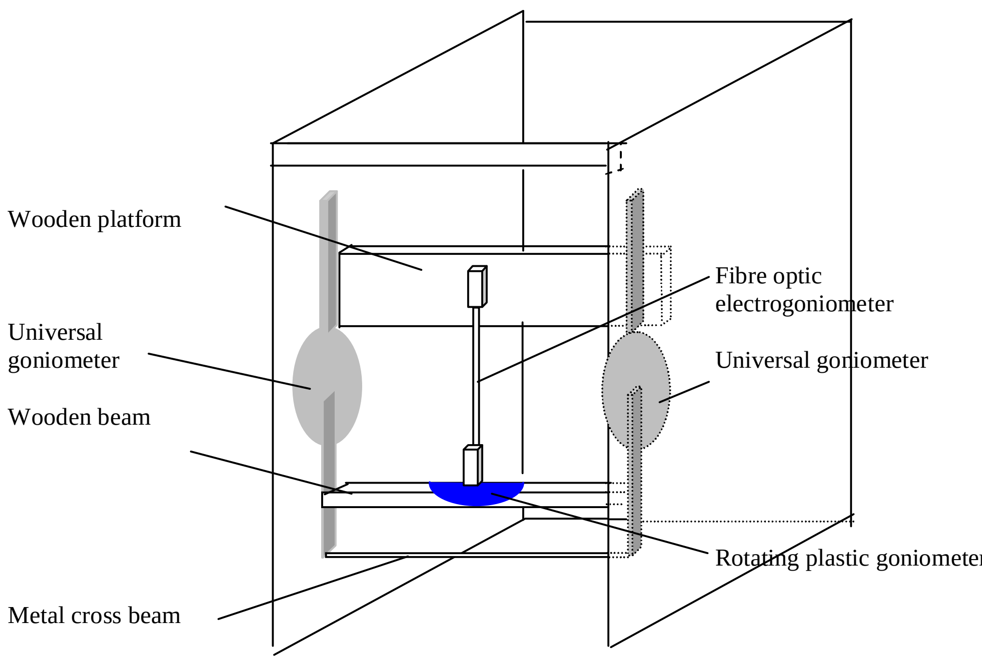


Figure 10.8: Schematic of internal and external rotation set-up

Manipulating the electrogoniometer through a range of angular displacements, using the universal goniometers, from 0° to $+120^{\circ}$ in neutral i.e. no internal or external rotation the calibration of the jig was checked. The electrogoniometer was then reversed and moved through range from 0 to -120° in neutral. The regression equation for the jig in neutral was y = 4.61 + 1511 indicating that the output from the jig reflected the values obtained from the previous calibration set-ups (y = 4.62x + 1514).

Internal rotations were applied 0° to +30° in 10° increments by rotating the distal end box around the long axis of the device using the rotating plastic goniometer platform. For each 10° rotation increment the device was then moved through 0° to 120° sagittal plane motion whilst maintaining the concurrent internal rotation angle. The procedure was repeated for external rotation 0 to -30°.

10.8.6 Results and Conclusions

The effects of internal and external rotation on the output of the fibreoptic electrogoniometer are shown in Tables 10.12 and 10.13. The mean errors were under 5° for both internal and external rotation 0° to 30°. The maximum errors were under 5° for the ranges 0° to +/- 110°, except at 110° during 30° rotation external rotation an error of 8° was recorded. Sagittal movements of the device appeared relatively unaffected by axial rotations, except at the extremes of sagittal movement.

Table 10.12: Effect of internal and external rotation at 0° - Errors (degrees)

10° Internal	1.0	10° External	1.0
20° Internal	1.0	20° External	1.0
30° Internal	1.0	30° External	1.0

Table 10.13: Effect of axial rotation through range 0° to +120° and 0° to -120°

Range of rotation motion	Sagittal motion 0° to +120° Mean error (degrees)	Sagittal motion 0° to +120° Maximum error (degrees)	Sagittal motion 0° to -120° Mean error (degrees)	Sagittal motion 0° to -120° Maximum error (degrees)
+10°	2.1	6.6	1.0	2.4
-10°	1.4	6.1	1.0	2.0
+20°	2.1	5.9	1.4	3.3
-20°	1.6	5.3	1.5	3.3
+30°	2.5	6.0	2.5	8.2
-30°	1.4	5.9	2.1	2.9

10.8.7 Experiment Aim- Effect of Translations

The aim of this experiment was to investigate the effect of joint translations on the electrogoniometer. It has been demonstrated that during gait 2.3 mm medial shift occurs during stance phase followed by 1.5mm lateral shift as the knee is extended during the middle part of stance phase. Posterior drawer amounted to 3.6mm during the first half of stance phase while knee extension was associated with a maximum displacement of 1.3mm past the neutral position. After heel strike a maximum distraction of 3.2mm during flexion occurred followed by a 0.2mm compression accompanying knee extension (Ramsay and Wretenberg, 1999). Vergis and Gillquist (1998) recorded maximum anterior posterior translation values in healthy knees of 8mm and 7mm for stair ascent and descent respectively, using an electrogoniometer system.

10.8.8 Methods

Anterior and posterior translations

The electrogoniometer was calibrated using a plastic goniometer as previously described. A three sided box structure (open at the front) was constructed (60cm x 27cm x 27cm) from MDF wood. A wooden platform was placed within the box.

For anterior posterior translations the proximal electrogoniometer end box was secured in the centre of the platform with a clamp in the sagittal plane. The distal end box was attached directly below the proximal box with its lower surface parallel and in contact with a wooden MDF base. The cantilever was thus positioned in the neutral position i.e. neither abducted, adducted, internally or externally rotated. The distal end box was held by a slide rule, modified by applying two sliding arms orthogonal to the ruler. The slide rule was secured to the wooden base using wooden supports fixed to the base. A small lightweight clamp fixed both slide rule arms against the distal end box and ensured that both arms of the slide rule remained in contact with end box throughout the test. The distal end box could thus be slid in an anterior and posterior direction using the slide rule arms in tandem. The end box was moved in 5mm increments from 0mm to 30mm first in an anterior direction and secondly in a posterior direction. One hundred values were recorded at each incremental translation. The set up is shown in Figures 10.9 and 10.10.

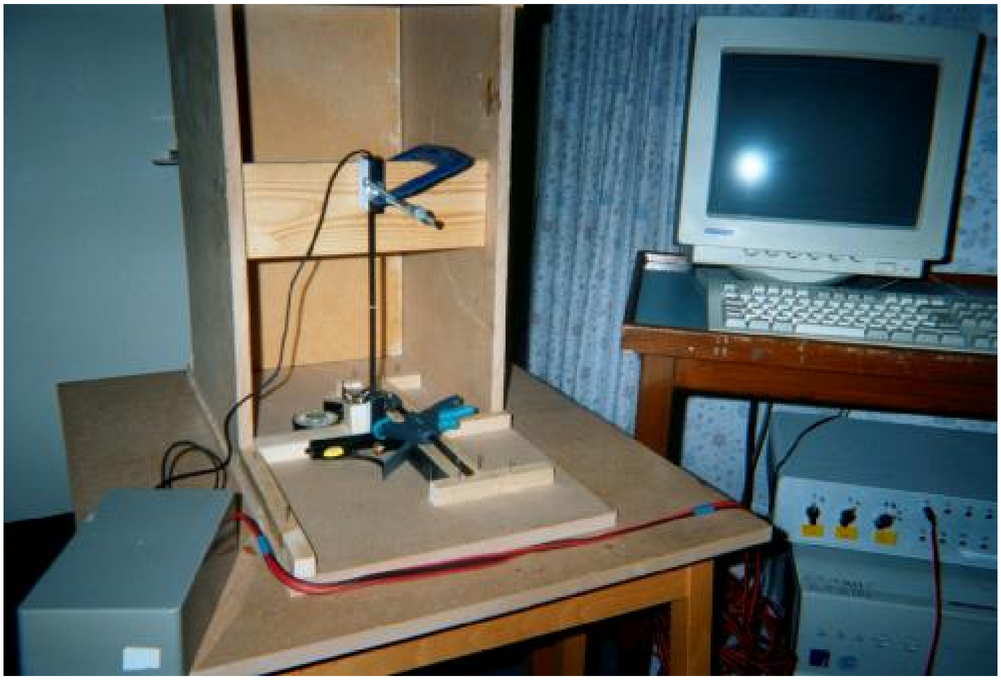


Figure 10.9: Experimental set up for anterior posterior translation

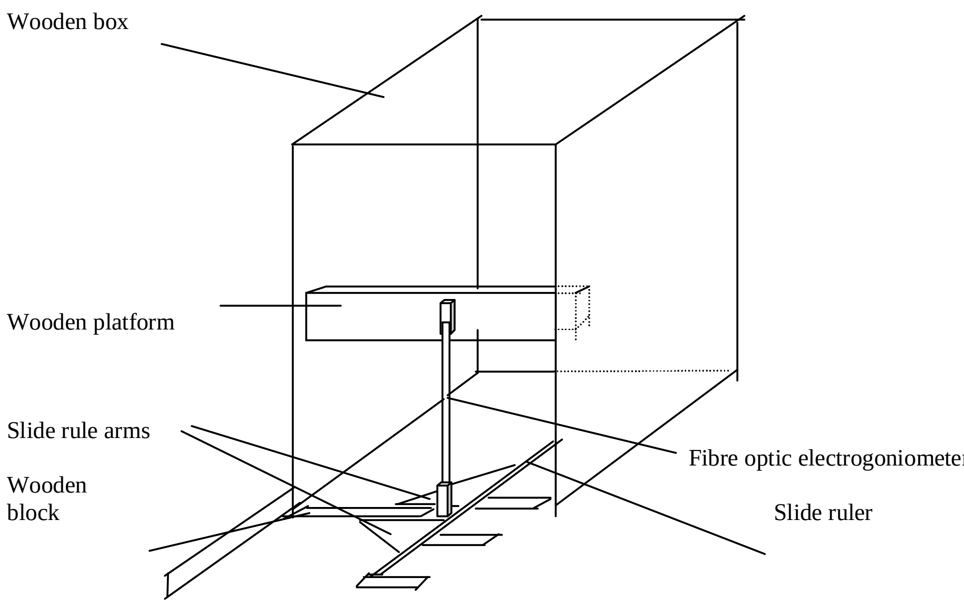


Figure 10.10: Schematic diagram of anterior posterior translations experimental set-up

Medial and lateral translations

For medial and lateral translations a similar set up was employed. The end boxes however were turned side on and secured in the coronal plane.

Proximal and distal translations

The device was again placed on an MDF surface. On this occasion the electrogoniometer end boxes were placed in neutral (0°) i.e. neither bent to the right or left. This was achieved by positioning one side of the end boxes against the long side of a 12 x 3 x 2 cm piece of wood. Attached to the upper surface of this wood was a slide rule with a sliding moveable arm. The sliding arm was situated against the base of the distal end box. The distal end box was secured to the arm using double side adhesive tape and a block of wood attached to the slide rule arm. This allowed the proximal end box to be slid along the wood in a proximal or distal direction. Small blocks of wood glued to the MDF surface secured the proximal end box. The distal end box was moved in a proximal direction in 5mm increments from 0mm to 30mm. 100 computer values were recorded at each increment. With distal movement limited at 0° the procedure was repeated, but with the proximal end box moved at 90° relative to the distal end box. In this position the cantilever demonstrated a greater degree of ‘slack’ permitting both proximal and distal translations. The distal end box was moved in first a proximal direction in 5mm increments from 0mm to 30mm and then in a distal direction from 0mm to 30mm. The test set up for the 90° angles is demonstrated in Figure 10.11.

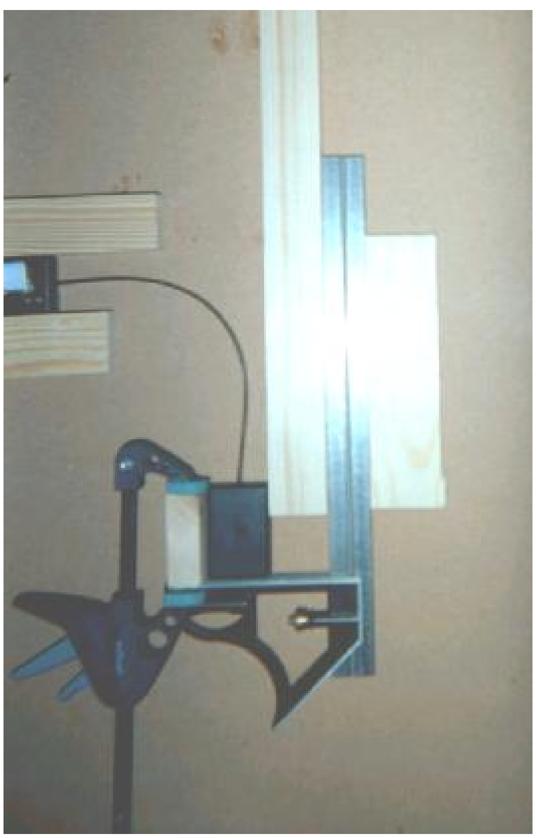


Figure 10.11: Test set-up for compression and distraction at 90°

10.8.9 Results and Conclusions

The results of the effect of anterior and posterior translations and medial and lateral translations are shown in Tables 10.14 and 10.15 respectively. Errors were less than 5° for + / -30mm anterior posterior movement and + / -30mm medial lateral translations. It was noted that beyond 30mm translations the distal end box began to rotate owing to tension in the cantilever, thus not reflecting true translation. For proximal-distal translation it was noted that at 0° no obvious longitudinal distraction movement of the distal end box was feasible, owing to the fixed length of the cantilever. At the 0° position errors were less than 5° at 5mm compression translation and over 5° at 10mm compression translation (Table 10.16). At 90° there was greater 'slack' in the cantilever and errors were recorded at less than 5°, even at 30mm translation in both compression and distraction (proximal distal translation) (Table 10.17).

Table 10.14: Errors induced by increasing translation in anterior and posterior directions - Errors (degrees)

Anterior posterior translations	**+ve (anterior)**	**-ve (posterior)**
0	0.2	0.6
5mm	0.9	0.9
10mm	0.4	1.3
15mm	1.3	1.1
20mm	1.5	1.5
25mm	1.7	1.7
30mm	3.0	2.4
35mm	3.9	2.6

Table 10.15 Errors induced by induced by increasing medial and lateral translations - Errors (degrees)

Medial / lateral translations	+ve (lateral)	-ve (medial)
0	0.2	0.6
5mm	0.9	0.9
10mm	0.4	1.3
15mm	1.3	1.1
20mm	1.5	1.5
25mm	1.7	1.8
30mm	3.0	2.4
35mm	3.9	2.6

Table 10.16: Effect of proximal translation at 0° angle - Errors (degrees)

Compression / distraction translations	**Compression**	**Distraction**
0	0.6	-
5mm	4.8	-
10mm	6.1	-
15mm	7.8	-
20mm	8.7	-
25mm	9.7	-
30mm	10.2	-

Table 10.17: Effect of proximal and distal translation at 90° angle - Errors (degrees)

Compression / distraction translations	Compression	Distraction
0	1.1	1.9
5mm	2.0	1.5
10mm	2.4	0.8
15mm	2.9	0.3
20mm	3.3	2.3
25mm	3.7	3.0
30mm	4.4	4.6

These results indicate that the device is not unduly sensitive to relative translations of the end boxes in anterior-posterior, medial-lateral directions and proximal-distal directions. The device however at angles around 0° lacks an ability to undergo distraction translation owing to the fixed cantilever distance between the two end boxes. In clinical practice movement of the soft tissues could potentially compensate for this small limitation.

10.9 EFFECT OF OFF-CENTRE AXIAL ROTATION - BOTH END BOXES DISPLACED

10.9.1 Experiment Aim

Accurate placement of the goniometers axis of rotation has been thought by to be essential for accurate angular measurement (Miller, 1985). It is, however, apparent that the knee joint is not a simple hinge joint (Bull and Amis, 1998) and during knee joint excursion, there exists a unique point, the instantaneous axis of rotation, about which pure rotation of one segment relative to the other occurs (Hollman and Deusinger. 1999). To make goniometry reliable consistent results are said to be achieved by emphasising the importance of aligning the arms of the goniometer in relation to identifiable anatomical landmarks, rather than attempting to locate a specific axis of rotation (Miller, 1985). The identification of bony landmarks is often difficult owing to the relatively large and curved areas and has been associated with intra and inter-reliability errors in the range of 6 to 25 millimetres (della Croce et al, 1999). This experiment was designed to investigate the effect of locating the fibreoptic electrogoniometer away from the axis of rotation of the universal goniometer.

109.9.2 Method

It was evident from simple observation that owing to the fixed distance between the end boxes that the goniometer cantilever underwent non-linear and potentially damaging movement when moved away from the axis of rotation of the measured object. This was especially true when the end boxes were moved more than approximately 2cm orthogonal to the reference axis of the plastic goniometer or in anatomical terms in anterior posterior directions relative to the reference measured joint angle.

The arm widths of a universal plastic goniometer were extended using wood and Perspex sheets to produce flat even arms 5cm wide (Figure 10.12).

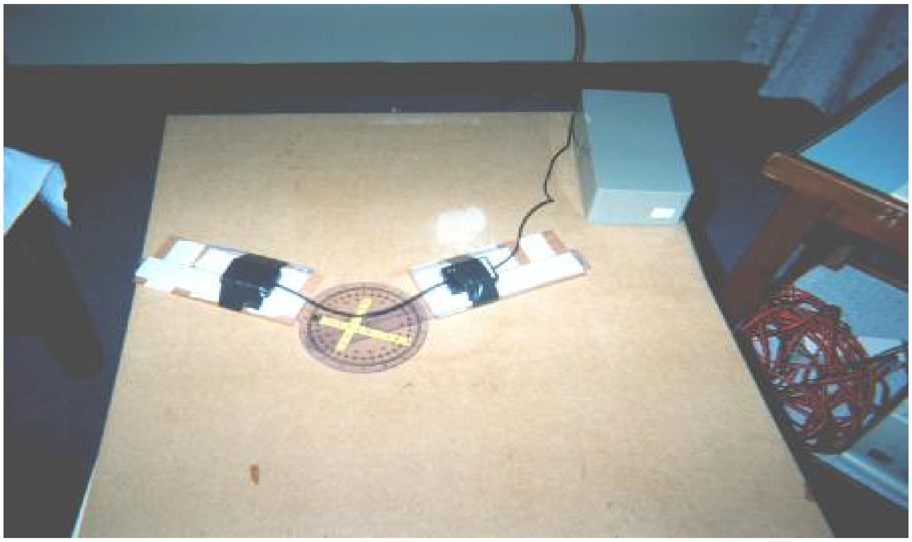


Figure 10.12: Off-centre experimental set-up

This set-up afforded the opportunity to move the fibreoptic cantilever not only in a longitudinal direction (inferior superior direction), but also in perpendicular (anterior posterior) directions, relative to the long axis of the plastic goniometer. The fibreoptic electrogoniometer end boxes were secured with single-sided tape and Velcro. A two dimensional orthogonal scale calibrated in 1cm intervals was marked on the centre of the plastic goniometer. The centre of the long axis of the fibreoptic cantilever was initially placed directly over axis centre of the universal plastic goniometer. Then keeping the centre of the long axis of the electrogoniometer cantilever in line with long axis of the plastic goniometer the fibreoptic electrogoniometer was moved 5cms in 1cm intervals, firstly in a negative (inferior) direction and then in a positive (superior) direction. At each 1cm interval the electrogoniometer was manipulated through 30°, 60° and 90° ranges of angular displacements in both positive and negative directions, using the plastic goniometer. These limited angles were chosen to minimise any undue stress on the fibreoptic cantilever. 100 values were recorded at each angle.

For anterior posterior movement the centre of the cantilever was aligned directly over the plastic goniometer centre. The electrogoniometer cantilever and end boxes were then simultaneously moved 2cm in 1cm intervals firstly in a positive (anterior) direction then in a negative (posterior) direction. At each 1cm interval the electrogoniometer was manipulated through 30°, 60° and 90° ranges of angular displacements in both positive and negative directions, using the plastic goniometer. 100 values were recorded at each angle.

10.9.3 Results and Conclusions

The results of the effect of superior inferior longitudinal movement and anterior posterior perpendicular movements are shown in Tables 10.18 and 10.19. The results indicated that the device was less sensitive to changes in longitudinal displacement of the cantilever relative to the applied axis of rotation than when the electrogoniometer was moved perpendicular to the long axis of the applied axis of the plastic goniometer. For superior inferior motion the errors were less than 5° + / -4cm. The results however of anterior posterior movement induced errors greater than 5° even with 1cm displacement.

Table 10.18: Errors (degrees) induced when centre of electrogoniometer cantilever and end boxes moved in a longitudinal (superior/inferior) direction relative to the axis of the universal goniometer

	Longitudinal distance from centre of rotation										
Range of motion	**5cm**	**4cm**	**3cm**	**2cm**	**1cm**	**0**	**1cm**	**2cm**	**3cm**	**4cm**	**5cm**
0°	1.0	0.0	0.4	0.0	0.6	0.4	0.4	0.9	1.1	0.9	1.1
+30°	1.5	0.8	0.8	0.1	0.1	0.8	0.8	1.8	1.2	1.2	1.6
+60°	2.8	1.1	0.2	1.0	0.8	0.4	0.4	3.0	3.0	2.1	1.9
+90	1.1	0.0	1.8	1.8	1.8	2.0	2.0	3.7	3.5	3.1	3.7
-30°	3.2	0.6	1.2	0.3	0.3	1.2	1.2	0.8	0.3	0.7	0.3
-60°	4.4	1.6	1.9	0.2	0.2	1.9	1.9	0.7	0.2	0.8	0.6
-90°	6.8	4.5	0.2	2.6	2.6	0.2	0.2	2.1	1.2	0.2	0.6

Table 10.19: Errors (degrees) induced when centre of electrogoniometer cantilever and end boxes moved in an orthogonal (anterior posterior) direction relative to the long axis of the universal goniometer

	Distance orthogonal to centre of rotation				
Range of motion	**2cm**	**1cm**	**0cm**	**1cm**	**2cm**
0°	1.7	0.4	0.4	0.3	1.2
+30°	5.4	2.6	0.7	0.7	8.3
+60°	7.4	4.9	0.4	0.5	1.5
+90	10.4	8.1	2.0	2.5	1.8
-30°	9.4	2.1	1.2	3.1	8.8
-60°	4.3	0.0	1.9	3.7	2.5
-90°	3.0	0.0	0.2	3.2	2.4

These results were concerning as the knee joint axis of rotation is often difficult to define accurately in a clinical situation. Furthermore, it was noted that when the electrogoniometer was applied to the human knee joint that if the centre of the electrogoniometer cantilever was not placed in close proximity of the knee axis (lateral femoral condyle) and the end boxes not aligned in a straight line then the cantilever would not move in a coherent and linear manner.

10.10 EFFECT OF OFF-CENTRE AXIAL ROTATION - SINGLE END BOX DISPLACEMENT

10.10.1 Experiment Aim

In light of the poor results when both end boxes were displaced relative to the axis of rotation it was therefore decided that a more realistic problem would be if one end box were placed anterior or posterior to the other.

10.10.2 Experiment Aim

The electrogoniometer was therefore attached to the plastic goniometer as before, but the distal end box and cantilever were moved 1cm anterior the plastic goniometer axis of rotation. The electrogoniometer was manipulated through a range of angular displacements, using the plastic goniometer, from 0° to +120° back through 0° to -120°. This was repeated for a 2cm displacement. The distal end box and cantilever were then moved through similar ranges for 1cm and 2cm posterior displacements.

10.10.3 Results and Conclusions

Results indicated that with a one-centimetre displacement mean absolute errors were less than 5° with a maximum absolute errors recorded at less than 5° for all angular excursion -120° to +110°. A maximum absolute error of 5.7° was recorded +120°. At 2cm absolute mean errors were greater than 5° reaching absolute maximum errors of 15° (Table 10.20).

Table 10.20: Errors (degrees) induced when centre of electrogoniometer distal end box moved in a perpendicular (anterior posterior) direction relative to the axis of the universal goniometer

Distal end box distance from longitudinal axis of rotation	Mean error (degrees)	Maximum error (degrees)
1cm +ve	4.8	10.9
1cm -ve	2.6	5.6
2cm +ve	7.7	15.3
2cm -ve	5.3	12.0

The electrogoniometer was sensitive to displacement of the end boxes in an anterior posterior direction. It is therefore important that the centre of the electrogoniometer cantilever be positioned as close to the joint axis of rotation as possible and that the end boxes be aligned as near as possible in a straight line. In practice when the electrogoniometer was applied to the knee the slight movement of the soft tissues appeared to compensate for the fixed distance between the goniometer end boxes and the device moved in a more coherent and uniform manner. It was, however, apparent that great care would have to be taken in applying the electrogoniometer to the human knee.

10.11 DYNAMIC RESPONSE

10.11.1 Experiment Aim

The purpose of the fibreoptic electrogoniometer was to measure dynamic motion during functional activities such as gait, stair climbing and sitting to standing. It was therefore imperative that the fibreoptic electrogoniometer remained accurate and precise during dynamic movement. The measurement of limb segment properties is not straightforward, owing to changing limb segment exomorphologies and endomorphologies, under the influence of external (inertial) and internal (muscular and passive viscoelastic forces). Segment boundaries are not fixed, but vary as the segment moves through its range of motion and the constantly changing volume of body fluids (mainly blood) within a segment also substantially alter the segments mass distribution (Hatze, 1980). With these limitations in mind the angular knee joint velocity is thought to reach values of approximately 300°/s during gait (Winter, 1987), 120°/s during squatting and standing tasks (Tang et al, 2001) and during step down activities 70°/s (Selfe, 1998). The dynamic response was evaluated in two ways 1) using a free-swinging pendulum 2) attaching the electrogoniometer to an isokinetic dynamometer. The aims of these experiments were to assess the electrogoniometer output under these dynamic conditions.

10.11.2 Method - Dynamic Response Using a Pendulum

A 12 cm universal plastic goniometer with a free moving axis was used in this experiment. The centre of electrogoniometer cantilever was aligned directly over the centre of the plastic goniometer and the end boxes attached to the arms of the goniometer using Velcro and single sided tape (Figure 10.13).

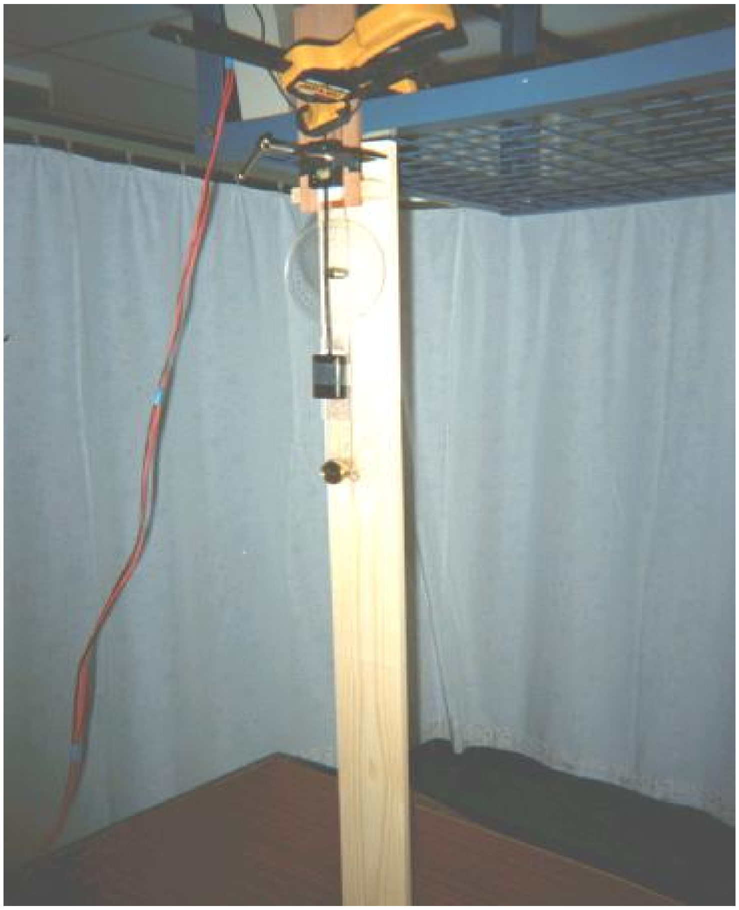


Figure 10.13: Pendulum experiment set-up

The axis mechanism and opposing contact surfaces were lubricated with silicone grease to reduce friction. The proximal arm of the goniometer was suspended vertically with the proximal arm free to swing from +40° to -40°. For small amplitudes (usually less than ≈ 10°) pendulums are said to exhibit simple harmonic motion (Hannah and Hillier, 1988). To overcome the inertia of the electrogoniometer cantilever a greater angle had to be used (40°), accepting that this would compromise the harmonic motion of the pendulum. Knee joints are said to move at approximately 1Hz during gait (Wall and Crosbie, 1997). To produce a pendulum oscillating at such a frequency requires the centre of mass of a pendulum bob to be placed 0.25m from the centre of motion (Figure 10.14).

$t_p = 2\pi\sqrt{(l/g)}$

$l = (t_p / 2\pi)^2$

$l = (1 / 2 \times 3.1415926542)^2 \times 9.8$

$l = 0.25$

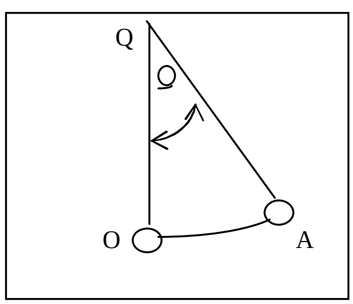
Pendulum length (l) = 0.25metres

where t_p = period time, l = pendulum length, g = gravity ($9.8 m/s^2$).

Figure 10.14: Calculation of pendulum length with 1Hz oscillation

This is independent of the mass. The centre of an arbitrary 0.028kg weight was place 0.25m from the centre of the plastic goniometer. The pendulum and electrogoniometer were then displaced $+40^{\circ}$ and released. Data were simultaneously collected from the electrogoniometer for a 2 second period at a sampling rate of 50Hz. It was noted that the pendulum exhibited rapid decay in motion after one period, presumably owing to resistance of the electrogoniometer steel sprung cantilever and inherent resistance of the plastic goniometer axis mechanism. The results of 0.5 of a period $+40^{\circ}$ to -40° were therefore analysed. The output the electrogoniometer was compared with the theoretical sinusoidal simple harmonic motion of the pendulum. The theoretical maximum angular velocity can be calculated using the equations in Figure 10.15.

	Theoretical values
1) $\omega = 2\pi / t_p$	$= 2 \times 3.141592654 / 1 = 6.283$
2) r = arc OA = OQ x angleOQA	$= 0.25 \times 40 \times \pi / 180 = 0.174$



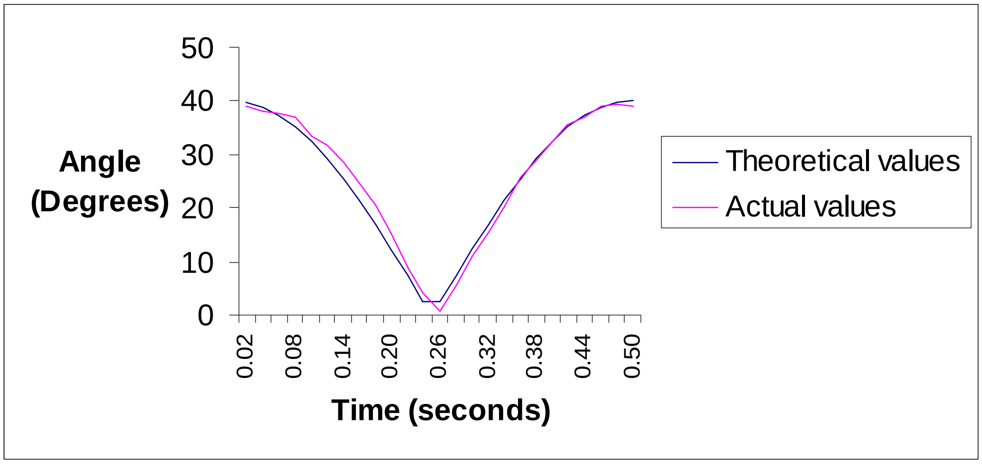
3) $\nu_{max} = \omega r$	$= 6.283 \times 0.174 = 1.096$
4) $\omega_{max} = \nu_{max} / l$	$= 1.096 / 0.25 = 4.384$ rads/sec
	= <u>251.203 degrees/sec</u>

where X = angular velocity, ν_{max} = maximum linear velocity, ω_{max} = maximum angular velocity

Figure 10.15: Equations for calculating theoretical maximum angular velocity

10.11.3 Results and Conclusions

Graph 10.10 demonstrates 0.5 of a period from +40° to -40°. The mean and maximum difference between the theoretical output of the pendulum and the actual output of the electrogoniometer were 1.3° and 3.3° respectively, indicating that the device accurately recorded movement at angular velocities up to a theoretical maximum value of 251° per second.



Graph 10.10: Demonstrates 0.5 of a pendulum period from +40° to -40°

10.11.4 Method - Dynamic Response Using an Isokinetic Dynamometer

During functional movements the limb segments of the body tend to accelerate and decelerate (Winter, 1990). This experiment used a System 3 Pro Biodex Isokinetic dynamometer to examine how the electrogoniometer reacted to such dynamic phenomena. It has been shown to provide accurate, valid and reliable measures of torque and position in ranges normally used in clinical and research settings (Drouin et al, 2004). Prior to this experiment the accuracy of the range of motion output of the Biodex dynamometer was compared against that of a universal plastic goniometer and found to be comparable to within one degree. The mechanical head of the isokinetic dynamometer was rotated 90° to face the dynamometer chair and tilted 90° to bring the drive shaft to the vertical position (pointing towards the ceiling). The Biodex 'wrist attachment' arm was secured to the drive shaft in the mid position (pointing towards the dynamometer chair). A small wooden block of wood (10.5 x 4 x 3.5cm) was secured to the upper surface of the end of the attachment using Velcro and tape around both the wood and the attachment. The distal end box of the electrogoniometer could thus be fitted ensuring that the cantilever cleared the attachment screw of the dynamometer drive shaft. A stable platform (height 1.23m) with a wooden extension to secure the proximal end box was constructed in front of the Biodex head. This allowed the proximal end box of the electrogoniometer to be aligned level and in a direct line with the distal end box. The centre of the electrogoniometer cantilever was sited directly above the centre of the dynamometer drive shaft (Figures 10.16 and 10.17).

Figure 10.16: Test set-up for dynamic response of fibreoptic electrogoniometer when attached to a Biodex isokinetic unit.

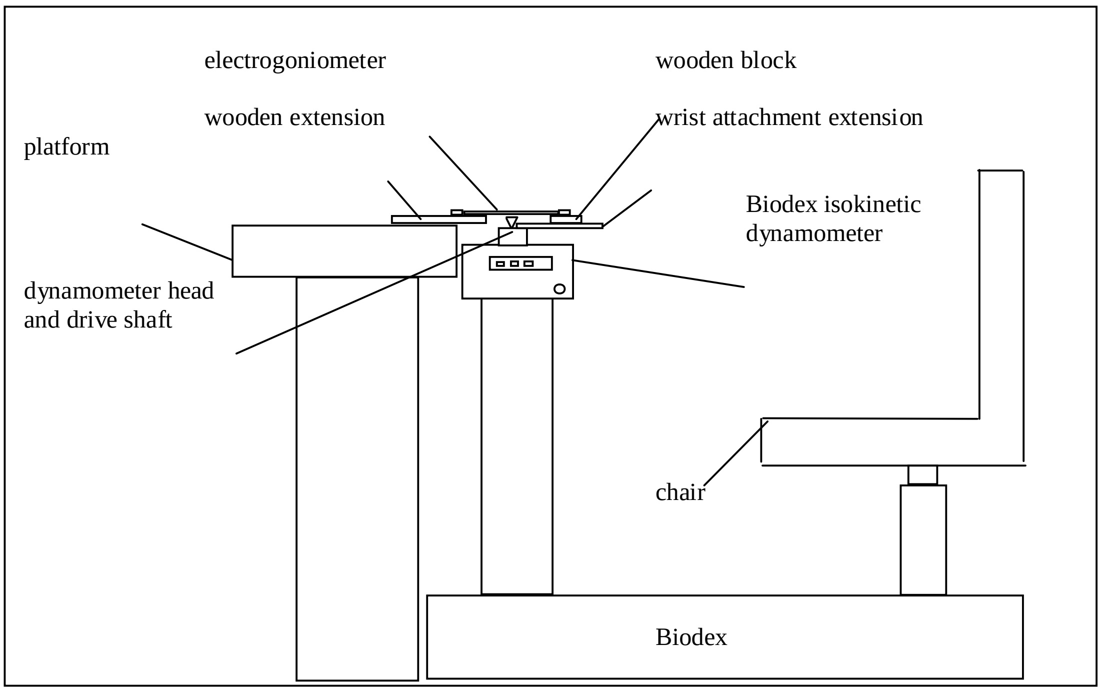


Figure 10.17: Schematic diagram of test set-up for dynamic response of fibreoptic electrogoniometer when attached to a Biodex isokinetic unit.

To check that this test set-up was valid the electrogoniometer was manipulated through a range of angular displacements, using the dynamometer protractor from 0° to +120° back through 0° to -120°, in ten–degree increments. Regression analysis was undertaken which confirmed the linear equation y = 4.60x + 1511 suggesting that the test set-up was valid. The dynamometer settings were set to wrist attachment; passive speed and hard end stop (1). Using the dynamometer range of motion setting the electrogoniometer and dynamometer attachment were positioned in neutral and the dynamometer set at 0° in this position. The dynamometer was then set individually to move through a spectrum of motion ranges +120° to -120°, +120° to -90°, +120° to -60°, +120° to -30°, -120° to +120°, -120° to +90°, -120° to +60° and -120° to +30°. At each motion range data were recorded from the electrogoniometer for one complete cycle at isokinetic velocities 30°/s, 75°/s, 150°/s, and 300°/s respectively. In reality dynamometer movement is not truly isokinetic and reaches such velocities for only brief periods, as it is accelerate towards and decelerates away from the required velocity during each cycle. This can be observed from the time-velocity curves on the dynamometer output graphs. The output of electrogoniometer was compared to the reference values of the dynamometer at the stop angle at the end of the ranges set i.e. -120, -90. -60, -30, +120, +90, +60 and +30. The electrogoniometer values were defined as the last value recorded before the direction of the values reversed back towards the starting angle indicating that the dynamometer was moving in the opposite direction.

10.11.4 Results and Conclusions

The results indicated that following exposure to angular velocities up to a maximum of 300°/s and decelerating to change direction the electrogoniometer was accurate to fewer than 5° (Table 9.21). The fibreoptic electrogoniometer appears to maintain an accurate output during and following acceleration and deceleration dynamic movement.

Table 10.21: Errors (degrees) recorded when output from fibreoptic electrogoniometer compared wit Biodex ‘isokinetic' range of motion

Angle measured from +120°	**30°/s**	**75°/s**	**150°/s**	**300°/s**
-120°	4.0	0.1	4.4	4.4
-90°	4.3	3.7	3.7	3.9
-60°	3.0	2.8	2.3	1.7
-30°	3.3	1.2	2.5	1.4
Angle measured from -120°	30°/s	75°/s	150°/s	300°/s
+120°	0.7	3.2	0.5	4.4
+90°	1.1	1.3	1.1	1.1
+90°	3.4	3.2	2.7	2.1
+30°	1.2	1.2	1.0	1.2

10.12 EFFECT OF TEMPERATURE ON THE FIBREOPTIC ELECTROGONIOMETER

10.12.1 Experiment Aim

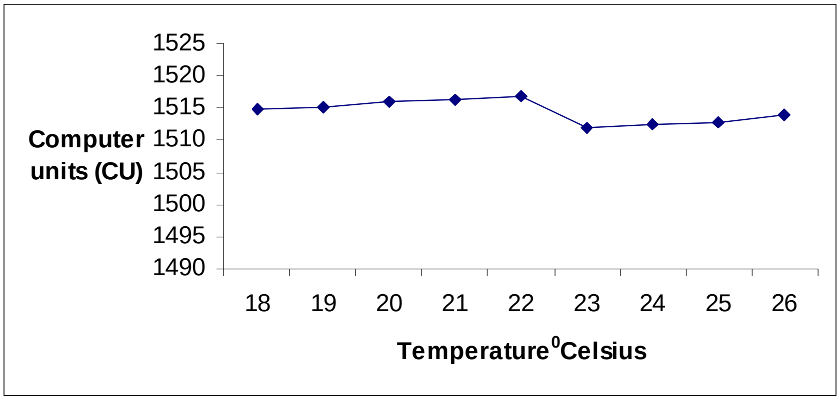
The fibreoptic electrogoniometer was to be used in a busy physiotherapy department. The response to varying room temperature was therefore assessed.

10.12.2 Method

The temperature of a small room was gently heated using an electrical heater. The electrogoniometer was attached in neutral (0°) to a wooden block of wood to reduce the risk of the electrogoniometer being influenced by any attachment device. Room temperature was recorded using a digital temperature monitor (MA 101, MA Medical Systems Ltd, UK).

10.12.3 Results and Conclusions

The device did not demonstrate a systematic response to temperature changes with a maximum error of 2.91 computer units, equivalent to 0.6°, with a standard deviation of 1.81 computer units, equivalent to 0.4° (Graph 10.11). These values were within acceptable limits for the study. The device did not appear unduly sensitive to environmental temperature changes.



Graph 10.11: Effect of temperature 18°C to 26°C on fibreoptic electrogoniometer output

10.13 INTERFERENCE DUE TO ENVIRONMENTAL POLLUTANTS

10.13.1 Experiment Aim

The civilised environment is continuously saturated with electrical energy transmitted through space from power lines, motors, lights, electrical equipment and radio stations (Schwartz, 1987). Accordingly the electrogoniometer can pick up this energy and the apparatus receives unwanted electrical noise signals that may affect its function. Unfortunately not all such noise can be eliminated; however it is useful to understand what sort of common environmental factors might unduly interfere with its output. Likewise it is important that the device provides a stable output when exposed to mechanical shock and vibration.

10.13.2 Method

The fibreoptic electrogoniometer was securely attached to a block of wood in neutral (0°) and exposed to electrical noise from an electric drill, hair dryer, isokinetic dynamometer electric motor, and local therapeutic short-wave wave diathermy machine. It was also exposed to the mechanical vibration and shock of the blow of a hand and hammer applied to the test bench.

10.13.3 Results and Conclusions

The fibreoptic electrogoniometer appeared stable to most of the applied environmental factors (Table 10.22). The device, however, was highly sensitive to electromagnetic energy from the short wave machine, which interrupted the output from the electrogoniometer. The device therefore is not unduly affected by most environmental pollutants; however when the electrogoniometer is used within a physiotherapy department care should be taken to ensure that strong electromagnetic machines are not in operation in the near vicinity.

Table 10.22: Effect of environmental factors on the fibreoptic electrogoniometer output- Errors in Degrees

Environmental factors	Mean	Standard deviation
Normal switch-on baseline	0.9	0.3
Hand vibration on table	1.3	0.3
Hammer on table	1.3	0.3
Hair dryer	1.5	0.4
Electric drill	0.0	0.3
Short wave diathermy	Un-interpretable output	Un-interpretable output
Biodex isokinetic motor	0.2	1.1

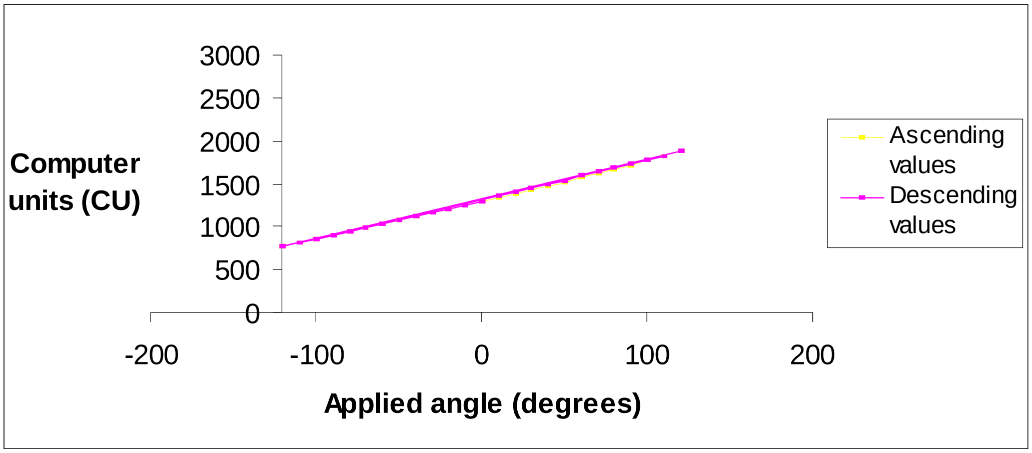
10.14 BETWEEN ELECTROGONIOMETER DIFFERENCES

109.14.1 Experiment Aim

To establish if output differences existed between S700™ fibre electrogoniometers (version 2)

9.14.2 Method

A similar fibreoptic electrogoniometer 2 to the one used in the previous experiments was tested. The device was calibrated from +120° to -120° using the same universal plastic goniometer and method as used for calibrating the first electrogoniometer (see section 8.2.2). Regression analysis was used to produce the best-fit line through the data relating to the applied input angle in degrees (x) to the recorded output in computer units (y) (Graph 10.12).



Graph 10.12: Relationship between the applied angle (true angle) and the measured output (in computer units) when the electrogoniometer is manipulated through a range from –120° to +120° in both ascending and descending directions.

Based on these individual regression equations the maximum absolute residual, mean residual, percentage linearity, coefficient of determination and standard error of the estimate were calculated and are shown in Table 10.23 for regression analysis between +120° to -120°.

Table 10.23: Regression analysis calculations

	Computer units (CU) (Degrees in brackets)				
	Calibration 1	**Calibration 2**	**Calibration 3**	**Calibration 4**	**Calibration 5**
Maximum absolute residual (degrees)	24.4 (5.3)	23.4 (5.1)	23.3 (5.0)	22.6 (4.9)	20.9 (4.5)
Mean absolute residual	7.8 (1.7)	6.6 (1.4)	7.3 (1.6)	7.7 (1.7)	6.5 (1.4)
Percentage linearity(240° range)	10.2%	9.8%	9.7%	9.4%	8.7%
Coefficient of determination	>0.99	>0.99	>0.99	>0.99	>0.99
Standard error of estimate in computer units (degrees in brackets)	10.1 (2.2)	9.0 (1.9)	9.7 (2.1)	9.6 (2.1)	8.3 (1.8)
2 standard errors of estimate in computer units (degrees in brackets)	20.2 (4.4)	18.0 (3.9)	19.4 (4.2)	19.2 (4.1)	16.6 (3.6)

Gradient value 4.62 used to convert to degrees

10.14.3 Results and Conclusions

The equation for the calibration line of the second electrogoniometer was y = 4.55x + 1304 indicating that there were 4.55 computer units generated per degree (95% CI 4.49 to 4.61) and that at 0° the computer would obtain a reading of 1304 units (95% CI 1300 to 1308). The R squared value for the line was > 0.99, indicating a highly significant and linear correlation between the applied angles and output with less than 1% of the variation in the output data remaining unexplained by the regression. The experiment was repeated a further five times with little variation in the slope of the line 4.55 to 4.69 or intercept value 1304 to 1310 (Table 10.24).

Table 10.24: Regression equations

	Ascending range (regression equations	**Descending range (regression equations)**	**Mean difference in computer units (Degrees in brackets)**	**Maximum difference in computer units (Degrees in brackets)**
Calibration 1	y = 4.55x + 1304	y = 4.66x + 1308	11.3 (2.4)	23.3 (5.0)
Calibration 2	y = 4.54x + 1307	y = 4.66x + 1309	12.3 (2.7)	21.2 (4.6)
Calibration 3	y = 4.56x + 1306	y = 4.67x + 1309	12.6 (2.7)	22.4 (4.8)
Calibration 4	y = 4.55x + 1307	y = 4.68x + 1309	13.3 (2.9)	25.3 (5.5)
Calibration 5	y = 4.57x + 1307	y = 4.69x + 1310	13.4 (2.9)	26.2 (5.7)

Mean values slope = 4.61, mean value intercept = 1308

The mean values for the slope and intercept were 4.61 (95% CI 4.57 to 4.65) and 1308 (95% CI 1307 to 1309) computer units respectively. The mean slope (4.61) compared favourably with the original fibreoptic electrogoniometer 1 value of 4.62 computer units; however the intercept of 1308 computer units was very different with the original value of 1514 computer units. This tended to support the findings of a sensitive offset potentiometer in the device. The second device demonstrated slightly greater hysteresis with greater discrepancies between the ascending and descending line at angles 0° to -30° with a maximum difference of 5.7° at -30° recorded on one test. The above calibration procedure was repeated again five times, but through a shorter excursions firstly -30° to +100° and then five times -30° to +60° (Table 10.25). It was evident that the hysteresis effect was related to the angle of excursion and this was reflected in that between -30° and +100° the absolute maximum errors reduced to fewer than 4° and between excursions angles -30° to +60° the maximum errors were fewer than 3°.

Table 10.25 Effect of reducing angular excursion on differences between ascending and descending values

	Range –30° to + 100° Mean difference in computer units (Degrees in brackets)	Maximum difference in computer units (Degrees in brackets)	Range –30° to + 60° Mean difference in computer units (Degrees in brackets)	Maximum difference in computer units (Degrees in brackets)
Calibration 1	9.7 (2.1)	17.5 (3.8)	2.4 (0.5)	6.1 (1.3)
Calibration 2	9.0 (2.0)	16.2 (3.5)	5.1 (1.1)	10.6 (2.2)
Calibration 3	9.8 (2.1)	15.1 (3.3)	7.0 (1.5)	10.7 (2.3)
Calibration 4	8.8 (1.9)	16.6 (3.6)	7.2 (1.6)	11.5 (2.5)
Calibration 5	10.3 (2.2)	16.9 (3.7)	5.5 (1.2)	10.7 (2.3)

The calibration of the second electrogoniometer was therefore repeatable and accurate. Slight hysteresis was noted in the second device and this might be related to slight differences during manufacture, for example it was observed that the plastic cover on the cantilever had been sealed on different sides of the cantilever on each fibreoptic electrogoniometer.

10.15 APPLICATION OF FIBREOPTIC ELECTROGONIOMETER IN VIVO

The end boxes of the electrogoniometer were found to exhibit considerable rotation in the sagittal plane when simply adhered to the skin using double-sided tape and secured using elasticated straps, placed circumferentially around the limbs. It was also noticeable that the electrogoniometer cantilever could not tolerate the large natural valgus angle of some knees, with abnormal bending and potentially damaging stresses applied to the cantilever in such circumstances. The manufacturers did supply some small plastic 'hinged brackets' presumably to help overcome the 'valgus angle' problem, however there were no instructions or obvious standard method advocated in which to apply and secure these to the end boxes and ultimately the human body.

A reliable method therefore had to be designed with which to apply and secure the electrogoniometer to the knee. Rowe et al (2001) presented a reliable and valid method of securing the end blocks of a strain gauge type electrogoniometer. In this protocol the electrogoniometer end blocks were attached to long pieces of flexible plastic strips and these were attached to the skin over the lateral border of the lower limb using double-sided tape at the proximal and distal ends. It was proposed that using such an arrangement significantly reduced the errors caused by skin distraction and movement (Rowe et al, 2001). The basis of this approach was used for the electrogoniometer attachment in this study, although significantly modified to respect the results of the bench tests and the different structural design. To prevent the end boxes themselves rotating they were secured into small rectangular trays open at the top and at one end. These were constructed from a cut down plastic box normally designed to hold 30mm photographic slides. The end boxes were secured to the tray using interference fit and Velcro. Each tray was then secured to a plastic hinge supplied by the manufacturers. The plastic hinges in turn were then secured by small screws to two flexible pieces of 'Aquaflex' plastic 30cm length by 3cm width and 10cm length by 3cm width, for the thigh and shank components respectively (Figure 10.18a). It was evident in practice that the end boxes tended to be pulled from the trays with compression and distraction movements during functional knee activity, hence small pieces of plastic were secured to the end boxes at the open end of the tray to prevent this (Figure 10.18b). It was also apparent during functional movements, involving knee excursions, greater than approximately 70° flexion angles that the hinged brackets tended to open laterally and buckle the cantilever. Attempts to control this with an elasticated strap placed circumferentially around the end box and limb failed, as movement of the hinge caused the strap to slip and slide down the limb. Thus 'a housing' was constructed for the end box mechanisms, which would allow some degree of bracket hinging, but limited complete lateral opening of the hinge. An overarching plastic bracket (constructed from a cut down flat channel plumbing connector) was therefore added with foam padding between the top of the end box and the plastic bracket to control the lateral movement (Figure 10.18a).

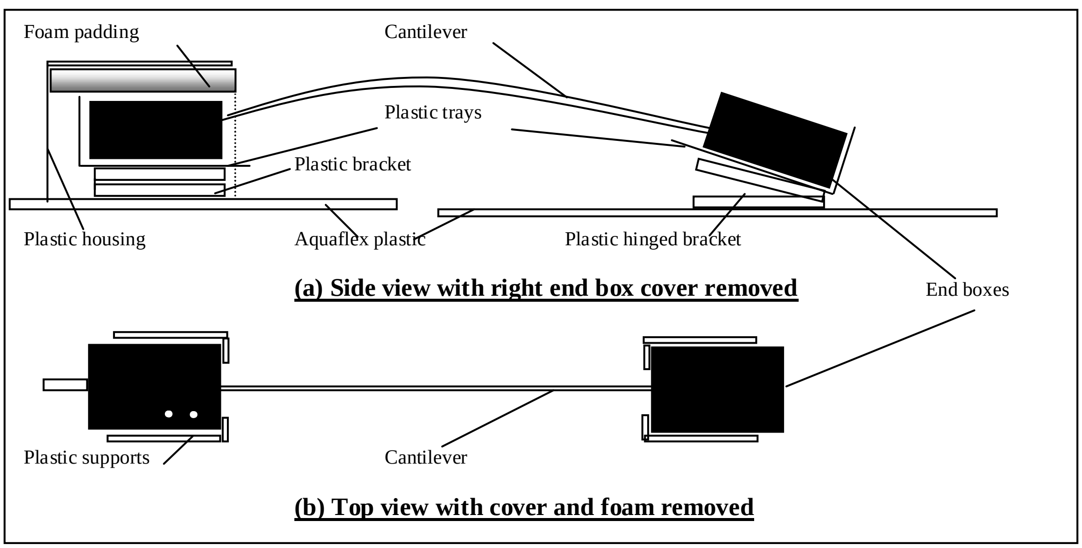


Figure 10.18a and b: Schematic of electrogoniometer end box configuration

10.15 VALIDATION OF FIBREOPTIC ELECTROGONIOMETER

10.15.1 Validation of the MacReflex® Output in Vitro

To establish the validity of the fibreoptic electrogoniometer the MacReflex® motion analysis system (Qualysis Inc) was used as the criterion measure against which to compare the output of the fibreoptic electrogoniometer. The MacReflex® motion analysis system has been shown to be a valid and reliable measure of joint kinematics (Batavia and Garcia, 1996; Levy and Smith, 1995). The validity and reliability of the MacReflex® motion analysis system, however, had to be checked both on the bench and clinically.

10.15.2 Experiment Aims

The following experiments set out to confirm the validity of the MacReflex® and also further investigate the accuracy of the fibreoptic electrogoniometer subject application method.

10.15.3 Method

The MacReflex® was calibrated prior to each test as outlined in the manufacturer's instruction booklet (Qualysis Inc). A section of wood (1.50m x 0.10m x 0.01m) was attached vertically to a small wooden stool (height 0.32m). A standard universal plastic goniometer was attached vertically to the section of wood, with the centre axis 0.50m from the floor. This height was chosen to approximate to the height of an average adult knee joint (Figure 10.19).

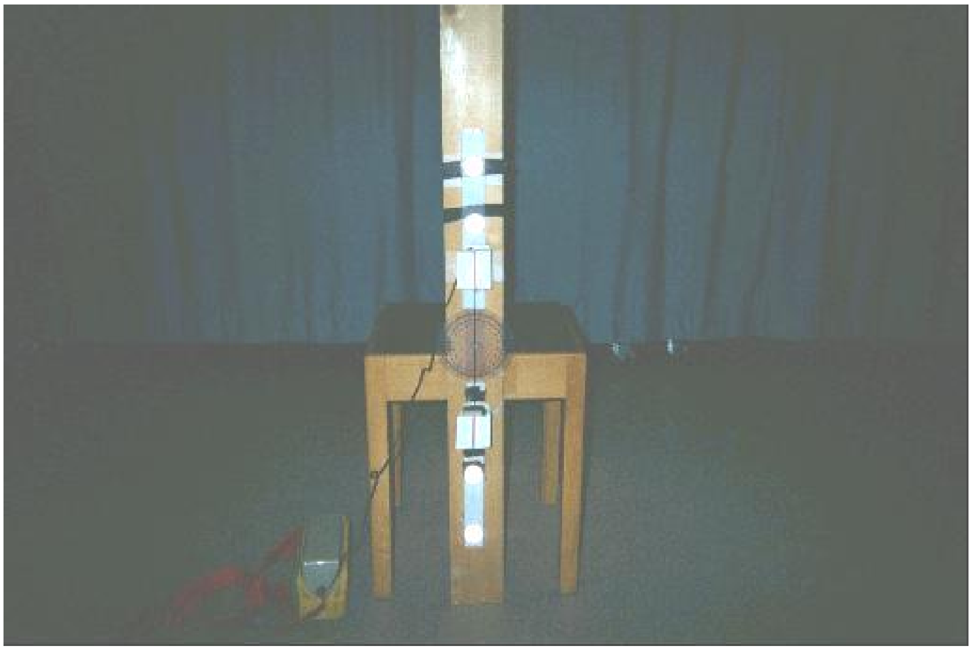


Figure 10.19: Set-up to confirm calibration of MacReflex® system

The fibreoptic electrogoniometer was then placed within the end box restraining mechanisms attached to the hinged plastic strips. These strips were then affixed to the universal goniometer using double sided adhesive tape with single adhesive tape wrapped around the universal goniometer arms and plastic strips for further security. Four MacReflex® reflective marker balls were applied in a straight-line configuration with two reflective markers, two centimetres in diameter, applied to the proximal arm and distal arm of the universal goniometer respectively. The universal goniometer and fibreoptic electrogoniometer were then manipulated through 0° to $+120^{\circ}$ and 0° to -120° in 30° increments. At each 30° increment 5 seconds of data were recorded simultaneously from both the fibreoptic electrogoniometer and MacReflex® systems. Two-dimensional analysis was used for the MacReflex® system.

10.15.4 Results and Conclusions

A comparison of the output obtained from both the fibreoptic electrogoniometer and MacReflex® against the criterion input universal goniometer angles is shown in Table 10.26.

Table 10.26: Comparison of Universal goniometer vs. Fibreoptic electrogoniometer vs. Mac Refle

Universal goniometer	Fibreoptic electrogoniometer	MacReflex®
0°	0.0°	2.4°
+30°	25.9°	28.8°
-30°	26.3°	31.1°
+60°	56.1°	58.6°
-60°	55.0°	60.8°
+90°	88.8°	89.2°
-90°	83.8°	90.9°
+120°	120.7°	119.5°
-120°	111.0°	121.6°

It was evident that the fibreoptic electrogoniometer incurred greater errors, relative to the MacReflex® system, with a maximum error of 9° recorded at -120°. The MacReflex® appeared relatively more accurate with a maximum-recorded error of 2.4° at 0°. The MacReflex® system appeared to be valid; however there was some doubt over the validity of the fibreoptic electrogoniometer system.

10.16 VALIDATION OF THE MACREFLEX® OUTPUT IN VIVO

10.16.1 Experiment Aim

This experiment was to establish the validity and accuracy of the fibreoptic electrogoniometer when attached to a subject.

10.16.2 Method

The laboratory tests confirmed that to ensure accuracy of the electrogoniometer the end boxes must be secured across to the lateral aspect of the thigh in a straight-line configuration with each other, with the cantilever in straight alignment. Furthermore the centre of the cantilever must be almost directly over the centre of the joint axis to be measured. Pilot studies revealed simply trying to apply the electrogoniometer by identifying the bony landmarks of the greater trochanter, lateral femoral condyle and lateral malleolus was almost impossible to achieve without flexing the cantilever or maligning the end boxes, with subsequent reapplication unreliable on the same subject. To facilitate this task an application jig was constructed.

To ensure that the electrogoniometers were applied in a reproducible manner in the standing position an application jig was constructed (Figures 10.20 and 10.21). This consisted of a flat wooden Medium Density Fibre (MDF) base (dimensions 1.25m x 1m x 0.02m) with batons of wood secured to the upper surface. Subjects placed the posterior aspect of their feet against a cross baton of wood to ensure both feet were level. Further batons also constrained two pieces of A3 paper. Subjects stood on the A3 paper and the outline of their feet could be traced to ensure reproducible positioning of their feet and lower limbs on subsequent re-applications. On either side of the wooden base were two vertical pieces of wood with metal rulers attached (measuring sticks). The measuring sticks were attached to moveable platforms that could be slid along between two plastic runners, constructed from spirit levels and secured to a wooden base (Figures 10.20 and 10.21). The vertical rulers could be moved in the sagittal plane relative to the lower limbs. The spirit levels had the distance from the backboard, measured in centimetres, marked on the upper surface, thus defining the accurate position of the measuring stick as it travelled along the ‘runner’ produced by the spirit levels. A wooden handrail sited on top of two adjustable tripod stands was positioned in front of the jig. The subject was instructed to hold this to reduce body sway and to enable a more reproducible standing position. The metal rulers allowed the magnetic fixation of a commercially available 'Land Laser Leveller' (LAND® LS95AII B & Q plc) (Figures 10.20 and 10.21), which was further secured by small plastic clamps. The 'Laser Levellers' produced a low intensity laser beam (Wavelength: 650nm, Maximum power output: 1mW) that could be directed at the knee (Figure 10.22). The application of a lens to the 'Land Leveller' projected a red coloured vertical laser line. The red coloured laser line could be rotated manually by turning the lens. To provide an accurate centre of rotation a small hole was bored in the centre of the lens. This produced a 'centre dot effect' with the vertical line passing thought it (Figures 10.22 and 10.23).

The laser lines and centre-dot were used as a guide to apply the electrogoniometer. The centre-dot was aligned with the lateral femoral condyle and the vertical line was manually adjusted such that the vertical line passed through the lateral malleolus and the lateral femoral condyle (Figure 10.23).

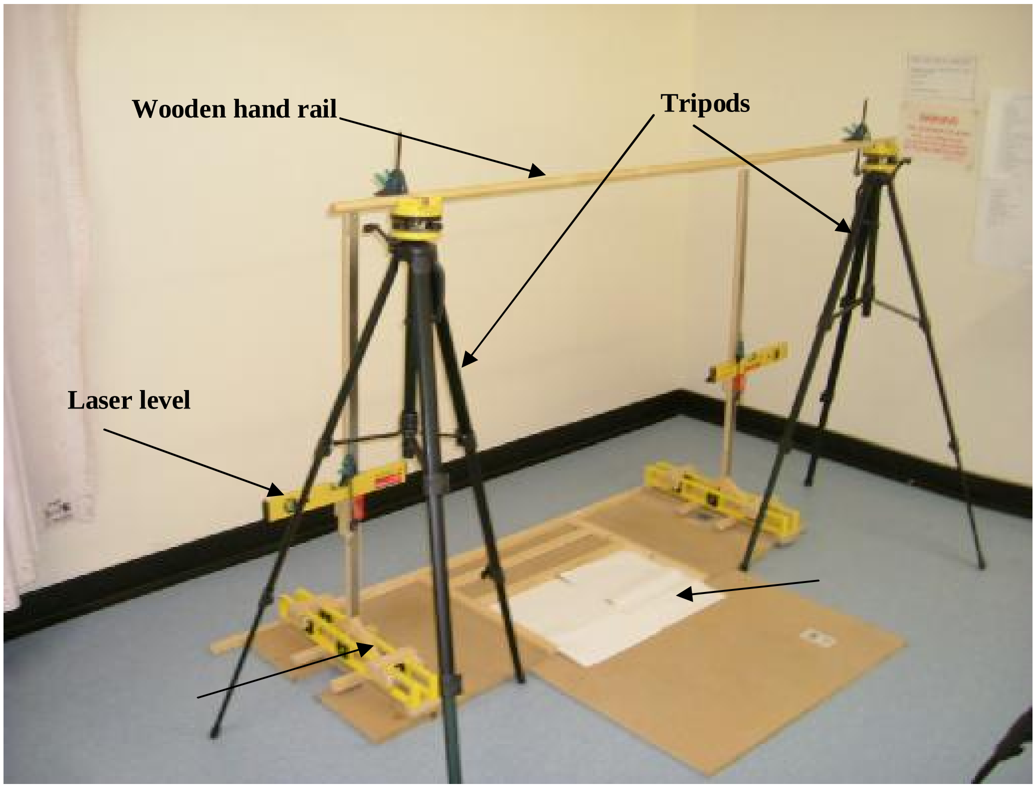


Figure 10.20: Electrogoniometer 'application jig'

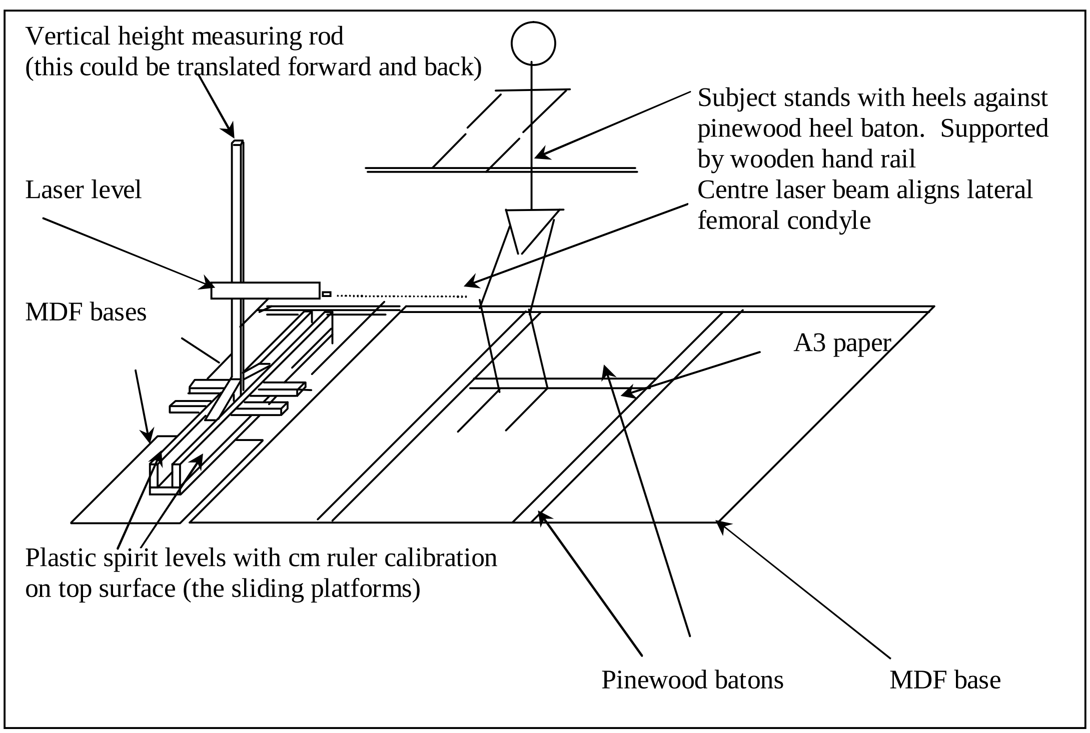


Figure 10.21: Schematic of electrogoniometer 'application' jig

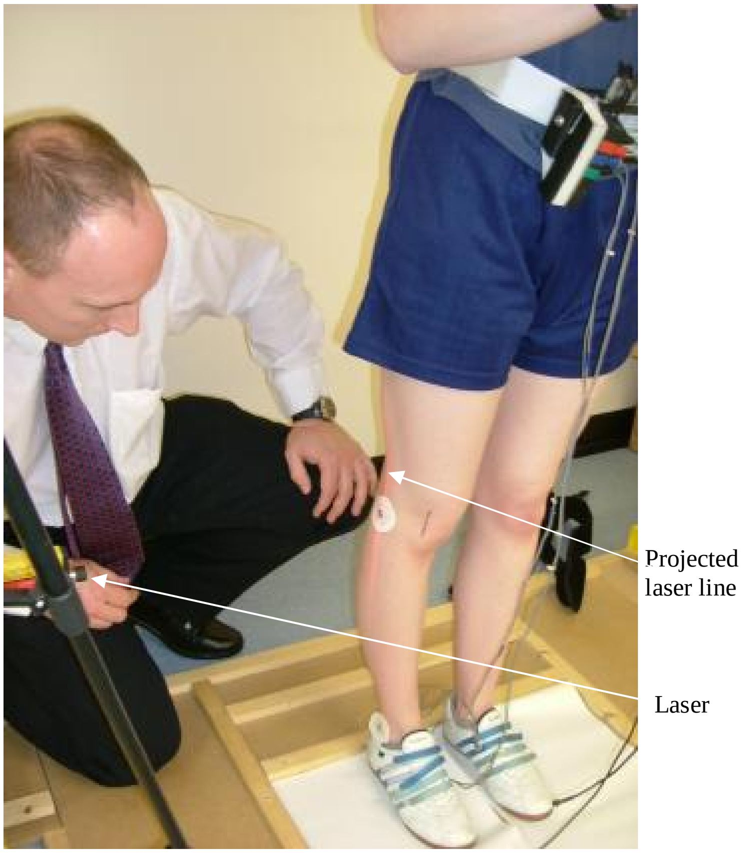


Figure 10.22: Projection of the reference laser line through the lateral malleolus and the lateral femoral condyle for electrogoniometer alignment

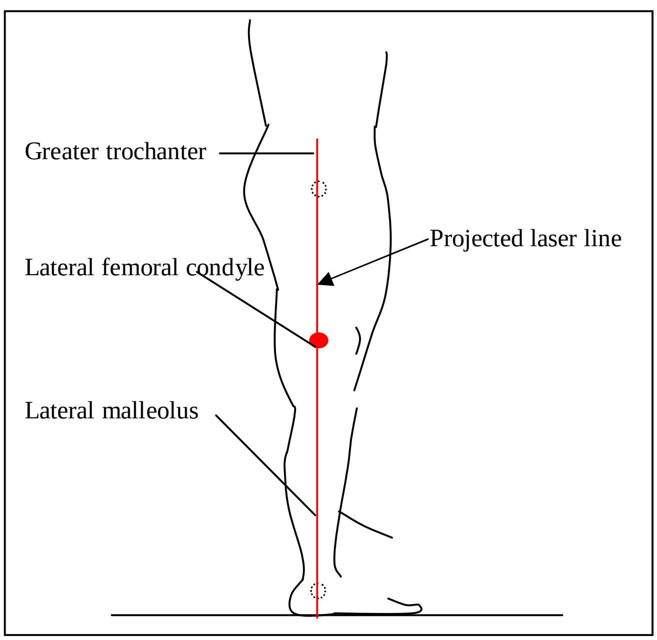


Figure 10.23: Diagram of reference laser line projected through the lateral malleolus and the lateral femoral condyle for electrogoniometer alignment

10.16.3 Attachment Procedure

The right limb lateral malleolus and lateral femoral condyle were identified in supine and marked with 2cm circumference adhesive markers. With the subject standing on the application jig the central laser dot was projected directly on to the marked lateral femoral condyle. The laser line was then projected and aligned with the lateral malleolus and the lateral femoral condyle. Using the laser lines as a guide, the centre of the fibreoptic electrogoniometer shim was directly aligned over the lateral femoral condyle and the distal lower leg plastic strip aligned with the lateral malleolus. The 'Aquaflex' plastic strips were attached to the subject's skin using double sided medical grade adhesive tape, using the projected laser lines as a guide. The 'Aquaflex' plastic strips were further secured using four elastic straps (straps from a knee brace Donjoy® Sports Brace) wrapped circumferentially around the thigh and lower leg, two for each thigh and two for each lower leg respectively. Each electrogoniometer took approximately five minutes to apply to each lower limb using this method.

A subject was positioned in sitting with feet in contact and flat on the floor at the foot of a standard physiotherapy adjustable couch. The couch and the subject were positioned side on to the MacReflex® cameras (Figure 10.24). The knees were then flexed incrementally to 30°, 60°, 90° and 120° by adjusting the height of the couch. The knee angles were measured using a standard hand held long arm universal metal goniometer. Four MacReflex® reflective markers balls were applied to the distal and proximal arms of the plastic strips. At each increment five seconds of data were recorded simultaneously from the fibreoptic electrogoniometer and MacReflex® motion analysis system.

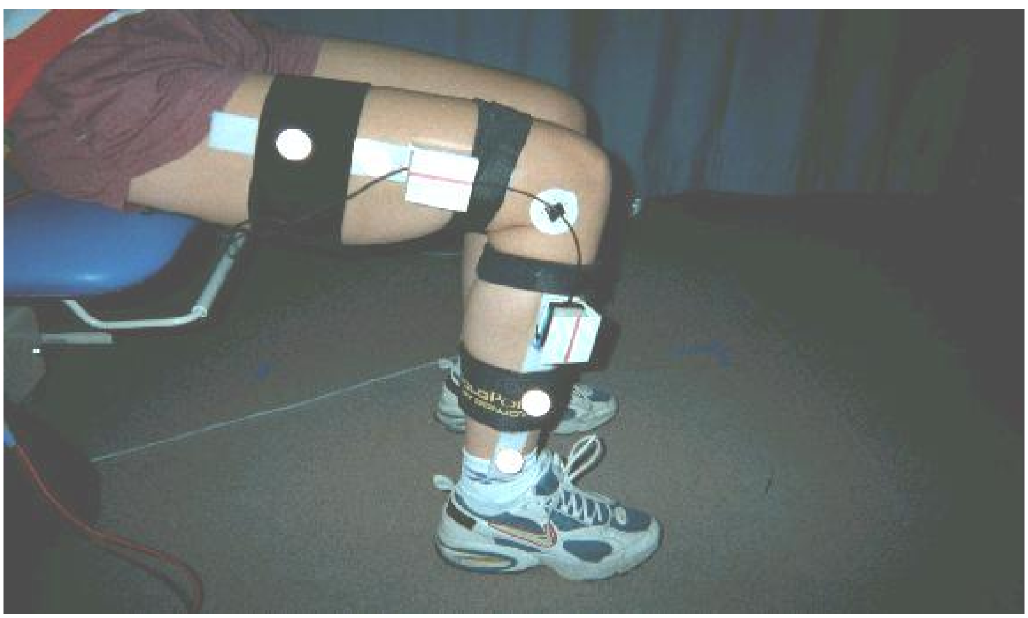


Figure 10.24: Set-up to investigate fibreoptic and MacReflex® system validity on subject

10.16.4 Results and Conclusions

Table 10.27 demonstrates the comparison of the standard universal goniometer, the fibreoptic electrogoniometer and MacReflex® system recorded values.

Table 10.27 Comparison of Universal goniometer vs. Fibreoptic electrogoniometer vs. Mac Reflex

Universal goniometer	Fibreoptic electrogoniometer	MacReflex®
30°	26.5°	34.0°
60°	51.5°	61.9°
90°	72.0°	88.6°
120°	101.5°	122.4°

Given the limitations of measuring knee angles with the standard universal goniometer with errors approximately 6° (Boone et al, 1978). The output of the MacReflex® system appeared to compare favourably with the universal goniometer with a maximum error of 4°. The fibreoptic values, however, demonstrated greater errors with an error of 18.5° recorded at 120°. These findings raised serious doubt regarding the validity of the fibreoptic electrogoniometer when attached to the human body became to be questioned.

10.17 FUNCTIONAL VALIDATION OF THE FIBREOPTIC ELECTROGONIOMETER AGAINST THE MACREFLEX®

10.17.1 Experiment Aim

Despite doubts over the validity of the fibreoptic electrogoniometry output it was deemed appropriate to complete the validation procedure by observing its response during functional tasks. This would also provide further information as to whether it would be worth persevering with the fibreoptic electrogoniometer and readdressing the issues over its validity or whether there was a conceptual flaw in its design.

10.17.2 Method - Validity

Six healthy subjects (2 males and 4 females) with no history of knee injury or surgery (mean age 31 1SD 1.8 years, age range 28-33 years; mean mass 69.8 kgs 1SD 8.5 kg, range 60-81 kg; height 1.73 1SD 0.05 metres, range 1.68-1.79 metres; mean BMI 23.2, range 21.2-25.3 1SD 1.7) were recruited for this study. Informed written consent was obtained from all subjects. The study was granted ethical approval by the Queen Margaret University College, Edinburgh ethics committee. The sample was one of convenience, subjects being recruited using informal contacts and recruitment posters.

The MacReflex® system was calibrated individually for each subject. The experiment took place within the Human Movement Laboratory at Queen Margaret University College, Edinburgh. Subjects were requested to wear training shorts and training shoes for the duration of the experiments. The amplifier box of the fibreoptic electrogoniometer was placed in a small ‘waist bag’ and secured to the subject using the waist belt. To reduce the risk of the subject tripping trailing cables were fed out in a controlled manner to reduce any potential for tripping and Velcro patches were attached to the light weight straps to contain any trailing leads and ensure that the leads were held in close contact with the limb.

The subjects were asked to perform 9 consecutive functional activities. These were level walking; static sitting in a low chair, static sitting in a standard chair, sitting to standing and standing to sitting from chairs of standard and low seat heights, stair ascent and descent. The choices of activities were designed to not only reflect normal activities of daily living, but also to stress the patellofemoral joint.

Walking is central to human locomotion and many other functional tasks (Wall, 1999). Abnormal gait patterns may cause pain due to tissue damage or promote pain due to abnormal loading, or promote the development of skeletal deformity as a result of abnormal joints moments (McHugh, 1993). It has been hypothesised that PFPS subjects use less flexion at knee joint to decrease force at the patellofemoral joint and thus potentially avoid pain (Nadeau et al, 1997). A small number of studies have shown that knee flexion during free walking is reduced in PFPS patients compared with healthy individuals (Dillon et al, 1983; Nadeau et al, 1997), while other investigators have failed to demonstrate a difference (Chesworth et al, 1989, Brechter and Powers, 2002; Powers et al, 1996; Powers et al, 1997a; Powers et al, 1999). However it is possible that walking does not sufficiently load the patellofemoral joint to cause alterations in knee flexion and that stair ambulation may be a more appropriate activity to observe kinematic knee changes. Large extensor muscle moments are produced with stair activities, especially during stair descent (Andriacchi et al, 1980), hence high patellofemoral joint reaction forces are induced. Moreover stair ascent and descent have been associated with exacerbating PFPS (Bentley, 1989; Blønd and Hansen, 1998; Ruffin and Kinningham, 1993) and the social importance of such activities in modern society is acknowledged (Gill et al, 1994). However studies examining knee joint motion during stair ambulation are also conflicting. Studies have reported decreased knee flexion at initial contact and midstance during stair descent (Crossley et al, 2004a; Greenwald et al, 1996), while Powers et al (1997a) and Heino Brechter and Powers (2002) found no significant difference in sagittal plane knee joint motion between PFPS patients and healthy controls during ascending or descending stairs or ramps.

The importance of sitting to standing and standing to sitting may be associated with upright bipedal walking (Baer and Durward, 1999), with PFPS often associated with prolonged sitting (Arroll et al, 1997; Dillon et al, 1983; Doucette and Goble; 1992; Hérbert et al, 1994; Tria et al, 1992). Patellofemoral joint reaction forces have been estimated to be in the region of 2.36 times body weight during sitting to standing manoeuvres (Seedholm and Terayama, 1976). A comparison of the maximal knee extension moments produced during gait, stair ascent and descent and sit to stand activities are shown in Table 10.28.

Table 10.28: Moments across knee joint during various functional tasks

Study	Task	Maximal knee extension moment
Kawagoe et al (2000)	Sit to stand (Chair height 40cm)	1.4 N.m/kg
McFadyen and Winter (1988)	Stair ascent/descent	Stair ascent ≈ 1.5 N.m/kg Stair descent ≈ 1.5 N.m/kg
Nadeau et al (1997)	Gait	0.5 N.m/kg
Salsich et al (2001)	Stair ascent/descent	Stair ascent 1.1 N.m/kg Stair descent 0.78 N.m/kg

Subjects performed a practice of the activity prior to recording to familiarise themselves with the equipment and functional task. All tasks were performed at the subjects' selected speed. The wooden stairs were custom made, which consisted of three up and over steps (Figure 10.25).

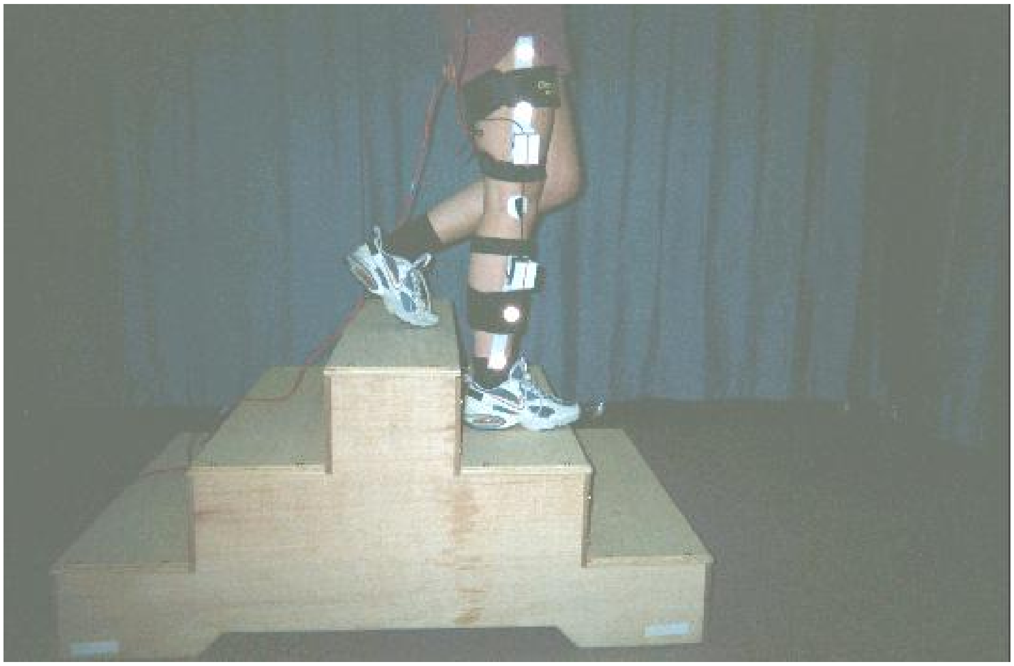


Figure 10.25: Stairs used for validation experiment

No handrail was provided or needed. Subjects were requested to initiate each task with the right lower limb. In order to assess the mainly the reliability of the electrogoniometer, and not the natural variability in the functional task, the starting position of the subjects' feet, the position of the chairs and stairs were marked by adhesive tape on the floor. Baseline recordings were taken in quiet standing prior to the functional activities, by asking the subject to stand in bilateral stance with feet shoulder width apart and actively contract their thigh muscles and then relax. Data were recorded for five seconds simultaneously from the MacReflex® system and fibreoptic electrogoniometer. These recordings were defined as the baseline value 0°. All subsequent recordings were measured relative to this baseline. The nine functional tasks were executed in the following order:

1) Static sitting in a low chair (Seat height 0.36m)
2) Sitting to standing from a low chair: ascent from a low chair to standing (Seat height 0.36m)
3) Standing to sitting to a low chair: descent from standing to a low chair (Seat height 0.36m)
4) Static sitting in a standard chair (Seat height 0.46m)
5) Sitting to standing from a standard chair: ascent from a standard chair to standing (Seat height 0.46m)
6) Standing to sitting to a standard chair: descent from standing to a standard chair (Seat height 0.46m)
7) Level walking: gait
8) Ascend stairs: ascend a 3 step flight of stairs (0.20m riser, 0.26m tread, 25° slope, width 0.90m and no hand rail)
9) Descend stairs: descend a 3 step flight of stairs (0.20m riser, 0.26m tread, 25° slope, width 0.90m and no hand rail)

The data from the fibreoptic electrogoniometer was exported to Excel for Windows for data processing and analysis. The data from the MacReflex® was analysed two-dimensionally calculating the angle made between lines formed by joining the position of the reflective marker balls on the thigh and shank respectively. These angles were then exported to Excel for Windows for data processing and analysis. For each of the nine functional activities a single corresponding cycle of the right leg was identified from the MacReflex® and fibreoptic electrogoniometry data.

Where a number of cycles were available, such as during gait and stair negotiation, a cycle was selected from the middle of the data stream to avoid cycles during initiation or termination of the activity. With the aims of the randomised controlled trial in mind specific aspects of the dynamic cycles related to the knee loading responses with the foot in contact with the ground were examined along with some more general aspects of the cycles, for example maximum knee flexion angle. Hence specific kinematic parameters related to patellofemoral joint loading and quadriceps activity were selected, for example peak stance knee flexion angle during gait and stair descent, and minimum knee flexion angle at midstance during stair ascent. The kinematic data were not normalised, this was a deliberate decision to ascertain if the raw data could provide clinically useful data, which was rapidly obtainable and interpretable in the routine clinical environment. The knee joint angles measured are shown below.

1) Static sitting in a low chair: right knee joint angle
2) Sit to stand low chair: right knee joint excursion angle
3) Stand to sit low chair: right knee joint excursion angle
4) Static sitting in standard chair: static right knee joint angle
5) Sit to stand standard chair: right knee joint excursion angle
6) Stand to sit standard chair: right knee joint excursion angle
7) Level walking: maximum right knee flexion angle during the second full gait cycle
8) Level walking: right knee midstance angle during the second full gait cycle
9) Ascend stairs: maximum right knee joint angle as right lower limb moved up from foot strike on the first step (Step 1) to foot strike on the third step (Step 3)
10) Ascend stairs: minimum right knee joint angle as left lower limb moved up from foot strike on the floor to foot strike on the third step (Step 3)
11) Ascend stairs: excursion angle between minimum right knee joint angle as left lower limb moved up from foot strike on the floor to foot strike on the third step (Step 3) and the maximum right knee joint angle as right lower limb moved up from foot strike on the first step (Step 1) to foot strike on the third step (Step 3)
12) Descend stairs: right knee maximum knee joint angle as the right lower limb moved down from the second step (Step 2) to heel strike on the floor
13) Descend stairs: descend a 3-step flight of stairs and walk: right knee joint midstance angle as the left lower limb moved down from the first step (Step 1) to the floor
14) Descend stairs: excursion angle between the midstance right knee joint angle as the left lower limb moved down from the first step (Step 1) to the floor and the right knee maximum knee joint angle as the right lower limb moved down from the second step (Step 2) to heel strike on the floor

10.17.3 Method- Reliability

The ‘Aquaflex’ plastic strips, fibreoptic electrogoniometer and MacReflex® reflective marker balls were completely removed from the subject on completion of the nine functional tasks. After a period of approximately 10 minutes the device was reapplied in an identical manner and the nine functional tasks repeated. The data were recorded and analysed also in a similar way.

10.17.4 Results (Validity)

Not all aspects of the gait and stair cycles could be examined as some of the data near 0° knee extension were almost indeterminable from the cycle traces; however a best estimation was made.

A comparison from the Measurand™ fibreoptic electrogoniometer and MacReflex®, mean and maximum absolute differences angles respectively, are shown for each activity in Tables 10.29, 10.30 and 10.31. Test 1 is the initial test and Test 2 the repeated intra-session test. The full results for each subject and each activity are shown in Electronic Appendix 11.

Table 10.29: Measurand™ Test 1

Function	Measurand™ Fibreoptic electrogoniometer Mean (S.D.)		MacReflex® Mean (S.D.)		Absolute Difference Mean (S.D.)		Absolute maximum difference and (CI = 95% confidence intervals of mean)	
Low chair								
static knee flexion angle	93.6	(8.5)	107.8	(3.1)	14.2	(8.5)	22.5	(CI 5.2 to 23.1)
Low chair sit to stand								
minimum knee flexion angle	4.7	(2.0)	1.7	(2.9)	3.5	(1.5)	5.0	(CI 1.9 to5.0)
maximum knee flexion angle	95.8	(7.3)	110.0	(3.9)	14.2	(8.3)	23.7	(CI -5.5 to 22.9)
knee excursion angle	91.1	(7.9)	108.3	(5.6)	17.2	(3.8)	25.3	(CI 9.8 to 24.6)
Low chair stand to sit								
minimum knee flexion angle	1.6	(3.2)	1.2	(1.0)	2.6	(1.5)	4.8	(CI 1.0 to 4.2)
maximum knee flexion angle	96.2	(7.6)	110.5	(5.0)	13.6	(10.9)	31.3	(CI 2.2 to 5.0)
knee excursion angle	94.6	(8.6)	109.2	(5.3)	14.6	(4.8)	21.0	(CI 9.6 to 19.7)
Standard chair sitting								
static knee flexion angle	84.2	(6.3)	94.5	(6.7)	11.0	(6.7)	19.3	(CI 3.9 to 18.1)
Standard chair sit to stand								
minimum knee flexion angle	4.0	(0.8)	2.3	(2.9)	2.6	(1.6)	4.7	(CI 1.0 to 4.2)
maximum knee flexion angle	85.3	(6.5)	96.5	(9.2)	12.5	(9.7)	30.3	(CI 2.4 to 22.7)
knee excursion angle	81.2	(6.1)	94.2	(6.7)	13.0	(9.4)	28.6	(CI 3.1 to 22.8)
Standard chair stand to sit								
minimum knee flexion angle	1.6	(1.4)	2.0	(3.9)	2.8	(2.5)	6.4	(CI 0.2 to 5.4)
maximum knee flexion angle	84.1	(6.0)	96.7	(10.9)	13.6	(10.9)	31.3	(CI 2.1 to 25.0)
knee excursion angle	82.4	(4.7)	94.6	(7.1)	12.2	(8.5)	24.9	(CI 3.3 to 21.1)
Gait								
minimum knee extension angle at terminal swing phase	3.1	(5.6)	-1.1	(1.4)	5.8	(2.6)	8.9	(CI 3.0 to 8.5)
maximum knee flexion angle	55.0	(7.7)	60.2	(7.1)	8.1	(4.9)	13.2	(CI 2.9 to 13.3)
midstance phase peak angle	9.7	(4.4)	12.6	(3.6)	2.9	(2.6)	6.5	(CI 0.2 to 5.6)
minimum knee extension to midstance peak angle excursion	6.6	(6.3)	13.7	(3.2)	9.2	(8.4)	12.0	(CI 4.7 to 12.2)
minimum knee extension to maximum knee flexion excursion	51.9	(5.5)	61.3	(6.1)	9.4	(6.5)	18.9	(CI 2.6 to 16.3)
Stairs ascent								
knee mid stance angle	7.3	(5.2)	9.7	(6.8)	4.7	(3.4)	9.9	(CI 1.1 to 8.2)
knee maximum angle	82.4	(9.8)	96.0	(8.2)	13.8	(9.6)	28.4	(CI 3.8 to 23.8)
knee midstance to maximum angle excursion	75.1	(5.6)	86.2	(4.9)	11.1	(7.1)	18.5	(CI 3.7 to 18.6)
Stairs descent								
knee midstance joint angle	21.4	(12.8)	27.6	(12.1)	7.4	(4.5)	12.7	(CI 2.8 to 12.1)
knee maximum joint angle	84.5	(8.6)	93.8	(5.2)	10.6	(4.3)	15.7	(CI 6.1 to 15.1)
knee maximum to midstance excursion angle	63.1	(4.5)	71.5	(9.4)	11.3	(2.9)	15.3	(CI 8.2 to 14.3)

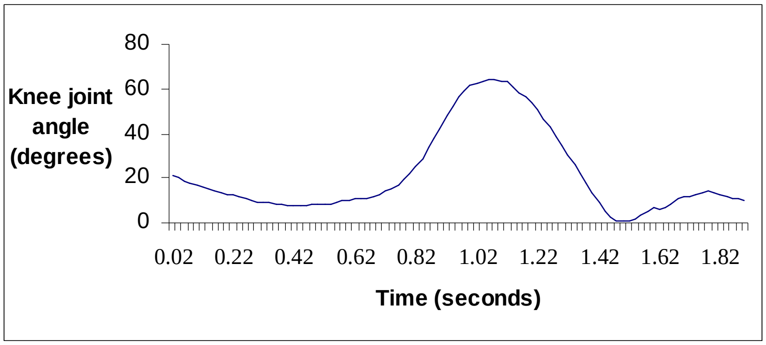
Table 10.30: Measurand™ Test 2

Function	Measurand™ Fibreoptic electrogoniometer Mean (S.D.)		MacReflex® Motion analysis Mean (S.D.)		Absolute Difference Mean (S.D.)		Absolute maximum difference and (CI = 95% confidence intervals of mean)	
Low chair								
static knee flexion angle	93.5	(7.4)	108.4	(4.7)	14.9	(6.9)	26.4	(CI 7.6 to 22.1)
Low chair sit to stand								
minimum knee flexion angle	1.9	(0.8)	2.4	(3.3)	2.5	(1.7)	5.4	(CI 0.6 to 4.3)
maximum knee flexion angle	93.7	(4.4)	111.6	(4.5)	17.8	(4.2)	24.3	(CI 13.5 to 22.2)
knee excursion angle	91.9	(4.1)	109.2	(3.8)	17.9	(7.0)	26.8	(CI 11.8 to 23.9)
Low chair stand to sit								
minimum knee flexion angle	2.0	(2.5)	3.0	(3.4)	2.7	(1.6)	5.0	(CI 1.0 to 4.3)
maximum knee flexion angle	93.9	(6.0)	111.0	(3.0)	17.1	(4.9)	23.9	(CI 12.0 to 22.2)
knee excursion angle	91.9	(6.6)	108.0	(5.5)	16.1	(5.4)	25.3	(CI 10.5 to 21.8)
Standard chair sitting								
static knee flexion angle	82.0	(6.8)	97.6	(12.1)	15.6	(10.1)	32.8	(CI 5.0 to 26.1)
Standard chair sit to stand								
minimum knee flexion angle	2.8	(1.1)	5.0	(4.0)	3.0	(2.5)	6.9	(CI 0.3 to 5.6)
maximum knee flexion angle	83.2	(6.0)	98.1	(6.6)	15.0	(5.0)	21.8	(CI 9.7 to 20.3)
knee excursion angle	80.5	(6.9)	93.0	(6.8)	12.5	(6.0)	12.5	(CI 6.2 to 18.8)
Standard chair stand to sit								
minimum knee flexion angle	1.7	(1.3)	5.6	(2.7)	4.0	(2.6)	7.2	(CI 1.3 to 6.8)
maximum knee flexion angle	83.0	(6.2)	100.5	(6.1)	17.5	(4.2)	22.2	(CI 13.1 to 21.9)
knee excursion angle	81.3	(7.1)	94.9	(6.5)	13.6	(5.3)	20.1	(CI 8.0 to 19.1)
Gait								
minimum knee extension angle at terminal swing phase	3.1	(3.1)	0.0	(2.2)	3.3	(2.8)	7.5	(CI 0.4 to 6.2)
maximum knee flexion angle	51.9	(5.6)	61.1	(5.7)	9.2	(3.8)	15.0	(CI 5.1 to 13.2)
midstance phase peak angle	8.6	(4.9)	16.5	(7.0)	7.9	(3.5)	11.2	(CI 4.2 to 11.6)
minimum knee extension to midstance peak angle excursion	5.5	(2.4)	16.6	(5.5)	11.1	(4.4)	16.3	(CI 6.3 to 16.0)
minimum knee extension to maximum knee flexion excursion	48.8	(5.7)	61.2	(4.7)	15.1	(12.4)	17.1	(CI 7.3 to 17.5)
Stairs ascent								
knee mid stance angle	7.3	(6.3)	11.2	(5.8)	5.7	(2.3)	8.4	(CI 3.2 to 8.1)
knee maximum angle	82.7	(7.4)	97.2	(5.8)	14.6	(8.2)	27.3	(CI 5.9 to 23.2)
knee midstance to maximum angle excursion	75.4	(6.4)	84.4	(4.3)	9.0	(4.4)	13.4	(CI 4.4 to 13.7)
Stairs descent								
knee midstance joint angle	17.5	(9.5)	30.2	(12.1)	12.7	(5.4)	18.3	(CI 7.0 to 18.4)
knee maximum joint angle	83.0	(7.5)	99.0	(8.0)	16.0	(6.0)	23.4	(CI 9.7 to 22.2)
knee maximum to midstance excursion angle	65.5	(5.5)	68.8	(8.4)	4.8	(2.4)	8.5	(CI 2.3 to 7.3)

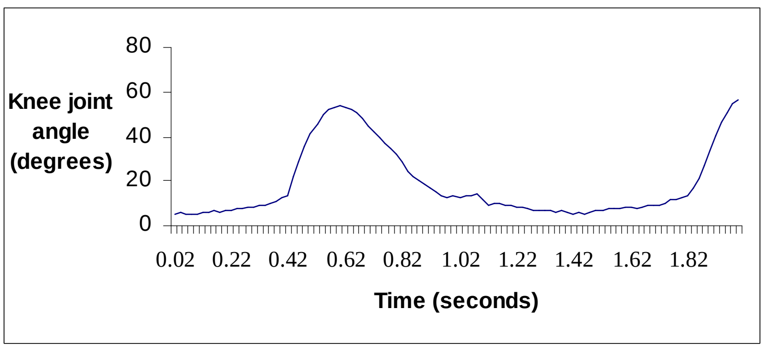
Table 10.31: Difference between Measurand^{TM} fibreoptic electrogoniometer and MacReflex®

Function	Test 1 Average absolute difference between electrogoniometer and MacReflex® (angles in degrees)	Test 1 Maximum absolute difference between electrogoniometer and MacReflex® (angles in degrees)	Test 2 Average absolute difference between electrogoniometer and MacReflex® (angles in degrees)	Test 2 Maximum absolute difference between electrogoniometer and MacReflex® (angles in degrees)
Low chair sitting (knee flexion angle)	14.2	22.5	14.9	26.4
Low chair sit to stand (minimum knee flexion angle)	3.5	5.0	2.5	5.4
Low chair sit to stand (maximum knee flexion angle)	14.2	23.7	17.8	24.3
Low chair sit to stand (knee excursion angle)	17.2	25.3	17.9	26.8
Low chair stand to sit (minimum knee flexion angle)	2.6	4.8	2.7	5.0
Low chair stand to sit (maximum knee flexion angle)	13.6	31.3	17.1	23.9
Low chair stand to sit (excursion angle)	14.6	21.0	16.1	25.3
Standard chair sitting (knee flexion angle)	11.0	19.3	15.6	32.8
Standard chair sit to stand (minimum knee flexion angle)	2.6	4.7	3.0	6.9
Standard chair sit to stand (maximum knee flexion angle)	12.5	30.3	15.0	21.8
Standard chair sit to stand (excursion angle)	13	28.6	12.5	23.1
Standard chair stand to sit (minimum knee flexion angle)	2.8	6.4	4.0	7.2
Standard chair stand to sit (maximum knee flexion angle)	13.6	31.3	17.5	22.2
Standard chair stand to sit (excursion angle)	12.2	24.9	13.6	20.1
Gait maximum knee flexion angle	8.1	13.2	9.2	15
Gait minimum knee flexion angle	5.8	8.9	3.3	7.5
Gait knee midstance angle	2.9	6.5	7.9	11.2
Gait maximum to minimum	9.4	18.9	15.1	17.1
Gait peak stance to minimum	9.2	12.0	11.1	16.3
Stairs ascent knee maximum angle	13.8	28.4	14.6	27.3
Stairs ascent knee mid stance angle	4.7	9.9	5.7	8.4
Stair ascent excursion	11.1	18.5	9.0	13.4
Stairs descent knee maximum angle	10.6	15.7	16	23.4
Stairs descent knee midstance angle	7.4	12.7	12.7	18.3
Stair descent excursion	11.3	15.3	4.8	8.5

The results demonstrate large differences between the values recorded by the fibreoptic electrogoniometer and the MacReflex® system for each functional task, with a mean difference of 17.2° during sit to stand from a low chair and a maximum difference of 31.3° in maximum knee flexion angle, while sitting to standing from a standard chair. There was a marked difference between the values recorded by the fibreoptic electrogoniometer and the MacReflex® with the fibreoptic electrogoniometer values tending to be less than those of the MacReflex® system. It was also evident that at knee extension 0° that the fibreoptic electrogoniometer appeared to have problems discriminating relatively small knee flexion angles. Graphs 10.13a and 10.13b demonstrates this during gait with the knee flexion angles quite different between the two traces for similar phases of the gait cycle.



Graph 10.13a:



Graph 10.13b: Examples of data recorded from similar phases of the gait cycle a) MacReflex® system and b) Fibreoptic electrogoniometer system

This may have been due to the end boxes being held at a fixed distance which appeared to cause the following problems 1) as the knee naturally compressed and distracted, the fibreoptic shim appeared to be pulled taut and thus recording a near full extension angle when the knee was still in fact still flexed 2) as the knee reached full extension at terminal swing phase the effect of gravity tended to cause the shim to drop back and hence reduce the knee angle recorded 3) when the knee naturally abducted to adducted this again caused the shim to be pulled taut and thus alter the bend recorded 4) with active contraction of the quadriceps the output of the electrogoniometer could be altered considerably, again owing to the fixed distance arrangement of the end boxes.

10.17.5 Results (Reliability)

The test retest typical errors are presented in Tables 10.32 and 10.33 for both the fibreoptic electrogoniometer and MacReflex® systems respectively.

Table 10.32: Measurand™ fibreoptic reliability

Function	**Test 1 Measurand™ fibreoptic electrogoniometer (angles in degrees)**	**Test 2 Measurand™ fibreoptic electrogoniometer (angles in degrees)**	**Test 2 SEM (S_{diff} /Ö2) between Test 1 and Test 2 Measurand™ fibreoptic electrogoniometer**
Low chair sitting (knee flexion angle)	93.6	93.5	1.9
Low chair sit to stand (minimum knee flexion angle)	4.7	1.9	1.7
Low chair sit to stand (maximum knee flexion angle)	95.8	93.7	4.3
Low chair sit to stand (knee excursion)	91.1	91.9	5.1
Low chair stand to sit (minimum knee flexion angle)	1.6	2.0	1.7
Low chair stand to sit (maximum knee flexion angle)	96.2	93.9	6.1
Low chair stand to sit (excursion)	94.6	91.9	6.3
Standard chair sitting (knee flexion angle)	84.2	81.9	5.4
Standard chair sit to stand (minimum knee flexion angle)	4.0	2.8	0.8
Standard chair sit to stand (maximum knee flexion angle)	85.3	83.2	6.3
Standard chair sit to stand (excursion angle)	81.3	80.5	6.8
Standard chair stand to sit (minimum knee flexion angle)	1.6	1.7	1.3
Standard chair stand to sit (maximum knee flexion angle)	84.1	83.0	4.1
Standard chair stand to sit (excursion)	82.4	81.3	4.6
Gait maximum knee flexion angle	55.0	51.9	2.4
Gait minimum knee flexion angle	3.1	3.1	4.6
Gait knee midstance angle	9.7	8.6	1.8
Gait maximum to minimum	51.9	48.8	2.6
Gait peak stance to minimum	6.6	5.5	3.1
Stairs ascent knee maximum angle	82.5	82.7	3.9
Stairs ascent knee minimum angle	7.4	7.3	1.2
Stair ascent excursion	75.1	75.4	4.8
Stairs descent knee maximum angle	84.5	83.0	3.4
Stairs descent knee midstance angle	21.4	17.5	2.6
Stair descent excursion	63.1	65.5	4.0

Table 10.33: MacReflex® reliability with Measurand™ fibreoptic electrogoniometer

Function	**Test 1 MacReflex® (angles in degrees)**	**Test 2 MacReflex® (angles in degrees)**	**Test 2 SEM (S_{diff} /Ö2) between Test 1 and Test 2 MacReflex®**
Low chair sitting (knee flexion angle)	107.8	108.4	3.6
Low chair sit to stand (minimum knee flexion angle)	1.7	2.4	2.9
Low chair sit to stand (maximum knee flexion angle)	110.0	111.6	2.8
Low chair sit to stand (knee excursion)	108.3	109.2	4.0
Low chair stand to sit (minimum knee flexion angle)	1.2	3.0	2.6
Low chair stand to sit (maximum knee flexion angle)	110.5	111.0	3.3
Low chair stand to sit (excursion)	109.2	108.0	3.7
Standard chair sitting (knee flexion angle)	94.5	97.6	6.6
Standard chair sit to stand (minimum knee flexion angle)	2.3	5.0	3.5
Standard chair sit to stand (maximum knee flexion angle)	96.5	98.2	3.3
Standard chair sit to stand (excursion angle)	94.2	93.0	3.5
Standard chair stand to sit (minimum knee flexion angle)	2.0	5.6	3.2
Standard chair stand to sit (maximum knee flexion angle)	96.7	100.5	3.8
Standard chair stand to sit (excursion)	94.6	94.9	1.7
Gait maximum knee flexion angle	60.2	61.1	4.7
Gait minimum knee flexion angle	-1.1	-0.1	1.6
Gait knee midstance angle	12.6	16.5	3.6
Gait maximum to minimum	60.2	61.1	4.7
Gait peak stance to minimum	13.8	16.6	3.0
Stairs ascent knee maximum angle	96.0	97.2	4.1
Stairs ascent knee mid stance angle	9.7	11.2	2.8
Stair ascent excursion	86.3	86.1	3.8
Stairs descent knee maximum angle	93.8	99.0	4.6
Stairs descent knee midstance angle	27.6	30.2	3.5
Stair descent excursion	71.5	68.8	3.5

For both systems the test retest mean values for each activity were similar with the SEMS (S_{diff} /√2) all below 7° with most below 5°. Slightly higher values were recorded during some of the sitting tasks and this may merely reflect some natural variation in these tasks, despite attempts to standardise these, as opposed to unreliability in the measuring systems. The measuring devices and method of application using the platform and laser levels therefore appeared to be reliable.

It was postulated from the bench tests that perhaps failure to apply the electrogoniometer in a straight-line configuration might have contributed to the discrepancies recorded between the fibreoptic electrogoniometer and the MacReflex® system. The experiment was therefore repeated on a further three subjects. On this occasion the fibreoptic electrogoniometer was modified to incorporate an application guide wire, which could be used to apply the device in as straight line and then the guide wire removed. Although this appeared to greatly improve the ease of application of the device to the subject it failed to improve the validity.

10.17.6 Conclusions

The fibreoptic electrogoniometer appeared reliable. However it did not provide a valid measure of joint kinematics, when compared against the MacReflex® system. The device appeared conceptually flawed owing to the fixed distance arrangement of the end boxes, which appeared to cause the device to 'pull straight' when close to 0° extension, thus tending to obscure small flexion angles.

ELECTRONIC APPENDIX 11

11.1 FIBREOPTIC ELECTROGONIOMETER VERSION 2 VALIDITY AND RELIABILITY

Table 11.1: Low chair sitting knee flexion angle - test 1
Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®

Subject	Electrogoniometer (Angle in degrees)	MacReflex® (Angle in degrees)	Difference (Degrees)	Absolute Difference (Degrees)
1	103.0	112.0	-8.7	8.7
2	94.4	110.0	-15.6	15.6
3	89.0	105.3	-16.3	16.3
4	87.0	109.6	-22.5	22.5
5	104.1	104.2	-0.1	0.1
6	84.0	105.9	-21.9	21.9
Average	93.6	107.8	-14.2	14.2
Standard deviation	8.5	3.1	8.5	8.5
Lower Upper 95% Confidence Intervals	84.7 102.6	104.6 111.1	-23.1 -5.2	5.2 23.1
Median	91.7	107.8	-16.0	16.0
Maximum	104.1	112.0	-0.1	22.5
Minimum	84.0	104.2	-22.5	0.1

Table 11.2: Low chair sitting knee flexion angle - test 2
Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®

Subject	Electrogoniometer (Angle in degrees)	MacReflex® (Angle in degrees)	Difference (Degrees)	Absolute Difference (Degrees)
1	102.1	116.0	-13.9	13.9
2	93.3	101.4	-8.1	8.1
3	93.5	106.9	-13.4	13.4
4	88.4	107.4	-19.0	19.0
5	101.0	109.6	-8.6	8.6
6	82.5	108.9	-26.4	26.4
Average	93.5	108.4	-14.9	14.9
Standard deviation	7.4	4.7	6.9	6.9
Lower Upper 95% Confidence Intervals	85.7 101.3	108.7 103.4	-22.1 -7.7	7.6 22.1
Median	93.4	108.1	-13.7	13.7
Maximum	102.1	116.0	-8.1	26.4
Minimum	82.5	101.4	-26.4	8.1

Table 11.3: Low chair sitting to standing minimum knee flexion angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	4.5	0.6	3.9	3.9
2	2.9	-1.1	4.0	4.0
3	7.9	6.0	1.9	1.9
4	2.8	4.2	-1.4	1.4
5	3.6	-1.4	5.0	5.0
6	6.2	1.6	4.6	4.6
Average	4.7	1.7	3.0	3.5
Standard deviation	2.0	2.9	2.4	1.5
Lower Upper 95% Confidence Intervals	2.5 6.8	- 4.71.4	0.5 5.5	1.9 5.0
Median	4.1	1.1	4.0	4.0
Maximum	7.9	6.0	5.0	5.0
Minimum	2.8	-1.4	-1.4	1.4

Table 11.4: Low chair sitting to standing minimum knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	2.3	3.6	-1.3	1.3
2	2.7	0.2	2.5	2.5
3	1.8	-1.6	3.4	3.4
4	1.0	1.7	-0.7	0.7
5	2.6	8.0	-5.4	5.4
6	0.8	2.2	-1.4	1.4
Average	1.9	2.4	-0.5	2.5
Standard deviation	0.8	3.3	3.2	1.7
Lower Upper 95% Confidence Intervals	1.0 2.7	-1.1 5.8	-3.8 2.8	0.6 4.3
Median	2.1	2.0	-1.0	2.0
Maximum	2.7	8.0	3.4	5.4
Minimum	0.8	-1.6	-5.4	0.7

Table 7.5: Low chair sitting to standing maximum knee flexion angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	103.8	113.6	-9.8	9.8
2	94.3	110.1	-15.8	15.8
3	90.5	105.3	-14.8	14.8
4	86.9	110.6	-23.7	23.7
5	105.1	105.5	-0.4	0.4
6	93.9	114.6	-20.7	20.7
Average	95.8	110.0	-14.2	14.2
Standard deviation	7.3	3.9	8.3	8.3
Lower Upper 95% Confidence Intervals	88.1 103.4	105.8 114.1	-22.9 -5.5	-5.5 22.9
Median	94.1	110.4	-15.3	15.3
Maximum	105.1	114.6	-0.4	23.7
Minimum	86.9	105.3	-23.7	0.4

Table 11.6: Low chair sitting to standing maximum knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	102.3	116.5	-14.2	14.2
2	93.1	117.4	-24.3	24.3
3	93.7	107.1	-13.4	13.4
4	90.7	107.5	-16.8	16.8
5	92.2	109.4	-17.2	17.2
6	90.3	111.4	-21.1	21.1
Average	93.7	111.6	-17.8	17.8
Standard deviation	4.4	4.5	4.2	4.2
Lower Upper 95% Confidence Intervals	89.1 98.3	106.9 116.2	-22.2 -13.5	13.5 22.2
Median	92.7	110.4	-17.0	17.0
Maximum	102.3	117.4	-13.4	24.3
Minimum	90.3	107.1	-24.3	13.4

Table 11.7: Low chair sit to stand knee excursion angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	99.3	113.0	-13.7	13.7
2	91.4	111.2	-19.8	19.8
3	82.6	99.3	-16.7	16.7
4	84.1	106.2	-22.1	22.1
5	101.5	106.9	-5.4	5.4
6	87.7	113.0	-25.3	25.3
Average	91.1	108.2	-17.2	17.2
Standard deviation	7.9	5.6	7.0	3.8
Lower Upper 95% Confidence Intervals	82.9 99.3	102.7 113.8	-24.6 -9.8	9.8 24.6
Median	89.6	109.0	-18.2	18.2
Maximum	101.5	113.0	-5.4	25.3
Minimum	82.6	99.3	-25.3	5.4

Table 11.8 Low chair sit to stand knee excursion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	100.0	112.9	-12.9	12.9
2	90.4	117.2	-26.8	26.8
3	91.9	108.7	-16.8	16.8
4	89.7	105.8	-16.1	16.1
5	89.6	101.4	-11.8	11.8
6	89.5	109.2	-19.7	19.7
Average	91.9	109.2	-17.3	17.3
Standard deviation	4.1	5.5	5.4	5.4
Lower Upper 95% Confidence Intervals	87.6 96.1	103.4 115.0	-23.0 -11.7	11.7 23.0
Median	90.0	109.0	-16.4	16.4
Maximum	100.0	117.2	-11.8	26.8
Minimum	89.5	101.4	-26.8	11.8

Table 11.9: Low chair stand to sit knee minimum knee flexion angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	2.9	1.7	1.2	1.2
2	1.6	0.4	1.2	1.2
3	5.2	2.7	2.5	2.5
4	-0.1	1.7	-1.8	1.8
5	3.9	-0.1	4.0	4.0
6	-3.8	1.0	-4.8	4.8
Average	1.6	1.2	0.4	2.6
Standard deviation	3.2	1.0	3.2	1.5
Lower Upper 95% Confidence Intervals	-1.8 5.0	0.2 2.3	-3.0 3.7	1.0 4.2
Median	2.3	1.4	1.2	2.1
Maximum	5.2	2.7	4.0	4.8
Minimum	-3.8	-0.1	-4.8	1.2

Table 11.10: Low chair stand to sit minimum knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	-0.1	2.6	-2.7	2.7
2	1.7	0.3	1.4	1.4
3	6.6	6.1	0.5	0.5
4	1.4	-1.7	3.1	3.1
5	2.3	7.3	-5.0	5.0
6	0	3.2	-3.2	3.2
Average	2.0	3.0	-1.0	2.7
Standard deviation	2.5	3.4	3.1	1.6
Lower Upper 95% Confidence Intervals	-0.6 4.6	-0.6 6.5	-4.2 2.3	1.0 4.3
Median	1.6	2.9	-1.1	2.9
Maximum	6.6	7.3	3.1	5.0
Minimum	-0.1	-1.7	-5.0	0.5

Table 11.11: Low chair stand to sit maximum flexion knee angle - test 1 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	102.6	114.1	-7.2	7.2
2	92.3	108.5	-16.4	16.4
3	84.2	102.7	-4.2	4.2
4	96.1	113.2	-31.3	31.3
5	105.4	108.2	2.9	2.9
6	96.8	116.3	-19.3	19.3
Average	96.2	110.5	-12.6	13.6
Standard deviation	7.6	5.0	12.2	10.9
Lower Upper 95% Confidence Intervals	88.3 104.1	105.3 115.7	-25.4 0.3	2.1 25.0
Median	96.5	110.9	-11.8	11.8
Maximum	105.4	116.3	2.9	31.3
Minimum	84.2	102.7	-31.3	2.9

Table 11.12: Low chair stand to sit maximum knee flexion angle - test 2 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	103.7	116.0	-12.3	12.3
2	88.7	112.6	-23.9	23.9
3	94.8	107.4	-12.6	12.6
4	97.1	111.1	-14.0	14.0
5	91.3	110.2	-18.9	18.9
6	87.6	108.7	-21.1	21.1
Average	93.9	111.0	-17.1	17.1
Standard deviation	6.0	3.0	4.9	4.9
Lower Upper 95% Confidence Intervals	87.6 100.2	107.8 114.2	-22.2 -12.0	12.0 22.2
Median	93.1	110.7	-16.5	16.5
Maximum	103.7	116.0	-12.3	23.9
Minimum	87.6	107.4	-23.9	12.3

Table 11.13: Low chair stand to sit knee excursion angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	99.7	112.4	-12.7	12.7
2	90.7	108.1	-17.4	17.4
3	79.0	100.0	-21.0	21
4	96.2	111.5	-15.3	15.3
5	101.5	108.2	-6.7	6.7
6	100.6	115.3	-14.7	14.7
Average	94.6	109.2	-14.6	14.6
Standard deviation	8.6	5.3	4.8	4.8
Lower Upper 95% Confidence Intervals	85.6 103.7	103.7 114.8	-19.7 -9.6	9.6 19.7
Median	98.0	109.9	-15.0	15.0
Maximum	101.5	115.3	-6.7	21.0
Minimum	79.0	100.0	21.0	6.7

Table 11.14: Low chair stand to sit knee excursion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	103.8	113.0	-9.6	9.6
2	87.0	112.3	-25.3	25.3
3	88.2	101.3	-13.1	13.1
4	95.7	112.8	-17.1	17.1
5	89.0	102.9	-13.9	13.9
6	87.6	105.5	-17.9	17.9
Average	91.9	108.0	-16.1	16.1
Standard deviation	6.6	5.4	5.4	5.4
Lower Upper 95% Confidence Intervals	84.9 98.9	102.3 113.7	-21.8 -10.5	10.5 21.8
Median	88.6	108.9	-15.5	15.5
Maximum	103.8	113.4	-9.6	25.3
Minimum	87.0	101.3	-25.3	9.6

Table 11.15: Standard chair sitting knee flexion angle - test 1 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	95.0	101.0	-6.0	6
2	83.0	96.0	-13.0	13
3	78.3	86.4	-8.1	8.1
4	78.7	98.0	-19.3	19.3
5	88.0	85.9	2.1	2.1
6	82.3	99.8	-17.5	17.5
Average	84.2	94.5	-10.3	11.0
Standard deviation	6.3	6.7	8.0	6.7
Lower **Upper** **95% Confidence Intervals**	77.6 90.9	87.5 101.5	-18 -3.9	3.9 18.1
Median	82.7	97.0	-10.6	10.6
Maximum	95.0	101.0	-2.1	19.3
Minimum	78.3	85.9	-19.3	2.1

Table 11.16: Standard chair sitting knee flexion angle - test 2 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	91.1	99.8	-8.7	8.7
2	81.0	113.8	-32.8	32.8
3	75.8	78.7	-2.9	2.9
4	89.2	106.0	-16.8	16.8
5	74.5	91.3	-16.8	16.8
6	80.3	95.7	-15.4	15.4
Average	82.0	97.6	-15.6	15.6
Standard deviation	6.8	12.1	10.1	10.1
Lower **Upper** **95% Confidence Intervals**	74.8 89.1	84.8 110.3	-26.1 -5.0	5.0 26.1
Median	80.7	97.8	-16.1	16.1
Maximum	91.1	113.8	-2.9	32.8
Minimum	74.5	78.7	-32.8	2.9

Table 11.17: Standard chair sitting to standing minimum knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	4.5	3.2	1.3	1.3
2	4	0.2	3.8	3.8
3	2.7	-0.6	3.3	3.3
4	3.7	15.4	-1.7	1.7
5	4.2	-0.5	4.7	4.7
6	5.0	5.8	-0.8	0.8
Average	4.0	2.3	1.8	2.6
Standard deviation	0.8	2.9	2.6	1.6
Lower Upper 95% Confidence Intervals	3.2 4.8	-0.8 5.3	-1.0 4.5	1.0 4.2
Median	4.1	1.7	2.3	2.5
Maximum	5.0	5.8	4.7	4.7
Minimum	2.7	-0.6	-1.7	0.8

Table 11.18: Standard chair sitting to standing minimum knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	2.4	4.8	-2.4	2.4
2	2.9	0.6	2.3	2.3
3	2.6	2.7	-0.1	0.1
4	1.3	2.5	-1.2	1.2
5	4.6	11.5	-6.9	6.9
6	2.8	7.8	-5.0	5.0
Average	2.8	5.0	-2.2	3.0
Standard deviation	1.1	4.0	3.3	2.5
Lower Upper 95% Confidence Intervals	1.6 3.9	0.8	-5.7 1.3	0.3 5.6
Median	2.7	9.2	-1.8	2.4
Maximum	4.6	3.8	2.3	6.9
Minimum	1.3	11.5	-6.9	0.1

Table 11.19: Standard chair sitting to standing maximum knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	95.0	101.6	-6.6	6.6
2	83.6	95.8	-12.2	12.2
3	78.7	85.3	-6.6	6.6
4	79.2	109.5	-30.3	30.3
5	91.1	87.1	4.0	4.0
6	84.2	99.6	-15.4	15.4
Average	85.3	96.5	-11.2	12.5
Standard deviation	6.5	9.2	11.5	9.7
Lower Upper 95% Confidence Intervals	78.4 92.1	86.9 106.1	-23.2 0.8	2.4 22.7
Median	83.9	97.7	-9.4	9.4
Maximum	95.0	109.5	4.0	30.3
Minimum	78.7	85.3	-30.3	4.0

Table 11.20: Standard chair sitting to standing maximum knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	90.7	100.8	-10.1	10.1
2	81.8	103.6	-21.8	21.8
3	82.0	90.1	-8.1	8.1
4	89.7	106.6	-16.9	16.9
5	75.0	91.8	-16.8	16.8
6	80.0	96.8	-16.3	16.3
Average	83.2	98.2	-15.0	15.0
Standard deviation	6.0	6.6	5.0	5.0
Lower Upper 95% Confidence Intervals	76.9 89.5	91.3 105.1	-20.3 -9.7	9.7 20.3
Median	81.9	98.6	-16.6	16.6
Maximum	90.7	106.6	-8.1	21.8
Minimum	75.0	90.1	-21.8	8.1

Table 11.21: Standard chair sitting to standing knee excursion angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	90.5	98.4	-7.9	7.9
2	79.6	95.6	-16.0	16.0
3	76.0	85.9	-9.9	9.9
4	75.5	104.1	-28.6	28.6
5	86.9	87.6	-0.7	0.7
6	79.2	93.8	-14.6	14.6
Average	81.2	94.2	-12.9	13.0
Standard deviation	6.1	6.7	9.4	9.4
Lower **Upper** **95% Confidence Intervals**	74.9 87.7	87.1 101.3	-22.8 -3.0	3.1 22.8
Median	79.4	94.7	-12.2	12.2
Maximum	90.5	104.1	-0.7	28.6
Minimum	75.5	85.9	-28.6	0.7

Table 11.22: Standard chair sit to stand knee excursion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	88.3	96.0	-7.7	7.7
2	78.9	102.0	-23.1	23.1
3	79.9	87.4	-7.5	7.5
4	88.4	104.1	-15.7	15.7
5	70.4	80.3	-9.9	9.9
6	77.2	88.5	-11.3	11.3
Average	80.5	93.0	-12.5	12.5
Standard deviation	6.9	6.8	6.0	6.0
Lower **Upper** **95% Confidence Intervals**	73.3 87.8	83.4 102.7	-18.8 -6.2	6.2 18.8
Median	79.4	92.2	-10.6	10.1
Maximum	88.4	104.1	-7.5	23.1
Minimum	70.4	80.3	-23.1	7.5

Table 11.23: Standard chair standing to sitting knee minimum angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	3.4	3.2	0.2	0.2
2	0.2	0.2	0.0	0.0
3	0.2	-2.6	2.8	2.8
4	1.7	8.1	-6.4	6.4
5	3.3	-1.1	4.4	4.4
6	1.0	4.1	-3.1	3.1
Average	1.6	2.0	-0.4	2.8
Standard deviation	1.4	3.9	3.9	2.5
Lower Upper 95% Confidence Intervals	0.1 3.1	-2.1 6.1	-4.5 3.8	0.2 5.4
Median	1.4	1.7	0.1	3.0
Maximum	3.4	8.1	4.4	6.4
Minimum	0.2	-2.6	-6.4	0.0

Table 11.24: Standard chair standing to sitting knee minimum angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	1.5	4.8	-3.3	3.3
2	2.6	4.7	-2.1	2.1
3	2.2	2.0	0.2	0.2
4	0.3	6.0	-5.7	5.7
5	3.2	10.4	-7.2	7.2
6	0.1	5.7	-5.6	5.6
Average	1.7	5.6	-4.0	4.0
Standard deviation	1.3	2.7	2.7	2.6
Lower Upper 95% Confidence Intervals	0.3 3.0	2.7 8.5	-6.8 -1.1	1.3 6.8
Median	1.9	5.3	-4.5	4.5
Maximum	3.2	10.4	0.2	7.2
Minimum	0.1	2.0	-7.2	0.2

Table 11.25: Standard chair standing to sitting maximum angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	94.4	101.6	-7.2	7.2
2	79.3	95.7	-16.6	16.4
3	79.4	83.4	-4.2	4.2
4	81.0	112.3	-31.3	31.3
5	88.2	85.3	2.9	2.9
6	82.1	101.4	-19.3	19.3
Average	84.1	96.7	-12.6	13.6
Standard deviation	6.0	10.9	12.2	10.9
Lower Upper 95% Confidence Intervals	77.7 90.4	85.2 108.1	-25.4 0.3	2.1 25.0
Median	81.6	98.6	-11.8	11.8
Maximum	94.4	112.3	2.9	31.3
Minimum	79.3	83.6	-31.3	2.9

Table 11.26: Standard chair standing to sitting knee maximum angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	90.2	100.8	-10.6	10.6
2	79.2	101.4	-22.2	22.2
3	73.8	91.8	-18.0	18.0
4	88.1	108.3	-20.2	20.2
5	80.5	95.2	-14.7	14.7
6	86.0	105.3	-19.3	19.3
Average	83.0	100.5	-17.5	17.5
Standard deviation	6.2	6.1	4.2	4.2
Lower Upper 95% Confidence Intervals	76.5 89.5	94.0 106.9	-21.9 -13.1	13.1 21.9
Median	83.3	101.1	-18.7	18.7
Maximum	90.2	108.3	-10.6	22.2
Minimum	73.8	91.8	-22.2	10.6

Table 11.27: Standard chair standing to sitting knee excursion angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	91.0	98.2	-7.2	7.2
2	79.1	95.5	-16.4	16.4
3	79.2	86.2	-7.0	7.0
4	79.3	104.2	-24.9	24.9
5	84.9	86.4	-1.5	1.5
6	81.1	97.3	-16.2	16.2
Average	82.4	94.6	-12.2	12.2
Standard deviation	4.7	7.1	8.5	8.5
Lower Upper 95% Confidence Intervals	77.4 87.4	87.2 102.0	-21.1 -3.3	3.3 21.1
Median	80.2	96.4	-11.7	11.7
Maximum	91.0	104.2	-1.5	24.9
Minimum	79.1	86.2	-24.9	1.5

Table 11.28: Standard chair standing to sitting knee excursion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	88.7	96.0	-7.3	7.3
2	76.6	96.7	-20.1	20.1
3	71.6	89.8	-18.2	18.2
4	87.8	102.3	-14.5	14.5
5	77.3	84.8	-7.5	7.5
6	85.9	99.6	-13.7	13.7
Average	81.3	94.9	-13.6	13.6
Standard deviation	7.1	6.5	5.3	5.3
Lower Upper 95% Confidence Intervals	73.9 88.7	88.1 101.7	-19.1 -8.0	8.0 19.1
Median	81.6	96.3	-14.1	14.1
Maximum	88.7	102.3	-7.3	20.1
Minimum	71.6	84.8	-20.1	7.3

Table 11.29: Gait maximum knee flexion angle - test 1 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	55	67.2	-12.2	12.2
2	59.3	69.7	-10.4	10.4
3	48.3	51.1	-2.8	2.8
4	58.7	60.1	-1.4	1.4
5	43.7	56.9	-13.2	13.2
6	64.7	56.1	8.6	8.6
Average	55.0	60.2	-5.2	8.1
Standard deviation	7.7	7.1	8.4	4.9
Lower Upper 95% Confidence Intervals	46.8 63.1	52.8 67.6	-14.0 3.6	2.9 13.3
Median	56.9	58.5	-6.6	9.5
Maximum	64.7	69.7	8.6	13.2
Minimum	43.7	51.1	-13.2	1.4

Table 11.30 Gait maximum knee flexion angle - test 2 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	51.9	66.9	-15.0	15.0
2	55.2	61.0	-5.8	5.8
3	44.4	52.2	-7.8	7.8
4	52.4	58.5	-6.1	6.1
5	47.4	60.3	-12.9	12.9
6	60.2	67.8	-7.6	7.6
Average	51.9	61.1	-9.2	9.2
Standard deviation	5.6	5.7	3.8	3.8
Lower Upper 95% Confidence Intervals	46.0 57.8	55.1 67.1	-13.2 -5.2	5.1 13.2
Median	52.1	60.7	-7.7	7.7
Maximum	60.2	67.8	-5.8	15.0
Minimum	44.4	52.2	-15.0	5.8

Table 11.31: Gait minimum knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	6.7	0.0	6.7	6.7
2	2.8	0.0	2.8	2.8
3	5.2	-3.1	8.3	8.3
4	1.7	-1.5	3.2	3.2
5	-7.1	-2.5	-4.6	4.6
6	9.1	-0.2	8.9	8.9
Average	3.1	-1.1	4.2	5.8
Standard deviation	5.6	1.4	5.0	2.6
Lower Upper 95% Confidence Intervals	-2.9 9.0	-2.7 0.3	-1.0 9.5	3.0 8.5
Median	4.0	0.8	5.0	5.7
Maximum	9.1	0.3	8.9	8.9
Minimum	-7.1	-2.7	-4.6	2.8

Table 11.32 Gait minimum knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	3.7	1.6	2.1	2.1
2	-0.6	-0.5	-0.1	0.1
3	1.5	-3.8	5.3	5.3
4	0.9	-0.2	1.1	1.1
5	6.1	2.6	3.5	3.5
6	7.3	-0.2	7.5	7.5
Average	3.1	0.0	3.2	3.3
Standard deviation	3.1	2.2	2.8	2.8
Lower Upper 95% Confidence Intervals	-0.1 6.4	-2.4 2.2	0.3 6.2	0.4 6.2
Median	2.6	-0.2	2.8	2.8
Maximum	7.3	2.6	7.5	7.5
Minimum	-0.6	-3.8	-0.1	0.1

Table 11.33: Gait knee flexion midstance angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	11.9	17.2	-5.3	5.3
2	6.9	8.3	-1.4	1.4
3	6.5	9.9	-3.4	3.4
4	4.8	11.3	-6.5	6.5
5	11.7	12.3	-0.6	0.6
6	16.4	16.7	-0.3	0.3
Average	9.7	12.6	-2.9	2.9
Standard deviation	4.4	3.6	2.6	2.6
Lower Upper 95% Confidence Intervals	5.1 14.3	8.8 16.4	-5.6 -0.2	0.2 5.6
Median	9.3	11.8	-2.4	2.4
Maximum	16.4	17.2	-0.3	6.5
Minimum	4.8	8.3	-6.5	0.3

Table 11.34: Gait knee flexion midstance angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	8.2	19.4	-11.2	11.2
2	5.8	9.1	-3.3	3.3
3	5.8	9.4	-3.6	3.6
4	3.0	13.1	-10.1	10.1
5	15.4	25.8	-10.4	10.4
6	13.6	22.4	-8.8	8.8
Average	8.6	16.5	-7.9	7.9
Standard deviation	4.9	7.0	3.5	3.5
Lower Upper 95% Confidence Intervals	3.5 13.7	9.2 23.9	-11.6 -4.2	4.2 11.6
Median	7.0	16.2	-9.4	9.4
Maximum	15.4	25.8	-3.3	11.2
Minimum	3.0	9.1	-11.2	3.3

Table 11.35: Gait minimum maximum knee flexion angle excursion- test 2 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	48.3	67.2	-18.9	18.9
2	56.5	69.7	-13.2	13.2
3	43.1	54.2	-11.1	11.1
4	57.0	61.6	-4.6	4.6
5	50.8	59.4	-8.6	8.6
6	55.6	55.9	-0.3	0.3
Average	51.9	61.3	-9.4	9.4
Standard deviation	5.5	6.1	6.5	6.5
Lower Upper 95% Confidence Intervals	46.1 57.7	54.9 67.8	-16.3 -2.6	2.6 16.3
Median	53.2	60.5	-9.9	9.9
Maximum	57.0	69.7	-0.3	18.9
Minimum	43.1	54.2	-18.9	0.3

Table 11.36: Gait minimum maximum knee flexion angle excursion - test 2 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	48.2	65.3	-17.1	17.1
2	55.8	61.5	5.7	5.7
3	42.9	56.0	-13.1	13.1
4	51.5	58.7	-7.2	7.2
5	41.3	57.7	-16.2	16.2
6	52.9	68.0	-16.4	16.4
Average	48.8	61.2	-15.1	15.1
Standard deviation	4.7	4.7	-12.4	12.4
Lower Upper 95% Confidence Intervals	42.7 54.8	56.3 66.0	-17.5 -7.3	7.3 17.5
Median	49.9	60.1	-14.1	14.1
Maximum	55.8	68.0	-5.7	17.1
Minimum	41.3	56.0	-17.1	5.7

Table 11.37: Gait minimum to midstance knee flexion excursion- test 2 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	5.2	17.2	-12.0	12.0
2	4.1	8.3	-4.2	4.2
3	1.3	13.0	-11.7	11.7
4	3.1	12.8	-9.7	9.7
5	18.8	14.8	4.0	9.7
6	7.3	16.5	-9.2	4.0
Average	6.6	13.7	-7.1	9.2
Standard deviation	6.3	3.2	6.1	8.4
Lower Upper 95% Confidence Intervals	0.0 13.2	10.4 17.1	4.0 -12.0	4.7 12.2
Median	4.7	13.9	-9.4	9.4
Maximum	18.8	17.2	4.0	12.0
Minimum	1.3	8.3	-12.0	4.0

Table 11.38: Gait minimum to midstance knee flexion angle excursion - test 2 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	4.5	17.8	-13.3	13.3
2	6.4	9.6	-3.2	3.2
3	4.3	13.2	-8.9	8.9
4	2.1	13.3	-11.2	11.2
5	9.3	23.2	-13.9	13.9
6	6.3	22.6	-16.3	16.3
Average	5.5	16.6	-11.1	11.1
Standard deviation	2.4	5.5	4.6	4.0
Lower Upper 95% Confidence Intervals	2.9 8.0	9.6 23.2	-15.9 -6.3	6.3 16.0
Median	5.4	15.6	-12.2	12.2
Maximum	9.3	23.2	-3.2	16.3
Minimum	2.1	9.6	-16.3	3.2

Table 11.39: Stairs ascent maximum knee flexion angle - test 1 **Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®**				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	91.8	100.2	-8.4	8.4
2	74.4	86.5	-12.1	12.1
3	74.4	87.1	-12.7	12.7
4	72.9	101.3	-28.4	28.4
5	95.0	94.1	0.9	0.9
6	86.4	106.8	-20.4	20.4
Average	82.4	96.0	-13.5	13.8
Standard deviation	9.8	8.2	10.0	9.6
Lower **Upper** **95% Confidence Intervals**	72.2 92.8	87.4 104.6	-23.8 -3.8	3.8 23.8
Median	80.4	97.1	-12.4	12.4
Maximum	95.0	106.8	0.9	28.4
Minimum	72.9	86.5	-28.4	0.9

Table7.40: Stairs ascent maximum knee flexion angle - test 2 **Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®**				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	91.1	99.8	-8.7	8.7
2	70.5	97.8	-27.3	27.3
3	79.9	91.1	-11.2	11.2
4	80.1	95.6	-15.5	15.5
5	87.7	92.2	-4.5	4.5
6	86.8	106.9	-20.1	20.1
Average	82.7	97.2	-14.6	14.6
Standard deviation	7.4	5.8	8.2	8.2
Lower **Upper** **95% Confidence Intervals**	74.9 90.5	91.2 100.3	-23.2 -5.9	5.9 23.2
Median	83.4	96.7	-13.3	13.3
Maximum	91.1	106.9	-4.5	27.3
Minimum	70.5	91.1	-27.3	4.5

Table 11.41: Stairs ascent midstance knee flexion angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	9.7	16.8	-7.1	7.1
2	4.5	6.5	-2.0	2.0
3	-0.2	-1.7	1.5	1.5
4	5.2	15.1	-9.9	9.9
5	14.7	9.2	5.5	5.5
6	10.2	12.5	-2.3	2.3
Average	7.3	9.7	-2.4	4.7
Standard deviation	5.2	6.8	5.6	3.4
Lower **Upper** **95% Confidence Intervals**	1.8 12.9	2.6 16.8	-8.2 -1.1	1.1 8.2
Median	7.4	10.9	-2.1	3.9
Maximum	14.7	16.8	5.5	9.9
Minimum	-0.2	-1.7	-9.9	1.5

Table 11.42: Stairs ascent midstance knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	8.2	16.3	-8.1	8.1
2	4.5	8.5	-4.0	4.0
3	-0.4	2.0	-2.4	2.4
4	3.9	9.6	-5.7	1.6
5	18.0	12.6	5.4	5.4
6	9.7	18.1	-8.4	8.4
Average	7.3	11.2	-3.9	5.7
Standard deviation	6.3	5.8	5.1	2.3
Lower **Upper** **95% Confidence Intervals**	0.7 13.9	5.1 17.3	-9.2 1.5	3.2 8.1
Median	6.3	11.1	-4.9	5.6
Maximum	18.0	18.1	5.4	8.4
Minimum	-0.4	2.0	-8.4	2.4

Table 11.43: Gait ascent excursion - test 1 **Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®**				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	82.1	83.4	-1.3	1.3
2	69.9	80.0	-10.1	10.1
3	74.6	88.8	-14.2	14.2
4	67.7	86.2	-18.5	18.5
5	80.3	84.9	-4.6	4.6
6	76.2	94.3	-18.1	18.1
Average	75.1	86.2	-11.1	11.1
Standard deviation	5.6	4.9	7.1	7.1
Lower **Upper** **95% Confidence Intervals**	69.2 81.0	81.1 91.4	-18.6 -3.7	3.7 18.6
Median	75.4	85.6	-12.2	12.2
Maximum	82.1	94.3	-1.3	18.5
Minimum	**67.7**	**80.0**	**-18.5**	**1.3**

Table 11.44: Stairs ascent knee flexion excursion - test 2 **Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®**				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	82.9	83.5	-0.6	0.6
2	65.9	79.3	-13.4	13.6
3	80.3	89.1	-8.8	8.8
4	76.2	86.0	-9.8	9.8
5	69.7	79.6	-9.9	9.9
6	77.1	88.8	-11.7	11.7
Average	75.4	84.4	-9.0	9.0
Standard deviation	6.4	4.3	4.4	4.4
Lower **Upper** **95% Confidence Intervals**	68.6 82.1	79.8 88.9	-13.7 -4.4	4.4 13.7
Median	76.7	84.8	-9.9	9.9
Maximum	82.9	89.1	-0.6	13.4
Minimum	65.9	79.3	-13.4	0.6

Table 11.45: Stairs descent maximum flexion knee angle - test 1 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	88.7	97.1	-8.4	8.4
2	79.9	89.9	-10.0	10.0
3	77.7	88.6	-10.9	10.9
4	75.5	90.3	-14.8	14.8
5	98.7	94.7	4.0	4.0
6	86.4	102.1	-15.7	15.7
Average	84.5	93.8	-9.3	10.6
Standard deviation	8.6	5.2	7.1	4.3
Lower Upper 95% Confidence Intervals	75.4 93.5	88.3 99.2	-16.7 -1.9	6.1 15.1
Median	83.1	92.5	-10.4	10.4
Maximum	98.7	102.1	4.0	15.7
Minimum	75.5	88.6	-15.7	4.0

Table 11.46 Stairs descent maximum knee flexion angle - test 2 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	82.2	91.7	-9.5	9.5
2	76.6	92.0	-15.4	15.4
3	85.1	95.5	-10.4	10.4
4	73.4	96.8	-23.4	23.4
5	94.6	108.8	-14.2	14.2
6	86.6	109.2	-22.8	22.8
Average	83.0	99.0	-16.0	16.0
Standard deviation	7.5	8.0	6.0	6.0
Lower Upper 95% Confidence Intervals	75.1 91.0	90.6 107.0	-22.2 -9.7	9.7 22.2
Median	83.7	96.2	-14.8	14.8
Maximum	94.6	109.2	-9.5	23.4
Minimum	73.4	91.7	-23.4	9.5

Table 11.47: Stairs descent midstance knee flexion angle - test 1 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	28.1	40.8	-12.7	12.7
2	24.7	36.5	-11.8	11.8
3	13.9	18.1	-4.2	4.2
4	11.7	14.2	-2.5	2.5
5	7.8	17.5	-9.7	9.7
6	42.0	38.2	3.8	3.8
Average	21.4	27.6	-6.2	7.4
Standard deviation	12.8	12.1	6.4	4.5
Lower Upper 95% Confidence Intervals	8.0 34.8	14.8 40.3	-12.9 0.5	2.8 12.1
Median	19.3	27.3	-7.0	7.0
Maximum	42.0	40.8	3.8	12.7
Minimum	7.8	14.2	-12.7	2.5

Table 11.48: Stairs descent midstance knee flexion angle - test 2 Measurand™ fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	20.6	38.9	-18.3	18.3
2	20.8	34.9	-14.1	14.1
3	12.5	19.4	-6.9	6.9
4	9.1	14.8	-5.7	5.7
5	8.7	26.8	-18.1	18.1
6	33.5	46.7	-13.2	13.2
Average	17.5	30.2	-12.7	12.7
Standard deviation	9.5	12.1	5.4	5.4
Lower Upper 95% Confidence Intervals	7.6 27.5	17.5 43.0	-18.4 -7.0	7.0 18.4
Median	16.6	30.9	-13.7	13.7
Maximum	33.5	46.7	-5.7	18.3
Minimum	8.7	14.8	-18.3	5.7

Table 11.49: Stairs descent excursion- test 1 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	64.0	55.2	8.8	8.8
2	66.0	73.9	-7.9	7.9
3	66.0	81.3	-15.3	15.3
4	67.7	79.3	-11.6	11.6
5	56.7	70.6	-13.9	13.9
6	58.3	68.4	-10.1	10.1
Average	63.1	71.5	-8.3	11.3
Standard deviation	4.5	9.4	8.8	2.9
Lower Upper 95% Confidence Intervals	58.3 67.9	61.6 81.3	-17.6 0.9	8.2 14.3
Median	65.0	72.3	-10.9	10.9
Maximum	67.7	81.3	8.8	15.3
Minimum	56.7	55.2	-15.3	7.9

Table 11.50: Stairs descent excursion - test 2 Measurand^{TM} fibreoptic electrogoniometer version 2 compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	61.4	56.8	4.6	4.6
2	64.1	72.6	-8.5	8.5
3	76.0	80.7	-4.7	4.7
4	64.7	70.0	-5.3	5.3
5	61.1	62.1	-1.0	1.0
6	65.8	70.3	-4.5	4.5
Average	65.5	68.8	-3.2	4.8
Standard deviation	5.5	8.4	4.5	2.4
Lower Upper 95% Confidence Intervals	59.8 71.2	60.0 77.5	-8.0 1.5	2.3 7.3
Median	64.4	70.2	-4.6	4.7
Maximum	76.0	80.7	4.6	8.5
Minimum	61.1	56.8	-8.5	1.0

Table 11.51: Difference between Measurand™ fibreoptic electrogoniometer version 2 and MacReflex®				
Function	**Test 1 Average absolute difference between electrogoniometer and MacReflex® (angles in degrees)**	**Test 1 Maximum absolute difference between electrogoniometer and MacReflex® (angles in degrees)**	**Test 2 Average absolute difference between electrogoniometer and MacReflex® (angles in degrees)**	**Test 2 Maximum absolute difference between electrogoniometer and MacReflex® (angles in degrees)**
Low chair sitting (knee flexion angle)	14.2	22.5	14.9	26.4
Low chair sit to stand (minimum knee flexion angle)	3.5	5.0	2.5	5.4
Low chair sit to stand (maximum knee flexion angle)	14.2	23.7	17.8	24.3
Low chair sit to stand (knee excursion angle)	17.2	25.3	17.9	26.8
Low chair stand to sit (minimum knee flexion angle)	2.6	4.8	2.7	5.0
Low chair stand to sit (maximum knee flexion angle)	13.6	31.3	17.1	23.9
Low chair stand to sit (excursion angle)	14.6	21.0	16.1	25.3
Standard chair sitting (knee flexion angle)	11.0	19.3	15.6	32.8
Standard chair sit to stand (minimum knee flexion angle)	2.6	4.7	3.0	6.9
Standard chair sit to stand (maximum knee flexion angle)	12.5	30.3	15.0	21.8
Standard chair sit to stand (excursion angle)	13	28.6	12.5	23.1
Standard chair stand to sit (minimum knee flexion angle)	2.8	6.4	4.0	7.2
Standard chair stand to sit (maximum knee flexion angle)	13.6	31.3	17.5	22.2
Standard chair stand to sit (excursion angle)	12.2	24.9	13.6	20.1
Gait maximum knee flexion angle	8.1	13.2	9.2	15
Gait minimum knee flexion angle	5.8	8.9	3.3	7.5
Gait knee midstance angle	2.9	6.5	7.9	11.2
Gait maximum to minimum	9.4	18.9	15.1	17.1
Gait peak stance to minimum	9.2	12.0	11.1	16.3
Stairs ascent knee maximum angle	13.8	28.4	14.6	27.3
Stairs ascent knee mid stance angle	4.7	9.9	5.7	8.4
Stair ascent excursion	11.1	18.5	9.0	13.4
Stairs descent knee maximum angle	10.6	15.7	16	23.4
Stairs descent knee midstance angle	7.4	12.7	12.7	18.3
Stair descent excursion	11.3	15.3	4.8	8.5

ELECTRONIC APPENDIX 12

12.1 STRAIN GAUGE ELECTROGONIOMETER VALDITY AND RELIABILITY

Table 12.1: Low chair sitting knee flexion angle -test 1
Biometrics electrogoniometer compared with MacReflex®

Subject	Electrogoniometer (Angle in degrees)	MacReflex® (Angle in degrees)	Difference (Degrees)	Absolute Difference (Degrees)
1	96.7	96.5	0.2	0.2
2	103.8	106.4	-2.6	2.6
3	88.1	89.1	-1.0	1.0
4	99.9	105.5	-5.6	5.6
5	108.5	106.8	1.7	1.7
6	115.7	112.8	2.9	2.9
Average	102.1	102.9	-0.8	2.3
Standard deviation	9.6	8.5	3.1	1.9
Lower Upper 95% Confidence Intervals	92.1 112.2	93.9 111.8	-4.0 2.5	0.3 4.3
Median	101.8	106.0	-0.4	2.1
Maximum	115.7	112.8	2.9	5.6
Minimum	88.1	89.1	-5.6	0.2

Table 12.2: Low chair sitting knee flexion angle - test 2
Biometrics electrogoniometer compared with MacReflex®

Subject	Electrogoniometer (Angle in degrees)	MacReflex® (Angle in degrees)	Difference (Degrees)	Absolute Difference (Degrees)
1	95.9	100.6	-4.7	4.7
2	111.7	109.6	2.1	2.1
3	87.9	85.7	2.2	2.2
4	97.2	99.1	-1.9	1.9
5	108.5	107.6	0.9	0.9
6	114.6	105.2	9.4	9.4
Average	102.6	101.3	1.3	3.5
Standard deviation	10.5	8.6	4.8	3.2
Lower Upper 95% Confidence Intervals	91.6 113.7	92.2 110.3	-3.7 6.3	0.2 6.8
Median	102.8	102.9	1.5	2.2
Maximum	114.6	109.6	9.4	9.4
Minimum	87.9	85.7	-4.7	0.9

Table 12.3: Low chair sitting to standing minimum knee flexion angle - Test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	4.0	1.4	2.6	2.6
2	-0.8	-0.2	-0.6	0.6
3	0.0	0.6	-0.6	0.6
4	0.8	3.2	-2.4	2.4
5	5.6	0.0	5.6	5.6
6	2.1	1.1	1.0	1.0
Average	2.0	1.0	0.9	0.9
Standard deviation	2.4	1.2	2.8	2.1
Lower **Upper** **95% Confidence Intervals**	-0.6 4.5	0.3 2.3	-2.0 3.9	0.1 4.1
Median	1.4	0.9	0.2	1.7
Maximum	5.6	3.2	5.6	5.6
Minimum	-0.8	-0.2	-2.4	0.6

Table 12.4: Low chair sitting to standing minimum knee flexion angle - Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	2.2	0.0	2.2	2.2
2	1.2	0.9	0.3	0.3
3	3.4	2.2	1.2	1.2
4	-1.0	0.0	-1.0	1.0
5	1.5	0.2	1.3	1.3
6	3.7	1.5	2.2	2.2
Average	1.8	0.8	1.0	1.4
Standard deviation	1.7	0.9	1.2	0.7
Lower **Upper** **95% Confidence Intervals**	0.0 3.6	-0.1 1.7	-0.2 2.3	0.6 2.1
Median	1.9	0.6	1.2	0.2
Maximum	-1.0	0	2.2	2.2
Minimum	3.7	2.2	-1.0	0.3

Table 12.5: Low chair sitting to standing maximum knee flexion angle - Test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	92.9	95.6	-2.7	2.7
2	104.5	101.8	2.7	2.7
3	88.2	89.3	-1.1	1.1
4	100.0	109.6	-9.6	9.6
5	108.9	107.2	1.7	1.7
6	116.2	105.2	11	11
Average	101.8	101.4	0.3	4.8
Standard deviation	10.3	7.7	6.8	4.3
Lower Upper 95% Confidence Intervals	91.0 112.6	93.4 109.5	-6.8 7.5	0.2 9.3
Median	102.2	103.5	0.3	2.7
Maximum	114.2	109.6	11.0	11.0
Minimum	88.2	89.3	-9.6	1.1

Table 12.6: Low chair sitting to standing maximum knee flexion angle - Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	96.4	96.6	-1	1.4
2	112.3	110.5	-4.3	0.2
3	89.6	86.5	2.8	0.6
4	96.9	99.7	5.5	3.2
5	107.7	106.9	0.3	0
6	115.1	112.3	-8.2	1.1
Average	103.0	102.1	-0.8	1.1
Standard deviation	10.1	9.8	4.9	1.2
Lower Upper 95% Confidence Intervals	92.3 113.7	91.8 112.3	-6.0 4.3	-0.1 2.3
Median	102.3	103.3	-0.4	0.9
Maximum	115.1	112.3	5.5	3.2
Minimum	89.6	86.5	-8.2	0.0

Table 12.7: Low chair sit to stand knee excursion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	88.9	94.2	-5.3	5.3
2	105.2	102	3.2	3.2
3	88.2	88.7	-0.5	0.5
4	99.2	106.4	-7.2	7.2
5	103.3	107.2	-3.9	3.9
6	114.1	104.1	10.0	10.0
Average	99.8	100.4	-0.6	5.0
Standard deviation	10.0	7.4	6.4	3.3
Lower Upper 95% Confidence Intervals	89.3 110.3	92.7 108.2	-7.3 6.1	1.5 8.5
Median	101.3	103.0	-2.0	4.6
Maximum	114.1	107.2	10.0	10.0
Minimum	88.2	88.7	-5.3	0.5

Table 12.8: Low chair sit to stand knee excursion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	94.2	96.6	2.4	2.4
2	111.1	109.6	-1.5	1.5
3	86.2	84.3	-1.9	1.9
4	97.9	99.7	1.8	1.8
5	106.2	106.7	0.5	0.5
6	111.4	110.8	-0.6	0.6
Average	101.1	101.3	0.1	1.4
Standard deviation	10.1	10.0	1.8	0.8
Lower Upper 95% Confidence Intervals	90.5 111.8	90.8 111.8	-1.7 2.0	0.7 2.2
Median	102.0	103.2	0.0	1.7
Maximum	111.4	110.8	2.4	2.4
Minimum	86.2	84.3	-1.9	0.5

Table 12.9: Low chair standing to sitting minimum knee flexion angle -Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	3.6	1.5	2.1	2.1
2	0.2	0.7	-0.5	0.5
3	-0.4	2.5	-2.9	2.9
4	-0.2	2.7	-2.9	2.9
5	3.3	-1.0	4.3	4.3
6	0.0	-1.2	1.2	1.2
Average	1.1	0.9	0.2	2.3
Standard deviation	1.8	1.7	2.9	1.3
Lower Upper 95% Confidence Intervals	-0.9 3.0	-0.9 2.6	-2.9 4.3	0.9 3.7
Median	0.1	1.1	0.3	2.5
Maximum	-0.4	-1.2	4.3	4.3
Minimum	3.6	2.7	-2.9	0.5

Table 12.10: Low chair standing to sitting minimum knee flexion angle - Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	2.1	4.2	-2.1	2.1
2	-0.2	0.9	-1.1	1.1
3	1.0	0.6	0.4	0.4
4	-0.2	0.0	-0.2	0.2
5	1.1	0.3	0.8	0.8
6	0.5	-1.9	2.4	2.4
Average	0.7	0.7	0.0	1.2
Standard deviation	0.9	2.0	1.6	0.9
Lower Upper 95% Confidence Intervals	-0.2 1.6	-1.4 2.8	-1.6 1.7	0.2 2.1
Median	0.8	0.4	0.1	1.0
Maximum	2.1	4.2	2.4	2.4
Minimum	-0.2	-1.9	-2.1	0.2

Table 12.11: Low chair standing to sitting maximum knee flexion angle - Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	93.0	96.6	-3.6	3.6
2	104.4	110.6	-6.2	6.2
3	89.3	94.4	-5.1	5.1
4	106.4	105.7	0.7	0.7
5	109.6	106.1	3.5	3.5
6	114.7	113.8	0.9	0.9
Average	102.9	104.5	-1.6	3.3
Standard deviation	9.8	7.6	3.9	2.2
Lower Upper 95% Confidence Intervals	92.6 113.1	96.5 112.6	-5.7 2.4	1.0 5.6
Median	105.4	105.9	-1.4	0.7
Maximum	114.7	113.8	3.5	6.2
Minimum	89.3	94.4	-6.2	0.7

Table 12.12: Low chair standing to sitting maximum knee flexion angle - Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	92.2	101.0	-8.8	8.8
2	112.4	111.3	1.1	1.1
3	95.3	93.8	1.5	1.5
4	100.8	99.0	1.8	1.8
5	110.6	108.3	2.3	2.3
6	115.7	108.7	7.0	7.0
Average	104.5	103.7	0.8	3.8
Standard deviation	9.7	6.8	5.2	3.3
Lower Upper 95% Confidence Intervals	94.3 114.7	96.5 110.8	-4.6 6.2	0.3 7.2
Median	105.7	104.7	1.7	2.0
Maximum	92.2	111.3	7	8.8
Minimum	115.7	93.8	-8.8	1.1

Table 12.13: Low chair stand to sit knee excursion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	89.4	95.1	-5.7	5.7
2	104.2	109.9	-5.7	5.7
3	89.7	91.9	-2.2	2.2
4	106.6	103	3.6	3.6
5	106.3	107.1	-0.8	0.8
6	114.7	115.0	-0.3	0.3
Average	101.8	103.7	-1.9	3.0
Standard deviation	10.1	8.8	3.5	2.3
Lower Upper 95% Confidence Intervals	91.1 112.5	94.4 113.0	-5.6 1.9	0.6 5.5
Median	105.2	105.0	-1.5	2.9
Maximum	114.7	115.0	3.6	5.7
Minimum	89.4	91.9	-5.7	0.3

Table 12.14: Low chair stand to sit knee excursion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	90	96.8	-6.8	6.8
2	112.5	109.7	2.8	2.8
3	94.4	93.2	1.2	1.2
4	101	99.0	2.0	2
5	109.4	108.0	1.4	1.4
6	115.2	110.6	4.6	4.6
Average	103.8	102.9	0.9	3.1
Standard deviation	10.2	7.4	2.2	2.2
Lower Upper 95% Confidence Intervals	93.0 114.4	95.0 110.7	-3.3 5.0	0.8 5.4
Median	105.2	103.5	1.7	2.4
Maximum	115.2	110.6	4.6	6.8
Minimum	90.0	93.2	-6.8	1.2

Table 12.15: Standard chair sitting knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	79.7	78.6	1.1	1.1
2	98.5	100.4	-1.9	1.9
3	75.9	75.5	0.4	0.4
4	92.7	95.4	-2.7	2.7
5	93.6	90.7	2.9	2.9
6	96.3	91.3	5.0	5.0
Average	89.4	88.7	0.8	2.4
Standard deviation	9.3	9.7	2.9	1.6
Lower Upper 95% Confidence Intervals	79.7 99.2	78.5 98.8	-2.2 3.8	0.6 4.0
Median	93.1	91.0	0.8	2.3
Maximum	98.5	100.4	5.0	5.0
Minimum	75.9	75.5	-2.7	0.4

Table 12.16: Standard chair sitting knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	77.7	75.0	2.7	2.7
2	104.5	102.2	2.3	2.3
3	80.2	83.0	-2.8	2.8
4	85.9	86.4	-0.5	0.5
5	98.0	95.4	2.6	2.6
6	101.9	87.2	14.7	14.7
Average	91.4	88.2	3.2	4.3
Standard deviation	11.5	9.5	6.1	5.2
Lower Upper 95% Confidence Intervals	79.2 103.5	78.2 98.2	-3.1 9.5	-1.2 9.7
Median	92.0	86.8	2.4	2.7
Maximum	104.5	102.2	14.7	14.7
Minimum	77.7	75.0	-2.8	0.5

Table 12.17: Standard chair sitting to standing minimum knee flexion angle - Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	3.5	0.5	3.0	3.0
2	1.1	0.1	1.0	1.0
3	2.9	3.7	-0.8	0.8
4	2.0	4.7	-2.7	2.7
5	7.0	0.0	7.0	7.0
6	2.3	-0.5	2.8	2.8
Average	3.1	1.4	1.7	2.9
Standard deviation	2.1	2.2	3.4	2.2
Lower Upper 95% Confidence Intervals	1.0 5.3	-0.9 3.7	-1.8 5.3	0.5 5.2
Median	2.6	0.3	1.9	2.8
Maximum	7.0	4.7	7.0	7.0
Minimum	1.1	-0.5	-2.7	0.8

Table 12.18: Standard chair sitting to standing minimum knee flexion angle - Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	-2.7	-5.0	-2.2	2.2
2	1.4	2.0	-0.6	0.6
3	9.9	1.2	8.7	8.7
4	3.7	1.7	2.0	2.0
5	5.7	3.3	2.4	2.4
6	3.1	-2.7	5.8	5.8
Average	3.5	0.1	2.7	3.6
Standard deviation	4.2	2.1	4.0	3.0
Lower Upper 95% Confidence Intervals	-0.9 7.9	-1.4 3.1	-1.5 6.9	0.4 6.8
Median	3.4	1.4	2.2	2.3
Maximum	-2.7	3.3	8.7	8.7
Minimum	9.9	-2.7	-2.2	0.6

Table 12.19: Standard chair sitting to standing maximum knee flexion angle – Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	80.3	77.7	2.6	2.6
2	97.8	100.2	-2.4	2.4
3	77.3	75.5	1.8	1.8
4	93.5	95.7	-2.2	2.2
5	94.5	90.3	4.2	4.2
6	96.9	91.3	5.6	5.6
Average	90	88.4	1.6	3.1
Standard deviation	8.9	9.9	3.3	1.5
Lower Upper 95% Confidence Intervals	80.7 99.4	78.1 98.8	-1.9 5.0	1.6 4.7
Median	94.0	90.8	2.2	2.5
Maximum	97.8	100.2	-2.4	5.6
Minimum	77.3	75.5	5.6	1.8

Table 12.20: Standard chair sitting to standing maximum knee flexion angle – Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	78.0	74.1	3.9	3.9
2	104.8	105.2	-0.4	0.4
3	81.9	73.0	8.9	8.9
4	86.1	86.4	-0.3	0.3
5	97.70	93.8	3.9	3.9
6	102.1	90.3	11.8	11.8
Average	91.8	87.1	4.6	4.9
Standard deviation	12.0	12.2	4.9	4.6
Lower Upper 95% Confidence Intervals	80.0 103.6	74.3 100.0	-0.5 9.8	0.0 9.7
Median	91.9	88.3	3.9	3.9
Maximum	104.8	105.2	11.8	11.8
Minimum	78.0	73.0	-0.4	0.3

Table 12.21: Standard chair sit to stand knee excursion angle -test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	76.8	77.2	-0.4	0.4
2	96.7	100.1	-3.4	3.4
3	74.4	71.8	2.6	2.6
4	91.5	91	0.5	0.5
5	87.4	90.3	-2.9	2.9
6	94.6	91.8	2.8	2.8
Average	86.9	87.0	-0.1	2.1
Standard deviation	9.3	10.5	2.6	1.3
Lower Upper 95% Confidence Intervals	77.1 96.7	76.0 98.0	-2.9 2.6	0.7 3.5
Median	89.5	90.7	0.0	2.7
Maximum	96.7	100.0	2.8	3.4
Minimum	74.4	71.8	-3.4	0.4

Table 12.22: Standard chair sit to stand knee excursion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	80.7	79.1	1.6	1.6
2	103.4	103.2	0.2	0.2
3	72.0	71.8	0.2	0.2
4	82.4	84.7	-2.3	2.3
5	92.0	90.5	1.5	1.5
6	98.9	93.0	5.9	5.9
Average	88.2	87.0	1.2	2.0
Standard deviation	11.9	11.0	2.7	2.1
Lower Upper 95% Confidence Intervals	75.7 100.8	75.5 98.6	-1.7 4.0	-0.3 4.2
Median	87.2	87.6	0.9	1.6
Maximum	103.4	103.2	5.9	5.9
Minimum	72.0	71.8	-2.3	0.2

Table 12.23: Standard chair standing to sitting minimum knee flexion angle – Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	1.8	0.3	1.5	1.5
2	2.1	2.8	-0.7	0.7
3	2.8	4.3	-1.5	1.5
4	2.3	3.7	-1.4	1.4
5	3.6	4.0	-0.4	0.4
6	0.0	-1.2	1.2	1.2
Average	2.1	2.3	-0.2	1.1
Standard deviation	1.2	2.2	1.3	0.5
Lower Upper 95% Confidence Intervals	0.8 3.4	0.0 4.7	-1.6 1.1	0.6 1.6
Median	2.2	3.2	-0.6	1.3
Maximum	3.6	4.3	1.5	0.4
Minimum	0.0	-1.2	-1.5	1.5

Table 12.24: Standard chair standing to sitting minimum knee flexion angle – Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	-0.7	0.9	-1.6	1.6
2	1.2	2.1	-0.9	0.9
3	9.7	7.7	2.0	2.0
4	3.5	0.8	2.7	2.7
5	3.7	3.9	-0.2	0.2
6	0.1	-1.0	1.1	1.1
Average	2.9	2.4	0.5	1.4
Standard deviation	3.8	3.0	1.7	0.9
Lower Upper 95% Confidence Intervals	-1.0 6.9	-0.8 5.6	-1.2 2.3	0.5 2.3
Median	2.3	1.5	0.4	1.3
Maximum	-0.7	7.7	-1.6	2.7
Minimum	9.7	-1.0	2.7	0.2

Table 12.25: Standard chair standing to sitting maximum knee flexion angle – Test Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	76.4	75.4	1.0	1.0
2	98.8	99.4	-0.6	0.6
3	79.0	79.8	-0.8	0.8
4	93.1	91.5	1.6	1.6
5	96.6	92.4	4.2	4.2
6	94.9	92.3	2.6	2.0
Average	89.8	88.5	1.3	1.8
Standard deviation	9.6	9.0	1.9	1.4
Lower Upper 95% Confidence Intervals	79.7 99.8	79.0	-0.7 3.3	0.3 3.2
Median	99.0	97.9	1.3	1.3
Maximum	98.8	91.9	-0.8	0.6
Minimum	76.4	75.4	4.2	4.2

Table 12.26: Standard chair standing to sitting maximum knee flexion angle – Test Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	77.1	75.8	1.3	1.3
2	105.2	112.5	-7.3	7.3
3	86.4	82.4	4	4
4	85.6	85.4	0.2	0.2
5	96.7	95.2	1.5	1.5
6	98.4	89.3	9.1	9.1
Average	91.6	90.1	1.5	3.9
Standard deviation	10.3	12.8	5.3	3.6
Lower Upper 95% Confidence Intervals	80.8 102.4	70.7 103.5	-4.1 7.1	0.1 7.7
Median	91.6	87.4	1.4	2.8
Maximum	105.2	112.5	9.1	9.1
Minimum	77.1	75.8	-7.3	

Table 12.27: Standard chair stand to sit knee excursion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	74.6	75.1	-0.5	0.5
2	96.7	96.6	0.1	0.1
3	76.2	75.5	0.7	0.7
4	90.9	87.8	3.1	3.1
5	93.0	88.4	4.6	4.6
6	94.9	93.5	1.4	1.4
Average	87.7	86.1	1.6	1.7
Standard deviation	9.7	9.0	1.9	1.8
Lower Upper 95% Confidence Intervals	77.5 97.9	76.7 95.6	-0.5 3.6	-0.1 3.6
Median	91.9	88.1	1.0	1.0
Maximum	96.7	96.6	4.6	4.6
Minimum	74.6	75.1	-0.5	0.1

Table 12.28: Standard chair stand to sit knee excursion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Excursion angle in degrees)**	**MacReflex® (Excursion angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	77.7	74.9	2.8	2.8
2	104.0	110.4	-6.4	6.4
3	76.7	74.7	2.0	2.0
4	82.1	84.6	-2.5	2.5
5	93.0	91.3	1.7	1.7
6	98.3	90.3	8.0	8.0
Average	88.6	87.7	0.9	3.9
Standard deviation	11.4	13.2	4.9	2.6
Lower Upper 95% Confidence Intervals	76.6 100.6	73.8 101.6	-4.2 6.1	1.1 6.7
Median	87.5	87.4	1.8	2.7
Maximum	104.0	110.4	8.0	8.0
Minimum	76.7	74.7	-6.4	1.7

Table 12.29: Gait maximum knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	58.4	54.4	4.0	4.0
2	54.6	56.8	-2.2	2.2
3	62.6	62.1	0.5	0.5
4	63.2	64.0	-0.8	0.8
5	55.2	57.7	-2.5	2.5
6	72.0	68.3	3.7	3.7
Average	61.0	60.6	0.4	2.3
Standard deviation	6.5	5.2	2.9	1.4
Lower Upper 95% Confidence Intervals	54.2 67.8	55.1 66.0	-2.5 3.4	0.8 3.8
Median	60.5	59.9	-0.2	2.4
Maximum	72.0	68.3	4.0	4.0
Minimum	54.6	54.4	-2.5	0.5

Table 12.30: Gait maximum knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	54.8	51.3	3.5	3.5
2	51.7	49.7	2.0	2.0
3	66.0	62.3	3.7	3.7
4	62.1	64.1	-2.0	2.0
5	56.9	58.2	-1.3	1.3
6	73.2	65.4	7.8	7.8
Average	60.8	58.5	2.3	3.4
Standard deviation	8.0	6.7	3.6	2.4
Lower Upper 95% Confidence Intervals	52.4 69.1	51.5 65.5	-1.5 6.1	0.9 5.9
Median	59.5	60.2	2.7	2.7
Maximum	73.2	65.4	7.8	7.8
Minimum	51.7	49.7	-2.0	1.3

Table 12.31: Gait minimum knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	-3.6	-1.7	-1.9	1.9
2	1.7	0.2	1.5	1.5
3	-2.4	0.0	-2.4	2.4
4	-4.3	-2.6	-1.7	1.7
5	-4.6	-3.7	-0.9	0.9
6	1.4	1.5	-1	0.1
Average	-2.0	-1.0	-0.9	1.4
Standard deviation	2.8	2.0	1.4	0.8
Lower Upper 95% Confidence Intervals	-4.8 1.0	-3.1 1.0	-2.4 0.6	0.6 2.3
Median	-3.0	-0.9	-1.3	1.6
Maximum	1.7	1.5	1.5	2.4
Minimum	-4.6	-3.7	-2.4	0.1

Table 12.32: Gait minimum knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	1.4	-0.9	2.3	2.3
2	-1.7	0.9	-2.6	2.6
3	2.0	-0.7	2.7	2.7
4	0.2	-4.5	4.7	4.7
5	-2.9	-0.6	-2.3	2.3
6	1.5	-0.1	1.6	1.6
Average	0.1	-0.9	1.1	2.7
Standard deviation	2.0	1.8	2.9	1.0
Lower Upper 95% Confidence Intervals	-2.0 2.1	-3.0 0.9	-2.0 4.1	1.6 3.8
Median	0.8	-0.7	2.0	2.4
Maximum	2.0	0.9	4.7	4.7
Minimum	-2.9	-4.5	-2.6	1.6

Table 12.33: Gait knee flexion midstance angle -test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	28.7	24.5	4.2	4.2
2	16.3	17.9	-1.6	1.6
3	15.6	21.8	-6.2	6.2
4	9.1	15.6	-6.5	6.5
5	11.5	13.7	-2.2	2.2
6	17.9	17.0	0.9	0.9
Average	16.5	18.4	-1.9	3.6
Standard deviation	6.8	4.0	4.1	2.4
Lower Upper 95% Confidence Intervals	9.4 23.7	14.2 22.6	-6.2 2.4	1.1 6.1
Median	15.9	17.4	-1.9	3.2
Maximum	28.7	24.5	4.2	6.5
Minimum	9.1	13.7	-6.5	0.9

Table 12.34: Gait knee flexion midstance angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	26.4	27.7	-1.3	1.3
2	16.6	15.8	0.8	0.8
3	21.7	19.3	2.4	2.4
4	14.2	14.8	-0.6	0.6
5	10.1	13.8	-3.7	3.7
6	20.7	16.0	4.7	4.7
Average	18.3	17.9	0.4	0.4
Standard deviation	5.8	5.1	3.0	3.0
Lower Upper 95% Confidence Intervals	9.4 23.7	14.2 22.6	-6.2 2.4	1.1 6.1
Median	18.6	15.9	0.1	0.1
Maximum	26.4	27.7	4.7	4.7
Minimum	10.1	13.8	-3.7	-3.7

Table 12.35: Gait knee flexion minimum to maximum angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	62.0	56.1	5.9	5.9
2	52.9	56.6	-3.7	3.7
3	65.0	62.1	2.9	2.9
4	67.5	66.6	0.9	0.9
5	59.8	61.4	-1.6	1.6
6	70.6	66.8	3.8	3.8
Average	63.0	61.6	3.8	3.1
Standard deviation	6.2	4.6	1.4	1.8
Lower Upper 95% Confidence Intervals	56.4 69.5	56.7 66.5	-2.4 5.1	-1.3 5.0
Median	63.5	61.8	1.9	3.3
Maximum	52.9	66.8	5.9	5.9
Minimum	70.6	56.1	-3.7	0.9

Table 12.36: Gait knee flexion minimum to maximum angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	53.4	52.2	1.2	1.2
2	53.4	48.8	4.6	4.6
3	64.0	63	1.0	1.0
4	61.9	68.6	-6.7	6.7
5	59.8	58.8	1.0	1.0
6	71.7	65.5	6.2	6.2
Average	60.7	59.5	1.2	3.4
Standard deviation	6.9	7.7	4.4	2.7
Lower Upper 95% Confidence Intervals	53.4 68.0	51.4 67.6	-3.4 5.9	0.6 6.3
Median	60.9	60.9	1.1	2.9
Maximum	71.7	68.6	6.2	6.7
Minimum	53.4	48.8	-6.7	1.0

Table 12.37: Gait knee flexion minimum to midstance angle -test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	32.3	26.2	6.1	6.1
2	14.6	17.7	-3.1	3.1
3	18.0	21.8	-3.8	3.8
4	13.4	18.2	-4.8	4.8
5	16.1	17.4	-1.3	1.3
6	16.5	15.5	1.0	1.0
Average	18.5	19.5	-1.0	3.3
Standard deviation	7.0	3.9	4.0	2.0
Lower Upper 95% Confidence Intervals	11.2 25.8	15.4 23.5	-5.2 3.2	1.3 5.4
Median	16.3	18.0	-2.2	3.4
Maximum	32.3	26.2	6.1	6.1
Minimum	13.4	15.5	-4.8	1.0

Table 12.38: Gait knee flexion minimum to midstance angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	25.0	28.6	-3.6	3.6
2	18.3	14.9	3.4	3.4
3	19.7	20.0	-0.3	0.3
4	14.0	19.3	-5.3	5.3
5	13.0	14.4	-1.4	1.4
6	19.2	16.1	3.1	3.1
Average	18.2	18.9	-0.7	2.9
Standard deviation	4.3	5.3	-0.9	1.8
Lower Upper 95% Confidence Intervals	13.6 22.8	13.3 24.4	-4.4 3.0	1.0 4.7
Median	18.8	17.7	-0.9	3.2
Maximum	25.0	28.6	3.4	5.3
Minimum	13.0	14.4	-5.3	0.3

Table 12.39: Stairs ascent maximum knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	87.5	94.1	-6.6	6.6
2	85.2	88.9	-3.7	3.7
3	89.6	92.8	-3.2	3.2
4	87.0	94.8	-7.8	7.8
5	91.1	88.5	2.6	2.6
6	107.3	103.6	3.7	3.7
Average	91.3	93.8	-2.5	4.6
Standard deviation	8.1	5.5	4.7	2.1
Lower Upper 95% Confidence Intervals	82.8 99.8	88.0 99.5	-7.4 2.4	2.4 6.8
Median	88.6	93.4	-3.4	3.7
Maximum	107.3	103.6	3.7	7.8
Minimum	85.2	88.5	-7.8	2.6

Table 12.40: Stairs ascent maximum knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	83.7	90.8	-7.1	7.1
2	88.1	87.5	0.6	0.6
3	94.0	89.8	4.2	4.2
4	90.4	89.2	1.2	1.2
5	90.1	88.7	1.4	1.4
6	107.4	98.5	8.9	8.9
Average	92.3	90.8	1.5	3.9
Standard deviation	8.1	4.0	5.2	3.5
Lower Upper 95% Confidence Intervals	83.7 100.8	86.6 94.9	-4.0 7.0	0.3 7.5
Median	90.2	89.5	1.3	2.8
Maximum	107.4	98.5	8.9	8.9
Minimum	83.7	87.5	-7.1	0.6

Table 12.41: Stairs ascent midstance knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	8.0	6.1	1.9	1.9
2	15.7	16.7	-1.0	1.0
3	8.7	11.4	-2.7	2.7
4	15.2	20.2	-5.0	5.0
5	11.0	9.4	1.6	1.6
6	14.4	13.6	0.8	0.8
Average	12.2	12.9	-0.7	2.2
Standard deviation	3.4	5.1	2.7	1.5
Lower Upper 95% Confidence Intervals	8.6 15.7	7.6 18.2	-3.6 2.1	0.5 3.8
Median	12.7	12.5	-0.1	1.8
Maximum	15.7	20.2	1.9	5.0
Minimum	8.0	6.1	-5.0	0.8

Table 12.42: Stairs ascent midstance knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	6.7	9.2	-2.5	2.5
2	16.8	16.6	0.2	0.2
3	12.2	12.0	0.2	0.2
4	14.3	13.0	1.3	1.3
5	5.9	7.2	-1.3	1.3
6	17.4	11.4	6.0	6.0
Average	12.2	11.6	0.6	1.9
Standard deviation	5.0	3.2	2.9	2.2
Lower Upper 95% Confidence Intervals	7.0 17.4	8.2 15.0	-2.4 3.7	-0.4 4.2
Median	13.2	11.7	0.2	1.3
Maximum	17.4	16.6	6.0	6.0
Minimum	5.9	7.2	-2.5	0.2

Table 12.43: Stairs ascent excursion - Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	79.5	88.0	-8.5	8.5
2	69.5	72.2	-2.7	2.7
3	81.0	81.4	-0.4	0.4
4	71.7	76.6	-4.9	4.9
5	80.1	79.1	1.0	1.0
6	93.0	90.0	3.0	3.0
Average	79.1	81.2	-2.1	3.4
Standard deviation	8.3	6.8	4.2	3.0
Lower Upper 95% Confidence Intervals	70.4 87.8	74.0 88.3	-6.5 2.3	0.3 6.5
Median	79.8	80.2	-1.6	2.9
Maximum	93.0	90.0	3.0	8.5
Minimum	69.5	72.2	-8.5	0.4

Table 12.44: ascent excursion -Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	77.1	81.6	-4.5	4.5
2	71.3	70.9	0.4	0.4
3	81.8	77.8	4.0	4.0
4	76.1	76.2	-0.1	0.1
5	84.2	81.5	2.7	2.7
6	90.0	87.1	2.9	2.9
Average	80.1	79.2	0.9	2.4
Standard deviation	6.6	5.5	3.1	1.8
Lower Upper 95% Confidence Intervals	73.1 87.0	73.4 85.0	-2.3 4.1	0.5 4.3
Median	79.4	76.7	1.6	2.8
Maximum	90.0	87.1	4.0	4.5
Minimum	71.3	70.9	-4.5	0.1

Table 12.45: Stairs descent maximum knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	87.0	90.1	-3.1	3.1
2	84.4	91.9	-7.5	7.5
3	86.9	93.2	-6.3	6.3
4	93.0	96.3	-3.3	3.3
5	87.9	88.4	-0.5	0.5
6	99.6	93.9	5.7	5.7
Average	89.4	92.3	-2.5	4.4
Standard deviation	5.6	2.8	4.7	2.6
Lower Upper 95% Confidence Intervals	84.0 95.6	89.3 95.2	-7.4 2.4	1.7 7.1
Median	87.4	92.6	-3.2	4.5
Maximum	99.6	96.3	5.7	7.5
Minimum	84.4	88.4	-7.5	0.5

Table 12.46: Stairs descent maximum knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	85.9	91.4	-5.5	5.5
2	91.4	91.8	-0.4	0.4
3	92.8	91.4	1.4	1.4
4	91.9	89.4	2.5	2.5
5	88.1	90.4	-2.3	2.3
6	101.6	96.8	4.8	4.8
Average	92.0	91.9	0.1	2.8
Standard deviation	5.6	2.6	3.7	2.0
Lower Upper 95% Confidence Intervals	86.3 97.6	89.2 94.6	-3.8 3.9	0.8 4.9
Median	91.7	91.4	0.5	2.4
Maximum	99.6	96.8	4.8	5.5
Minimum	85.9	89.4	-5.5	0.4

Table 12.47: Stairs descent midstance knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	28.5	26.7	1.8	1.8
2	20.5	25.4	-4.9	4.9
3	21.8	27.7	-5.9	5.9
4	23.5	30.4	-6.9	6.9
5	14.7	17.5	-2.8	2.8
6	28.5	28.0	0.5	0.5
Average	22.9	26.0	-3.0	3.8
Standard deviation	5.3	4.4	3.6	2.5
Lower Upper 95% Confidence Intervals	17.4 28.4	21.3 30.6	-6.7 0.7	1.2 6.4
Median	22.6	27.2	-3.9	3.9
Maximum	28.5	30.4	1.8	6.9
Minimum	14.7	17.5	-6.9	0.5

Table 12.48: Stairs descent midstance knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	22.0	27.4	-5.4	5.4
2	17.2	20.5	-3.3	3.3
3	25.2	24.8	0.4	0.4
4	21.9	23.6	-1.7	1.7
5	13.3	19.4	-6.1	6.1
6	30.7	29.7	1.0	1.0
Average	21.7	24.2	-2.5	3.0
Standard deviation	6.1	3.9	3.0	2.4
Lower Upper 95% Confidence Intervals	15.3 28.1	20.1 28.4	-5.6 0.6	0.5 5.5
Median	21.9	24.2	-2.5	2.5
Maximum	30.7	29.7	1.0	6.1
Minimum	13.3	19.4	-6.1	0.4

Table 12.49: Standard descent excursion - Test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	58.4	63.4	-5.0	5.0
2	63.9	66.5	-2.6	2.6
3	65.1	65.5	-0.4	0.4
4	69.5	65.4	3.6	3.6
5	73.3	70.9	2.4	2.4
6	71.1	65.9	5.2	5.2
Average	66.9	66.3	0.5	3.2
Standard deviation	5.5	2.5	3.9	1.8
Lower Upper 95% Confidence Intervals	61.1 72.6	63.8 68.9	-3.6 4.6	1.3 5.1
Median	65.9	65.9	1.0	3.1
Maximum	70.9	70.9	5.2	5.2
Minimum	63.4	63.4	-5.0	0.4

Table 12.50: Standard descent excursion - Test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	63.9	64.0	-0.1	0.1
2	74.2	71.3	2.9	2.9
3	67.5	66.6	0.9	0.9
4	70.0	65.8	4.2	4.2
5	74.8	71.0	3.8	3.8
6	70.9	67.1	3.8	3.8
Average	70.2	67.6	2.6	2.6
Standard deviation	4.1	2.9	1.8	1.7
Lower Upper 95% Confidence Intervals	65.9 74.5	64.6 70.7	0.7 4.4	0.8 4.4
Median	70.4	66.9	3.3	3.3
Maximum	74.8	71.3	4.2	4.2
Minimum	63.9	64.0	-0.1	0.1

Table 12.51: Step down minimum knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	2.1	1.1	1.0	1.0
2	-0.7	0.2	-0.9	0.9
3	-1.2	1.8	-3.0	3.0
4	-2.7	2.2	-4.9	4.9
5	4.9	4.4	0.5	0.5
6	-1.1	-0.9	-0.2	0.2
Average	0.2	1.5	-1.2	1.8
Standard deviation	2.8	1.8	2.3	1.8
Lower Upper 95% Confidence Intervals	-2.7 3.1	-0.4 3.4	-3.6 1.1	-0.2 3.7
Median	-0.9	1.4	-0.6	1.0
Maximum	4.9	4.4	1.0	4.9
Minimum	-2.7	-0.9	-4.9	0.2

Table 12.52: Step down maximum knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	-0.5	5.8	-6.3	6.3
2	-0.3	1.2	-1.5	1.5
3	8.6	6.1	2.5	2.5
4	1.0	0.1	0.9	0.9
5	1.2	3.1	-1.9	1.9
6	1.5	-1.2	2.7	2.7
Average	1.9	2.5	-0.6	2.6
Standard deviation	3.4	3.0	3.4	1.9
Lower Upper 95% Confidence Intervals	-1.6 5.4	-0.6 5.7	-4.2 3.0	0.6 4.6
Median	1.1	2.1	-0.3	2.2
Maximum	8.6	6.1	2.7	6.3
Minimum	-0.5	-1.2	-6.3	0.9

Table 12.53: Step down maximum knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	55.5	55.4	0.1	0.1
2	74.2	80.0	-5.8	5.8
3	56.8	59.8	-3.0	3.0
4	40.2	47.8	-7.6	7.6
5	71.2	71.5	-0.3	0.3
6	61.3	61.7	-0.4	0.4
Average	59.9	62.7	-2.8	2.9
Standard deviation	12.2	11.5	3.2	3.2
Lower Upper 95% Confidence Intervals	47.0 72.7	50.6 74.8	-6.2 0.6	-0.5 6.2
Median	59.0	60.8	-1.7	1.7
Maximum	74.2	47.8	0.1	7.6
Minimum	40.2	80.0	-7.6	0.1

Table 12.54: Step down maximum knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	60.5	65.8	-5.3	5.3
2	76.9	76.5	0.4	0.4
3	63.1	61.3	1.8	1.8
4	30.4	34.7	-4.3	4.3
5	66.8	70.8	-4.0	4.0
6	61.3	54.4	6.9	6.9
Average	59.8	60.6	-0.8	3.8
Standard deviation	15.6	14.8	4.7	2.3
Lower Upper 95% Confidence Intervals	43.4 76.2	45.1 76.1	-5.7 4.2	1.3 6.2
Median	59.0	63.6	-1.8	4.1
Maximum	76.9	76.5	6.9	6.9
Minimum	30.4	34.7	-5.3	0.4

Table 5.55: Step down excursion knee flexion angle - test 1 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	53.4	54.3	-0.9	0.9
2	74.9	79.8	-4.9	4.9
3	58.0	58.0	0	0.0
4	42.9	45.6	-2.7	2.7
5	66.3	67.1	-0.8	0.8
6	62.4	62.6	-0.2	0.2
Average	59.7	61.2	-1.6	1.6
Standard deviation	11.0	11.7	1.9	1.9
Lower Upper 95% Confidence Intervals	48.1 71.2	49.0 73.4	-3.6 0.4	-0.4 3.6
Median	60.2	60.3	-0.9	0.9
Maximum	74.4	79.8	0.0	4.9
Minimum	42.9	45.6	-4.9	0.0

Table 12.56: Step down excursion knee flexion angle - test 2 Biometrics electrogoniometer compared with MacReflex®				
Subject	**Electrogoniometer (Angle in degrees)**	**MacReflex® (Angle in degrees)**	**Difference (Degrees)**	**Absolute Difference (Degrees)**
1	61.0	60.0	1.0	1.0
2	77.2	75.3	1.9	1.9
3	54.5	55.2	-0.7	0.7
4	29.5	34.6	-5.1	5.1
5	65.6	67.7	-2.1	2.1
6	59.7	55.6	-4.1	4.1
Average	57.9	58.0	-0.1	2.5
Standard deviation	15.9	13.8	3.2	1.8
Lower Upper 95% Confidence Intervals	41.2 74.6	43.5 72.6	-3.5 3.2	0.6 4.3
Median	60.3	57.8	0.1	2.0
Maximum	77.2	75.3	4.1	5.1
Minimum	29.5	34.6	-5.1	0.7

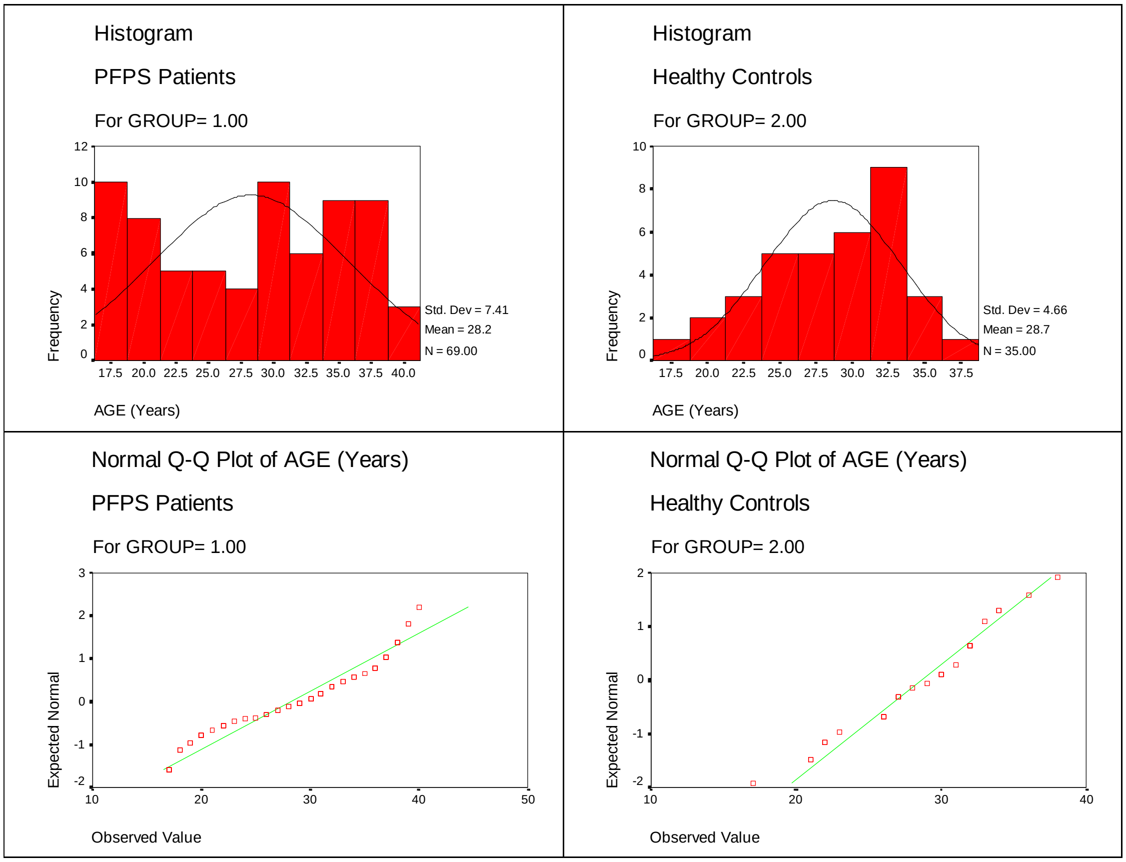
Table 12.57: Difference between Biometrics electrogoniometer and MacReflex®

Function	Test 1 Average absolute difference between electrogoniometer and MacReflex® (angles in degrees)	Test 1 Maximum absolute difference between electrogoniometer and MacReflex® (angles in degrees)	Test 2 Average absolute difference between electrogoniometer and MacReflex® (angles in degrees)	Test 2 Maximum absolute difference between electrogoniometer and MacReflex® (angles in degrees)
Low chair sitting (knee flexion angle)	2.3	5.6	3.5	9.4
Low chair sit to stand (knee excursion angle)	3.9	10.0	1.5	2.4
Low chair stand to sit (excursion angle)	3.1	5.7	3.2	6.8
Standard chair sitting (knee flexion angle)	2.4	5	4.3	14.7
Standard chair sit to stand (excursion angle)	1.9	3.4	3.2	8.6
Standard chair stand to sit (excursion angle)	2.3	4.6	3.9	8
Gait maximum knee flexion angle	3.6	4	3.4	7.8
Gait knee midstance angle	4.6	6.5	0.4	4.7
Stairs ascent knee maximum angle	2.2	7.8	3.9	8.9
Stairs ascent knee mid stance angle	4.4	5	1.9	6
Stairs descent knee maximum angle	3.8	7.5	2.8	5.5
Stairs descent knee midstance angle	4.5	6.9	3	6.1
Step down minimum knee flexion angle	1.8	4.9	2.6	6.3
Step down maximum knee flexion angle	2.9	7.6	3.8	6.9
Step down excursion knee flexion angle	1.6	4.9	2.5	5.1

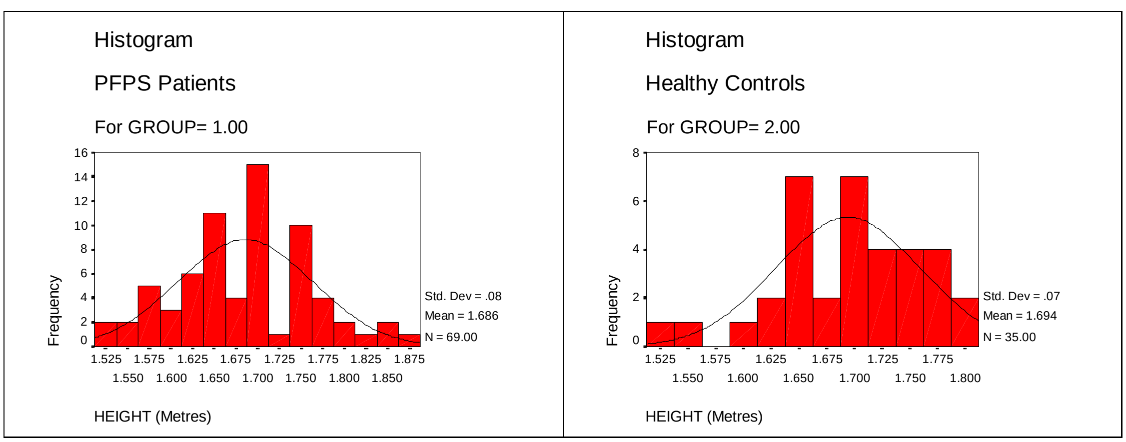
ELECTRONIC APPENDIX 13

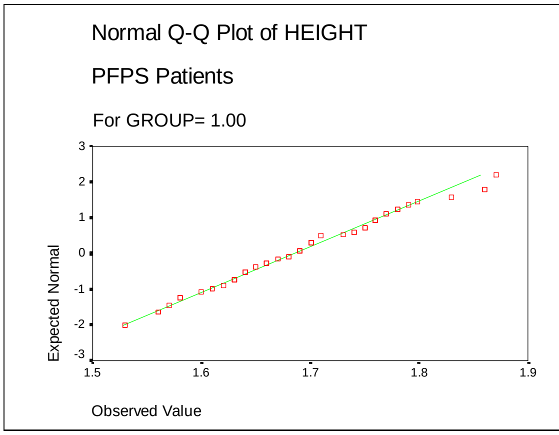
13.1. PFPS PATIENTS VS. HEALTHY CONTROLS NORMALITY GRAPHS AND PLOTS

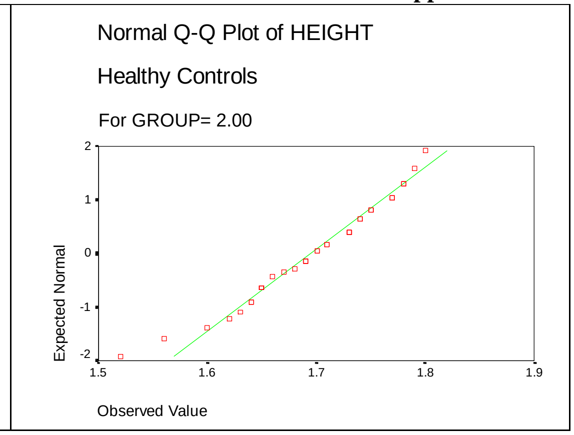
PATIENT CHARACTERISTICS



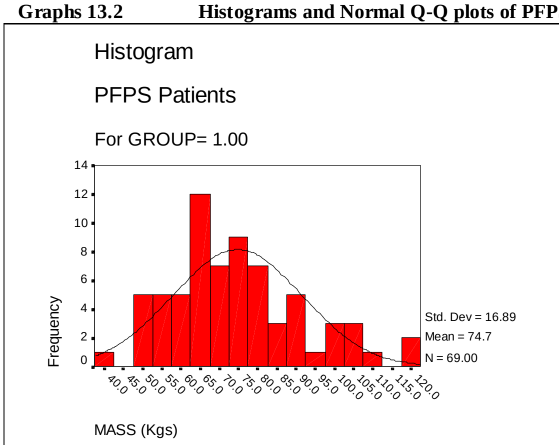
Graphs 13.1 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Age (Years)

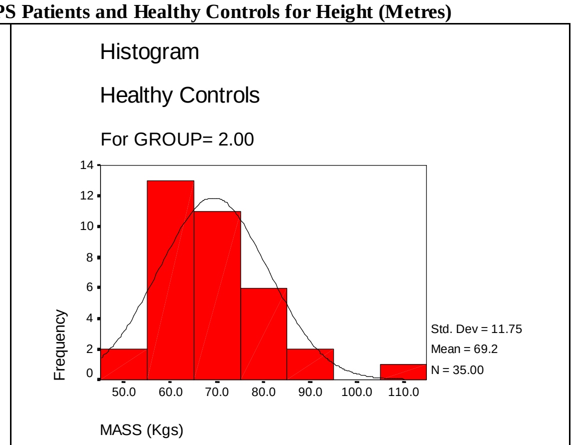


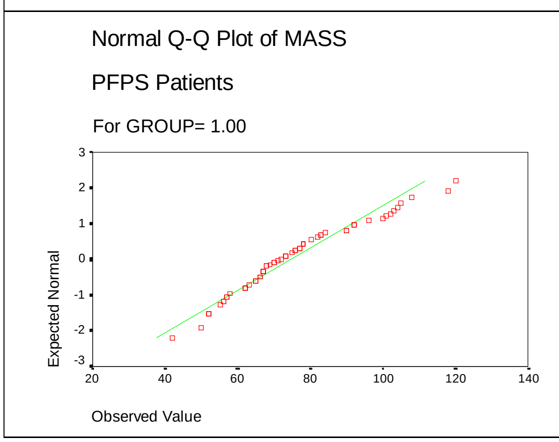


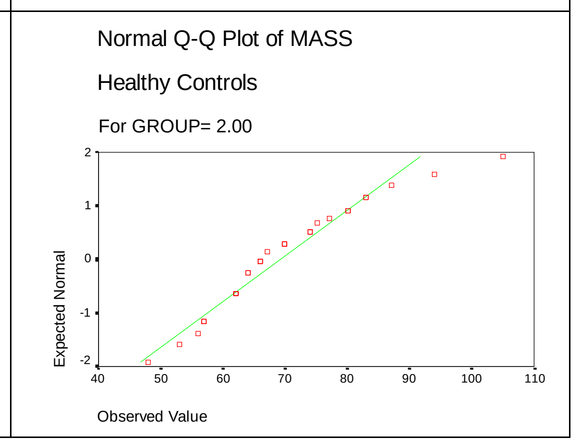


Graphs 13.2 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Height (Metres)**

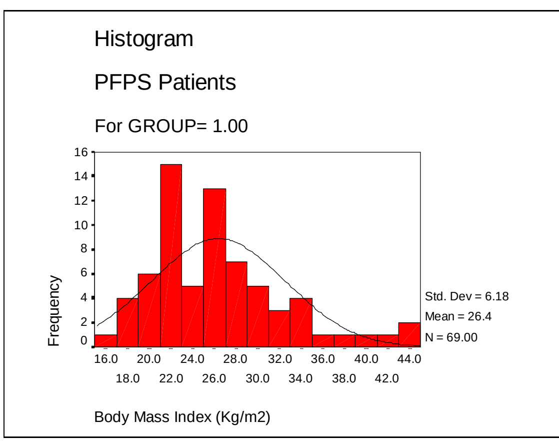


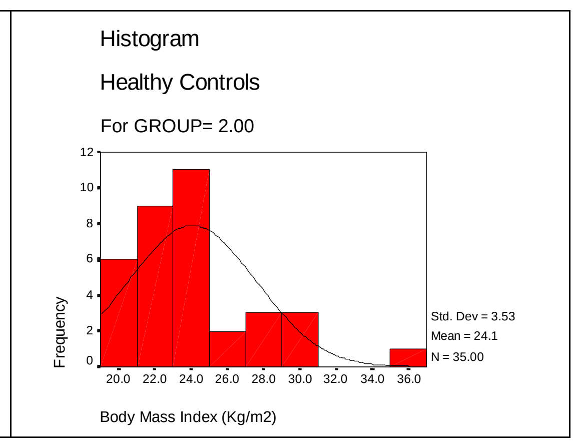


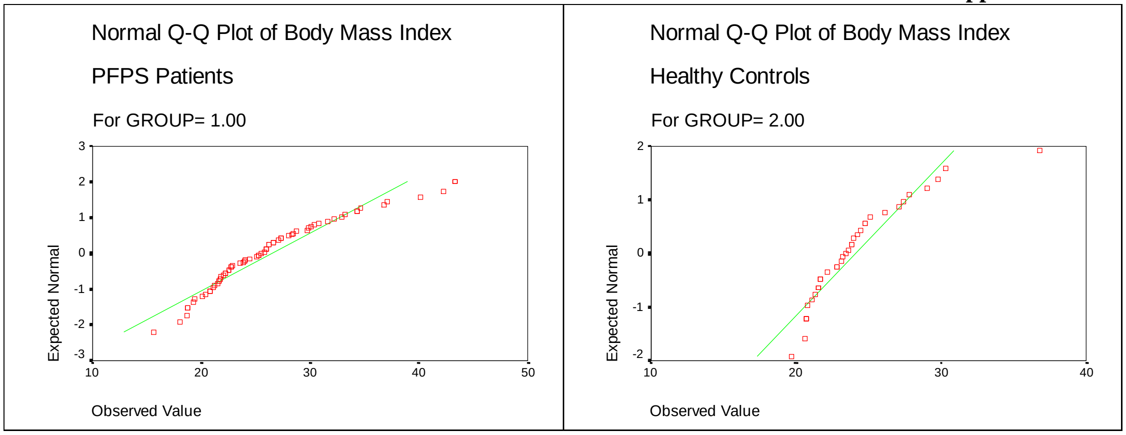




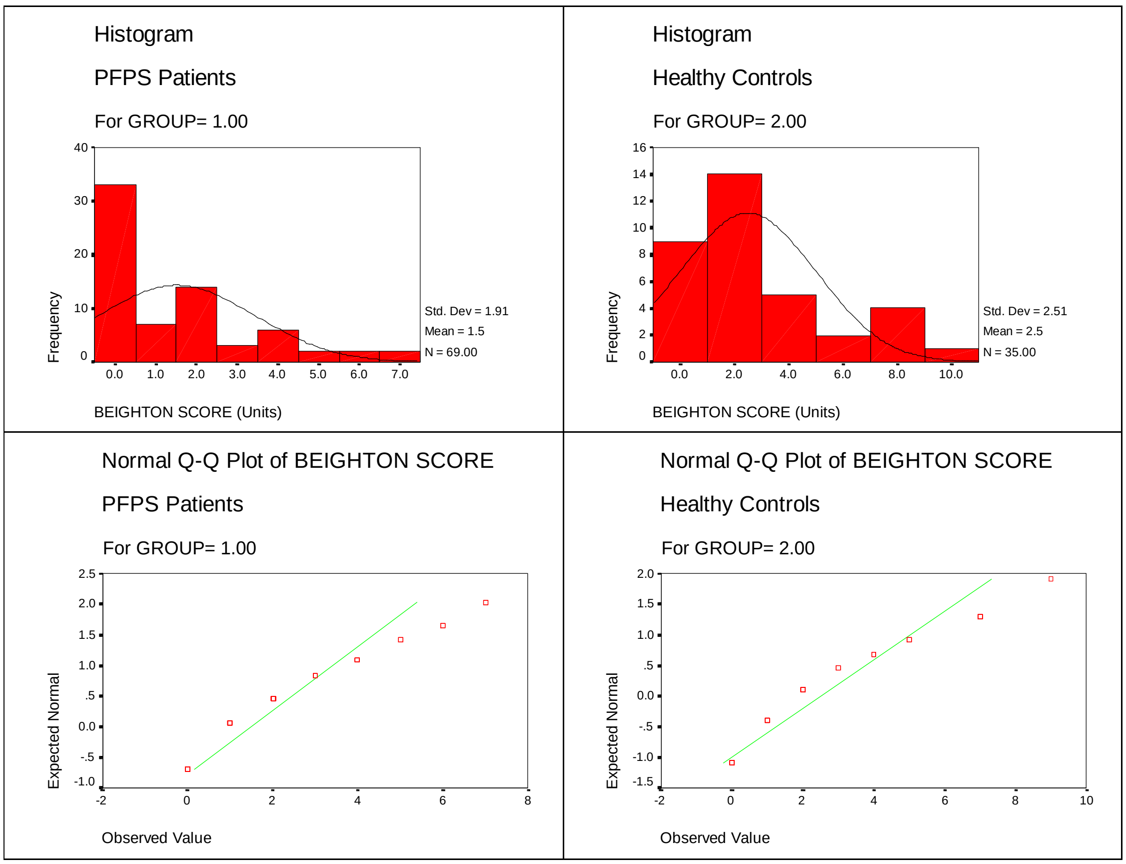
Graphs 13.3 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Body Mass (Kgs)**



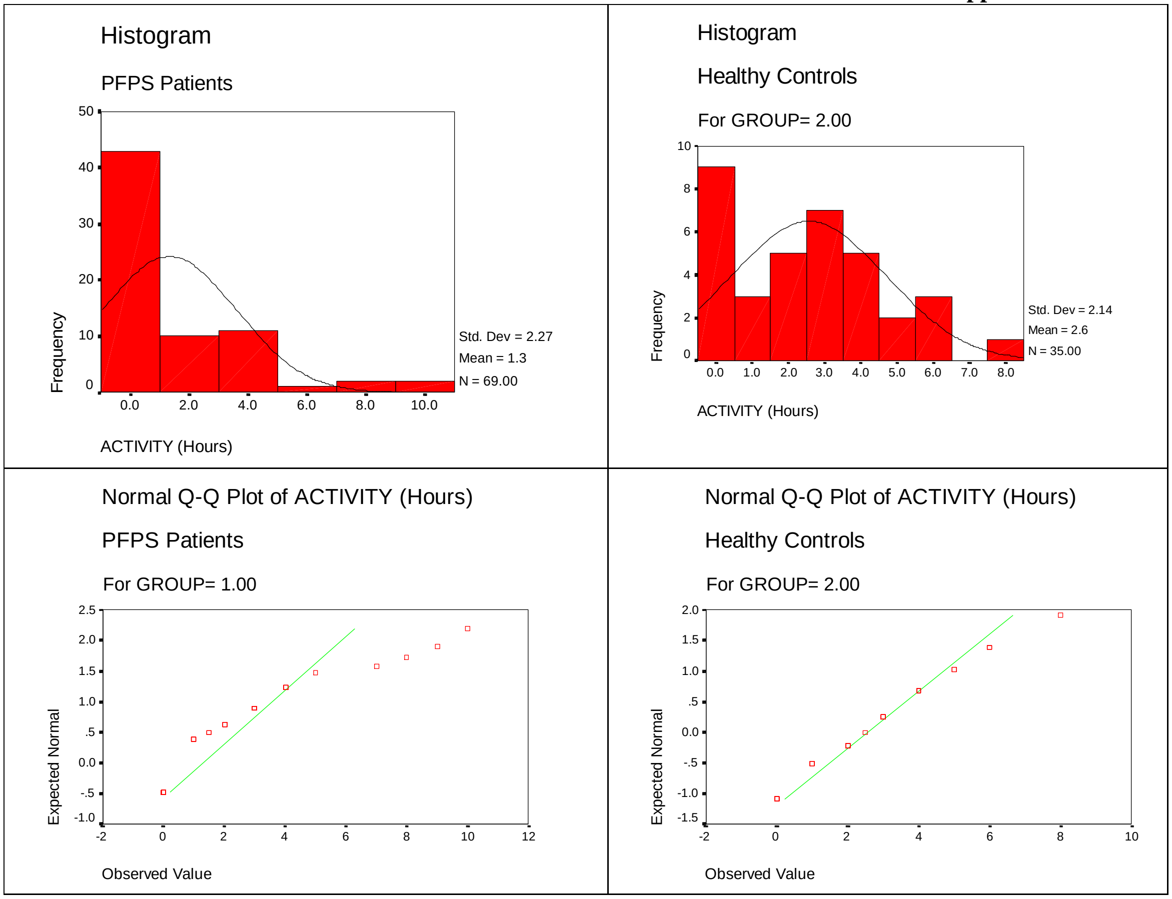




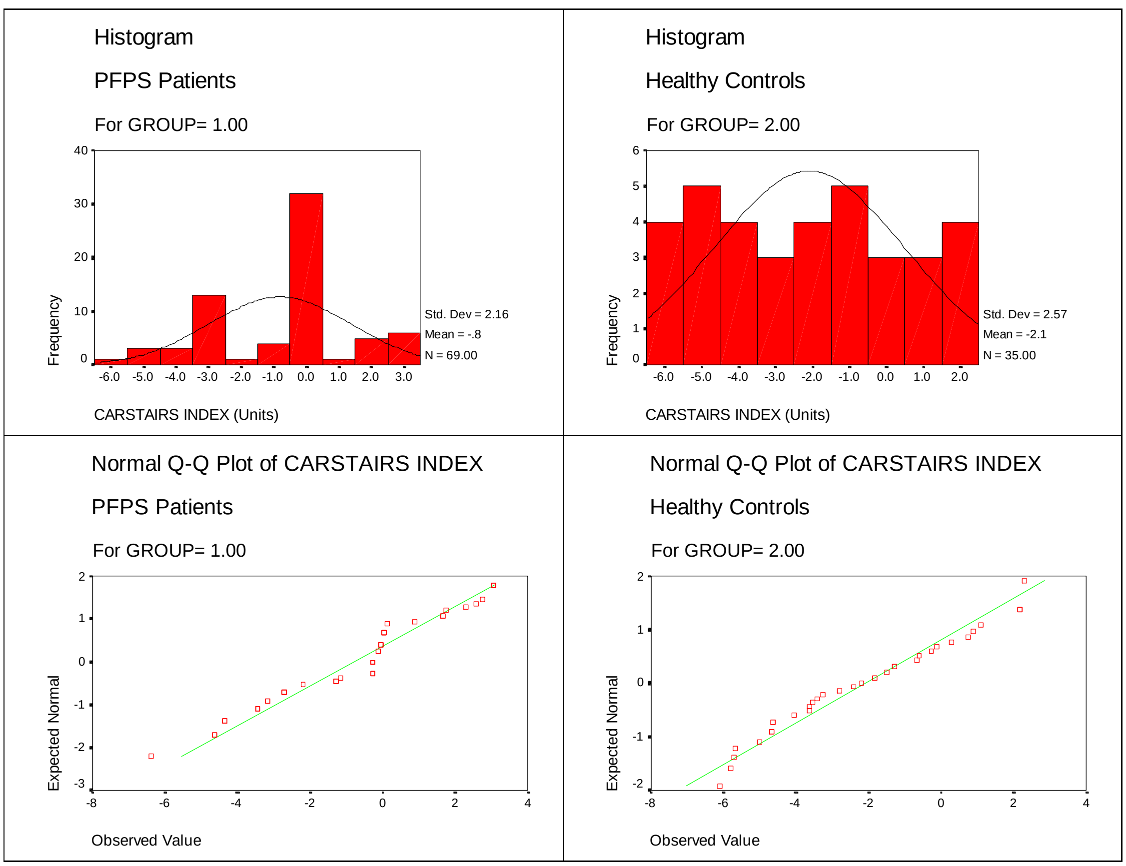
Graphs 13.4 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Body Mass Index (BMI) (Kg/m^2)**



Graphs 13.5 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Beighton Score (Units)**

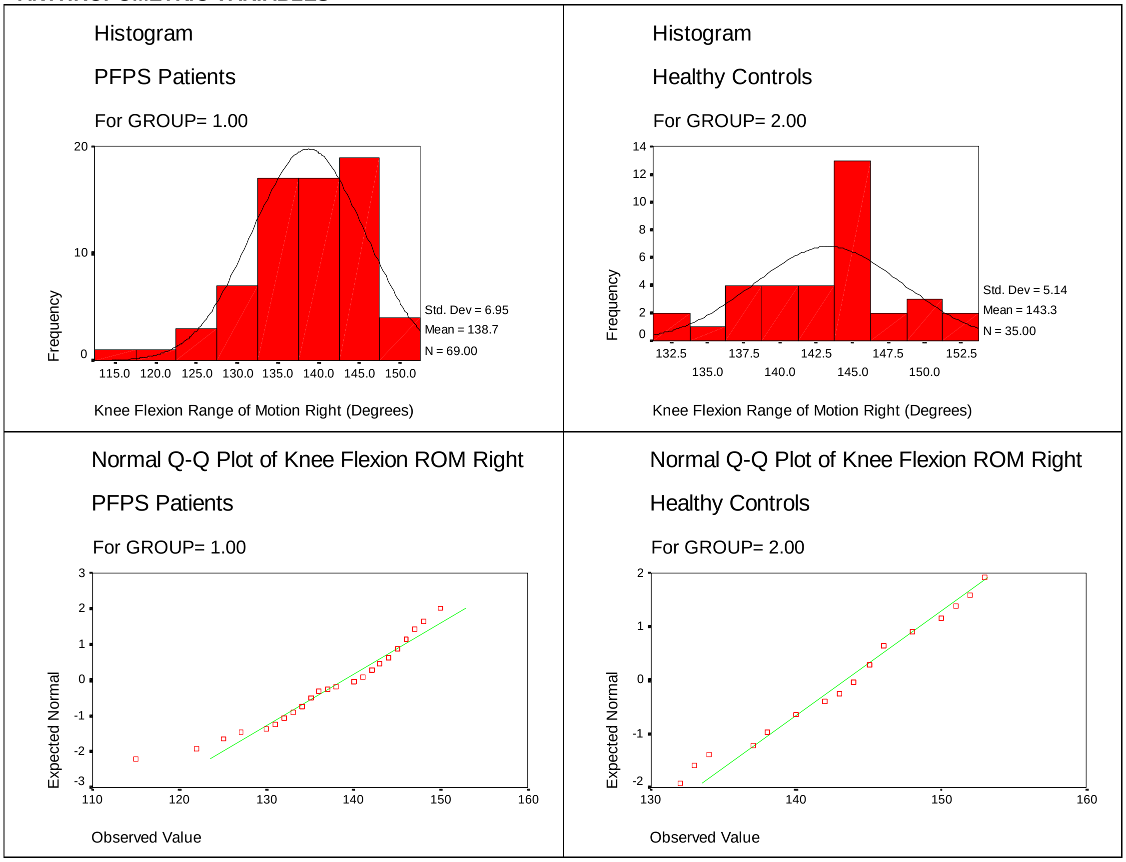


Graphs 13.6 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Activity (Hours)**

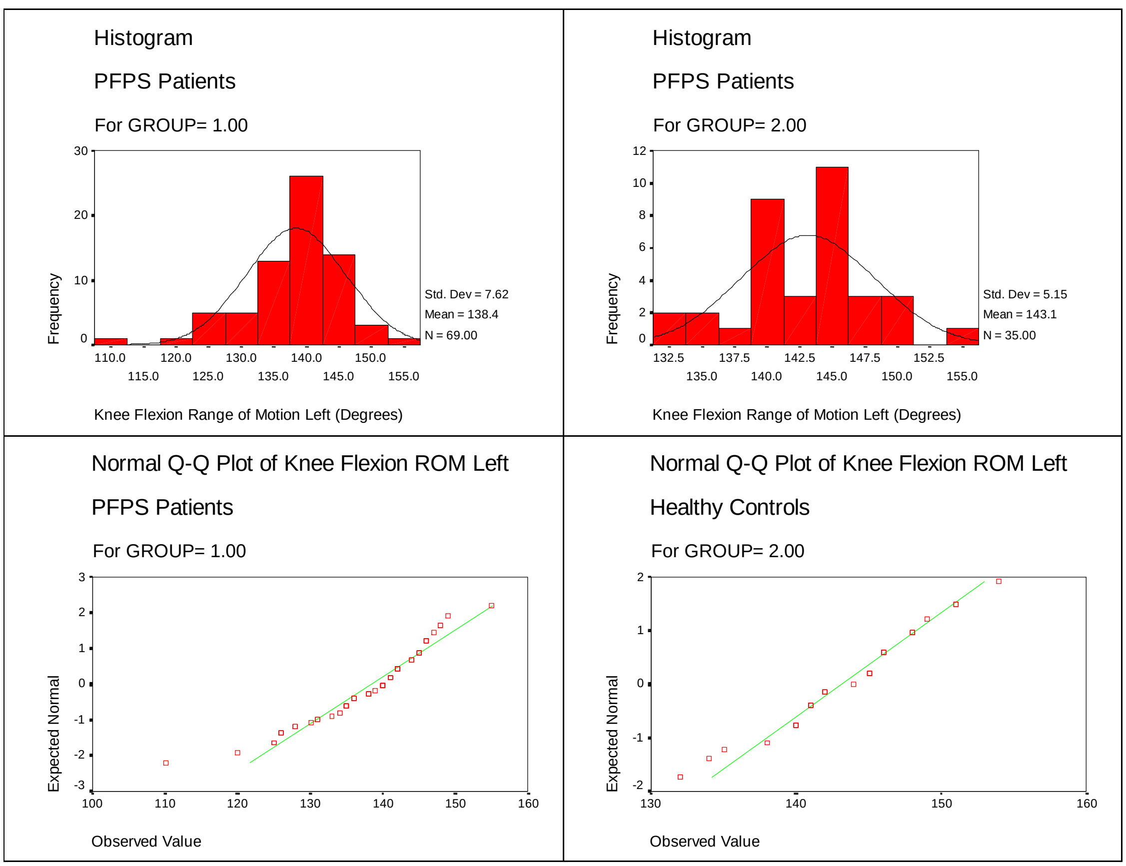


Graphs 13.7 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Carstairs Index (Units)**

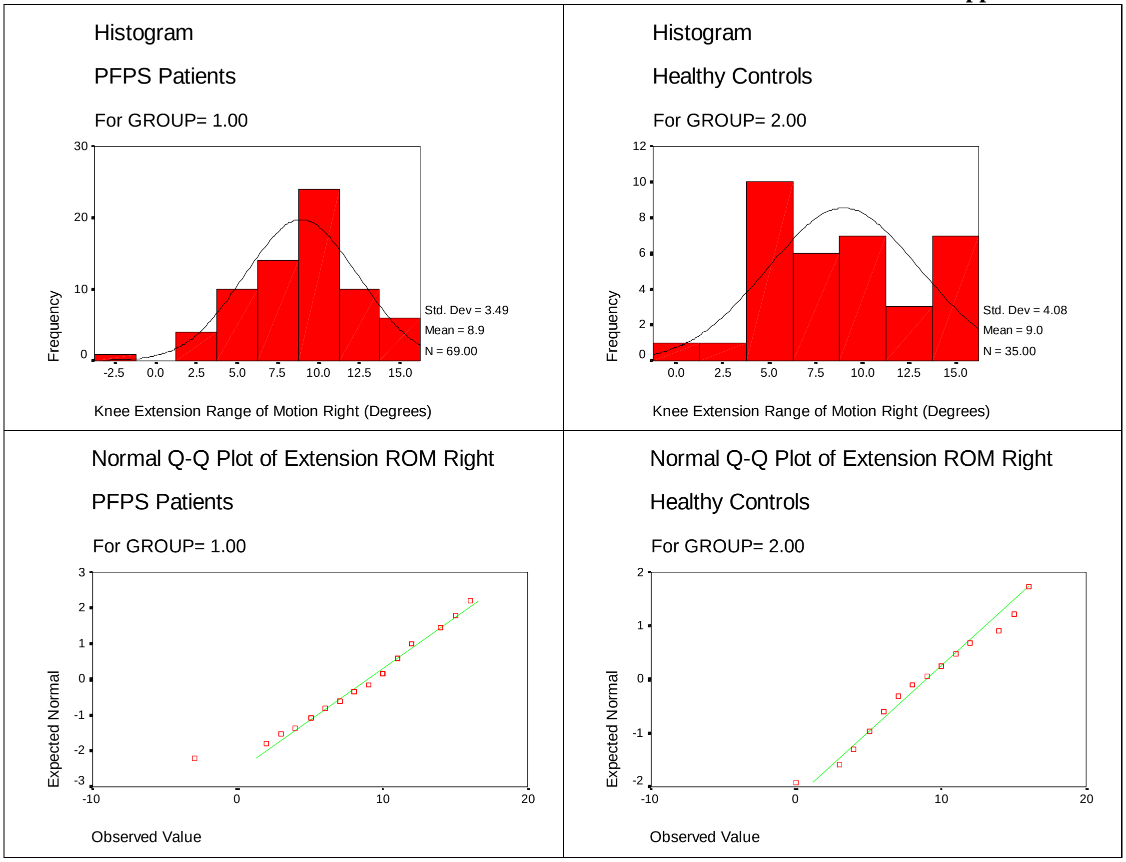
ANTHROPOMETRIC VARIABLES



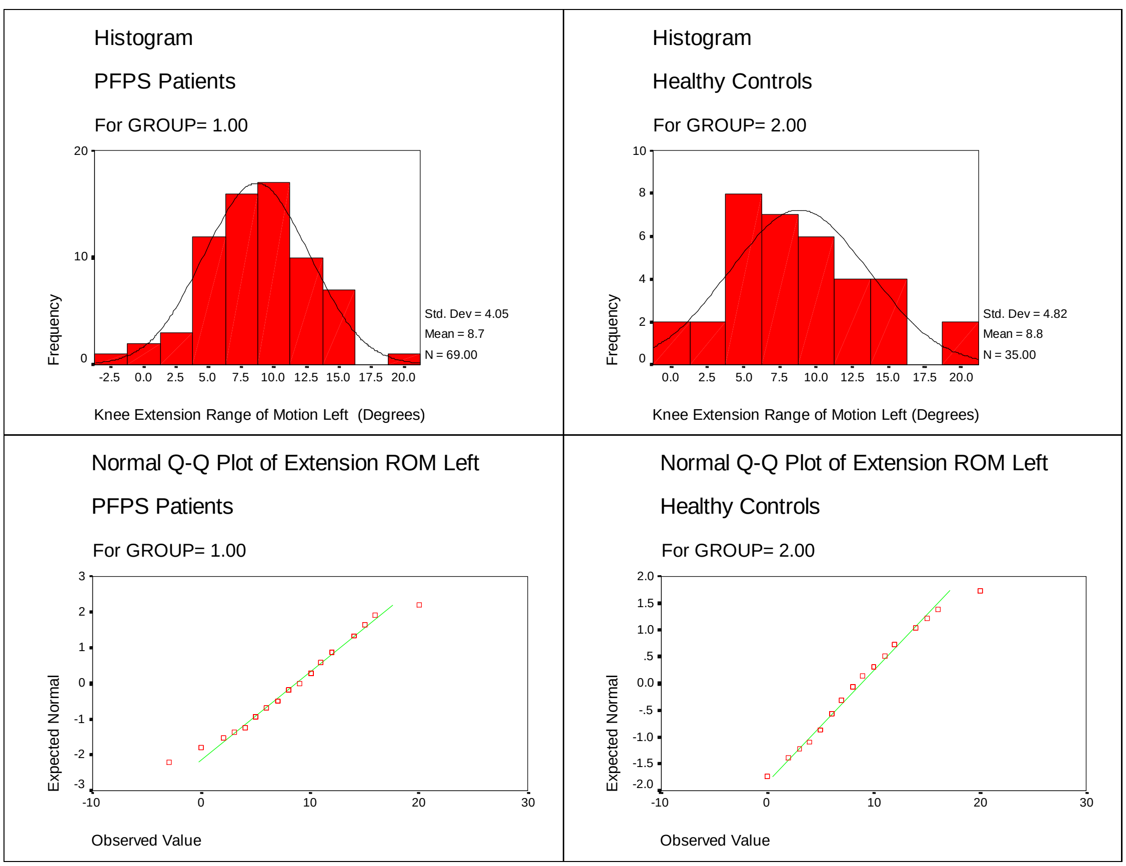
Graphs 13.8 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Flexion Range of Motion Right Knee (Degrees)**



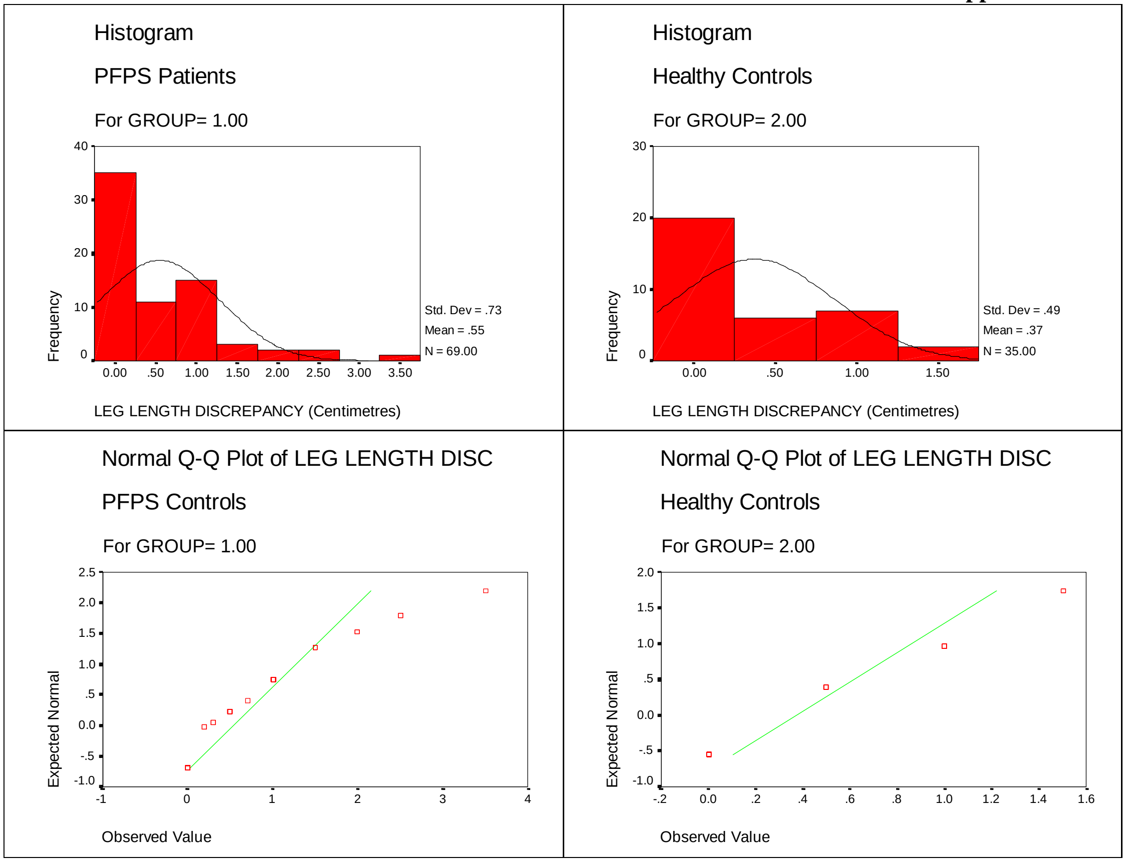
Graphs 13.9 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Flexion Range of Motion Left Knee (Degrees)**



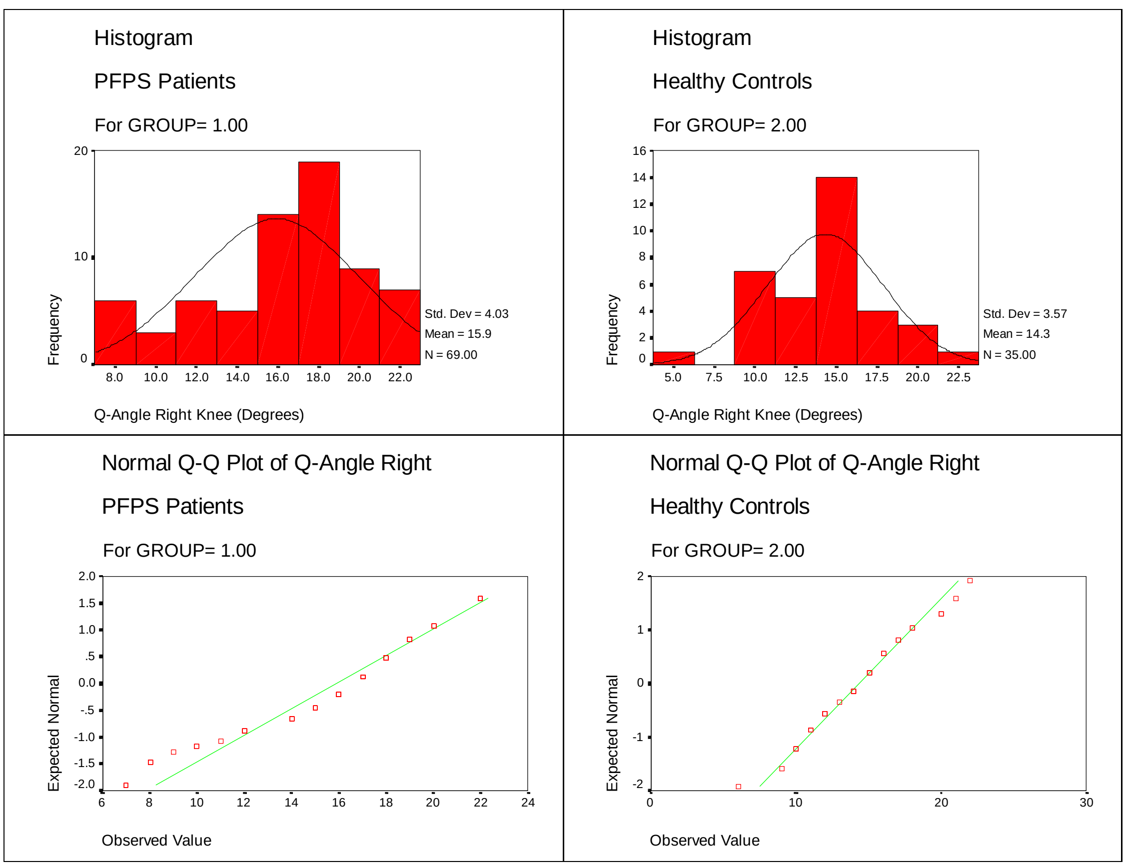
Graphs 13.10 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Extension Range of Motion Right Knee (Degrees)



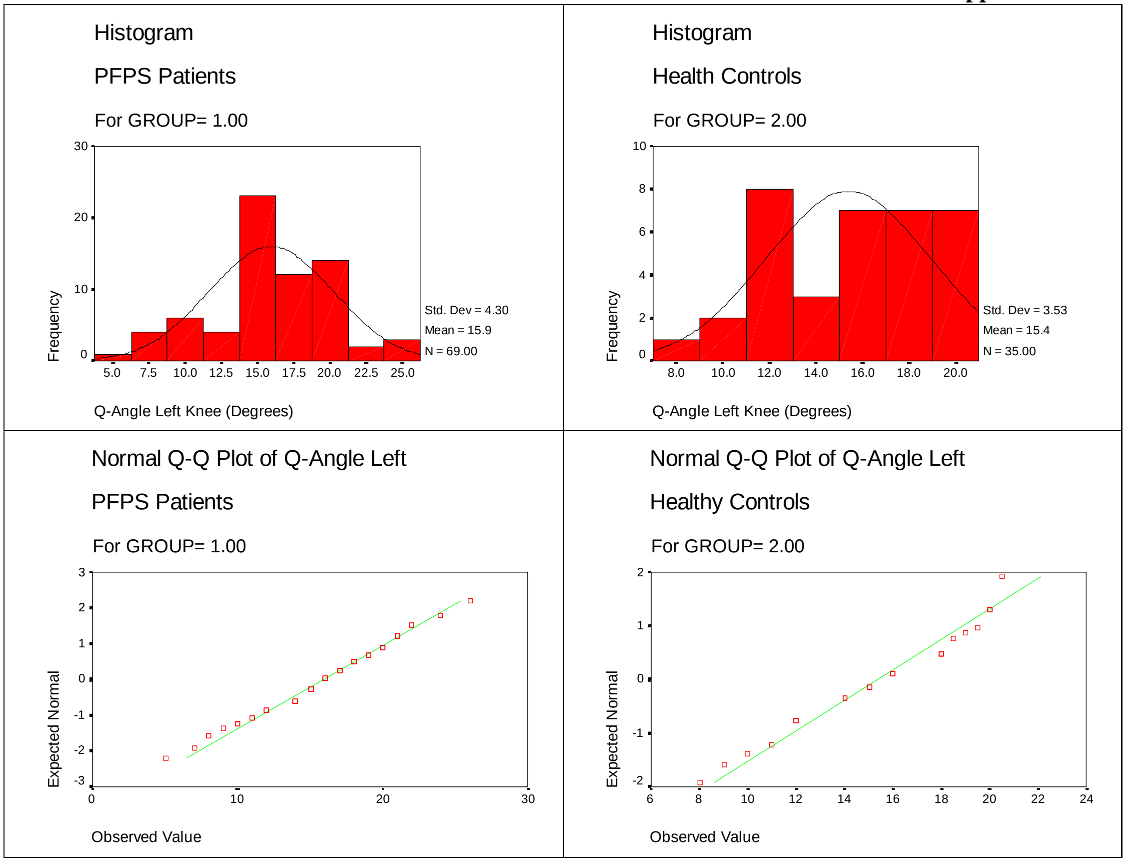
Graphs 13.11 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Extension Range of Motion Left Knee (Degrees)



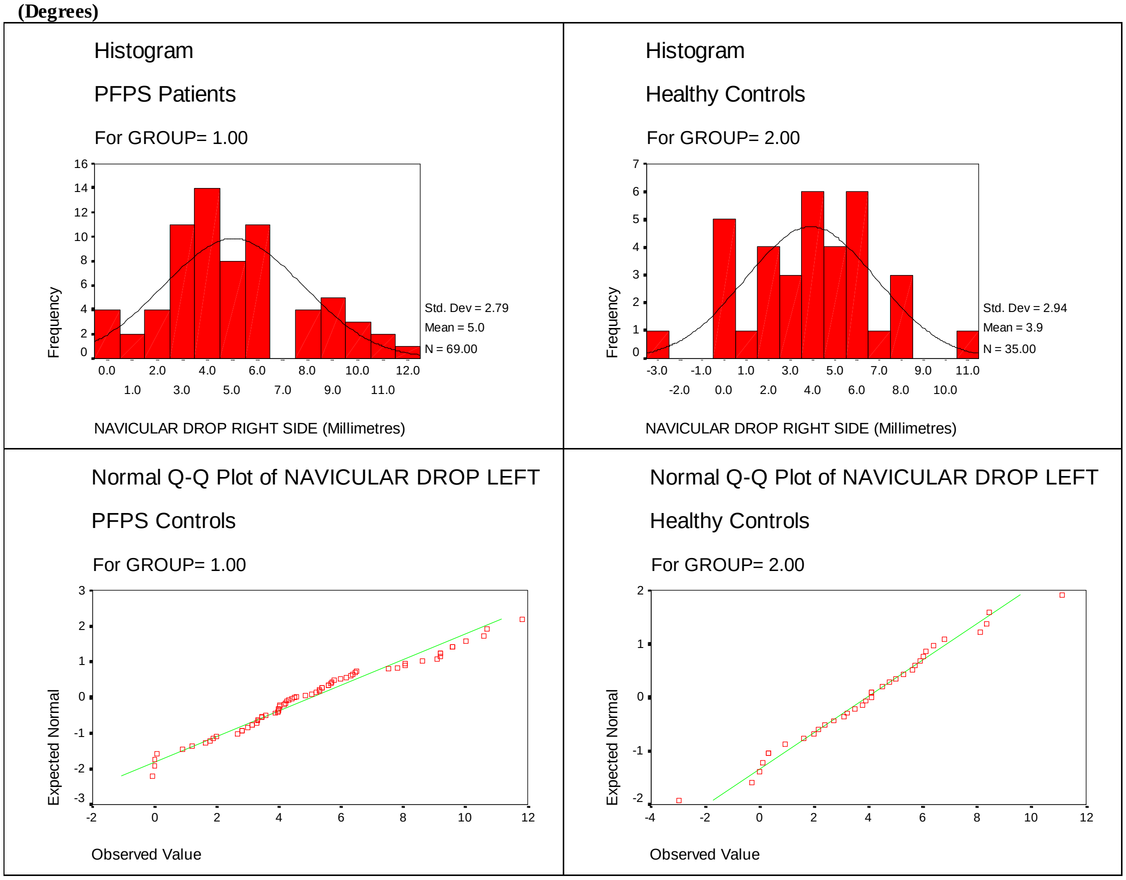
Graphs 13.12 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Leg Length Differences (Centimetres)**



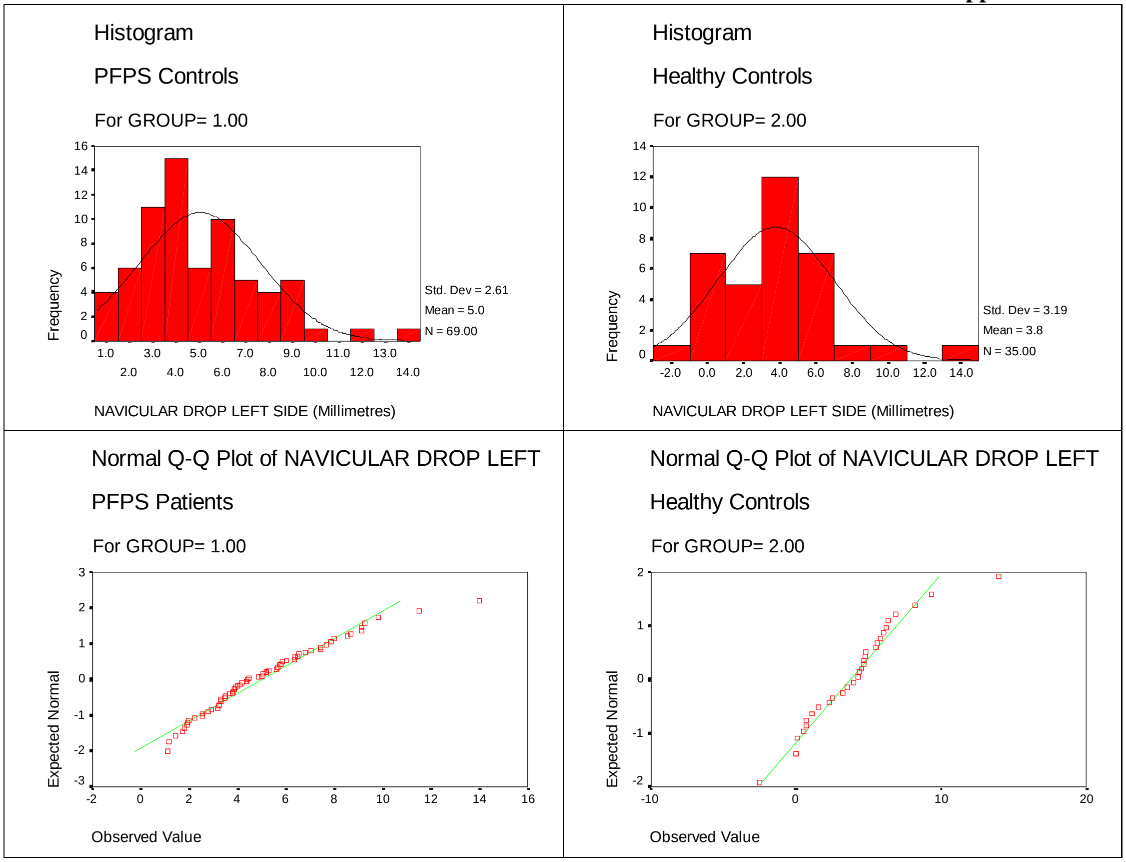
Graphs 13.13 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Q-Angle Right Side (Degrees)**



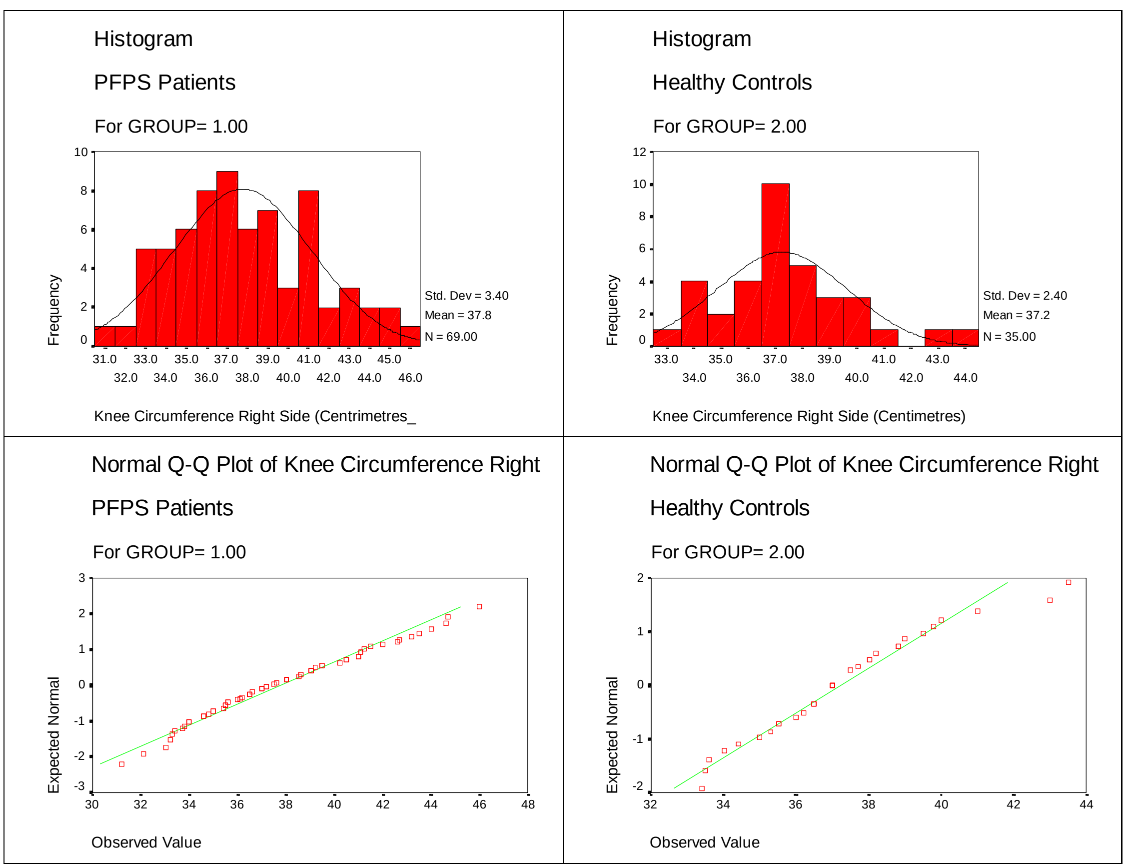
Graphs 13.14 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Q-Angle Left Side (Degrees)**



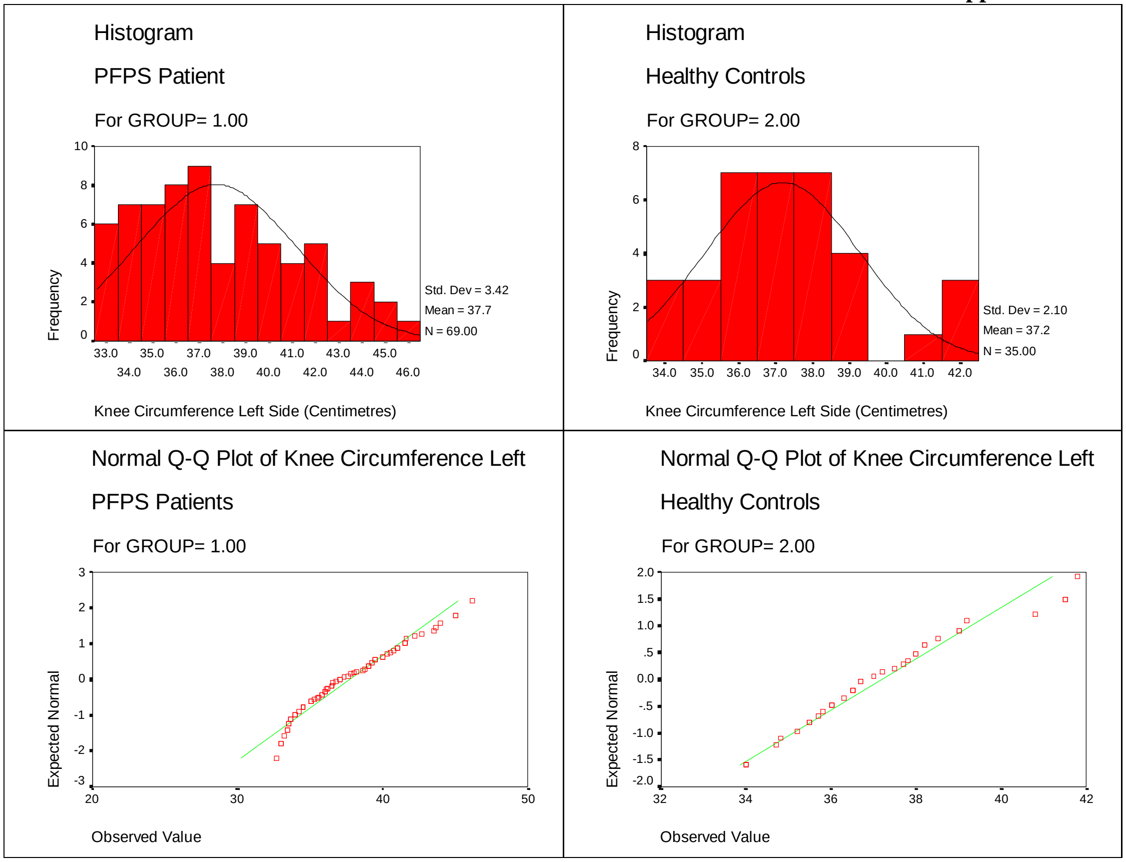
Graphs 13.15 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Navicular Drop Right Side (Millimetres)**



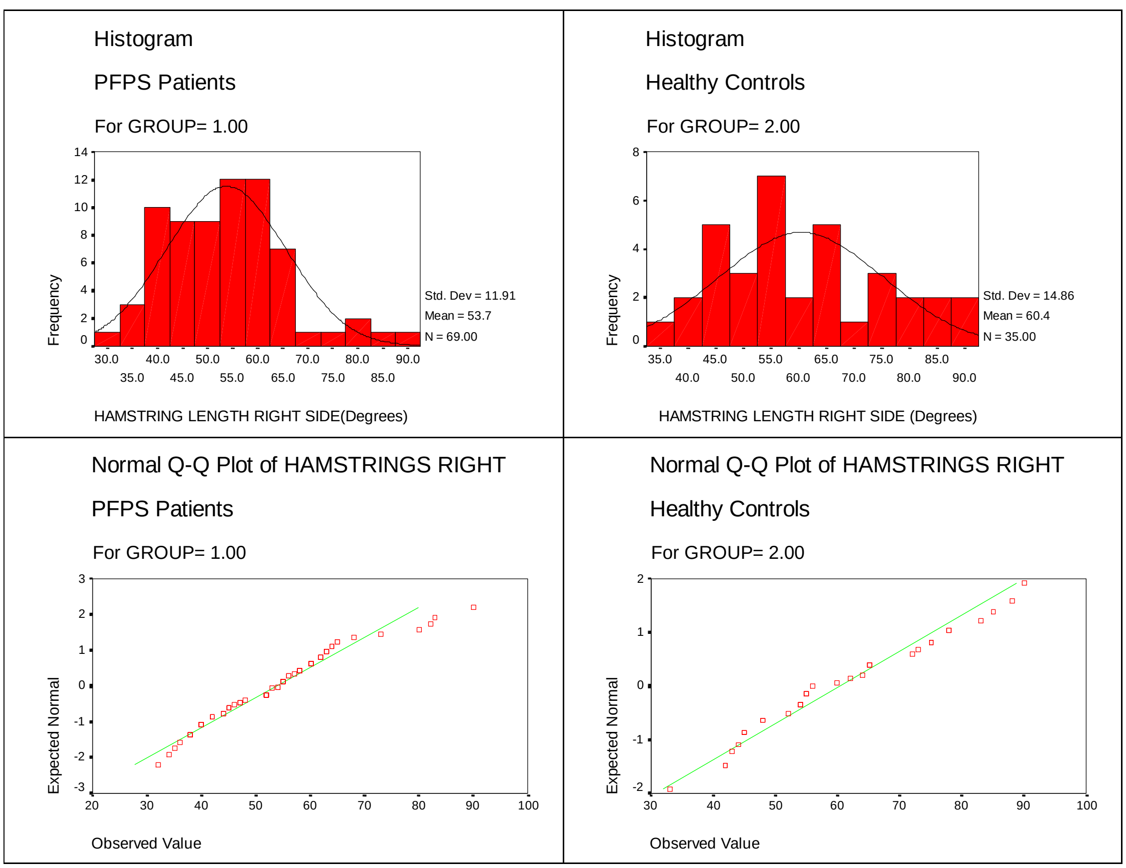
Graphs 13.16 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Navicular Drop Left Side (Millimetres)



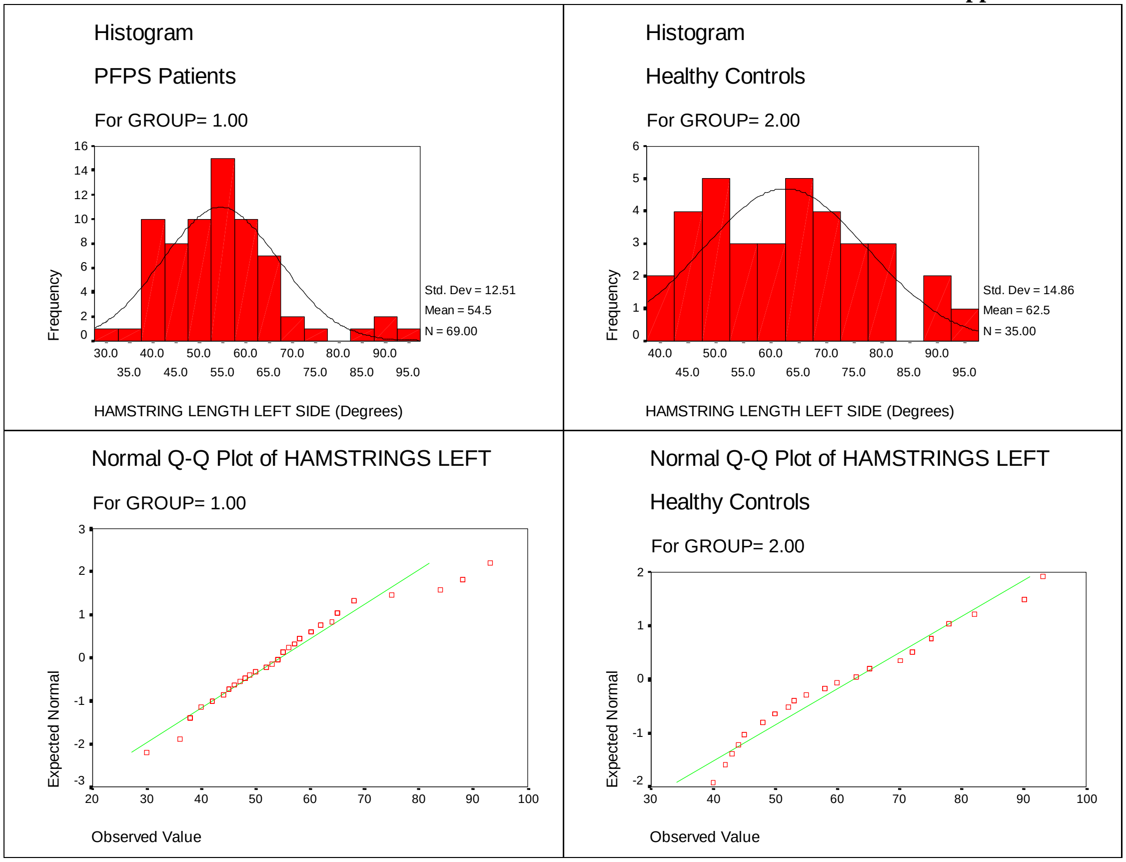
Graphs1217 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Circumferential Measurements Right Knee (Centimetres)



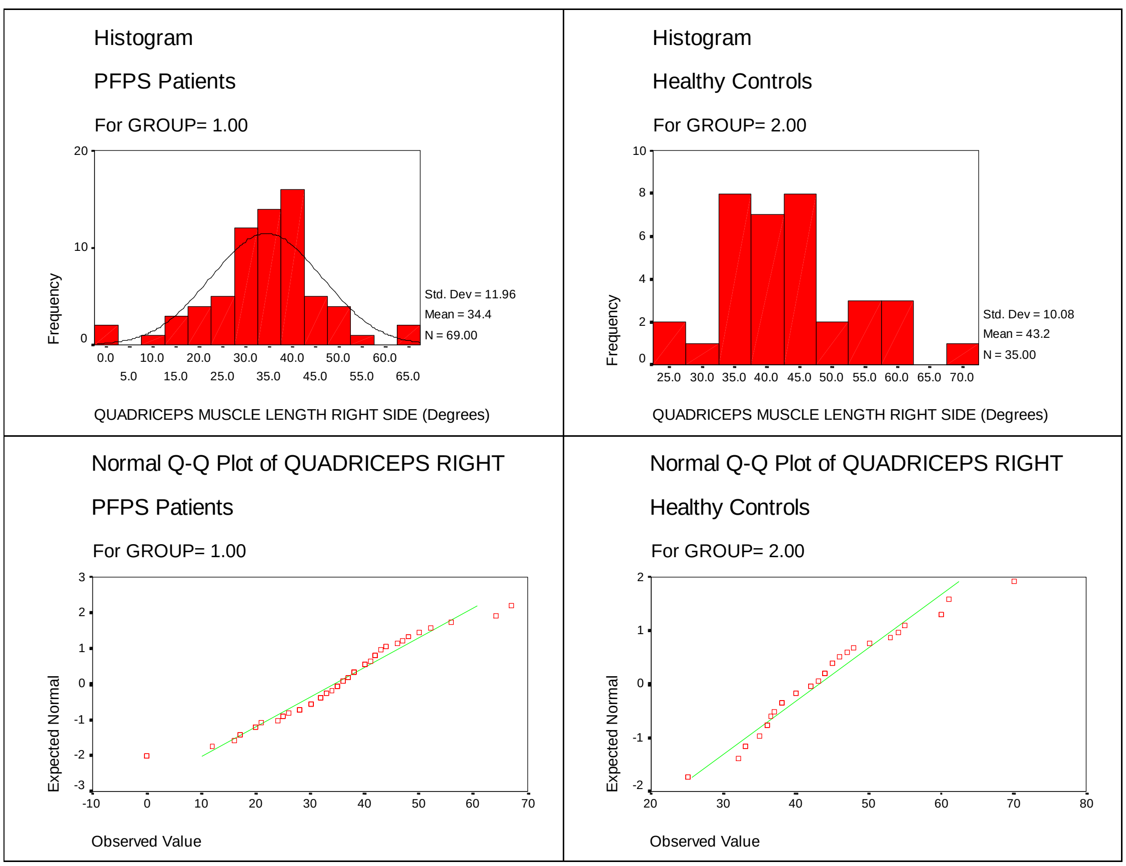
Graphs 13.18 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Circumferential Measurements Left Knee (Centimetres)



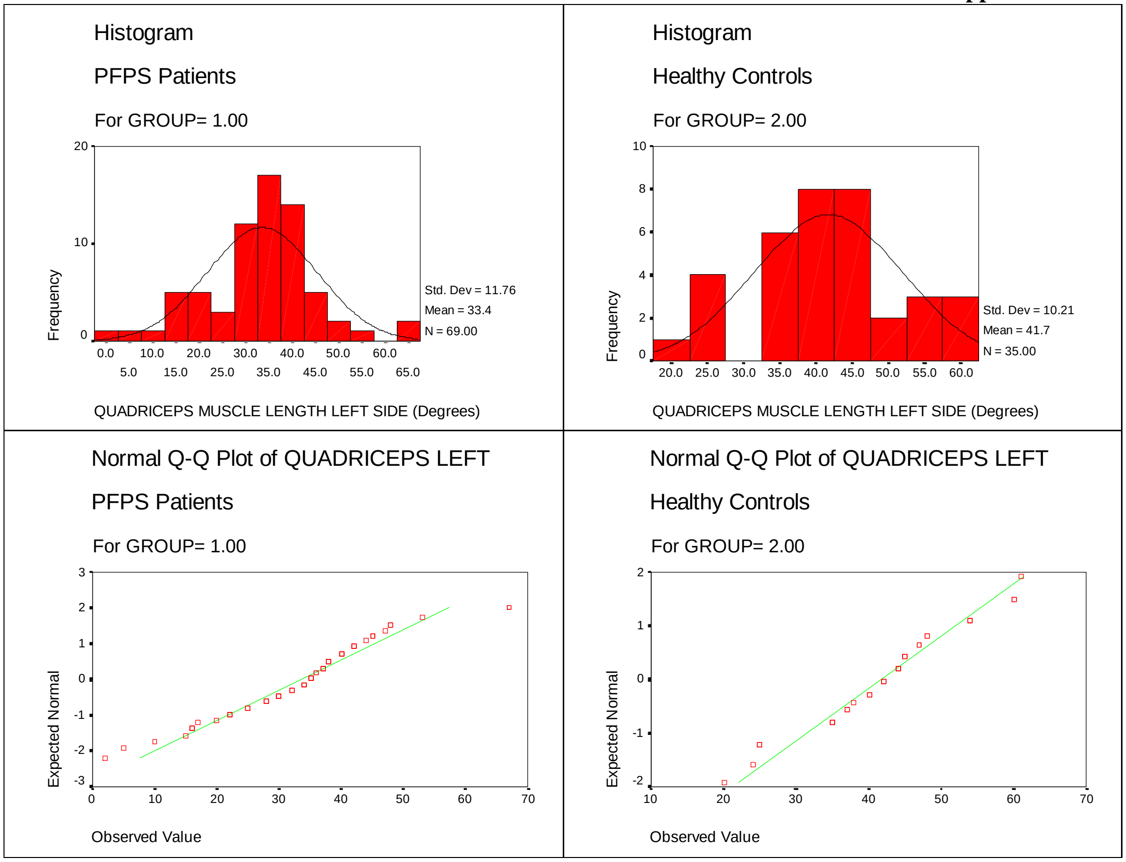
Graphs 13.19 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Hamstrings Length Right Side (Degrees)



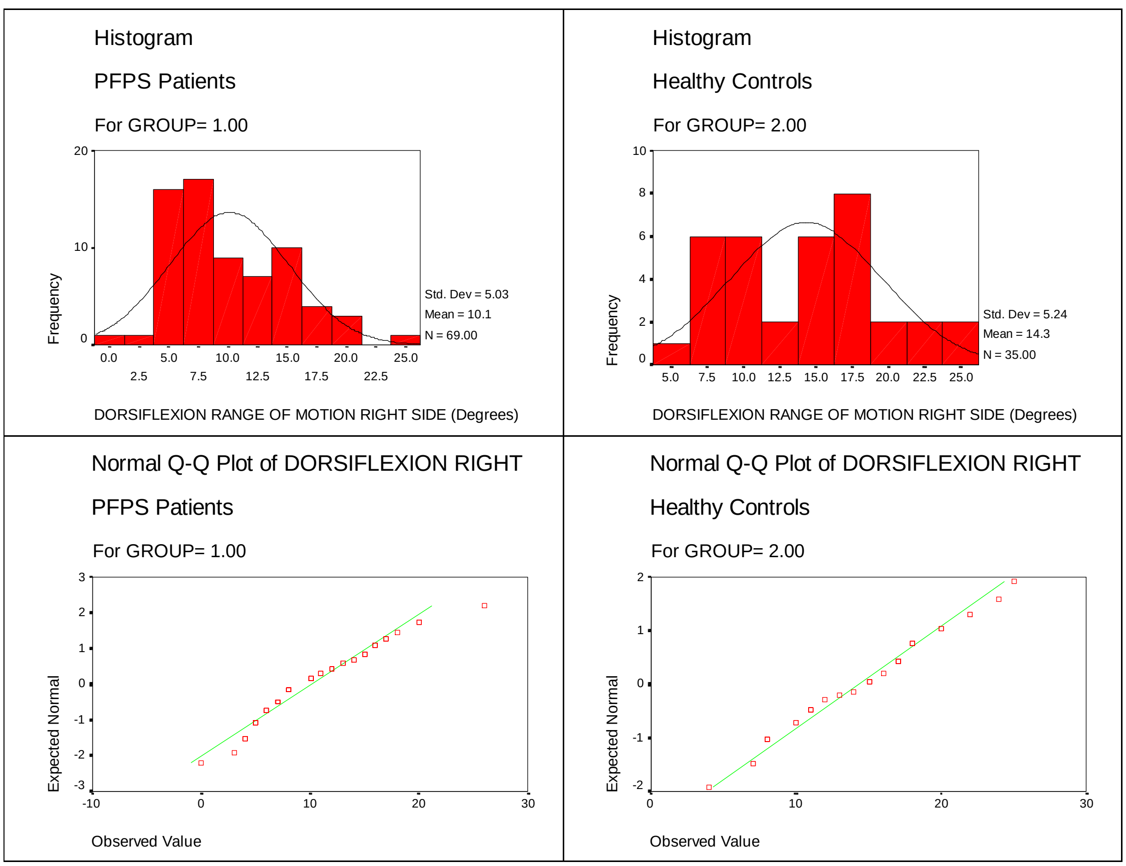
Graphs 13.20 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Hamstrings Length Left Side (Degrees)



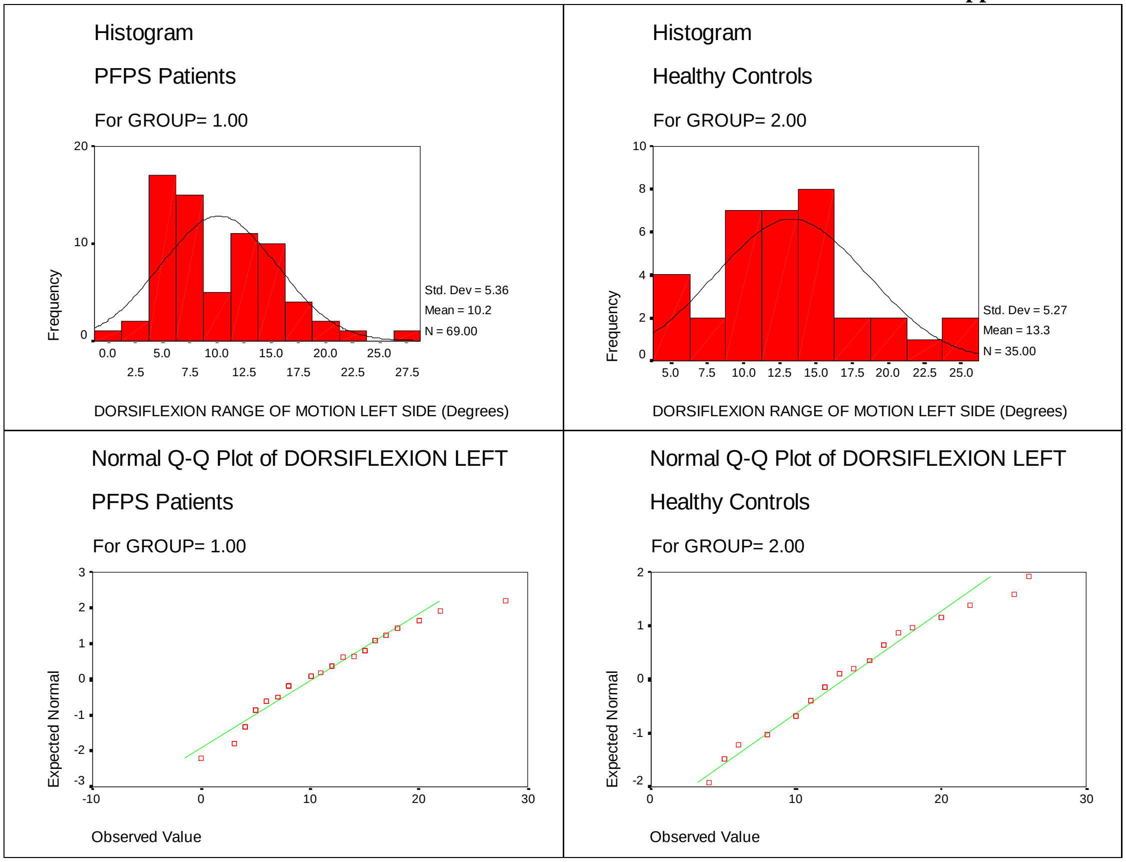
Graphs 13.21 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Quadriceps Length Right Side (Degrees)



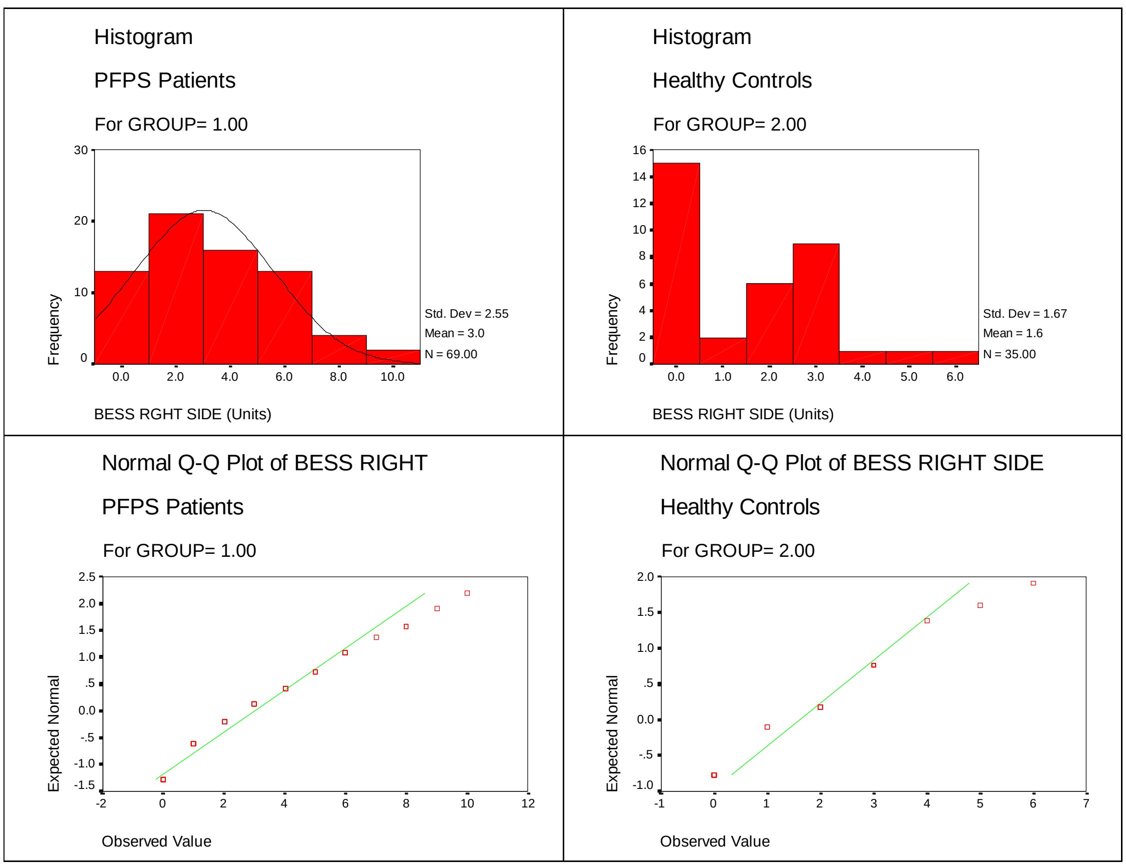
Graphs 13.22 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Quadriceps Length Left Side (Degrees)



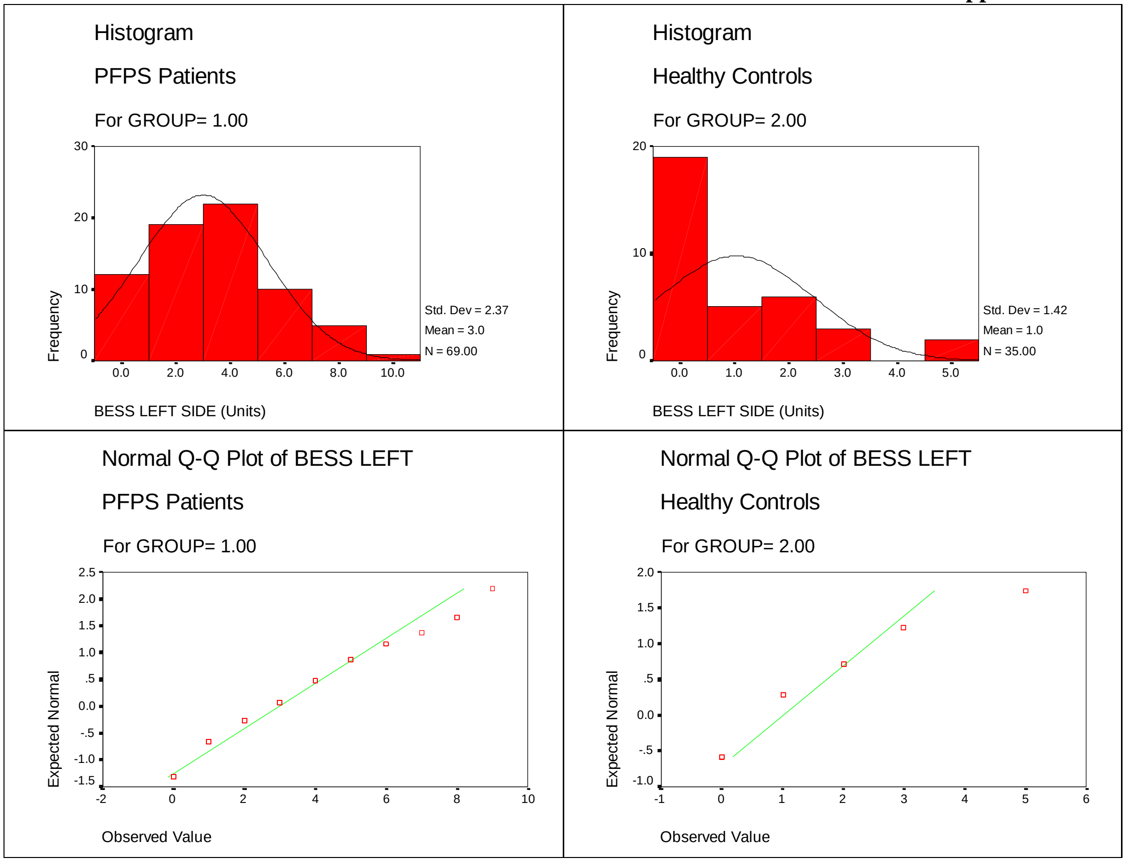
Graphs 13.23 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Equinus Right Side (Degrees)



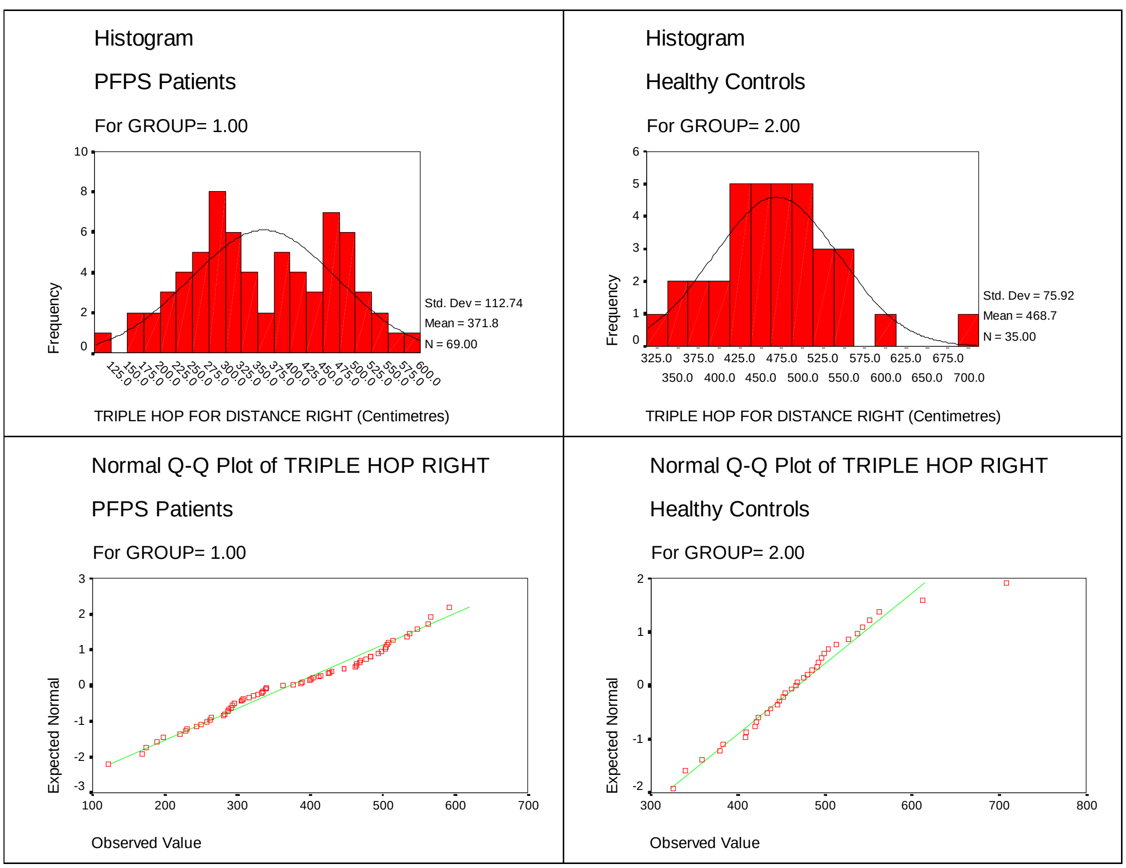
Graphs 13.24 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Equinus Right Side (Degrees)



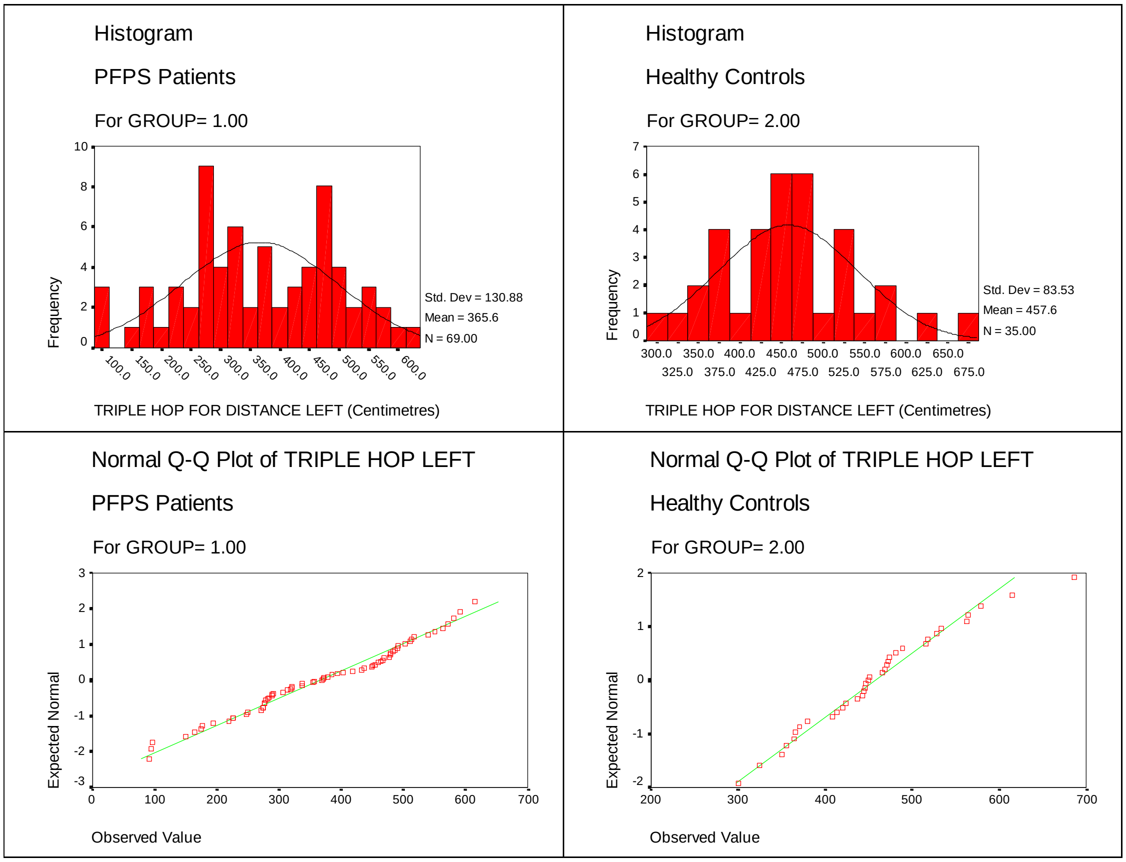
Graphs 725 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for BESS Test Right Side (Number of Errors)



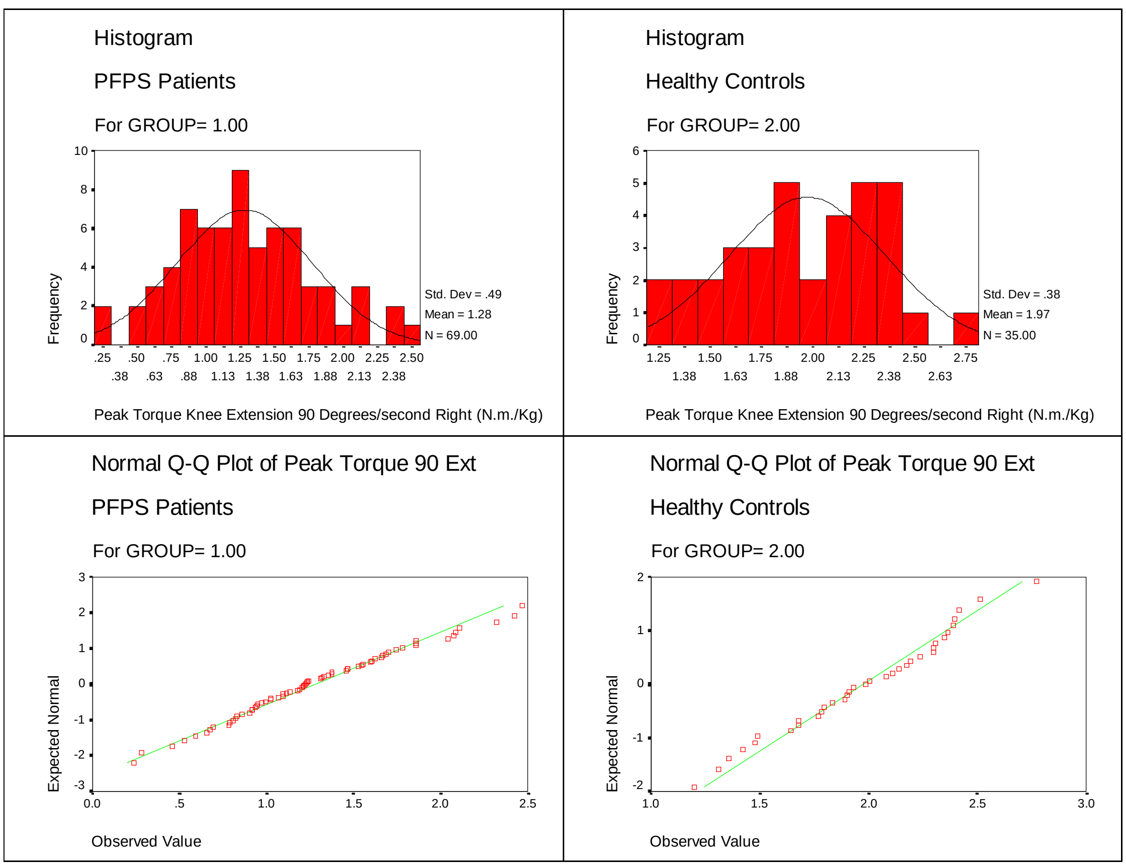
Graphs 13.26 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for BESS Test Left Side (Number of Errors)



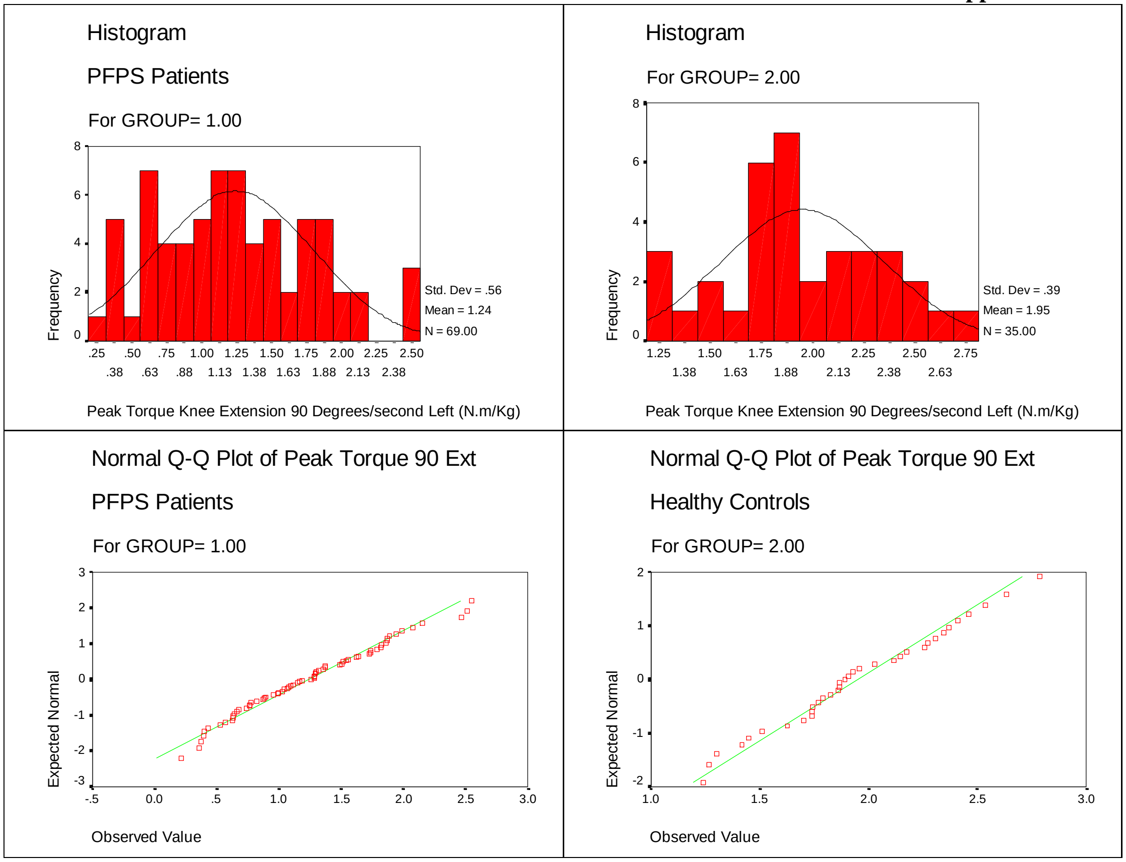
Graphs 727 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Triple Hop for Distance Right Side (Centimetres)



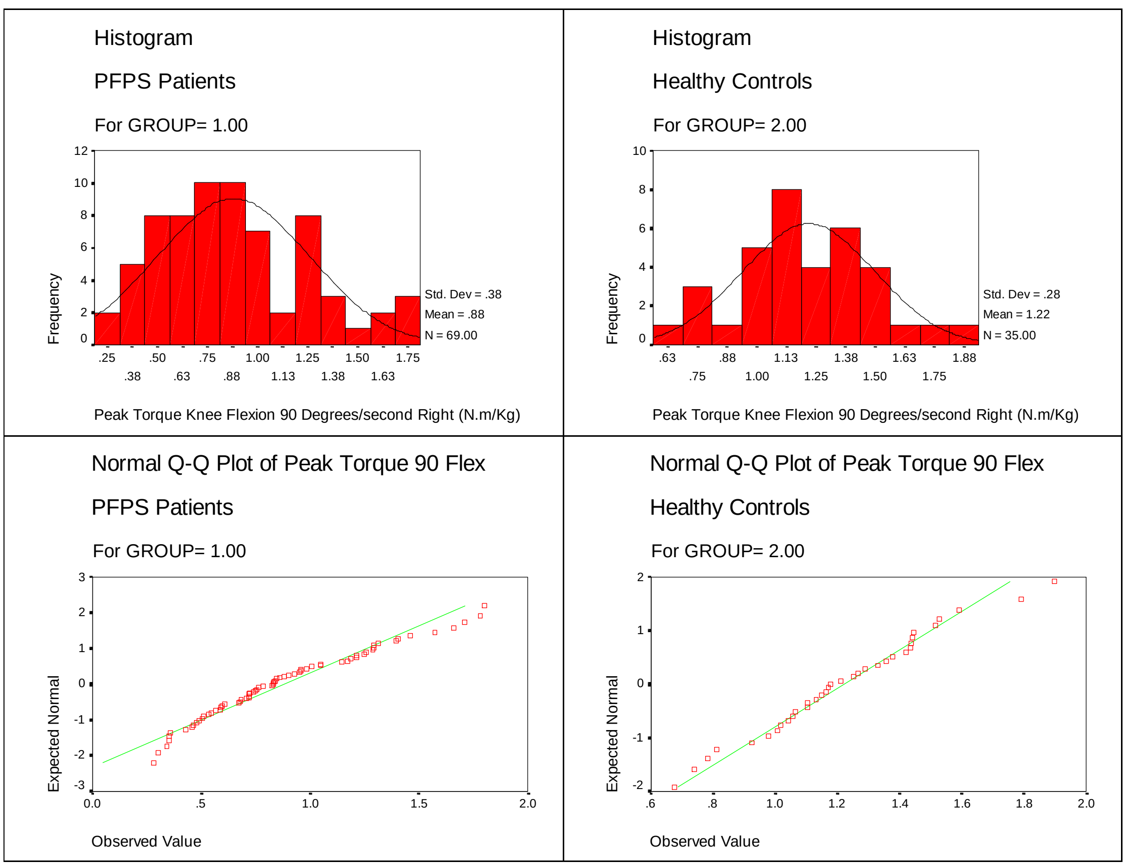
Graphs 13.28 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Triple Hop for Distance Left Side (Centimetres)



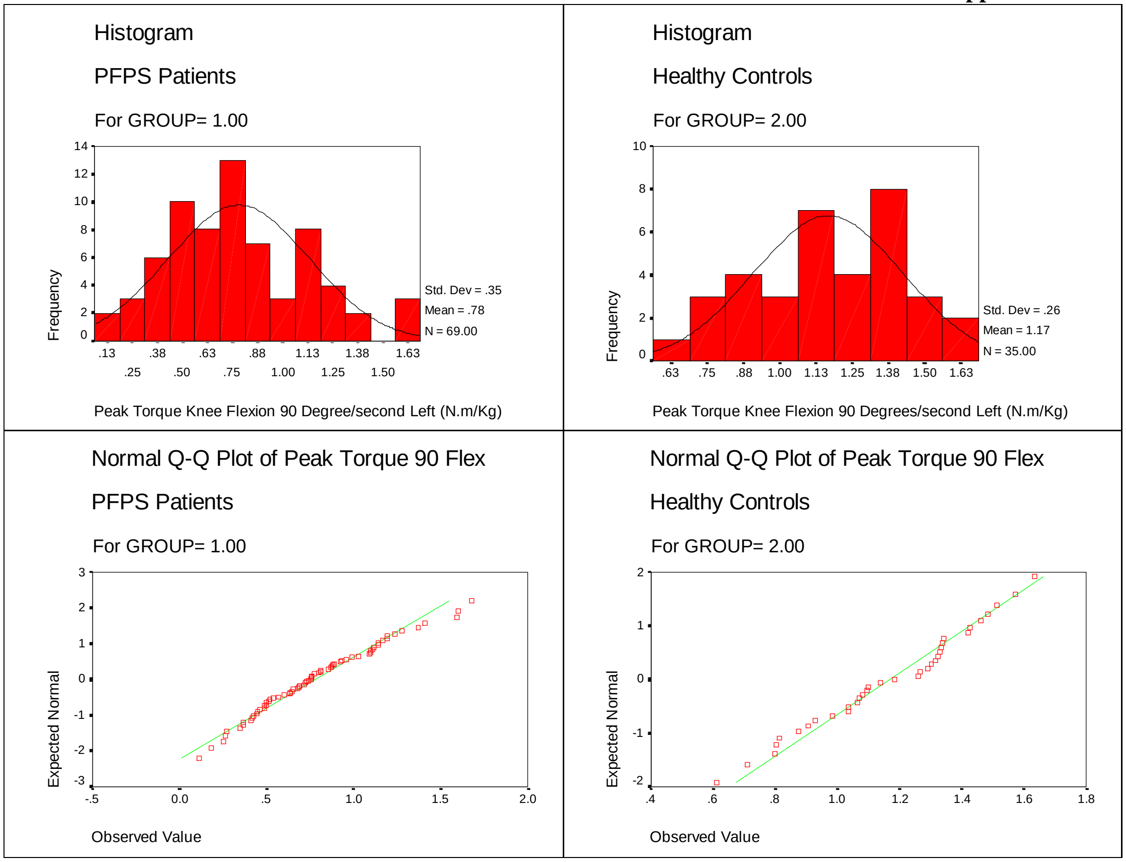
Graphs 13.29 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Extension Right Knee at 90°/s Nm/kg



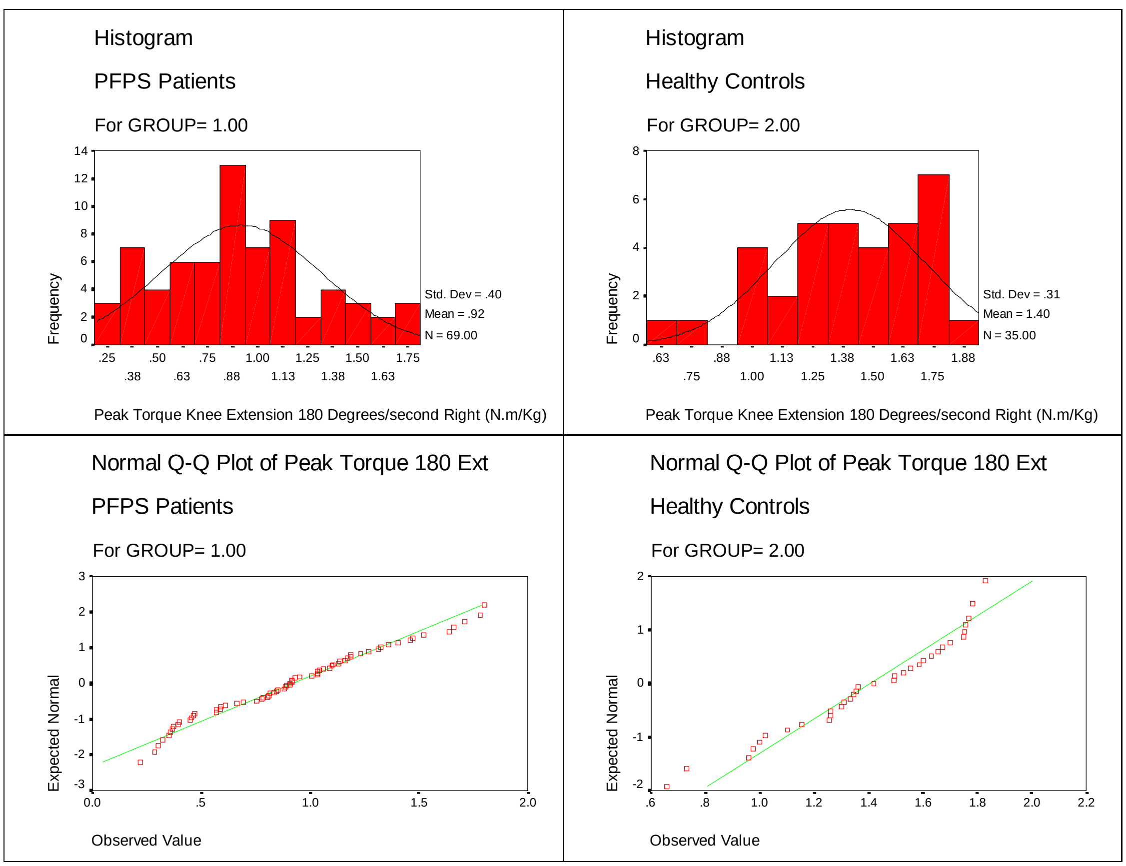
Graphs 71.30 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Extension Left Knee at 90°/s Nm/kg**



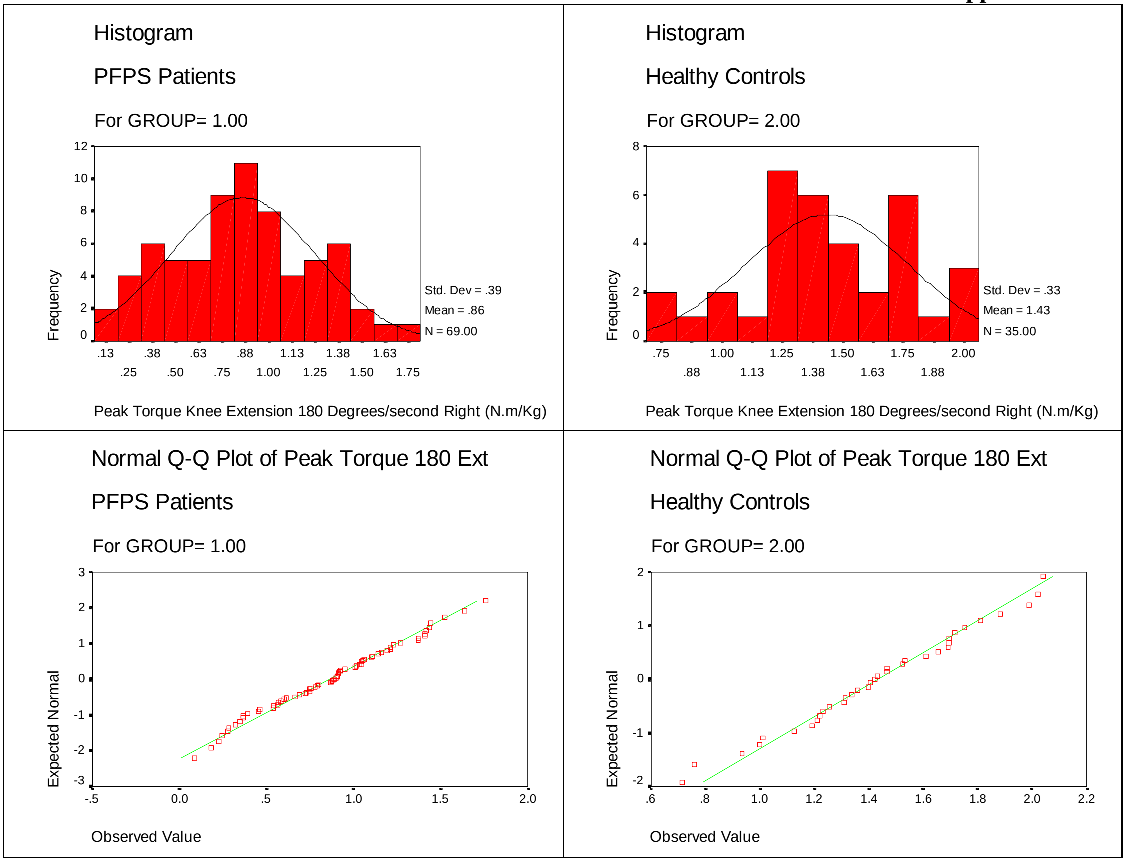
Graphs 13.31 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Flexion Right Knee at 90°/s Nm/kg**



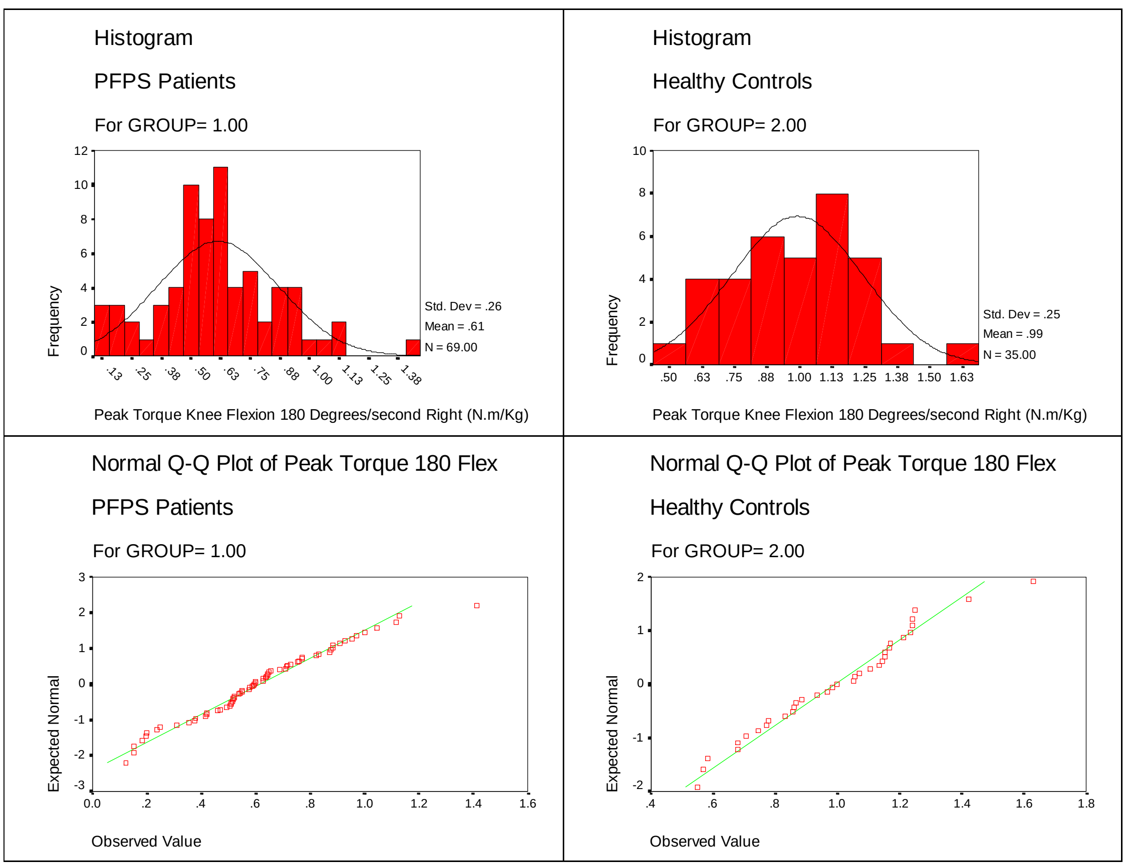
Graphs 13.32 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Flexion Left Knee at 90°/s Nm/kg



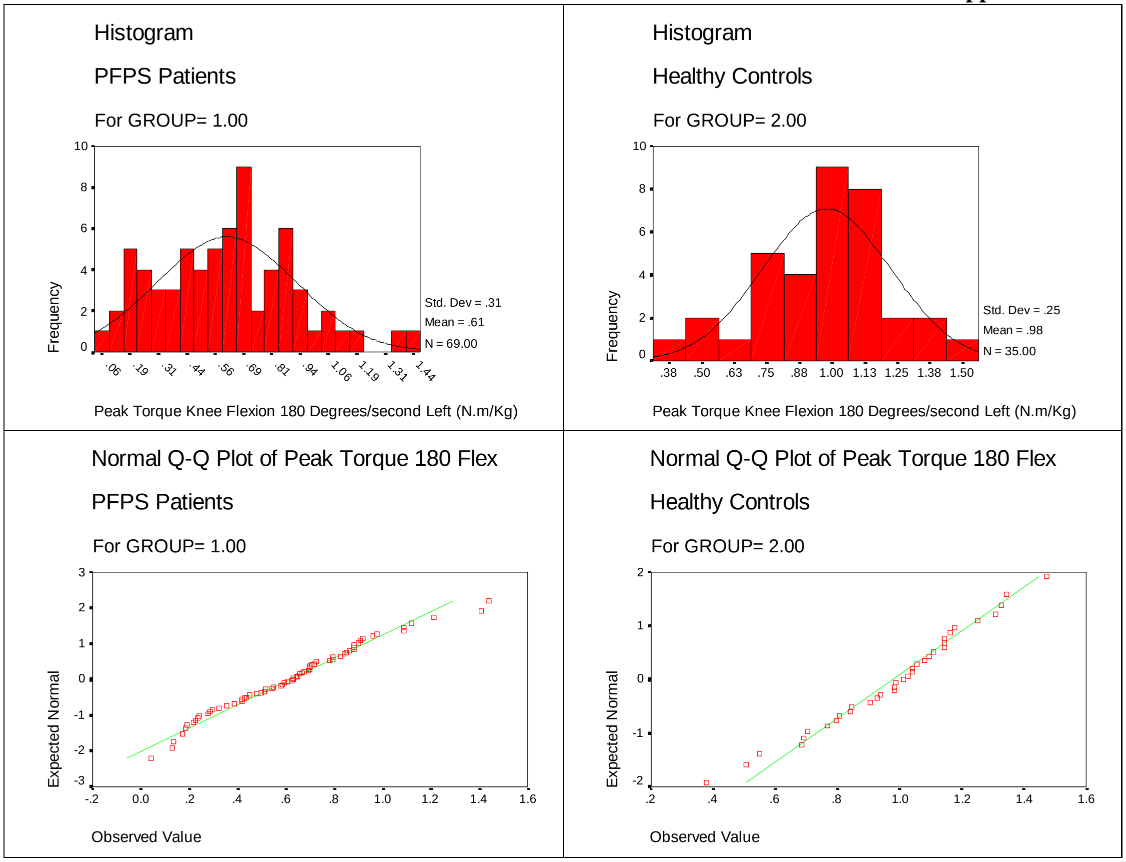
Graphs 13.33 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Extension Right Knee at 180°/s Nm/kg



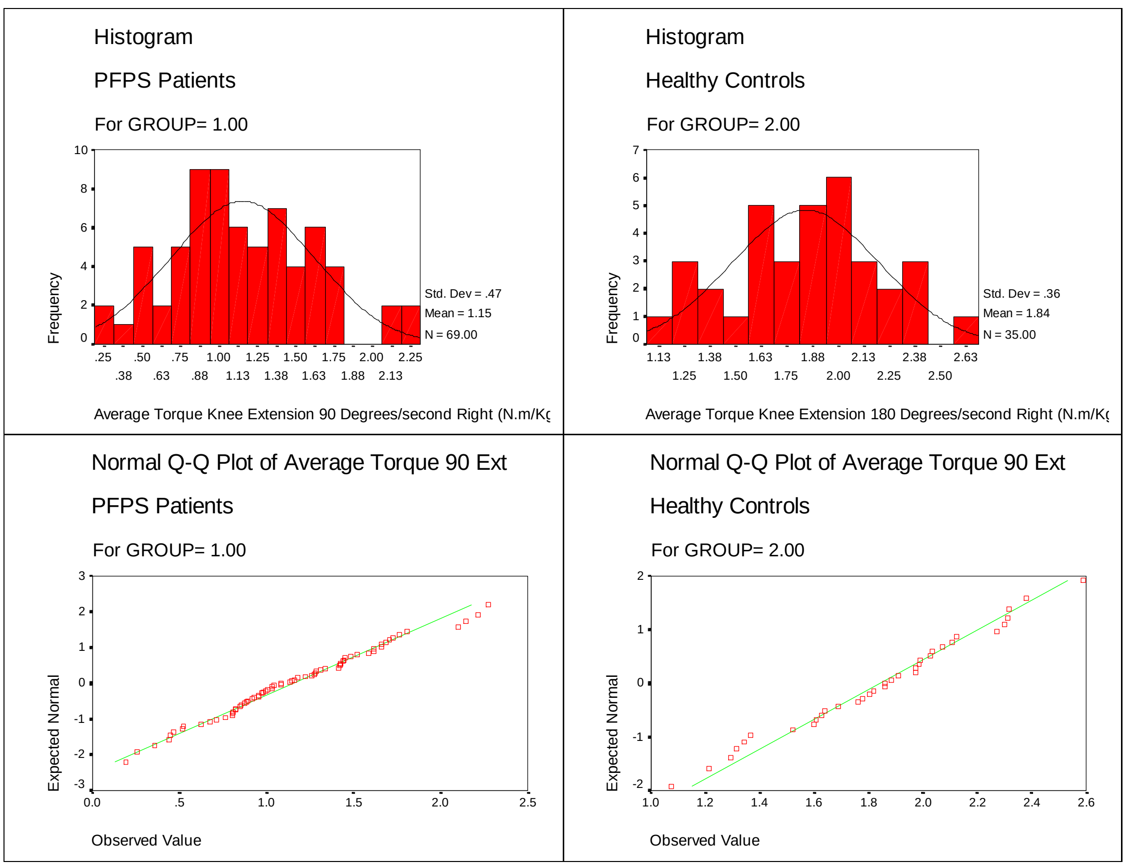
Graphs 13.34 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Extension Left Knee at 180˚/s Nm/kg**



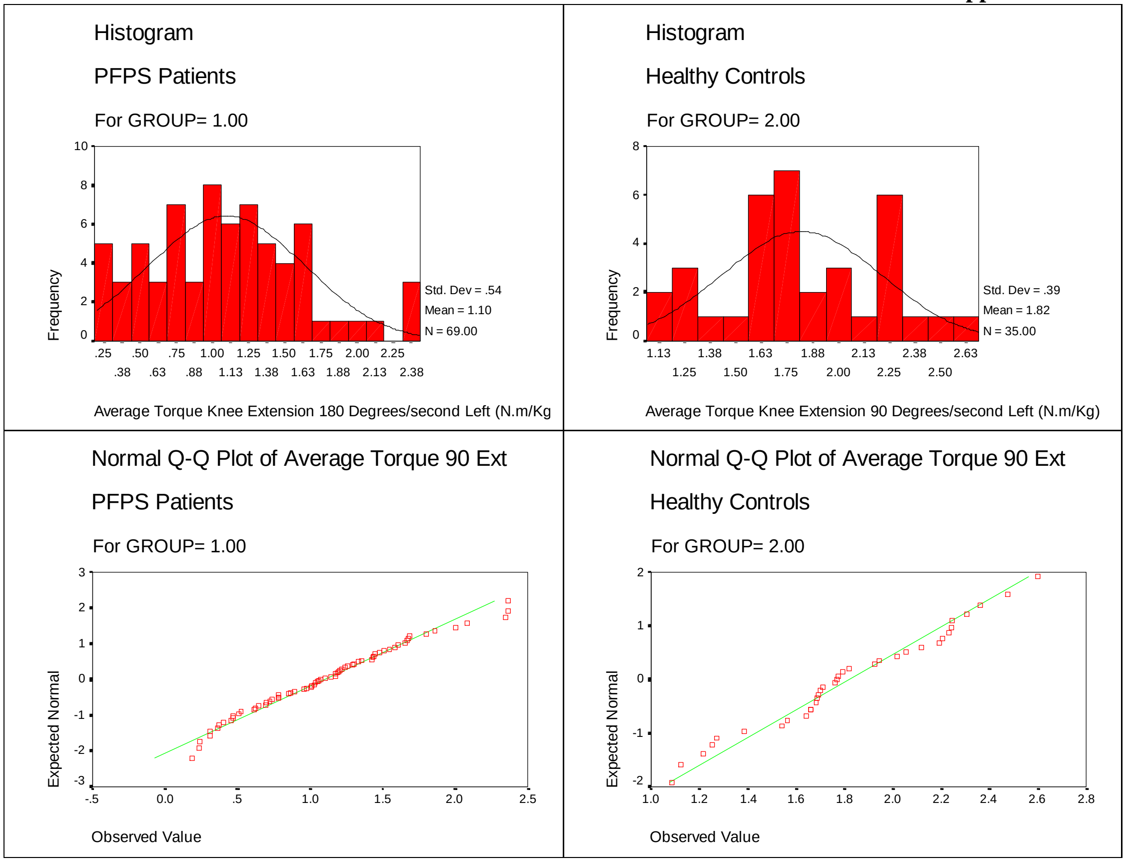
Graphs 13.35 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Flexion Right Knee at 180˚/s Nm/kg**



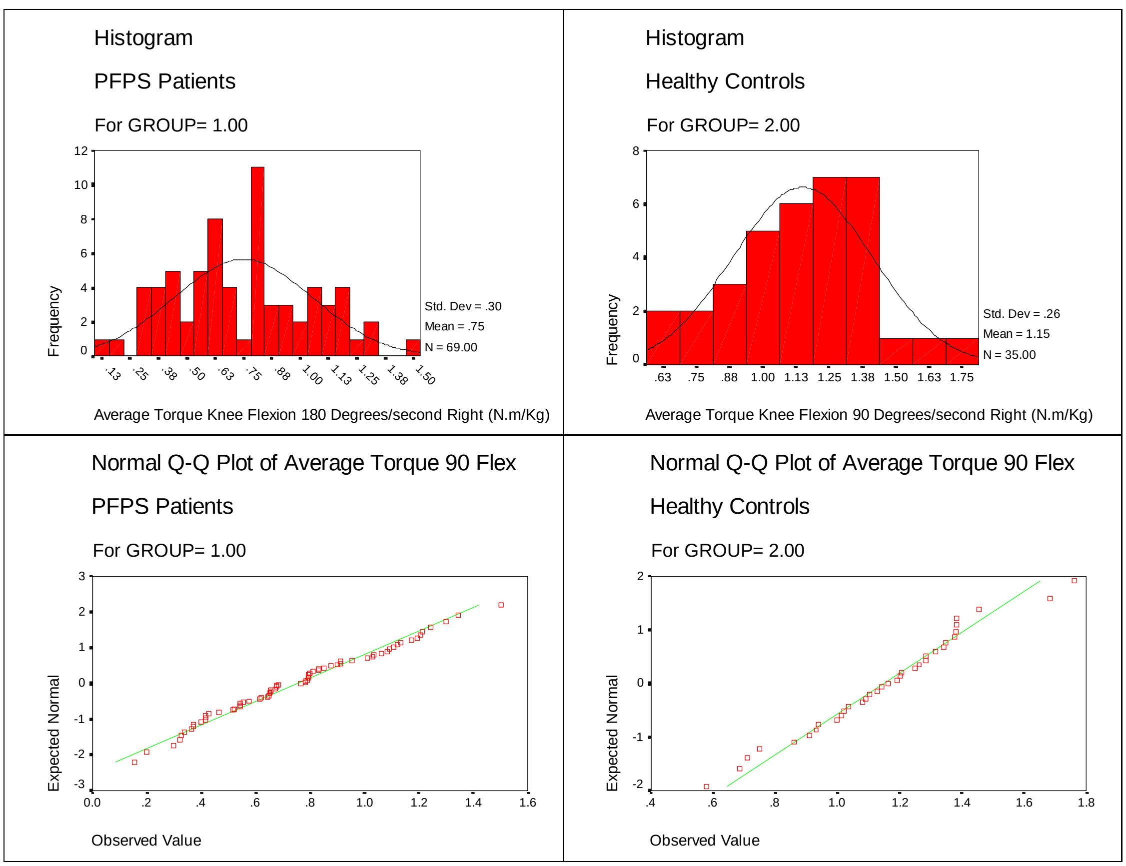
Graphs 13.36 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Flexion Left Knee at 180˚/s Nm/kg**



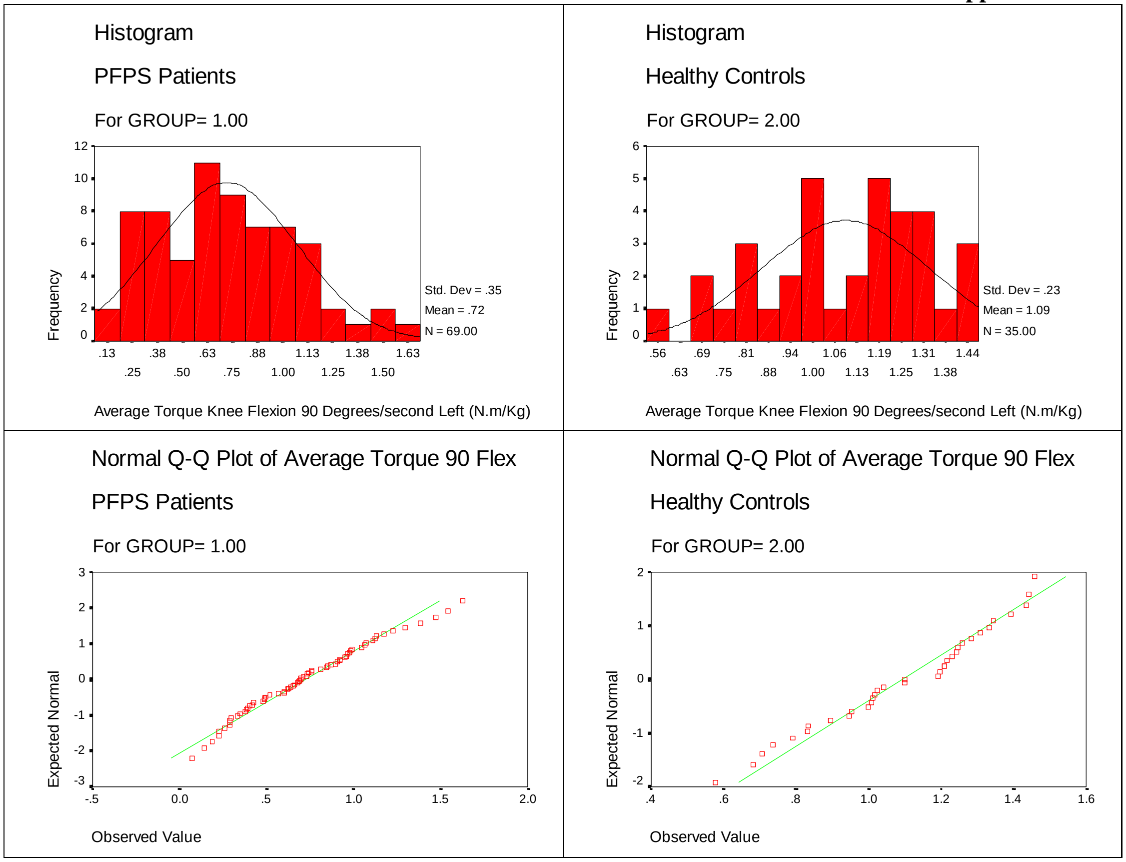
Graphs 13.37 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Extension Right Knee at 90˚/s Nm/kg**



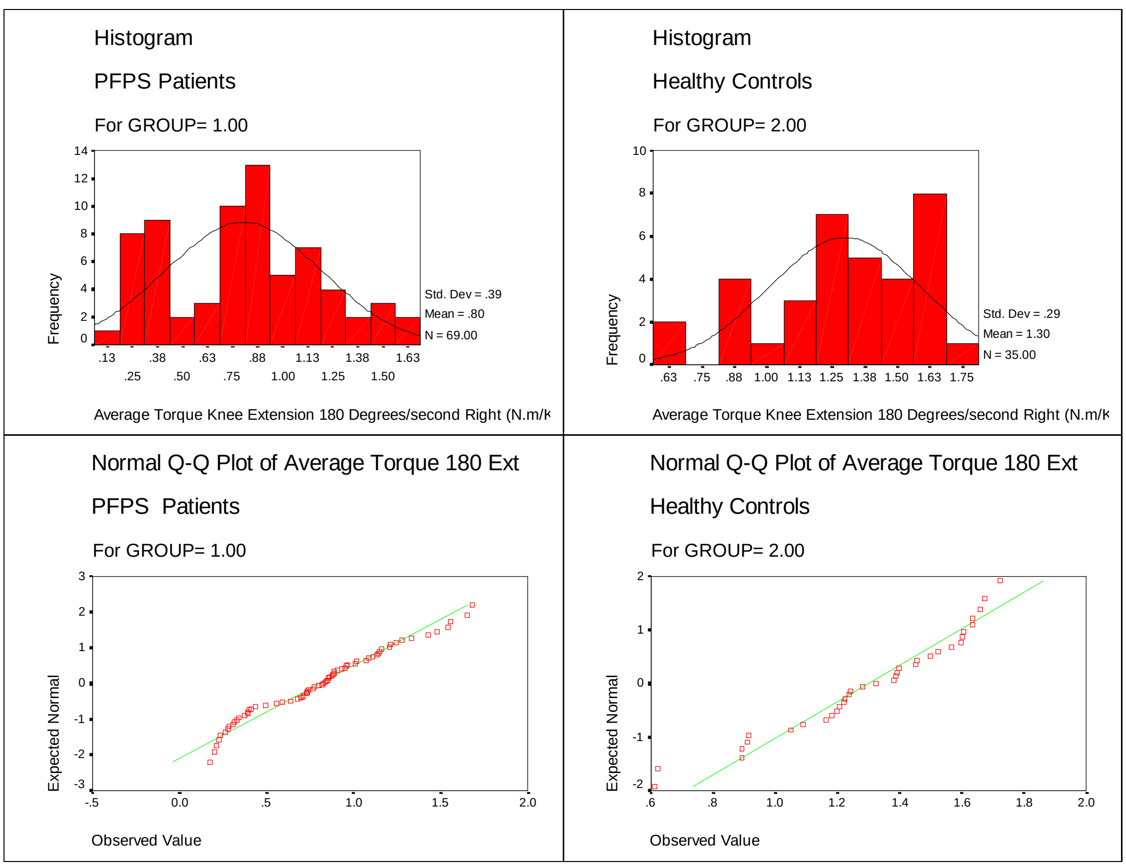
Graphs 13.38 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Extension Left Knee at 90°/s Nm/kg



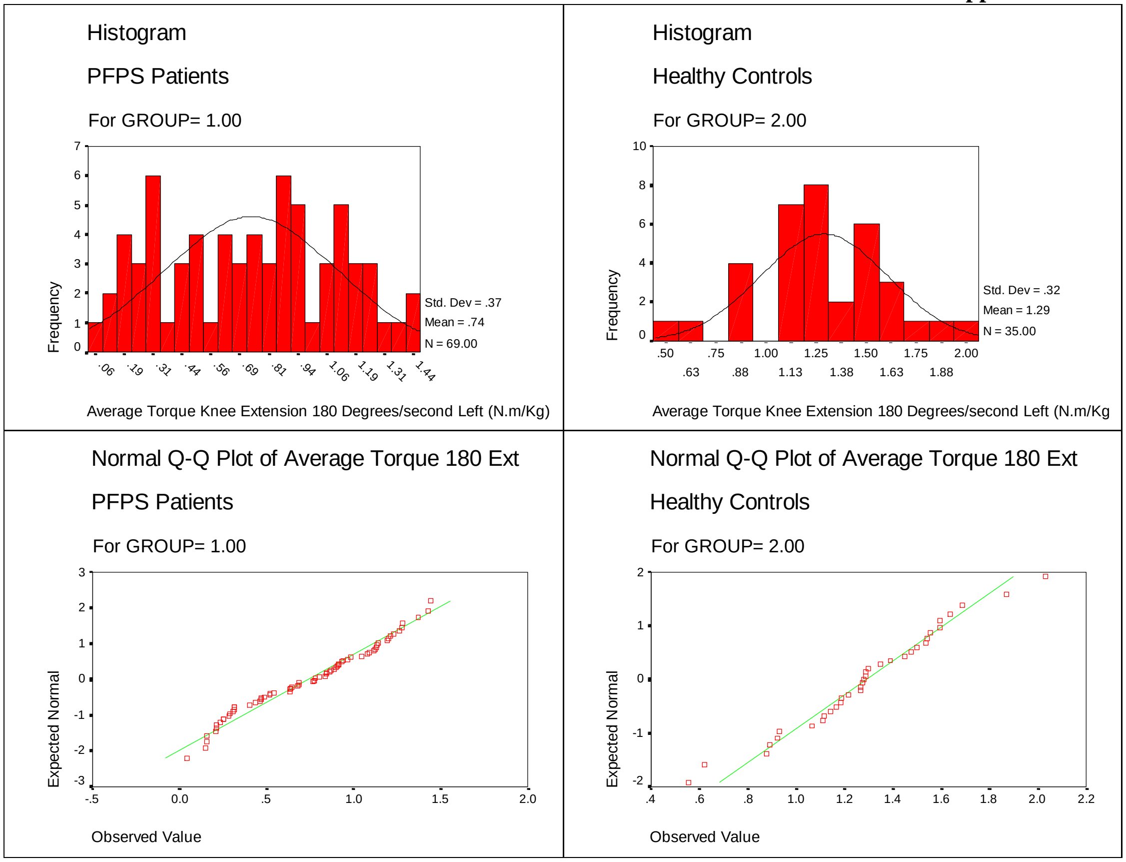
Graphs 13.39 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Flexion Right Knee at 90°/s Nm/kg



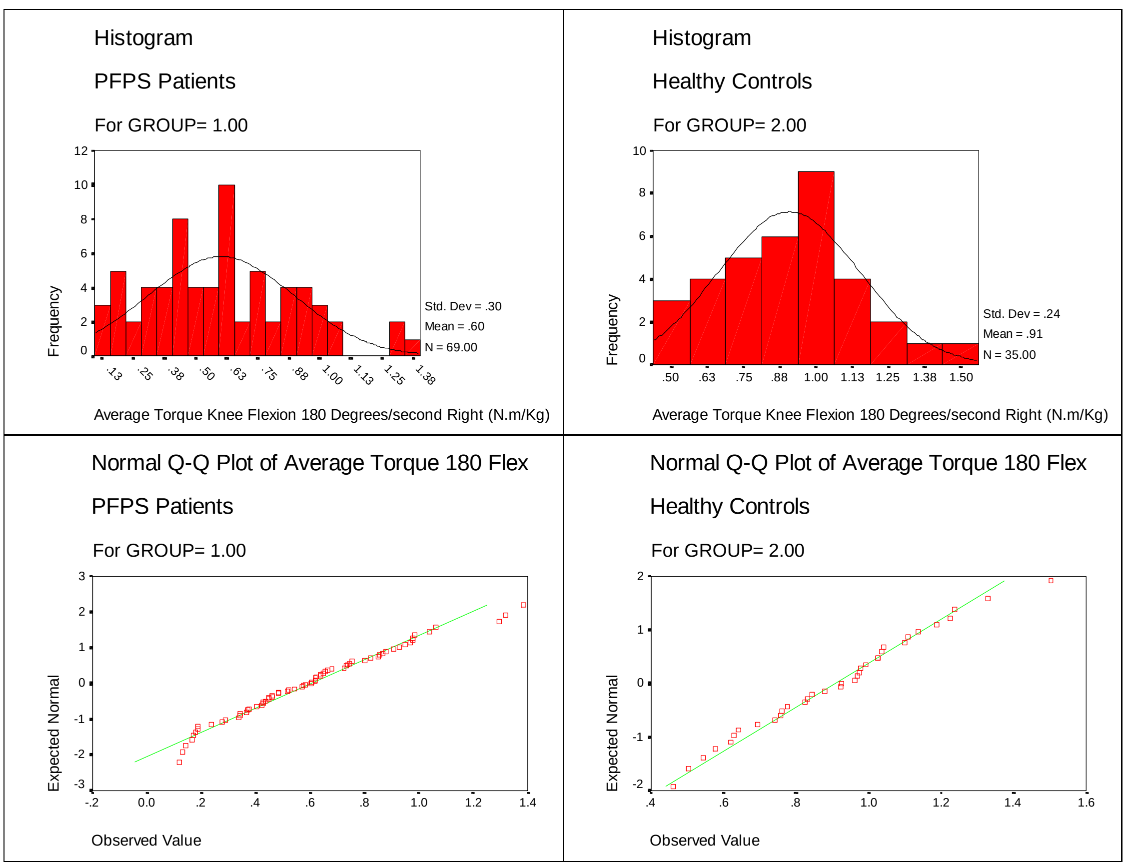
Graphs 13.40 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Flexion Left Knee at 90°/s Nm/kg



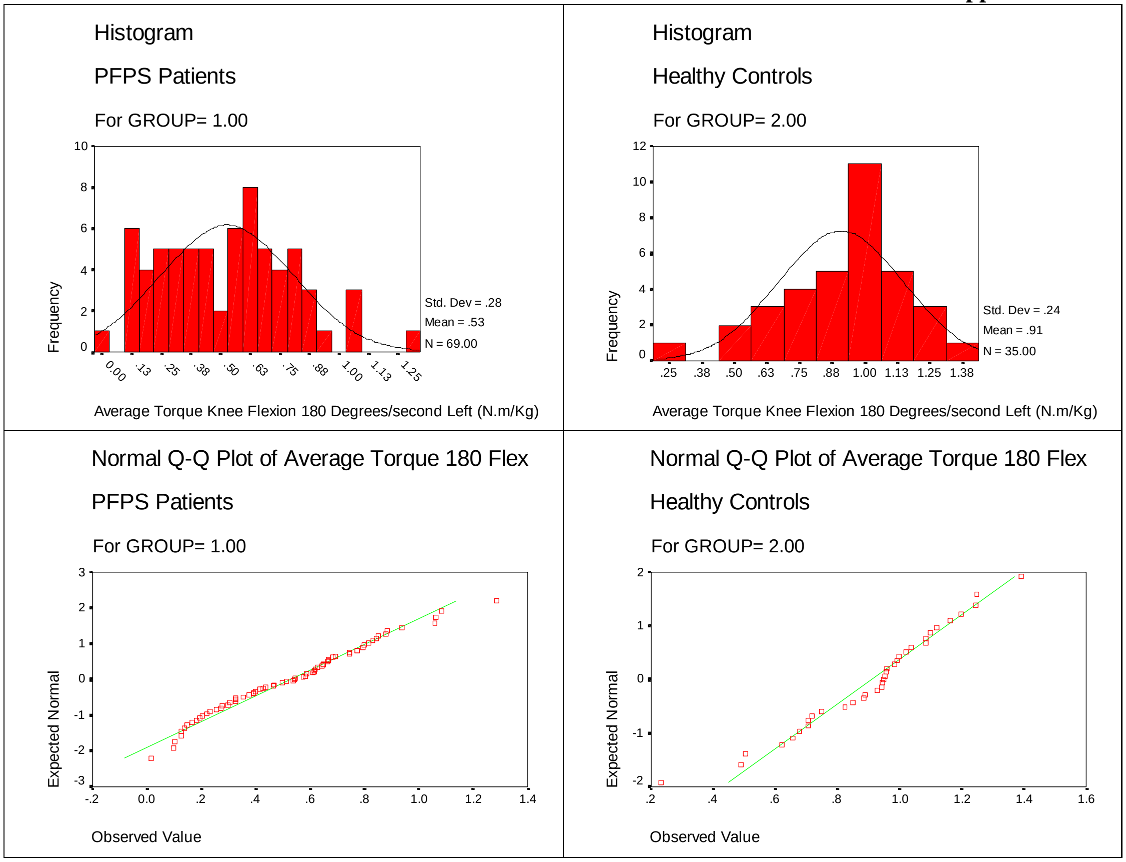
Graphs 741 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Extension Right Knee at 180°/s Nm/kg



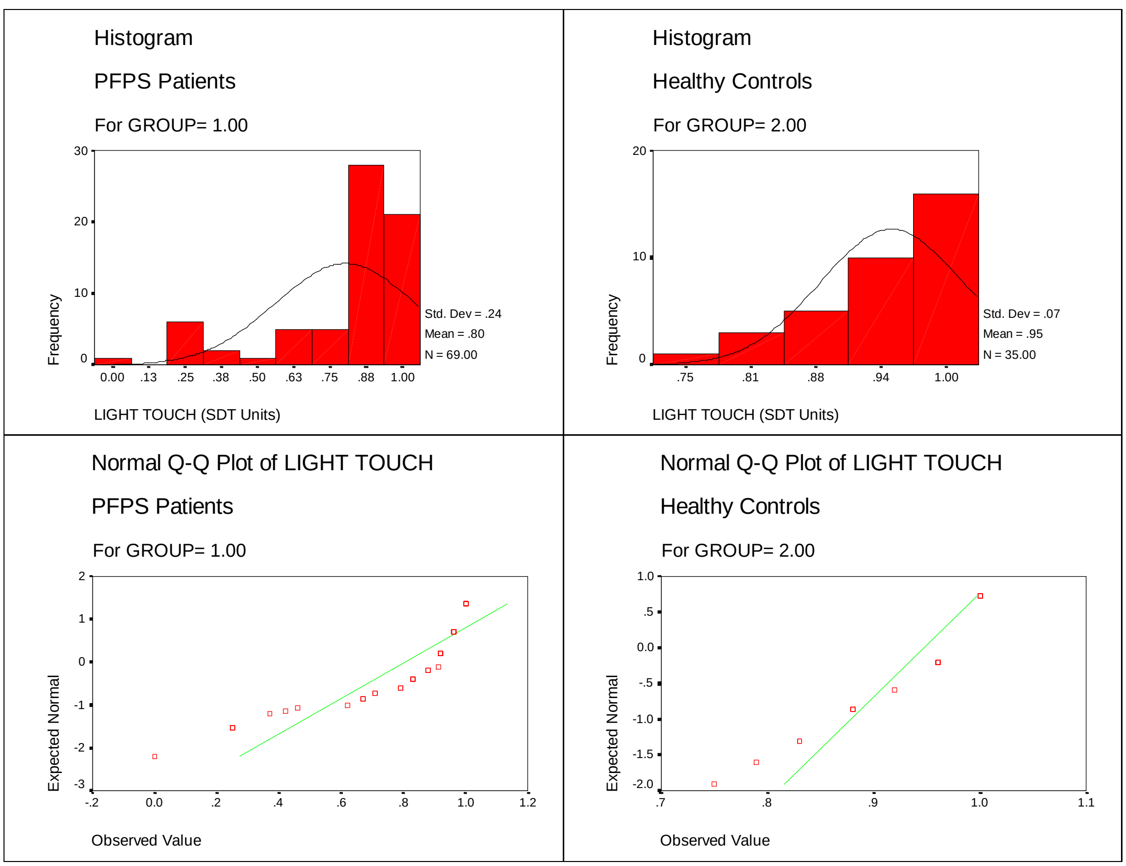
Graphs 13.42 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Extension Left Knee at 180°/s Nm/kg**



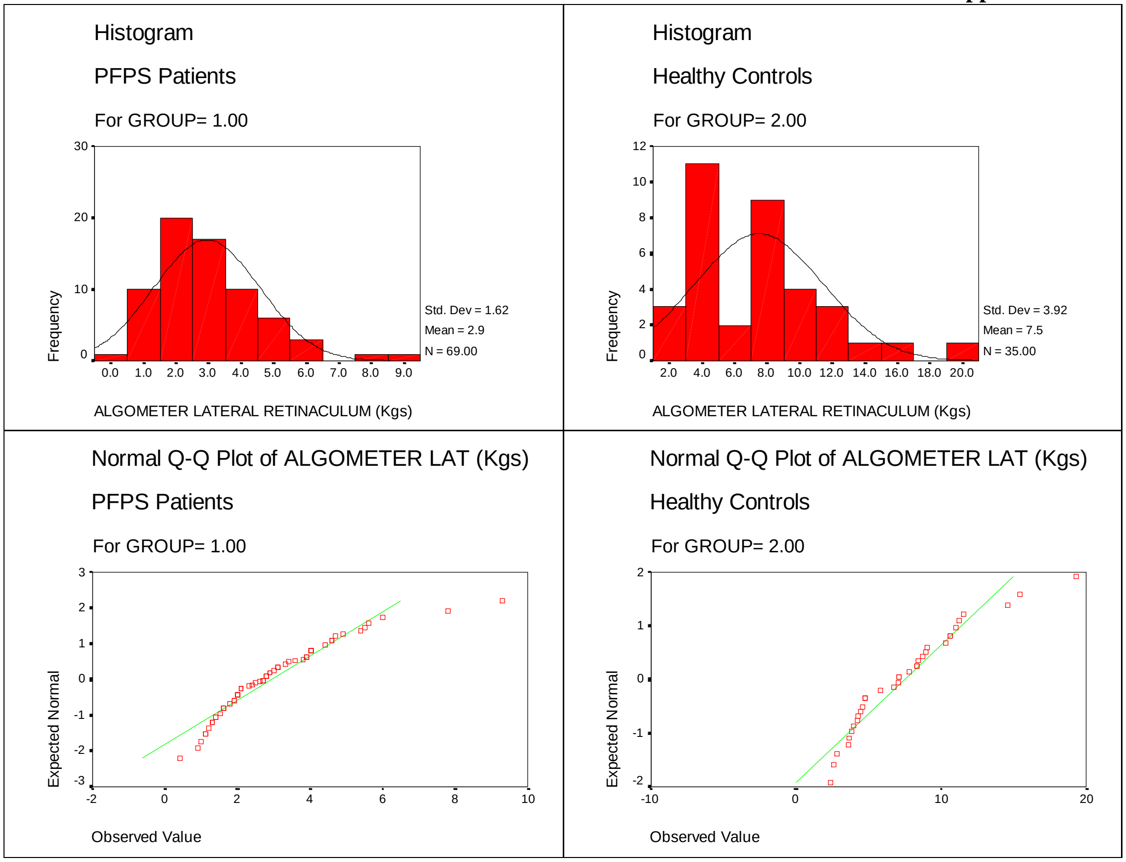
Graphs 13.43 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Flexion Right Knee at 180°/s Nm/kg**



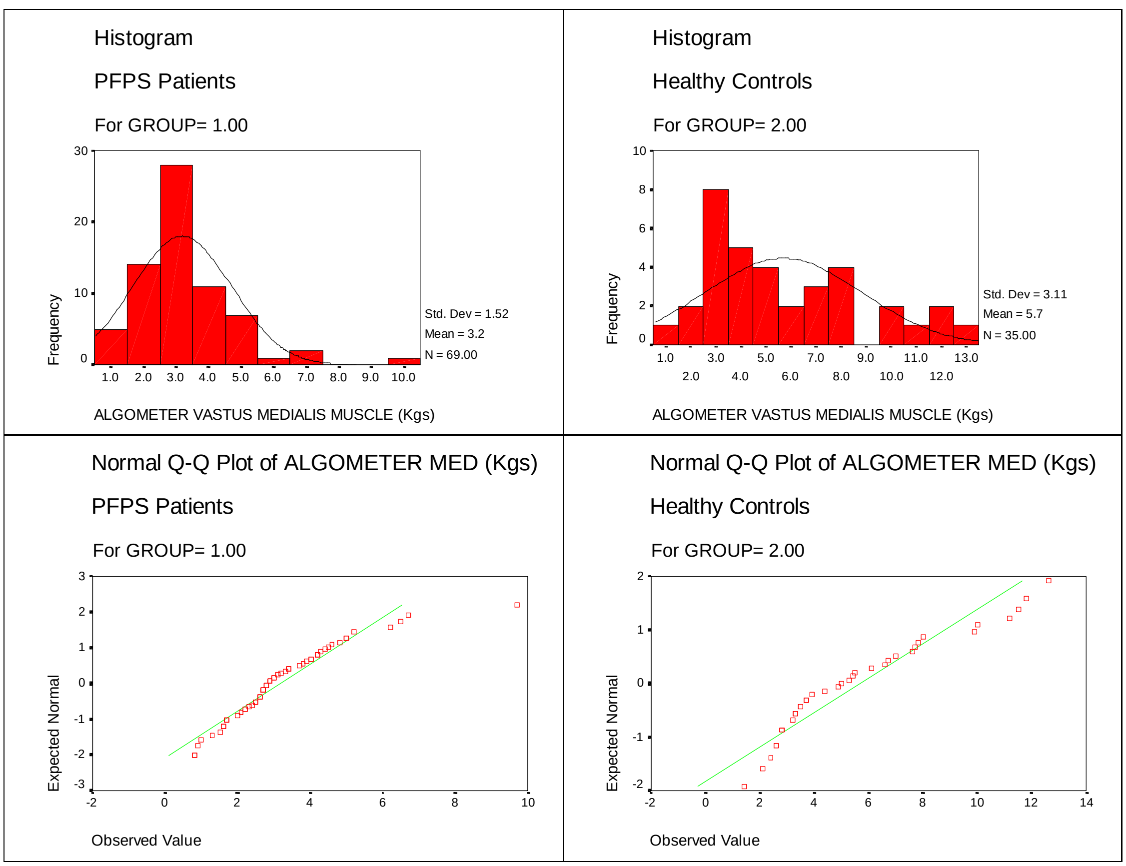
Graphs 13.44 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Flexion Left Knee at 180°/s Nm/kg**



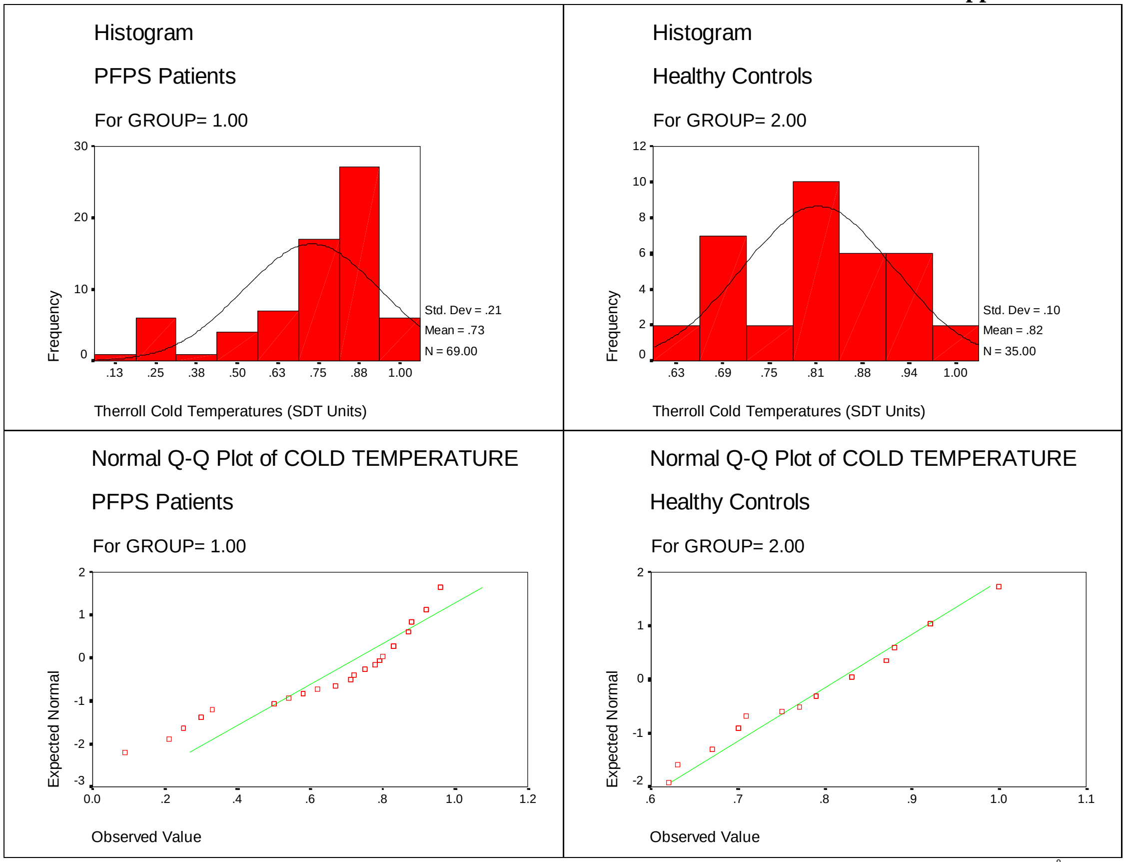
Graphs 13.45 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Light Touch SDT at Lateral Retinaculum (Units)**



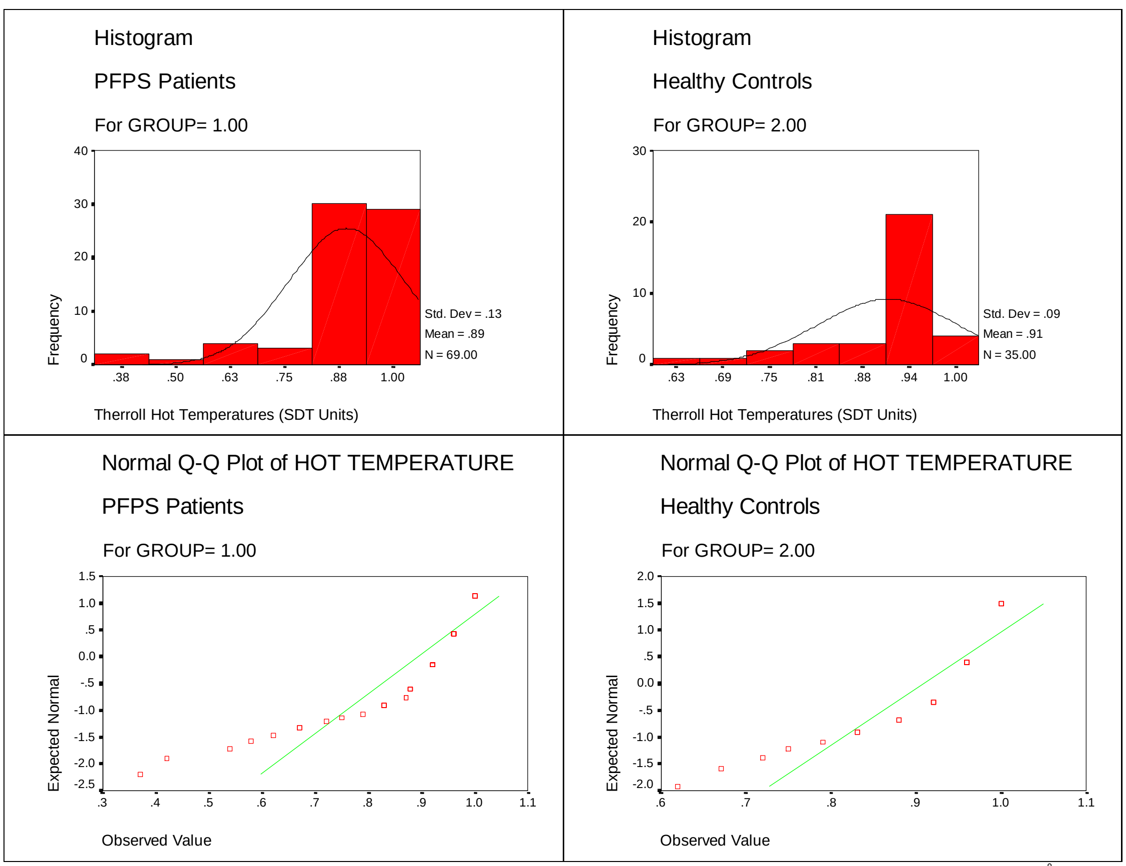
Graphs 13.46 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Algometer Measurements at Lateral Retinaculum (Kgs)



Graphs 13.47 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Algometer Measurements at Vastus Medialis Muscle (Kgs)



Graphs 13.48 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Therroll SDT Cold 12°/C (Units)**



Graphs 13.49 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Therroll SDT Hot 42°/C (Units)**

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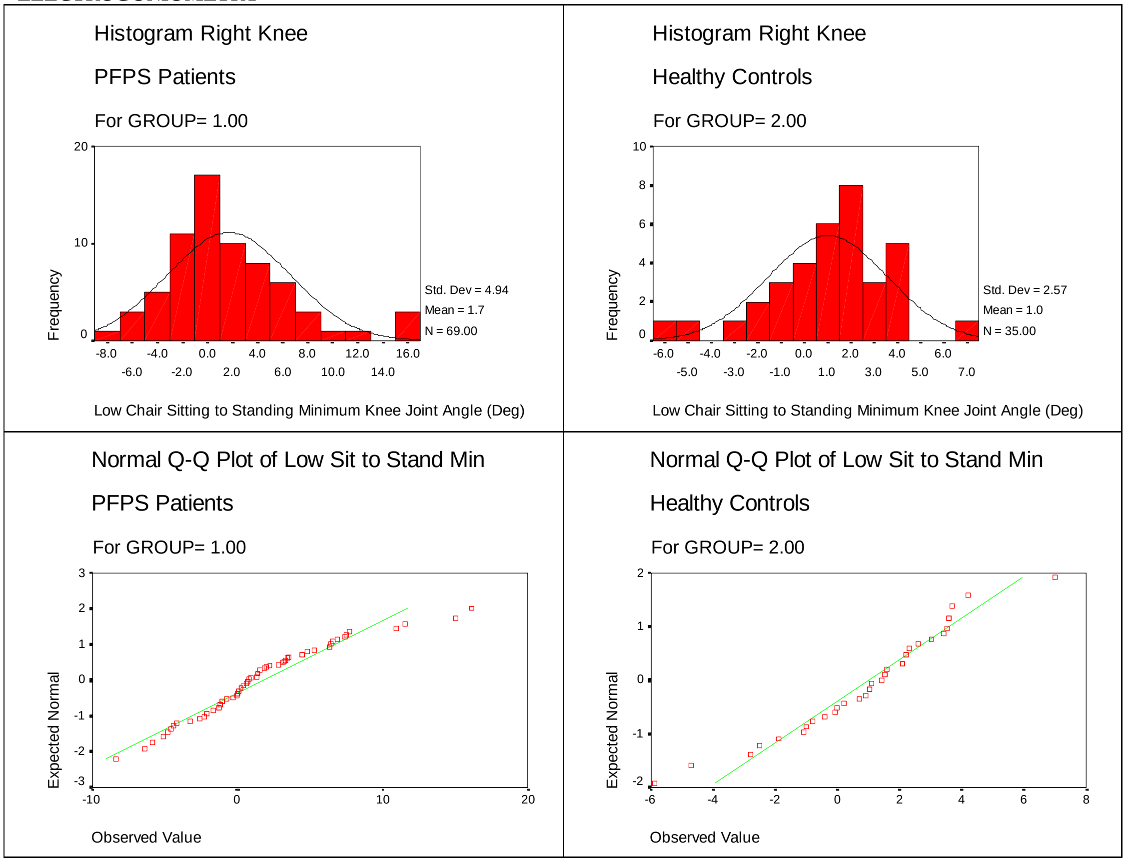
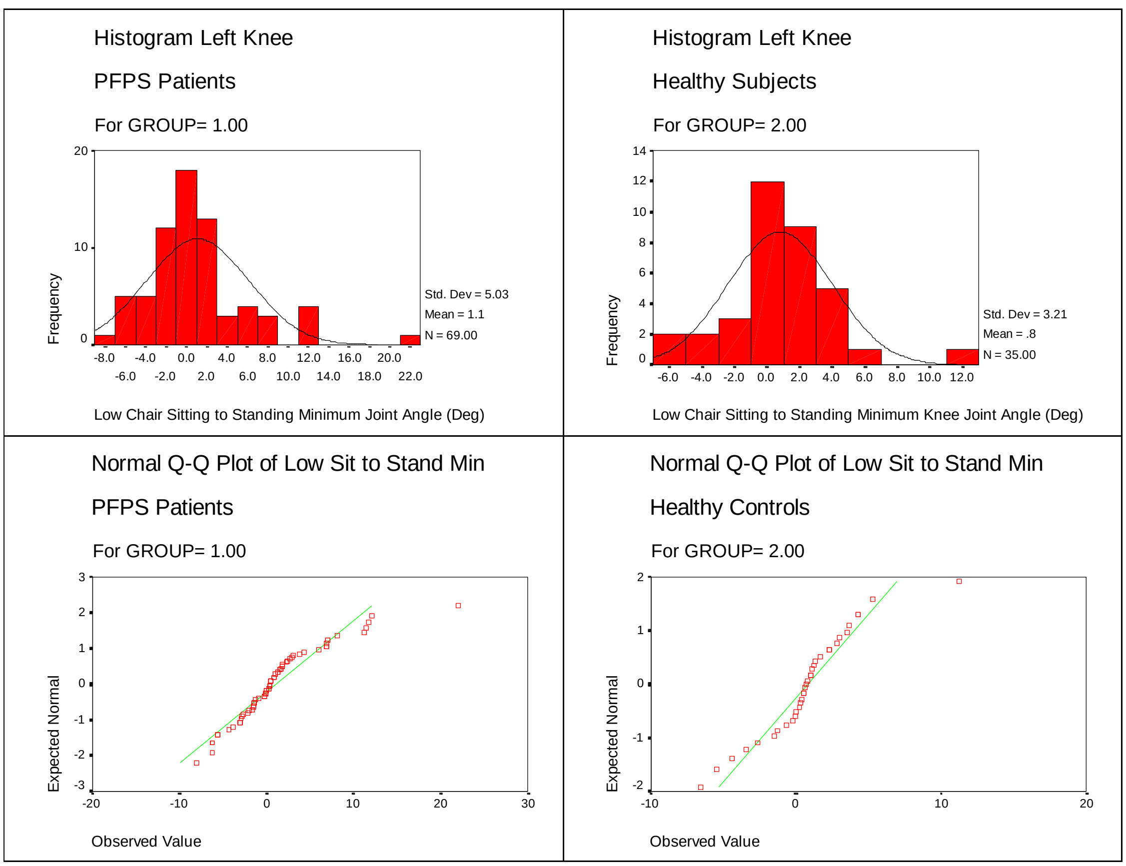
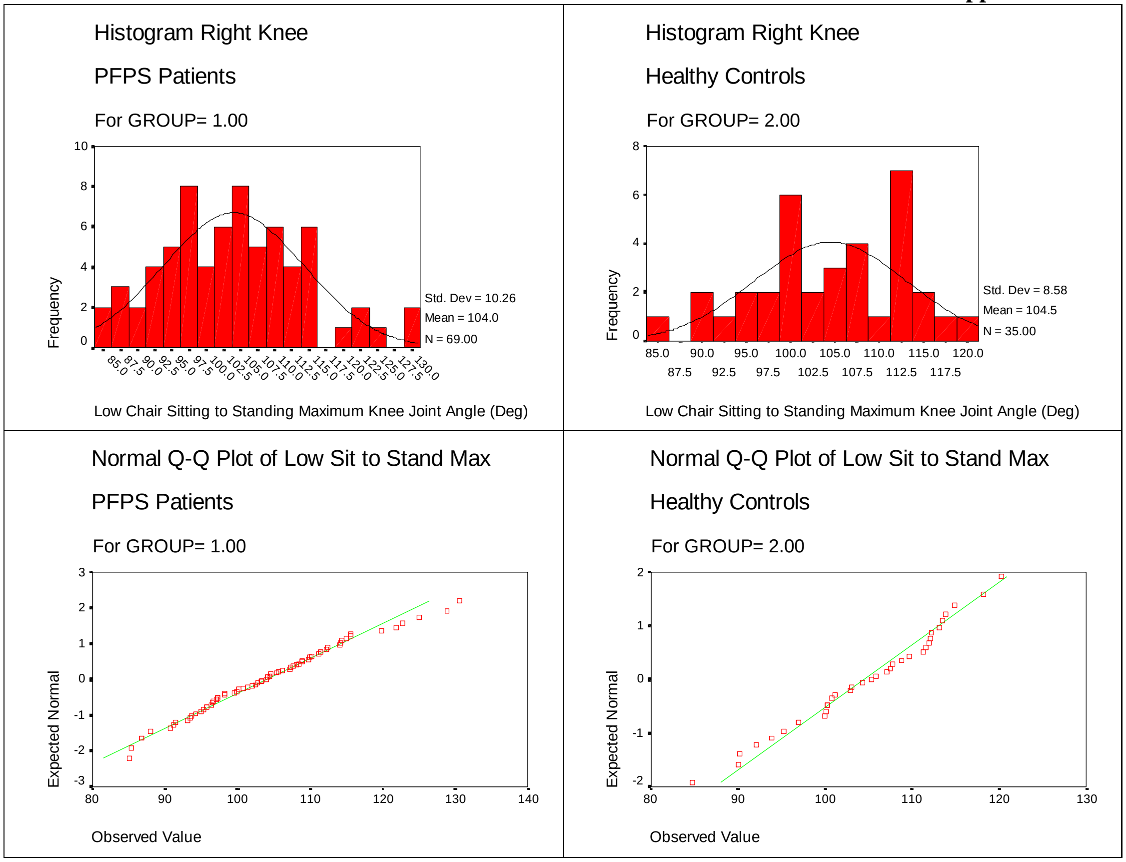


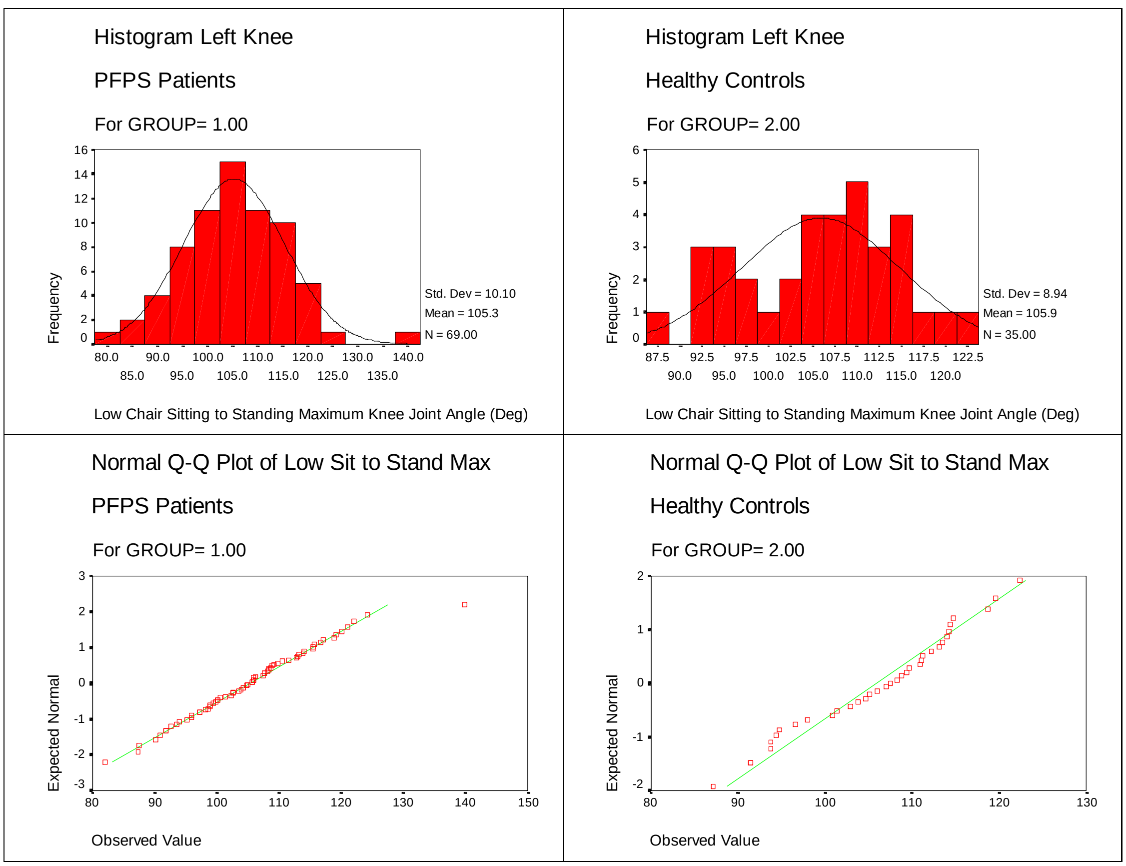
Graphs 13.50 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Minimum Right Knee Joint Angle (Degrees)



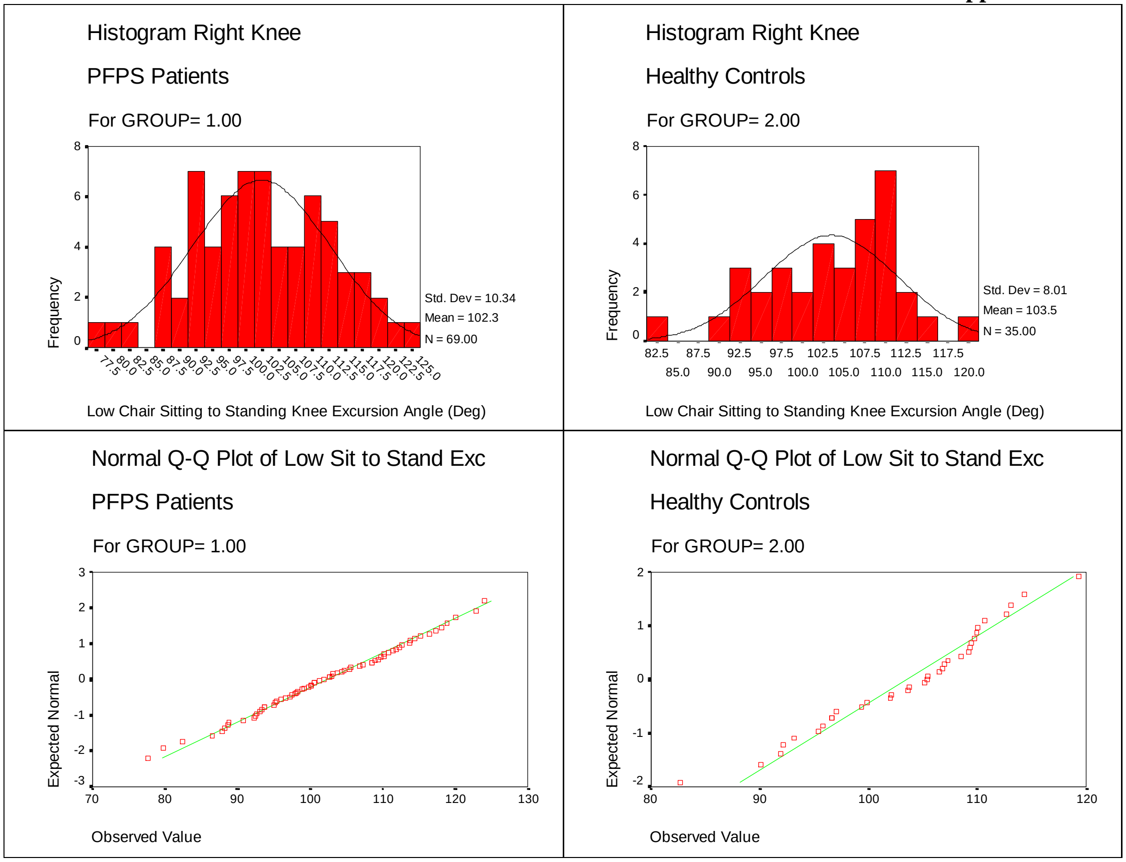
Graphs 13.52 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Minimum Left Knee Joint Angle (Degrees)



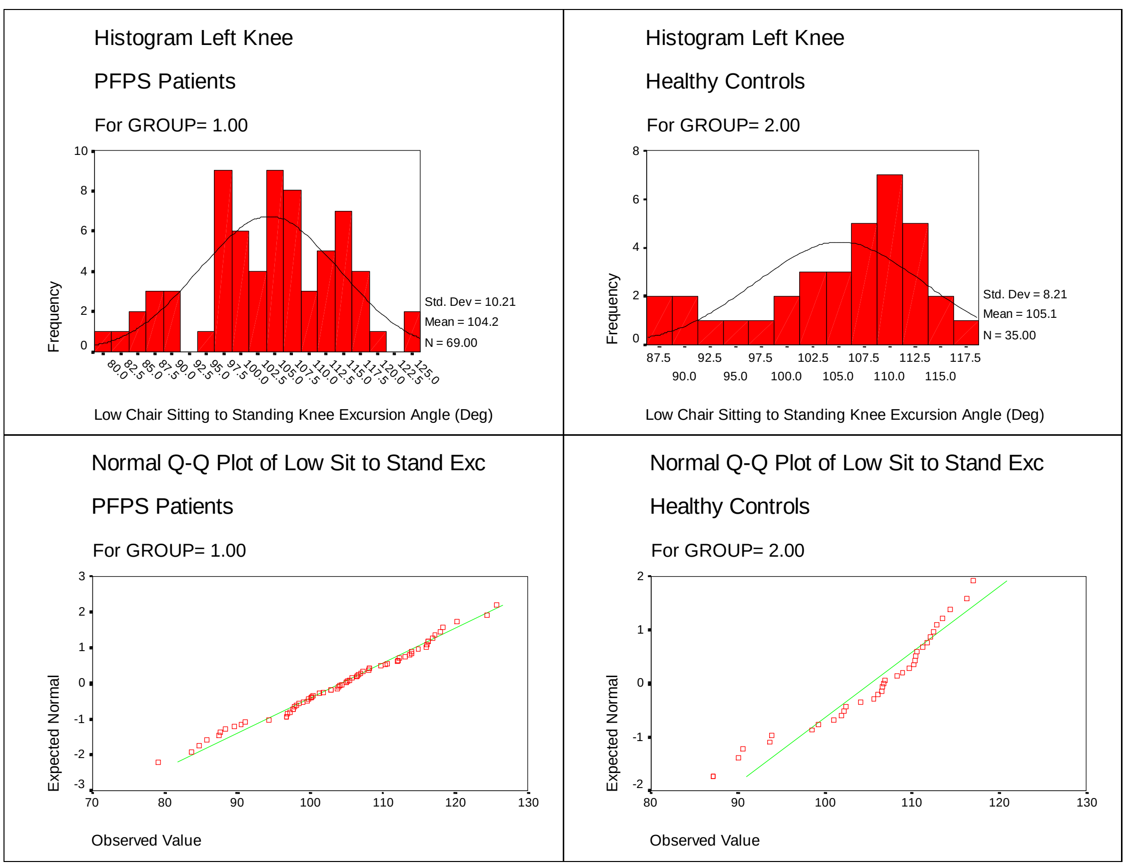
Graphs 13.53 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Maximum Right Knee Joint Angle (Degrees)



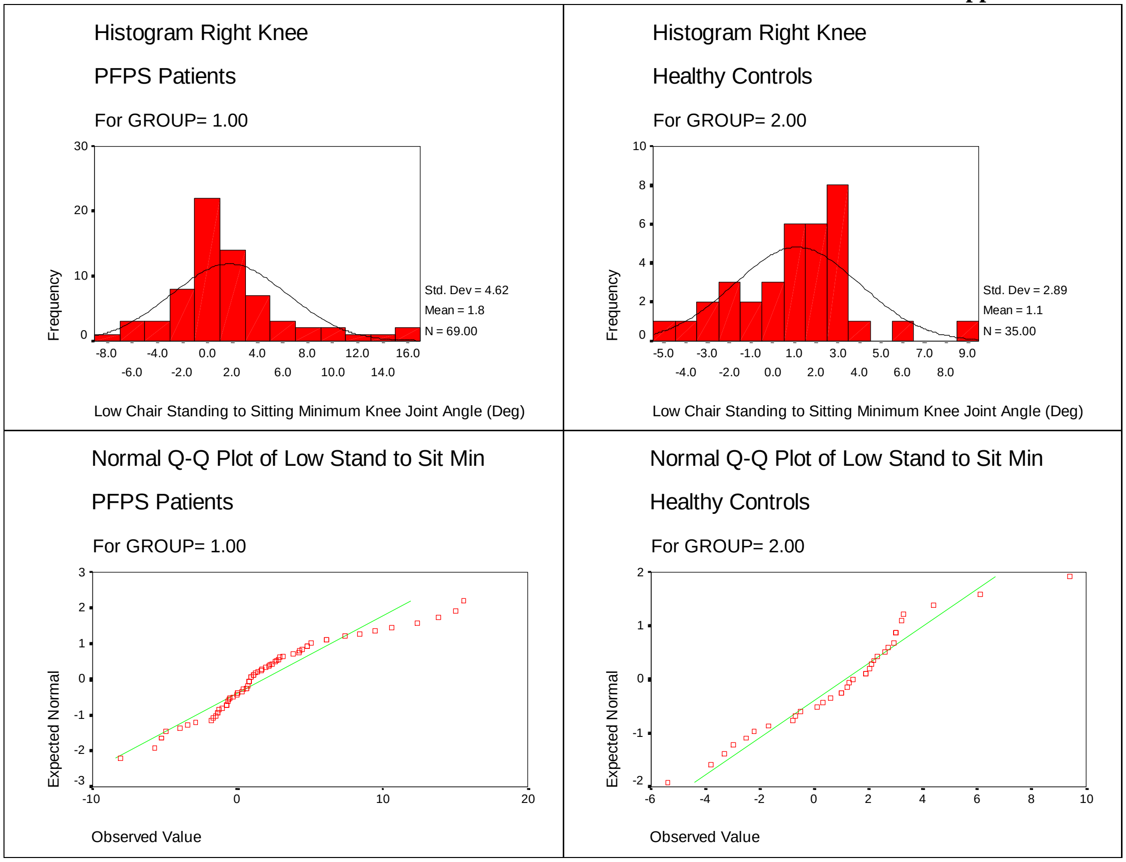
Graphs 13.54 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Maximum Left Knee Joint Angle (Degrees)



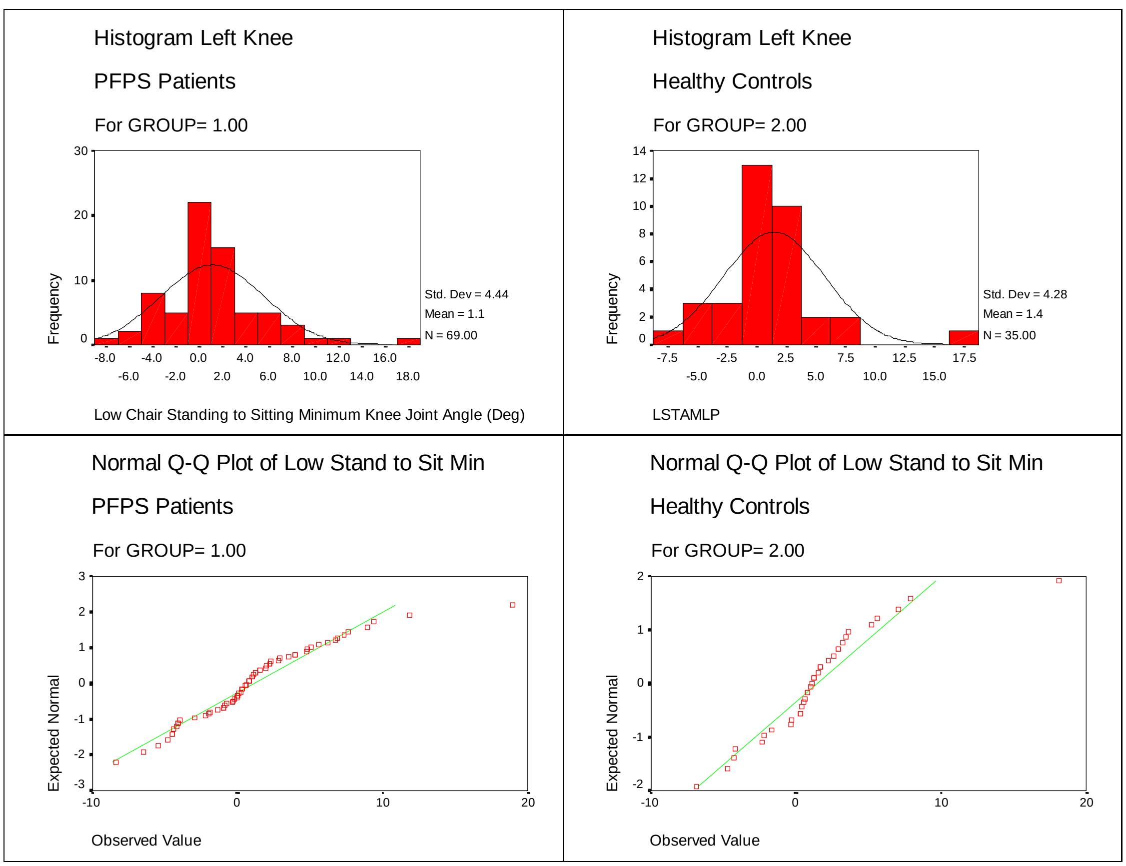
Graphs 13.55 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Right Knee Excursion Angle (Degrees)



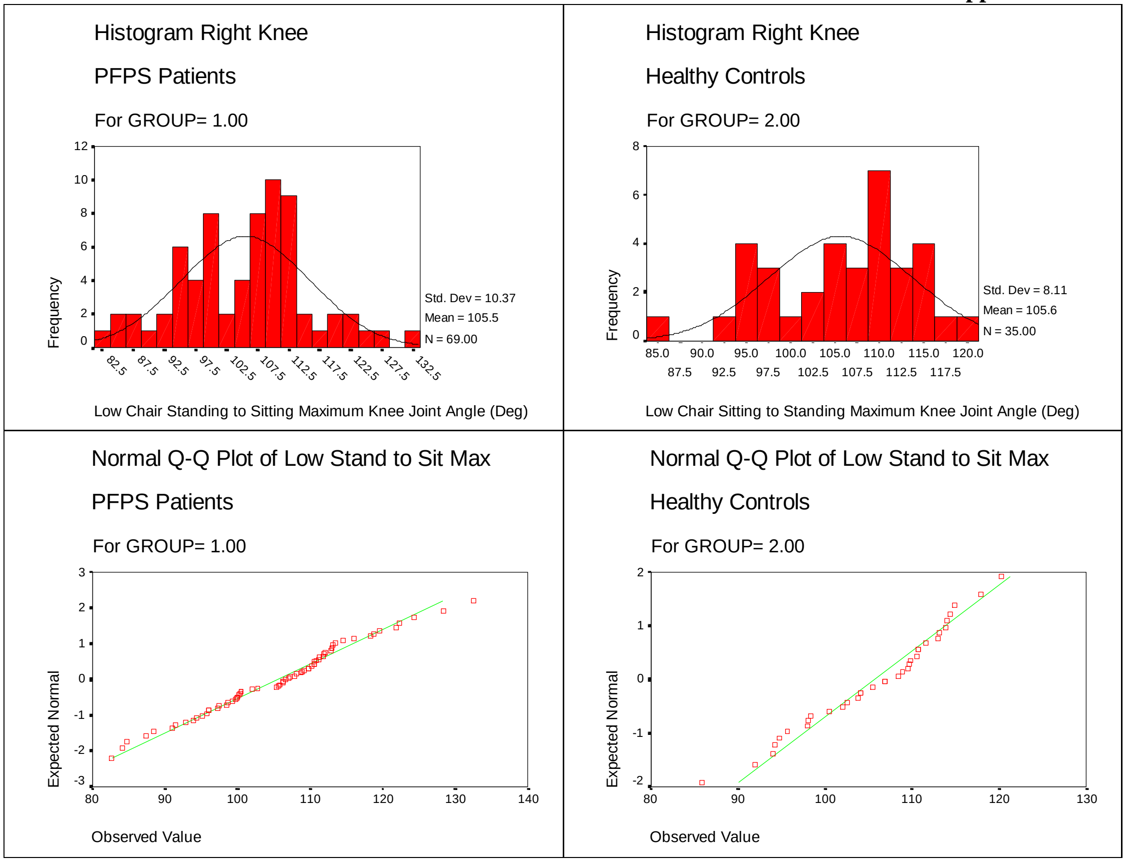
Graphs 13.56 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Left Knee Excursion Angle (Degrees)



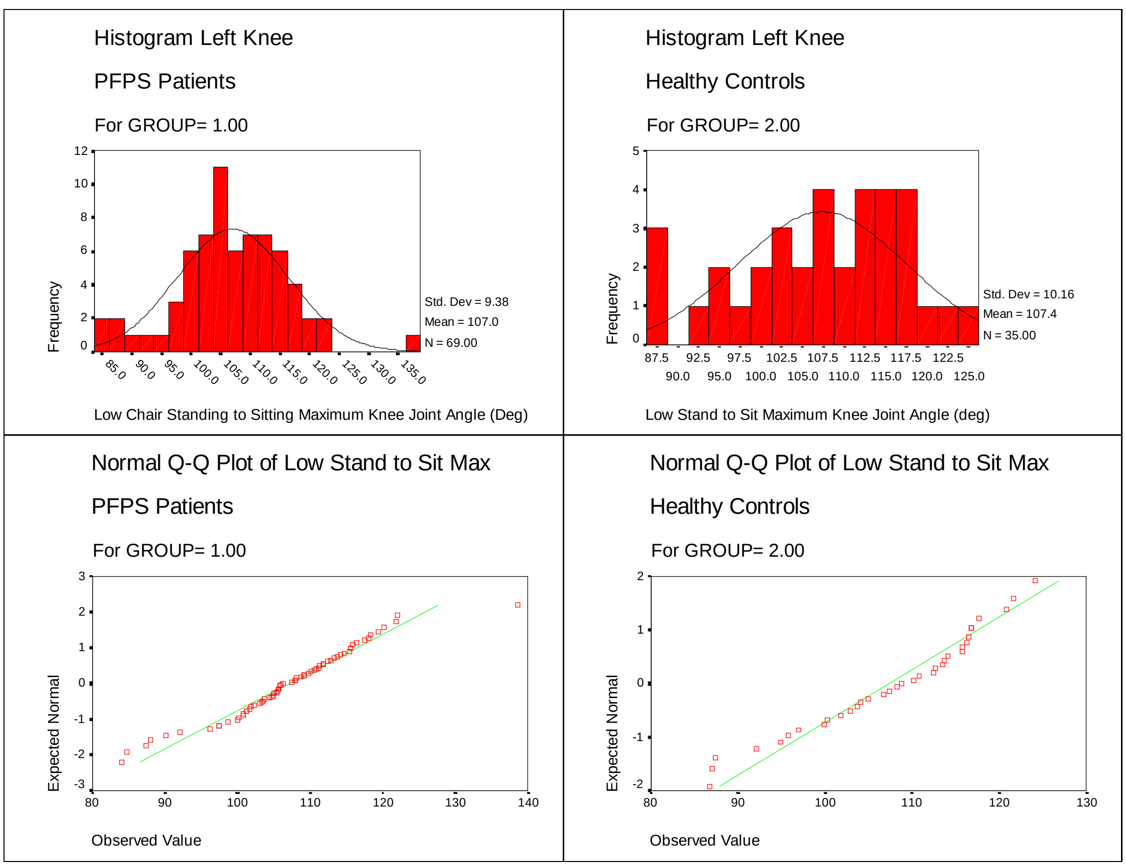
Graphs 13.57 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Minimum Right Knee Joint Angle (Degrees)



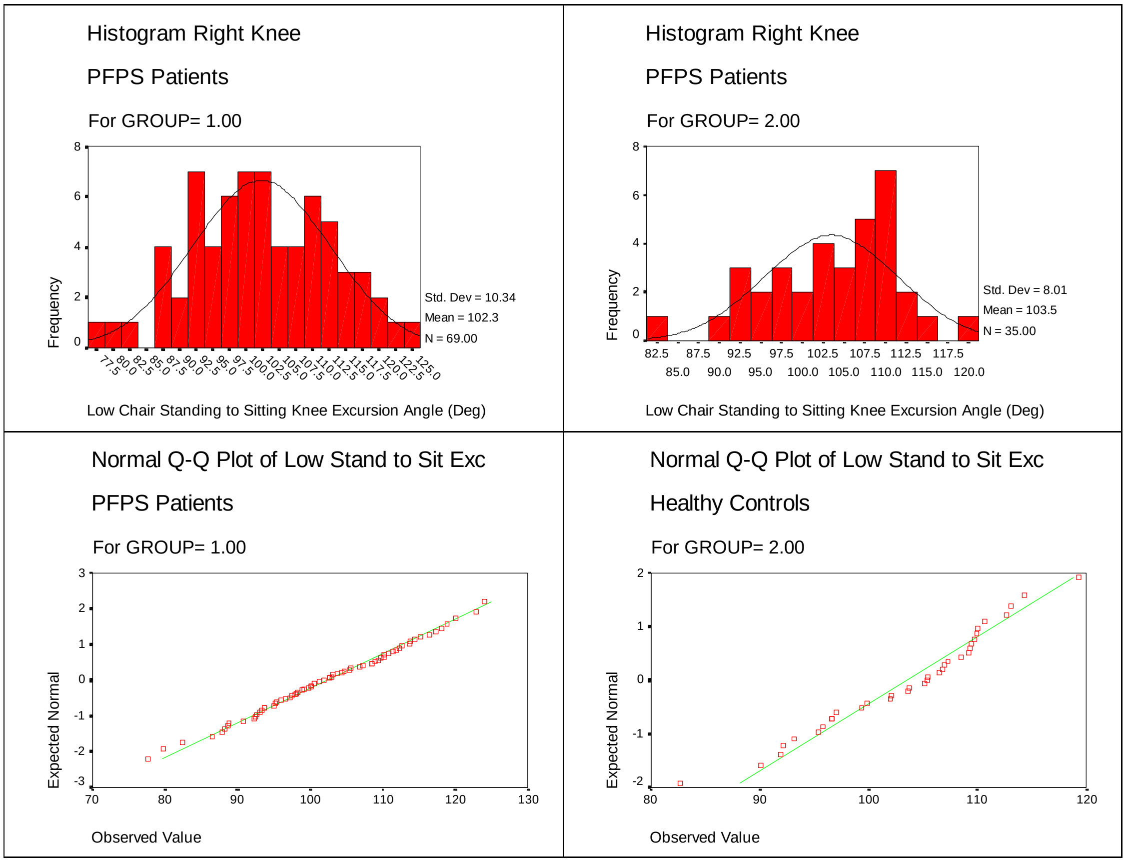
Graphs 13.58 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Minimum Left Knee Joint Angle (Degrees)



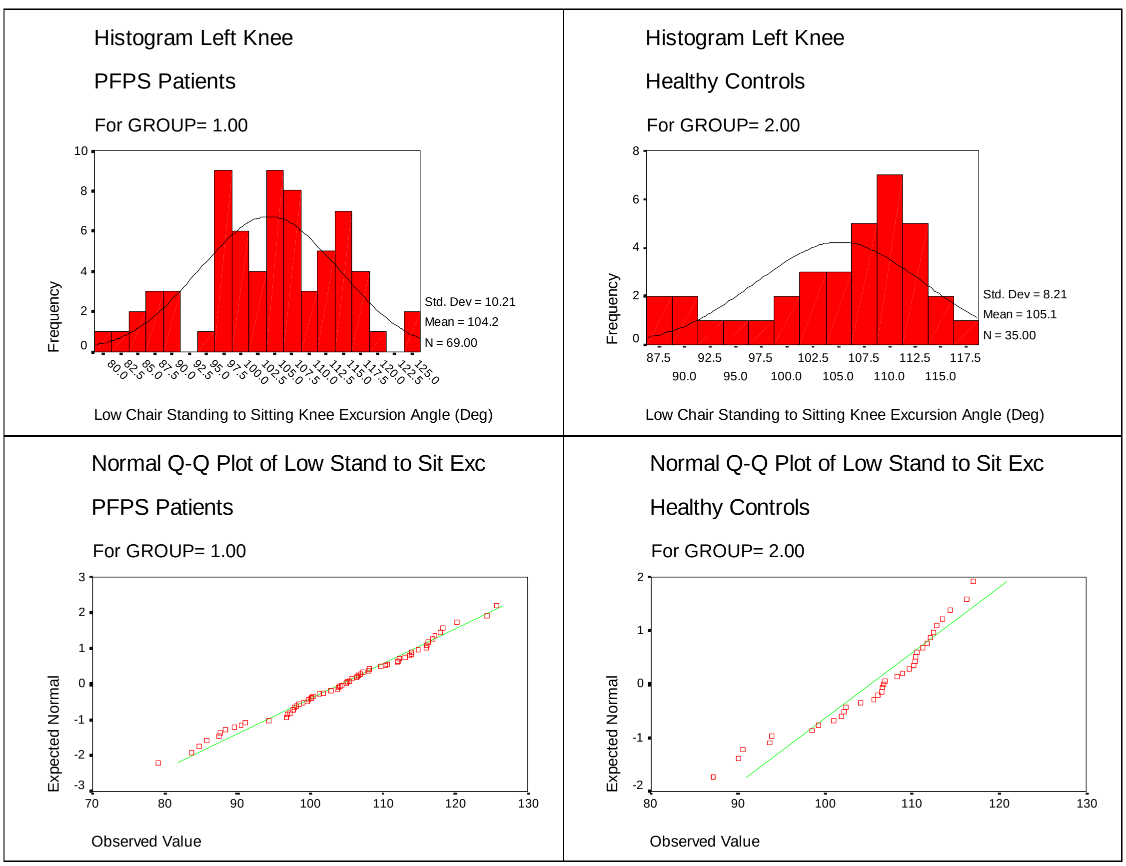
Graphs 13.59 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Maximum Right Knee Joint Angle (Degrees)



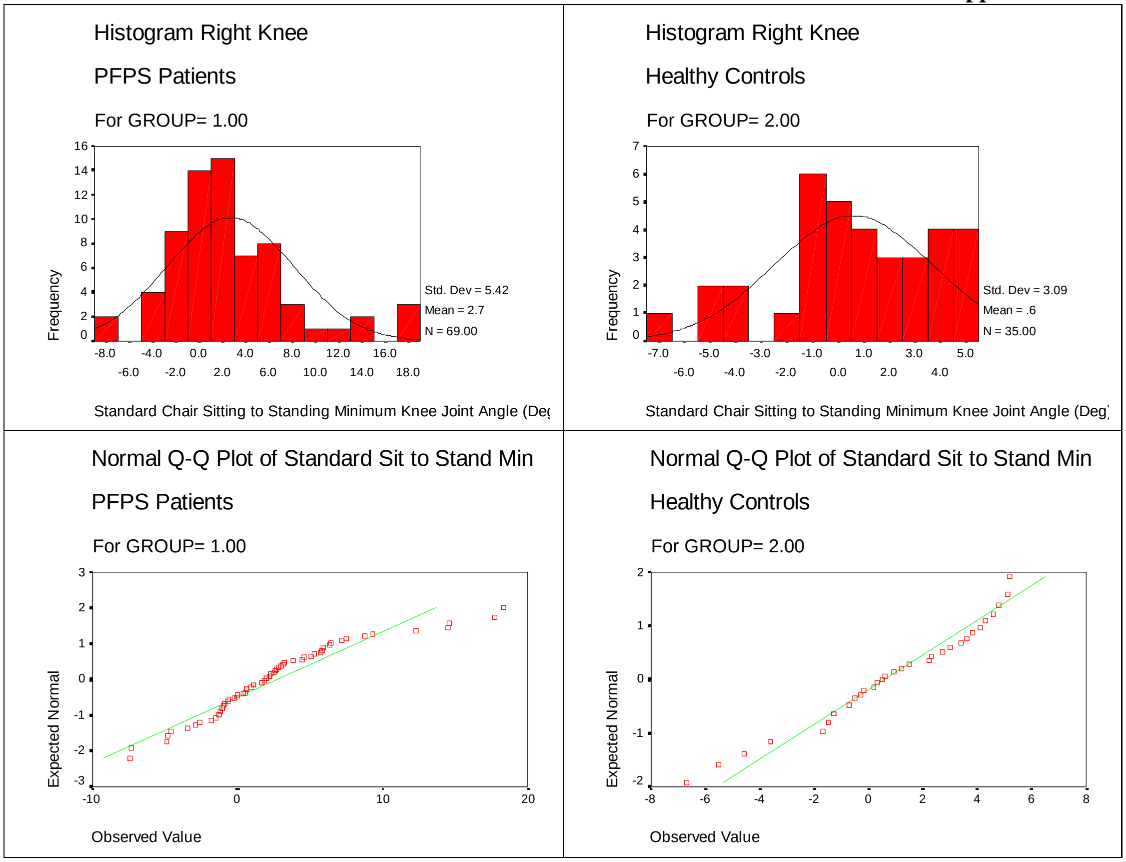
Graphs 13.60 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Maximum Left Knee Joint Angle (Degrees)



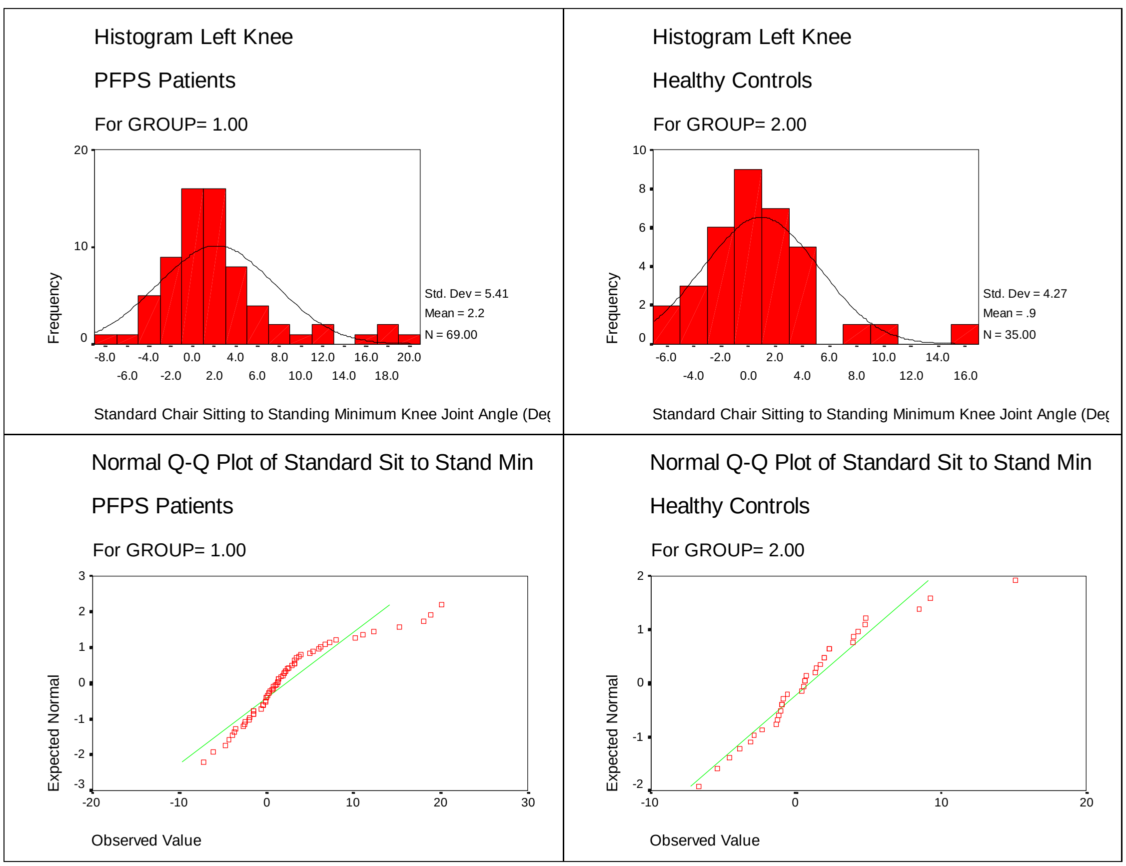
Graphs 13.61 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Right Knee Excursion Angle (Degrees)



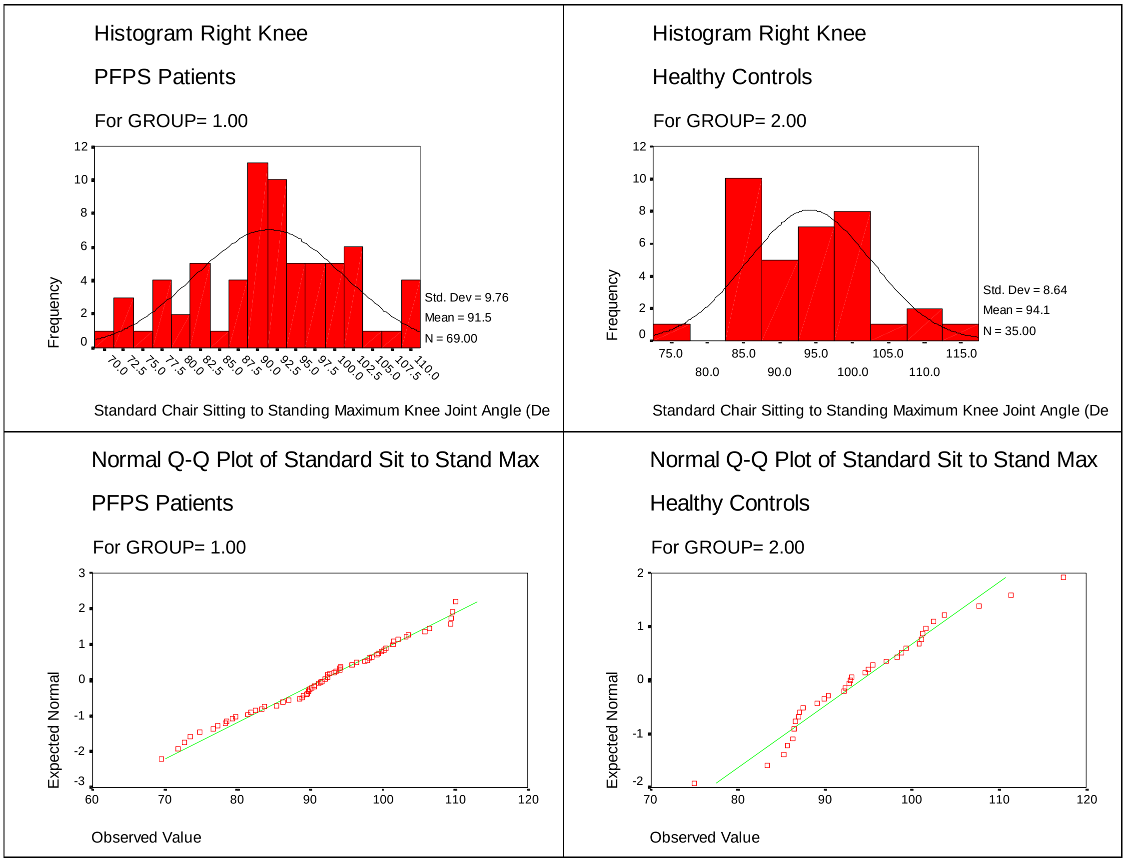
Graphs 13.62 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Left Knee Excursion Angle (Degrees)



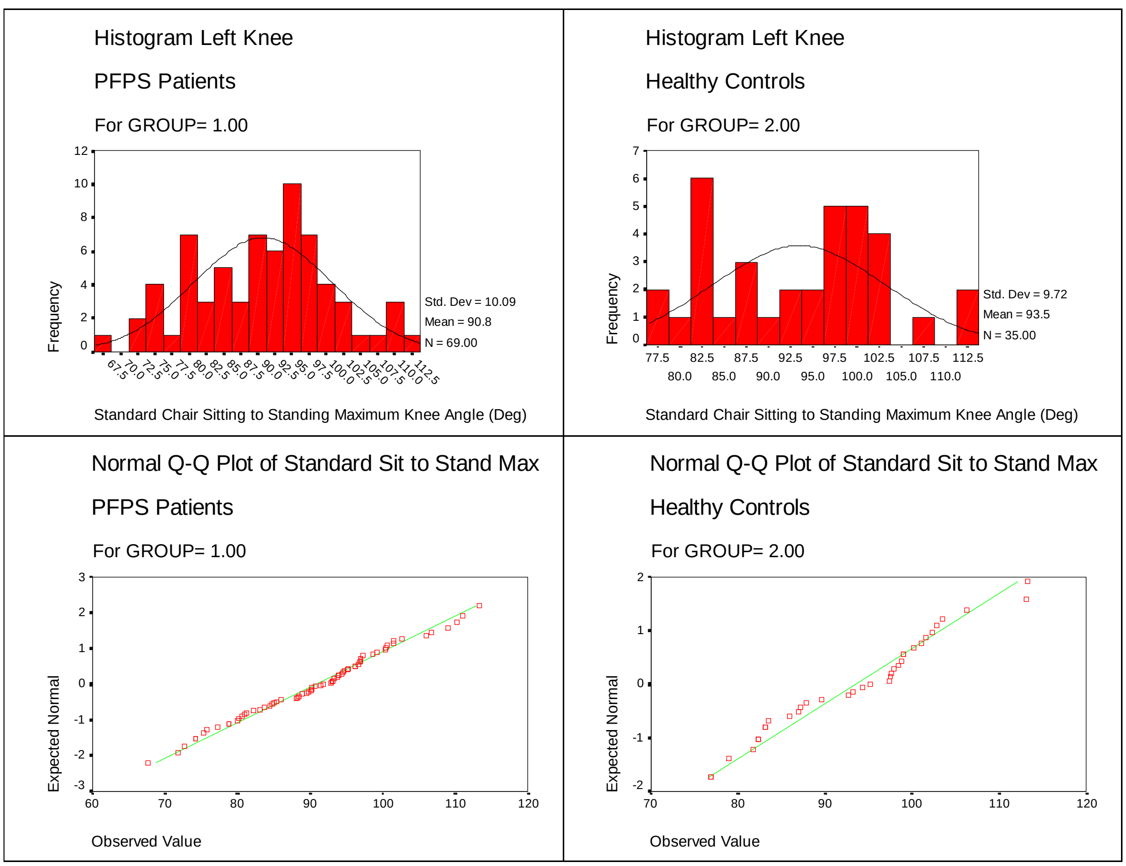
Graphs 13.63 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Minimum Right Knee Joint Angle (Degrees)**



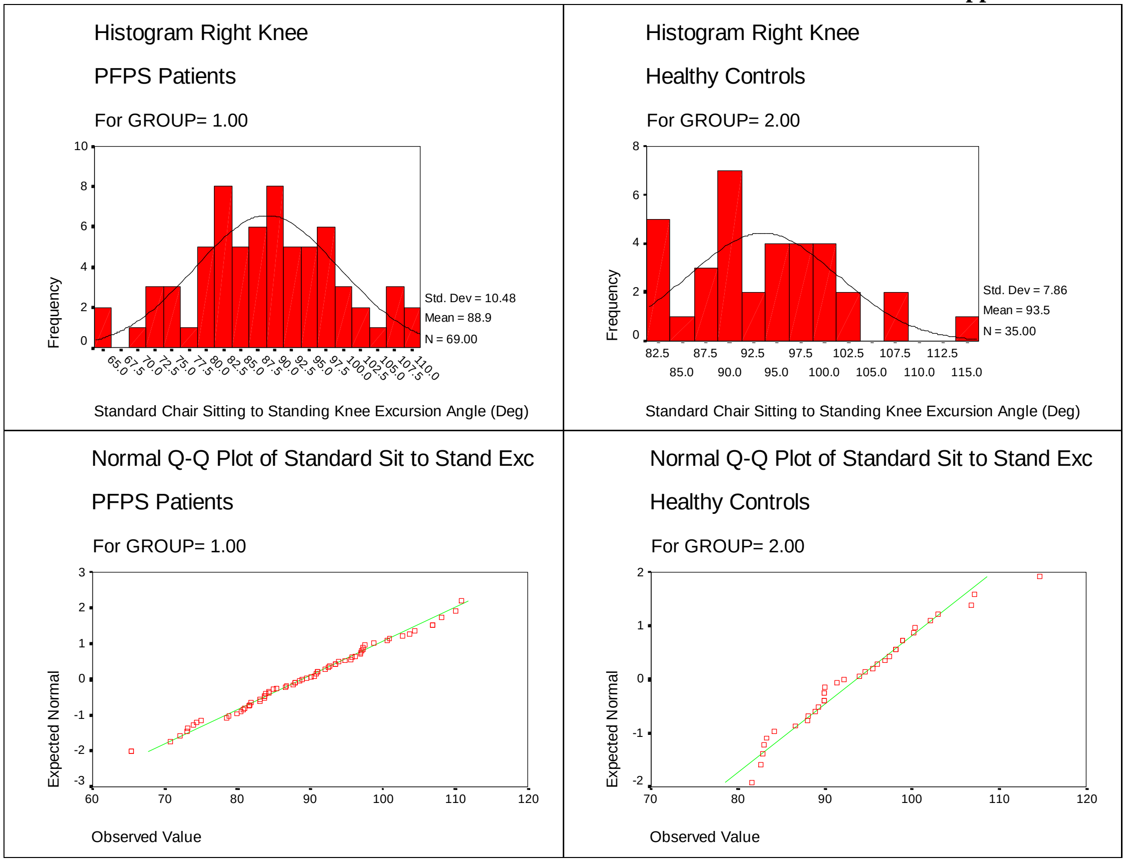
Graphs 13.64 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Minimum Left Knee Joint Angle (Degrees)**



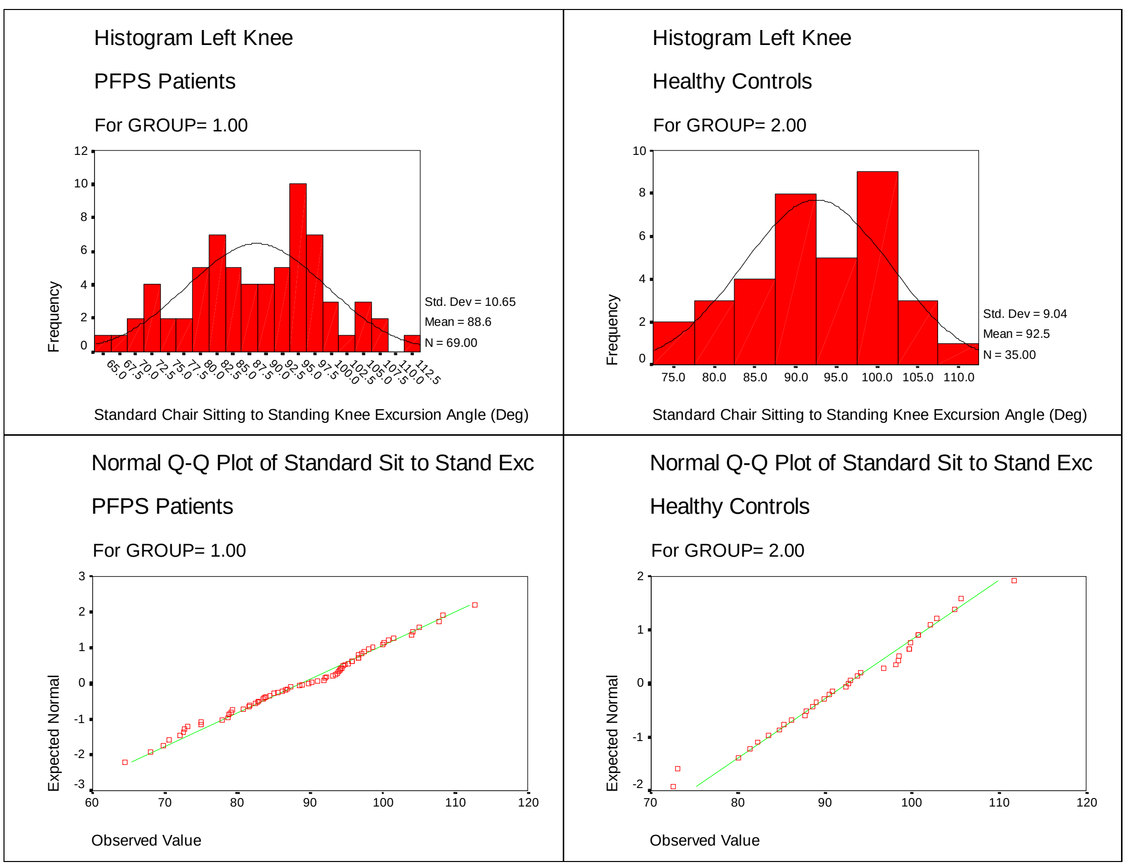
Graphs 13.65 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Maximum Right Knee Joint Angle (Degrees)



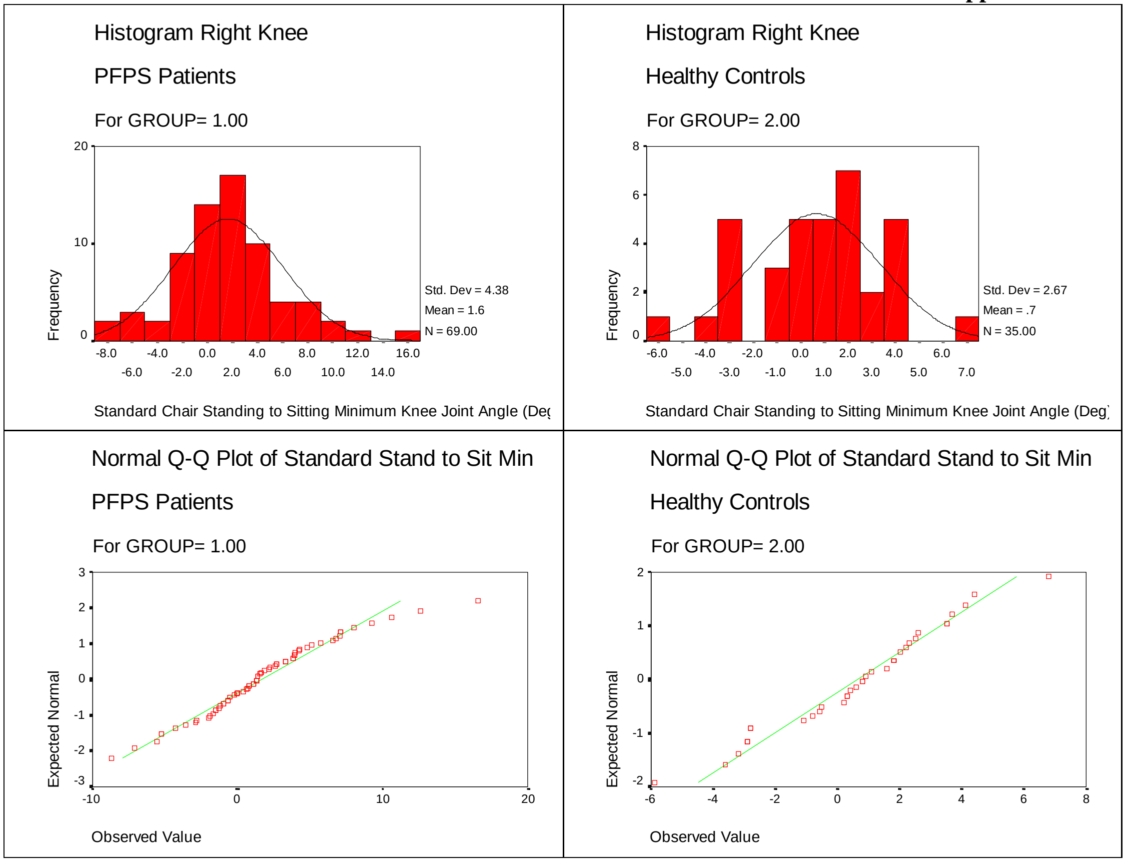
Graphs 13.66 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Minimum Left Knee Joint Angle (Degrees)



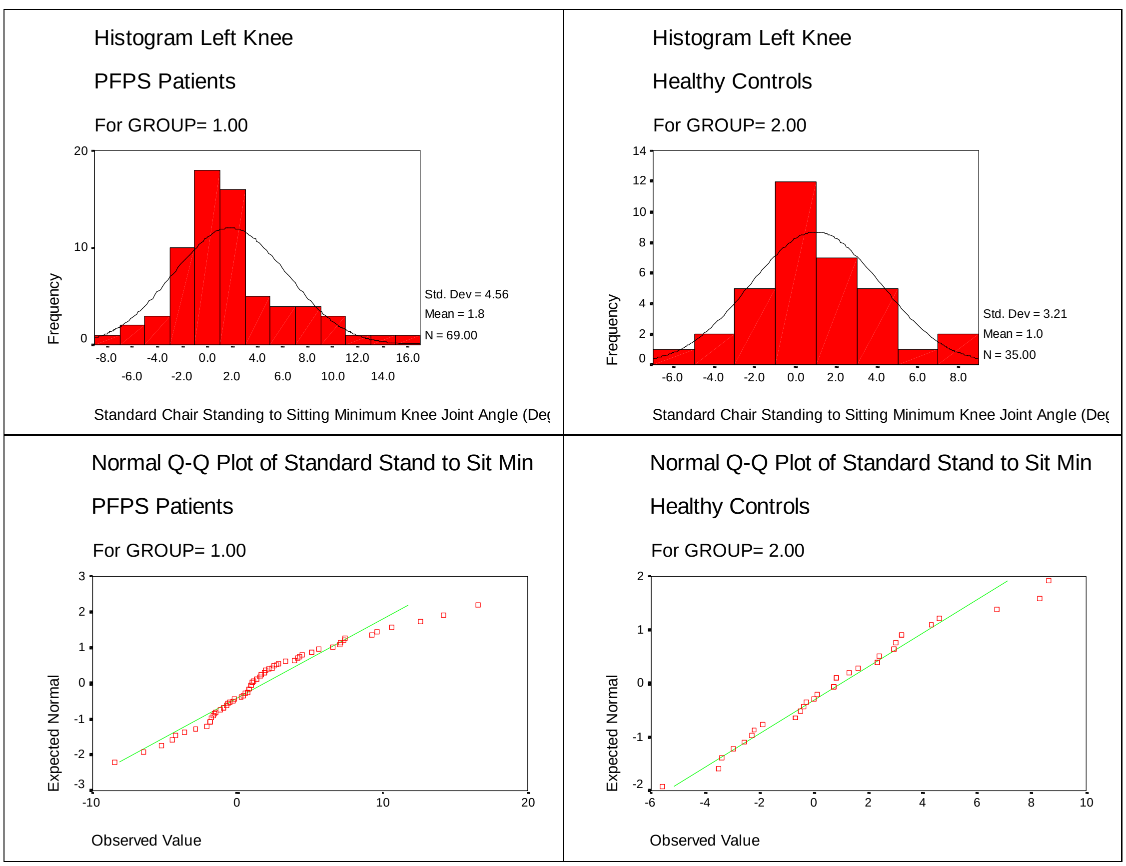
Graphs 13.67 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Right Knee Excursion Angle (Degrees)**



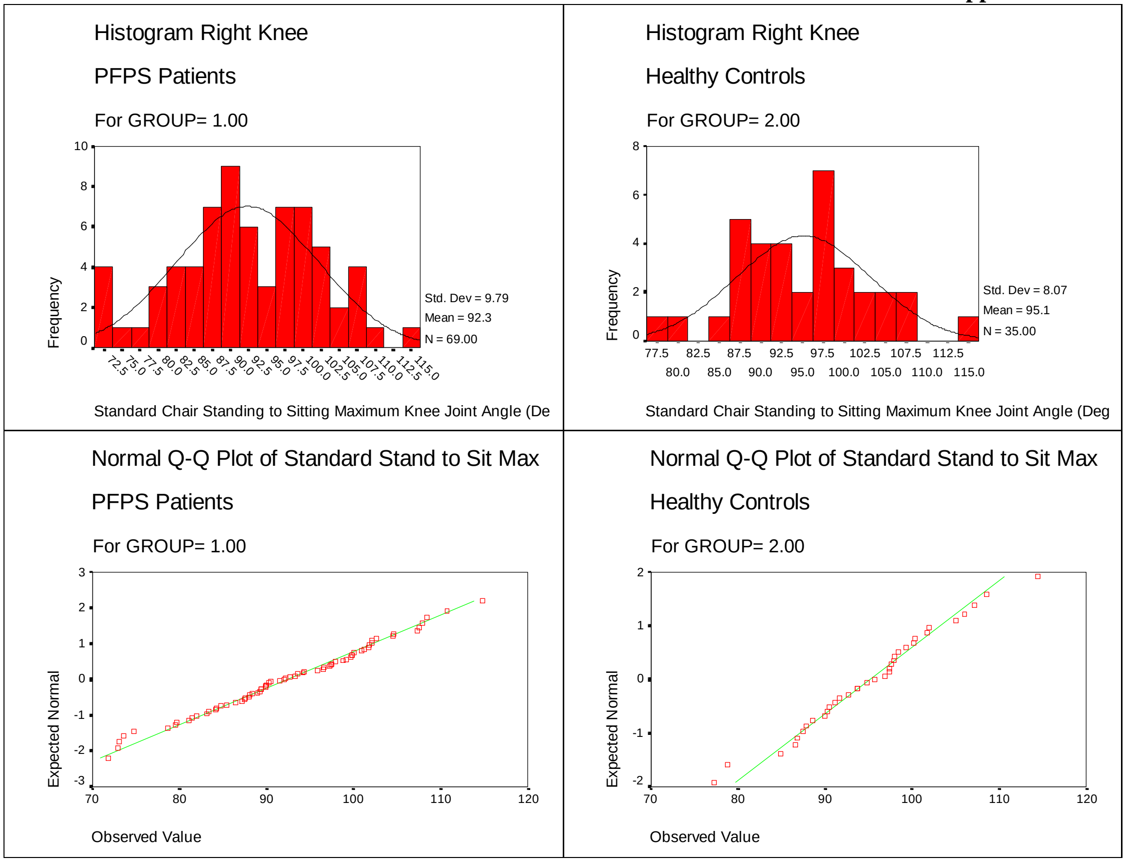
Graphs 13.68 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Left Knee Excursion Angle (Degrees)**



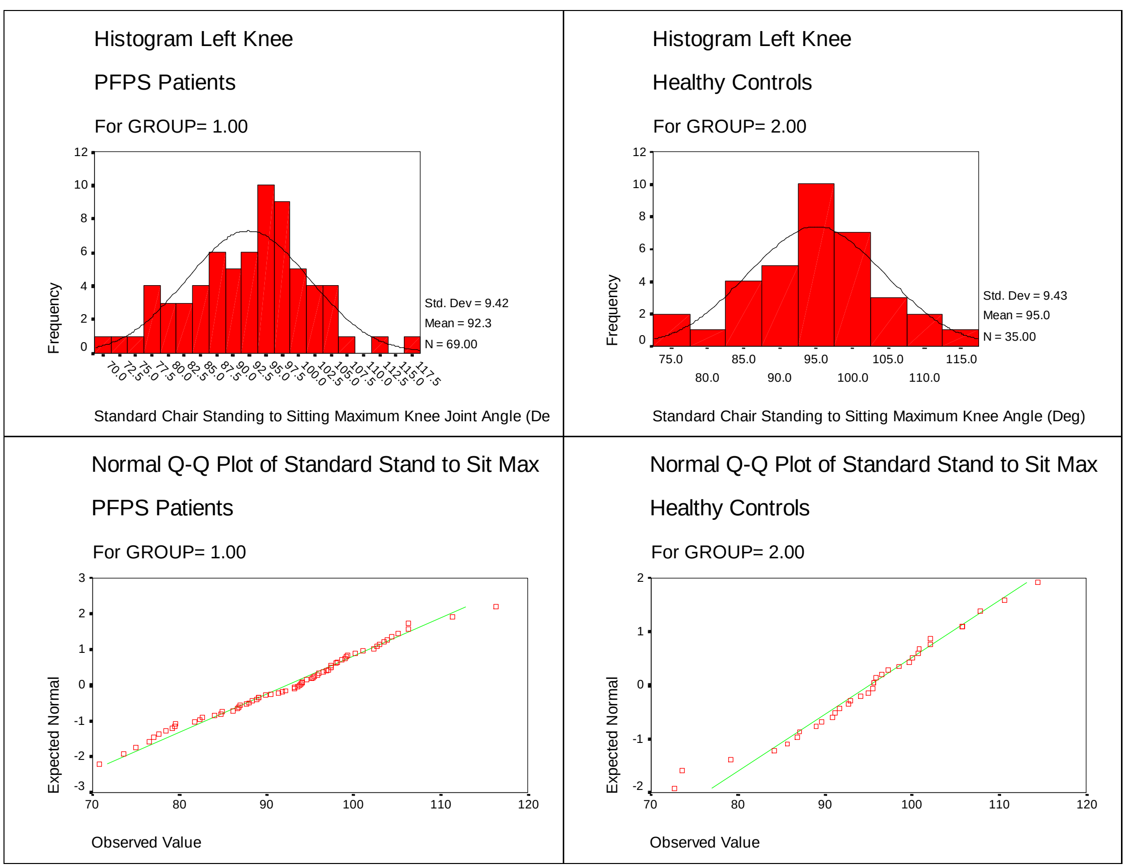
Graphs 13.69 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Standard Chair Minimum Right Knee Joint Angle (Degrees)**



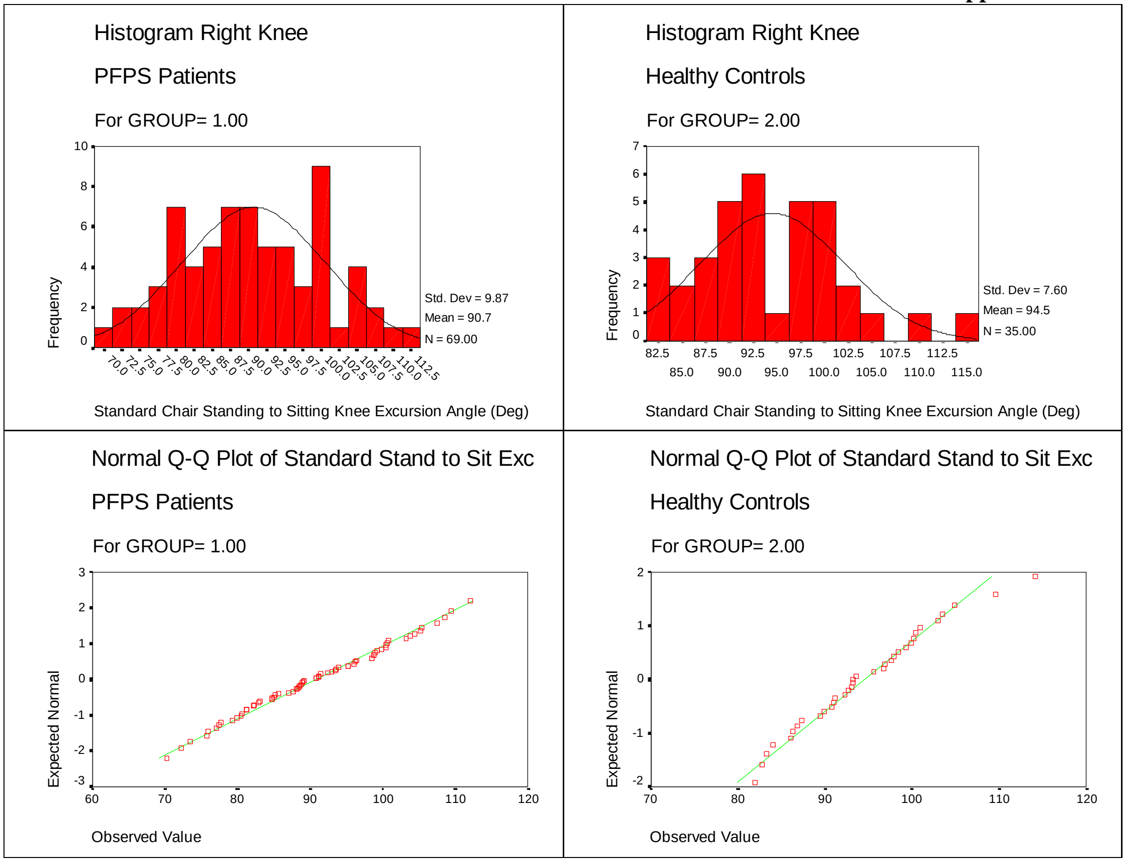
Graphs 13.70 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Minimum Left Knee Joint Angle (Degrees)**



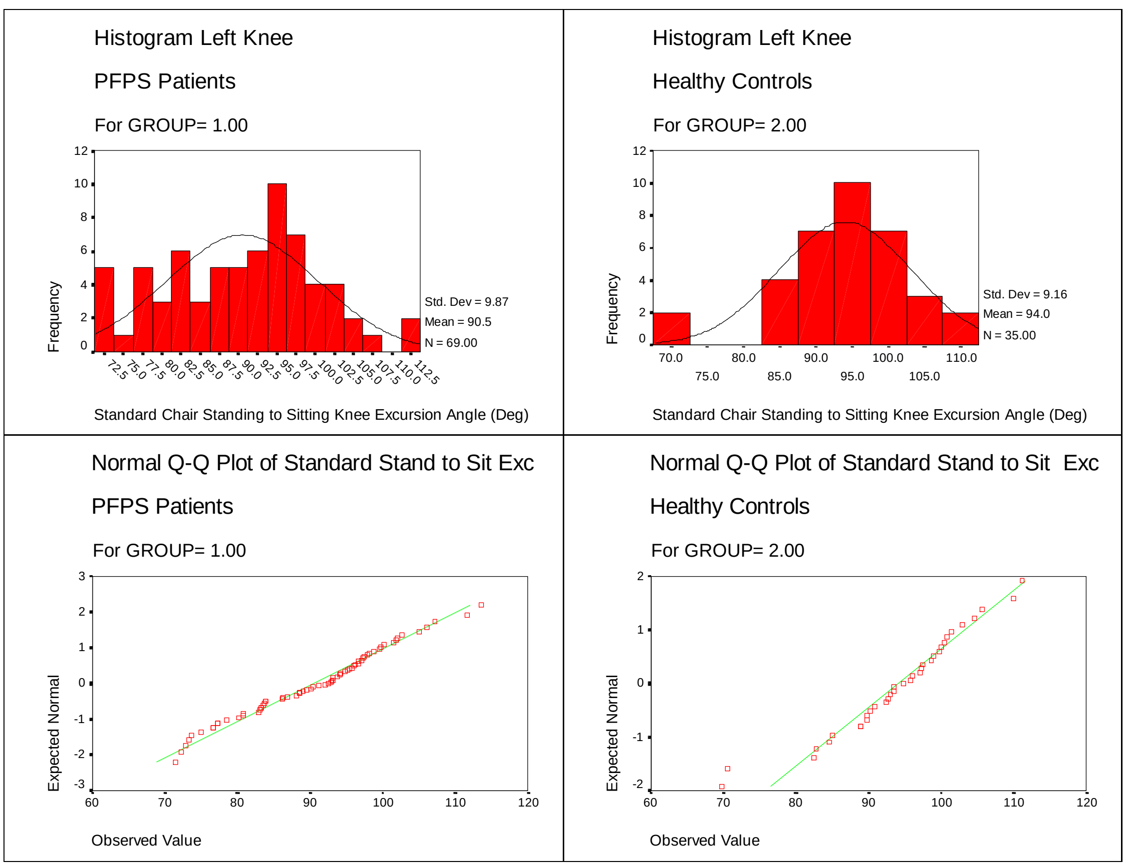
Graphs 771 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Maximum Right Knee Joint Angle (Degrees)**



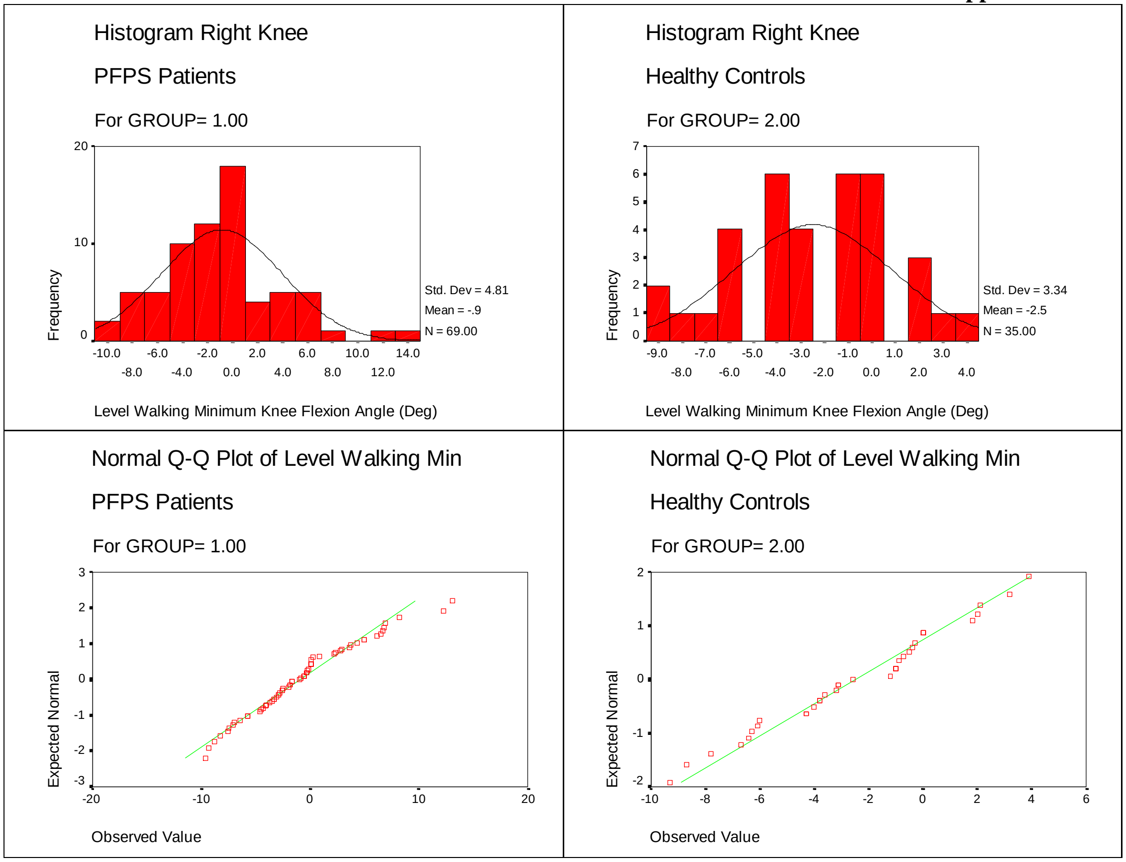
Graphs 13.72 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Maximum Left Knee Joint Angle (Degrees)**



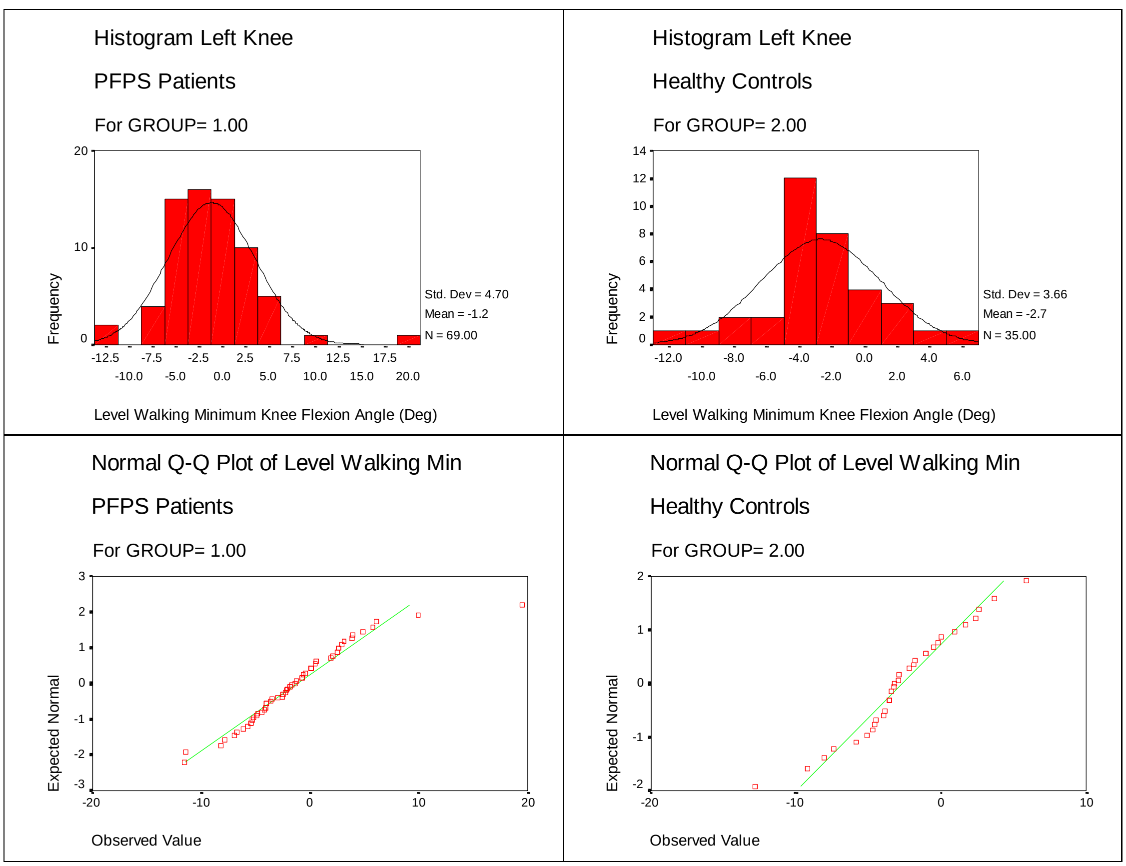
Graphs 13.73 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Right Knee Excursion Angle (Degrees)



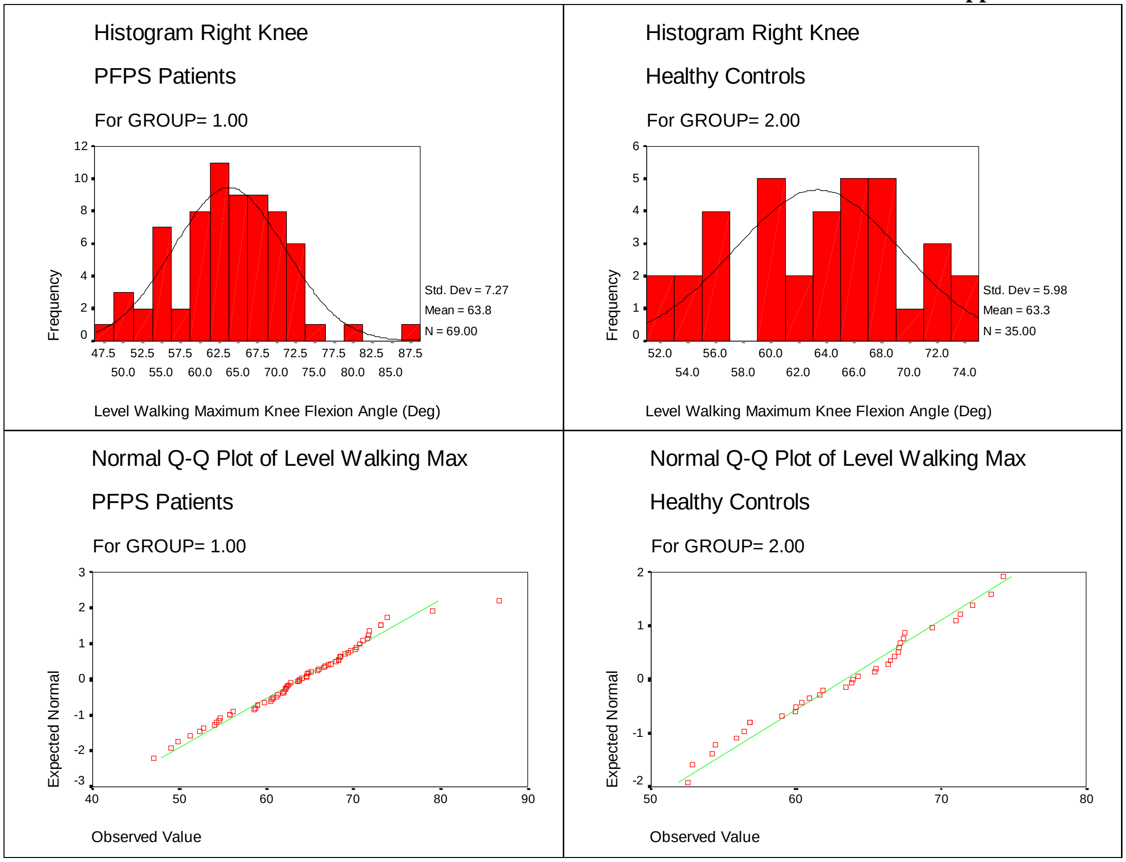
Graphs 13.74 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Left Knee Excursion Angle (Degrees)



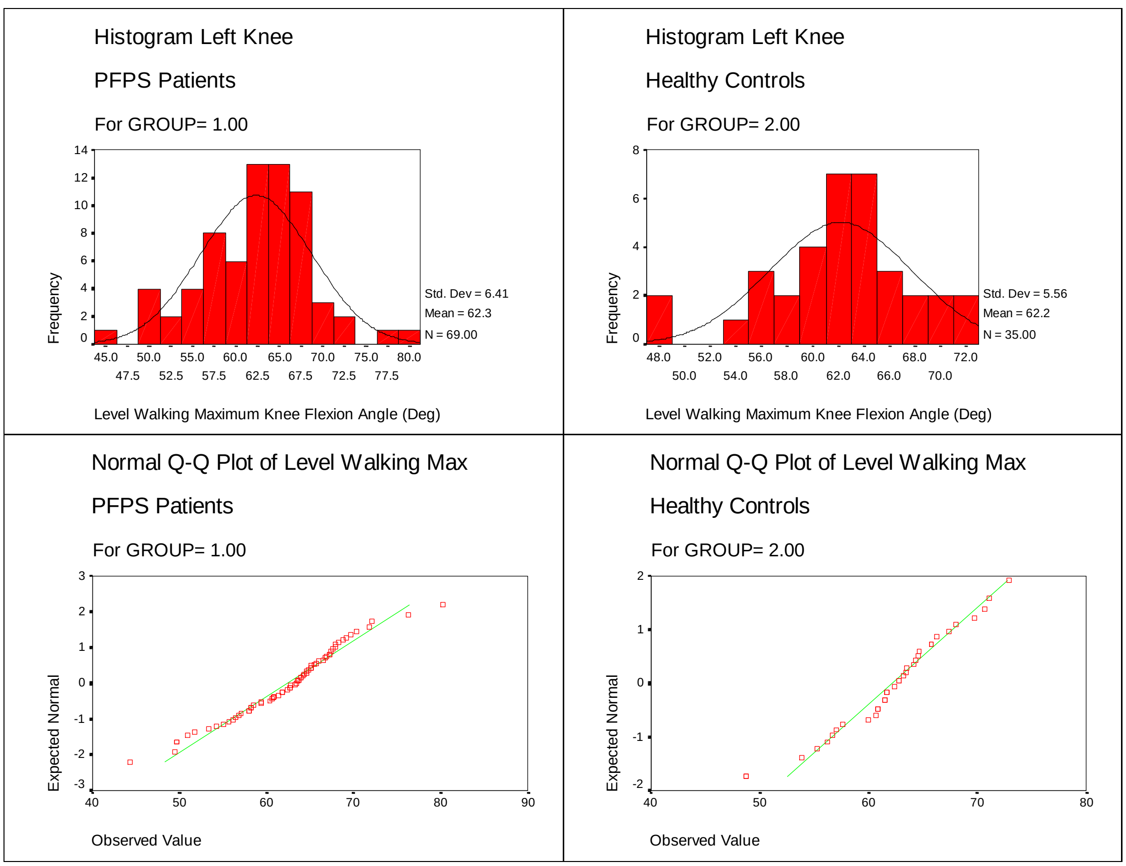
Graphs 13.75 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Minimum Right Knee Flexion Angle (Degrees)



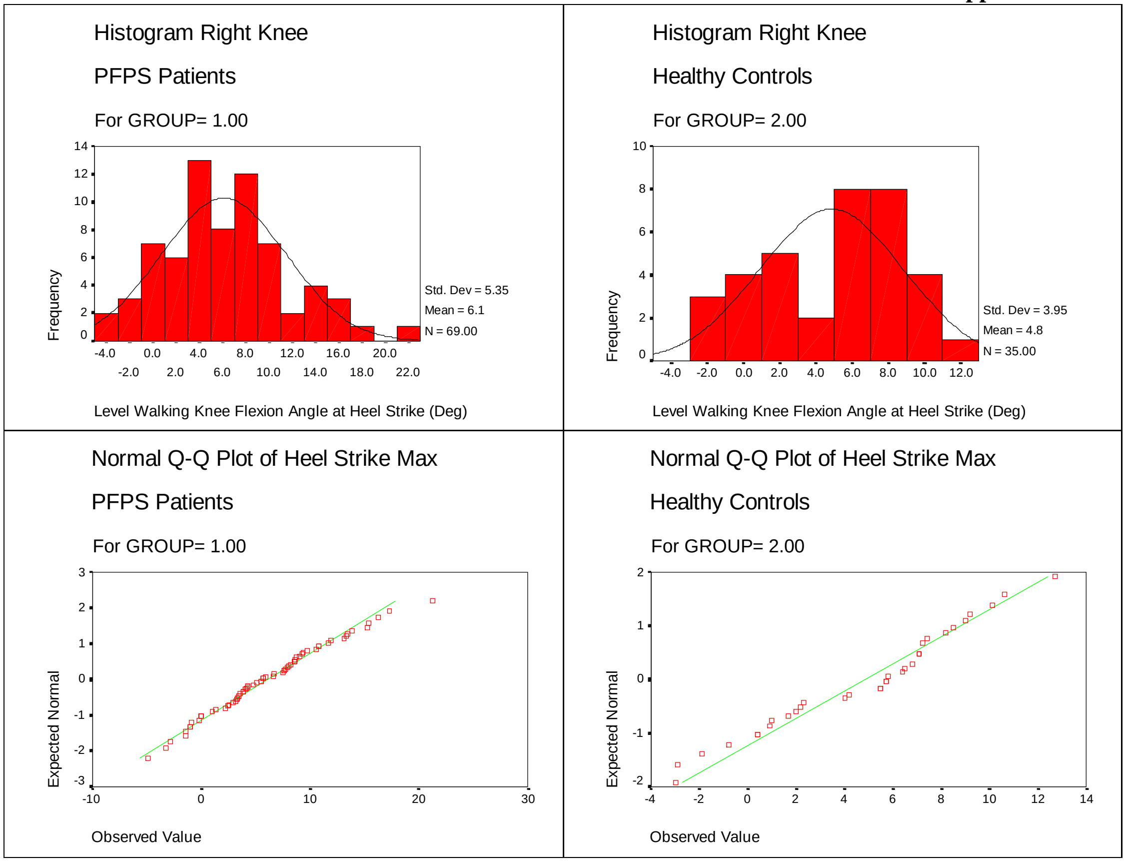
Graphs 13.76 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Minimum Left Knee Flexion Angle (Degrees)



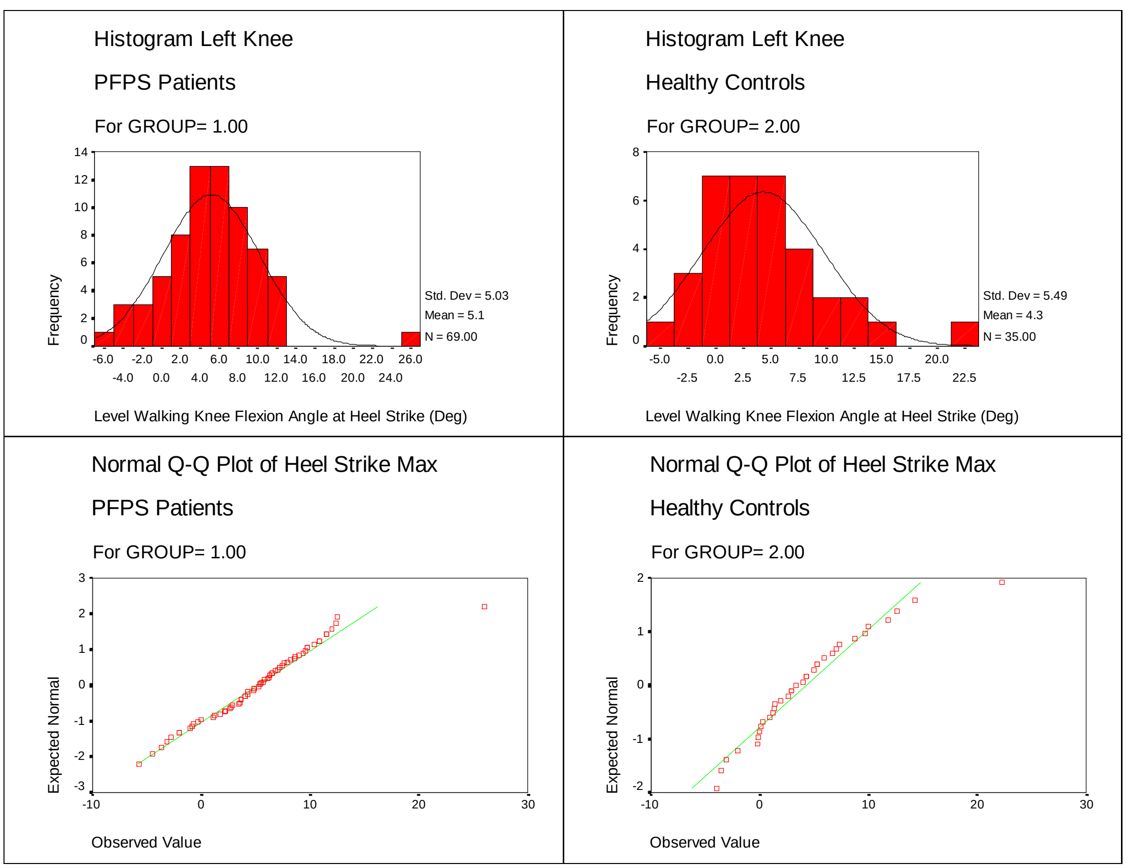
Graphs 13.77 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Right Knee Flexion Angle (Degrees)



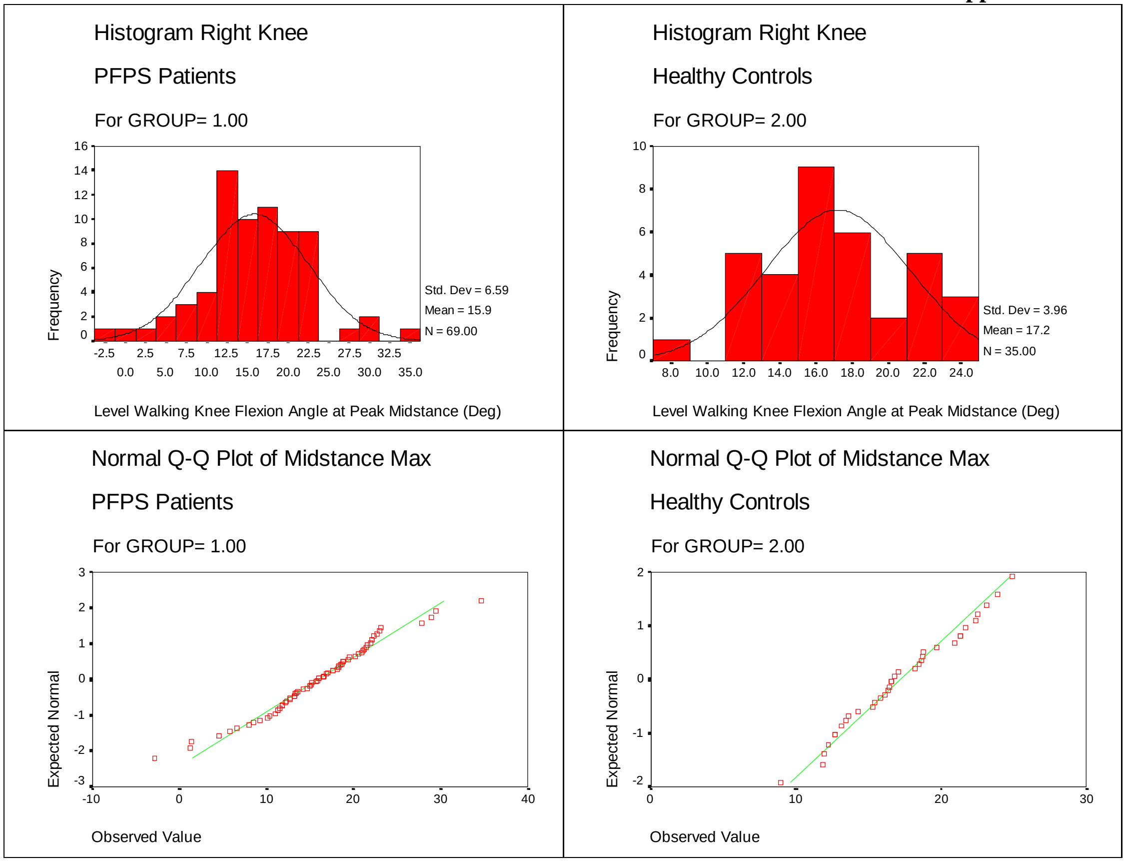
Graphs 13.78 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Left Knee Flexion Angle (Degrees)



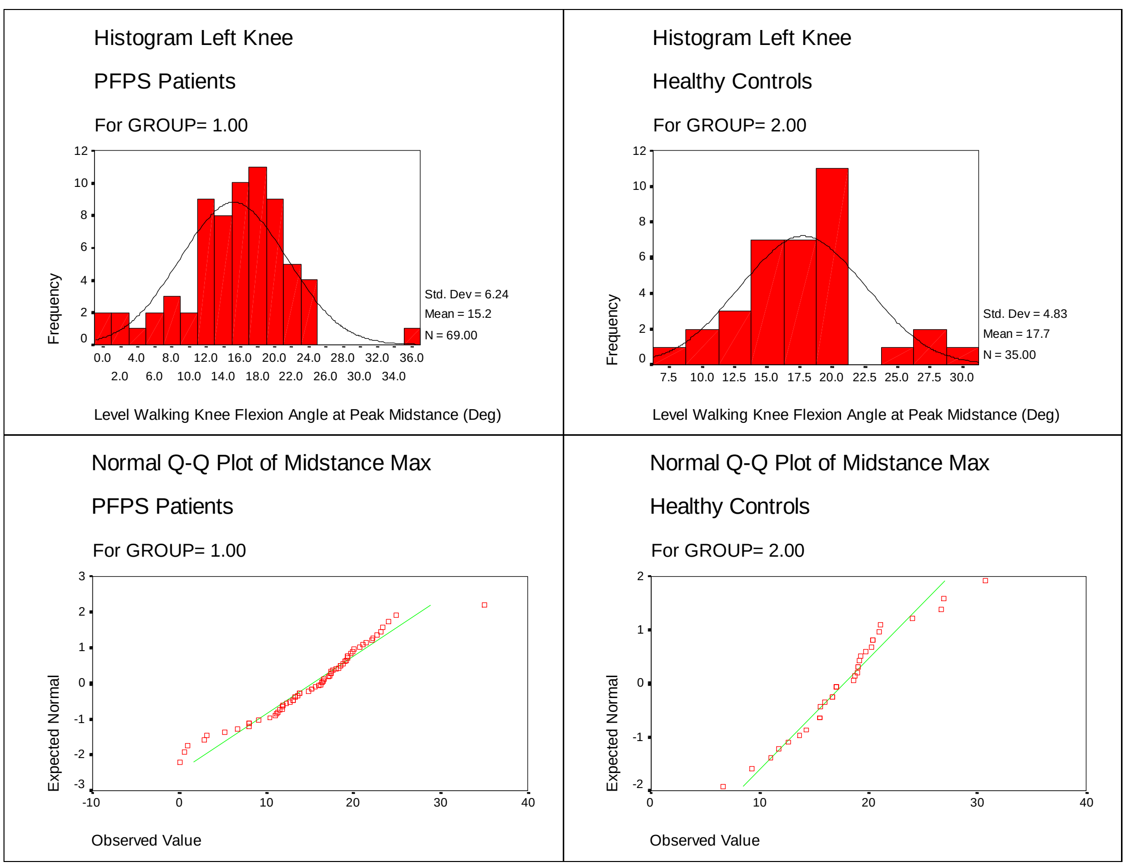
Graphs 13.79 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Right Knee Flexion Angle at Heel Strike (Degrees)



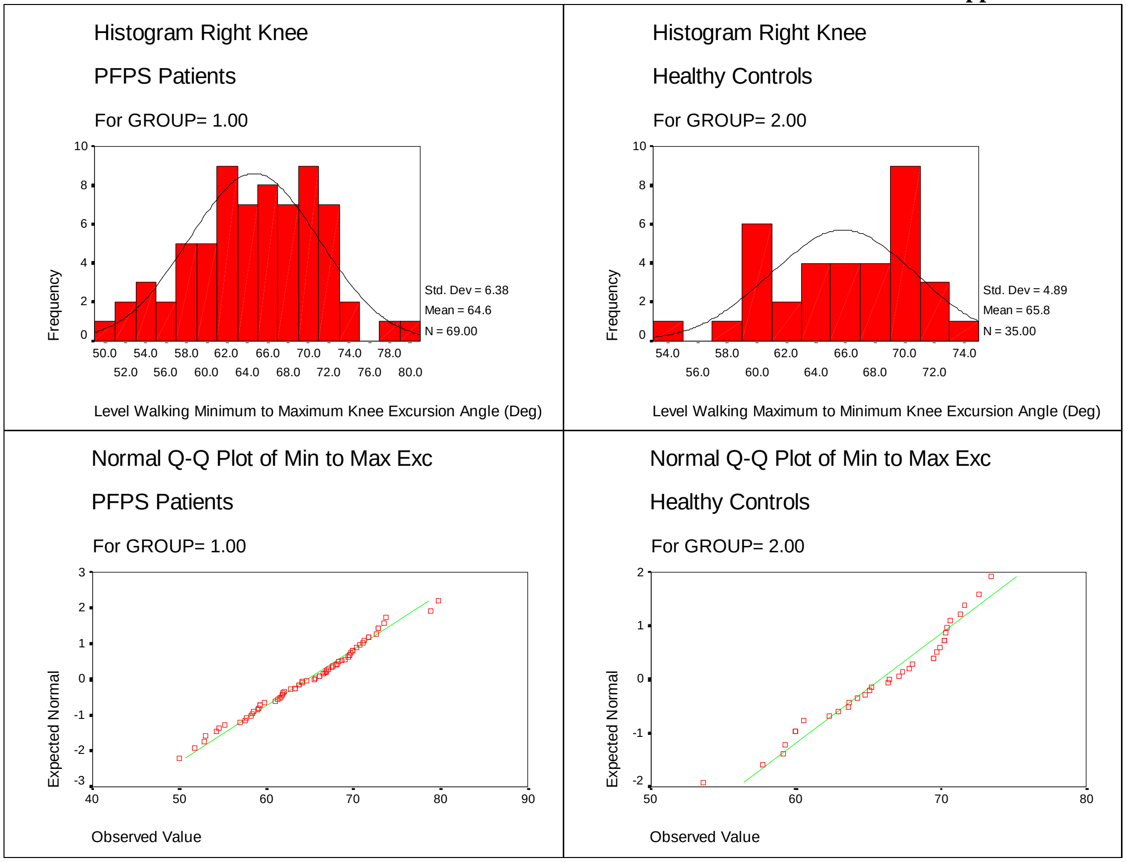
Graphs 13.80 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Left Knee Flexion Angle at Heel Strike (Degrees)



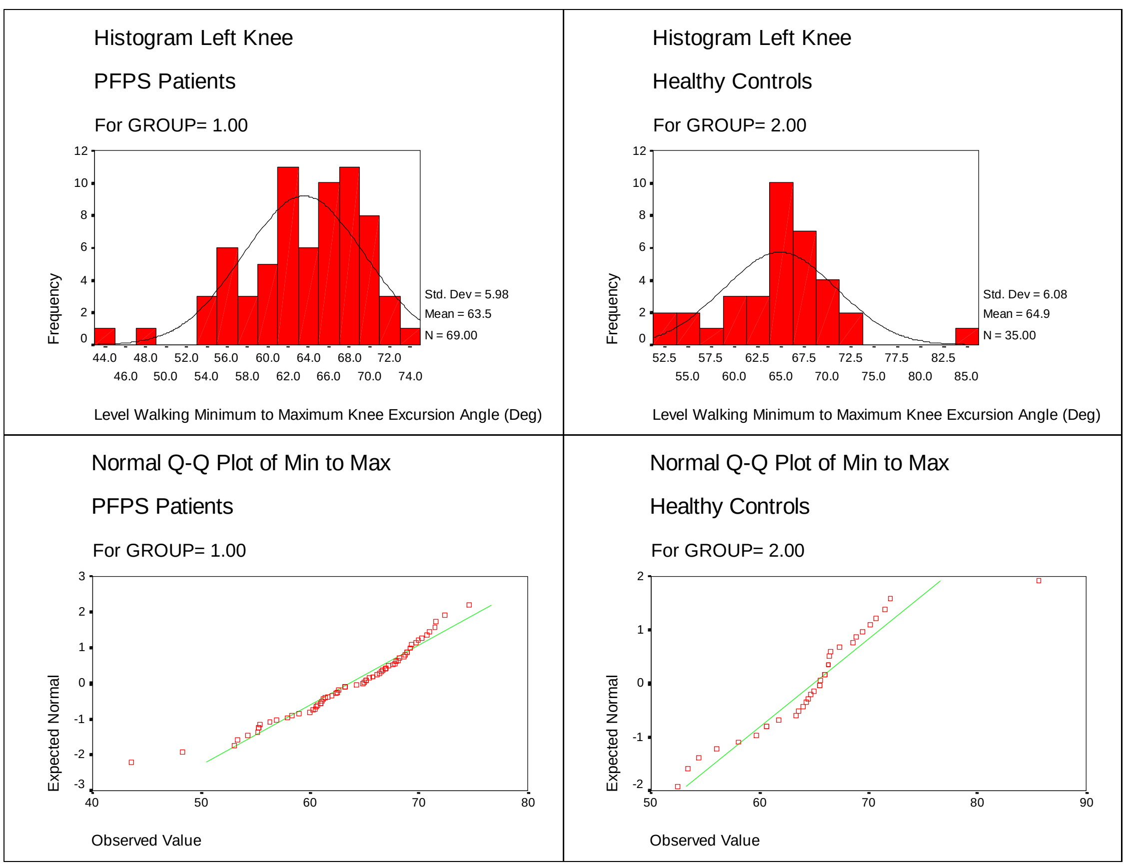
Graphs 13.81 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Right Knee Flexion Angle at Peak Midstance (Degrees)



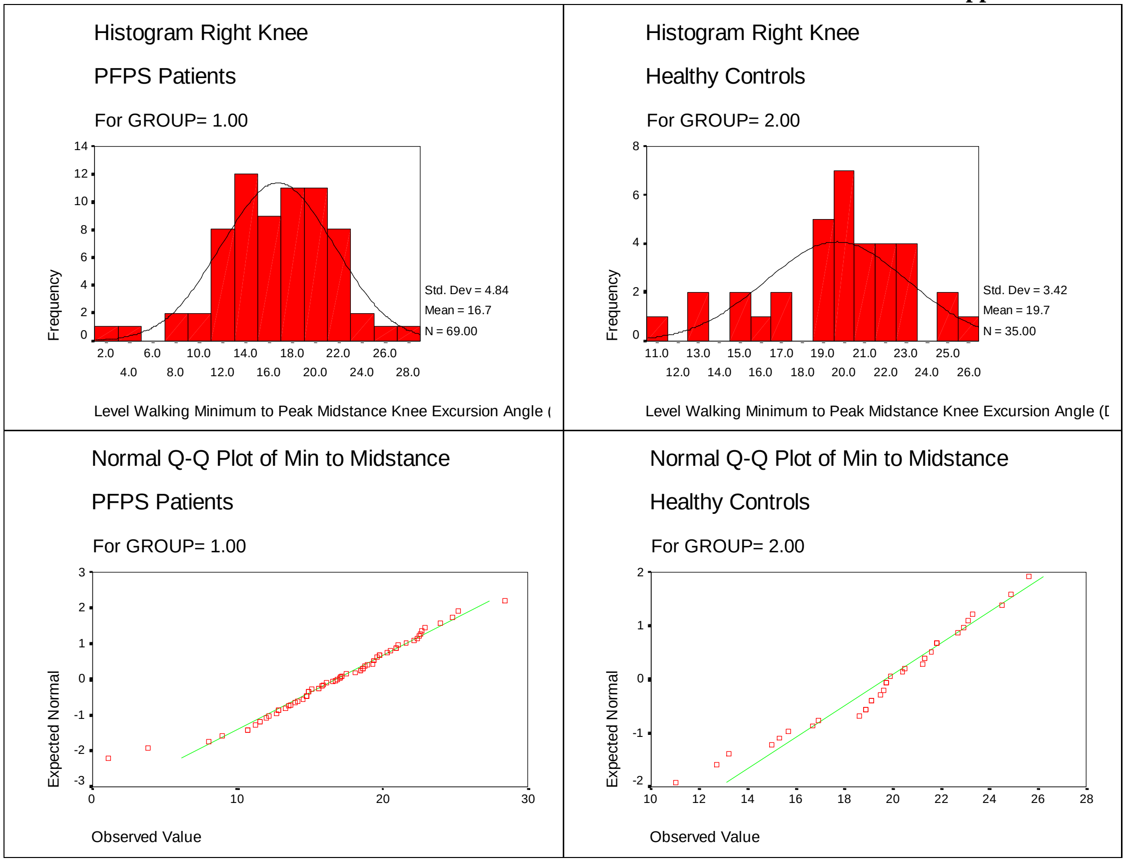
Graphs 13.82 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Left Knee Flexion Angle at Peak Midstance (Degrees)



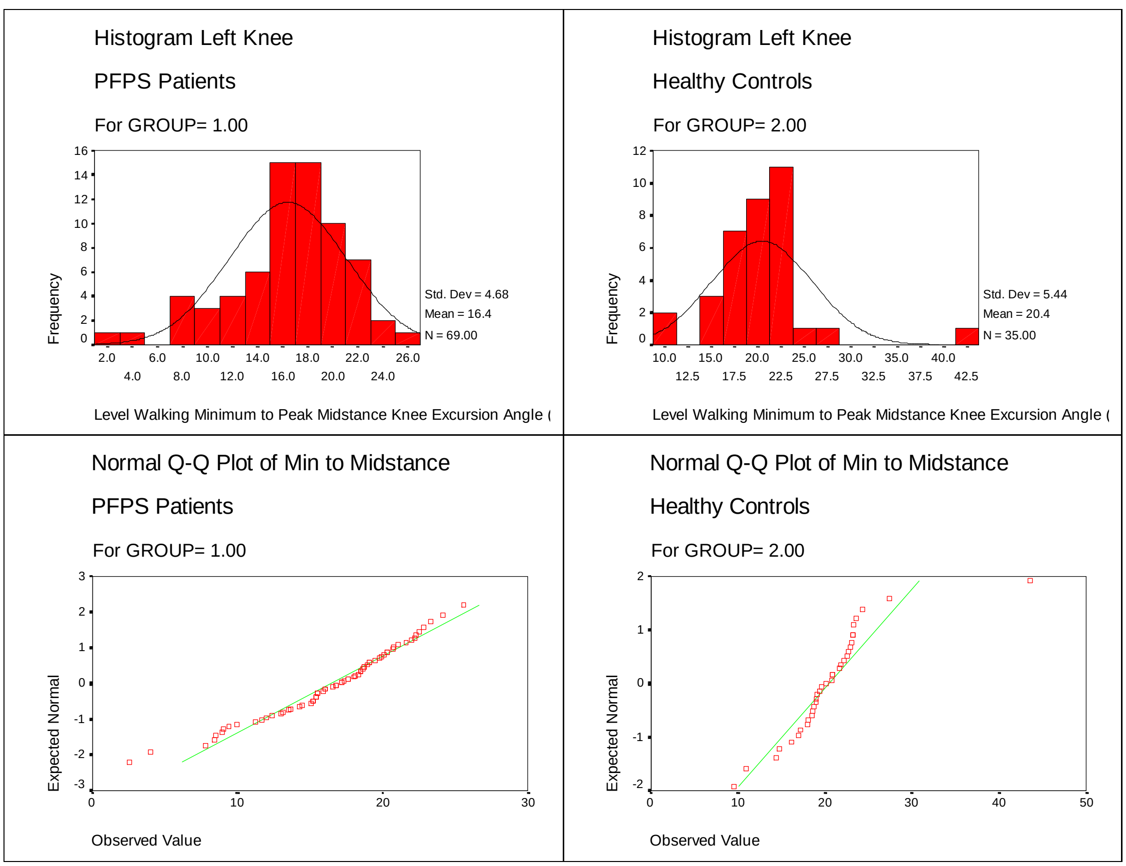
Graphs 13.83 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Right Knee Minimum to Maximum Excursion Angle (Degrees)**



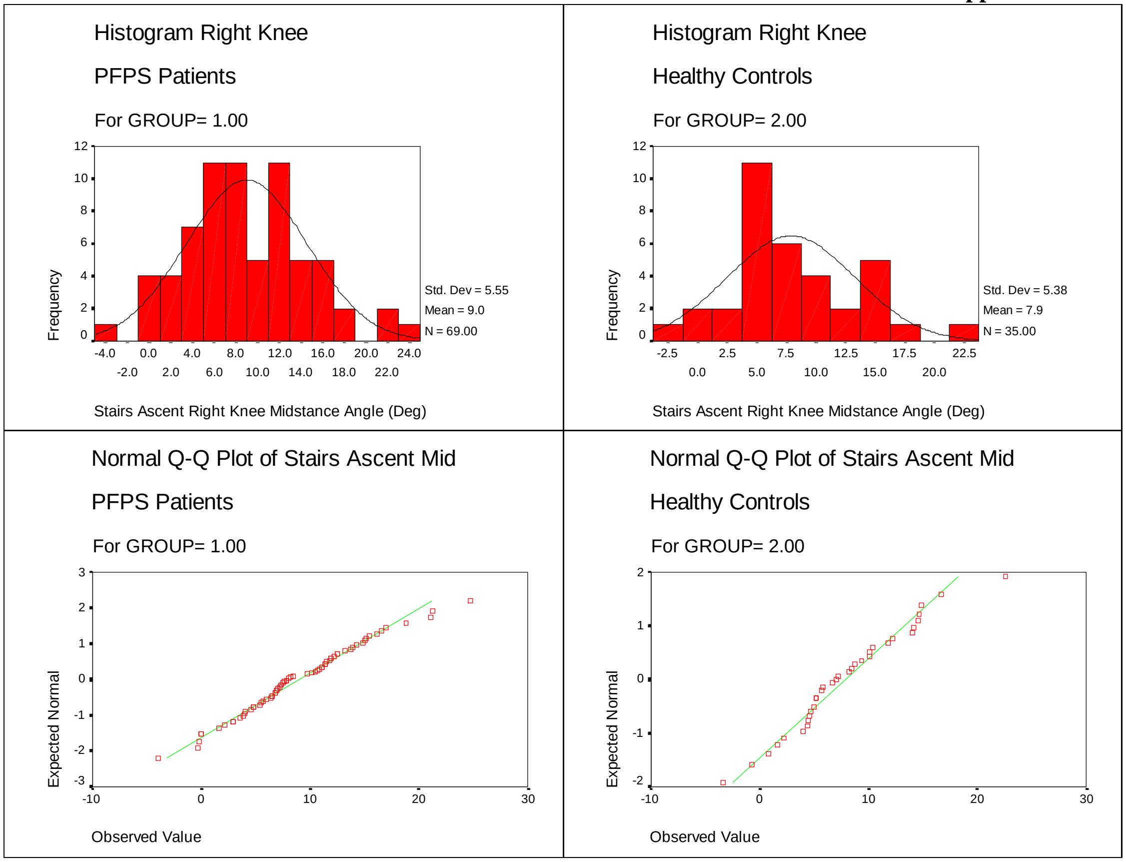
Graphs 13.84 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Left Knee Minimum to Maximum Excursion Angle (Degrees)**



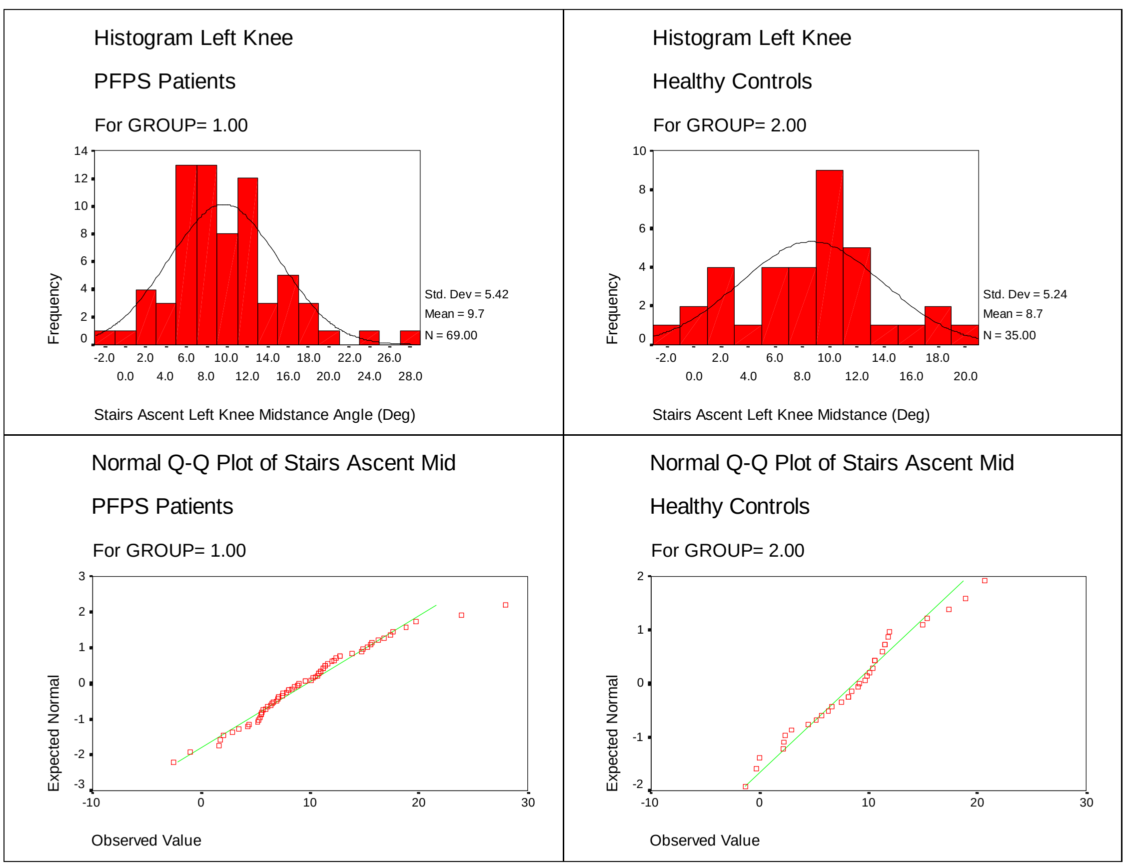
Graphs 13.85 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Right Knee Minimum to Peak Midstance Excursion Angle (Degrees)



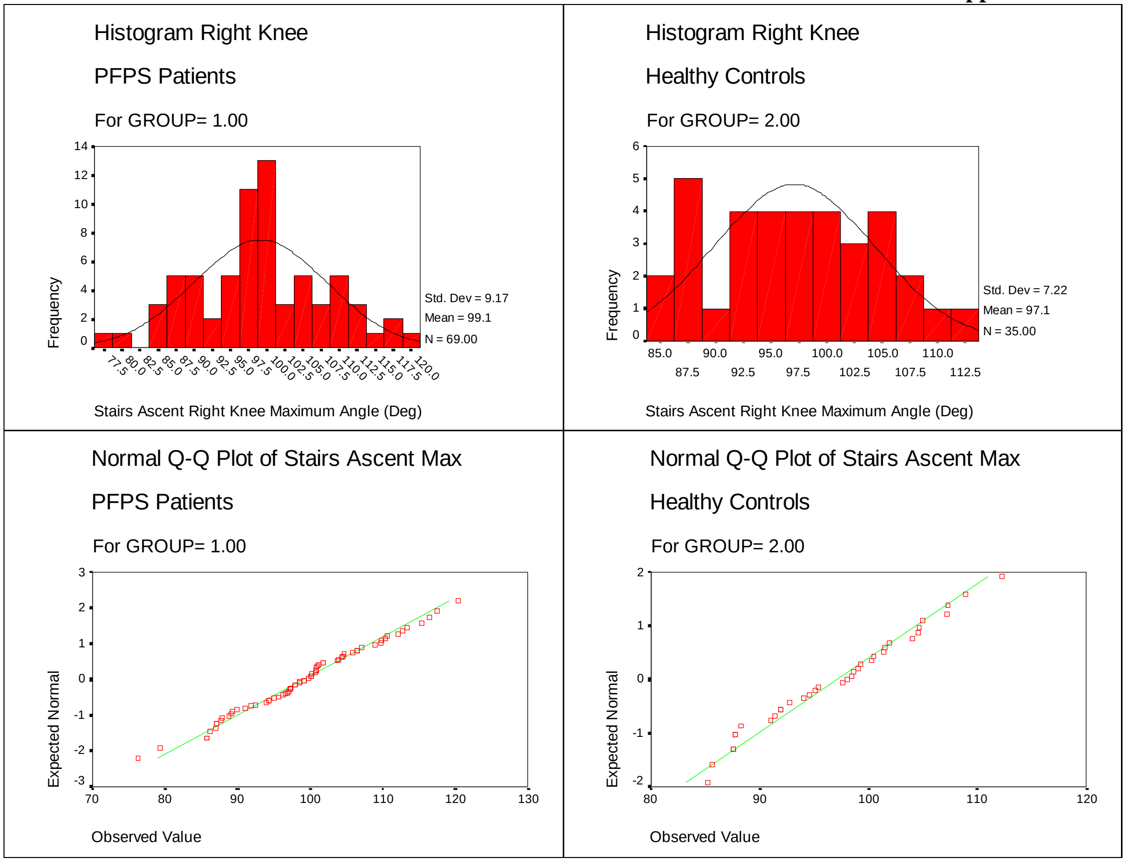
Graphs 13.86 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Left Knee Minimum to Peak Midstance Excursion Angle (Degrees)



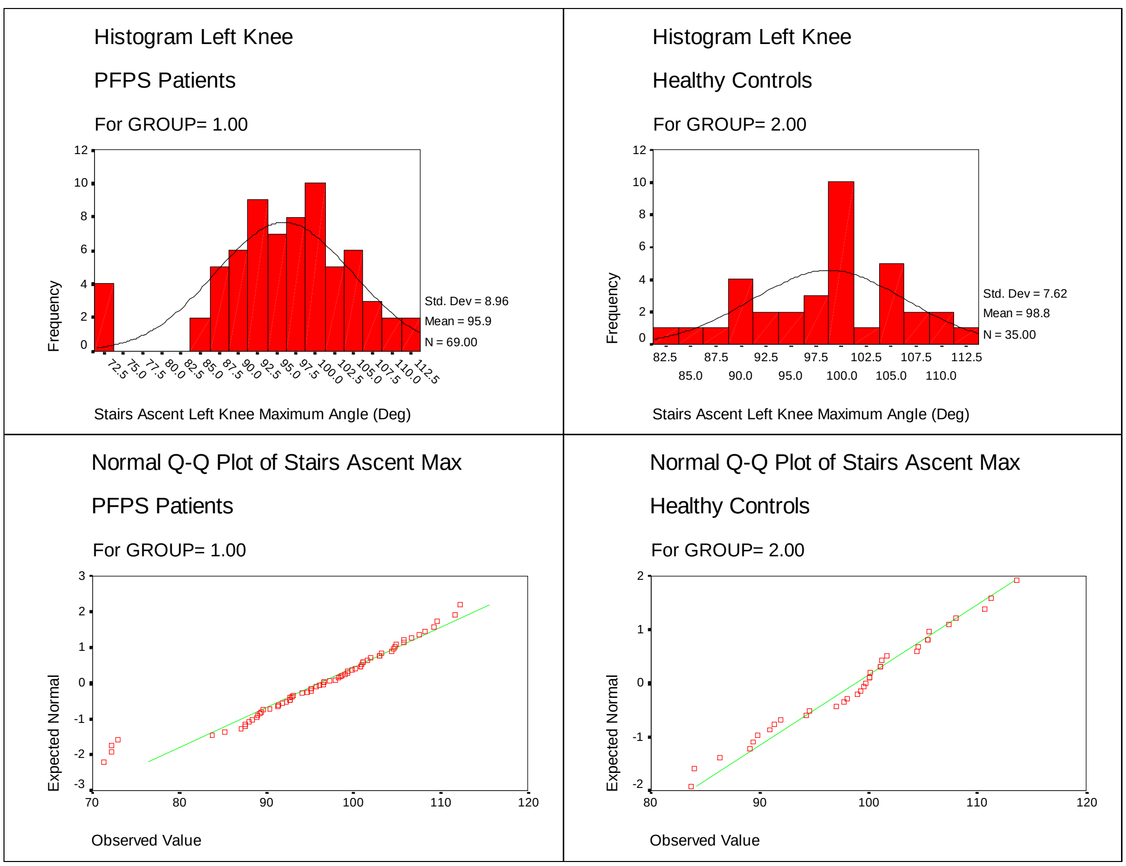
Graphs 13.87 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Right Knee Midstance Angle (Degrees)



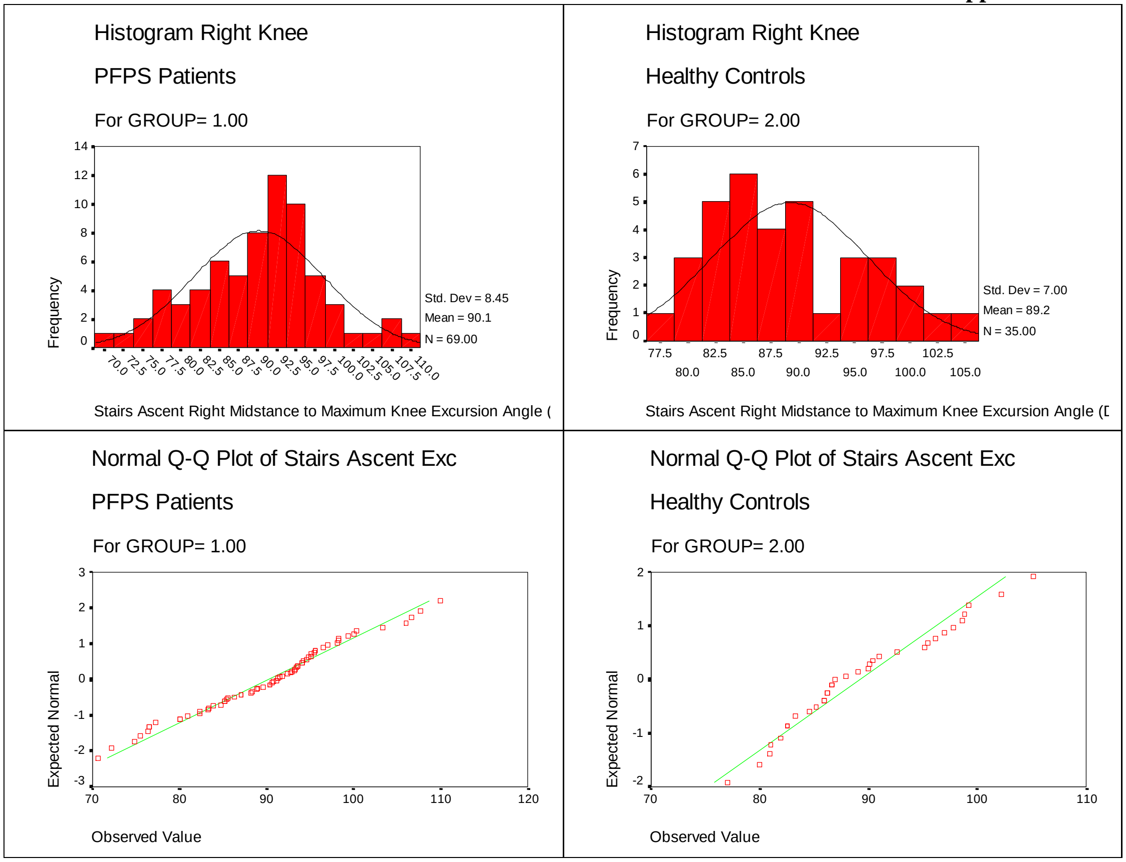
Graphs 13.88 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Right Knee Midstance Angle (Degrees)



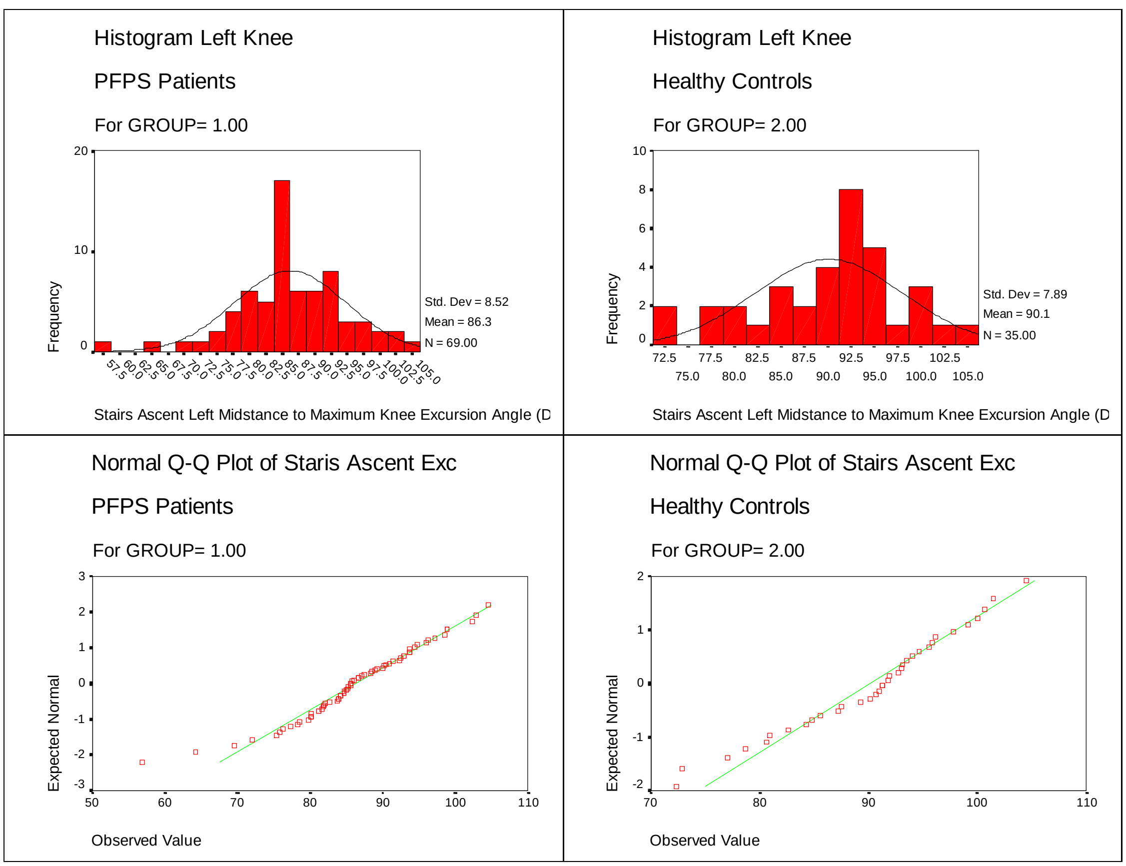
Graphs 13.89 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Right Knee Maximum Angle (Degrees)**



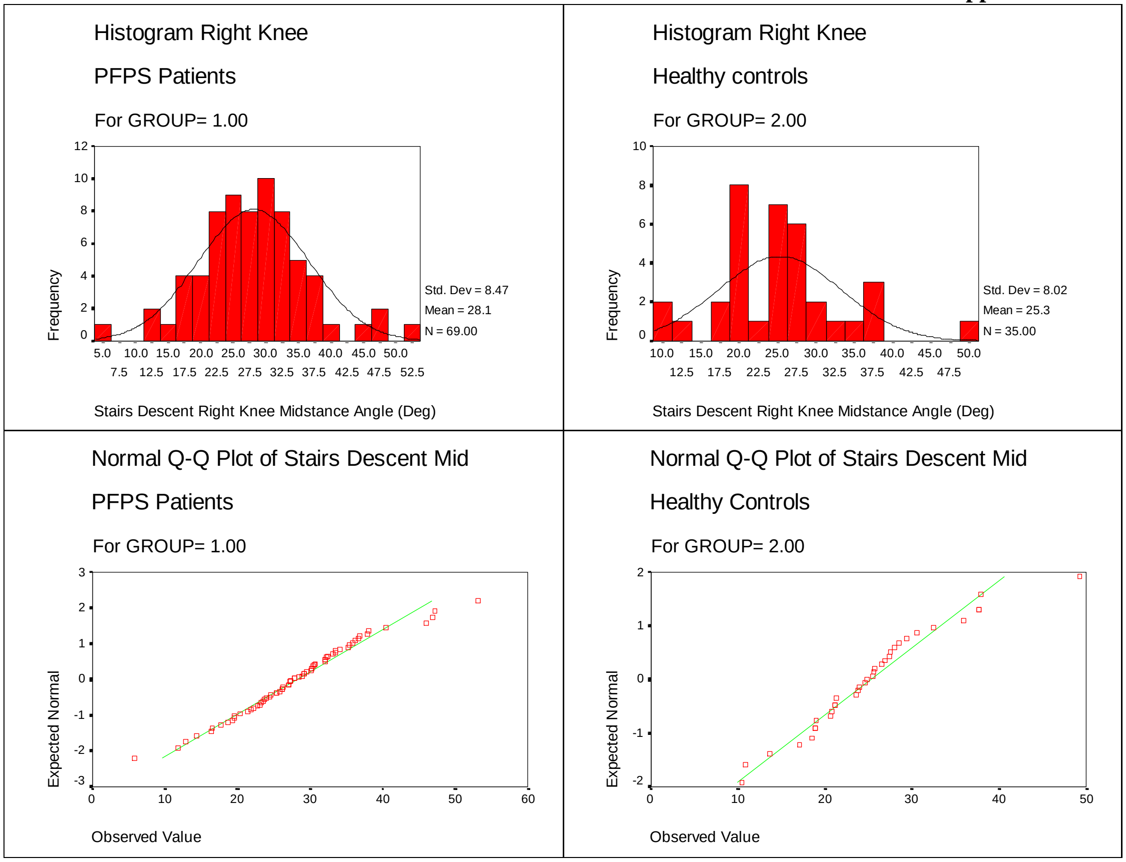
Graphs 13.90 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Left Knee Maximum Angle (Degrees)**



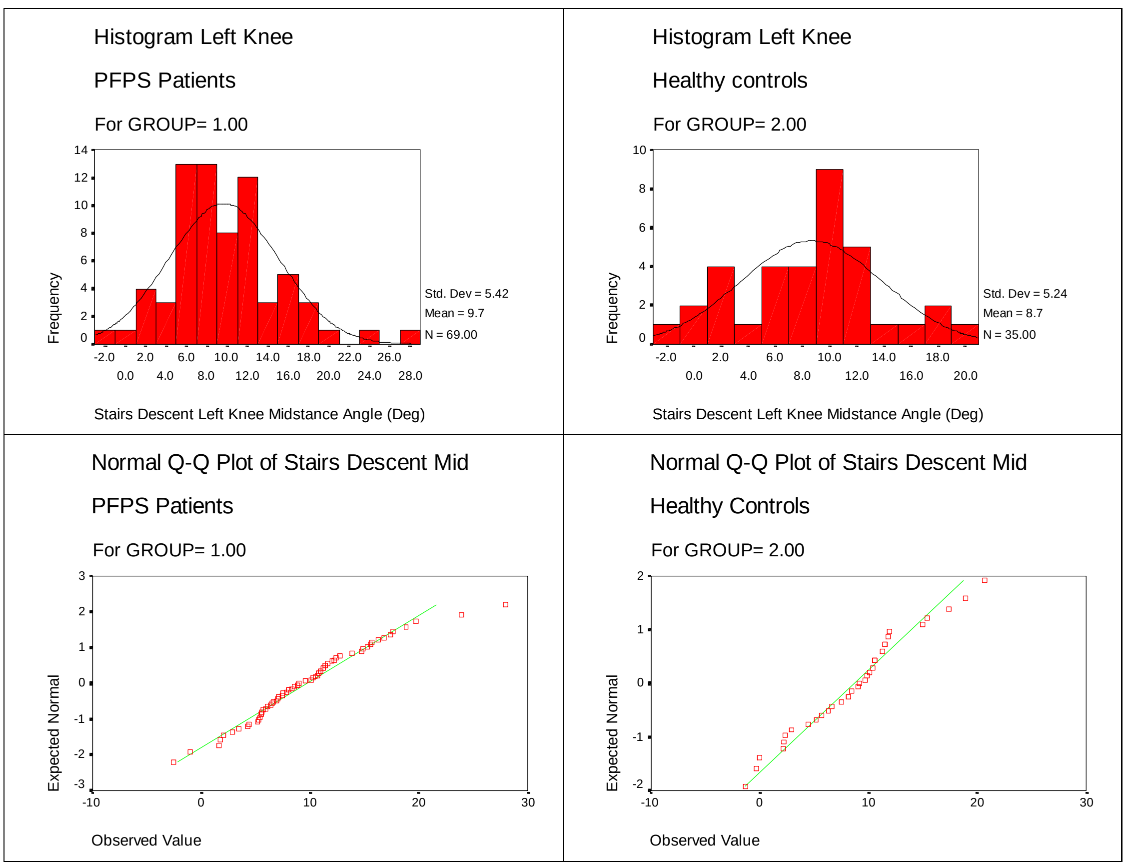
Graphs 13.91 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Right Knee Midstance to Maximum Excursion Angle (Degrees)



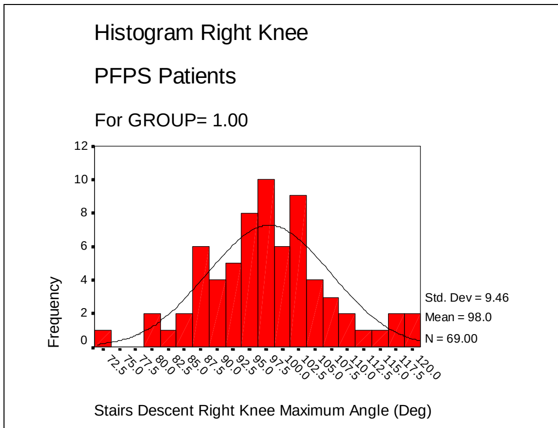
Graphs 13.92 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Left Knee Midstance to Maximum Excursion Angle (Degrees)

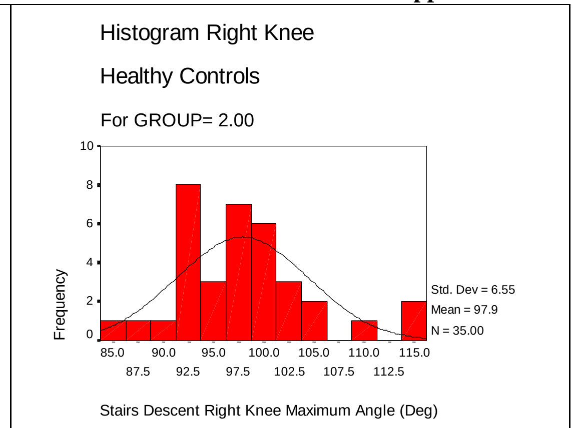


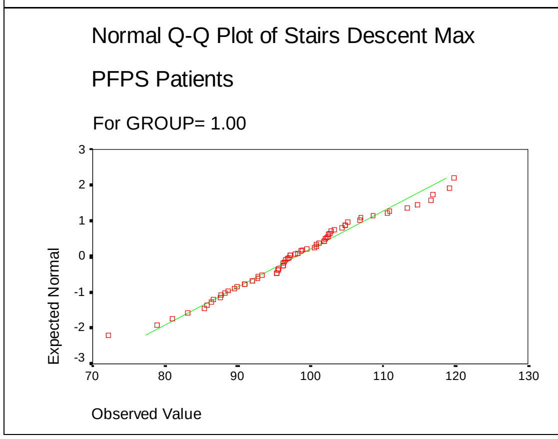
Graphs 13.93 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Right Knee Midstance Angle (Degrees)

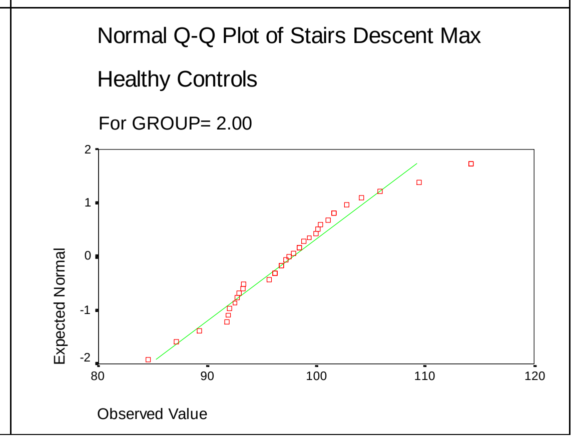


Graphs 13.94 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Left Knee Midstance Angle (Degrees)

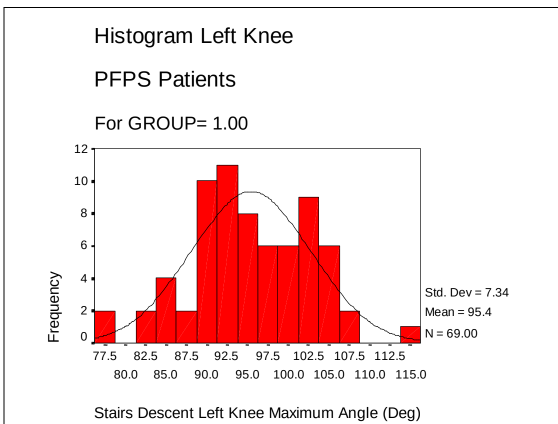


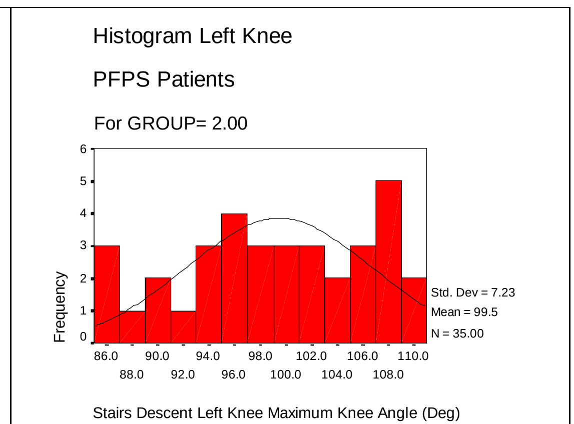


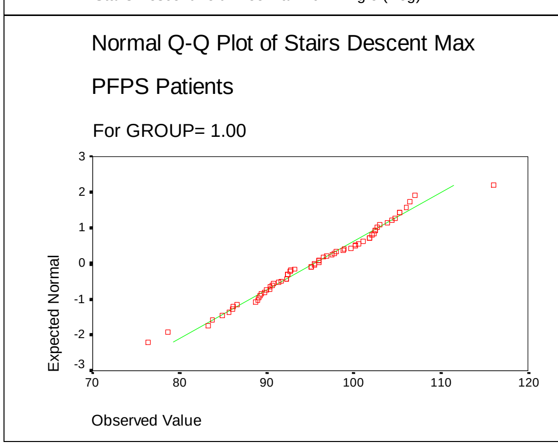


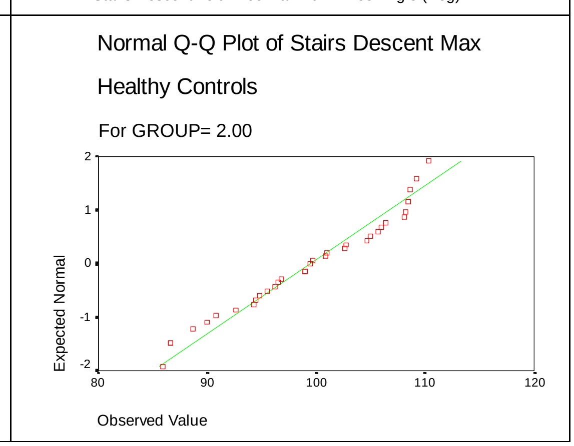


Graphs 13.95 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Right Knee Maximum Angle (Degrees)**

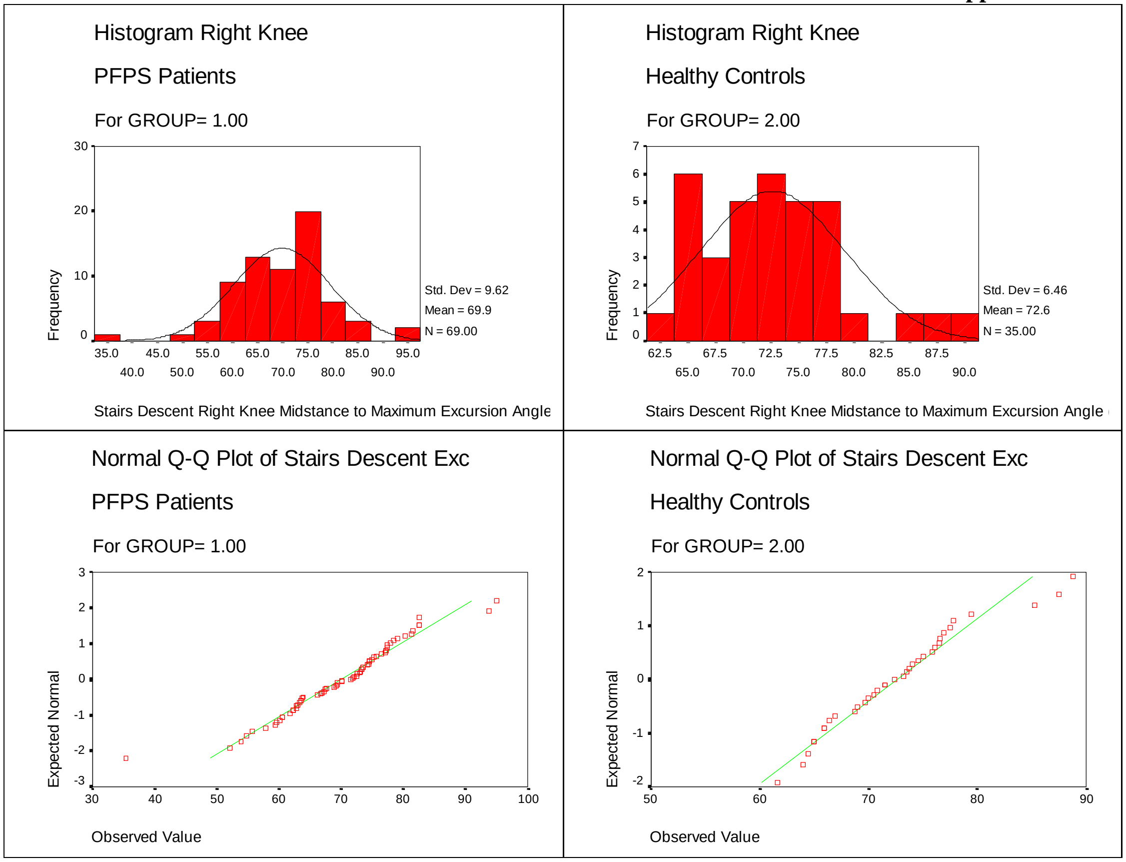




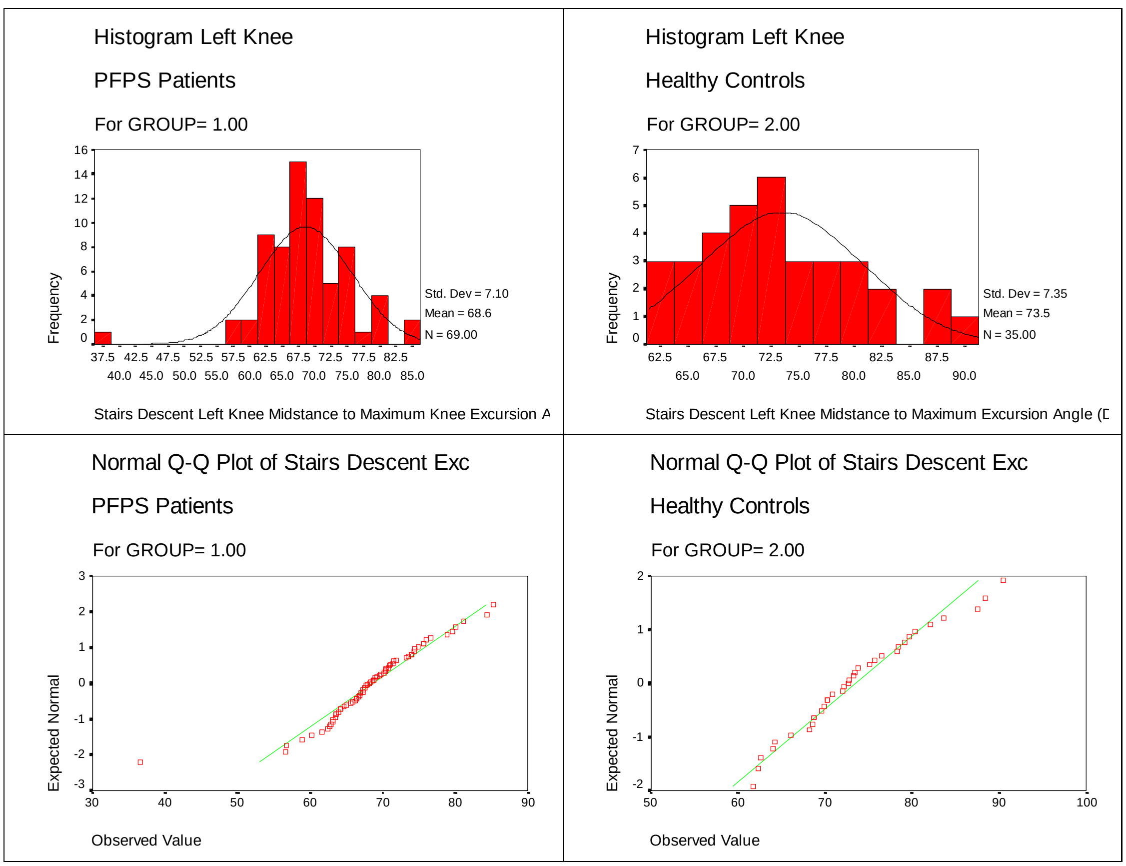




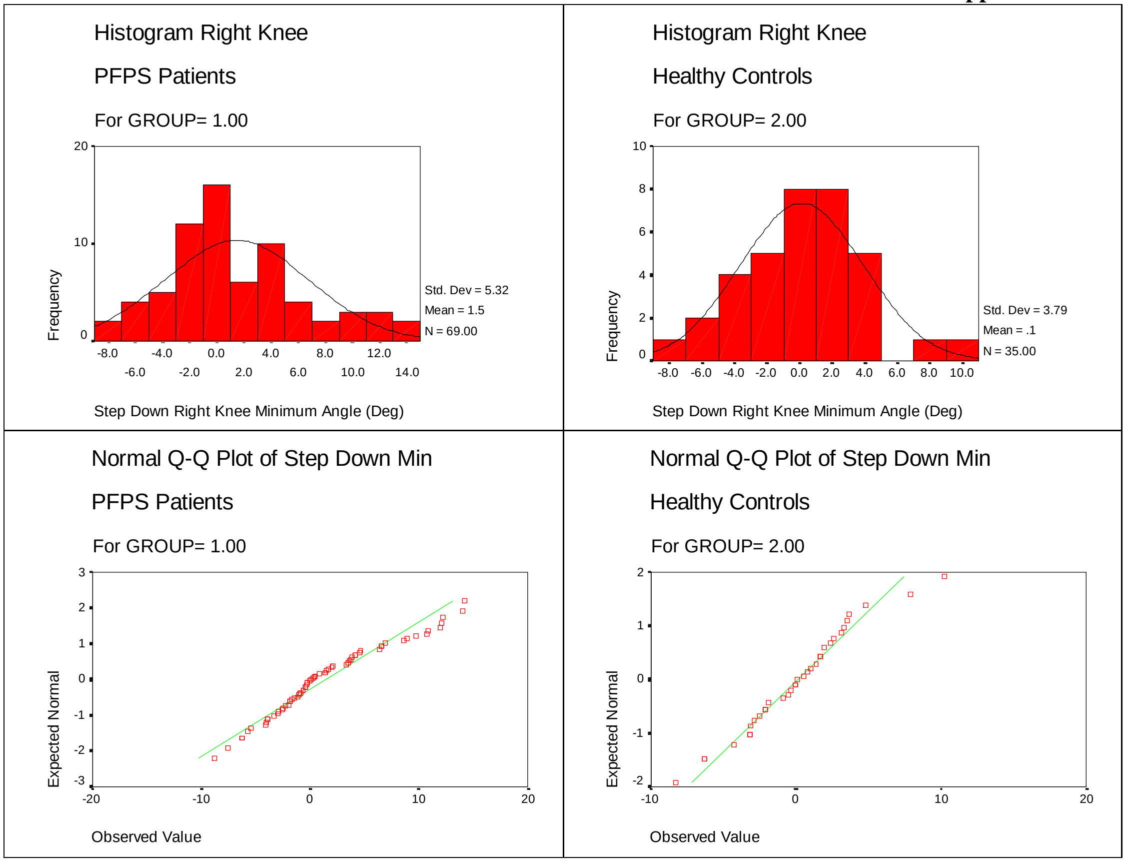
Graphs 13.96 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Left Knee Maximum Angle (Degrees)**



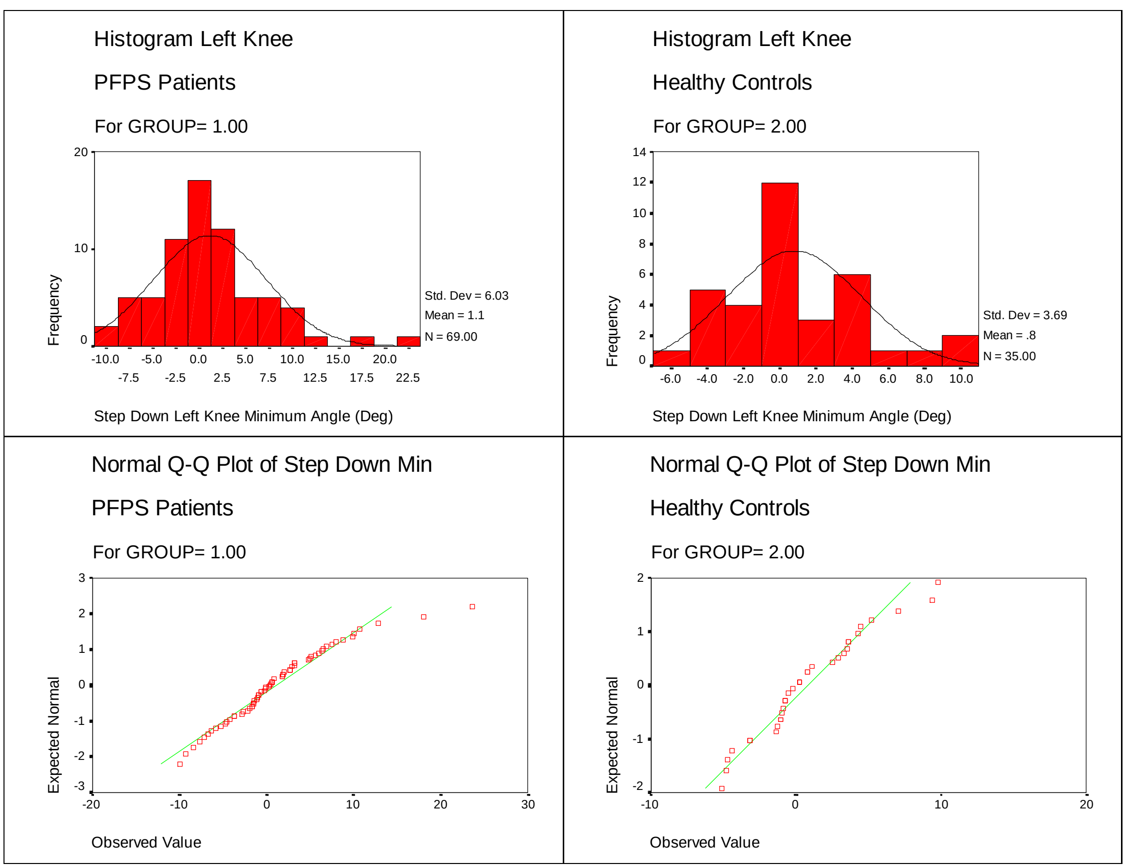
Graphs 13.97 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Right Knee Midstance to Maximum Excursion Angle (Degrees)



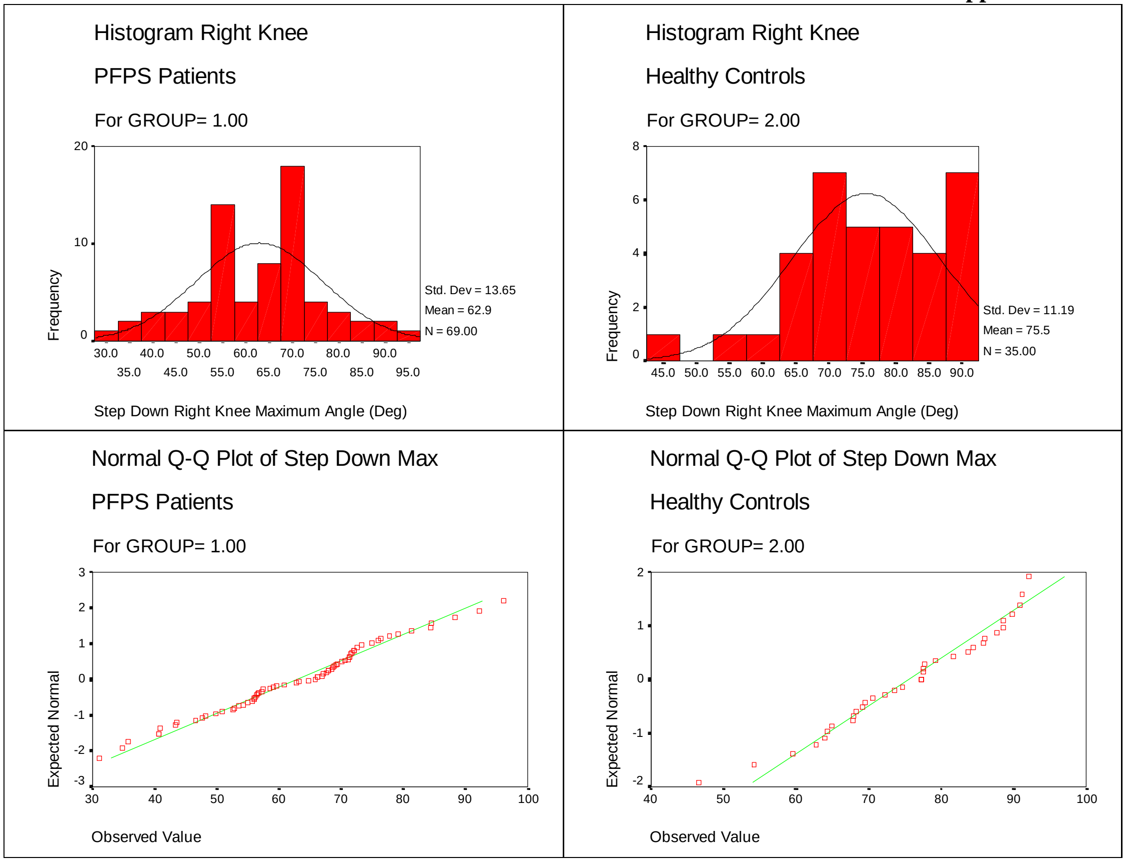
Graphs 13.98 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Left Knee Midstance to Maximum Excursion Angle (Degrees)



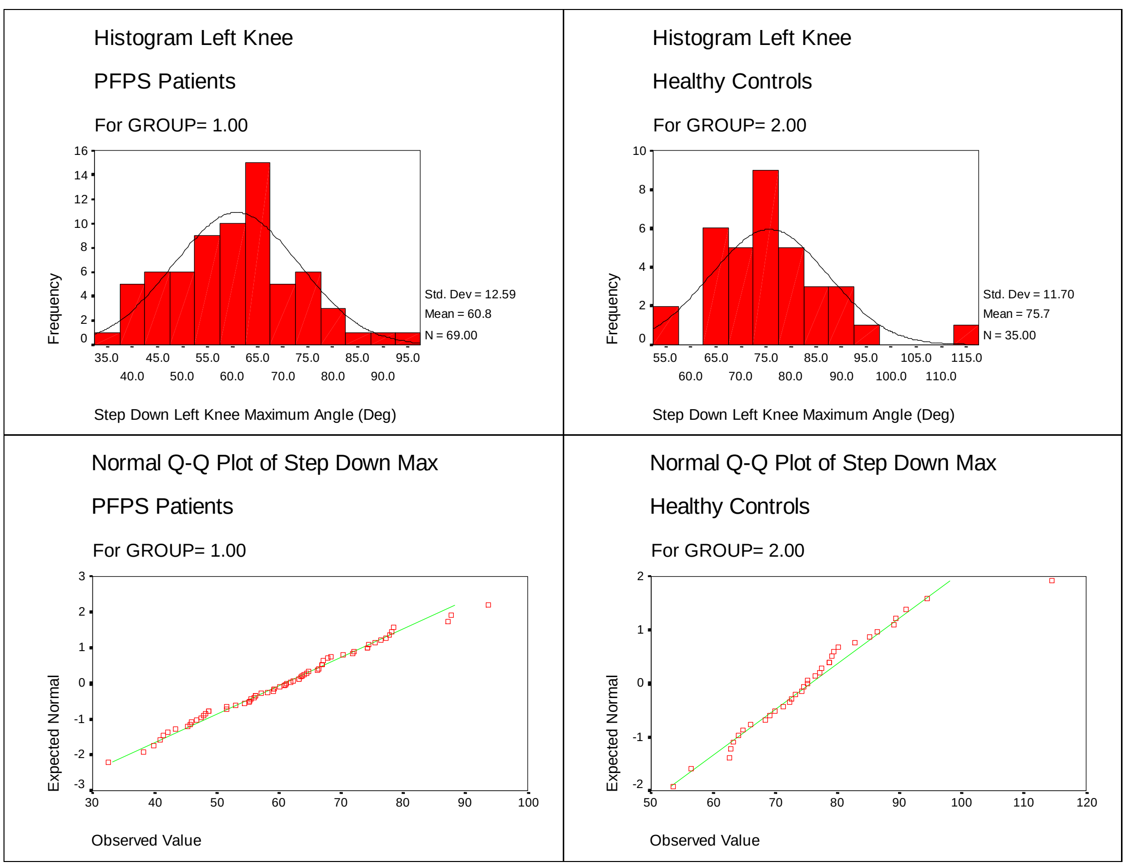
Graphs 13.99 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Minimum Right Knee Angle (Degrees)**



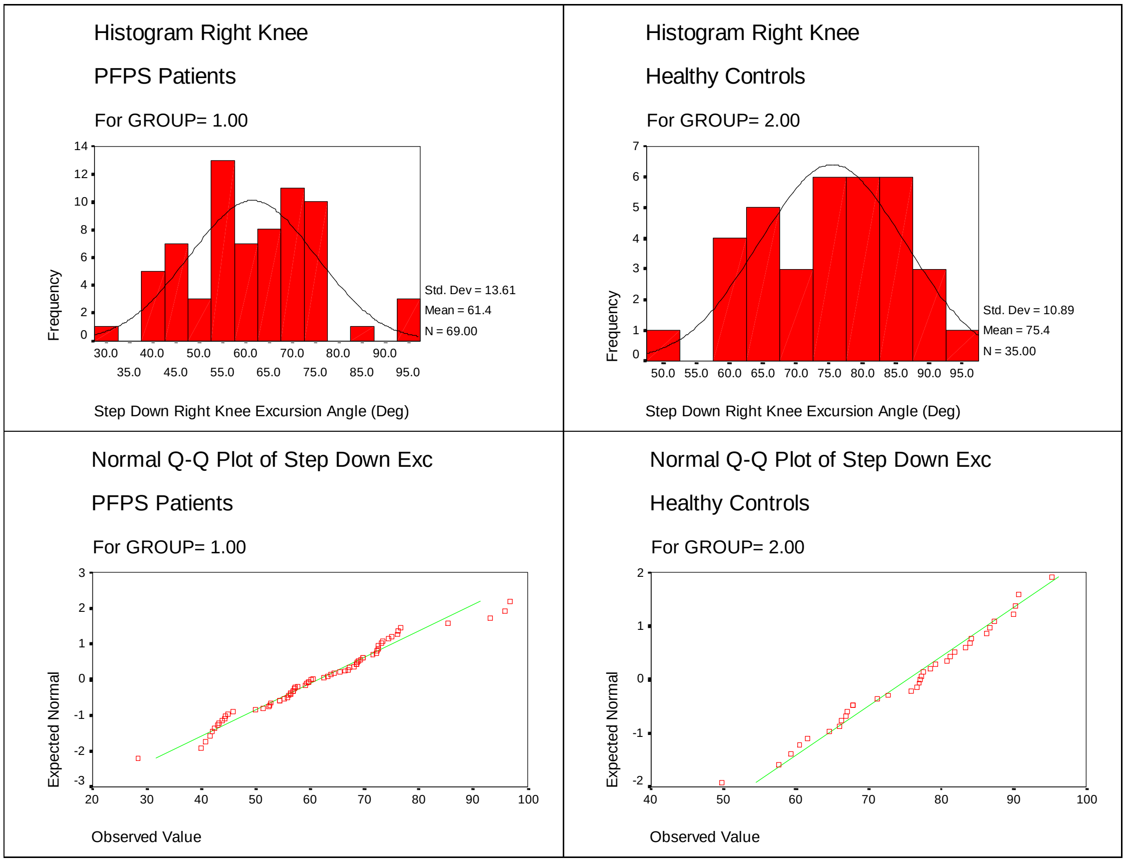
Graphs 13.100 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Minimum Left Knee Angle (Degrees)**



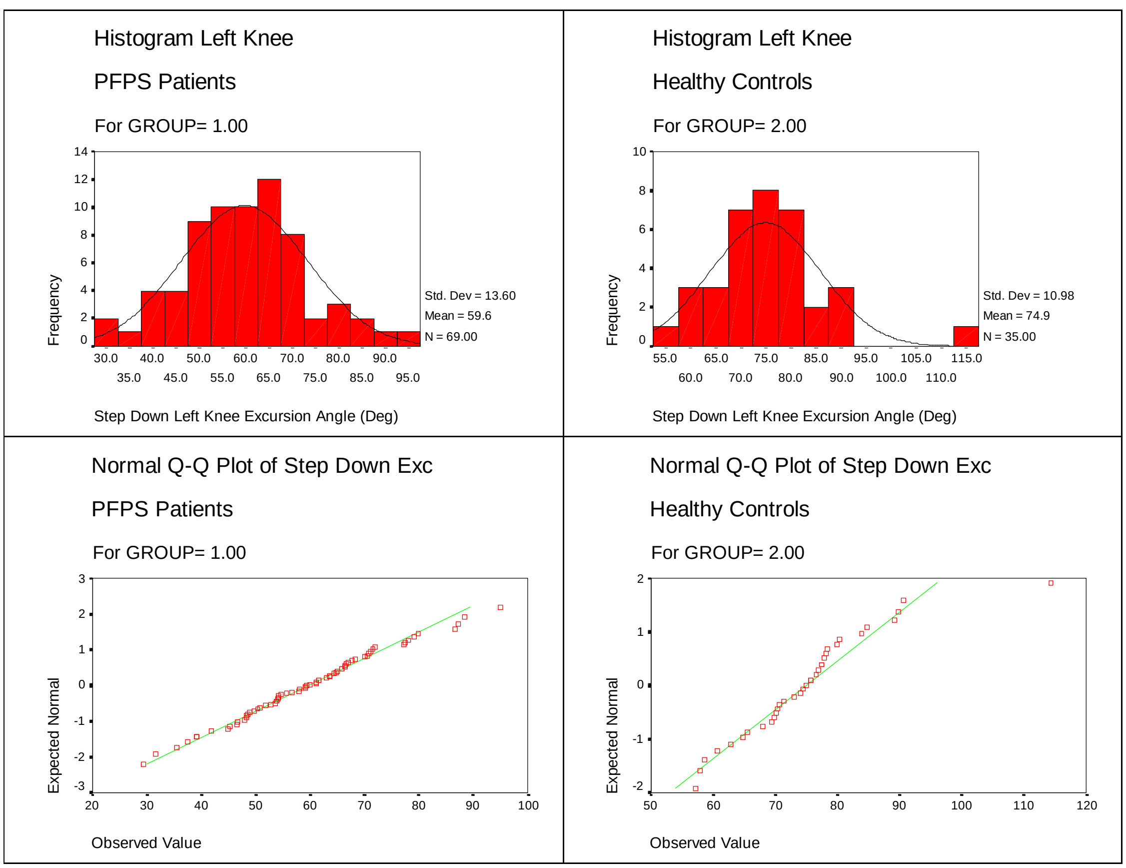
Graphs 13.101 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Maximum Right Knee Angle (Degrees)**



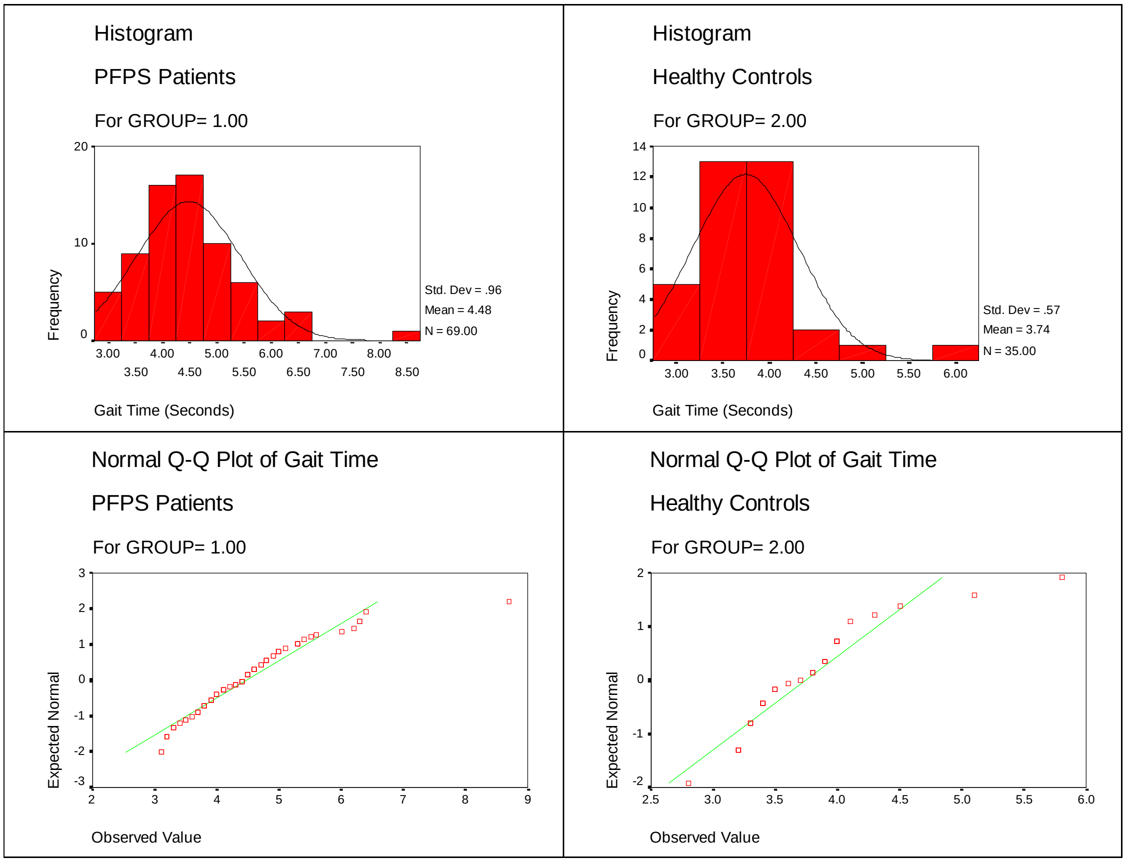
Graphs 12.102 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Maximum Left Knee Angle (Degrees)**



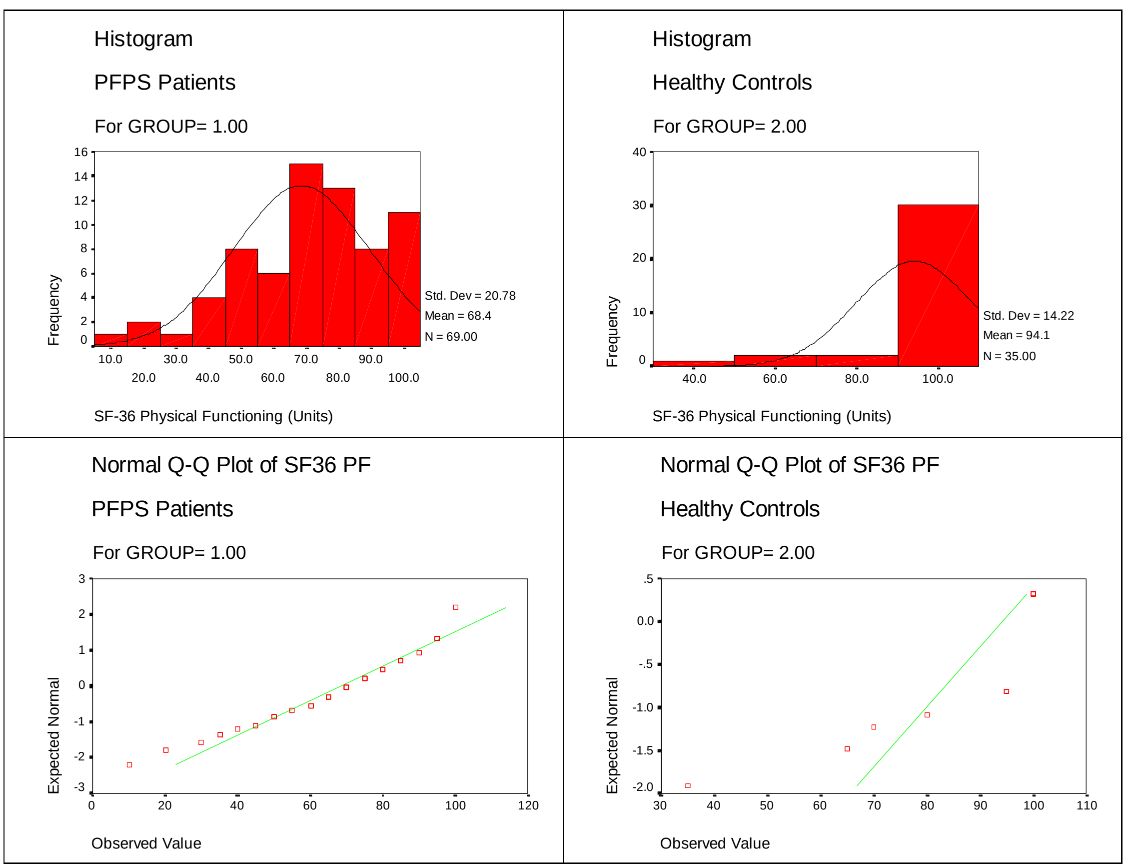
Graphs 13.103 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Right Knee Excursion Angle (Degrees)



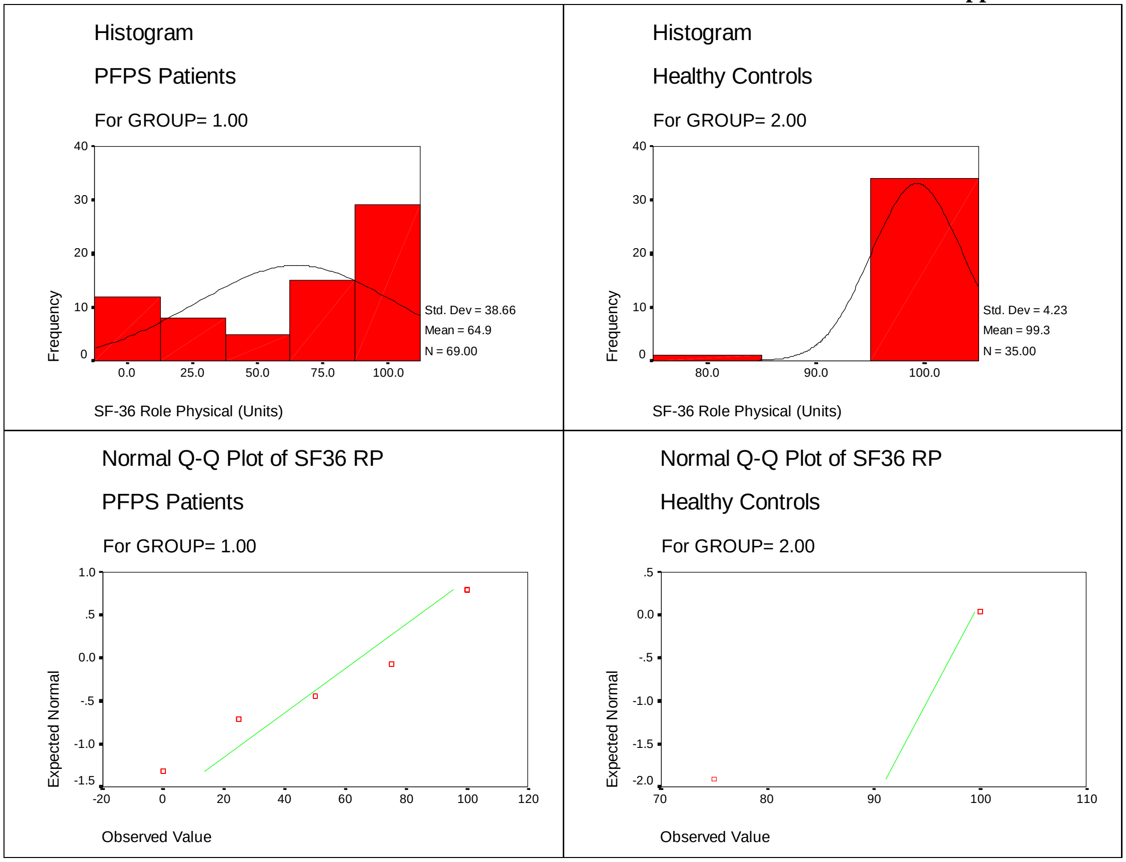
Graphs 13.104 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Left Knee Excursion Angle (Degrees)



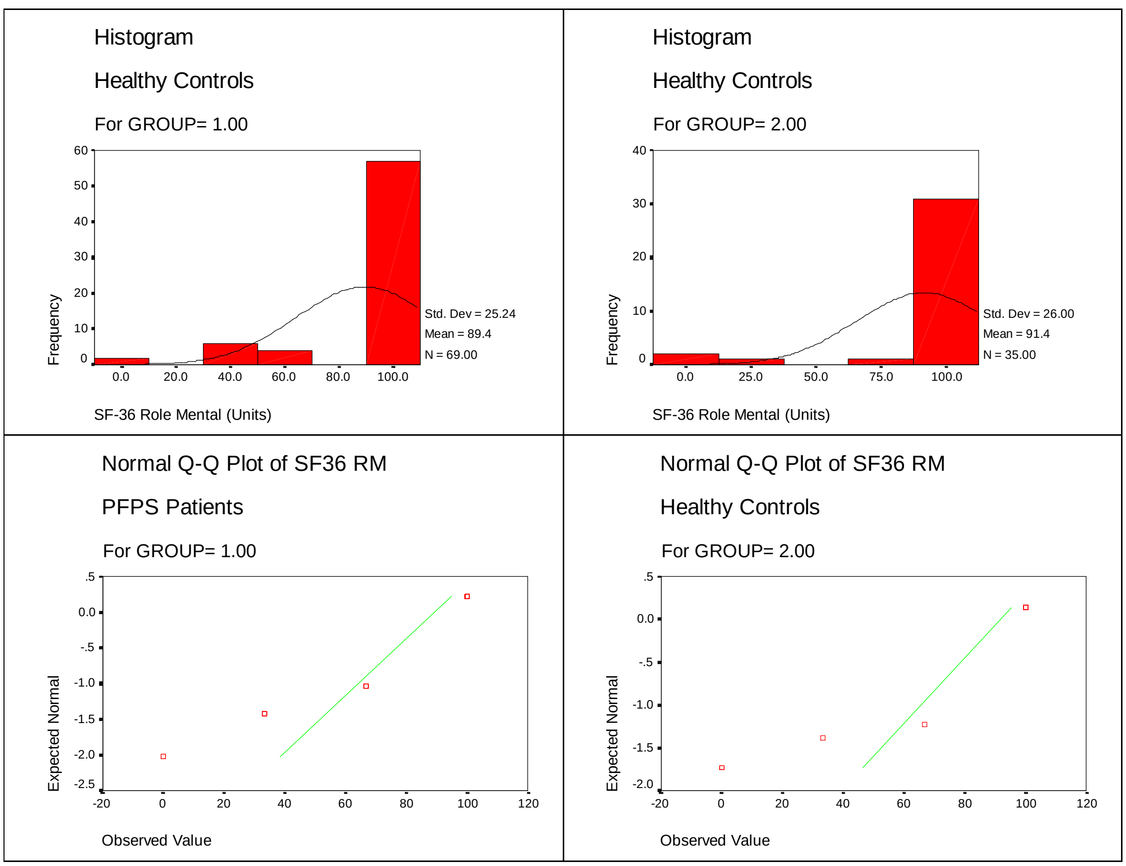
Graphs 13.105 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Gait Time for 5 Metres (Seconds)**



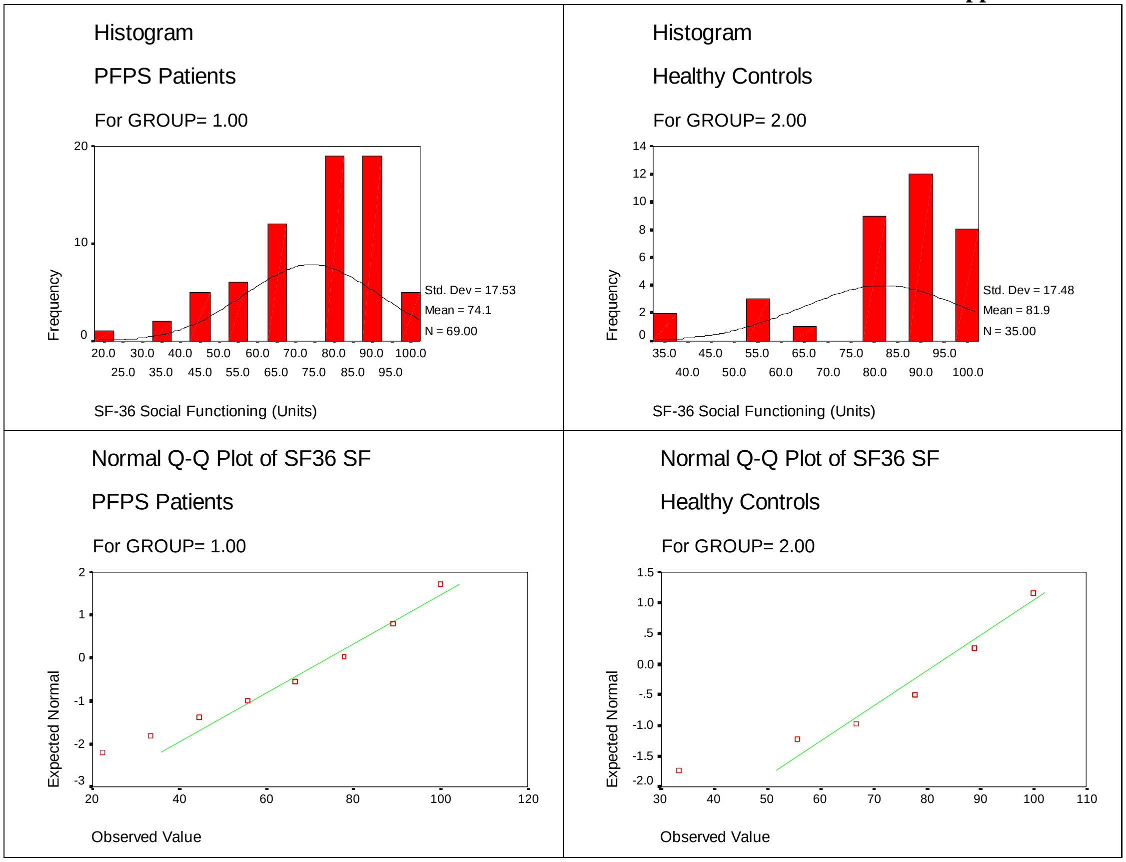
Graphs 13.106 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Physical Functioning (Units)**



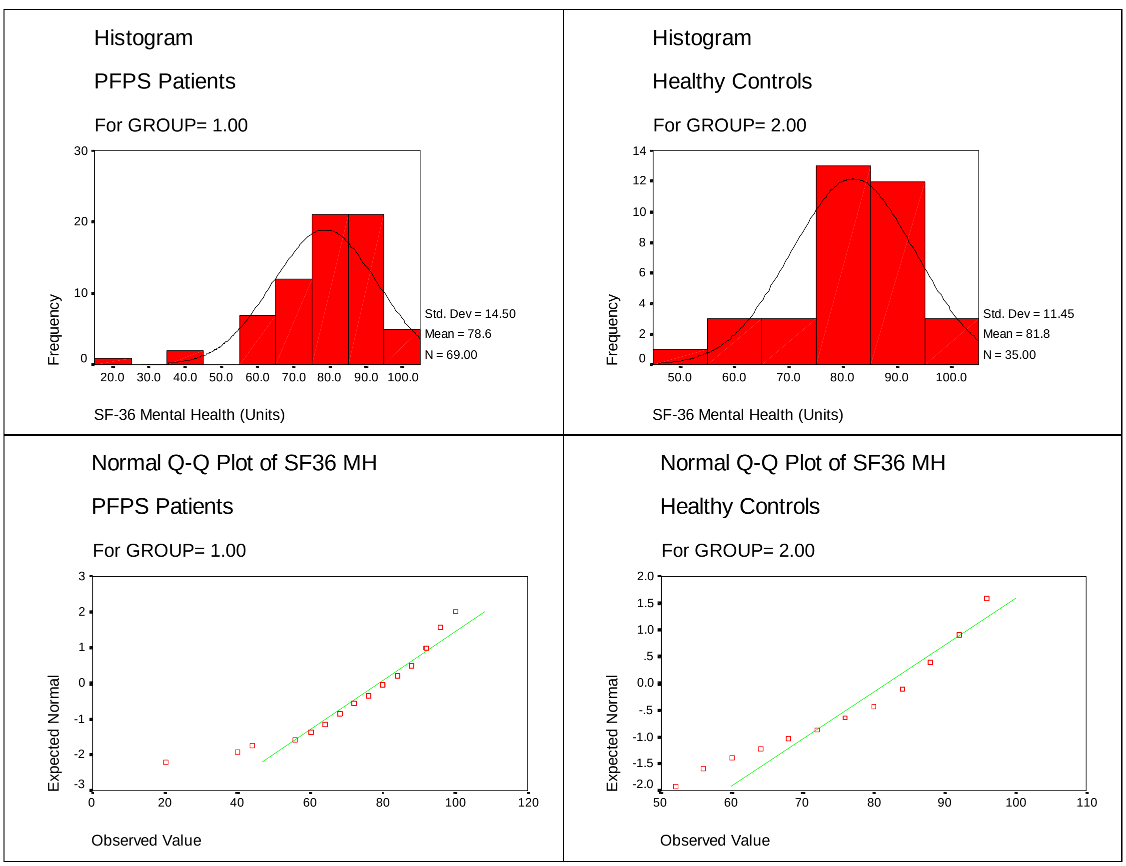
Graphs 13.107 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Role Physical (Units)**



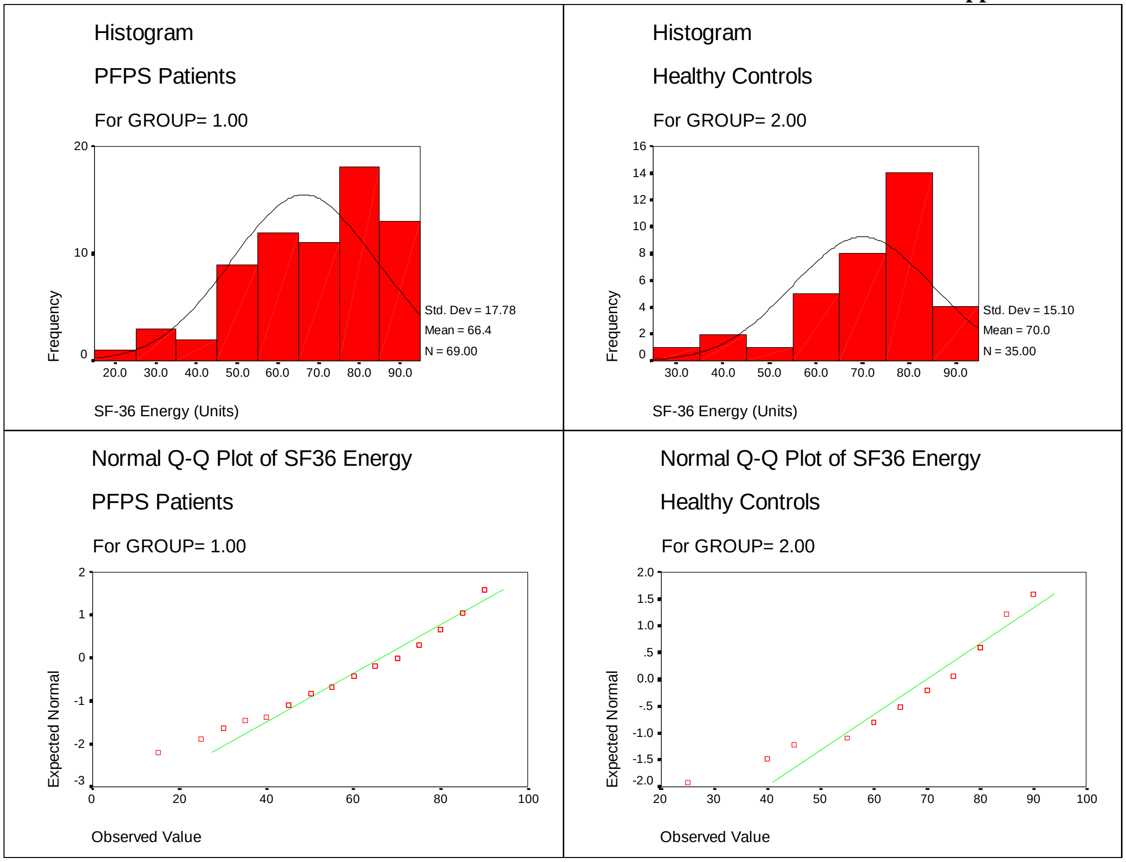
Graphs 13.108 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Role Mental (Units)**



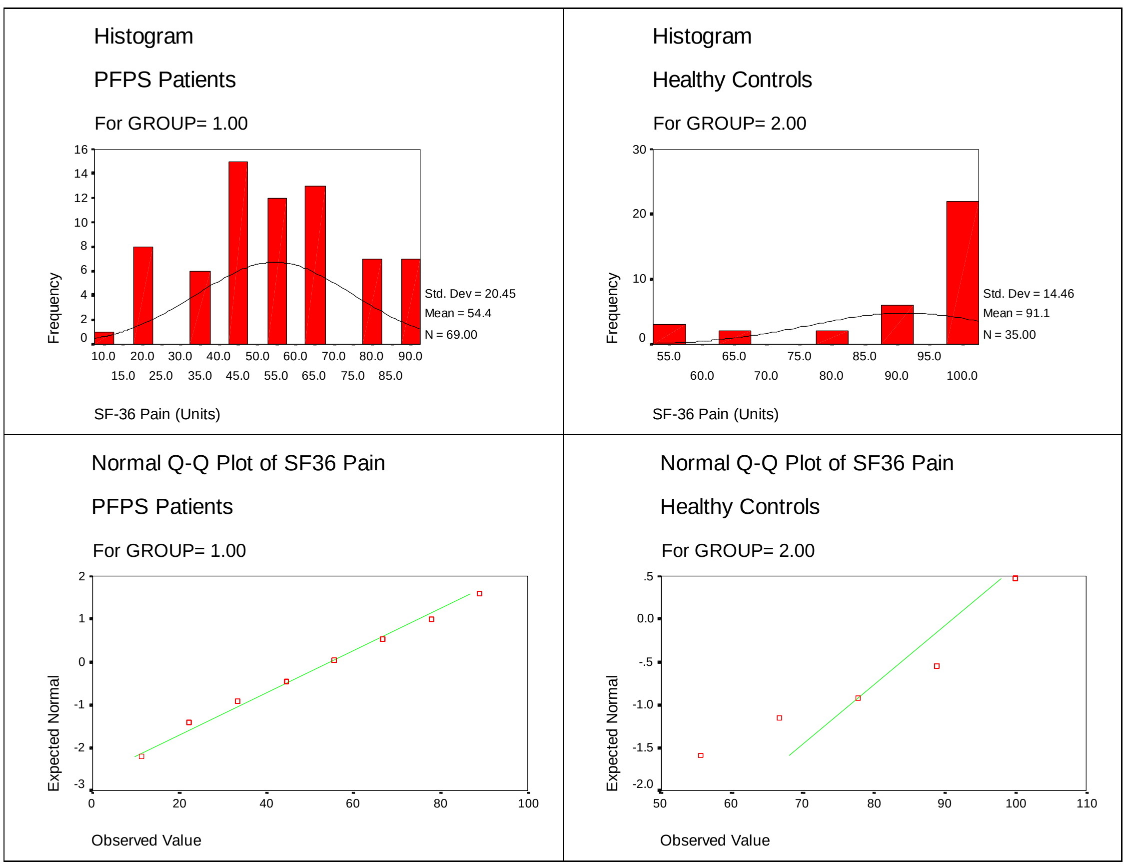
Graphs 13.109 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Social Functioning (Units)**



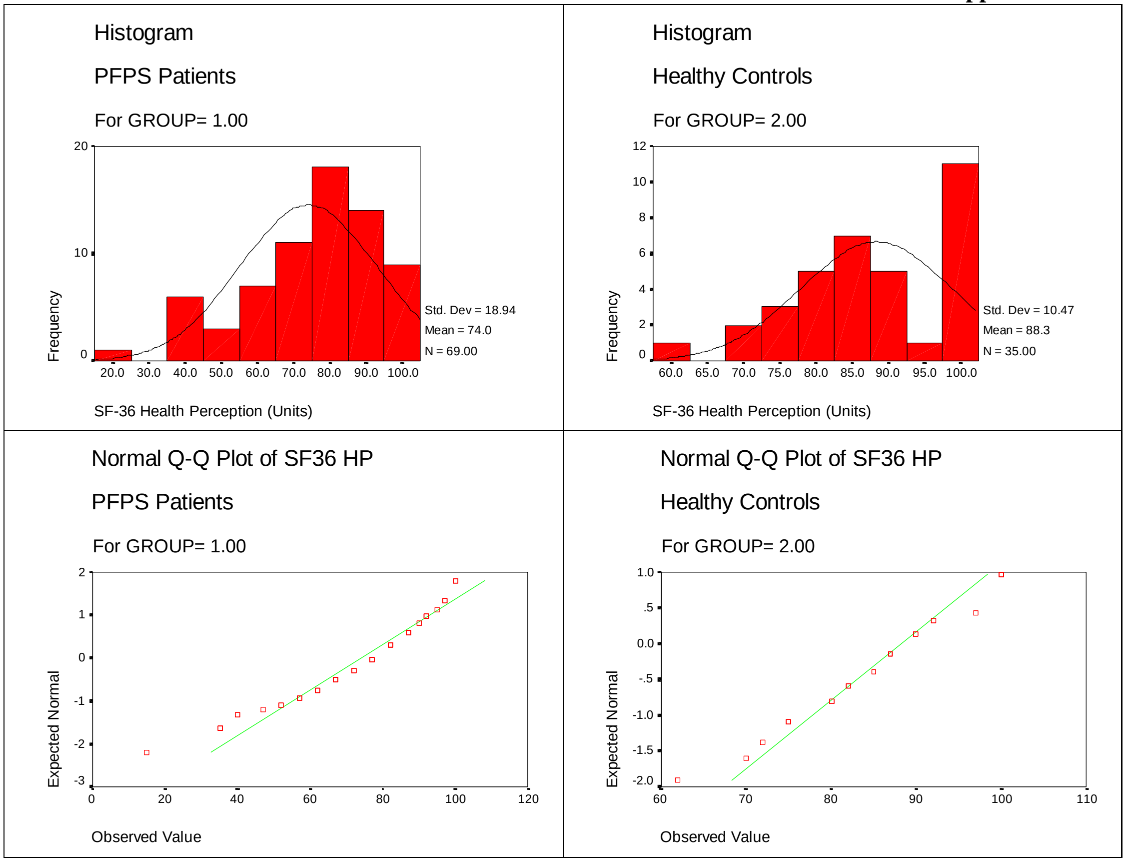
Graphs 13.110 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Mental Health (Units)**



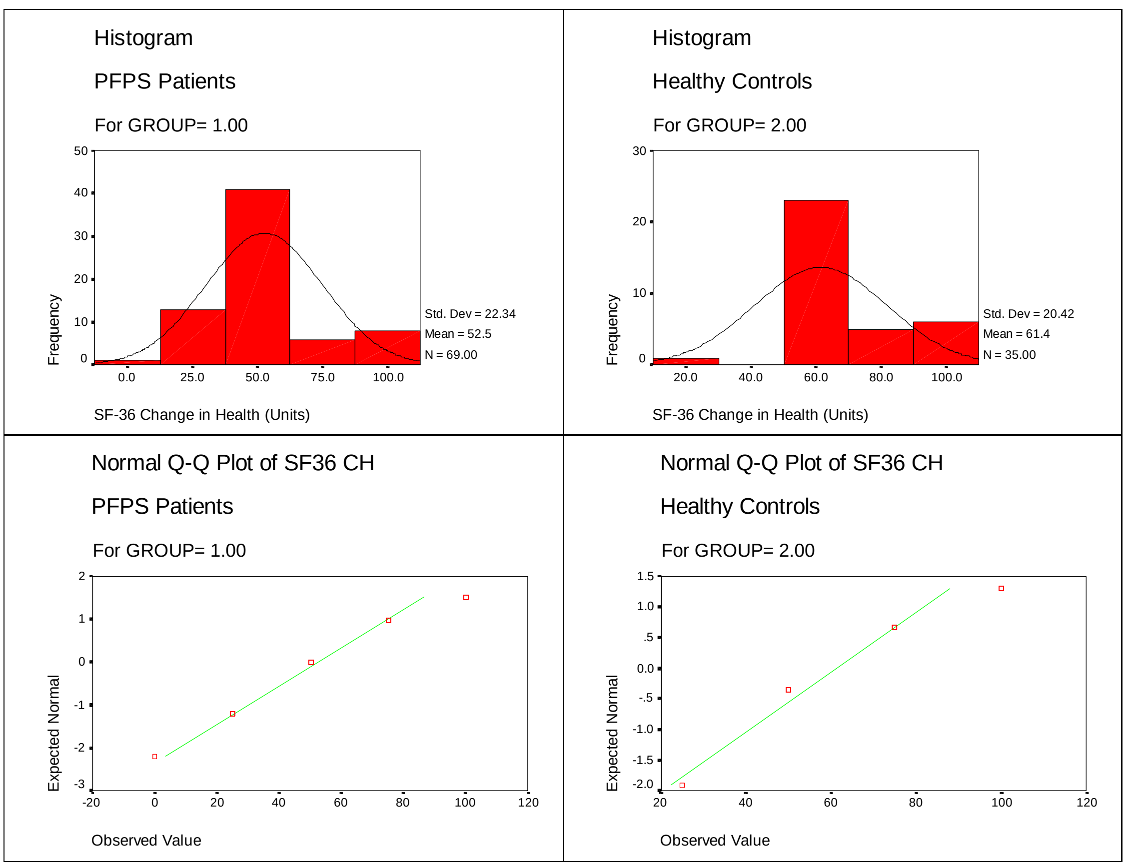
Graphs 13.111 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Energy (Units)**



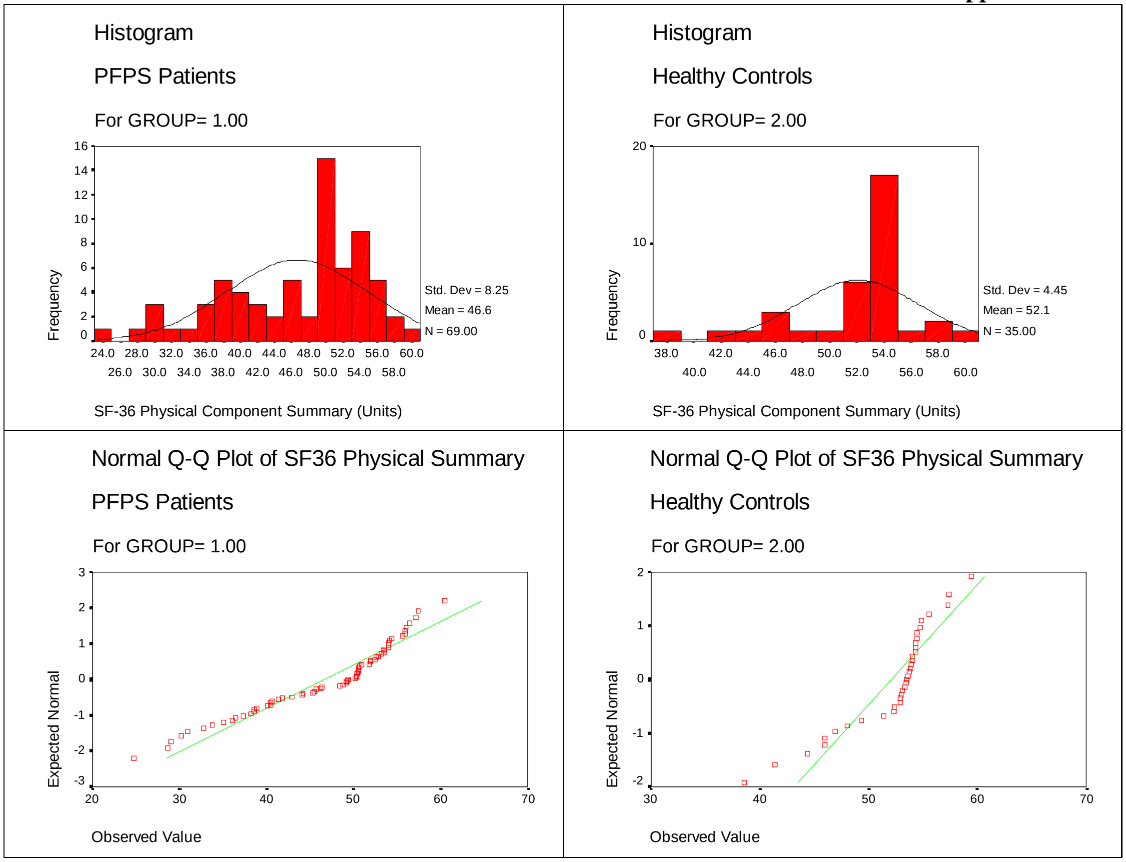
Graphs 13.112 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Pain (Units)**



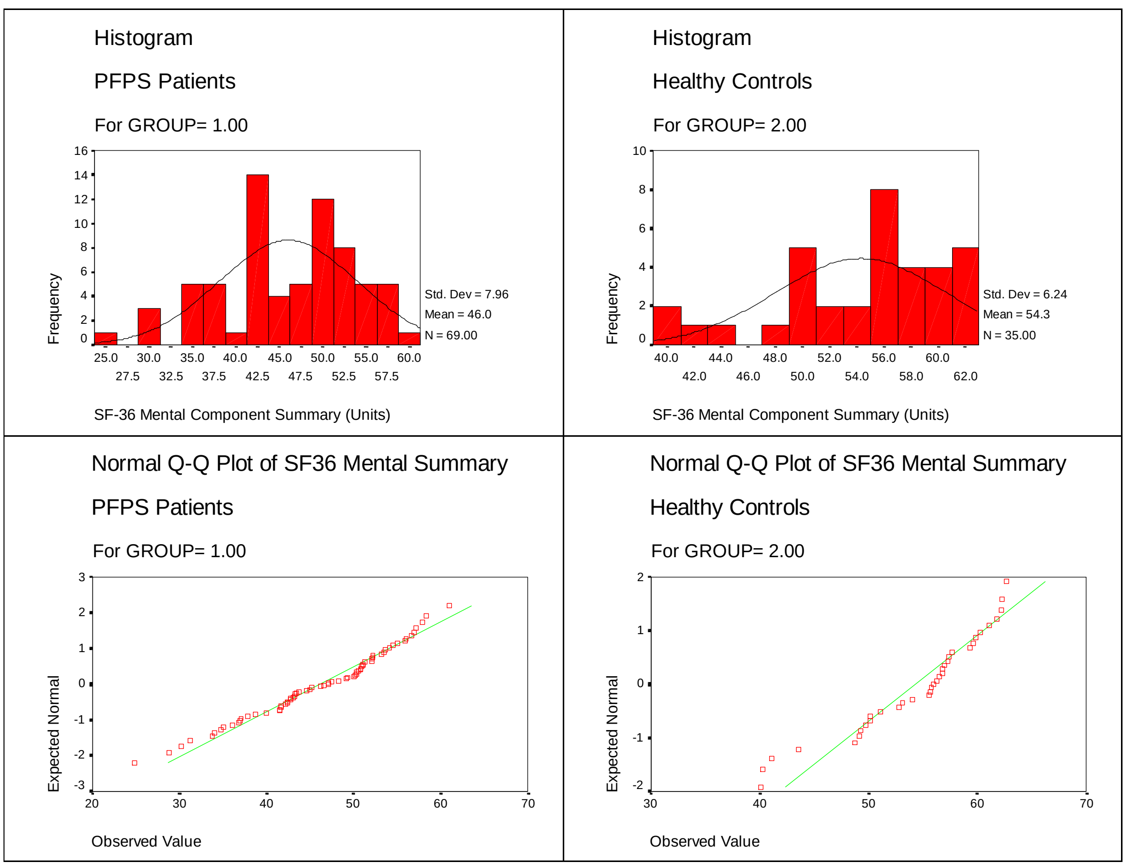
Graphs 13.113 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Health Perception (Units)**



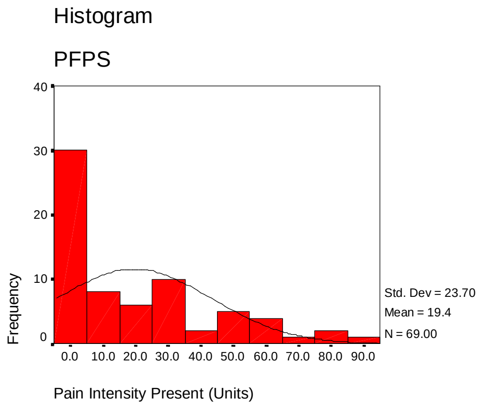
Graphs 13.114 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Change in Health (Units)**

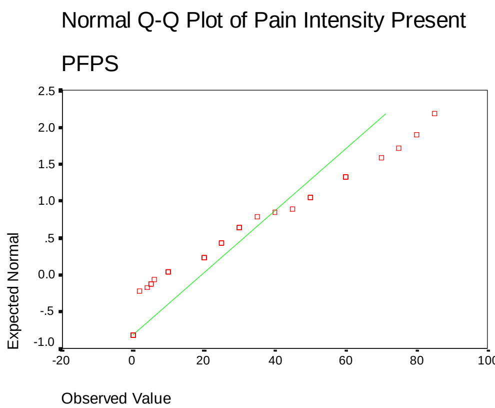


Graphs 13.115 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Physical Component Summary Score (Units)

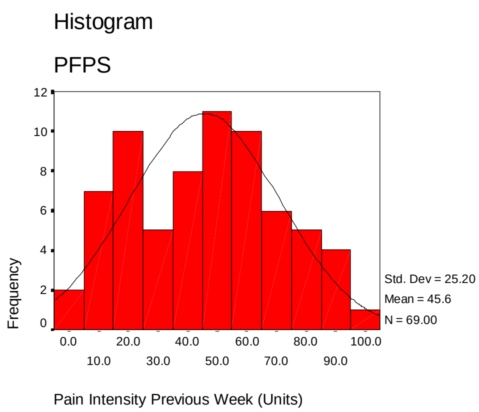


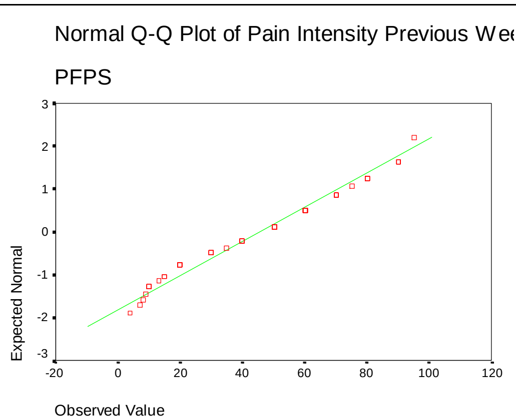
Graphs 13.116 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Mental Health Component Summary Score (Units)



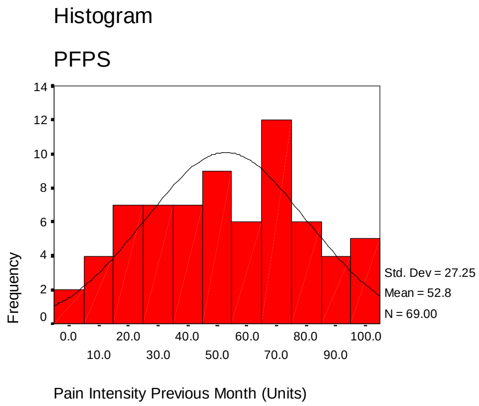


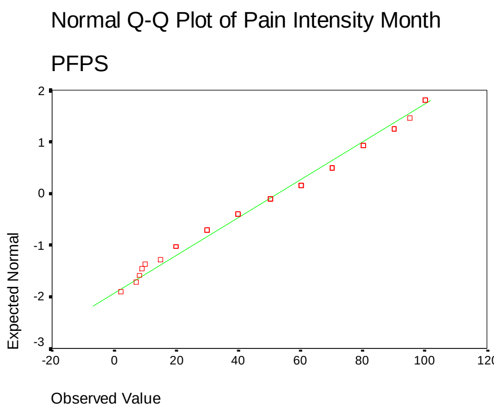
Graphs 13.117 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Pain Intensity Present (Units)



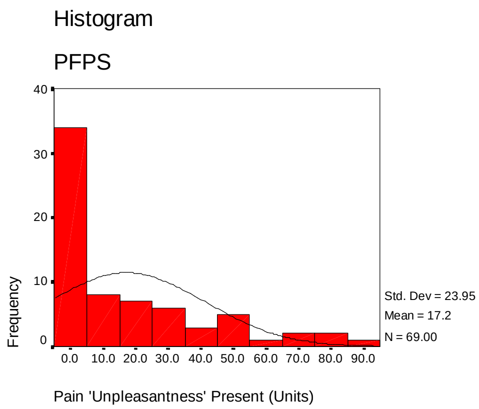


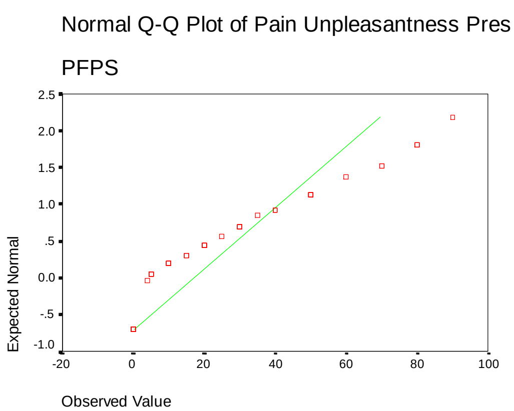
Graphs 13.118 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Average Pain Intensity Previous Week (Units)



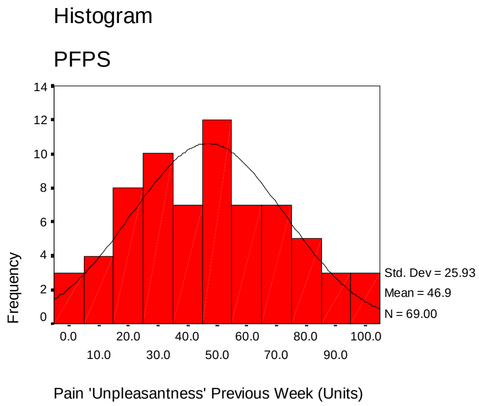


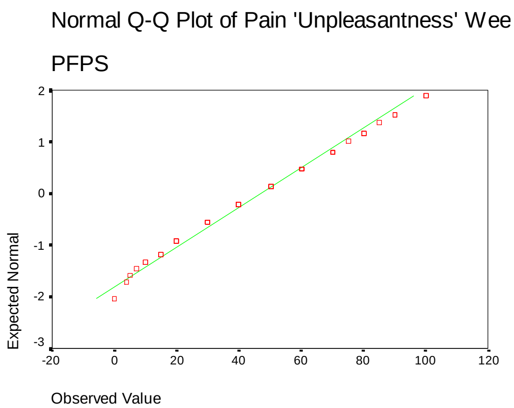
Graphs 13.119 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Average Pain Intensity Previous Month (Units)



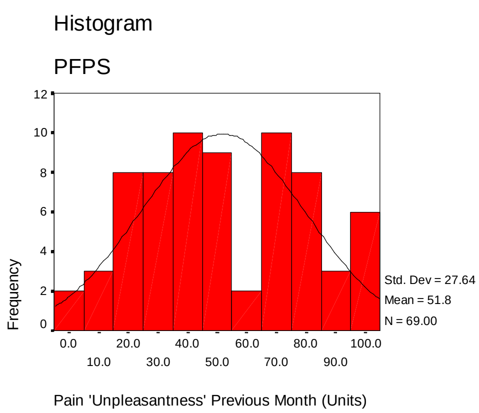


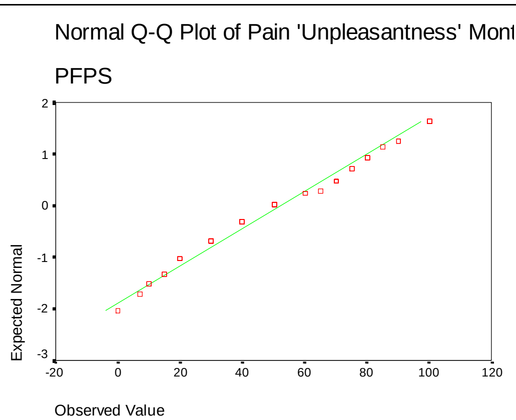
Graphs 13.120 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Pain 'Unpleasantness' Present (Units)



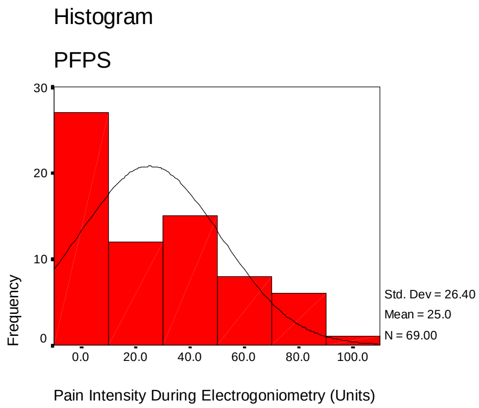


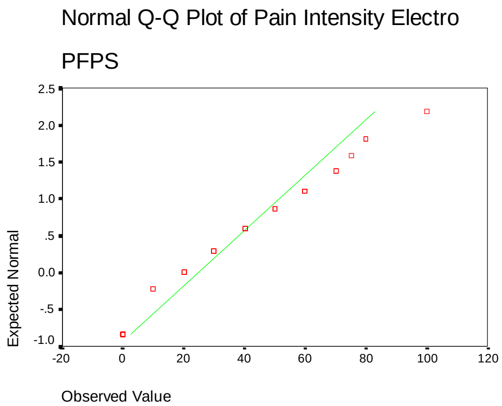
Graphs 13.121 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Average Pain 'Unpleasantness' Previous Week (Units)



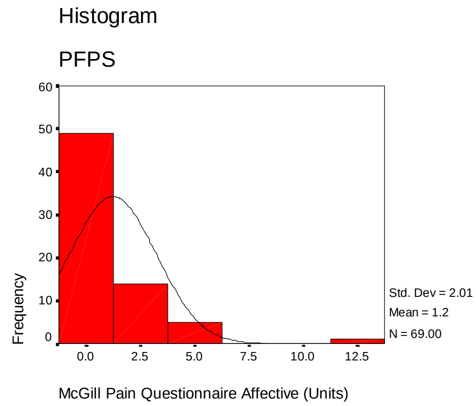


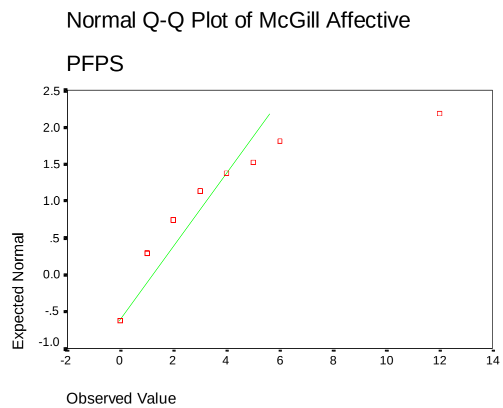
Graphs 13.122 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Average Pain 'Unpleasantness' Previous Month (Units)



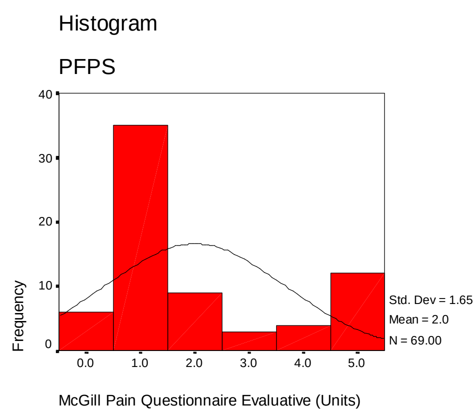


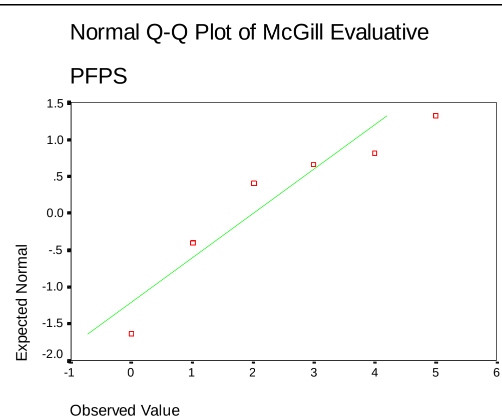
Graphs 13.123 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Pain Intensity Pre-Electrogoniometry Testing (units)



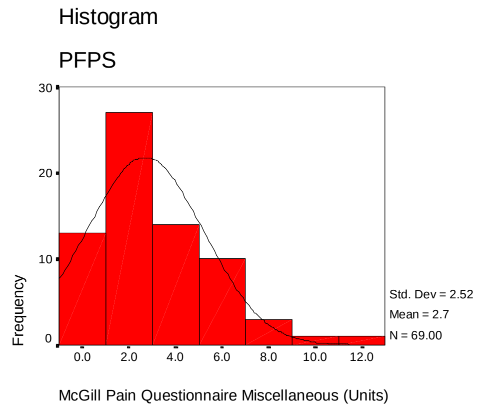


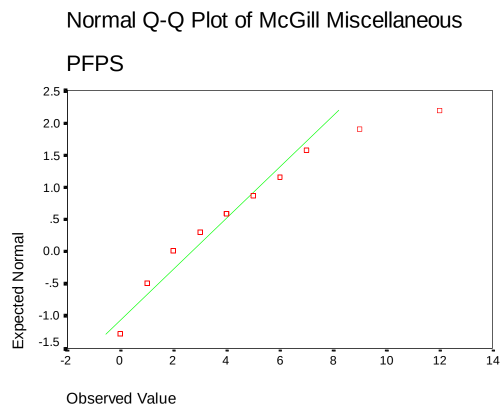
Graphs 13.124 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls McGill Pain Questionnaire Affective Score (Units)



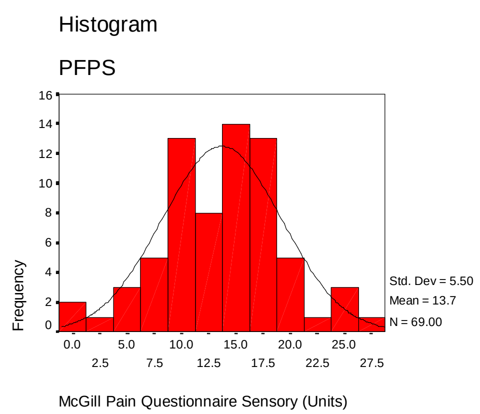


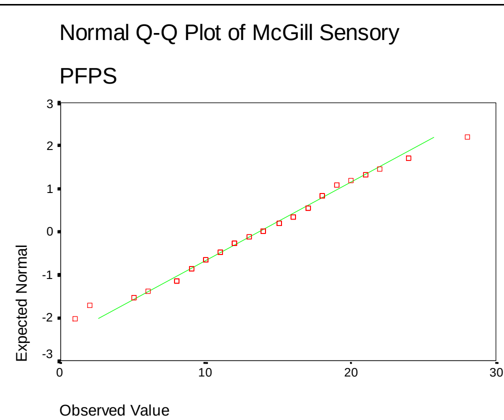
Graphs 13.125 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls McGill Pain Questionnaire Evaluative Score (Units)



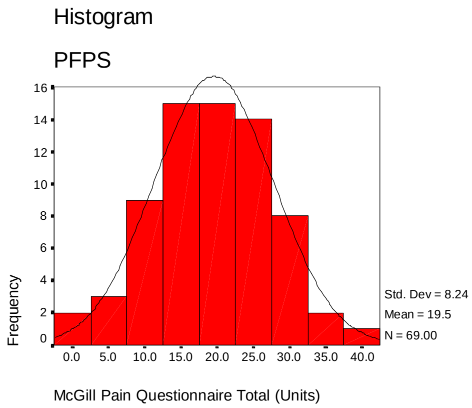


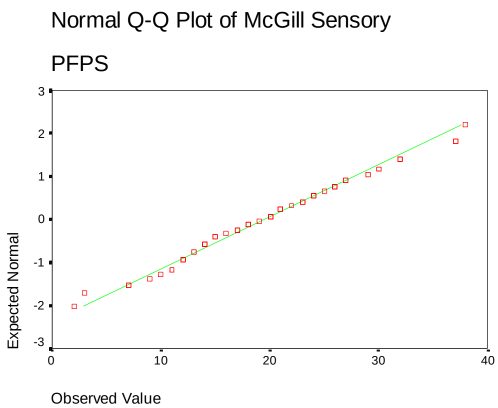
Graphs 13.126 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls McGill Pain Questionnaire Miscellaneous Score (Units)**



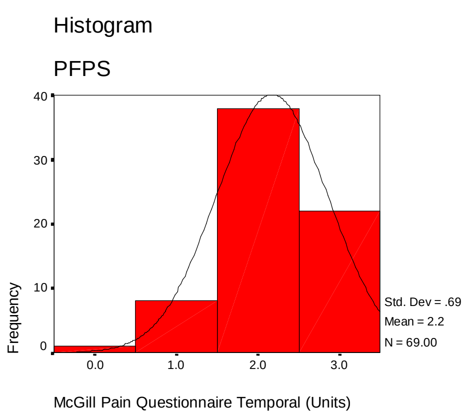


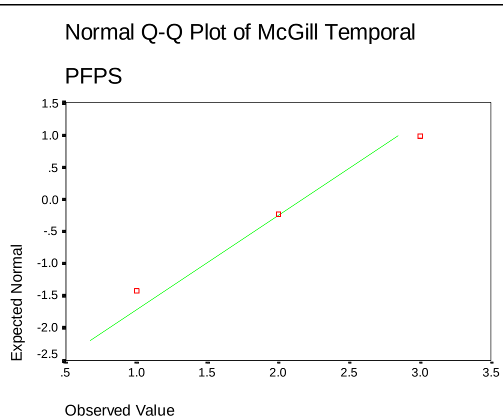
Graphs 13.127 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls McGill Pain Questionnaire Sensory Score (Units)**



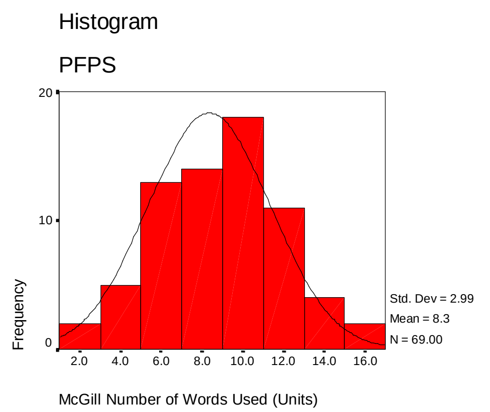


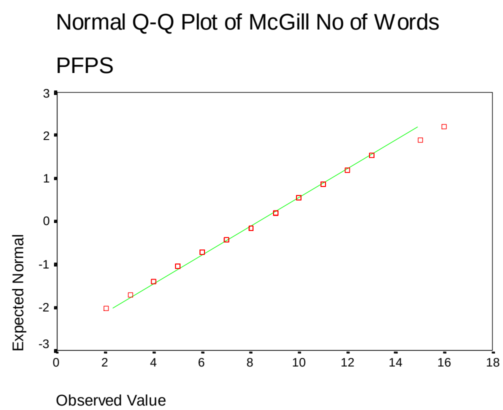
Graphs 13.128 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls McGill Pain Questionnaire Total Score (Units)



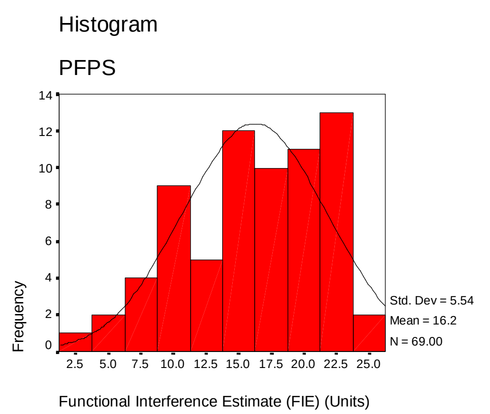


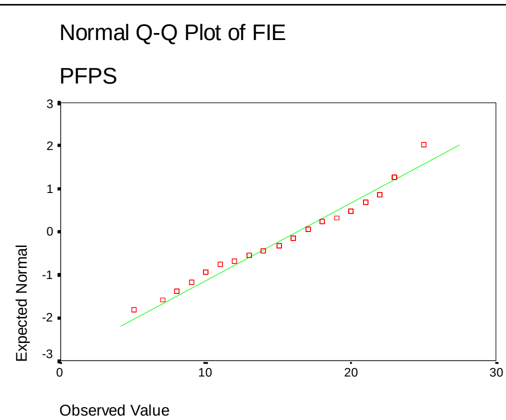
Graphs 13.129 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls McGill Pain Questionnaire Temporal Score (Units)



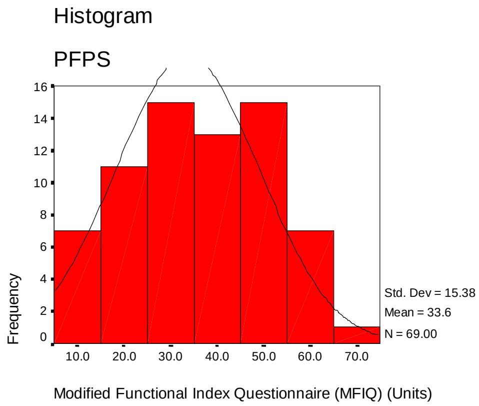


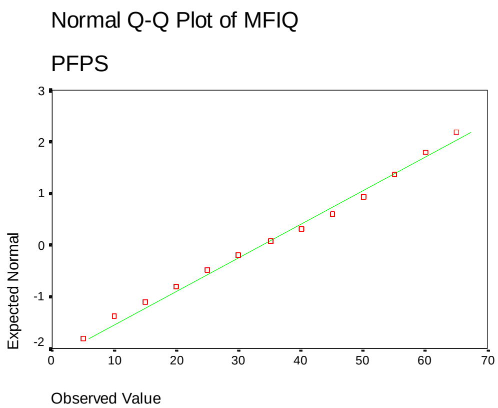
Graphs 13.130 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls McGill Pain Questionnaire Number of Words Used



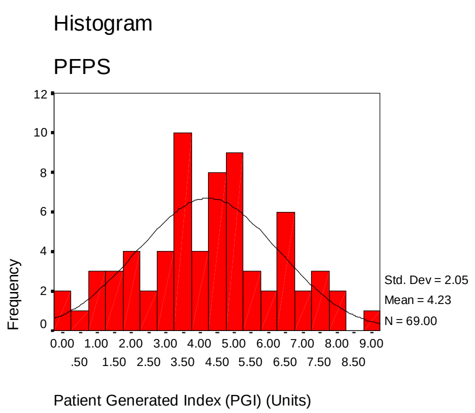


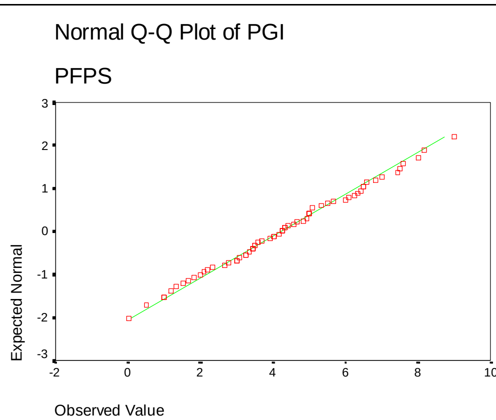
Graphs 13.131 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Functional Interference Estimate (Units)





Graphs 13.132 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Modified Functional Index Questionnaire (Units)

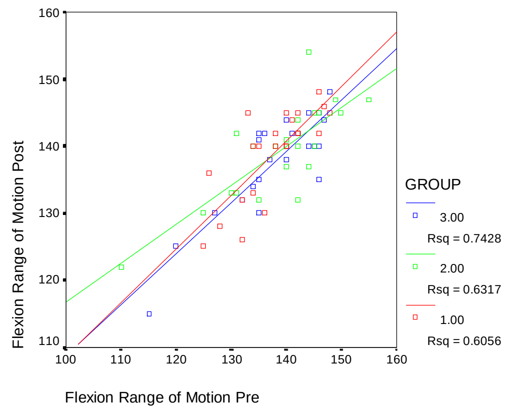




Graphs 13.133 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls Patient Generated Index (PGI) (Units)

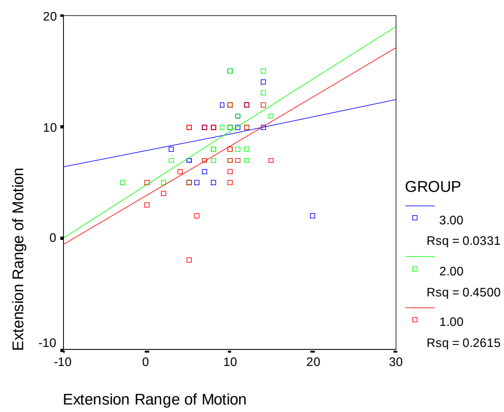
ELECTRONIC APPENDIX 14

14.1 POST RCT ANCOVA ASSUMPTIONS TESTS



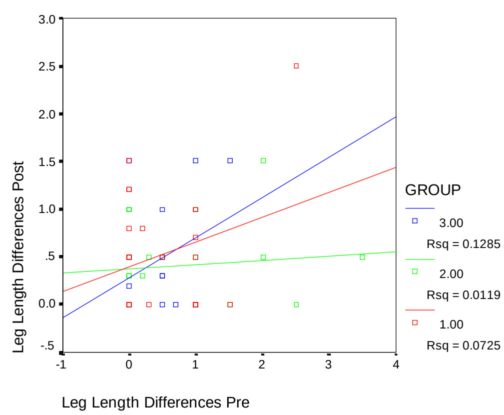
Homogeneity of regression slopes = 0.287

Graph 14.1 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Knee Flexion Range of Motion (Degrees)



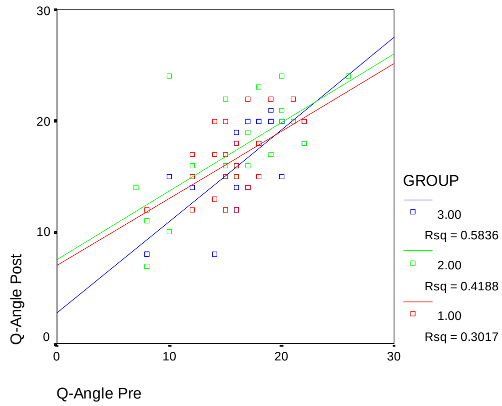
Homogeneity of regression slopes = 0.290

Graph 14.2 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Knee Extension Range of Motion (Degrees)



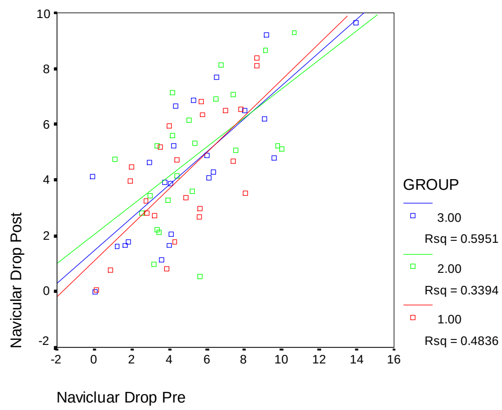
Homogeneity of regression slopes = 0.296

Graph 14.3 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Leg Length Difference (Centimetres)



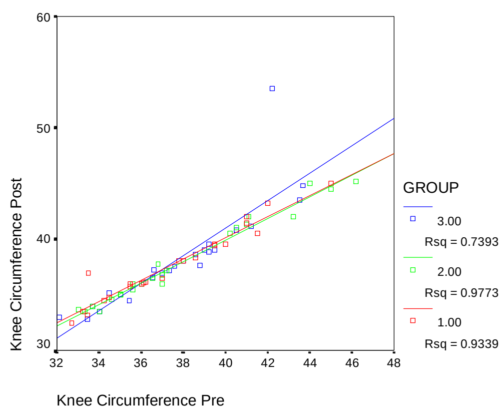
Homogeneity of regression slopes = 0.591

Graphs 13.4 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Q-Angle (Degrees)



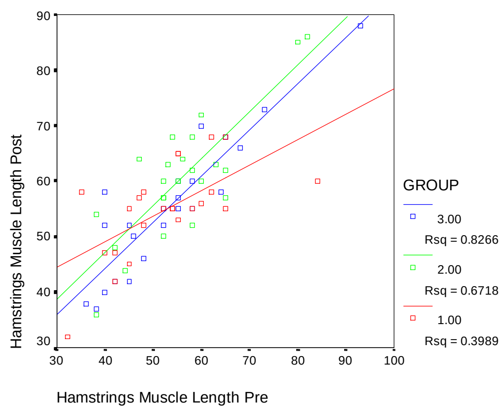
Homogeneity of regression slopes = 0.828

Graph 14.5 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Navicular Drop (Millimetres)



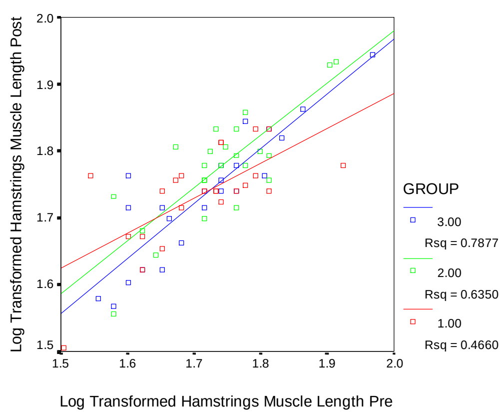
Homogeneity of regression slopes = 0.080

Graph 14.6 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Knee Circumferential Measurements (Centimetres)



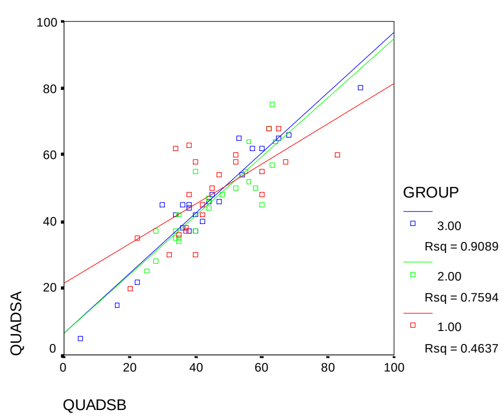
Homogeneity of regression slopes = 0.030

Graph 14.7 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Hamstrings Muscle Length (Degrees)



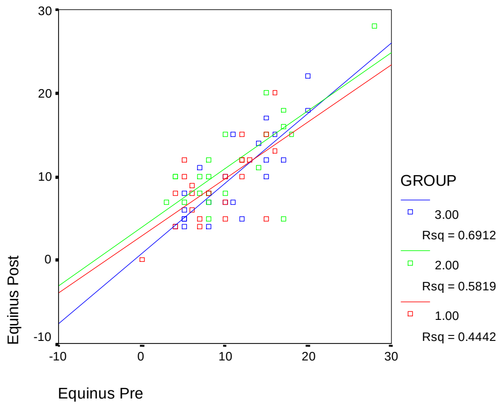
Homogeneity of regression slopes = 0.133

Graph 14.8 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Log Transformed Hamstrings Muscle Length (Degrees)



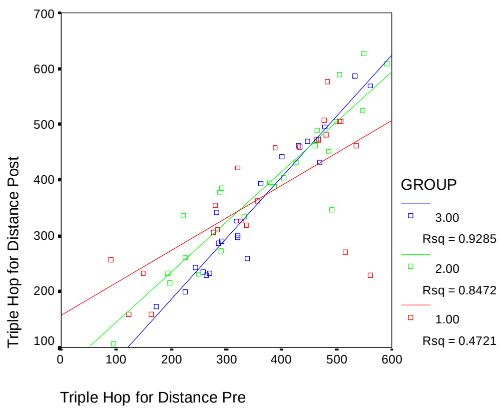
Homogeneity of regression slopes = 0.080

Graph 14.9 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Quadriceps Muscle Length (Degrees)



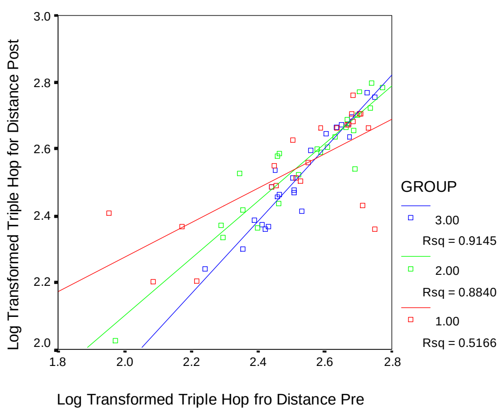
Homogeneity of regression slopes = 0.683

Graph 14.10 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Equinus (Degrees)



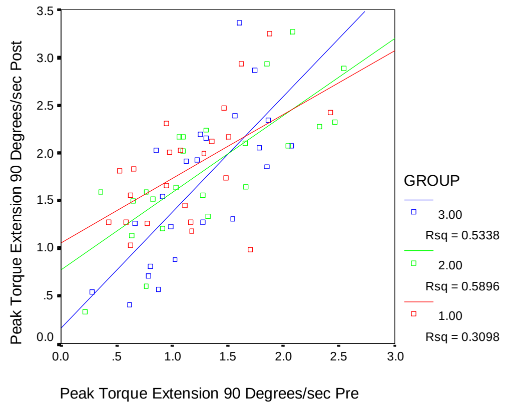
Homogeneity of regression slopes = 0.005

Graph 14.11 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Triple Hop Distance (Centimetres)



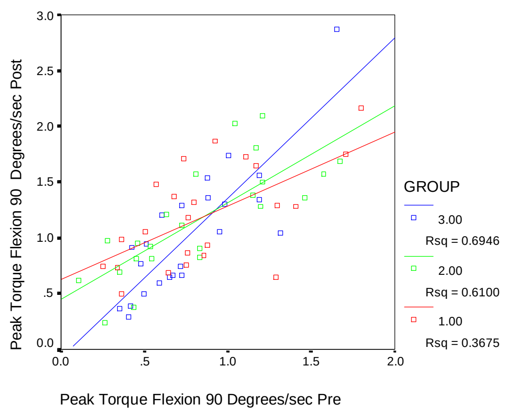
Homogeneity of regression slopes = 0.000

Graph 14.12 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Log Transformed Triple Hop Distance (Centimetres)



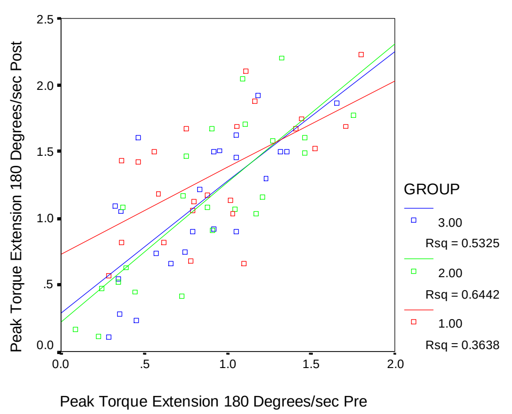
Homogeneity of regression slopes = 0.206

Graph 14.13 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Peak Torque Knee Extension at 90°/s Nm/kg



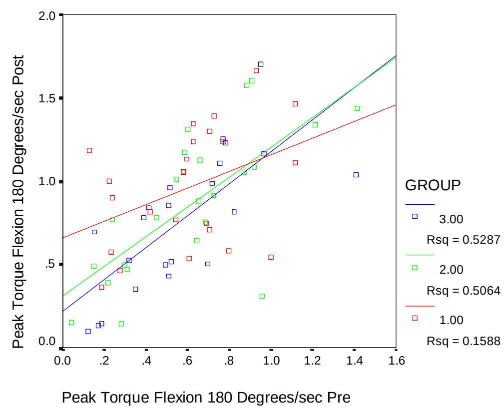
Homogeneity of regression slopes = 0.23

Graph 14.14 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Peak Torque Knee Flexion at 90°/s Nm/kg



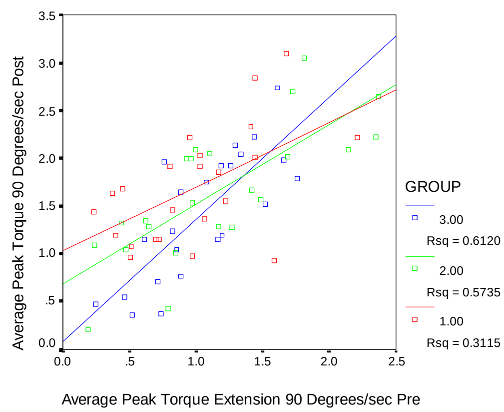
Homogeneity of regression slopes = 0.262

Graph 14.15 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Peak Torque Knee Extension at 180°/s Nm/kg



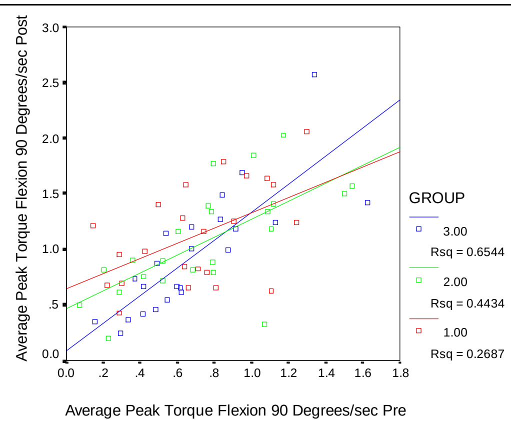
Homogeneity of regression slopes = 0.291

Graph 14.16 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Peak Torque Knee Flexion at 180°/s Nm/kg**



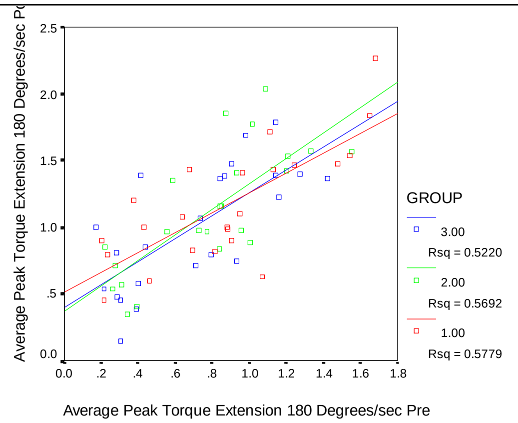
Homogeneity of regression slopes = 0.155

Graph 14.17 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Average Peak Torque Knee Extension at 90°/s Nm/kg**



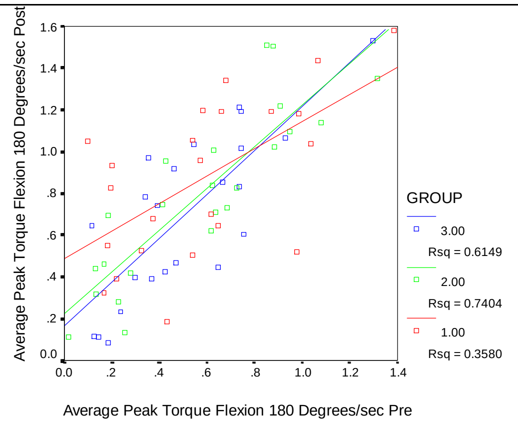
Homogeneity of regression slopes = 0.173

Graph 14.18 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Average Peak Torque Knee Flexion at 90°/s Nm/kg**



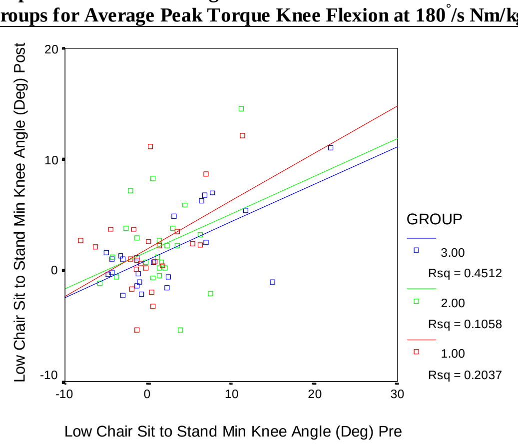
Homogeneity of regression slopes = 0.655

Graph 14.19 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Average Peak Torque Knee Extension at 180°/s Nm/kg



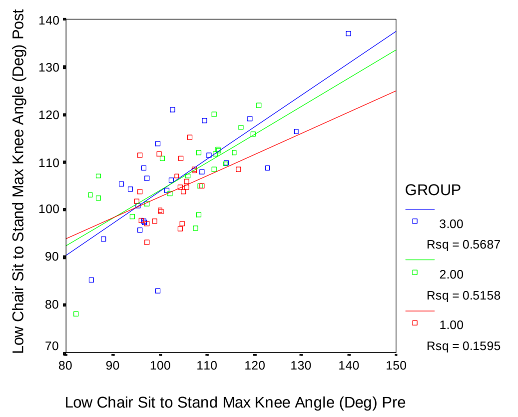
Homogeneity of regression slopes = 0.195

Graph 14.20 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Average Peak Torque Knee Flexion at 180°/s Nm/kg



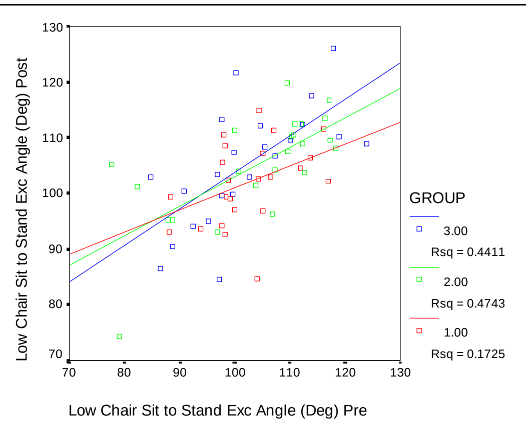
Homogeneity of regression slopes = 0.902

Graph 14.21 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for 0Sitting to Standing from Low Chair Minimum Knee Joint Angle (Degrees)



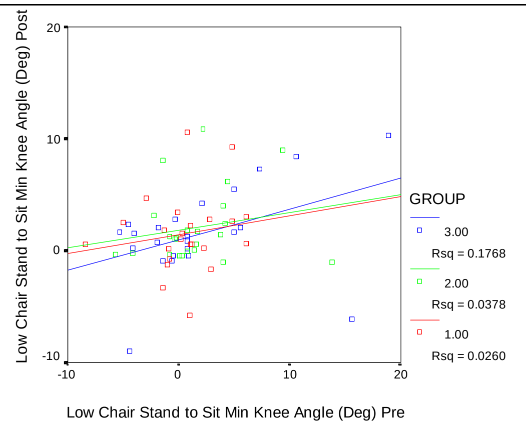
Homogeneity of regression slopes = 0.695

Graph 14.22 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Sitting to Standing from Low Chair Maximum Knee Joint Angle (Degrees)**



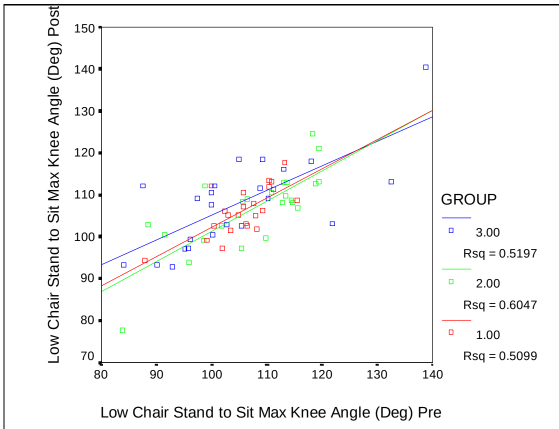
Homogeneity of regression slopes = 0.999

Graph 14.23 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Sitting to Standing from Low Chair Knee Joint Excursion Angle (Degrees)**



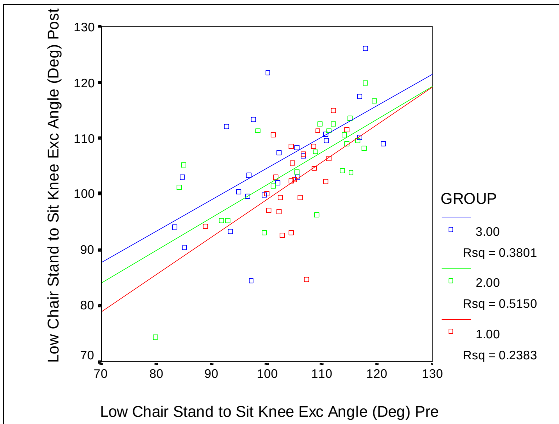
Homogeneity of regression slopes = 0.836

Graph 14.24 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Standing to Sitting to Low Chair Minimum Knee Joint Angle (Degrees)**



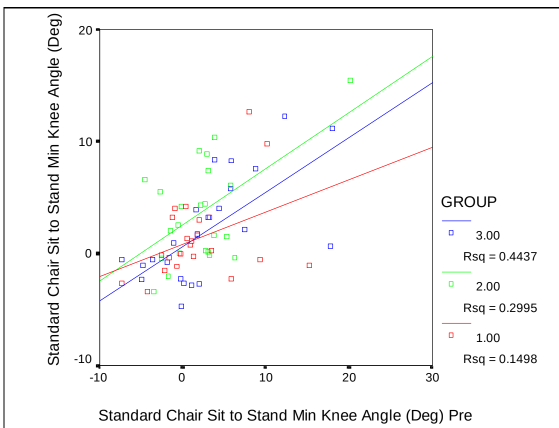
Homogeneity of regression slopes = 0.681

Graph 14.25 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Standing to Sitting to Low Chair Maximum Knee Joint Angle (Degrees)



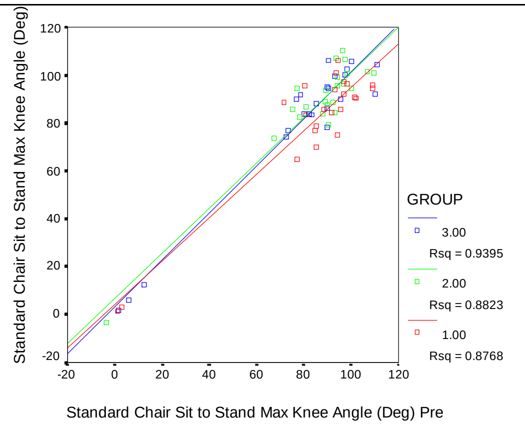
Homogeneity of regression slopes = 0.944

Graph 14.26 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Standing to Sitting to Low Chair Knee Joint Excursion Angle (Degrees)



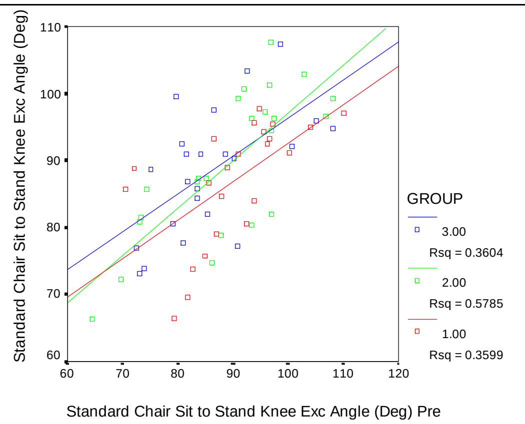
Homogeneity of regression slopes = 0.541

Graph 14.27 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Sitting to Standing from a Standard Chair Minimum Knee Joint Angle (Deg)



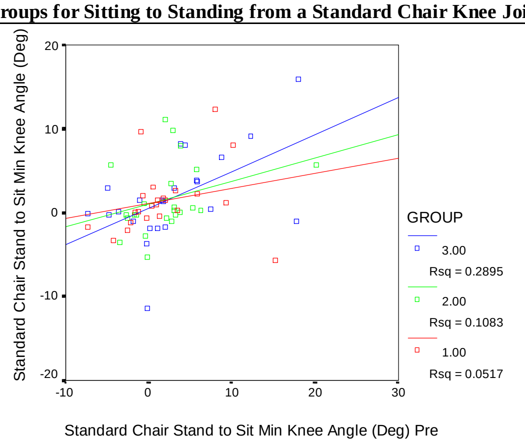
Homogeneity of regression slopes = 0.723

Graph 14.28 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Sitting to Standing from a Standard Chair Maximum Knee Joint Angle (Deg)**



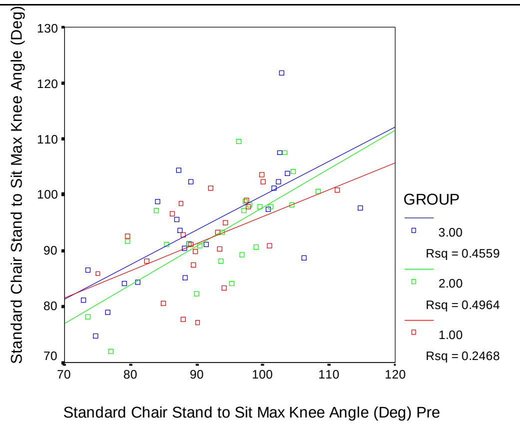
Homogeneity of regression slopes = 0.733

Graph 14.29 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Sitting to Standing from a Standard Chair Knee Joint Excursion Angle (Deg)**



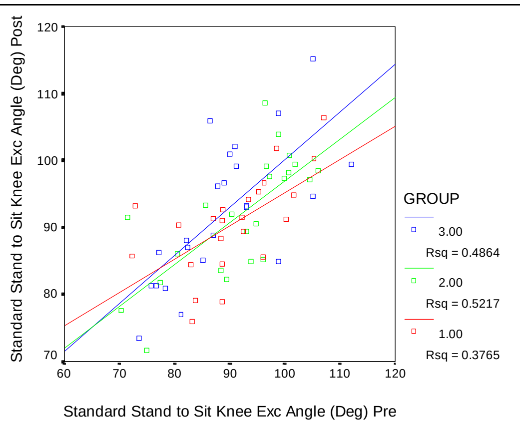
Homogeneity of regression slopes = 0.253

Graph 14.30 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Standing to Sitting to a Standard Chair Minimum Knee Joint Angle (Deg)**



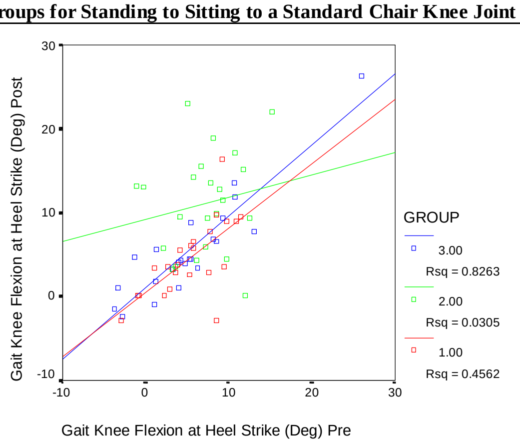
Homogeneity of regression slopes = 0.720

Graph 14.31 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Standing to Sitting to a Standard Chair Maximum Knee Joint Angle (Deg)



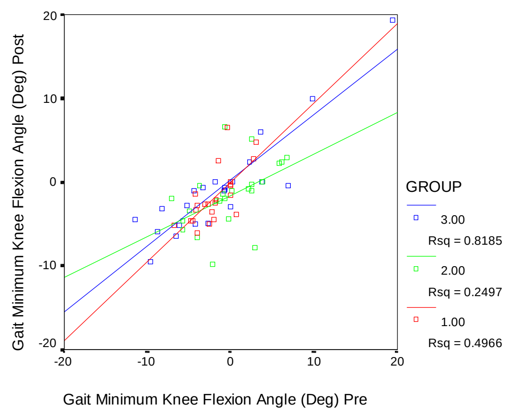
Homogeneity of regression slopes = 0.591

Graph 14.32 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Standing to Sitting to a Standard Chair Knee Joint Excursion Angle (Deg)



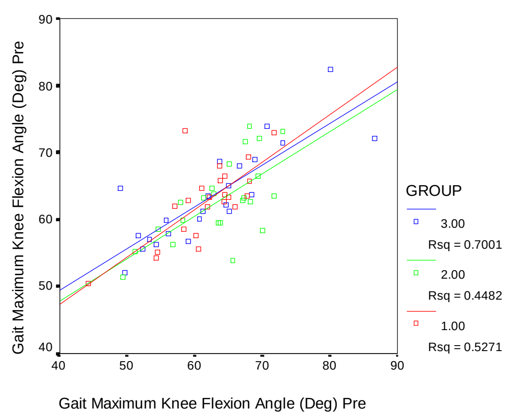
Homogeneity of regression slopes = 0.097

Graph 14.33 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Level Walking Knee Flexion Angle at Heel Strike (Degrees)



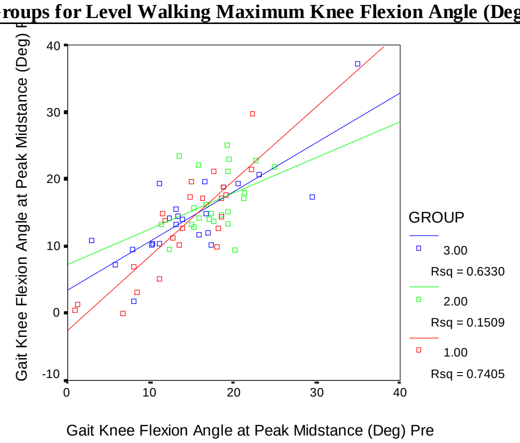
Homogeneity of regression slopes = 0.188

Graph 14.34 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Level Walking Minimum Knee Flexion Angle (Degrees)



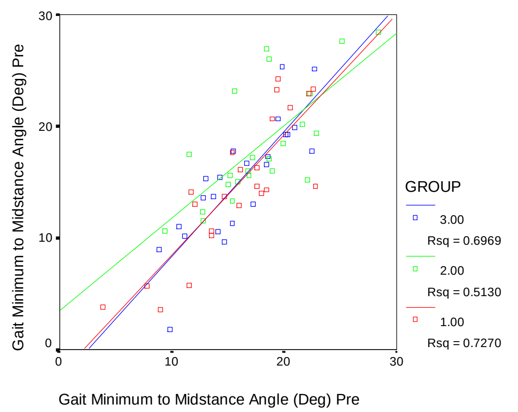
Homogeneity of regression slopes = 0.895

Graph 14.35 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Level Walking Maximum Knee Flexion Angle (Degrees)



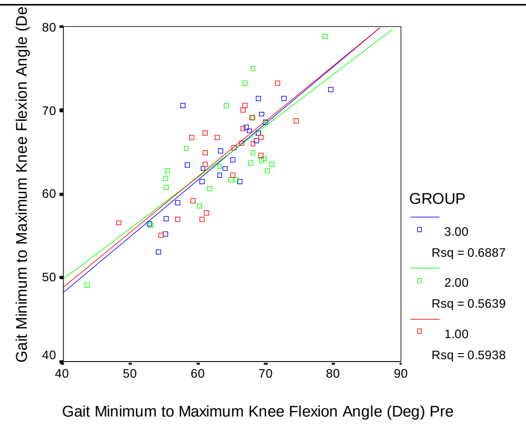
Homogeneity of regression slopes = 0.80

Graph 14.36 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Level Walking Knee Flexion at Peak Midstance Angle (Degrees)



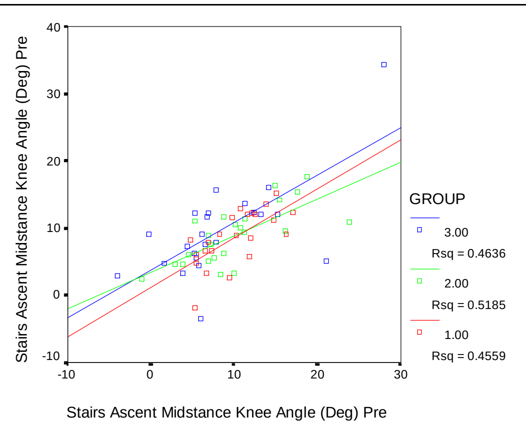
Homogeneity of regression slopes = 0.392

Graph 14.37 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Level Walking Minimum to Peak Midstance Knee Excursion Angle (Degrees)



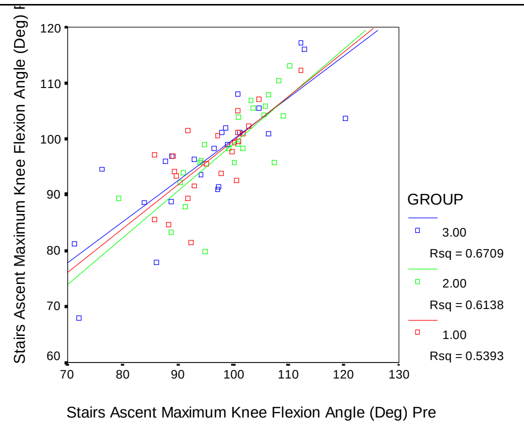
Homogeneity of regression slopes = 0.904

Graph 14.38 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Level Walking Minimum to Maximum Knee Excursion Angle (Degrees)



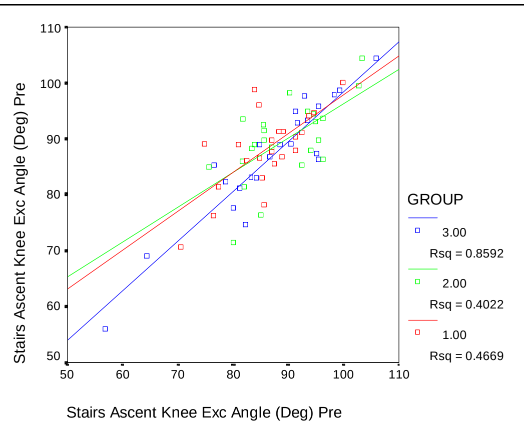
Homogeneity of regression slopes = 0.655

Graph 14.39 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Stairs Ascent Knee Midstance Angle (Degrees)



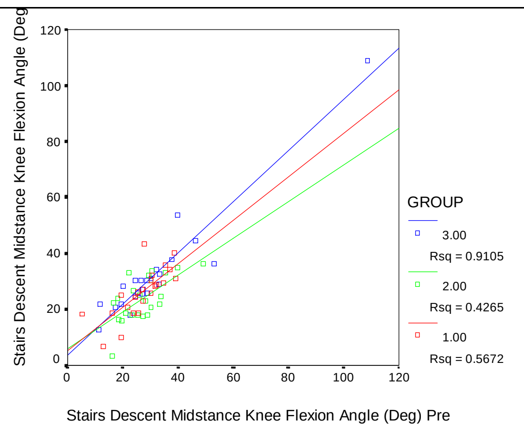
Homogeneity of regression slopes = 0.848

Graph 14.40 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Stairs Ascent Knee Maximum Angle (Degrees)**



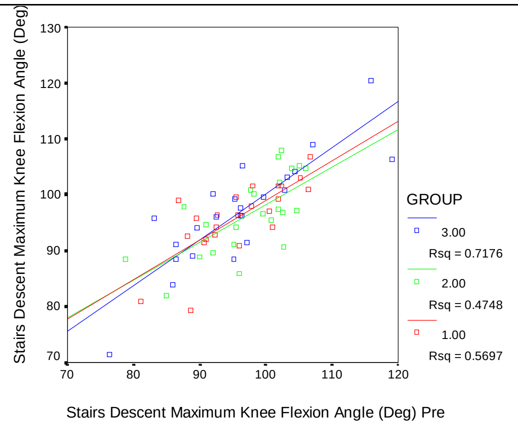
Homogeneity of regression slopes = 0.250

Graph 14.41 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Stairs Ascent Midstance to Maximum Knee Excursion Angle (Degrees)**



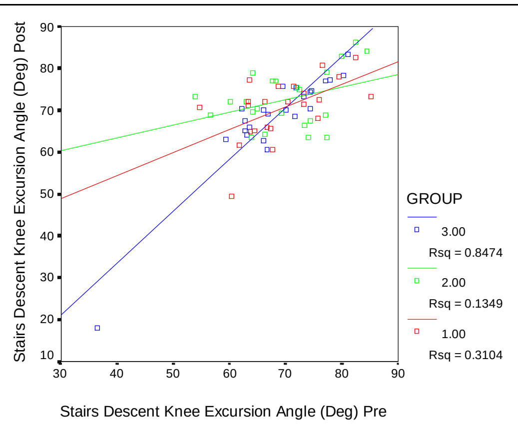
Homogeneity of regression slopes = 0.271

Graph 14.42 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Stairs Descent Knee Midstance Angle (Degrees)**



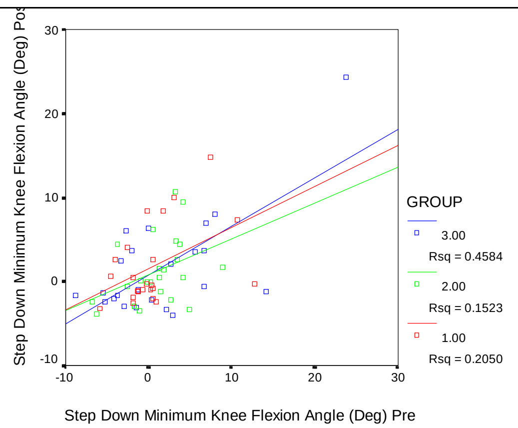
Homogeneity of regression slopes = 0.673

Graph 14.43 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Stairs Descent Maximum Knee Angle (Degrees)**



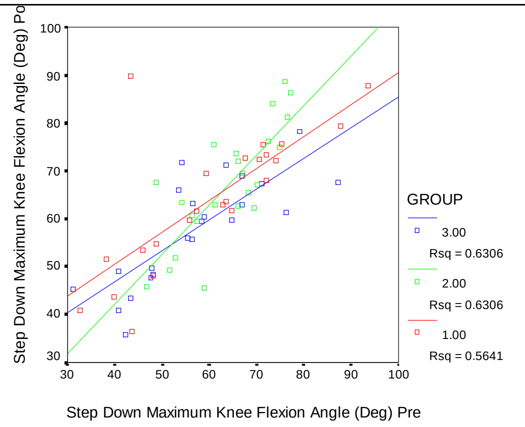
Homogeneity of regression slopes = 0.00

Graph 14.44 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Stairs Descent Midstance to Maximum Knee Angle (Degrees)**



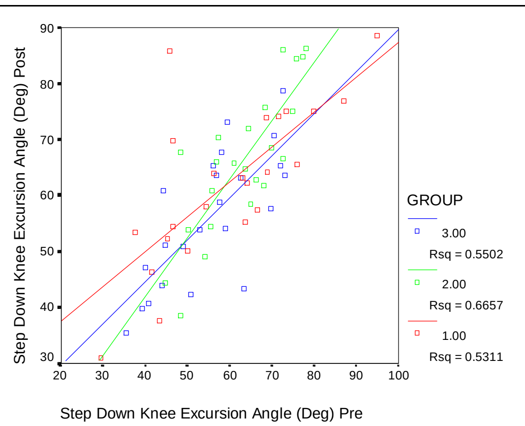
Homogeneity of regression slopes = 0.839

Graph 14.45 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Step Down Minimum Knee Angle (Degrees)**



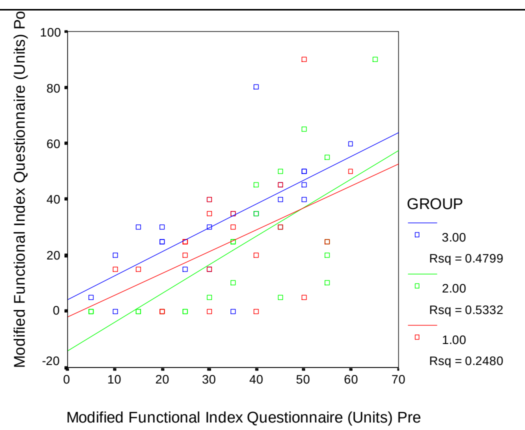
Homogeneity of regression slopes = 0.179

Graph 14.46 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Step Down Maximum Knee Angle (Degrees)**



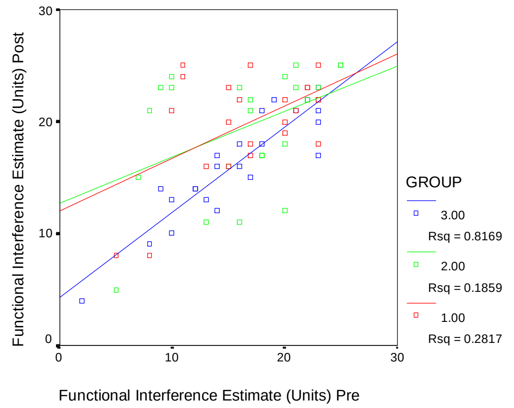
Homogeneity of regression slopes = 0.150

Graph 14.47 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Step Down Knee Excursion Angle (Degrees)**



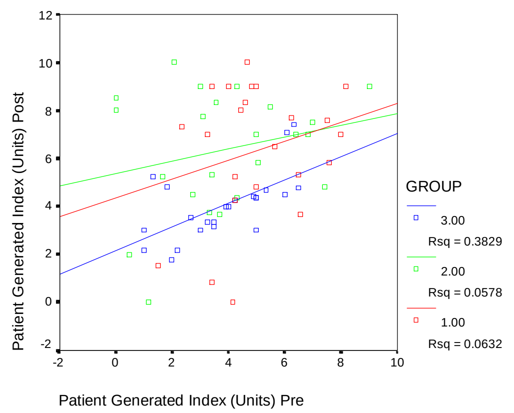
Homogeneity of regression slopes = 0.742

Graph 14.48 **Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Modified Functional Index Questionnaire (Units)**



Homogeneity of regression slopes = 0.203

Graph 14.49 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Functional Interference Estimate (Units)



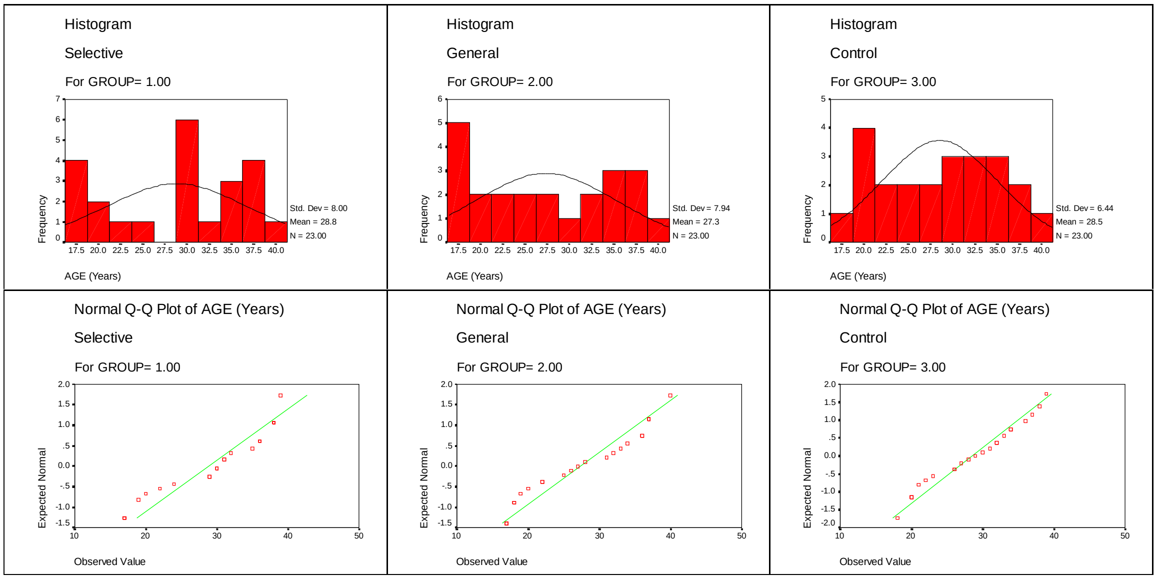
Homogeneity of regression slopes = 0.758

Graph 14.50 Pre against Post RCT Scatter Plots and Homogeneity of Regression Slope Values, General and Control Groups for Patient Generated Index (Units)

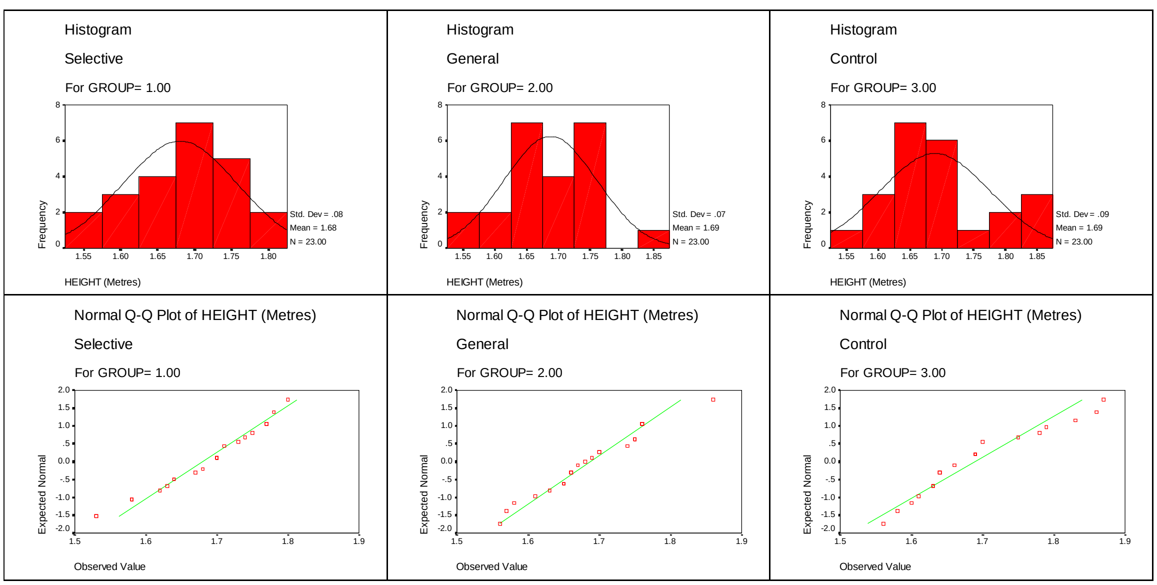
ELECTRONIC APPENDIX 15

15.1 PRE RCT NORMALITY GRAPHS AND Q-Q PLOTS

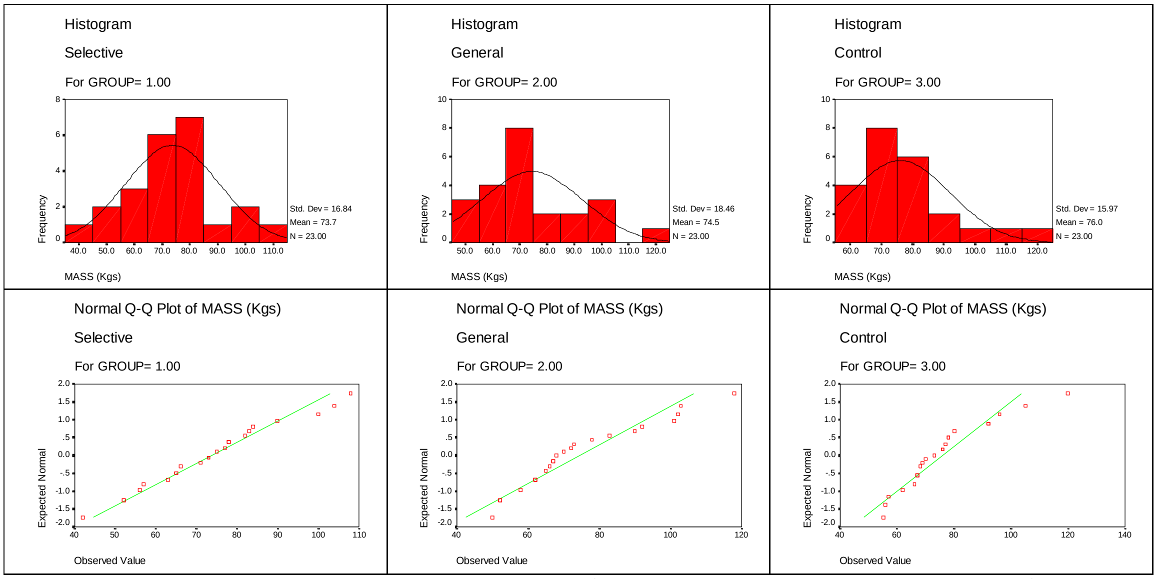
PATIENT CHARACTERISTICS



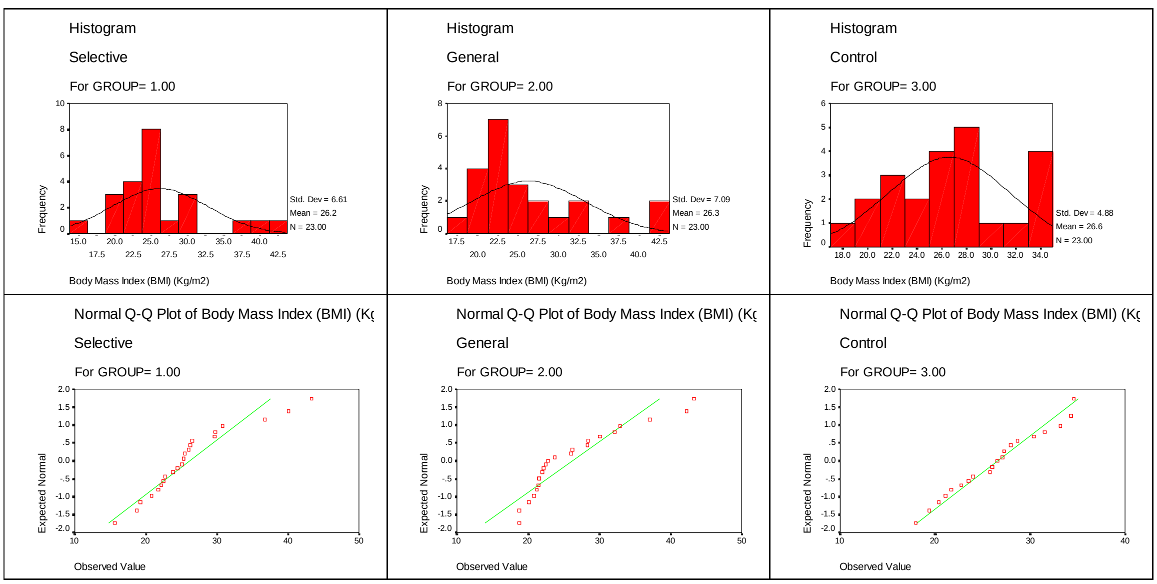
Graphs 15.1 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Age (Years)



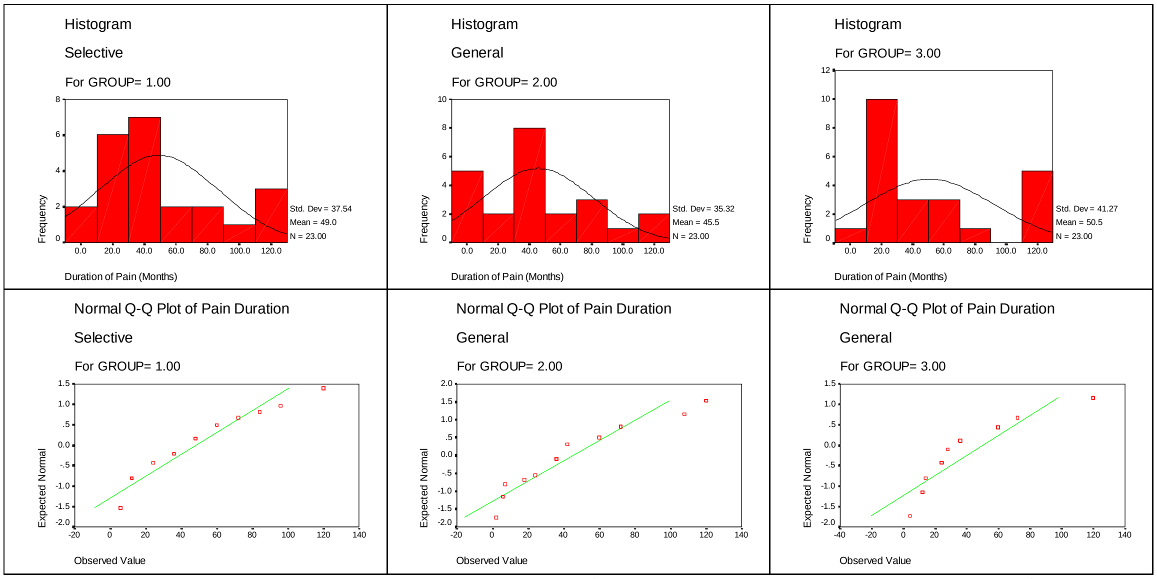
Graphs 15.2 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Height (Metres)



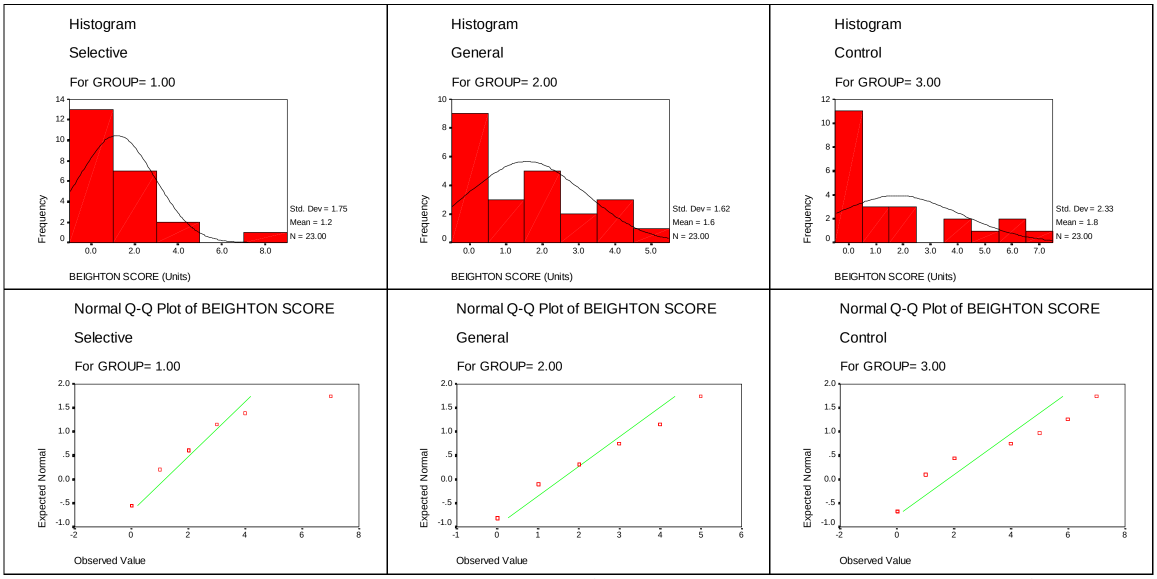
Graphs 15.3 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Body Mass (Kgs)



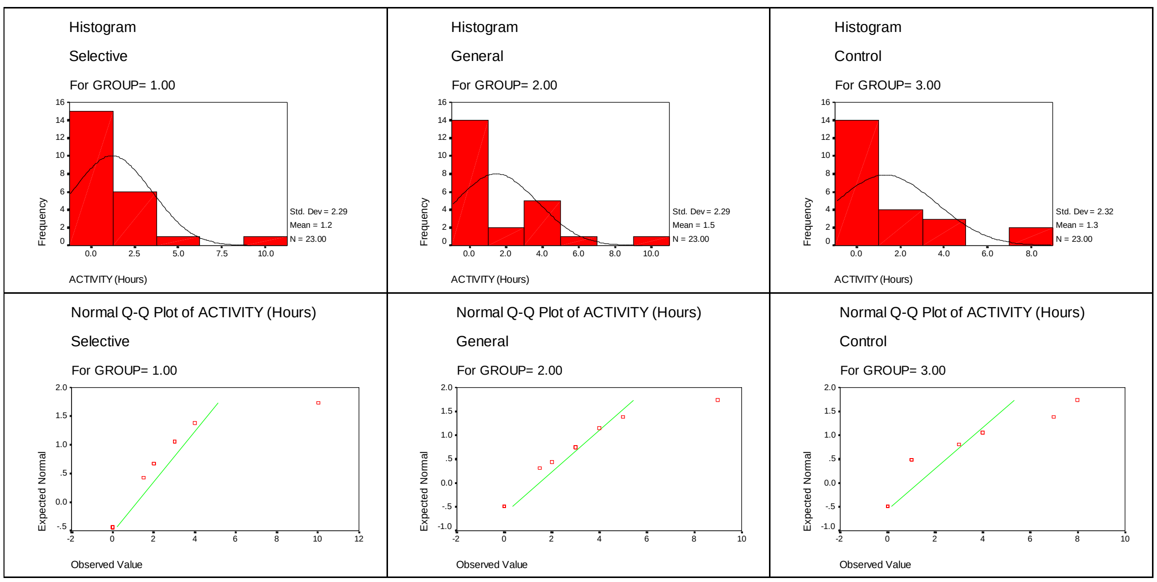
Graphs 15.4 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Body Mass Index (BMI) (Kgs/m^2)



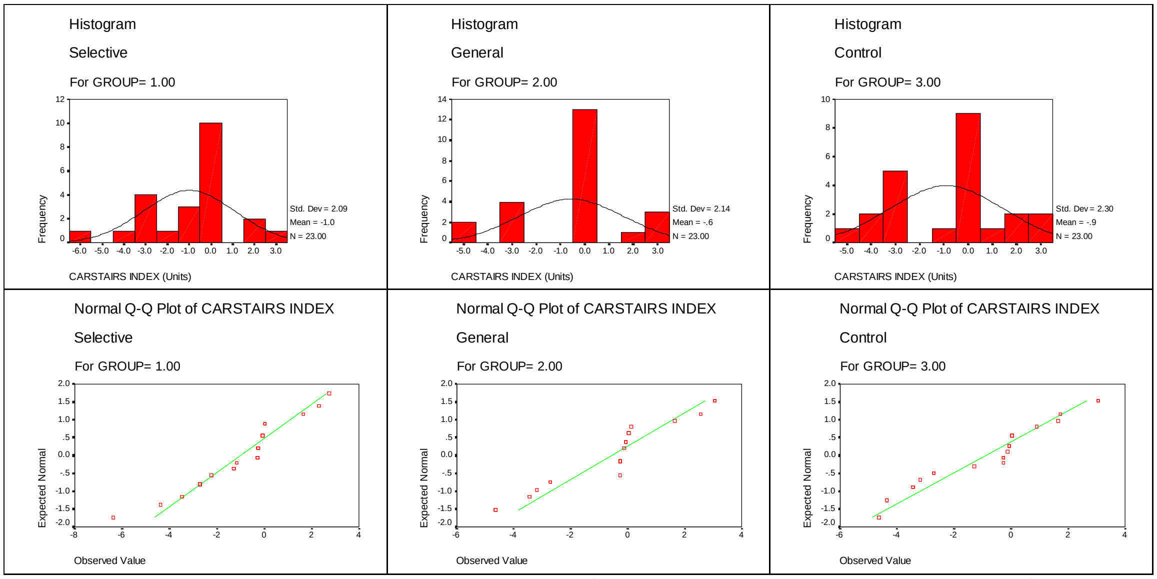
Graphs 15.4 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Pain Duration (Months)



Graphs 15.5 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Beighton Score (Units)

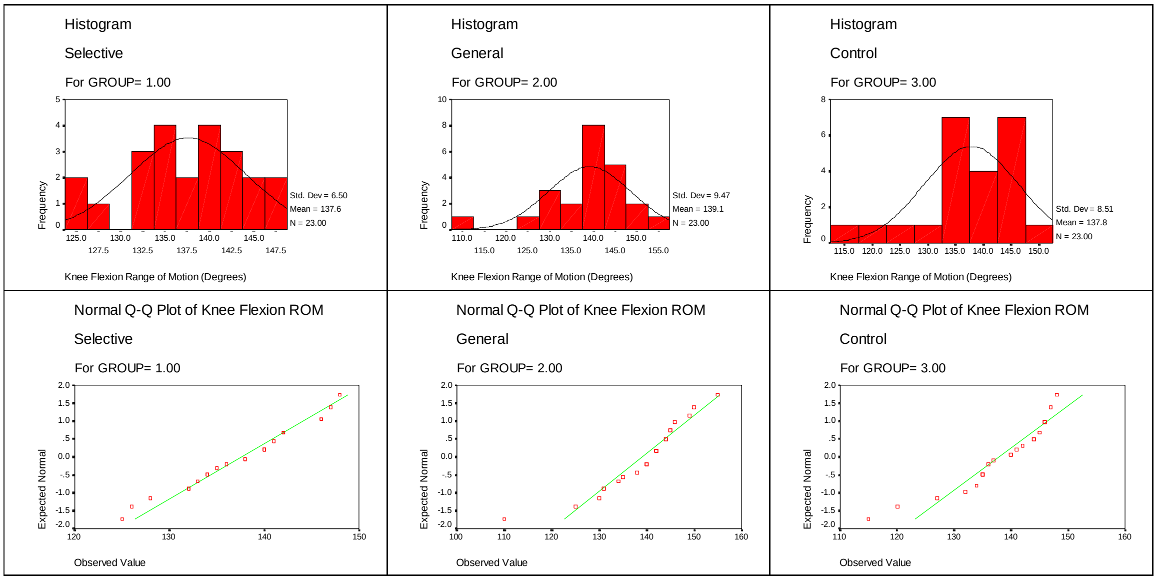


Graphs 15.6 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Activity (Hours)

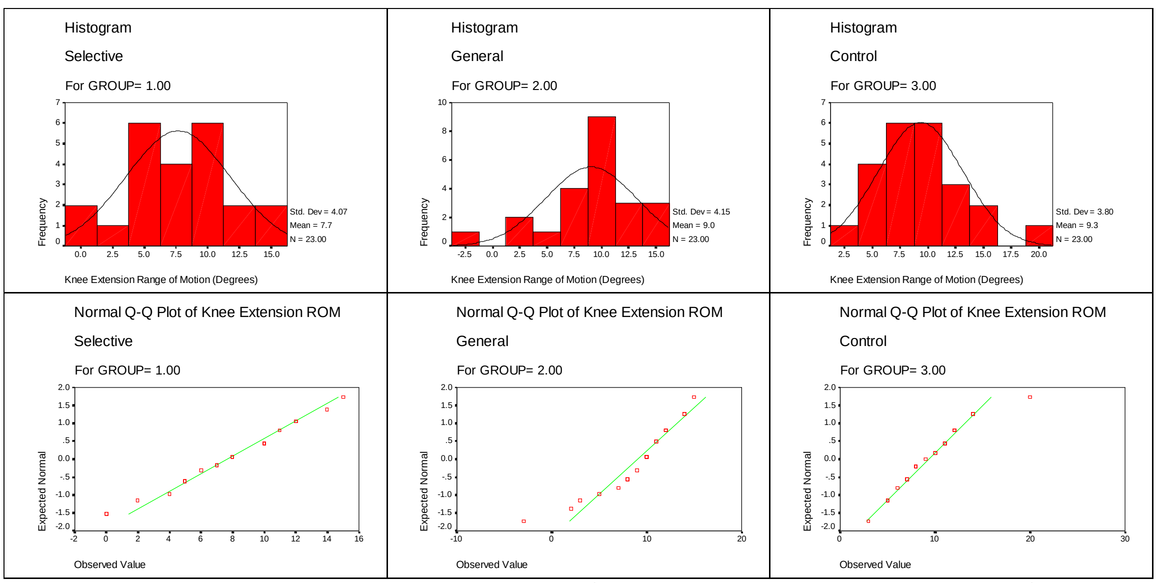


Graphs 15.7 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Carstairs Index (Units)

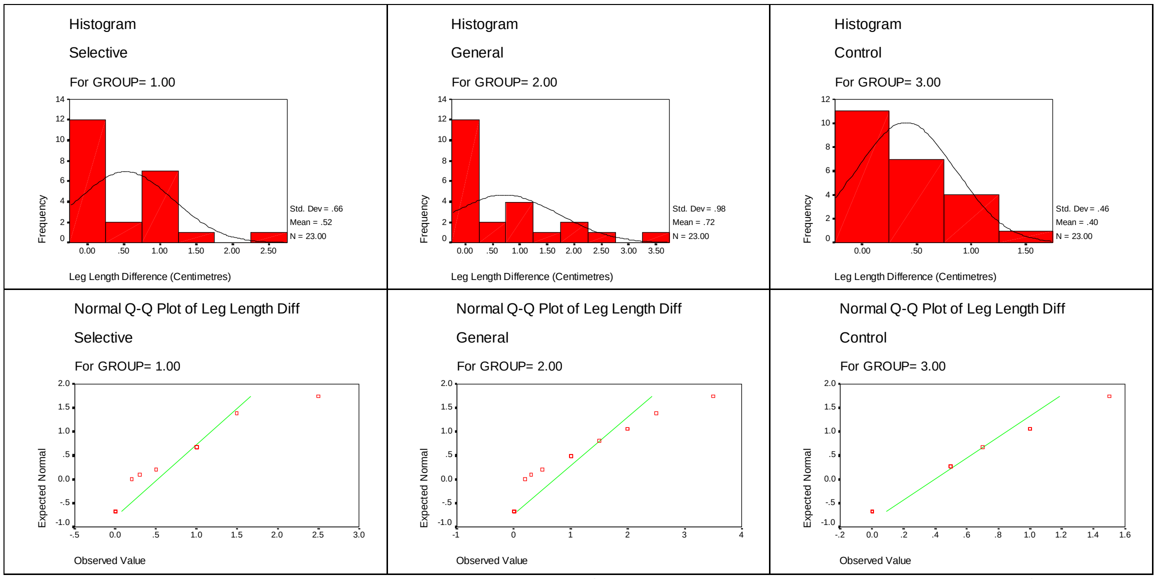
ANTHROPOMETRIC VARIABLES



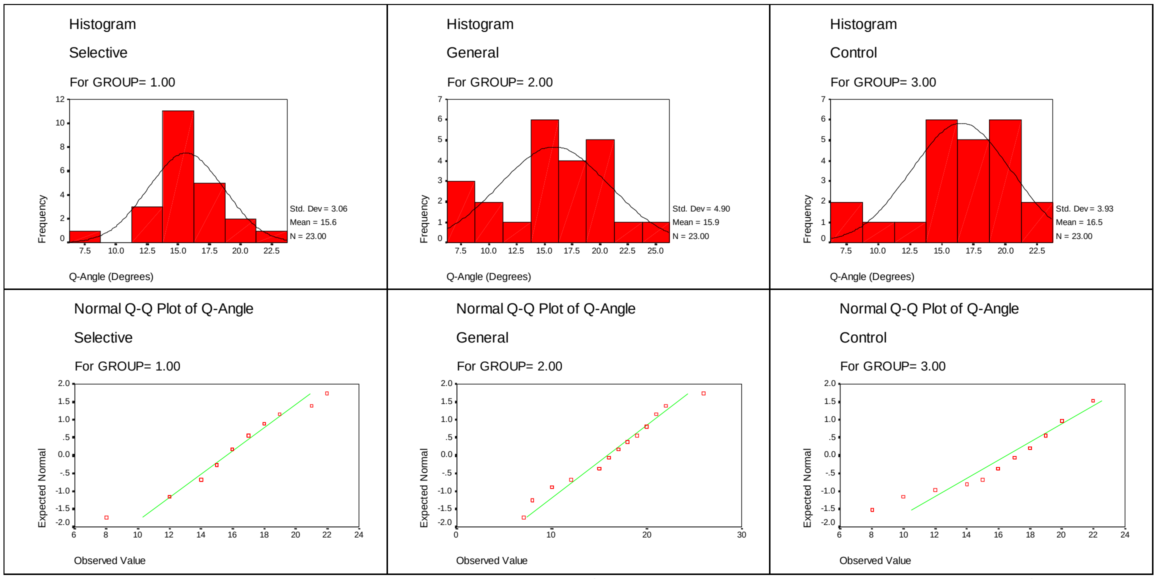
Graphs 15.8 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Knee Flexion Range of Motion (Degrees)



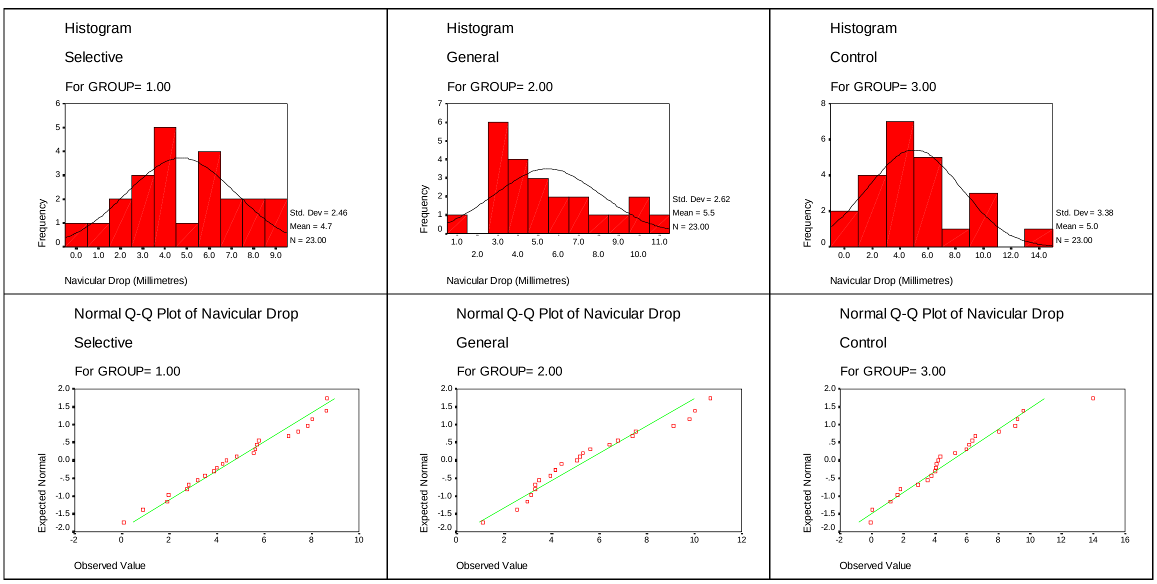
Graphs 15.9 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Knee Extension Range of Motion (Degrees)



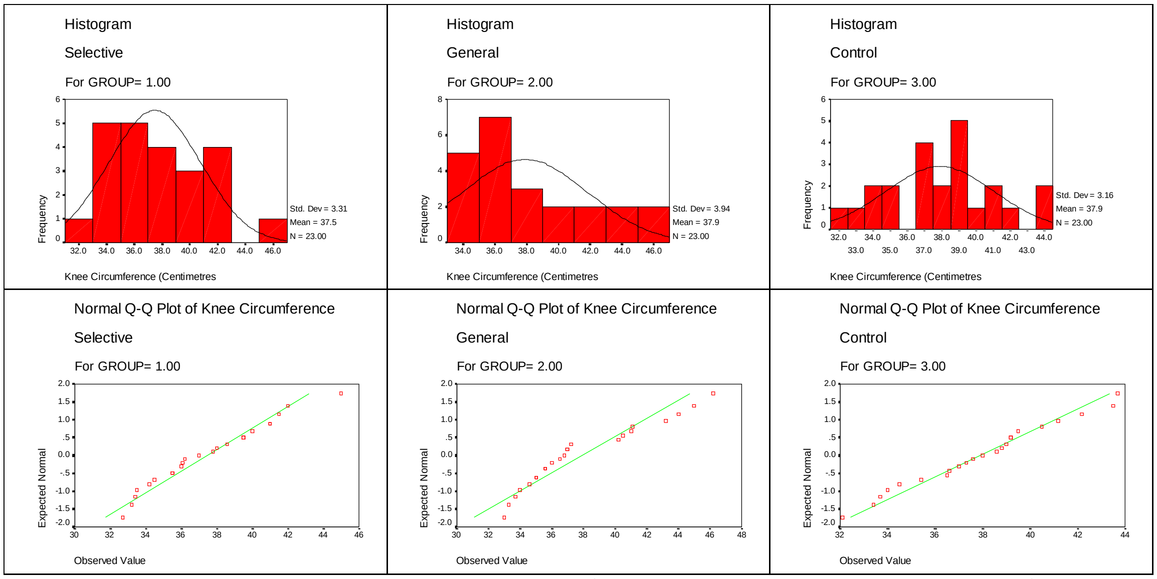
Graphs 15.10 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Leg Length Difference (Centimetres)



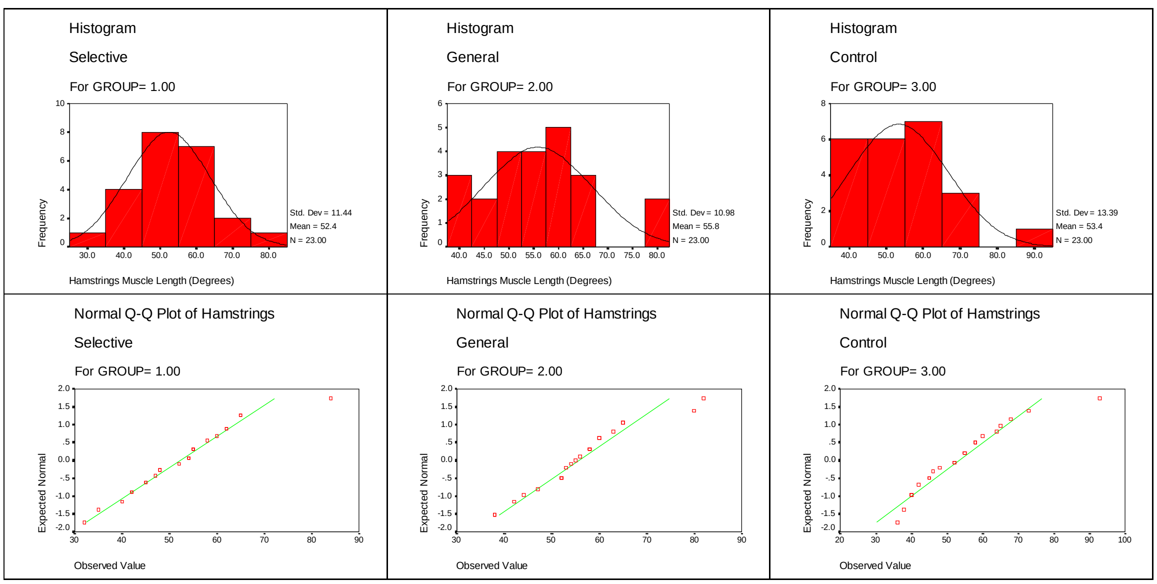
Graphs 15.11 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Q-Angle (Degrees)



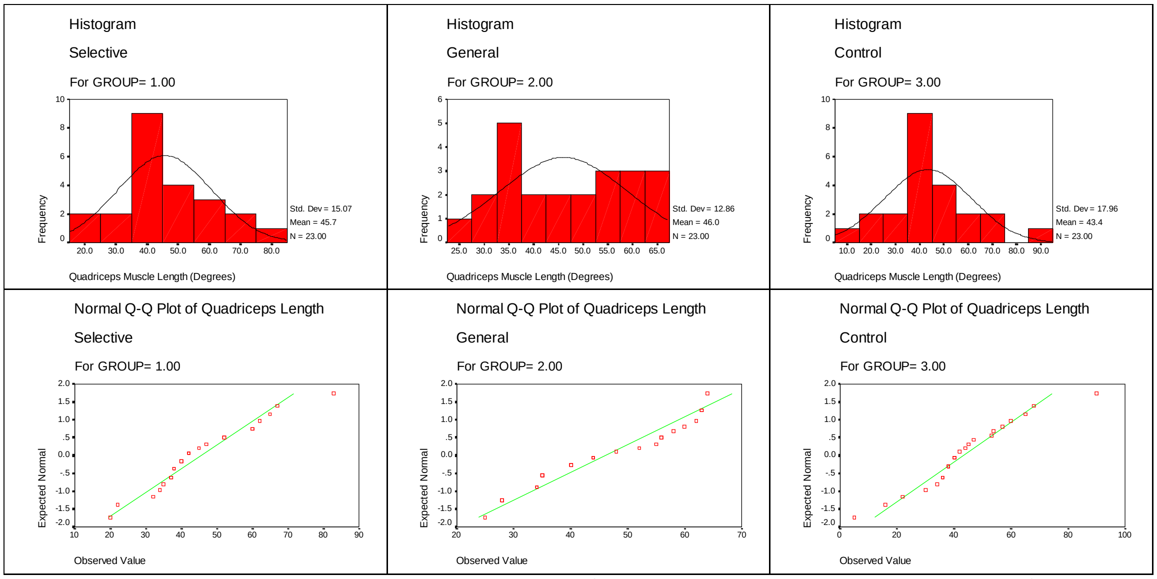
Graphs 15.12 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Navicular Drop (Millimetres)



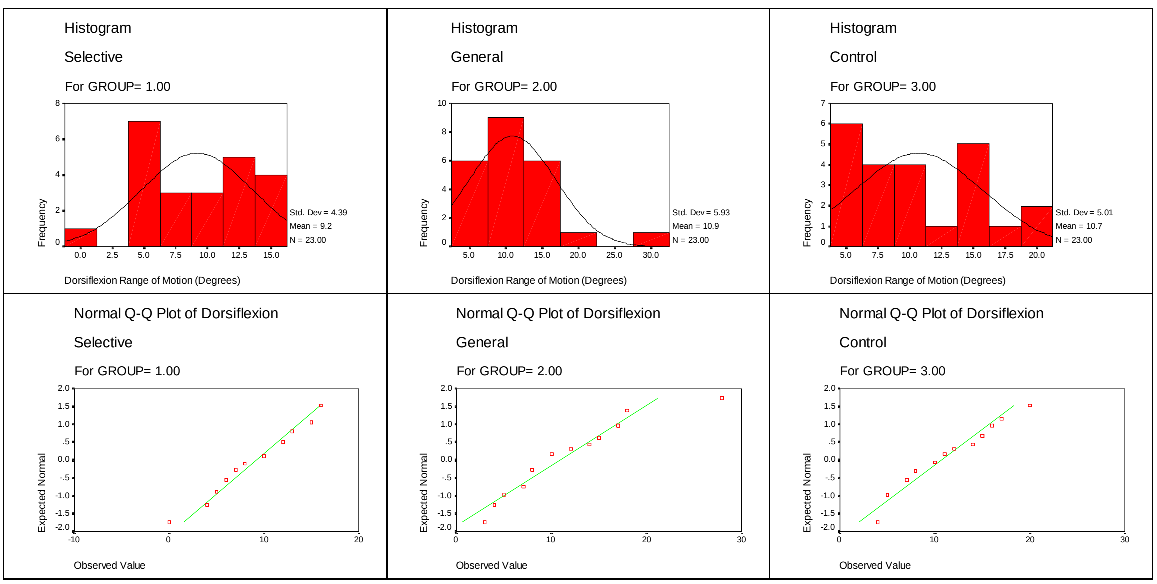
Graphs 15.13 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Knee Circumferential Measurements (Centimetres)



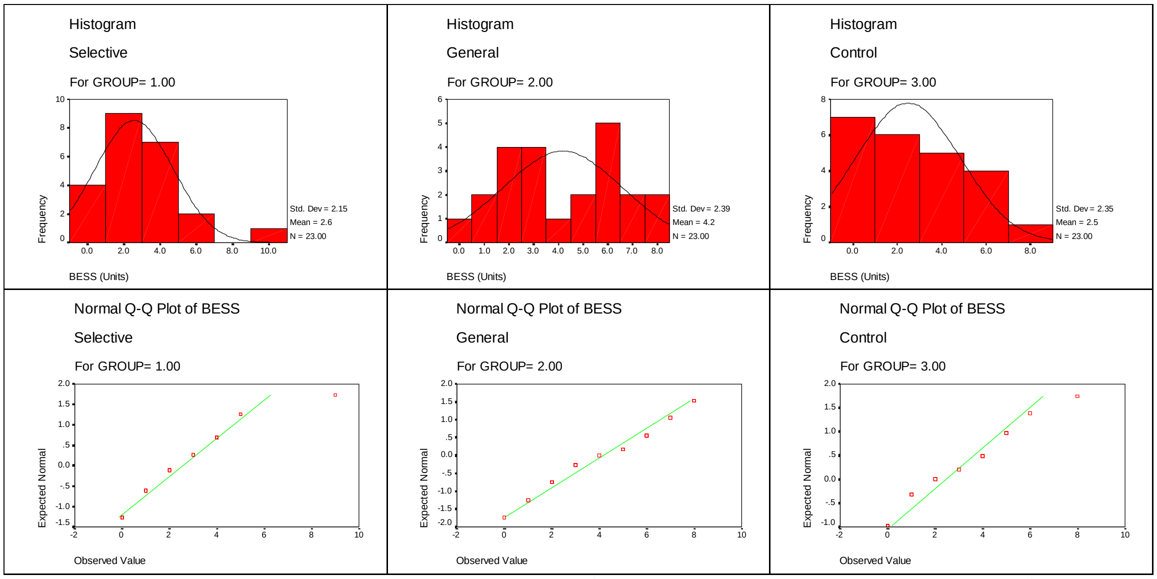
Graphs 15.14 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Hamstrings Muscle Length (Degrees)



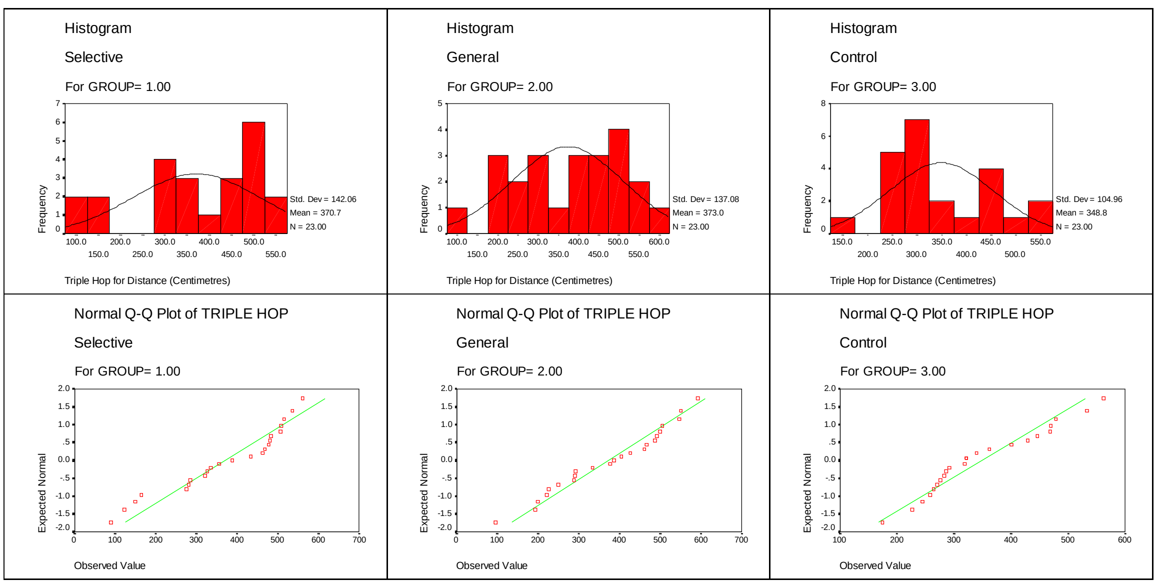
Graphs 15.15 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Quadriceps Muscle Length (Degrees)



Graphs 15.16 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Equinus (Degrees)

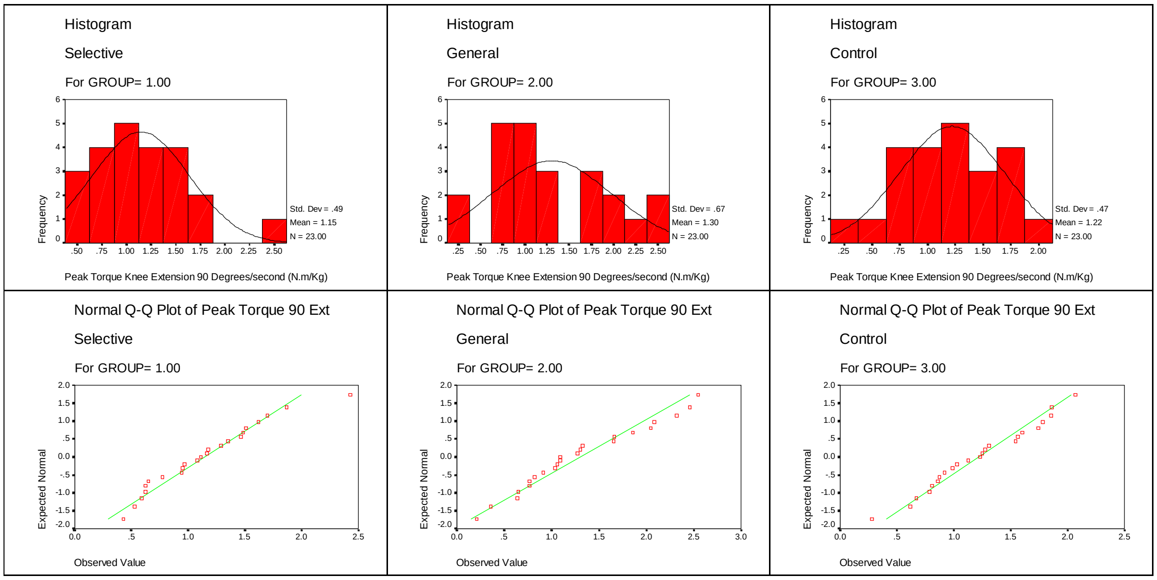


Graphs 15.17 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for BESS (Units)

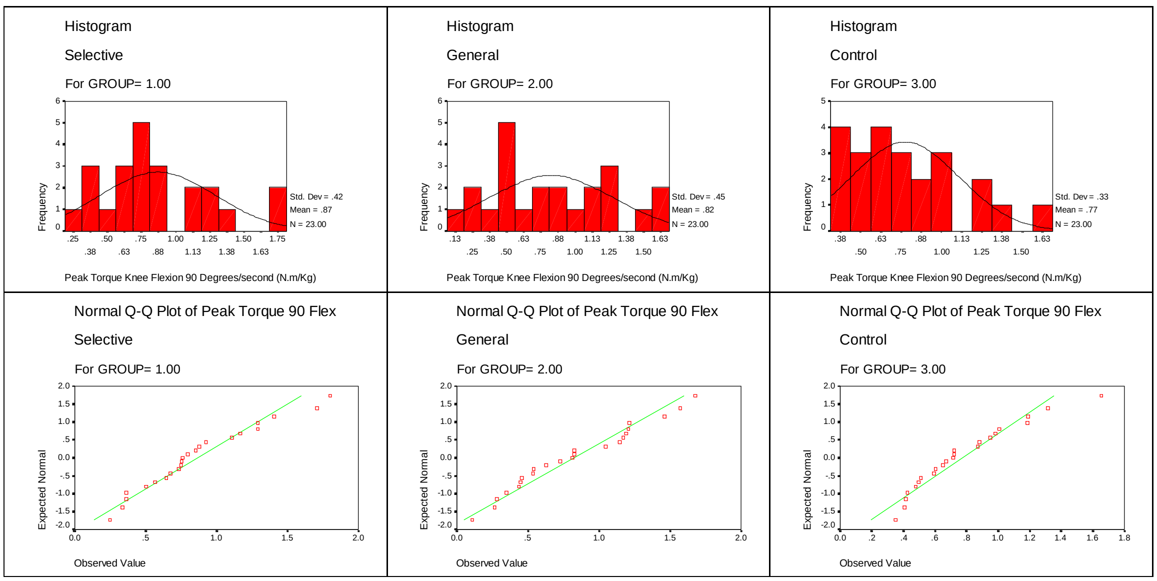


Graphs 15.18 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Triple Hop Distance (Centimetres)

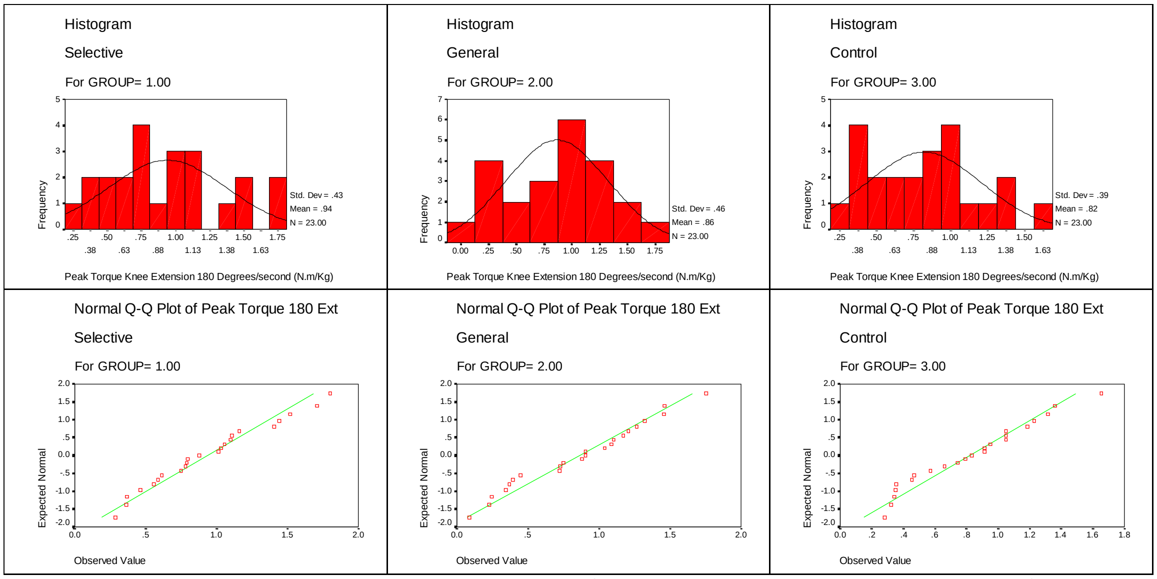
MUSCLE STRENGTH



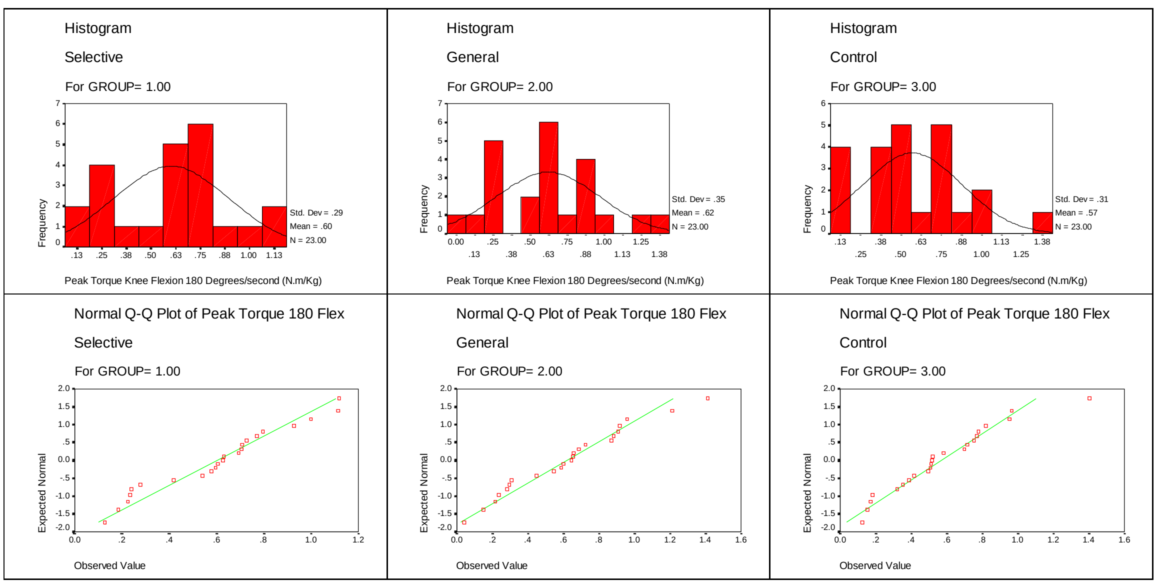
Graphs 15.19 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Peak Torque Knee Extension at 90˚/s Nm/kg



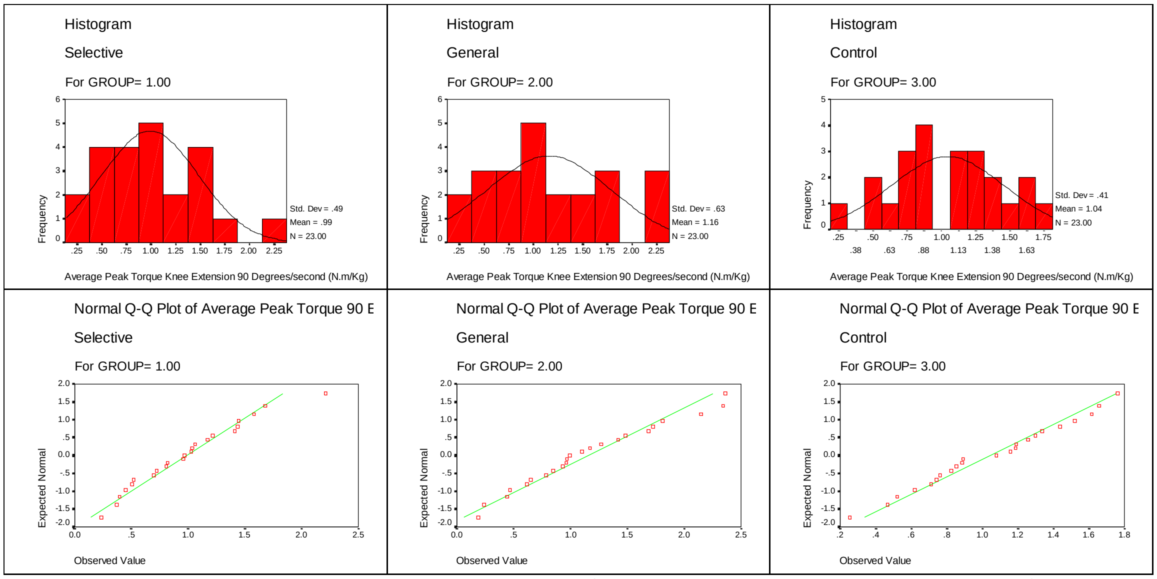
Graphs 15.20 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Peak Torque Knee Flexion at 90˚/s Nm/kg



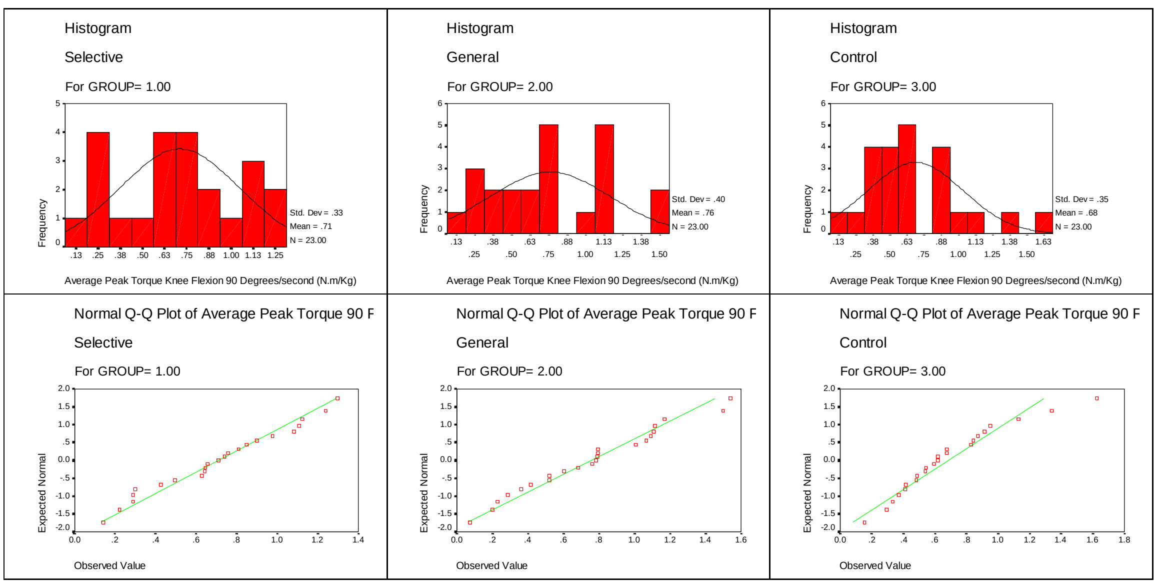
Graphs 15.21 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Peak Torque Knee Extension at 180˚/s Nm/kg



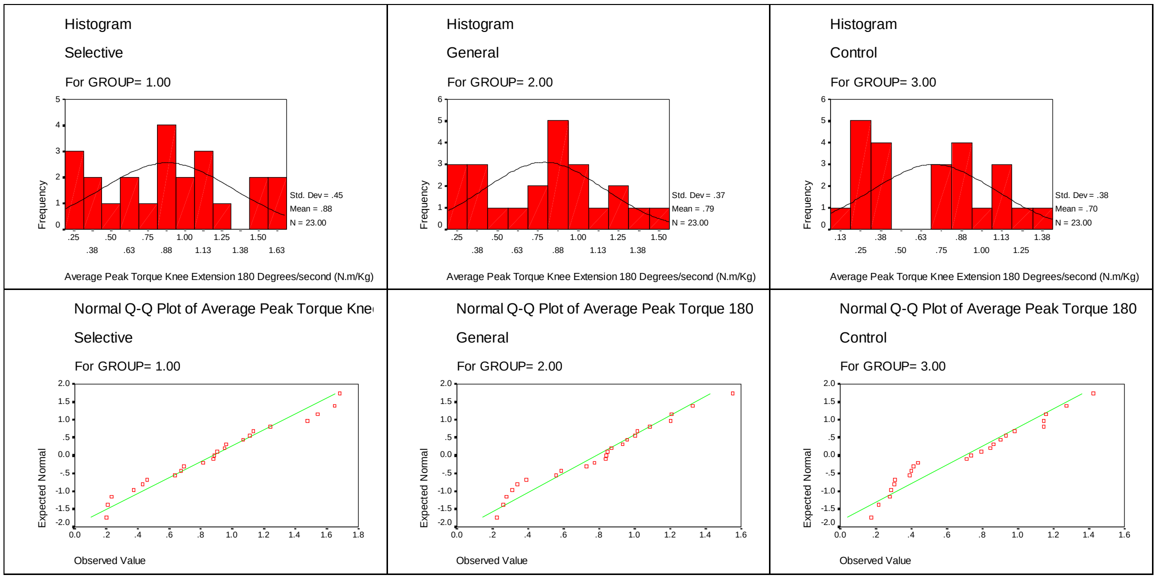
Graphs 15.22 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Peak Torque Knee Flexion at 180˚/s Nm/kg



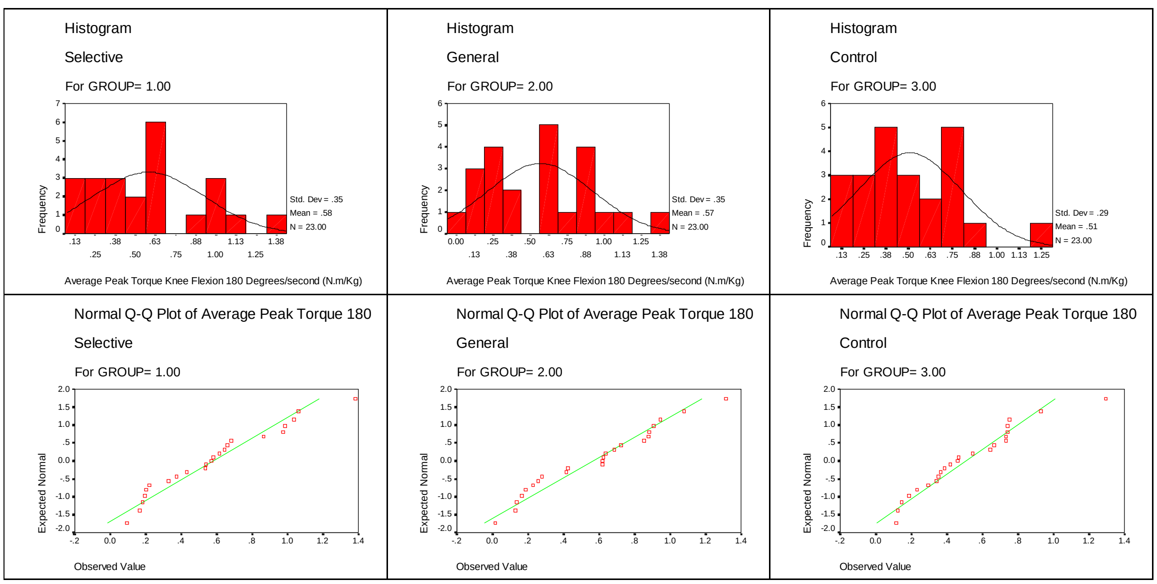
Graphs 15.23 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Average Peak Torque Knee Extension at 90°/s Nm/kg



Graphs 15.24 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Average Peak Torque Knee Flexion at 90°/s Nm/kg

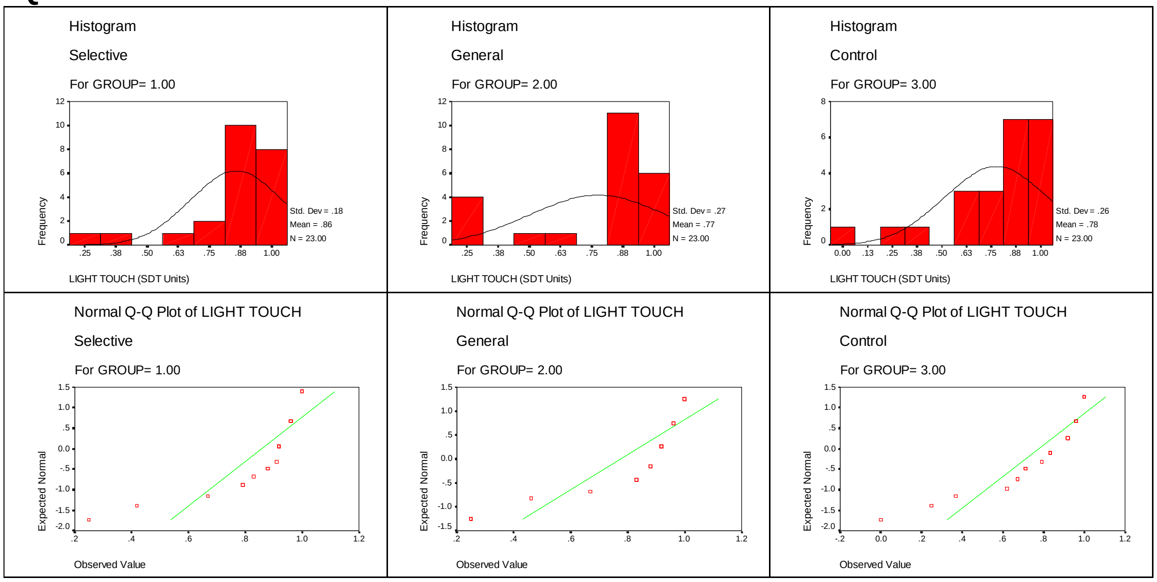


Graphs 15.25 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Average Peak Torque Knee Extension at 180°/s Nm/kg

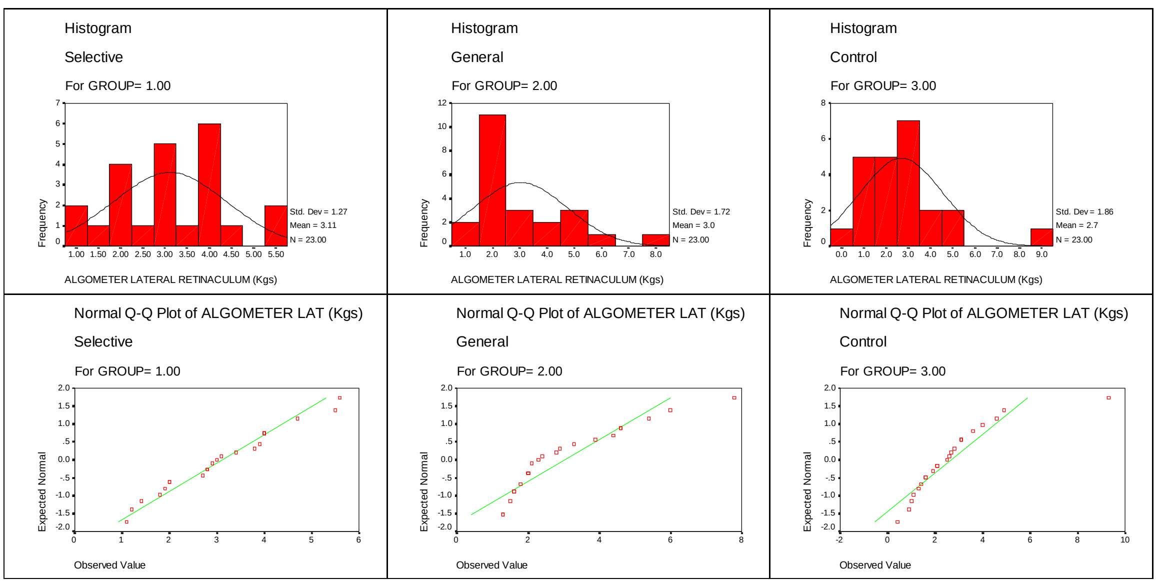


Graphs 15.26 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Average Peak Torque Knee Flexion at 180°/s Nm/kg

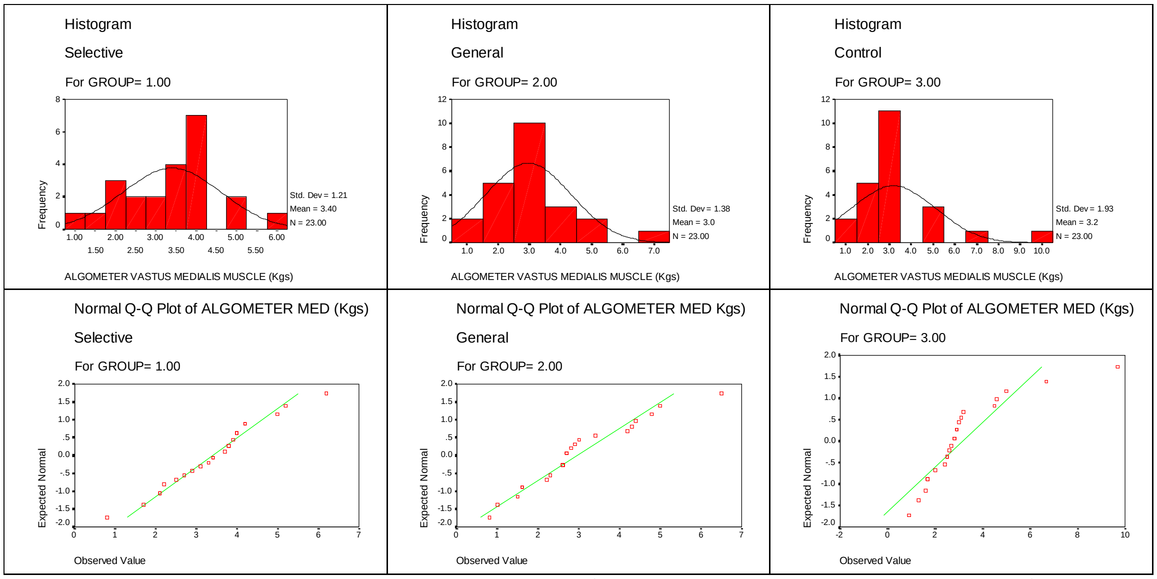
QUANTITATIVE SENSORY TESTING



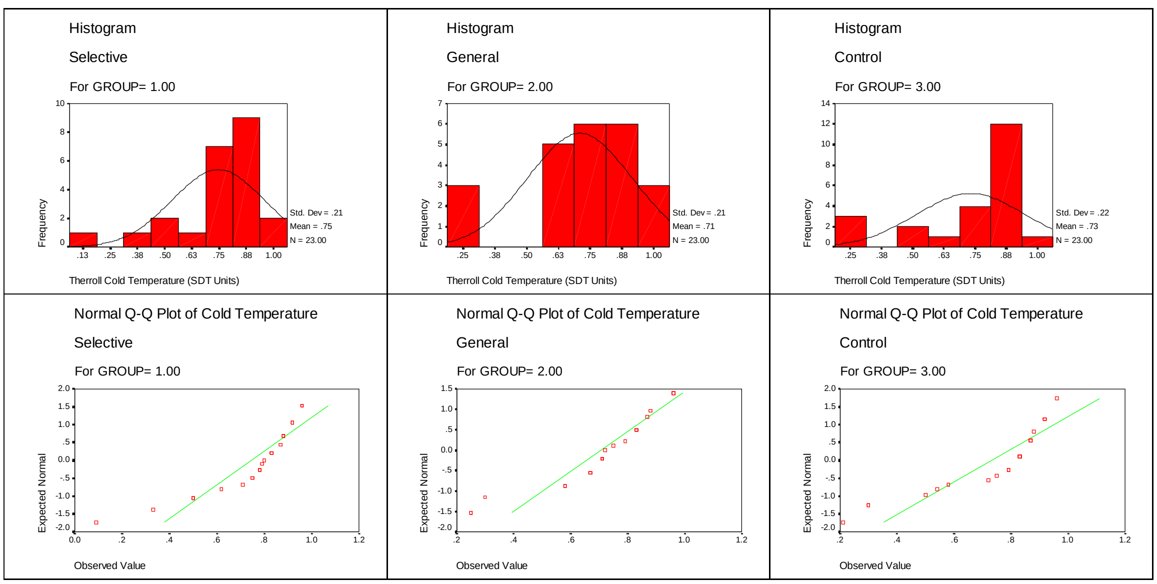
Graphs 15.27 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Light Touch SDT at Lateral Retinaculum (Units)



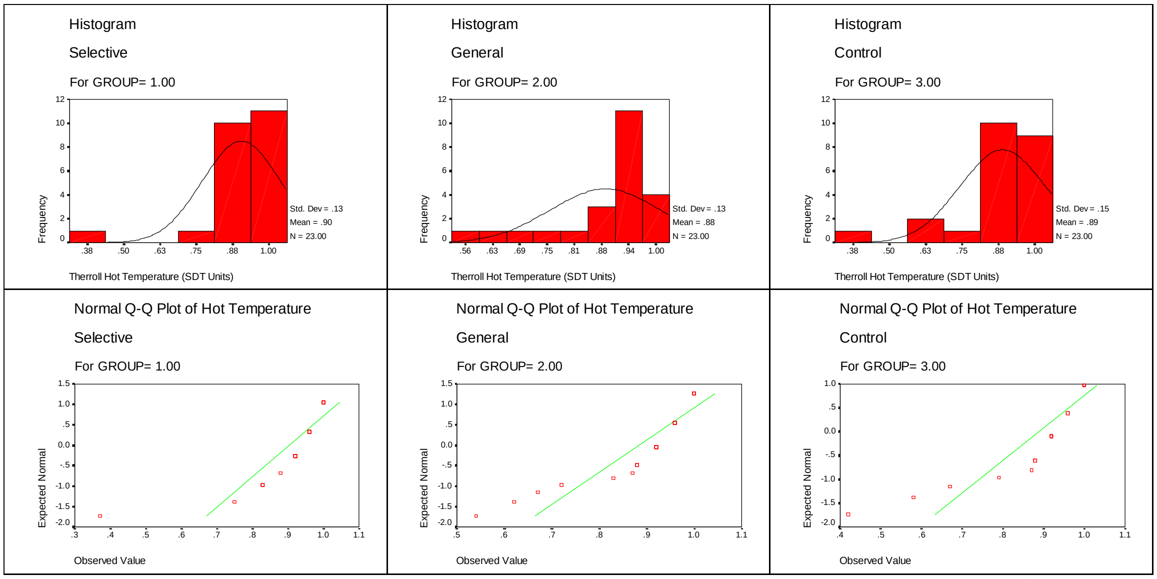
Graphs 15.28 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Algometer Measurements SDT at Lateral Retinaculum (Units)



Graphs 15.29 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Algometer Measurements SDT at Vastus Medialis Muscle (Units)

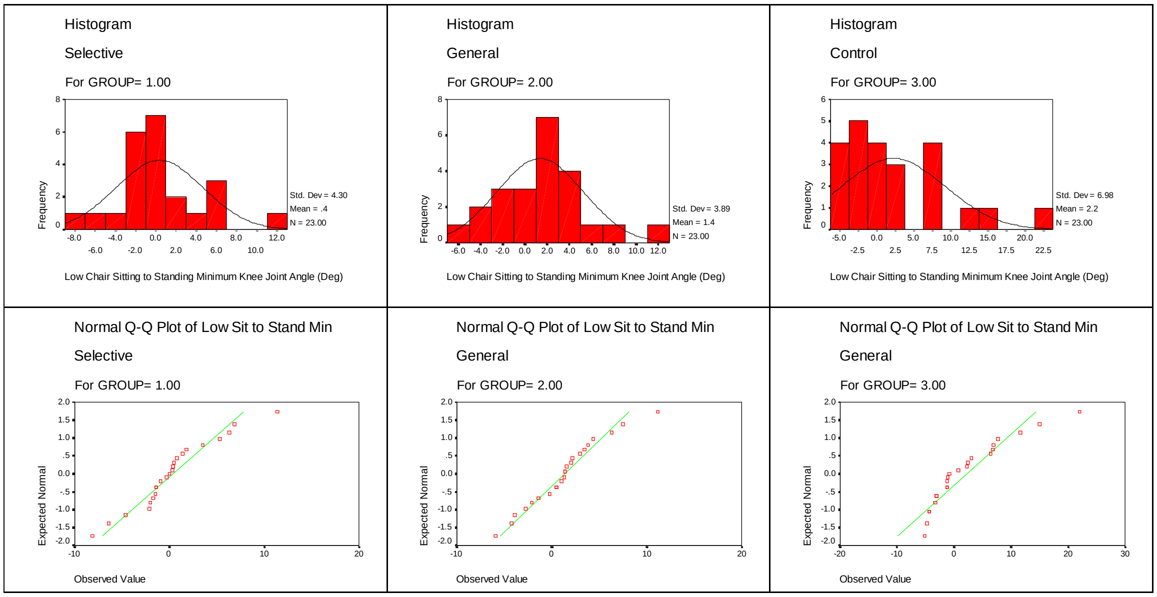


Graphs 15.30 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Therroll SDT Cold 12°/C (Units)

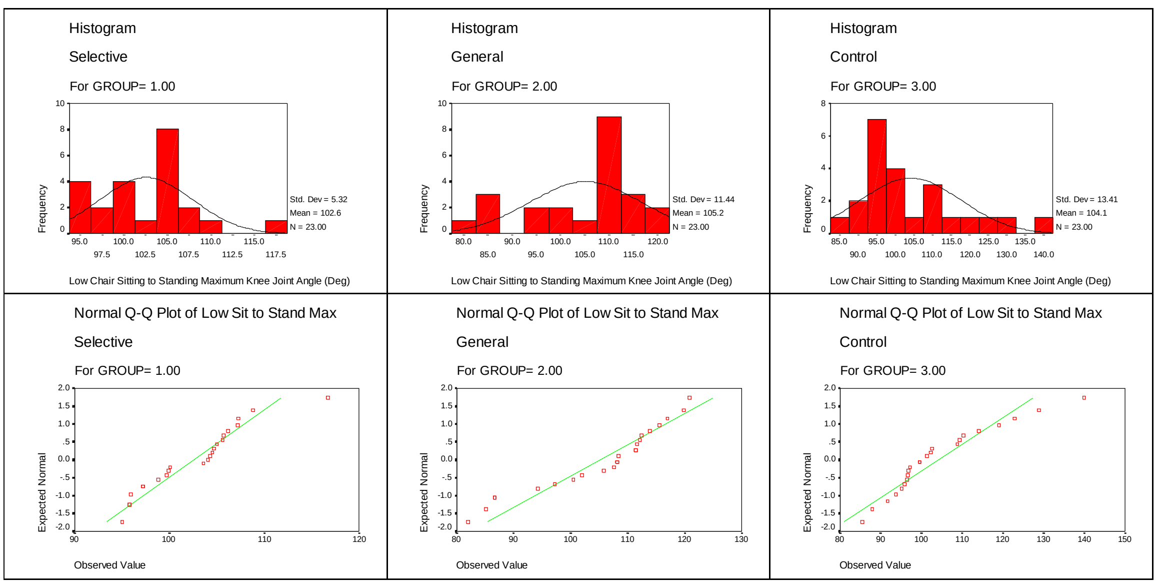


Graphs 15.31 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Therroll SDT Hot 42°/C (Units)

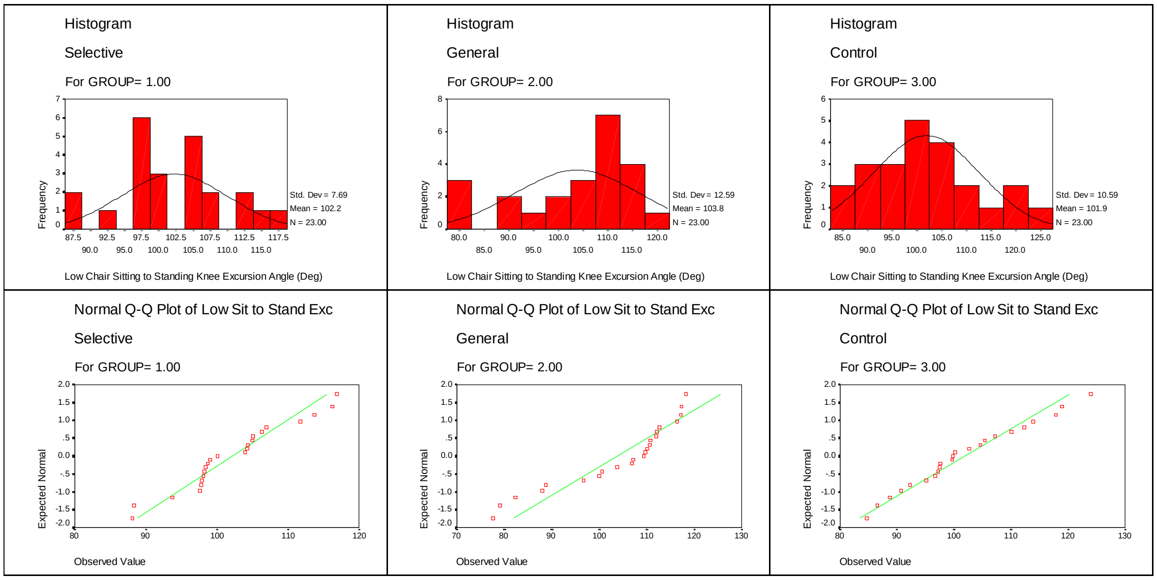
ELECTROGONIOMETRY



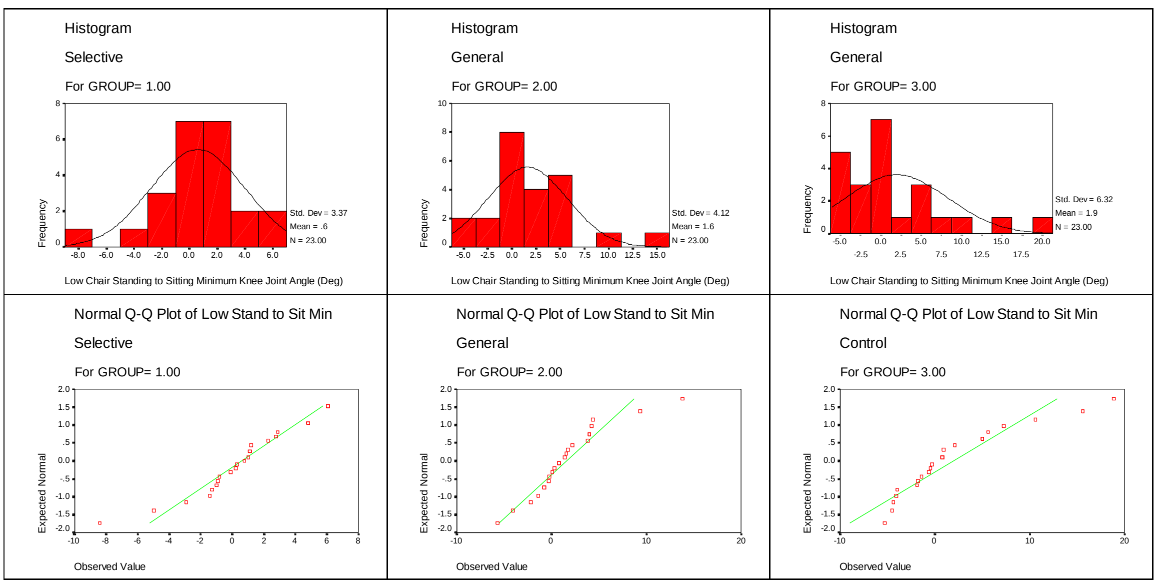
Graphs 15.32 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from Low Chair Minimum Knee Joint Angle (Degrees)



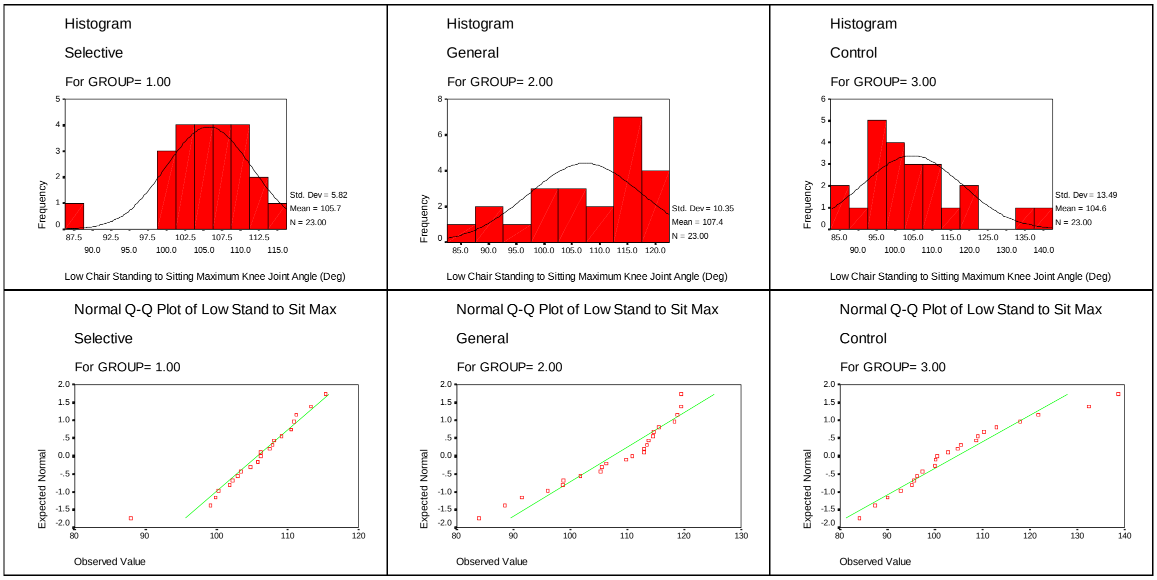
Graphs 15.33 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from Low Chair Maximum Knee Joint Angle (Degrees)



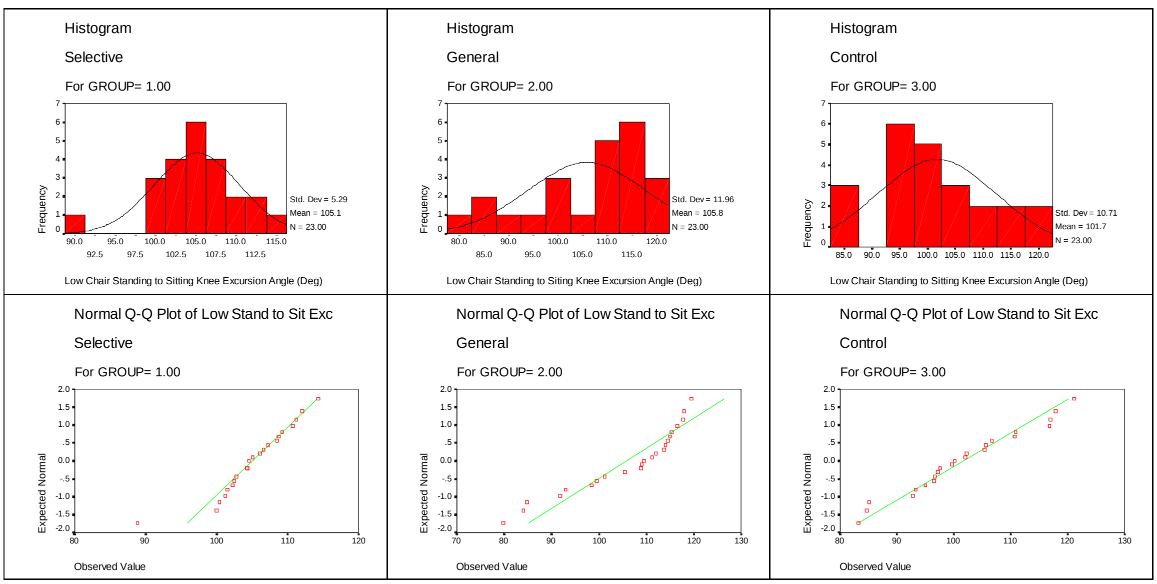
Graphs 15.34 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from Low Chair Knee Joint Excursion Angle (Degrees)



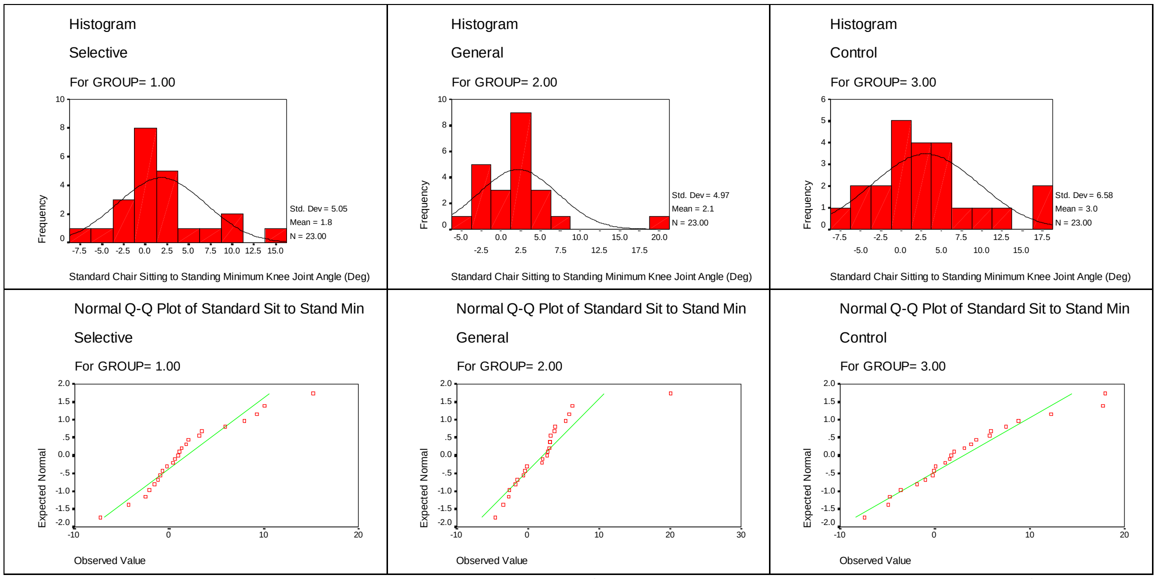
Graphs 15.35 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to Low Chair Minimum Knee Joint Angle (Degrees)



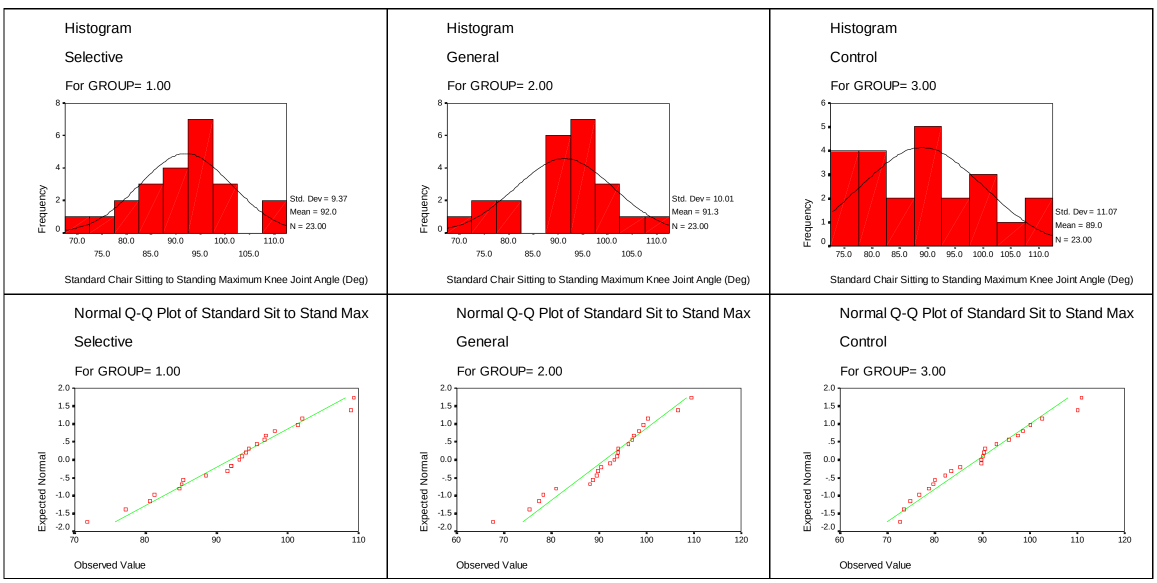
Graphs 15.36 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to Low Chair Maximum Knee Joint Angle (Degrees)



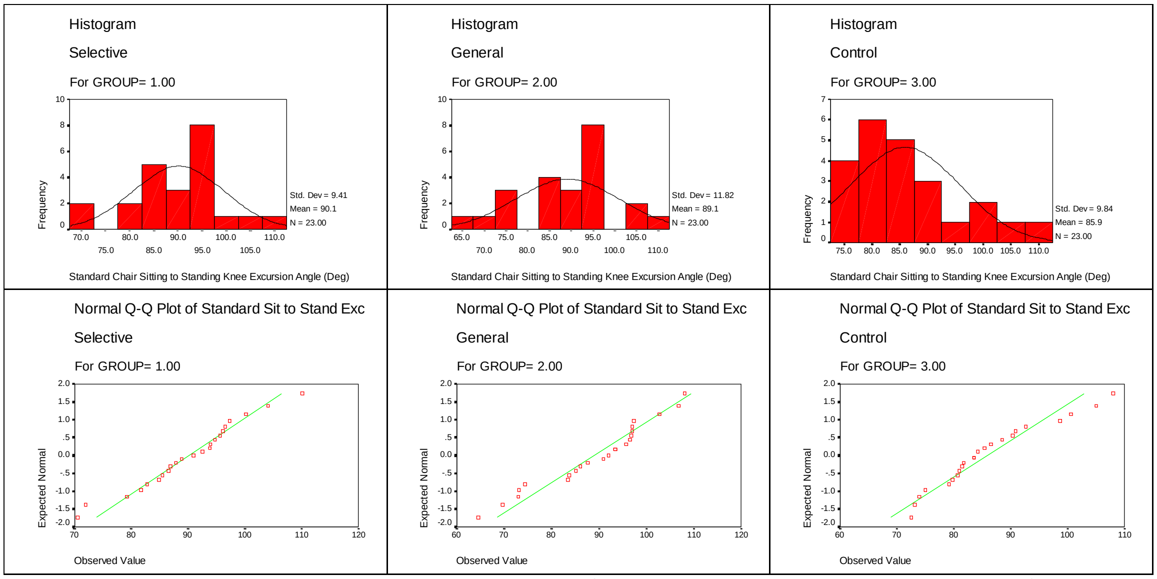
Graphs 15.37 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to Low Chair Knee Joint Excursion Angle (Degrees)



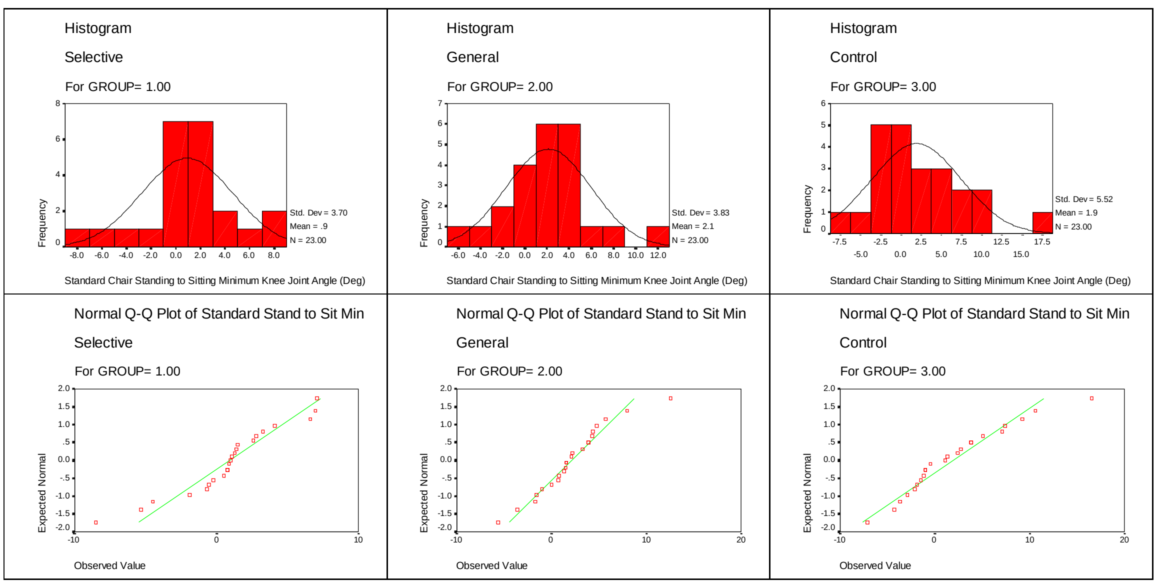
Graphs 15.38 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from a Standard Chair Minimum Knee Joint Angle (Deg)



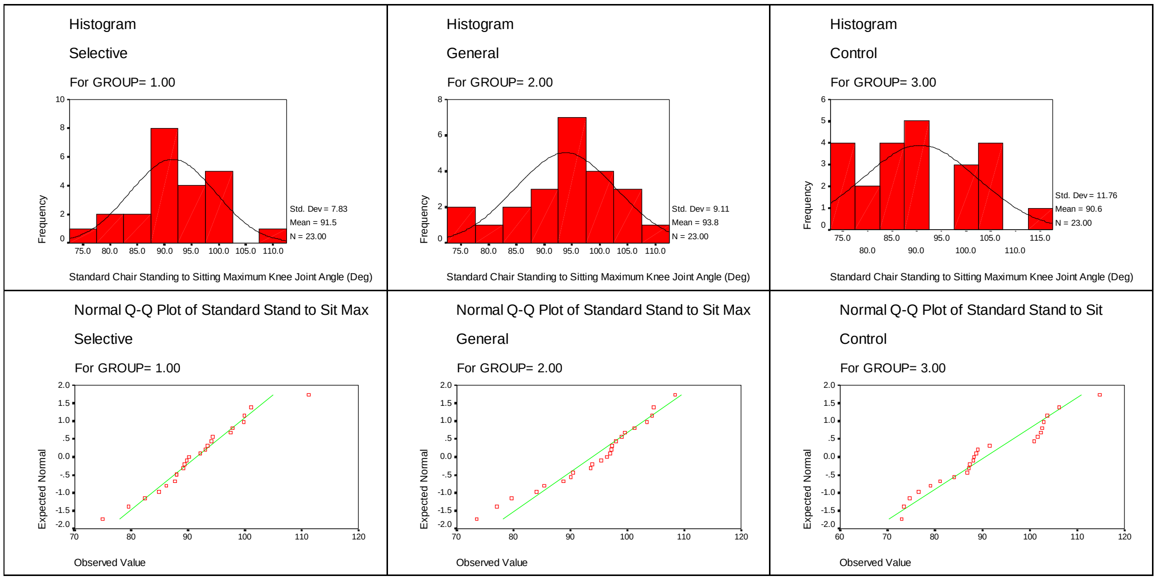
Graphs 15.39 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from a Standard Chair Maximum Knee Joint Angle (Deg)



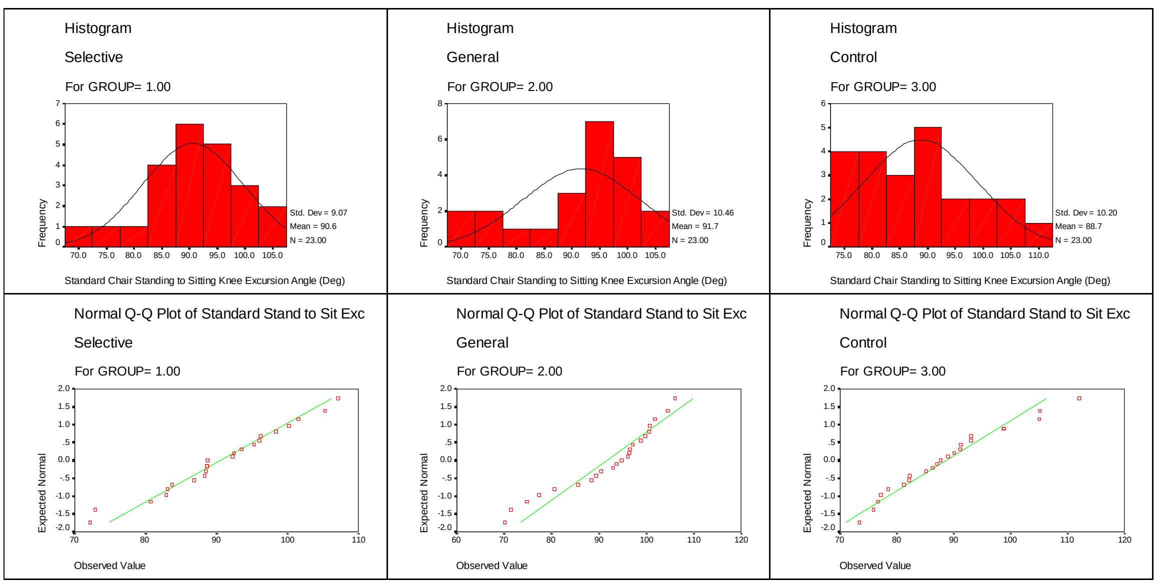
Graphs 15.40 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from a Standard Chair Knee Joint Excursion Angle (Deg)



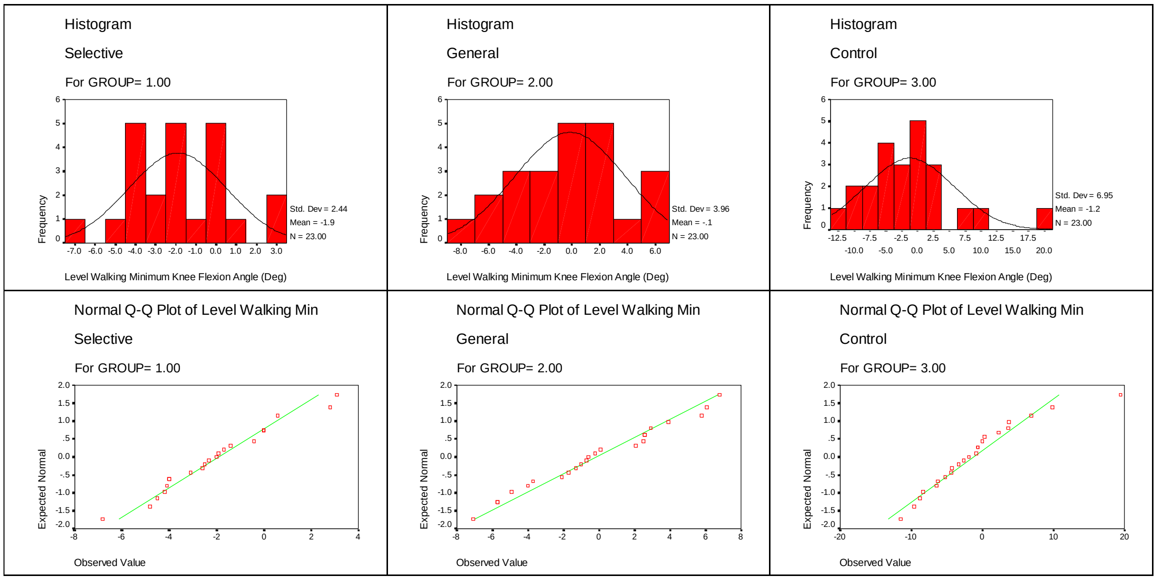
Graphs 15.41 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to a Standard Chair Minimum Knee Joint Angle (Deg)



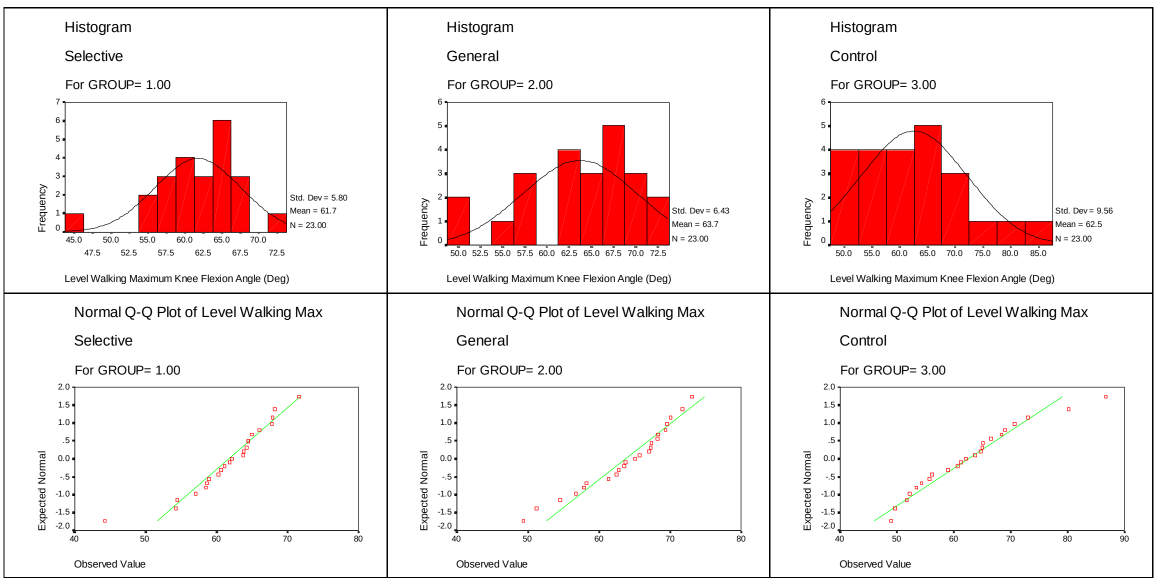
Graphs 15.42 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to a Standard Chair Maximum Knee Joint Angle (Deg)



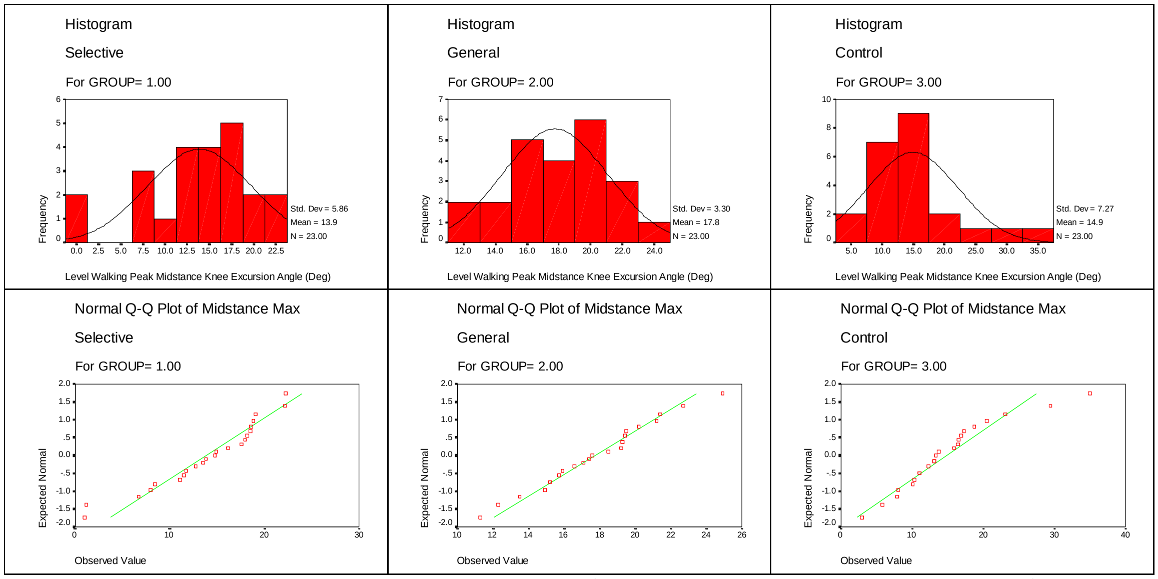
Graphs 15.43 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to a Standard Chair Knee Joint Excursion Angle (Deg)



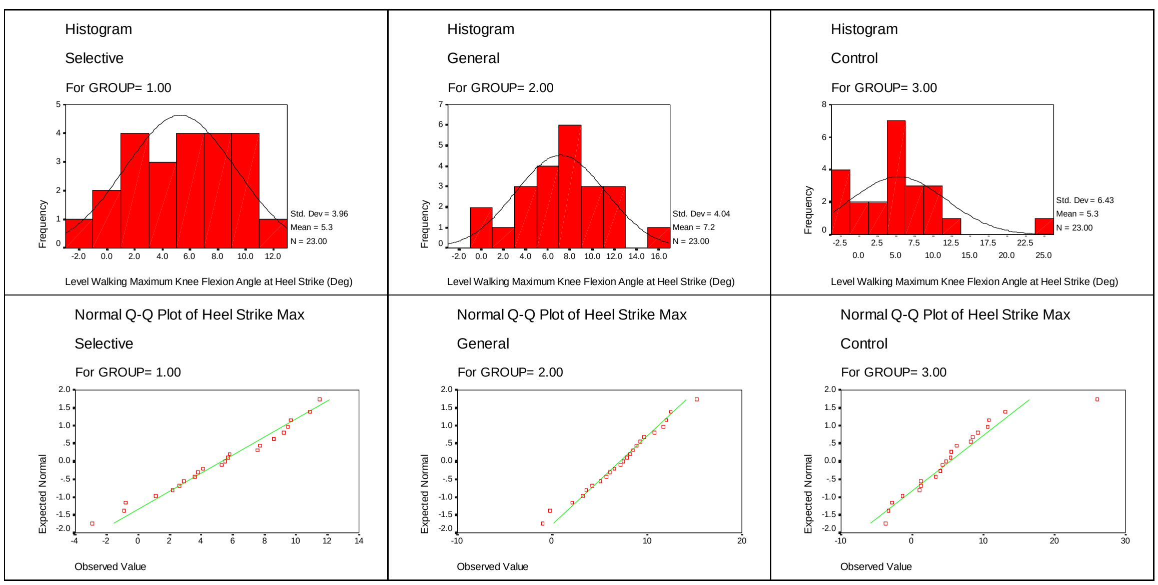
Graphs 15.44 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Minimum Knee Flexion Angle (Degrees)



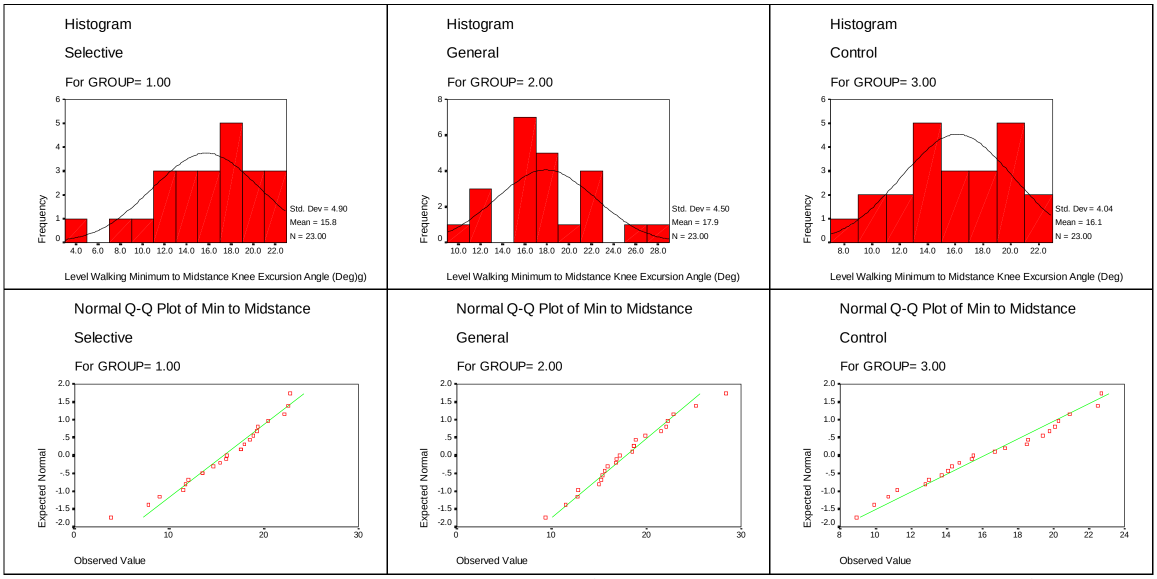
Graphs 15.45 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Maximum Knee Flexion Angle (Degrees)



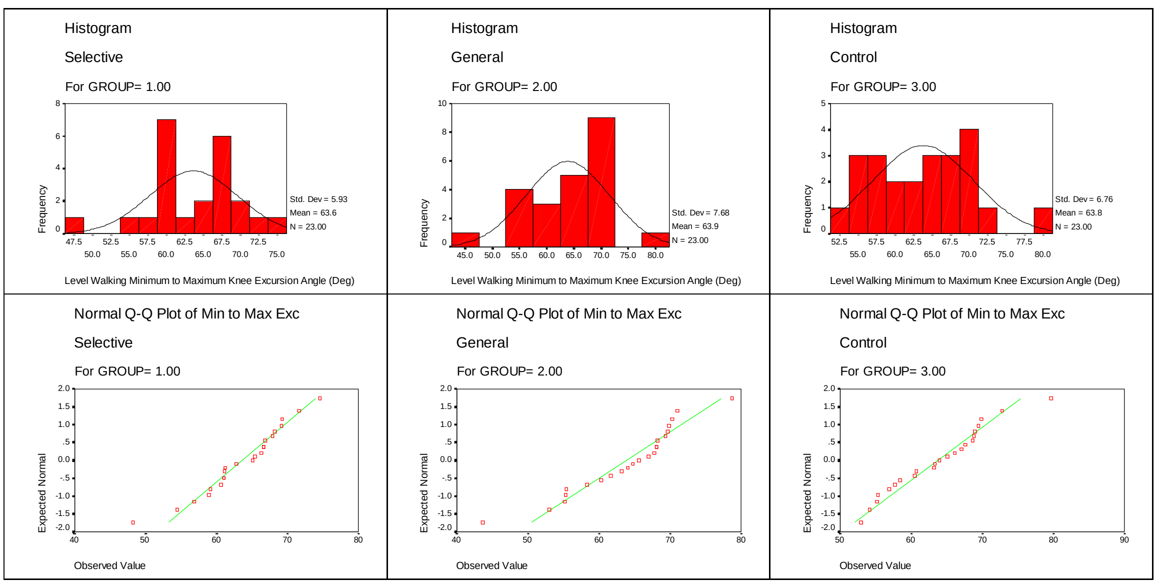
G Graphs 15.46 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Midstance Knee Flexion Angle (Degrees)



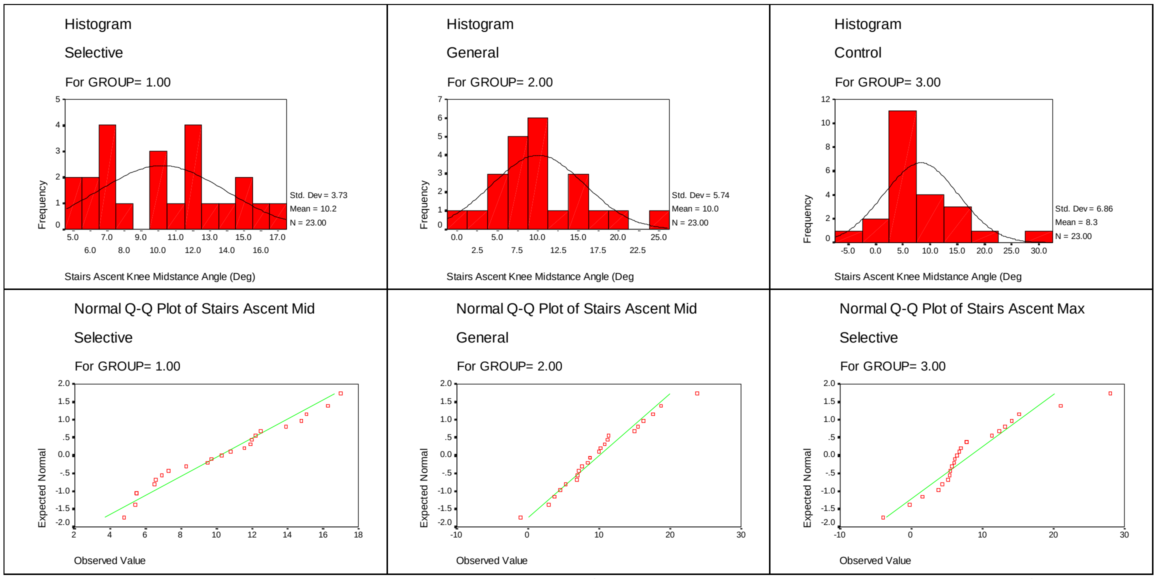
Graphs 15.47 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Maximum Knee Flexion Angle at Heel Strike (Degrees)



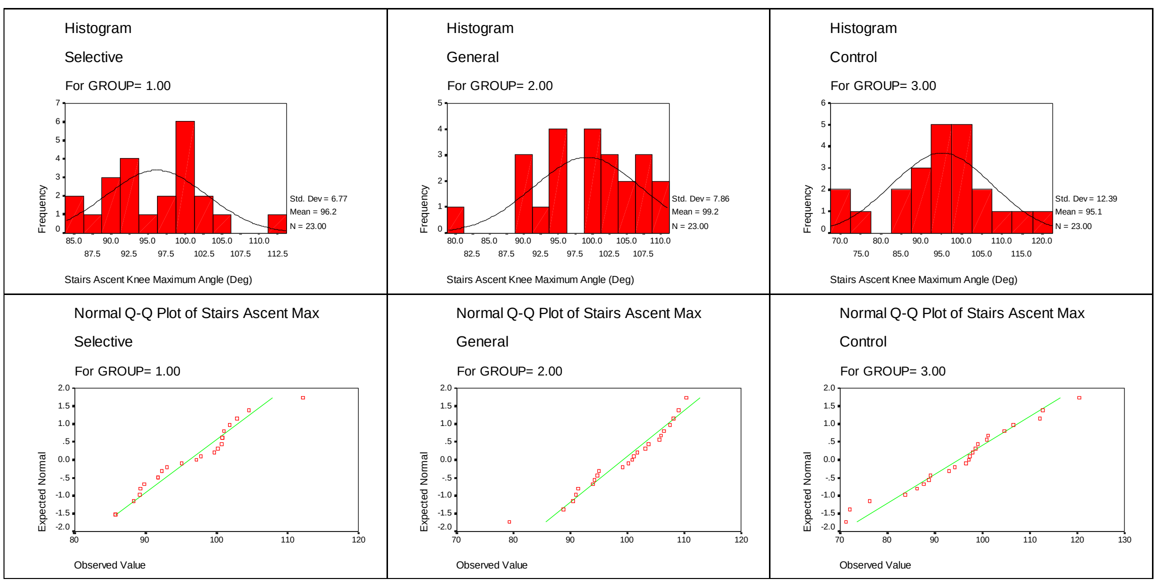
Graphs 15.48 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Minimum to Maximum Knee Excursion Angle (Degrees)



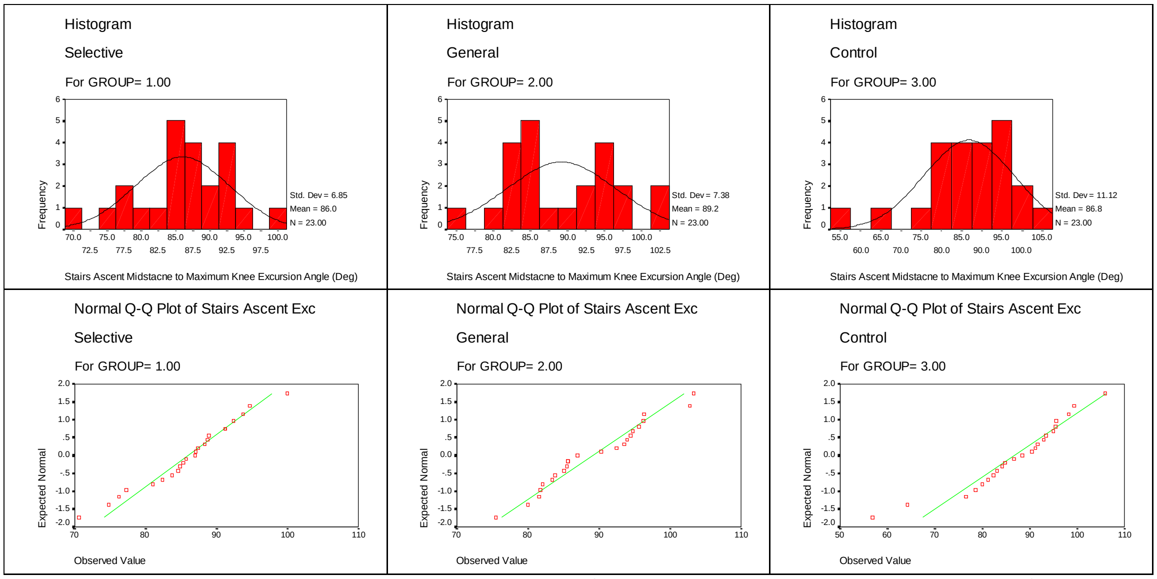
Graphs 15.49 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Minimum to Peak Midstance Knee Excursion Angle (Degrees)



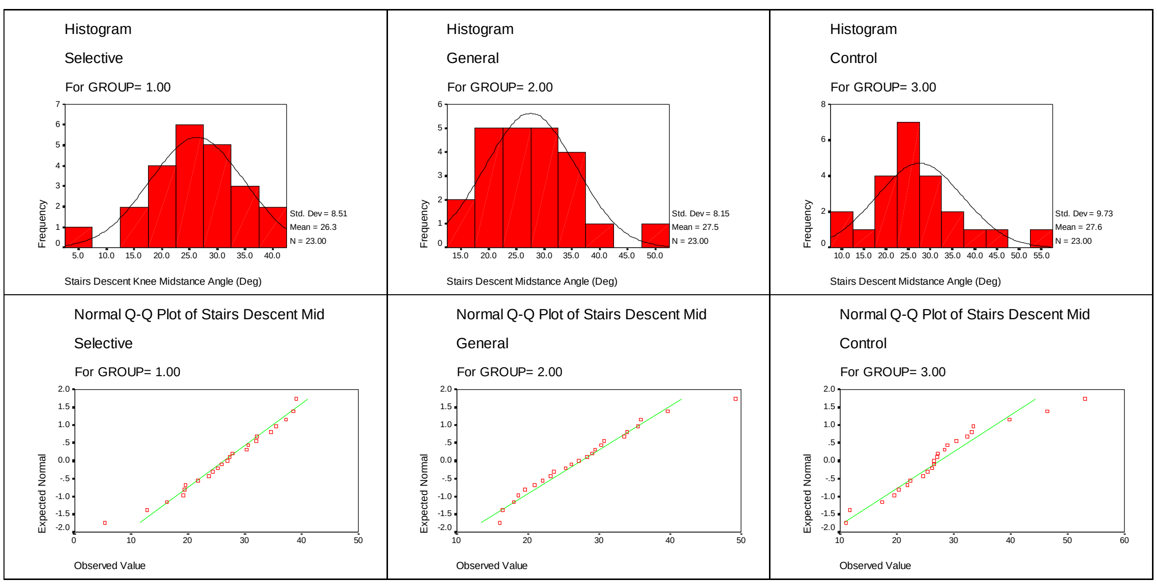
Graphs 15.50 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Ascent Knee Midstance Angle (Degrees)



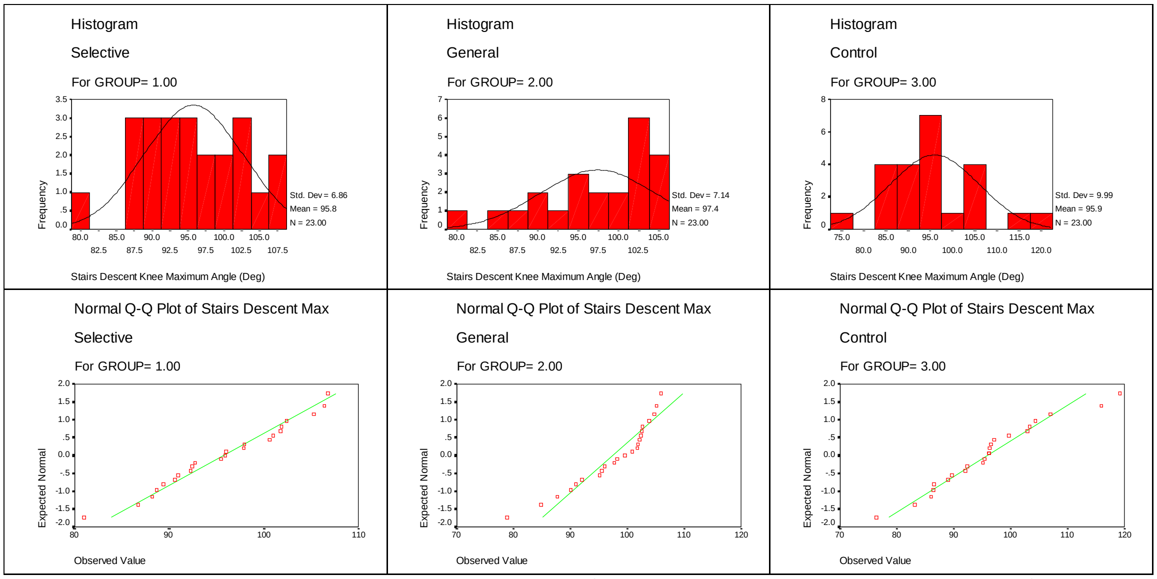
Graphs 15.51 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Ascent Knee Maximum Angle (Degrees)



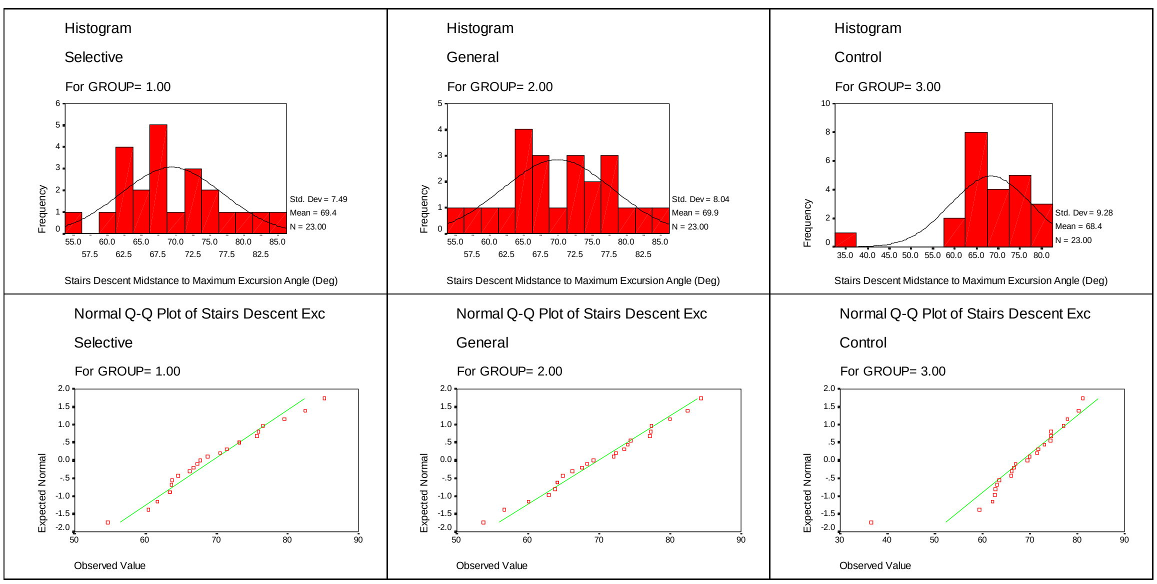
Graphs 15.52 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Ascent Midstance to Maximum Knee Excursion Angle (Degrees)



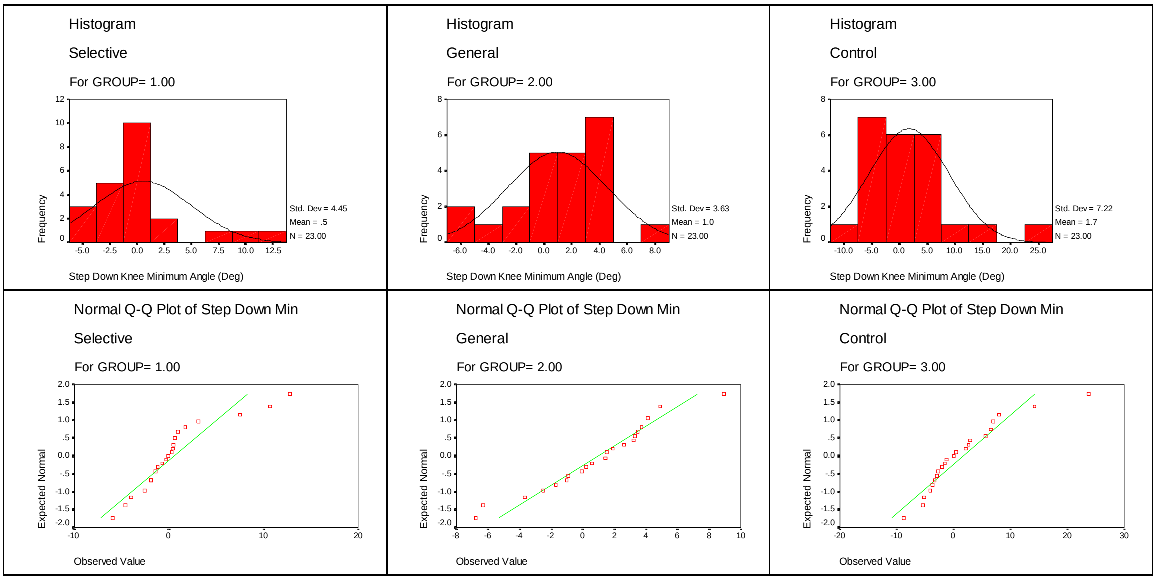
Graphs 15.53 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Descent Knee Midstance Angle (Degrees)



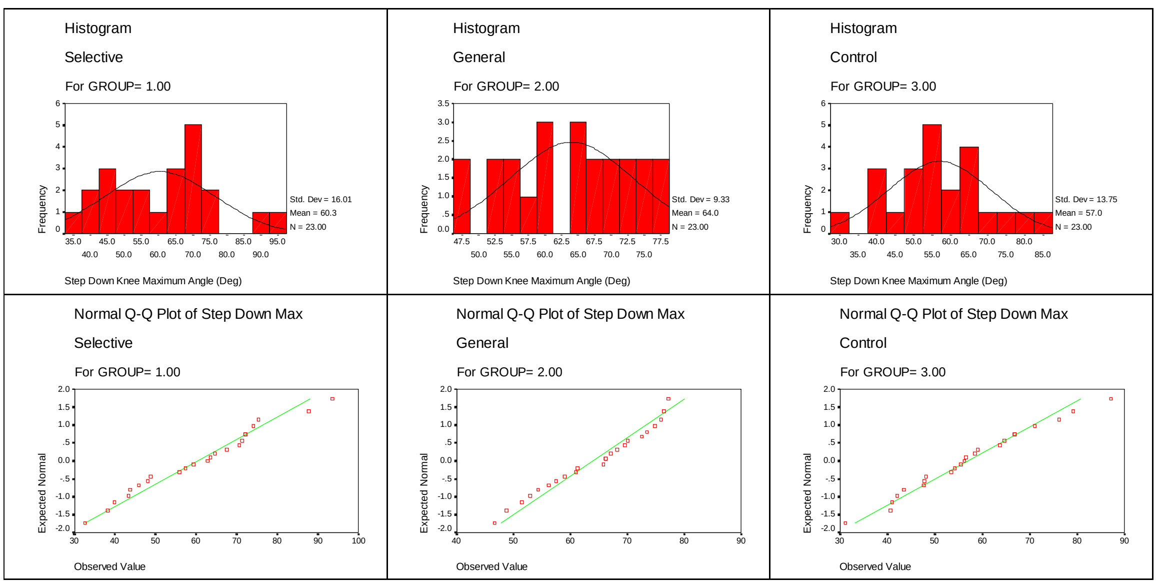
Graphs 15.54 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Descent Maximum Knee Angle (Degrees)



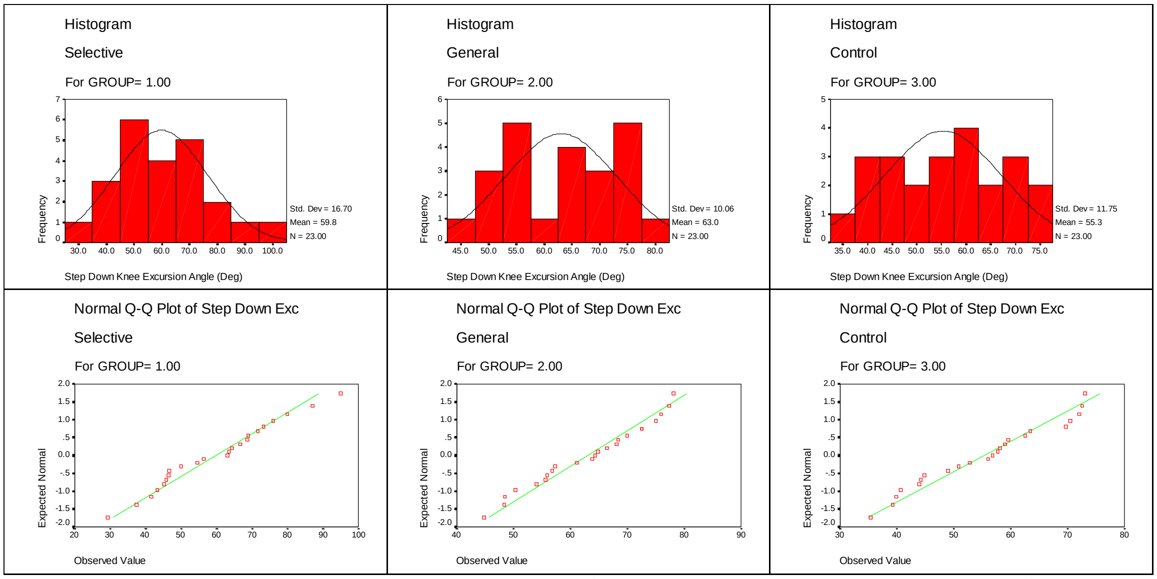
Graphs 15.55 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Descent Midstance to Maximum Knee Angle (Degrees)



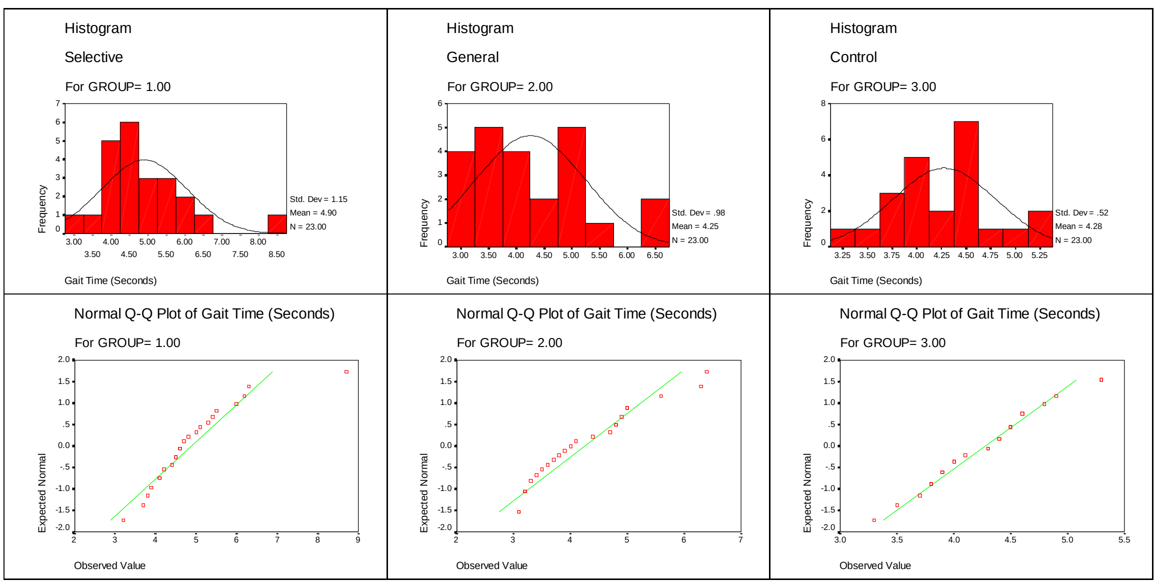
Graphs 15.56 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Step Down Minimum Knee Angle (Degrees)



Graphs 15.57 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Step Down Maximum Knee Angle (Degrees)

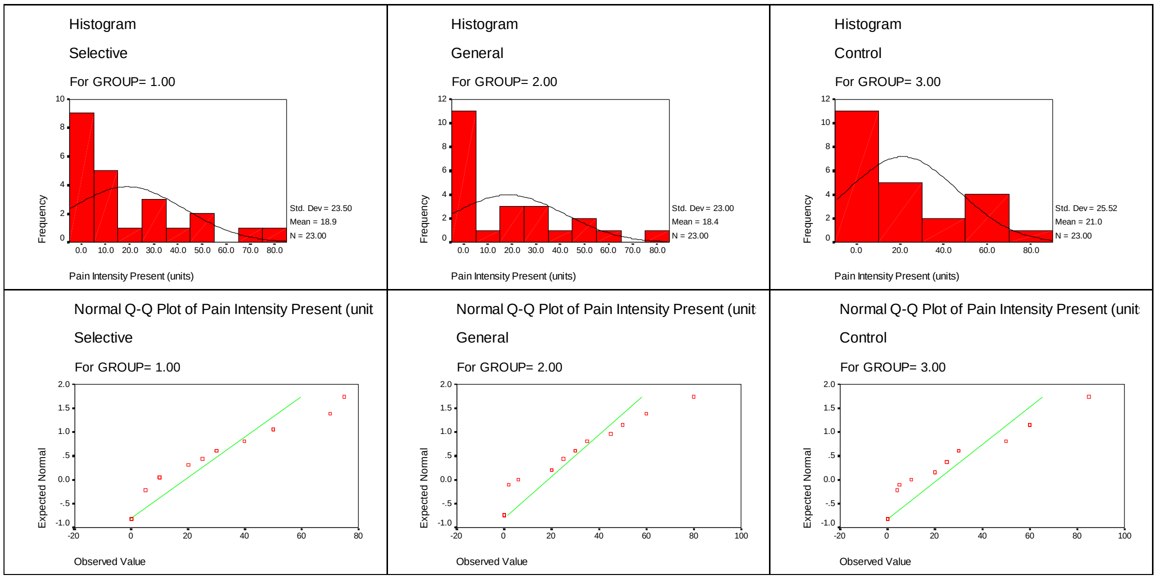


Graphs 15.58 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Step Down Knee Excursion Angle (Degrees)

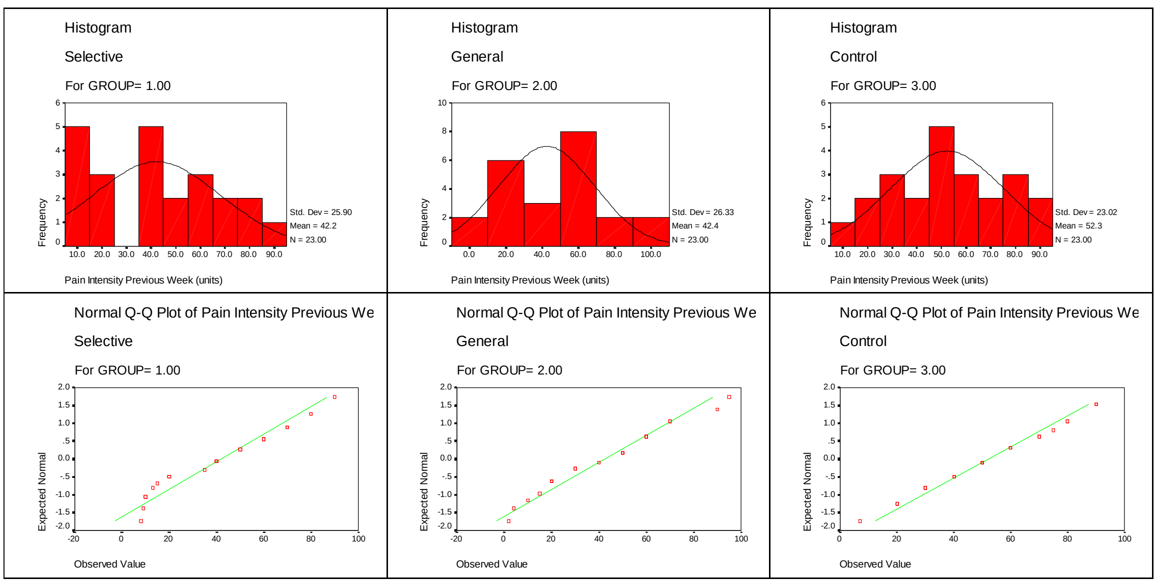


Graphs 15.59 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Gait Time for 5 Metres (Seconds)

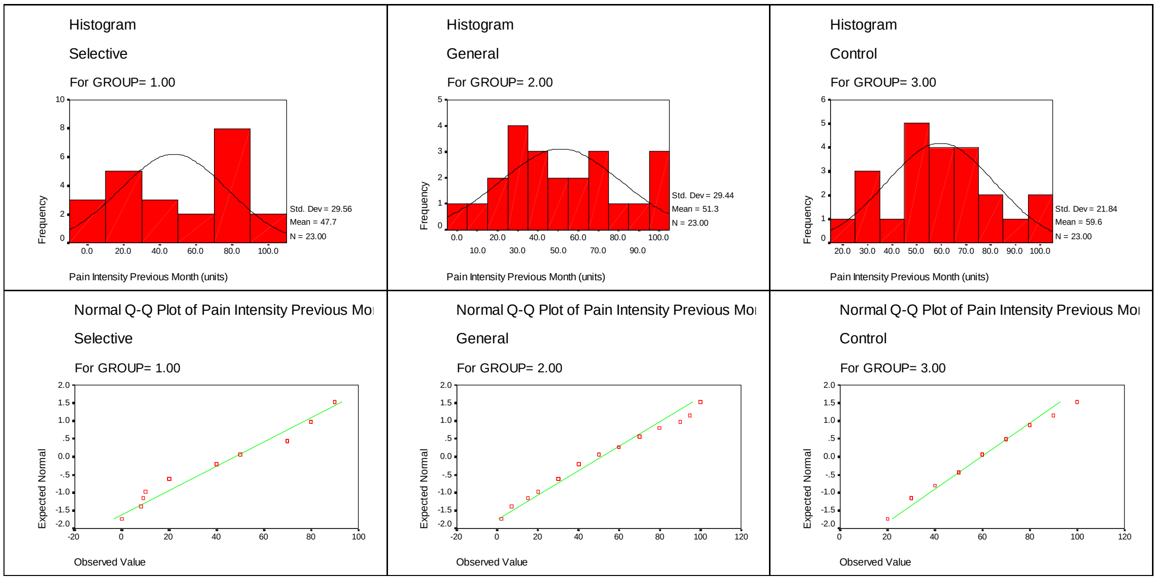
NUMERICAL PAIN RATING SCALES



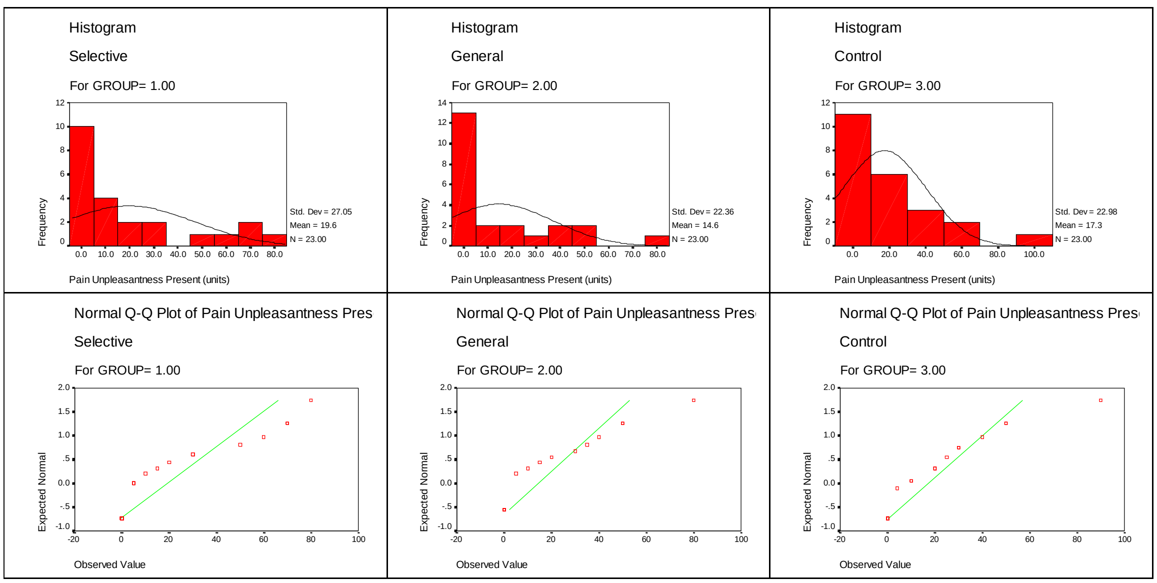
Graphs 15.60 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Intensity (Units)



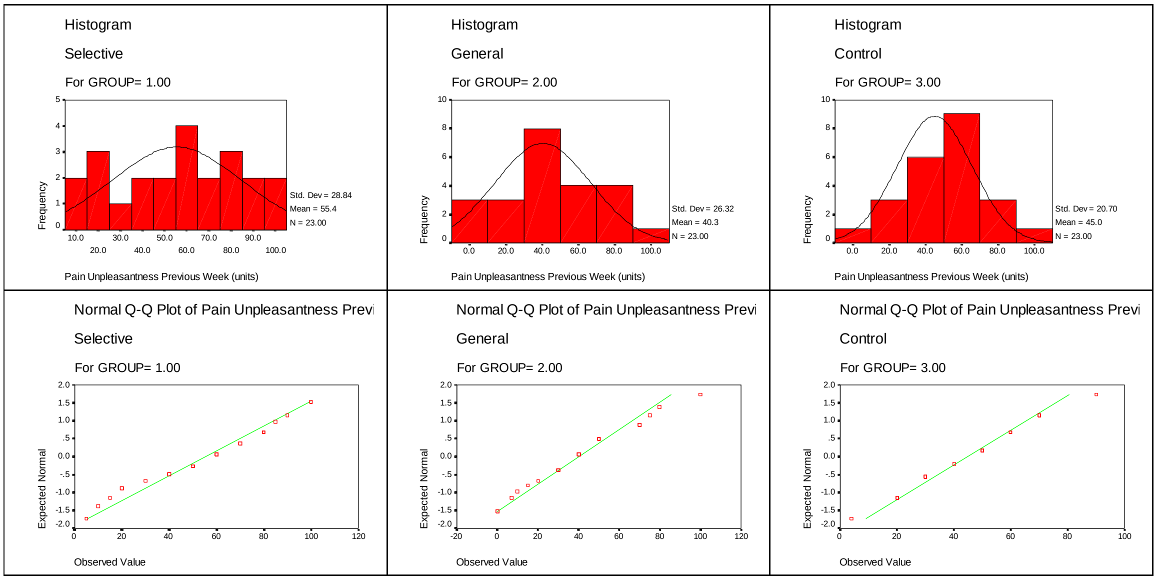
Graphs 15.61 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Intensity Previous Week (Units)



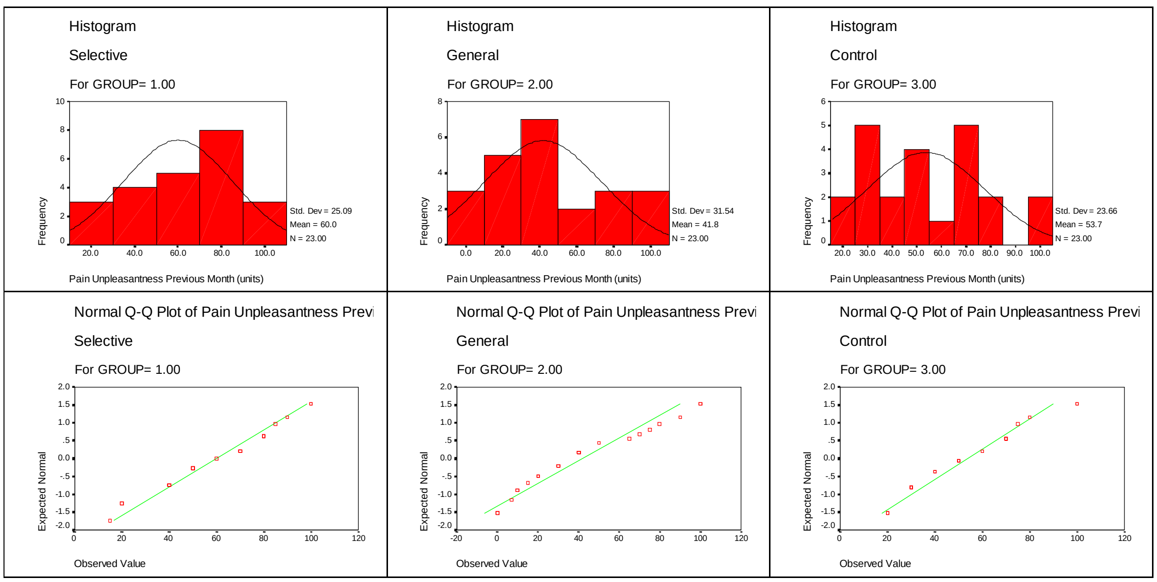
Graphs 15.62 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Intensity Previous Month (Units)



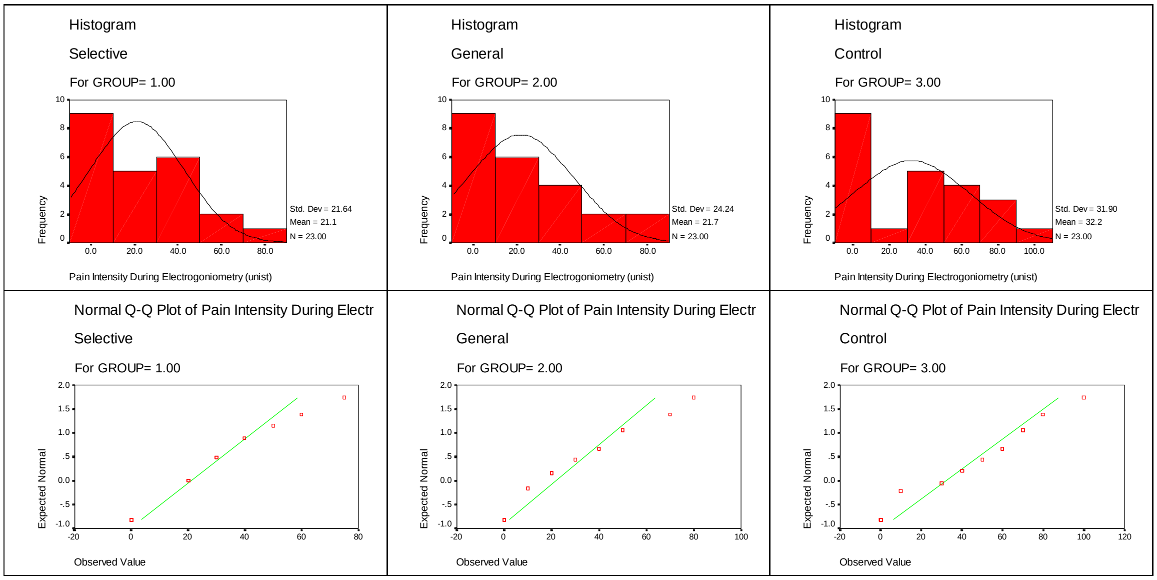
Graphs 15.63 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Unpleasantness Present (Units)



Graphs 15.64 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Unpleasantness Week (Units)

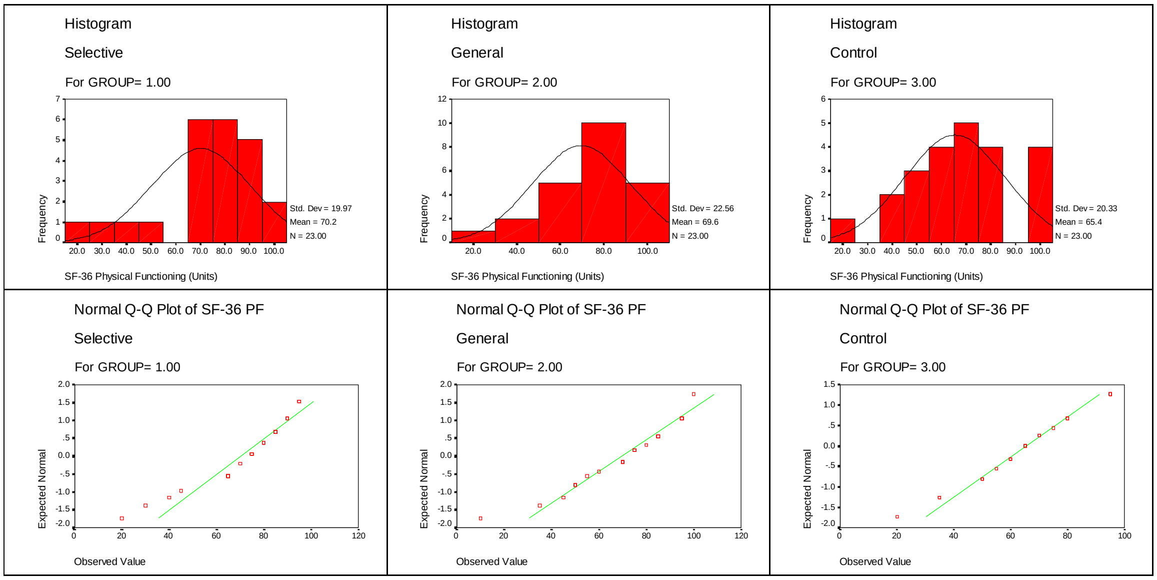


Graphs 15.65 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Unpleasantness Month (Units)

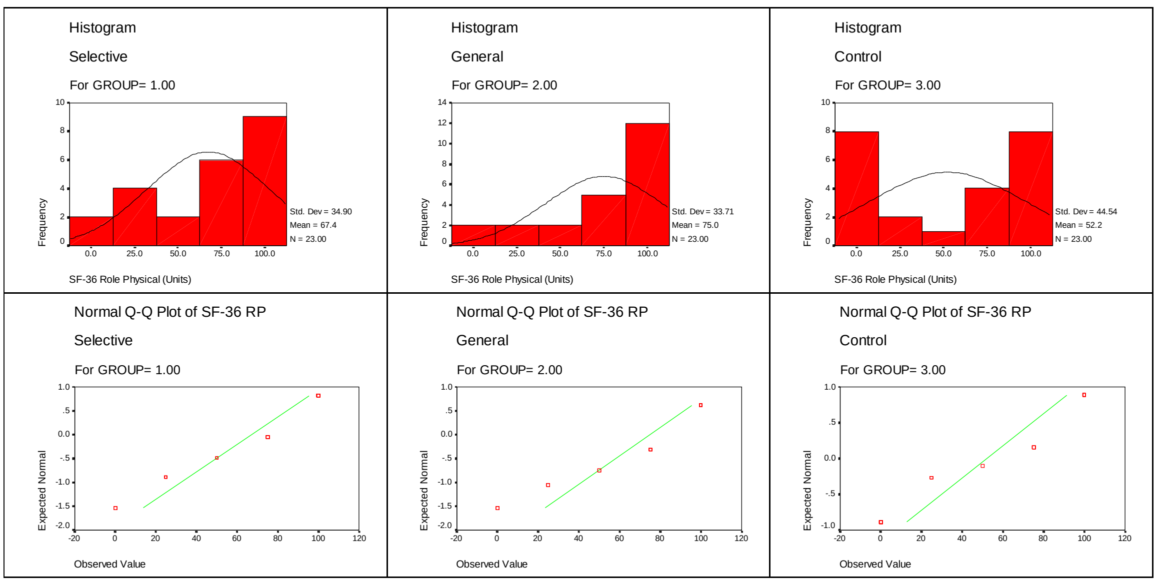


Graphs 15.66 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Intensity During Electrogoniometry (Units)

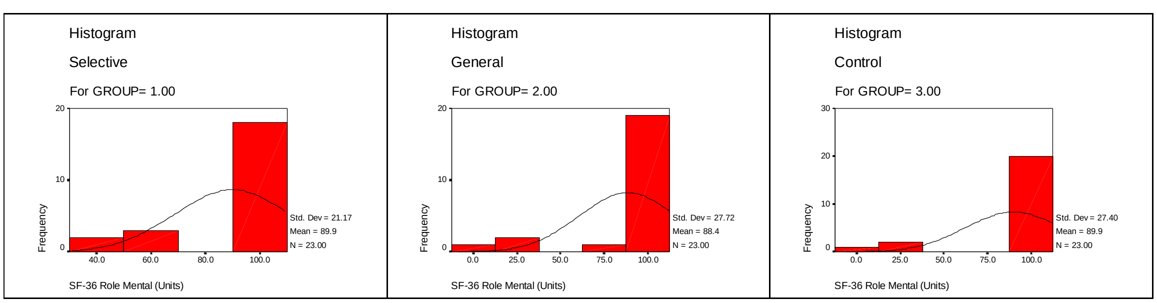
SF-36

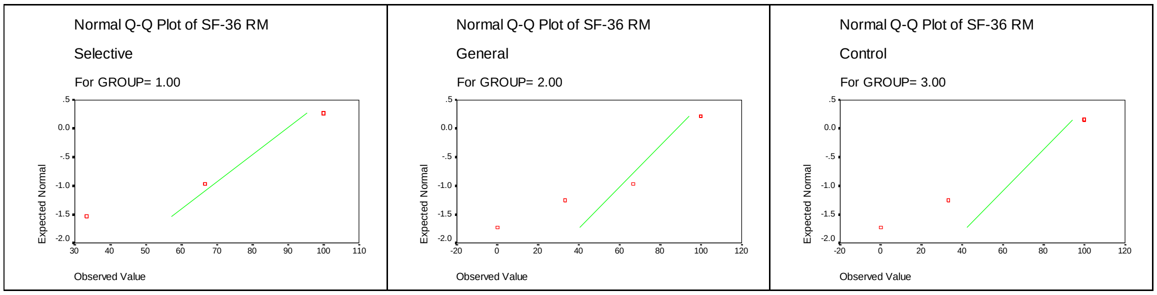


Graphs 15.67 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Physical Functioning (Units)

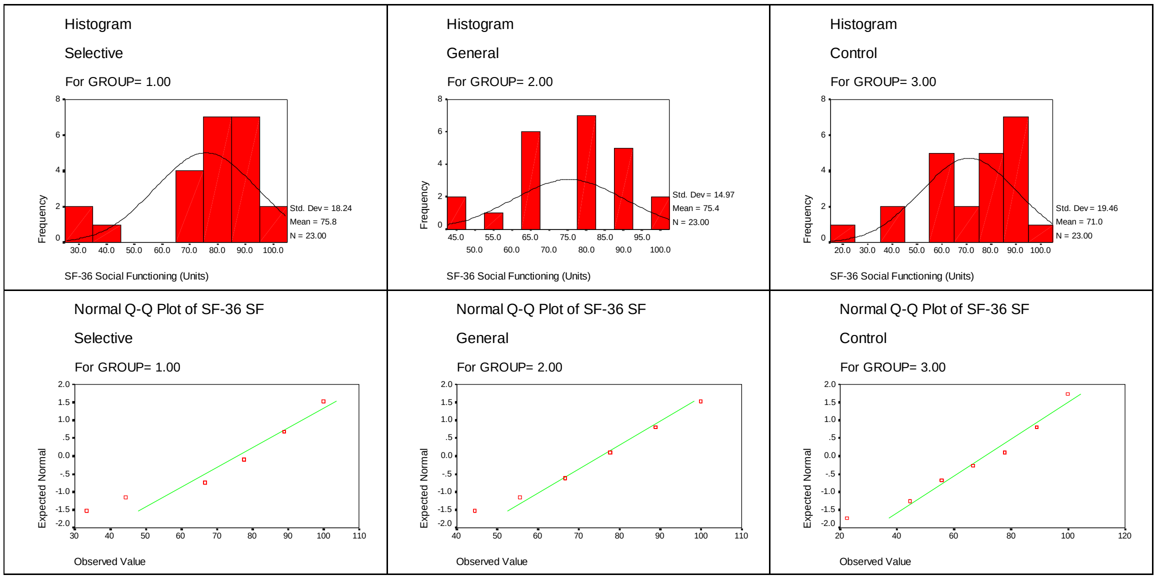


Graphs 15.68 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Role Physical (Units)

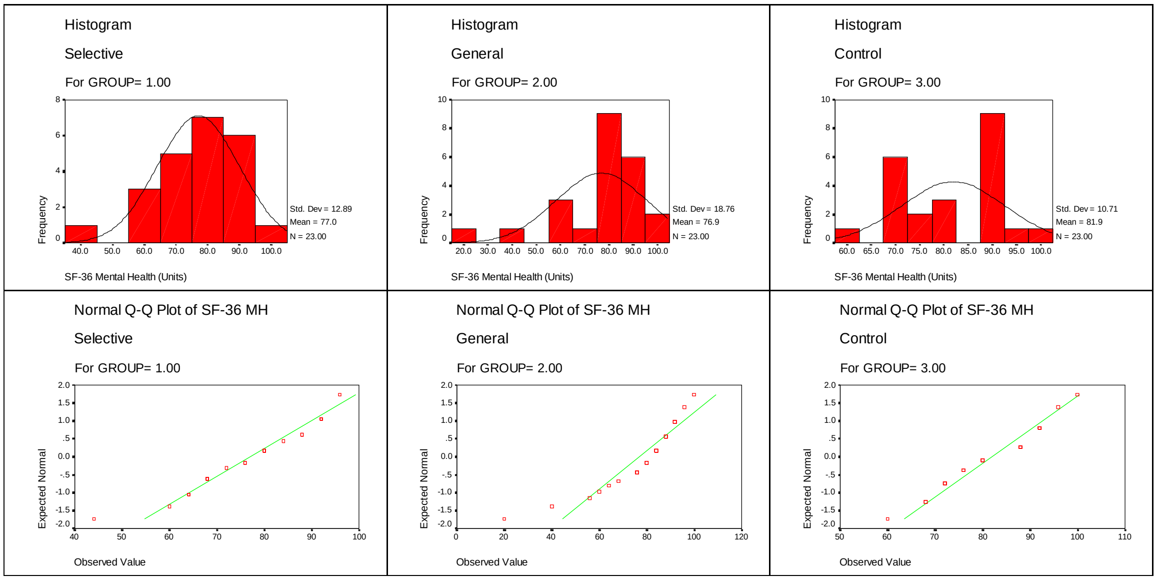




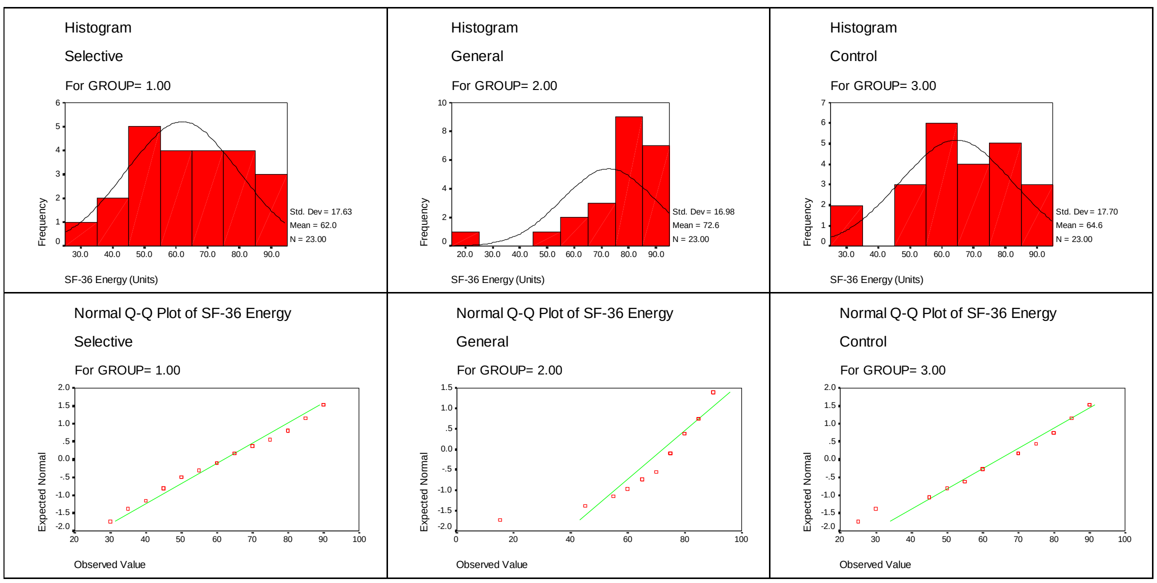
Graphs 15.69 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Role Mental (Units)



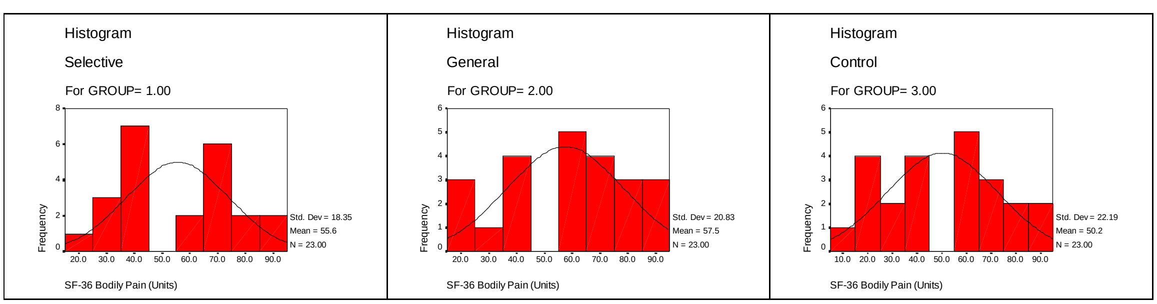
Graphs 15.70 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Social Functioning (Units)

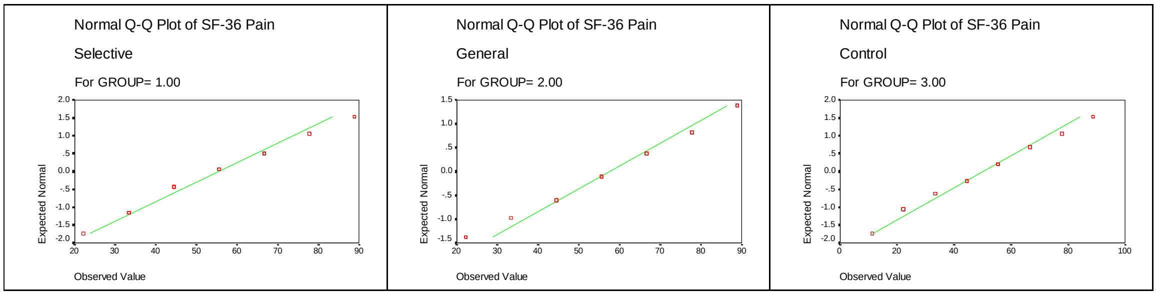


Graphs 15.71 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Mental Health (Units)

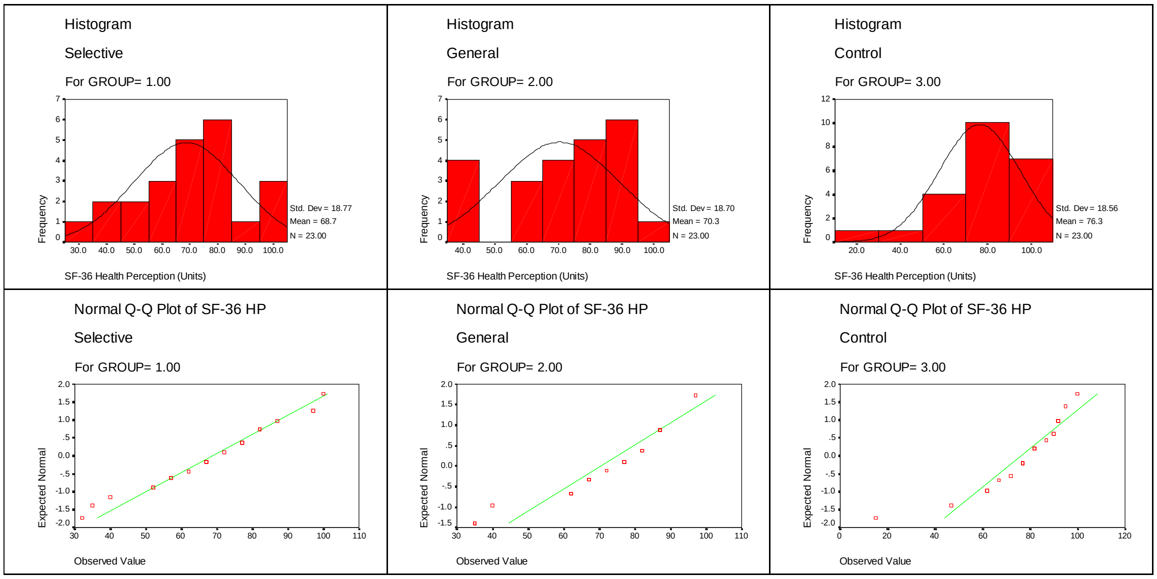


Graphs 15.72 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Energy (Units)

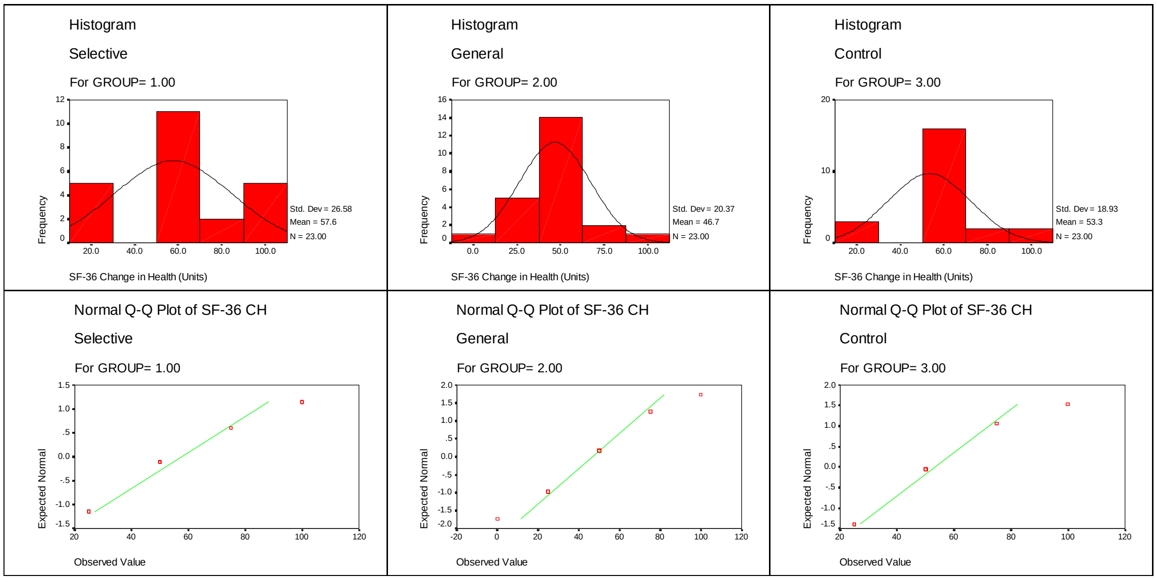




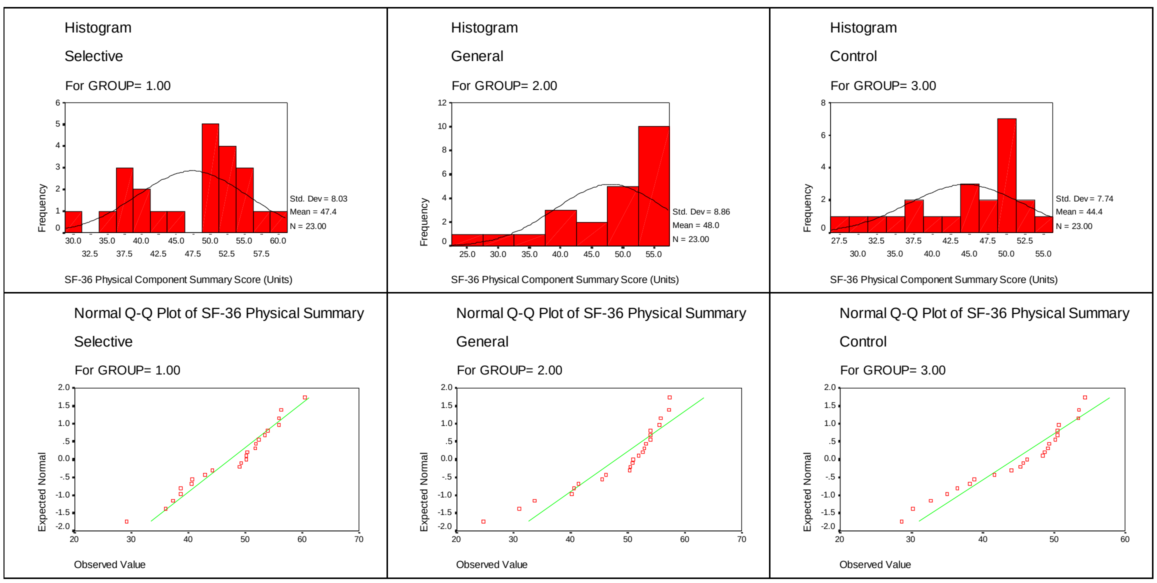
Graphs 15.73 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Pain (Units)



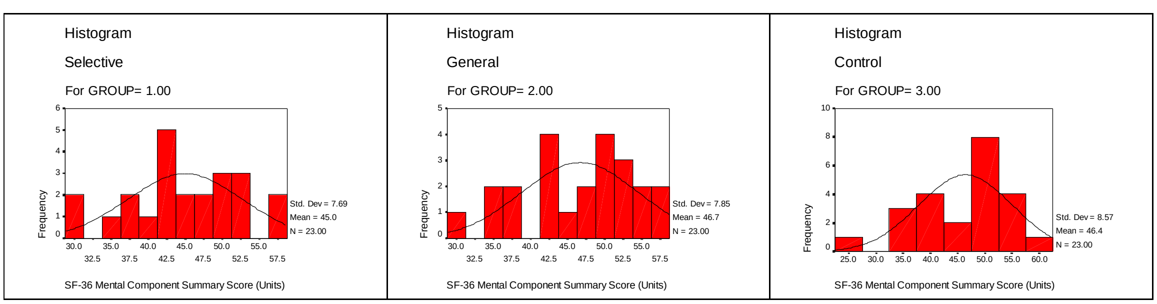
Graphs 15.74 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Health Perception (Units)

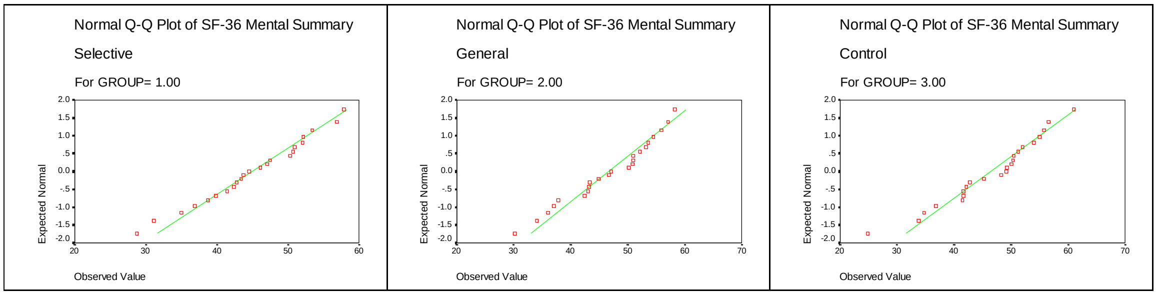


Graphs 15.75 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Change in Health (Units)



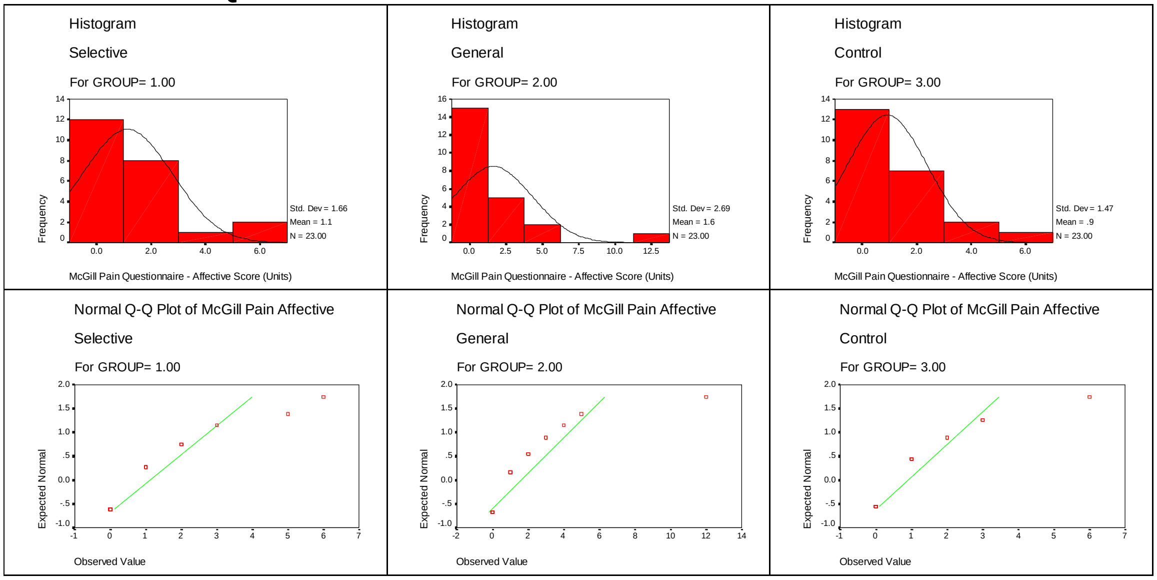
Graphs 15.76 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Physical Component Summary Score (Units)



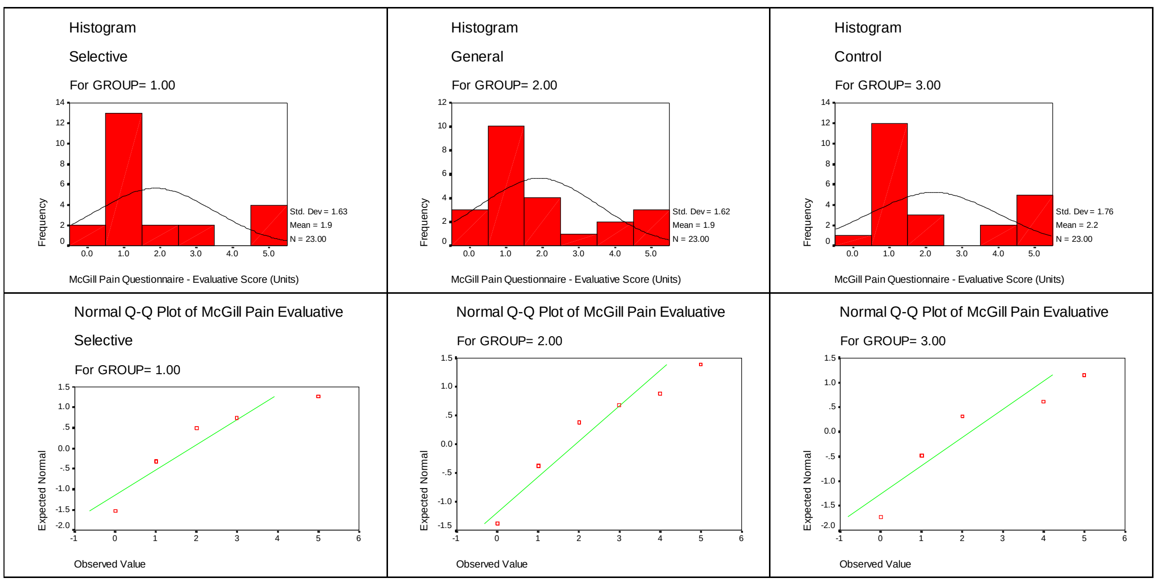


Graphs 15.77 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Mental Component Summary Score (Units)

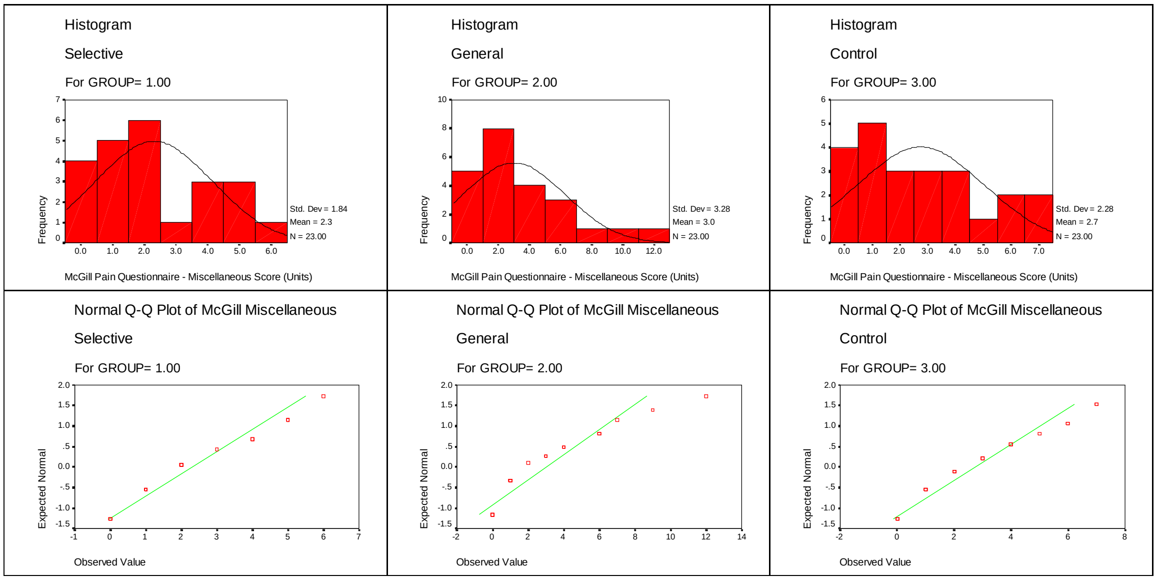
McGILL PAIN QUESTIONNAIRE



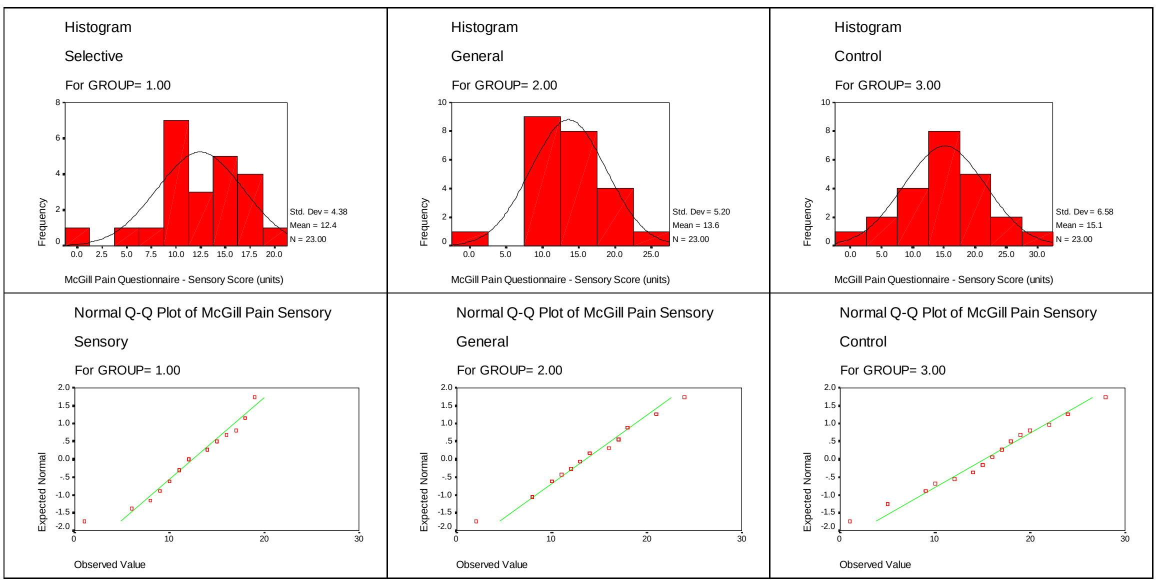
Graphs 15.78 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire - Affective Score (Units)



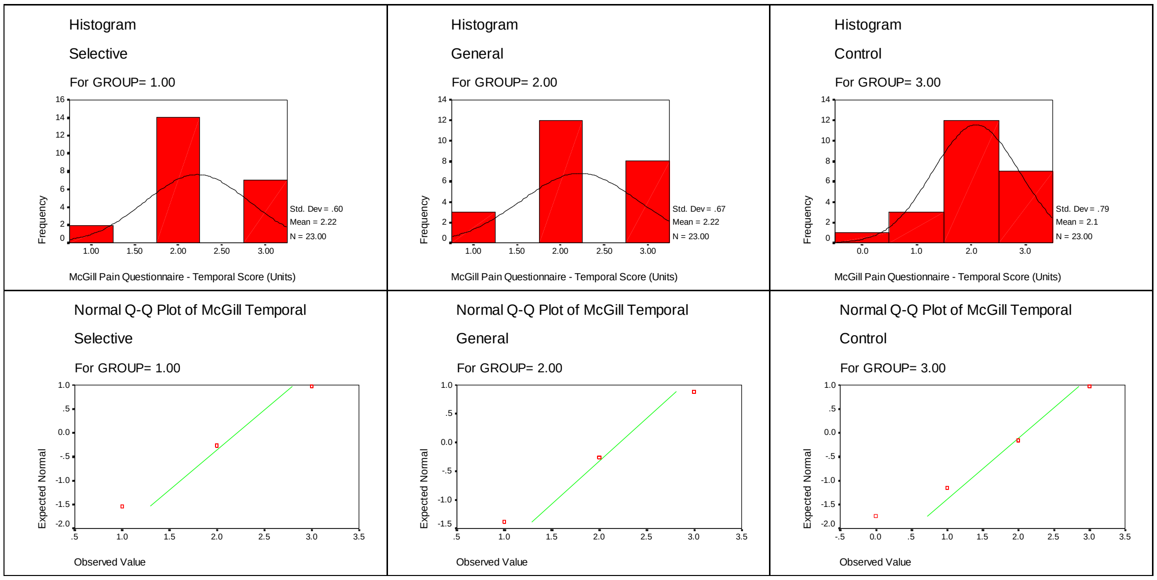
Graphs 15.79 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire - Evaluative Score (Units)



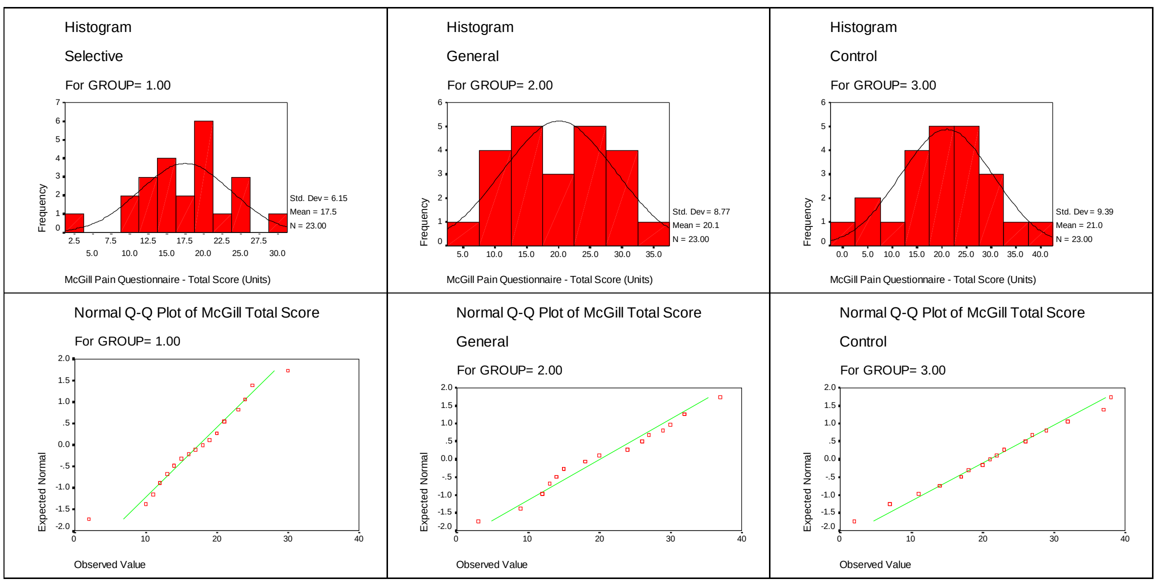
Graphs 15.80 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire - Miscellaneous Score (Units)



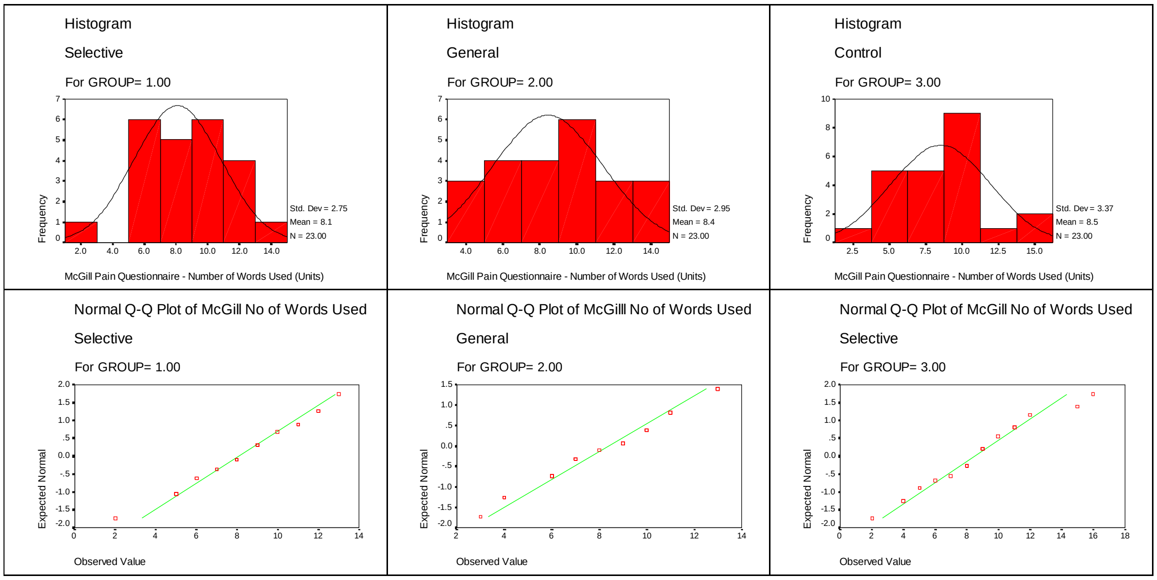
Graphs 15.81 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – Sensory Score (Units)



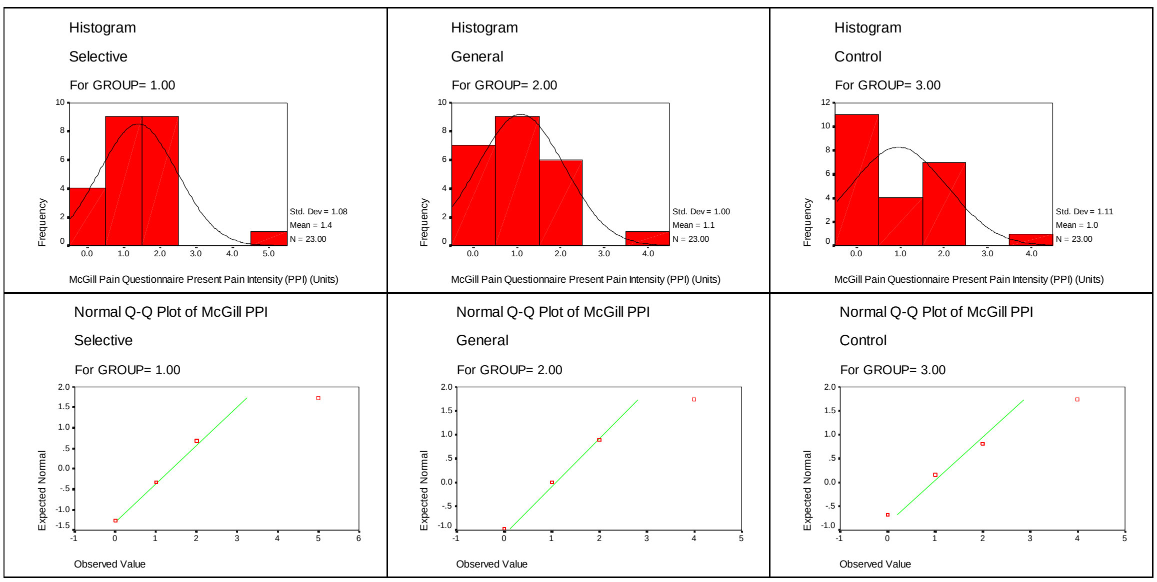
Graphs 15.82 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – Temporal Score (Units)



Graphs 15.83 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – Total Score (Units)

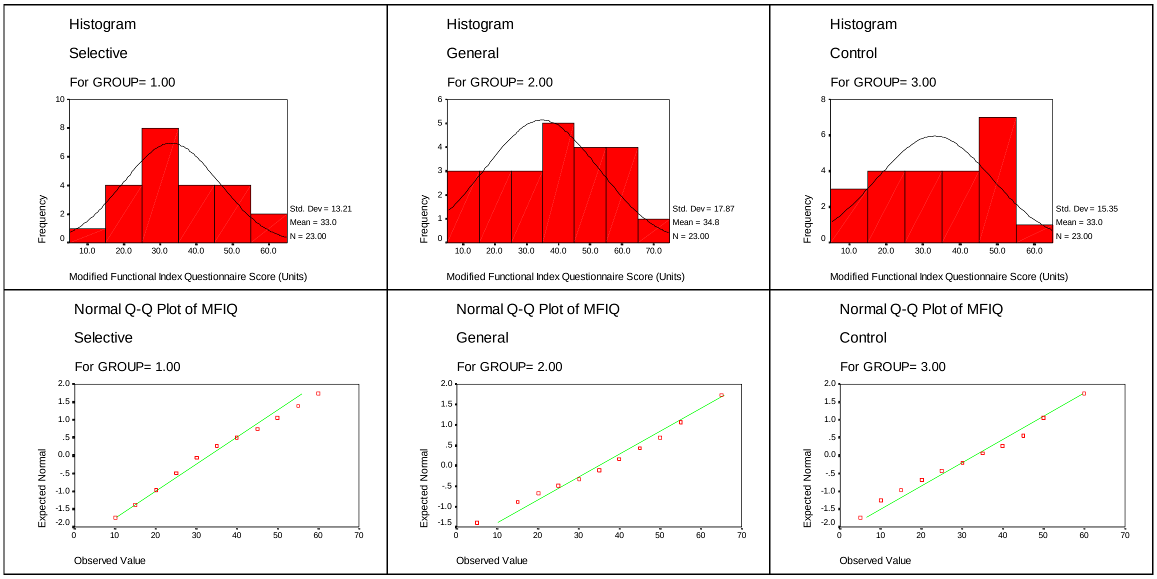


Graphs 15.84 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – Number of Words Used



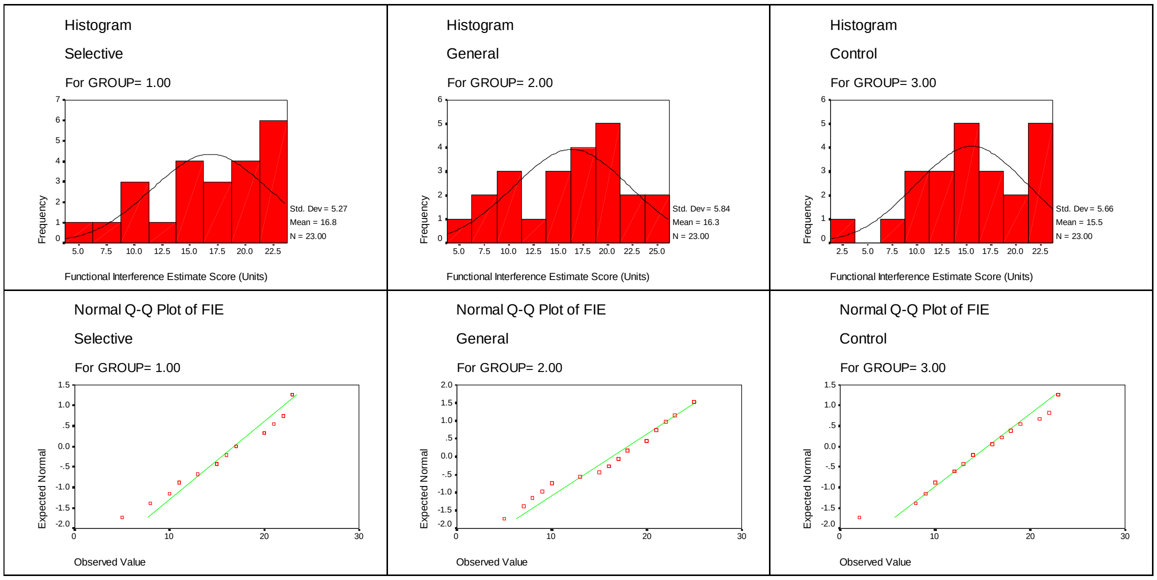
Graphs 15.85 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – PPI (Units)

MODIFIED FUNCTIONAL INDEX QUESTIONNAIRE (MFIQ)



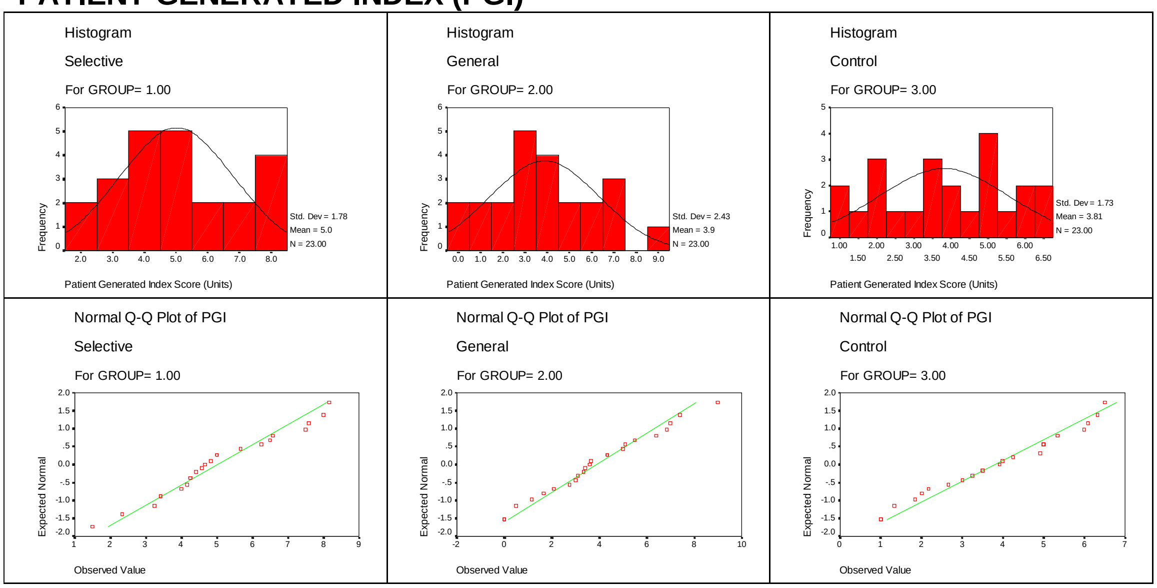
Graphs 15.86 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Modified Functional Index Questionnaire (MFIQ) Score (Units)

FUNCTIONAL INTERFERENCE ESTIMATE (FIE)

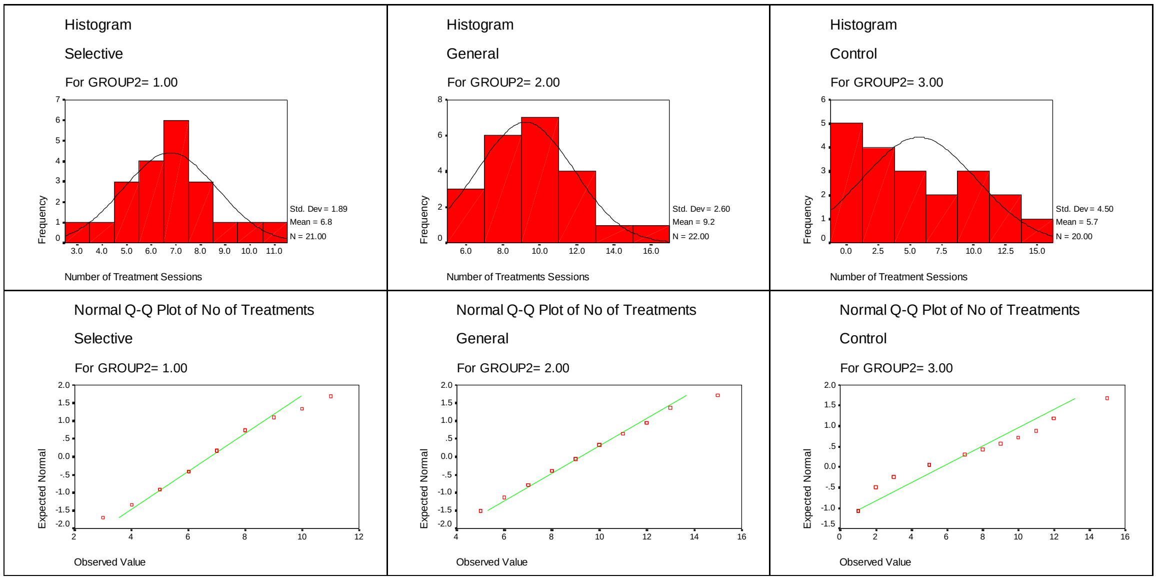


Graphs 15.87 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Functional Interference Estimate (FIE) Score (Units)

PATIENT GENERATED INDEX (PGI)



Graphs 15.88 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Patient Generated Index (PGI) Score (Units)

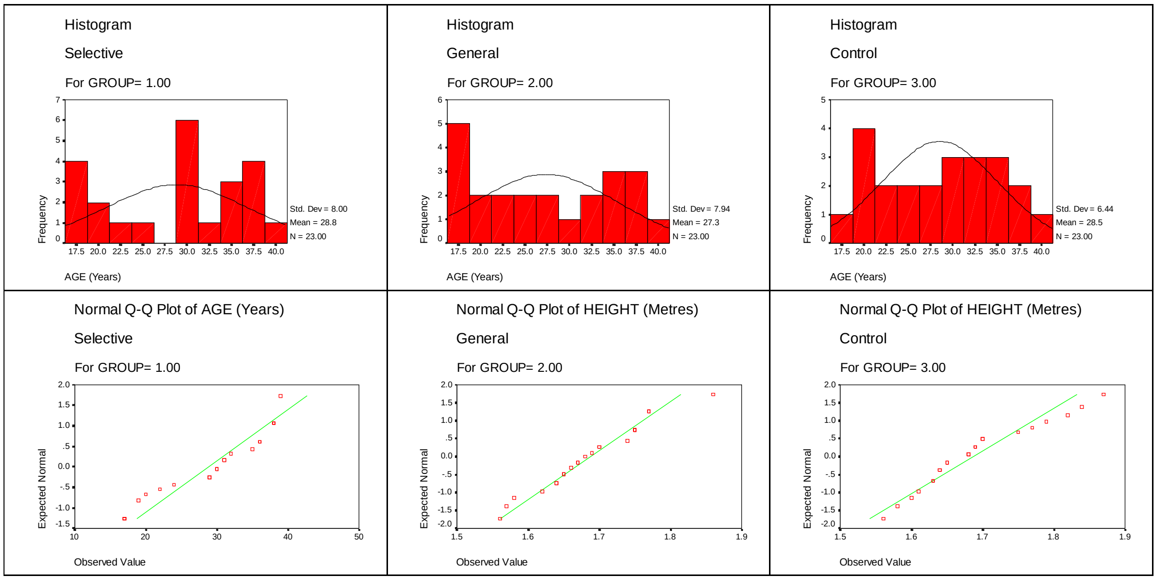


Graphs 15.89 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for the Number of Treatment Sessions

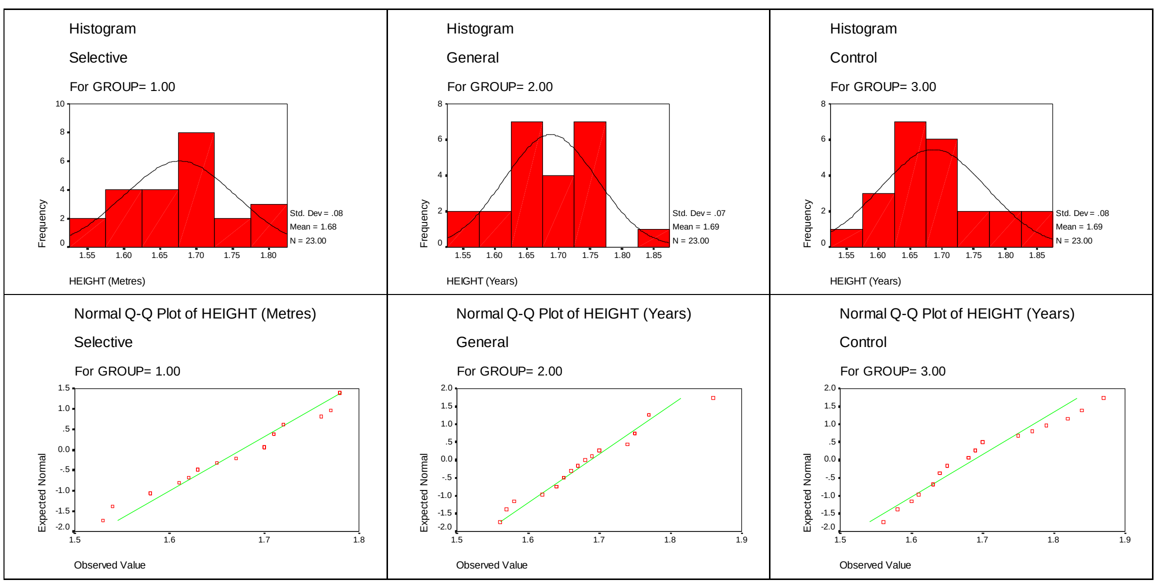
ELECTRONIC APPENDIX 16

16.1 POST RCT NORMALITY GRAPHS AND Q-Q PLOTS FOR PATELLOFEMORAL PAIN SYNDROME PATIENTS

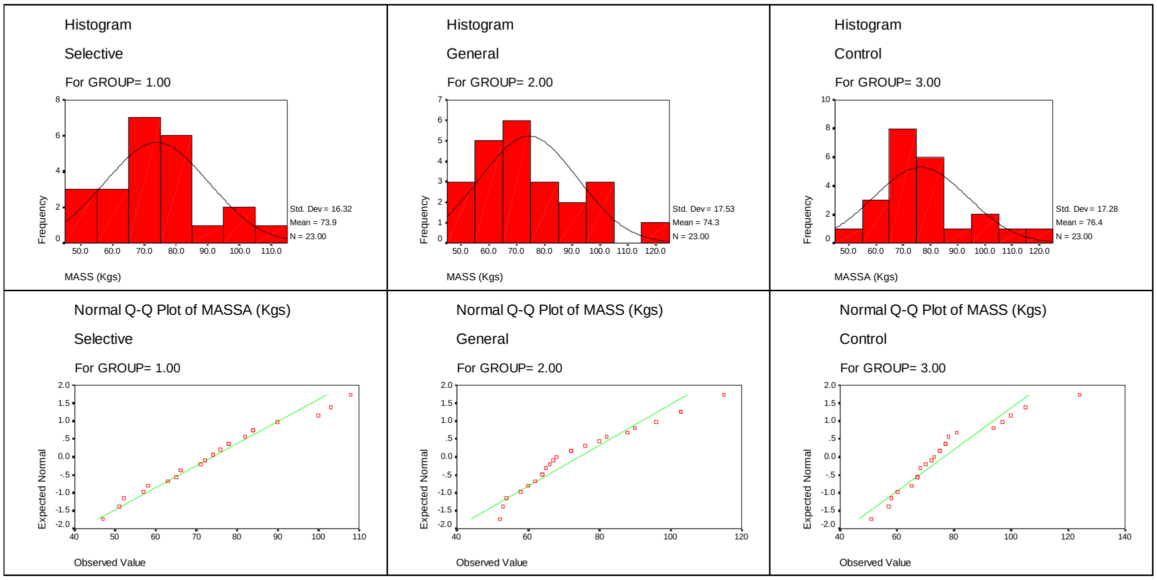
CHARACTERISTICS



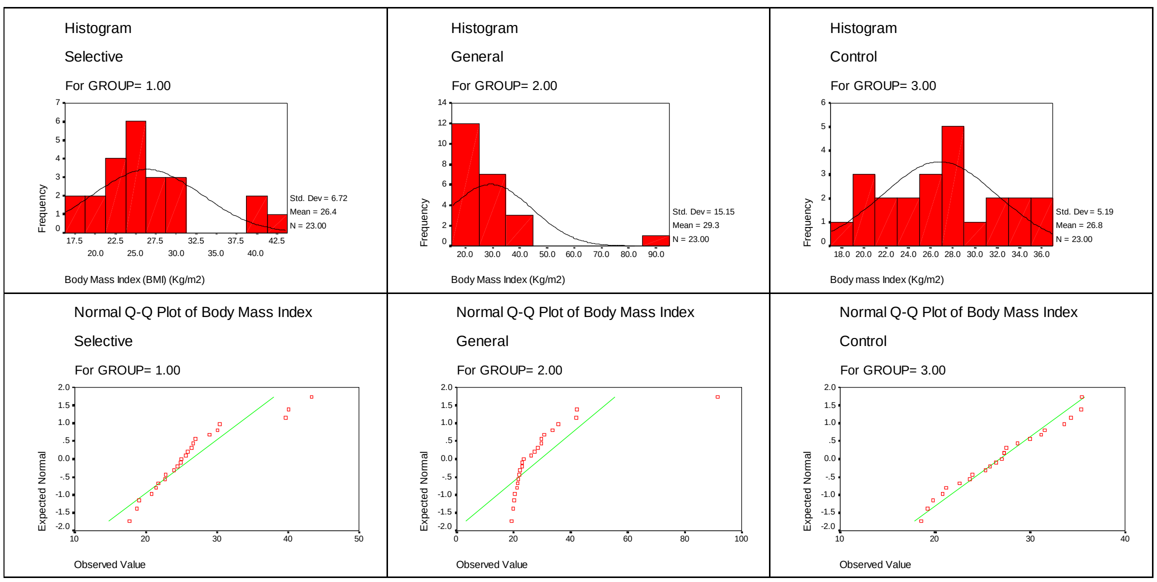
Graphs 16.1 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Age (Years)**



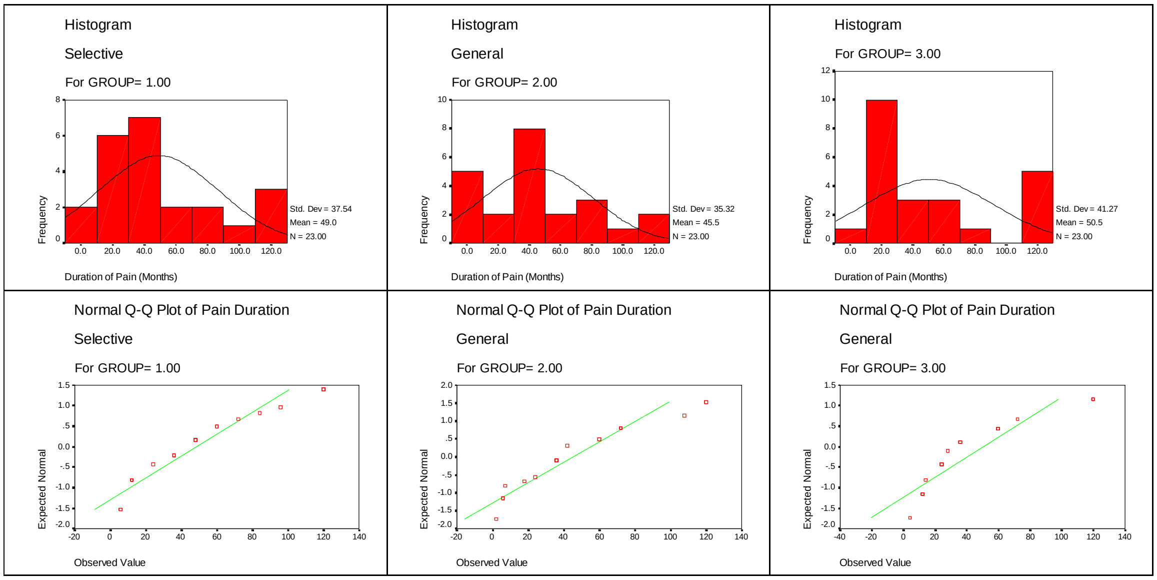
Graphs 16.2 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Height (Metres)**



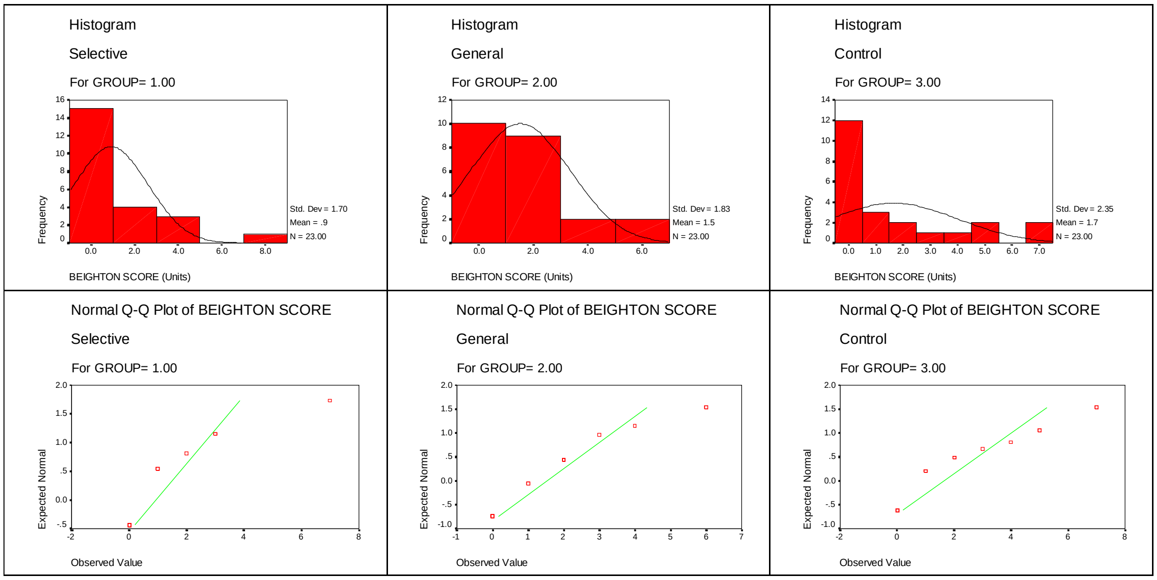
Graphs 16.3 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Body Mass (Kgs)**



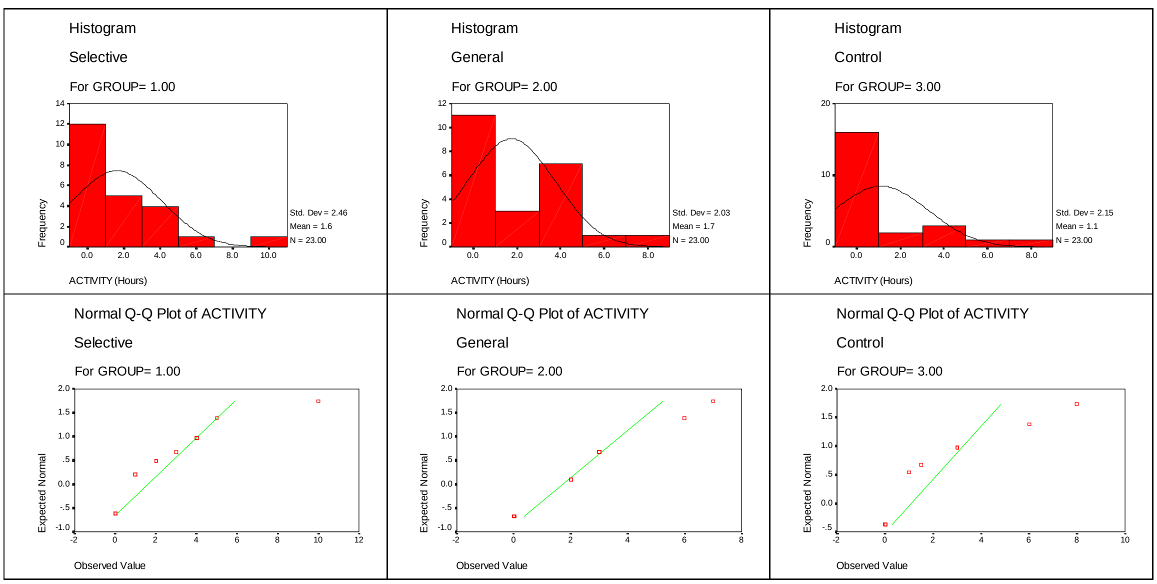
Graphs 16.4 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Body Mass Index (BMI) (Kgs/m^2)**



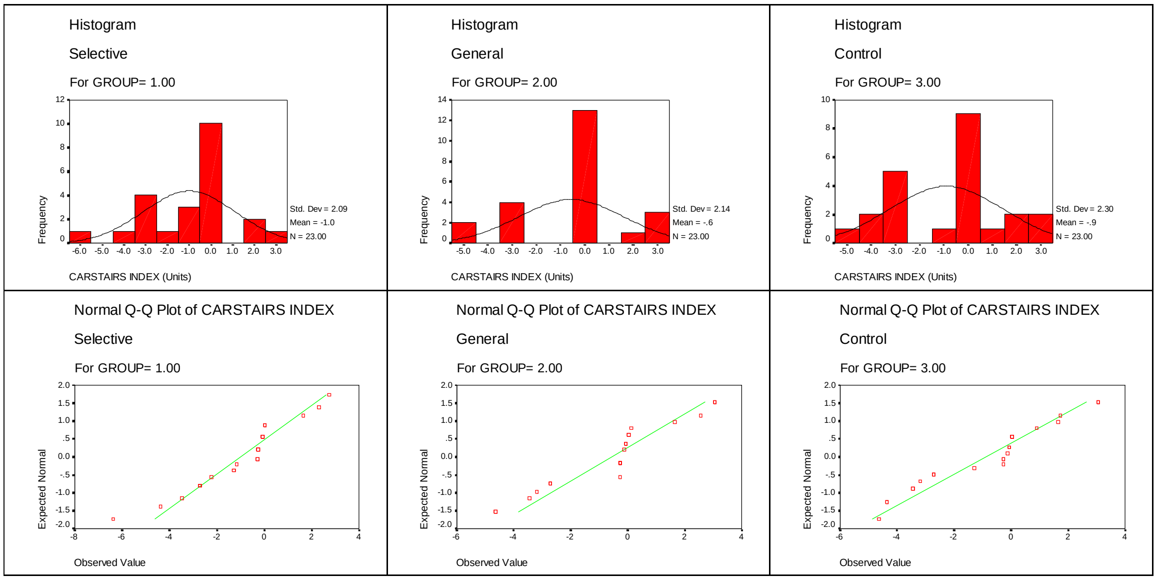
Graphs 16.4 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Pain Duration (Months)



Graphs 16.5 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Beighton Score (Units)**

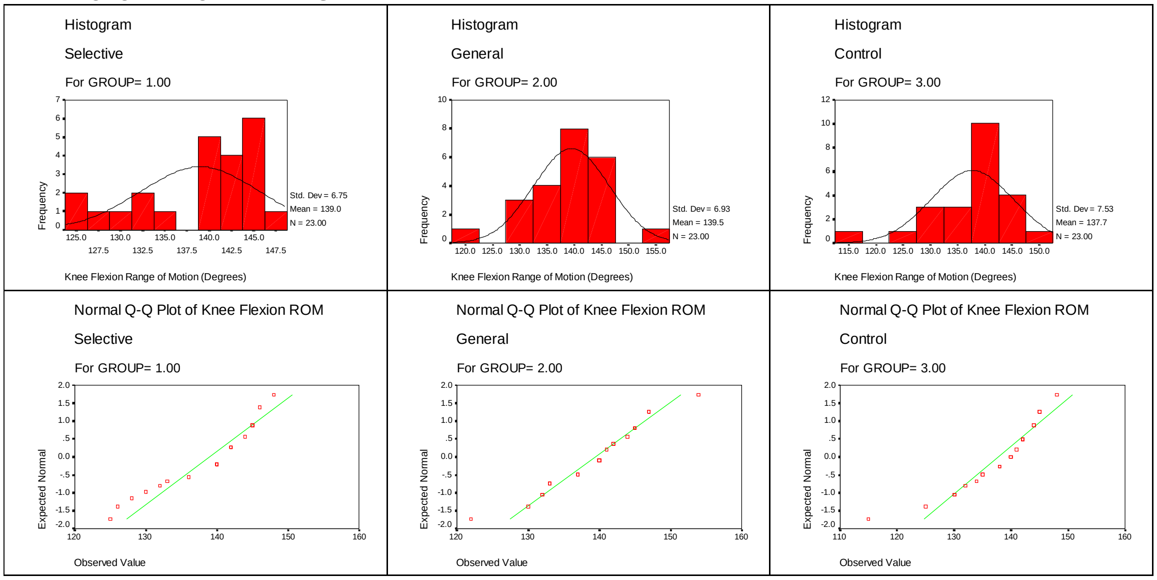


Graphs 16.6 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Activity (Hours)**

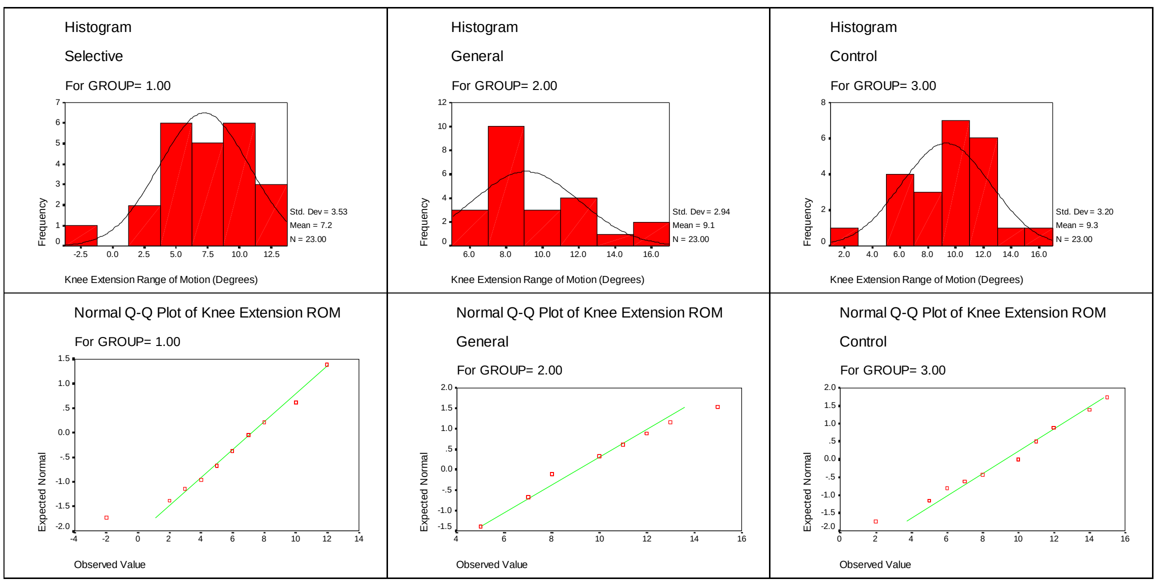


Graphs 16.7 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Carstairs Index (Units)**

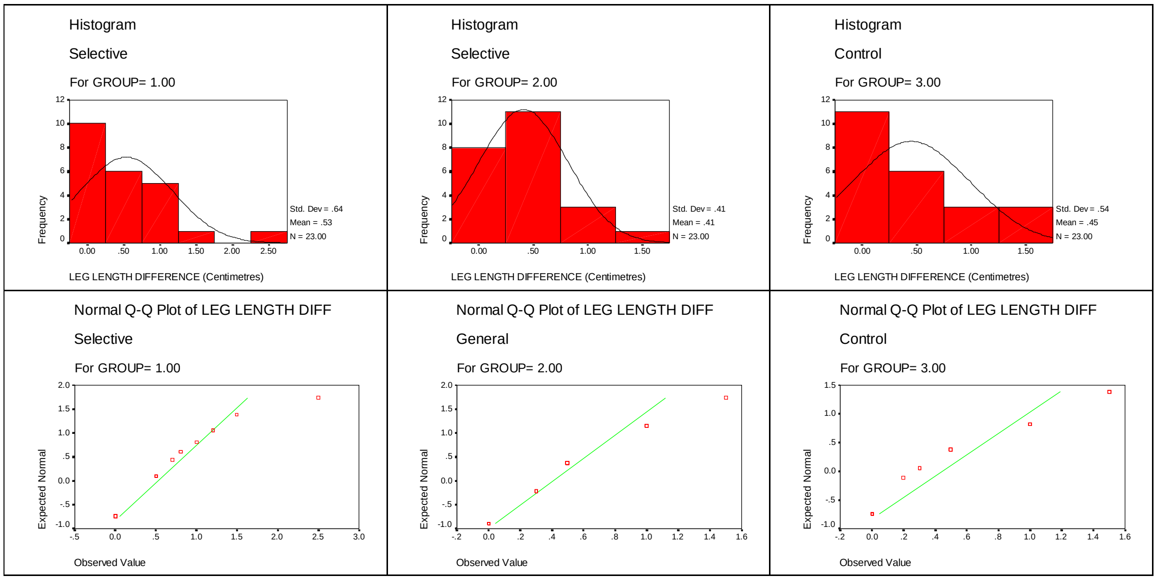
ANTHROPOMETRIC VARIABLES



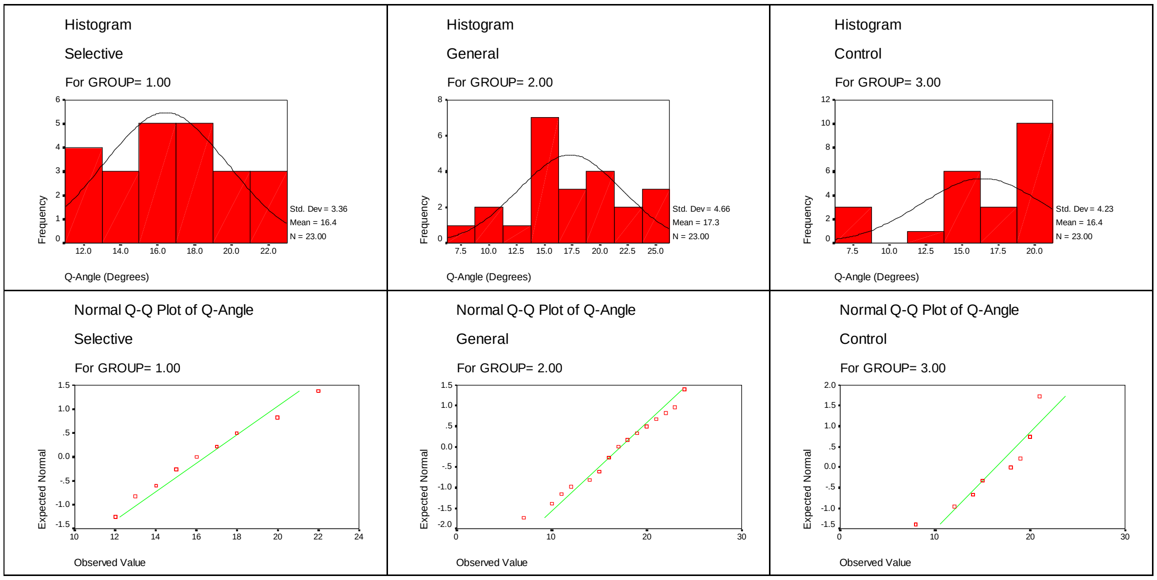
Graphs 16.8 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Knee Flexion Range of Motion (Degrees)



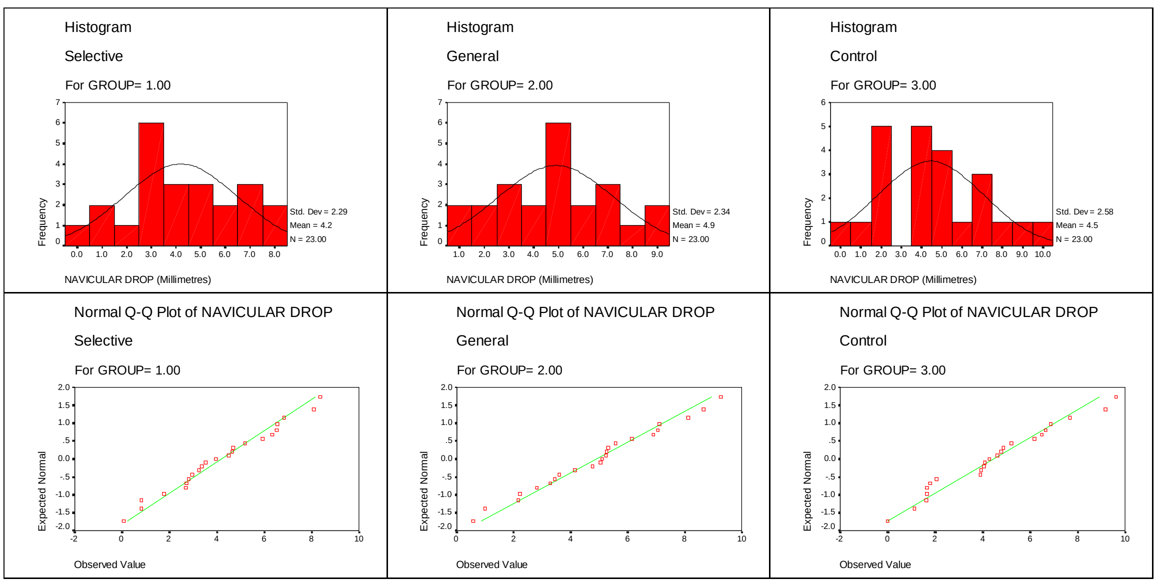
Graphs 16.9 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Knee Extension Range of Motion (Degrees)



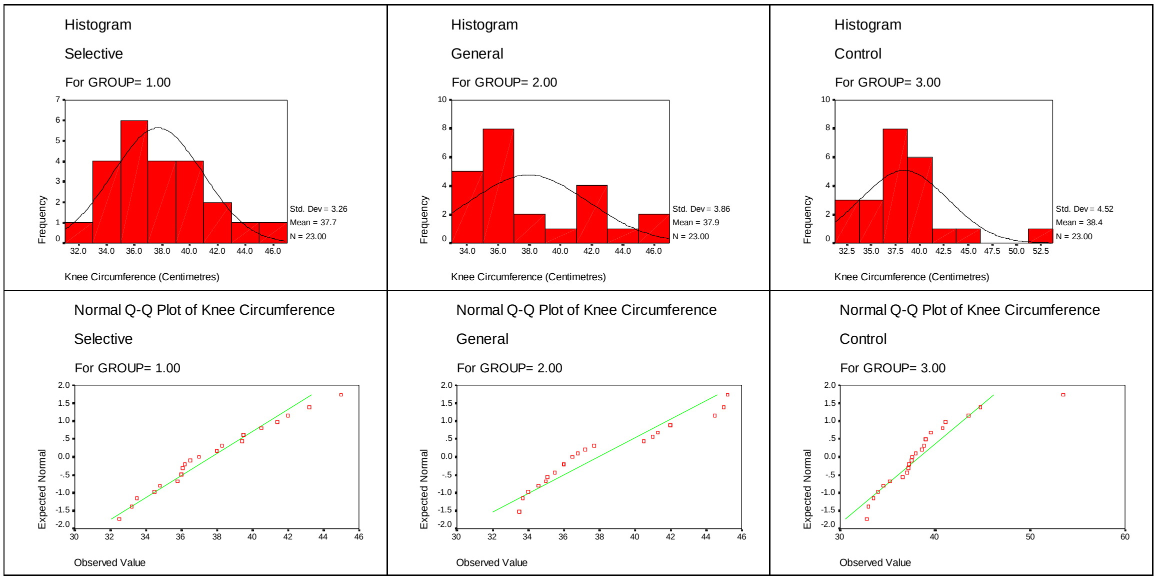
Graphs 16.10 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Leg Length Difference (Centimetres)



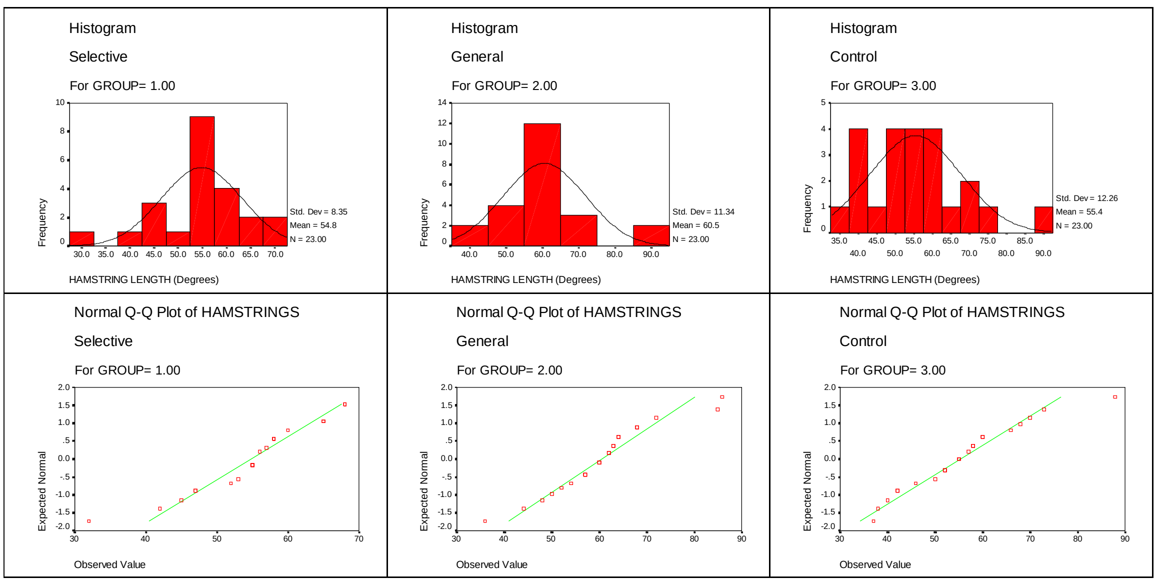
Graphs 16.11 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Q-Angle (Degrees)**



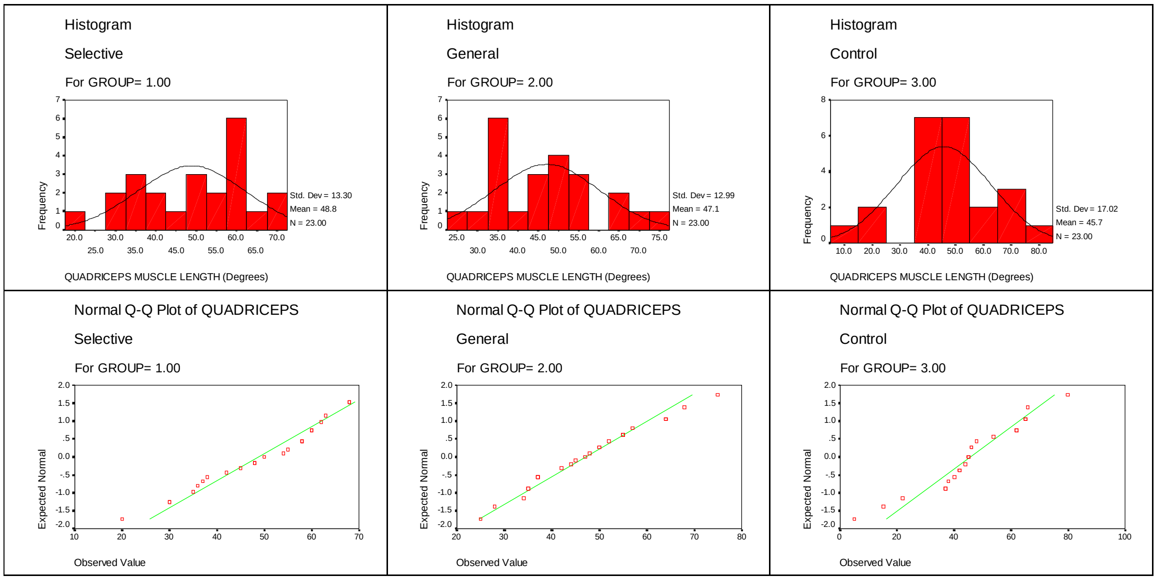
Graphs 16.12 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Navicular Drop (Millimetres)**



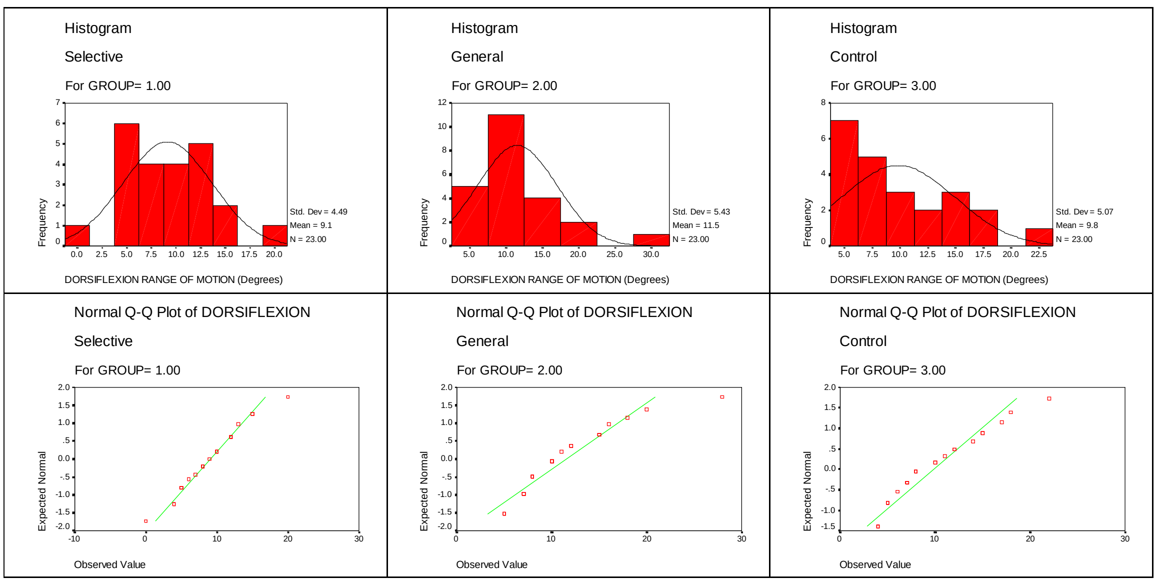
Graphs 16.13 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Knee Circumferential Measurements (Centimetres)



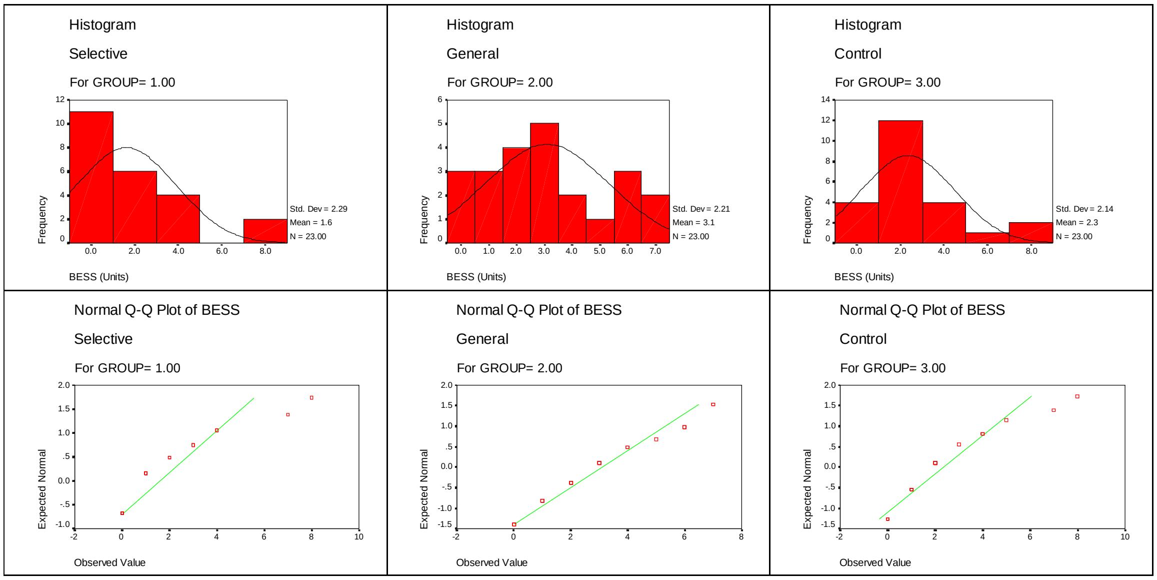
Graphs 16.14 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Hamstrings Muscle Length (Degrees)



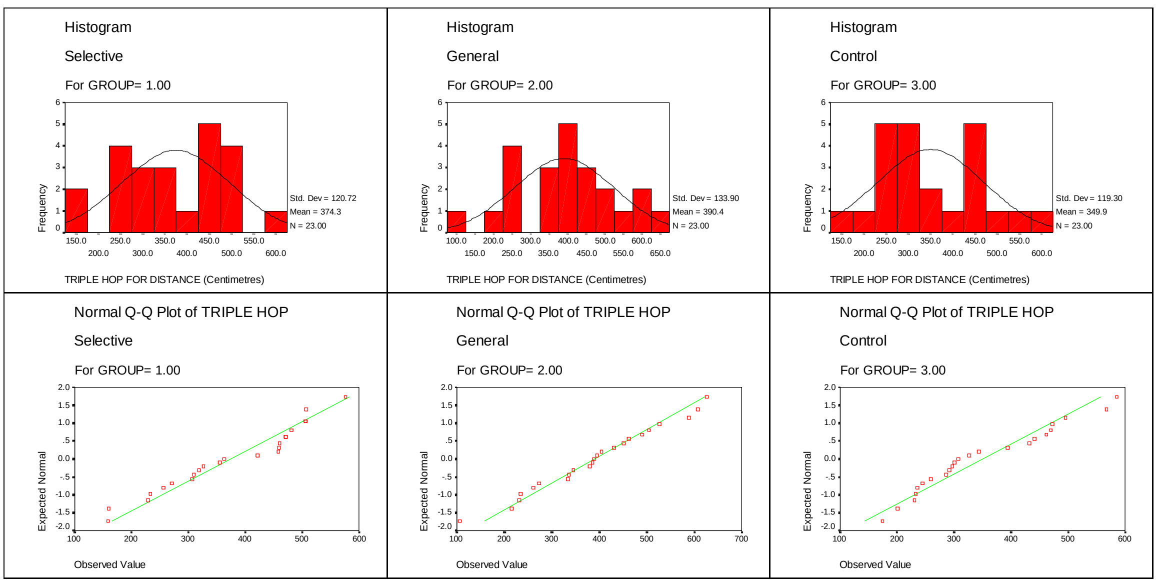
Graphs 16.15 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Quadriceps Muscle Length (Degrees)**



Graphs 16.16 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Equinus (Degrees)**

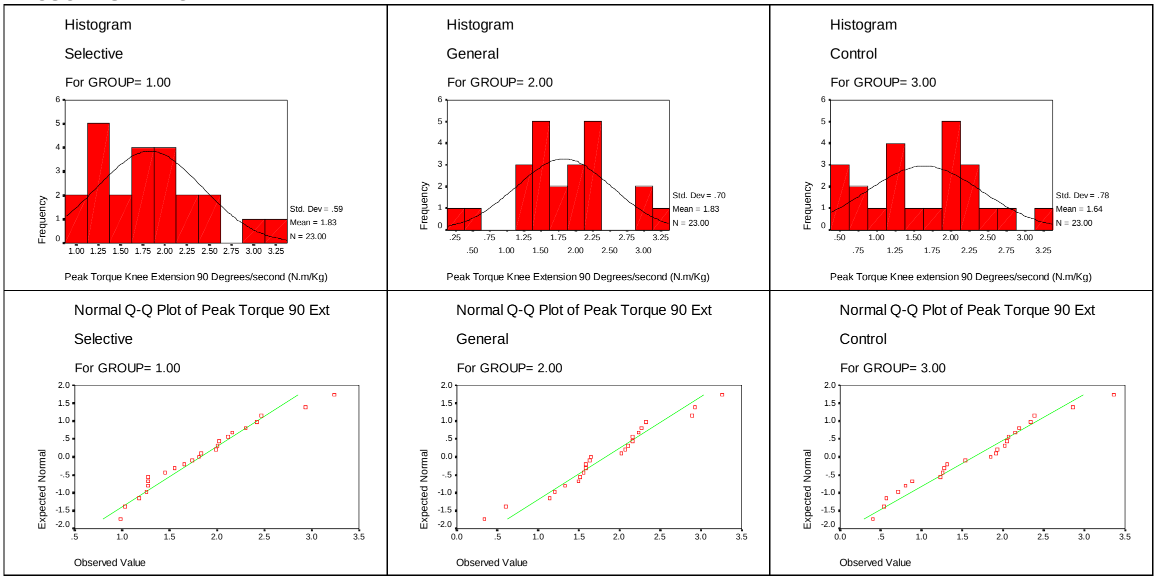


Graphs 16.17 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for BESS (Units)**

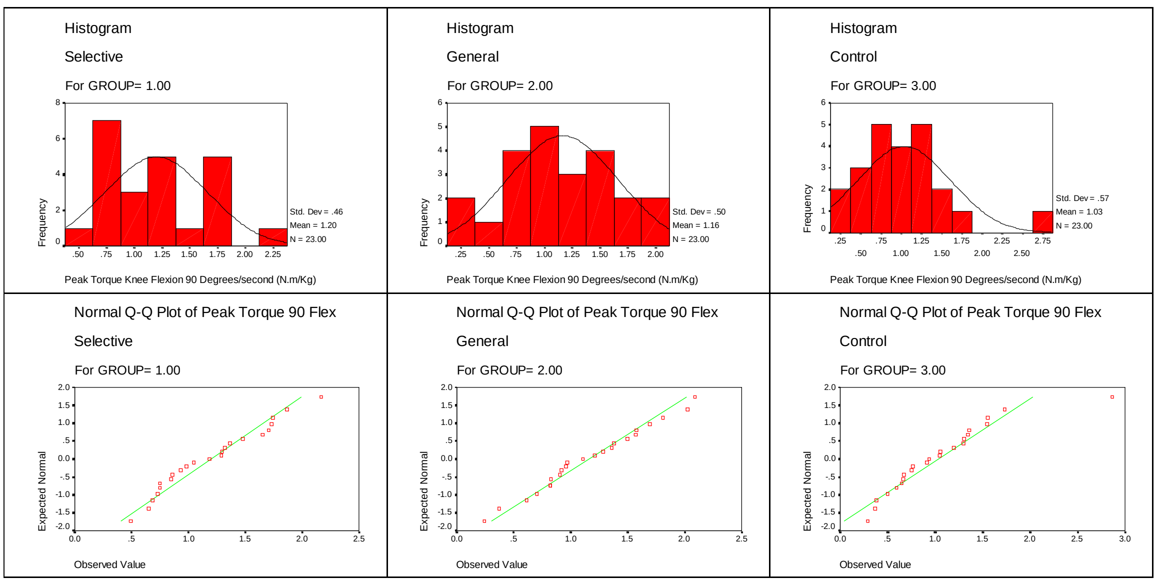


Graphs 16.18 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Triple Hop Distance (Centimetres)**

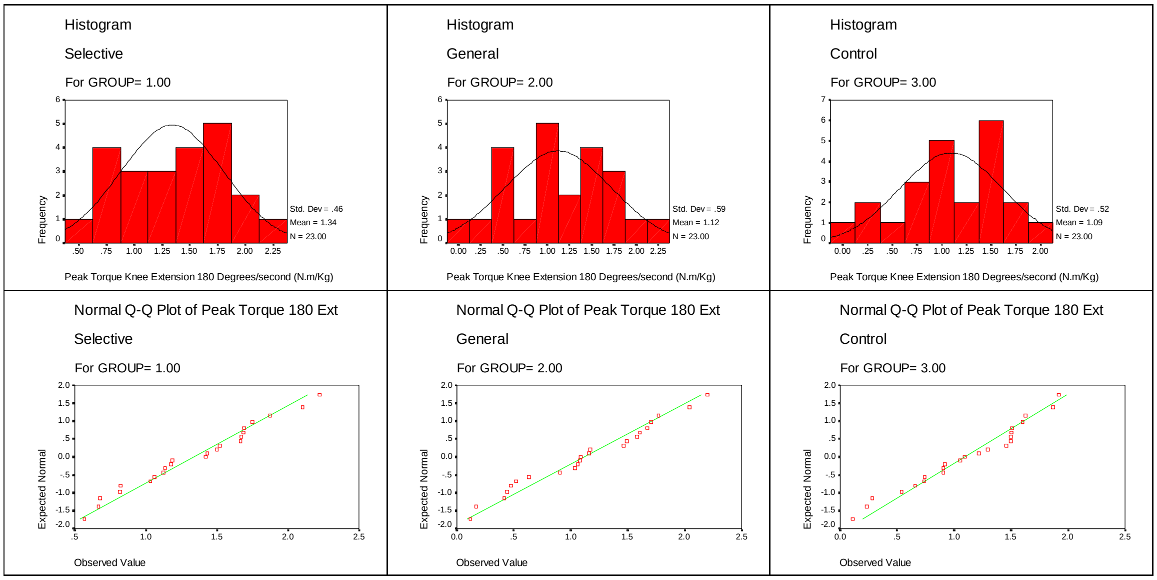
MUSCLE STRENGTH



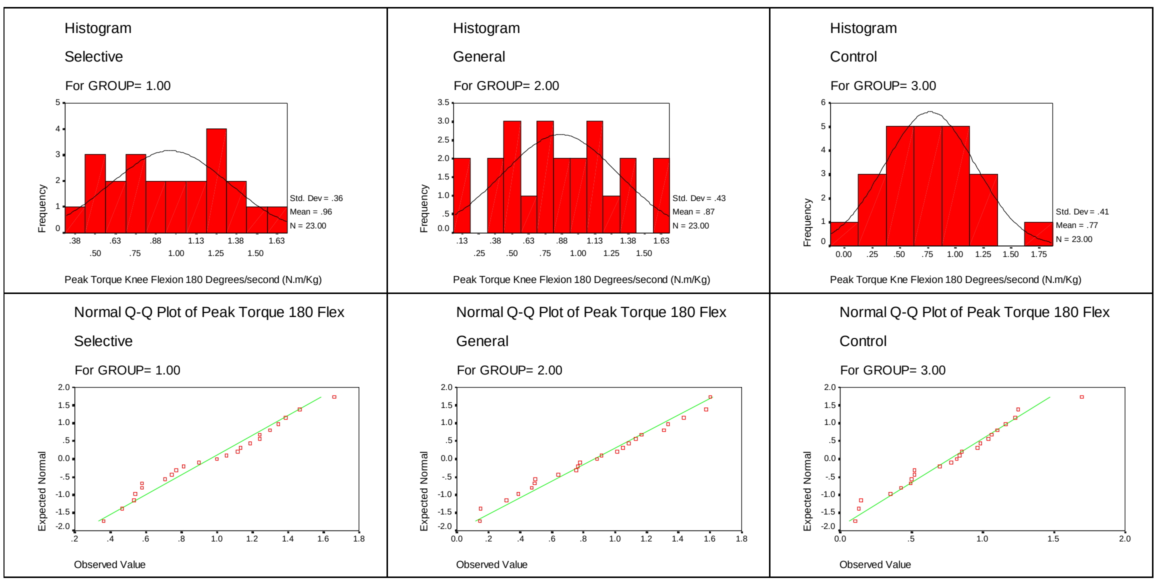
Graphs 16.19 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Peak Torque Knee Extension at 90°/s Nm/kg



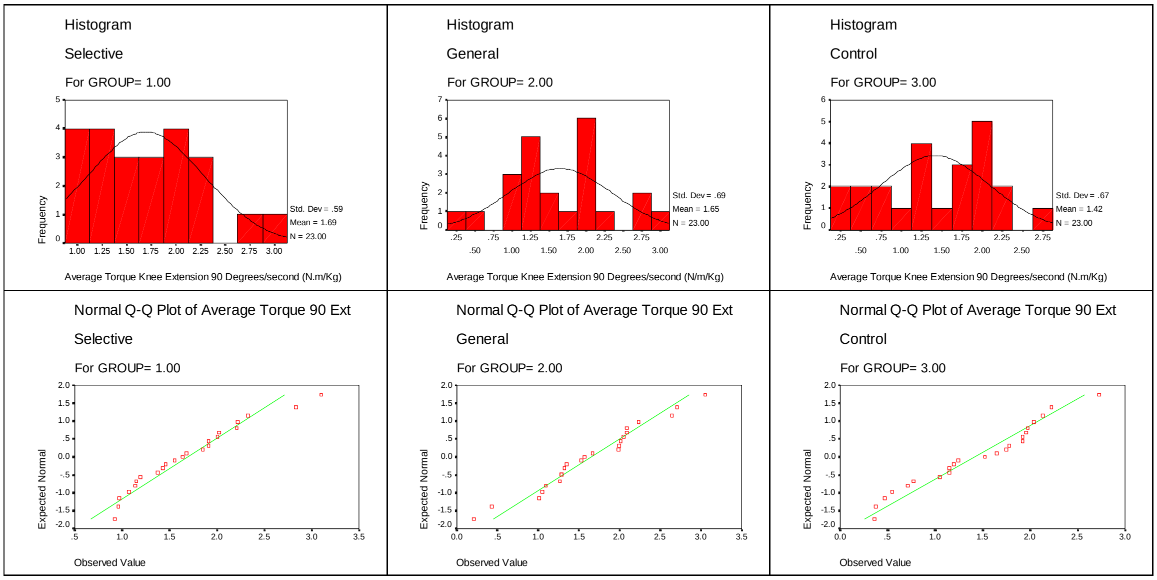
Graphs 16.20 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Peak Torque Knee Flexion at 90°/s Nm/kg



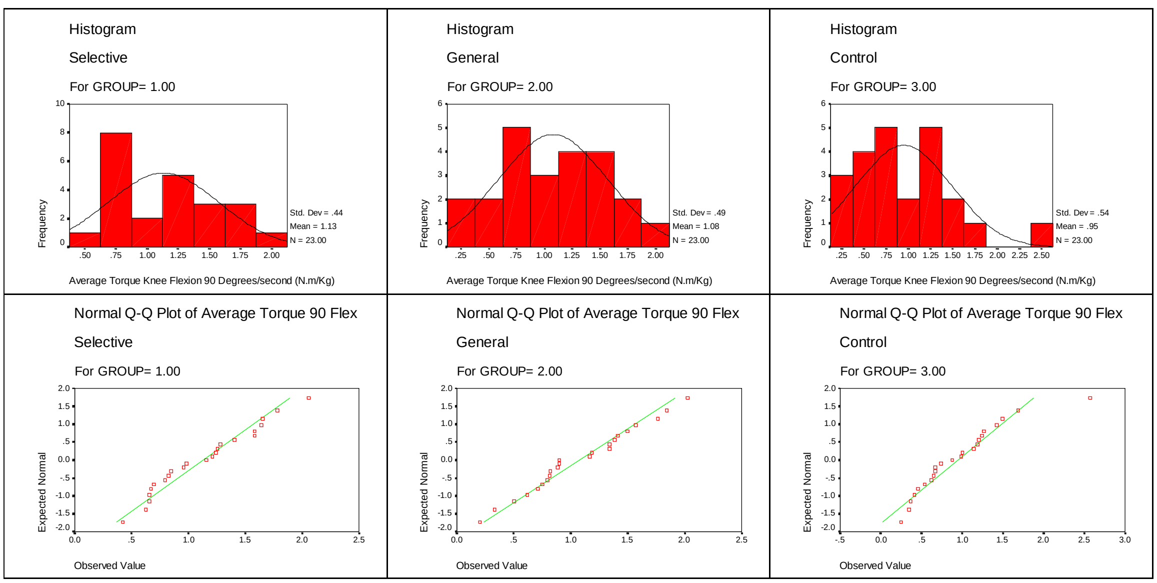
Graphs 16.21 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Peak Torque Knee Extension at 180°/s Nm/kg**



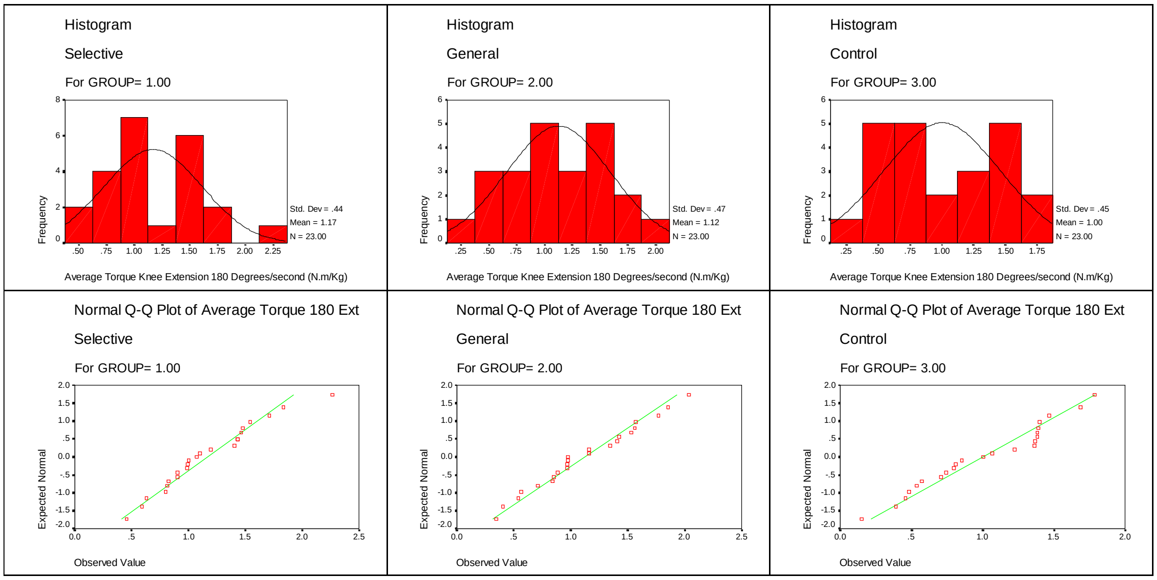
Graphs 16.22 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Peak Torque Knee Flexion at 180°/s Nm/kg**



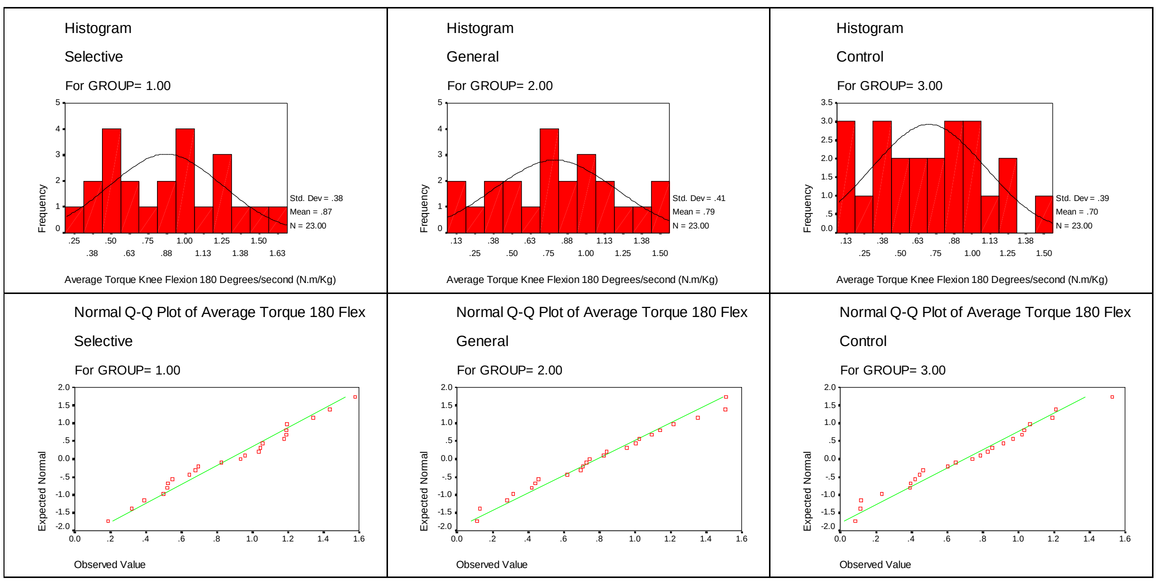
Graphs 16.23 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Average Peak Torque Knee Extension at 90˚/s Nm/kg



Graphs 16.24 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Average Peak Torque Knee Flexion at 90˚/s Nm/kg

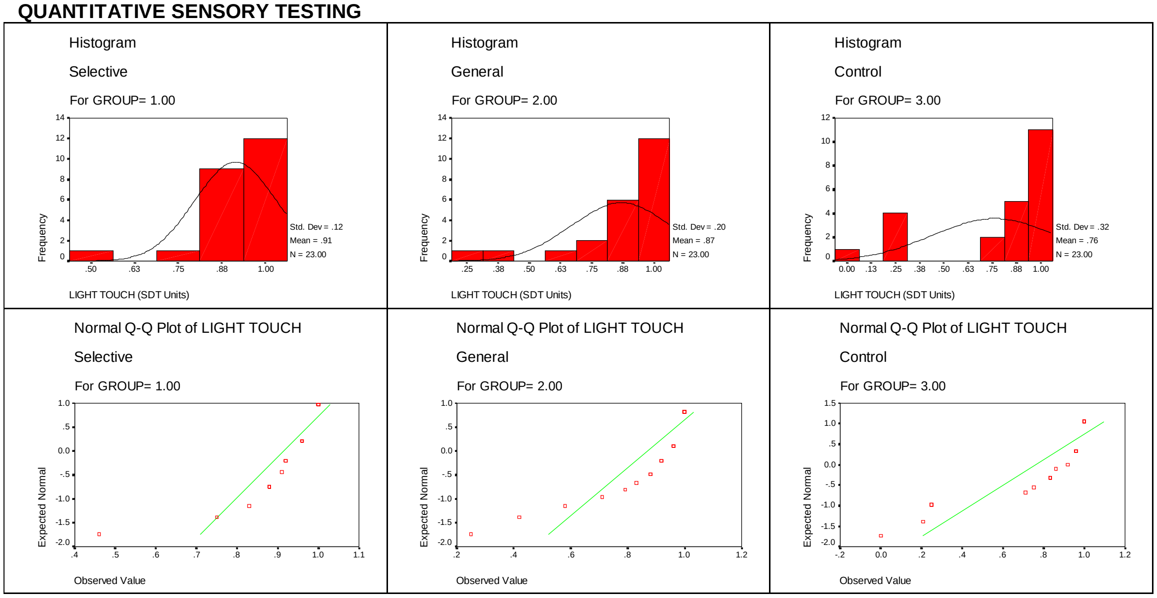


Graphs 16.25 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Average Peak Torque Knee Extension at 180°/s Nm/kg

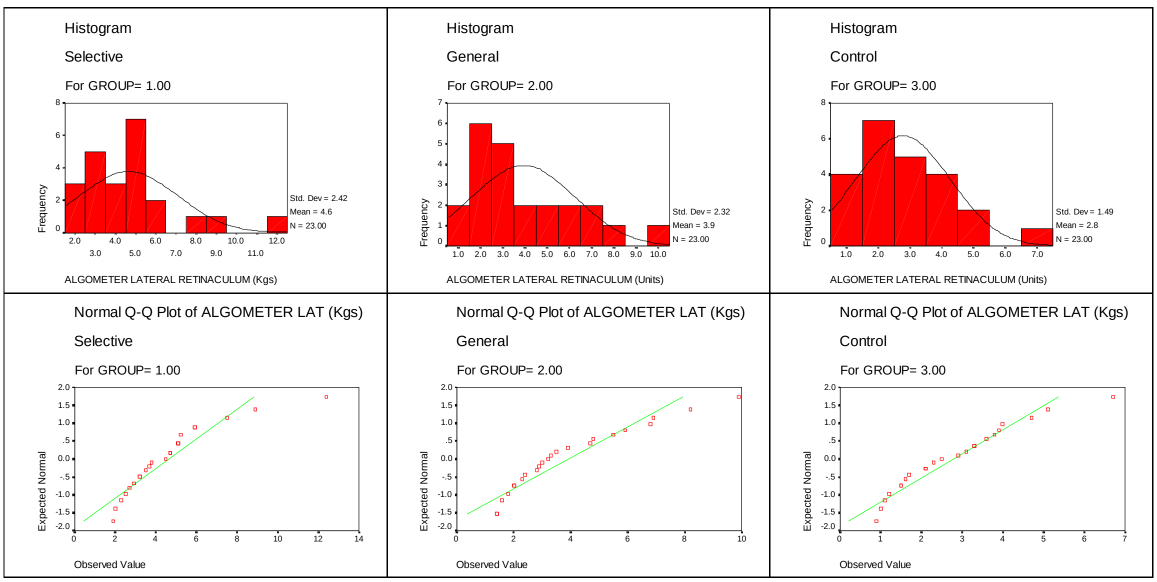


Graphs 16.26 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Average Peak Torque Knee Flexion at 180°/s Nm/kg

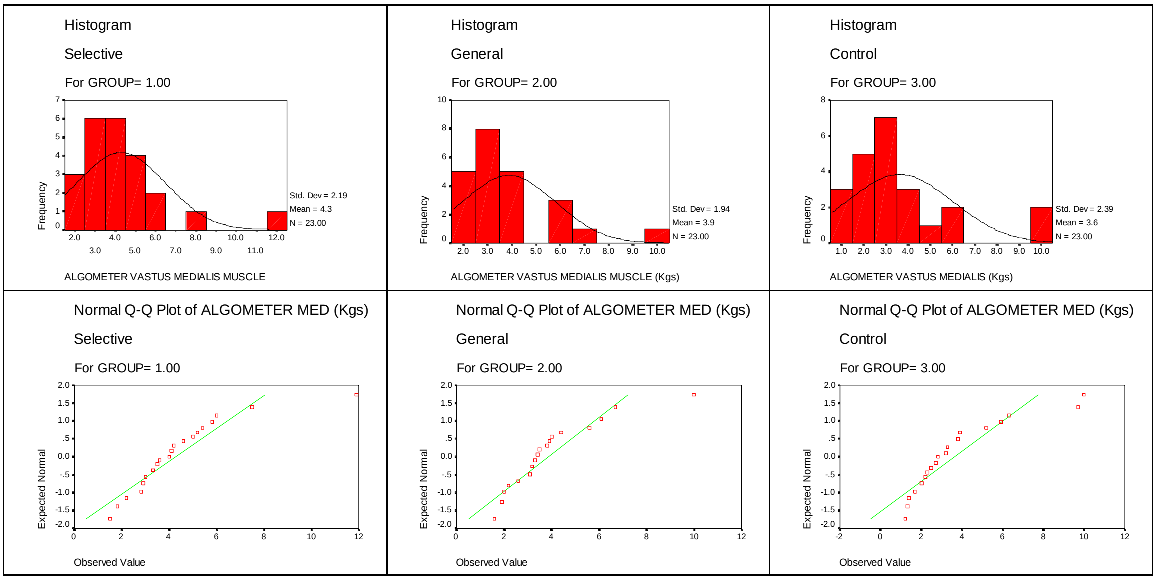
QUANTITATIVE SENSORY TESTING



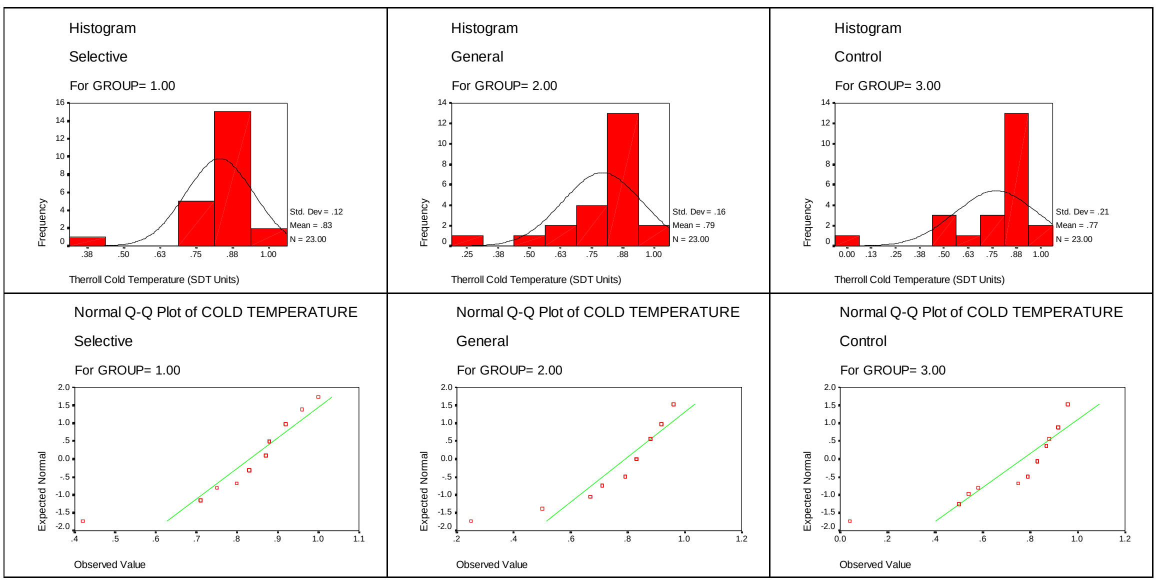
Graphs 16.27 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Light Touch SDT at Lateral Retinaculum (Units)



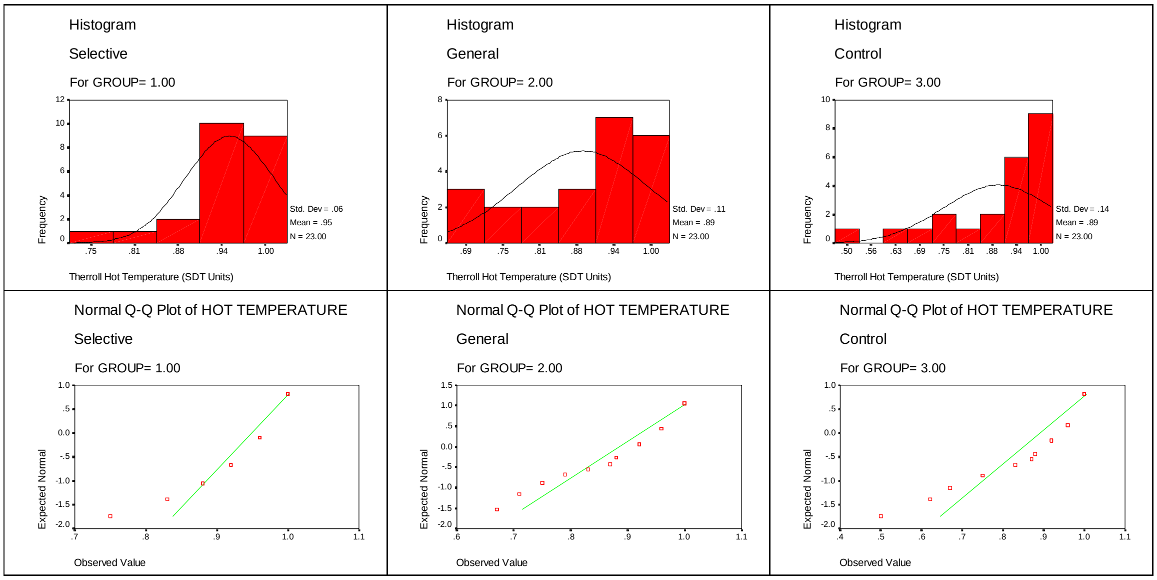
Graphs 16.28 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Algometer Measurements SDT at Lateral Retinaculum (Units)



Graphs 16.29 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Algometer Measurements SDT at Vastus Medialis Muscle (Units)

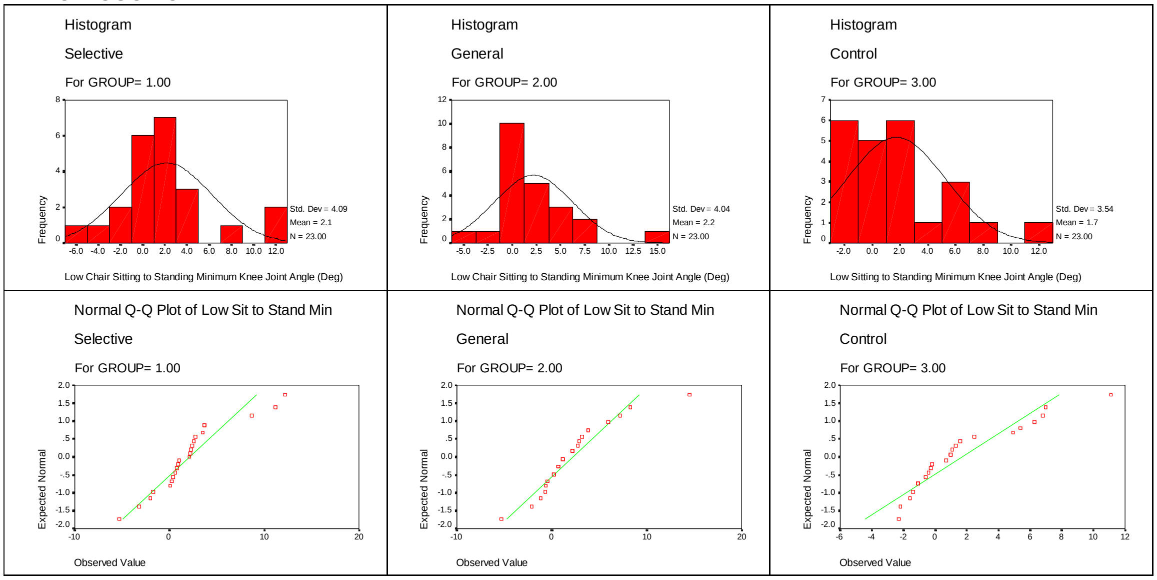


Graphs 16.30 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Therroll SDT Cold 12°/C (Units)

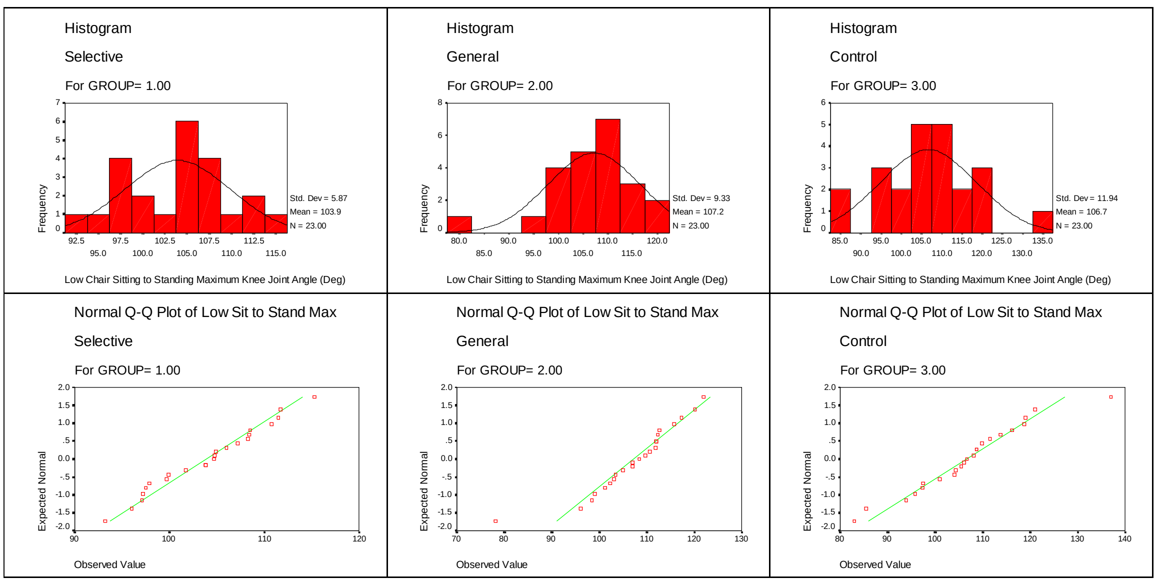


Graphs 16.31 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Therroll SDT Hot 42°/C (Units)**

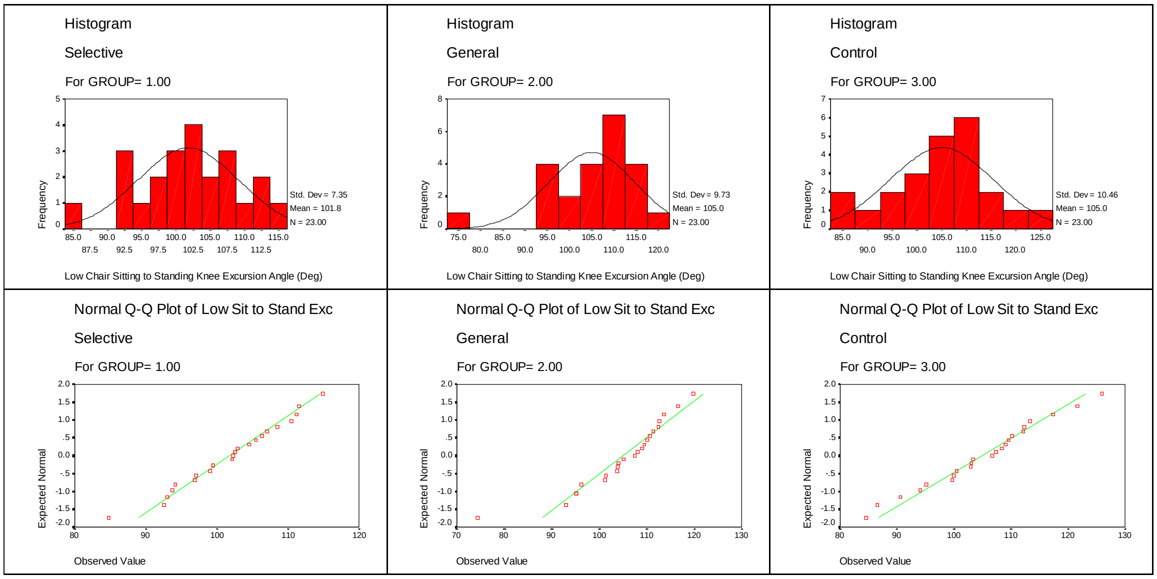
ELECTROGONIOMETRY



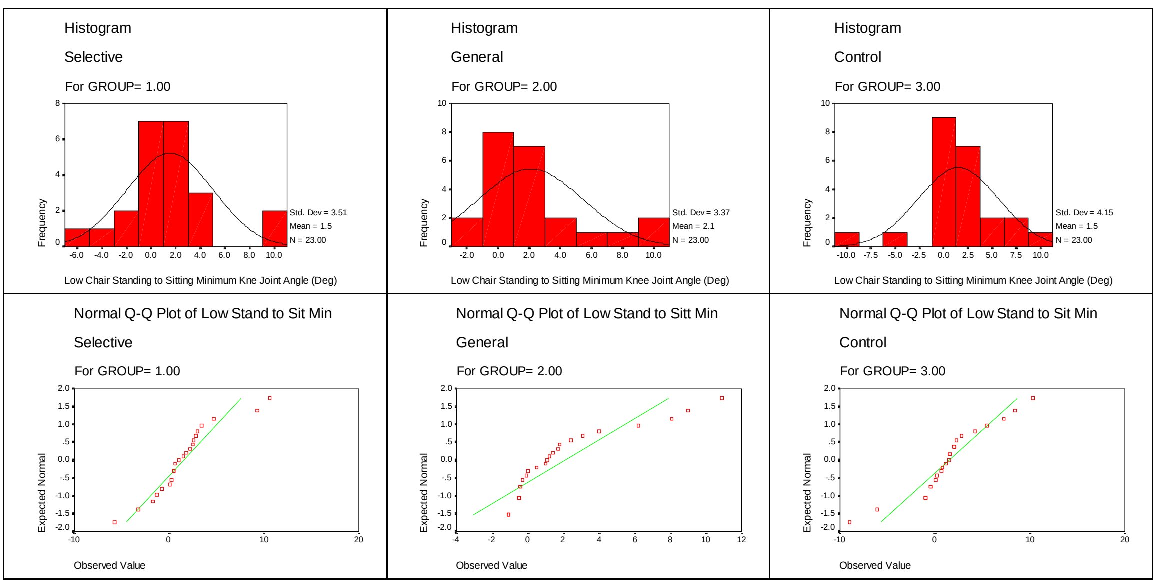
Graphs 16.32 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from Low Chair Minimum Knee Joint Angle (Degrees)



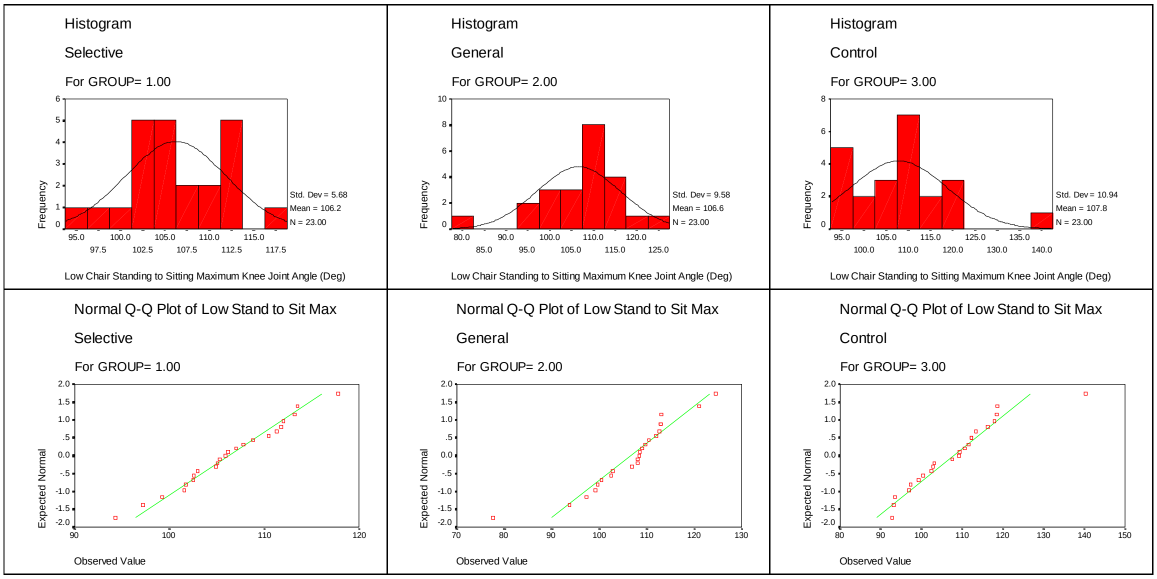
Graphs 16.33 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from Low Chair Maximum Knee Joint Angle (Degrees)



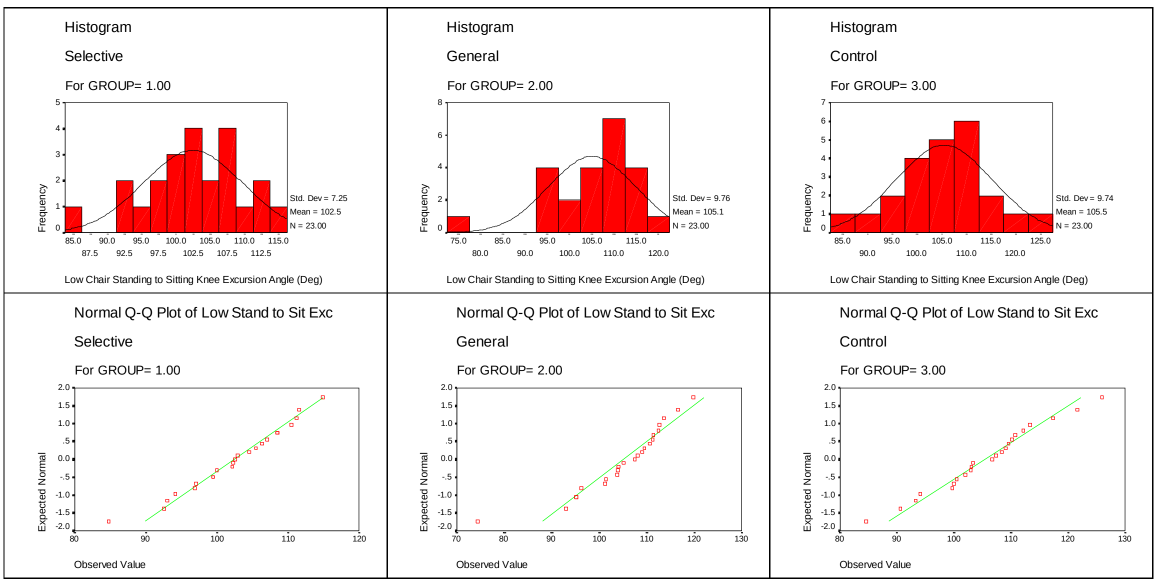
Graphs 16.34 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from Low Chair Knee Joint Excursion Angle (Degrees)



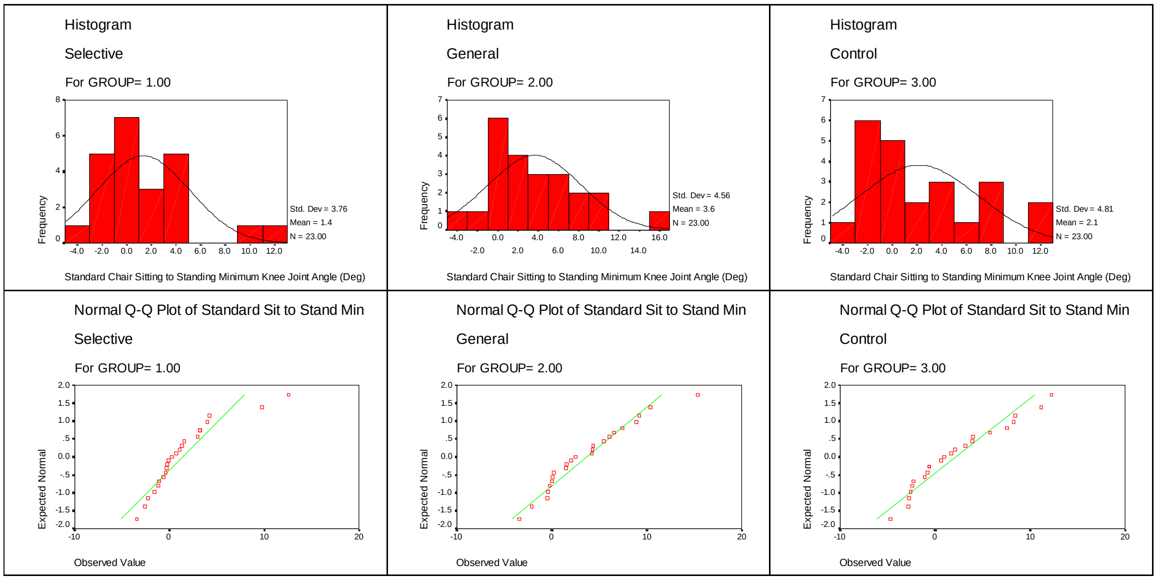
Graphs 16.35 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to Low Chair Minimum Knee Joint Angle (Degrees)



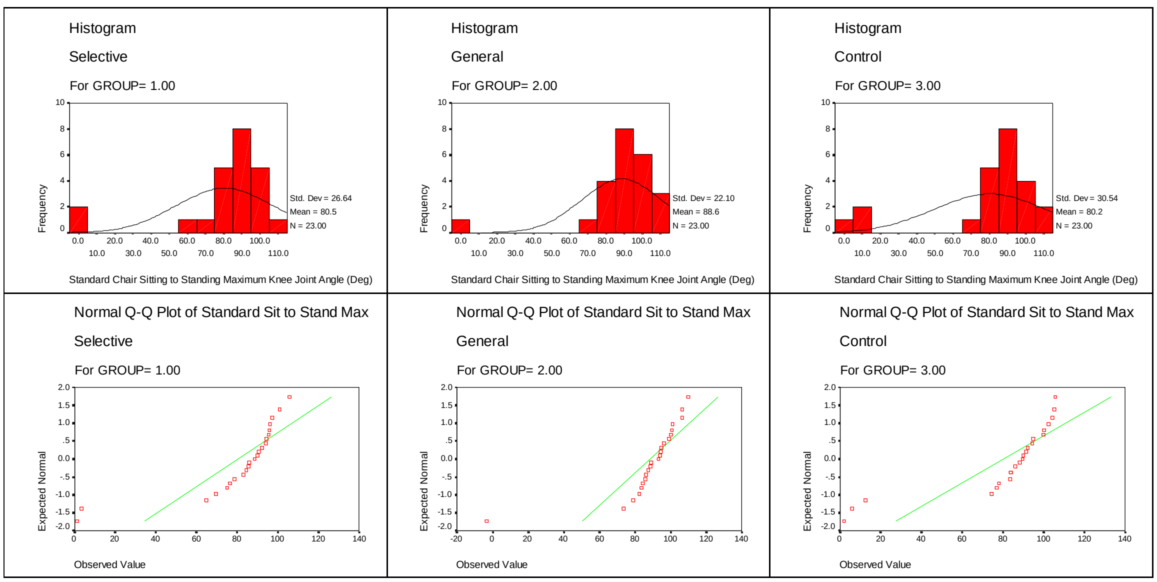
Graphs 16.36 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to Low Chair Maximum Knee Joint Angle (Degrees)



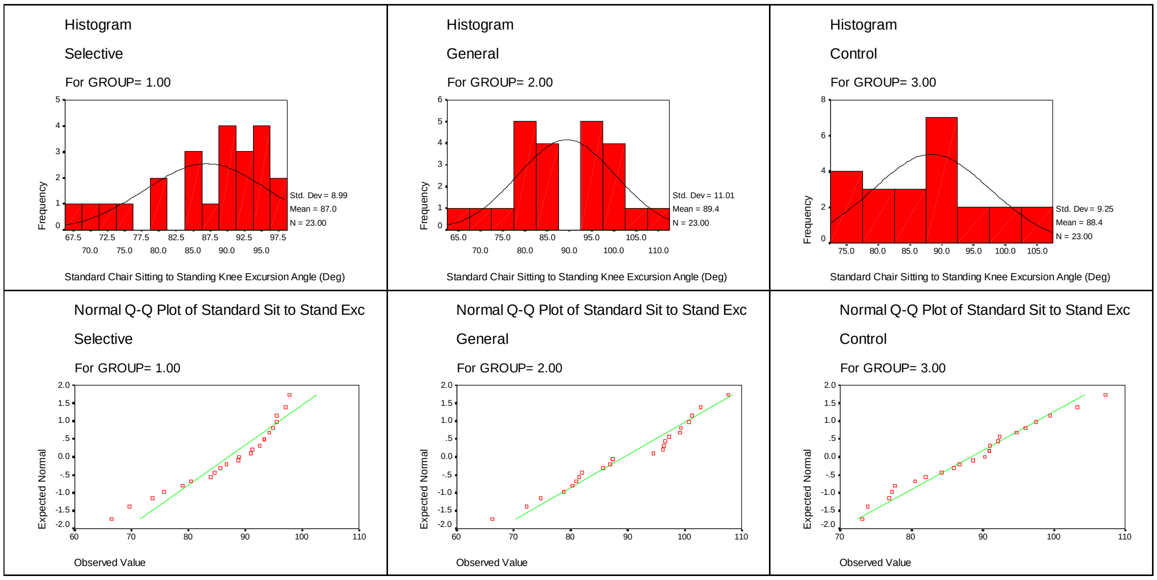
Graphs 16.37 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to Low Chair Knee Joint Excursion Angle (Degrees)



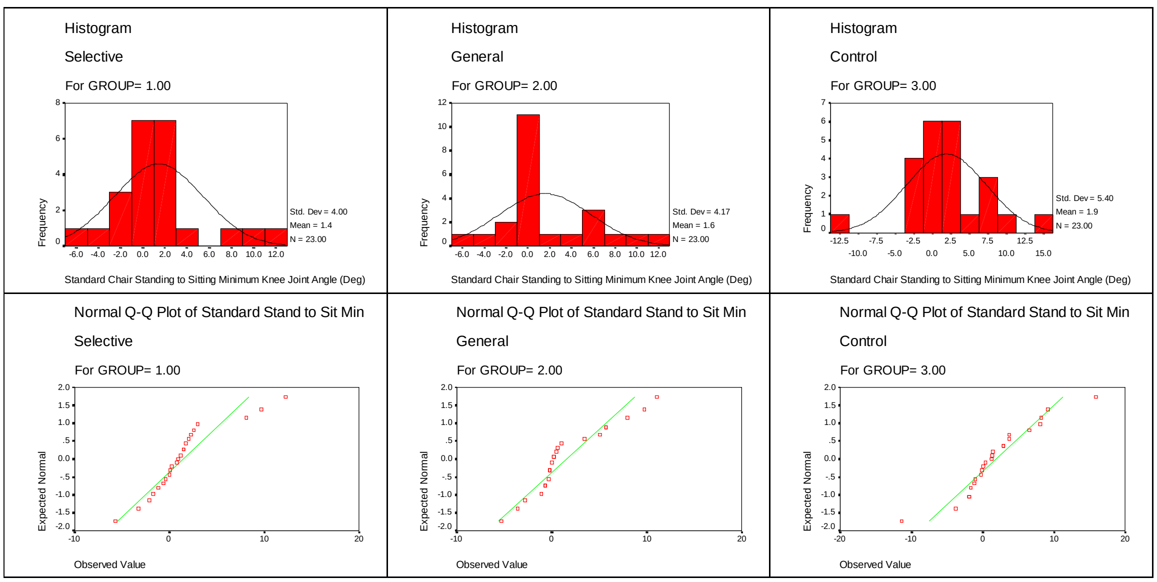
Graphs 16.38 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from a Standard Chair Minimum Knee Joint Angle (Deg)



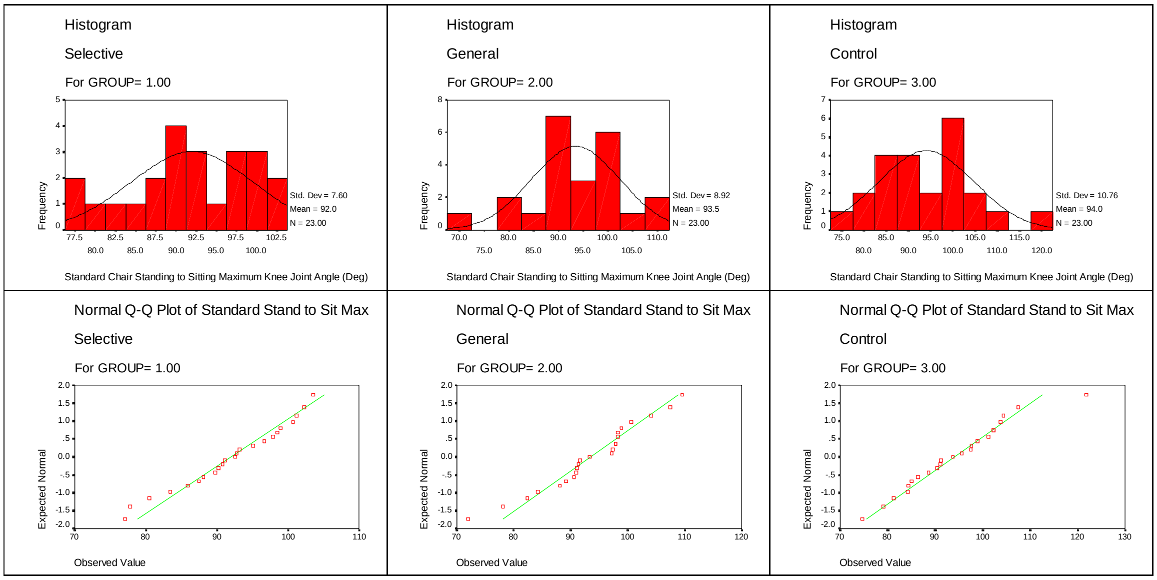
Graphs 16.39 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from a Standard Chair Maximum Knee Joint Angle (Deg)



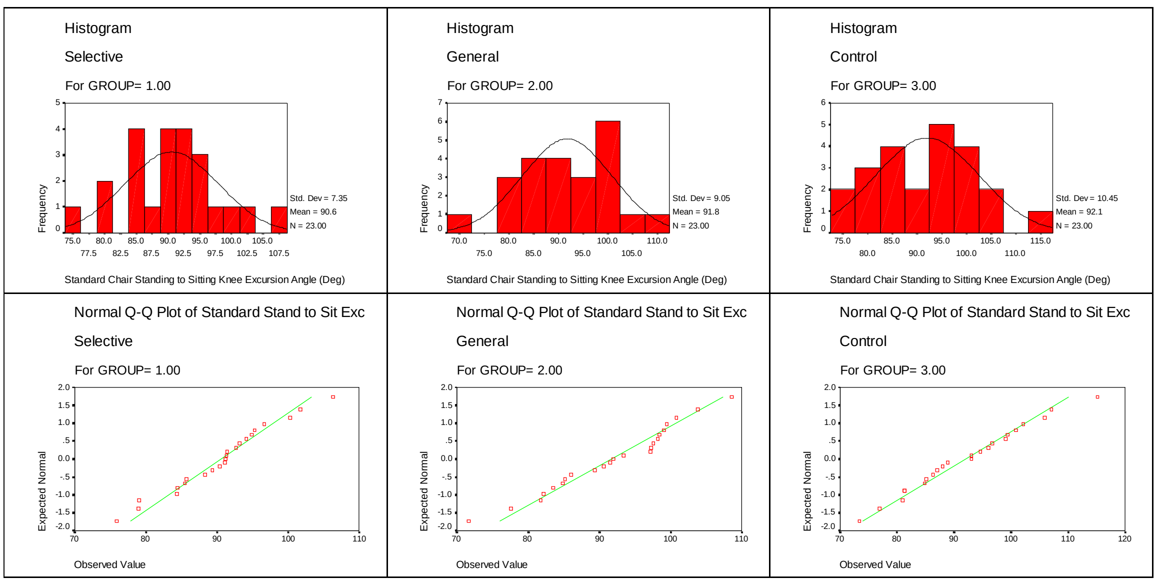
Graphs 16.40 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Sitting to Standing from a Standard Chair Knee Joint Excursion Angle (Deg)



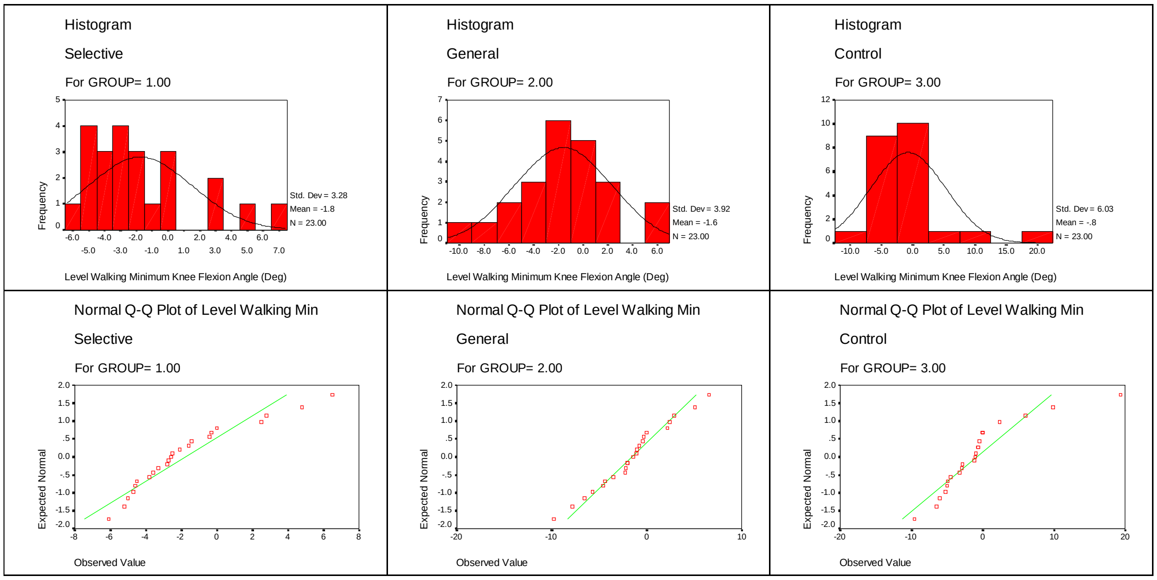
Graphs 16.41 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to a Standard Chair Minimum Knee Joint Angle (Deg)



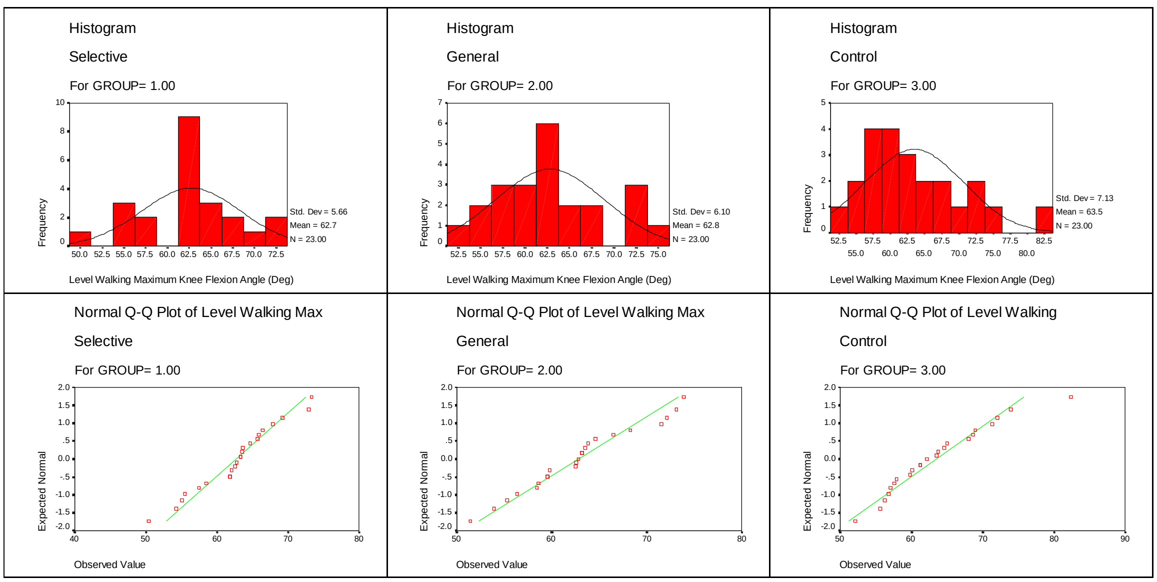
Graphs 16.42 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to a Standard Chair Maximum Knee Joint Angle (Deg)



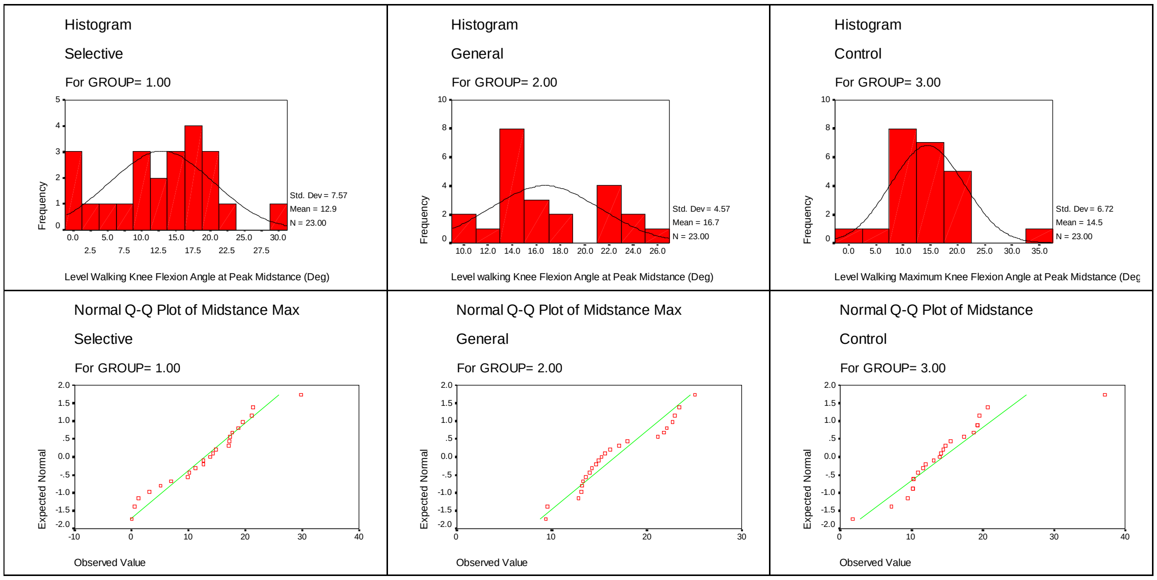
Graphs 16.43 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Standing to Sitting to a Standard Chair Knee Joint Excursion Angle (Deg)



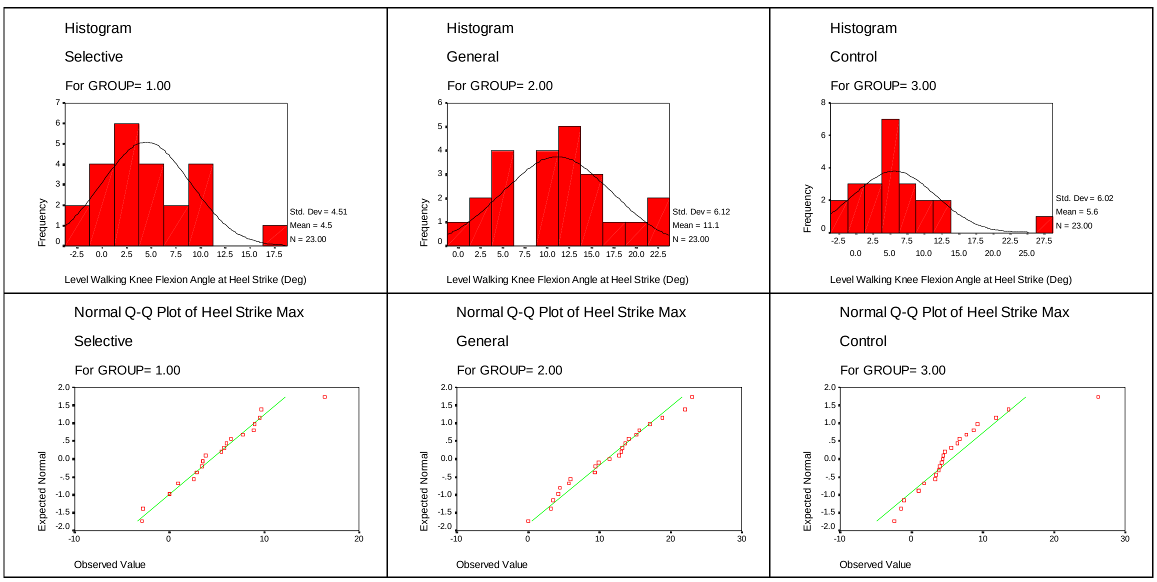
Graphs 16.44 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Minimum Knee Flexion Angle (Degrees)



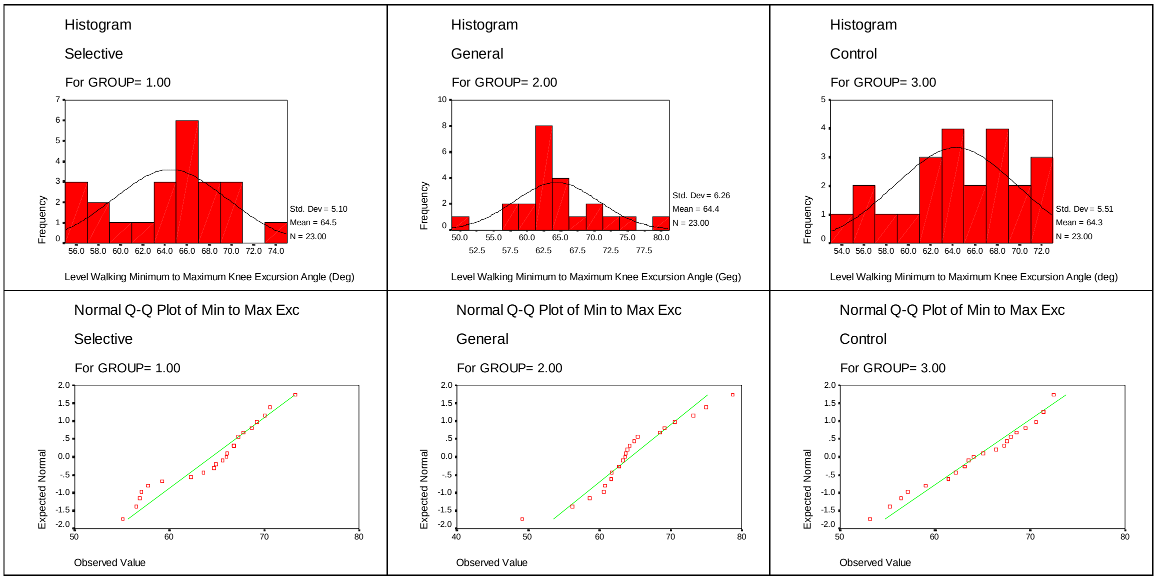
Graphs 16.45 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Maximum Knee Flexion Angle (Degrees)



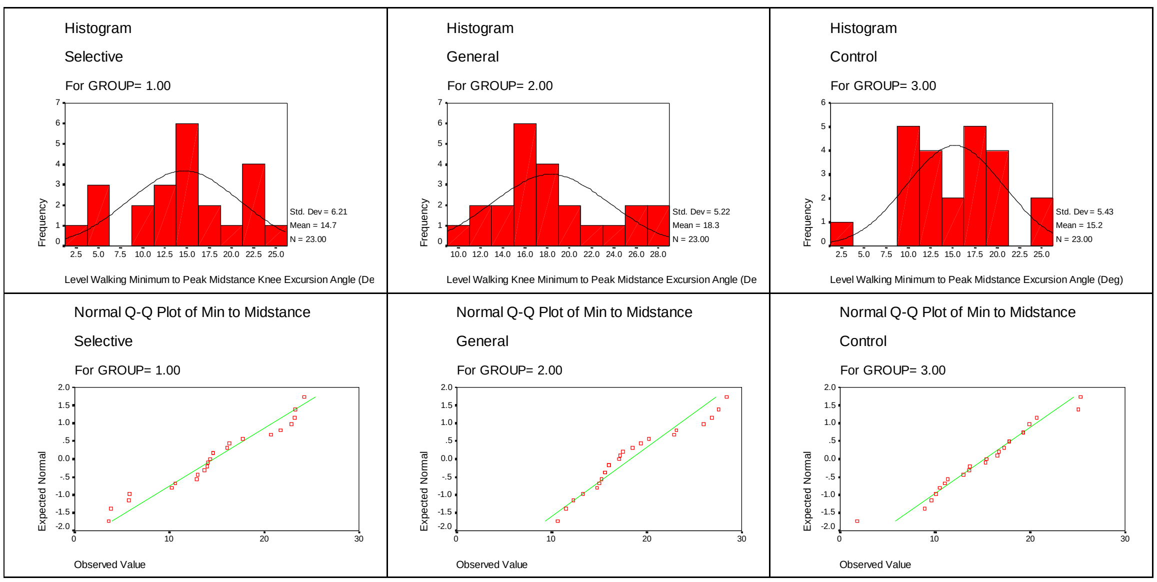
G Graphs 16.46 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Maximum Knee Flexion Angle (Degrees)



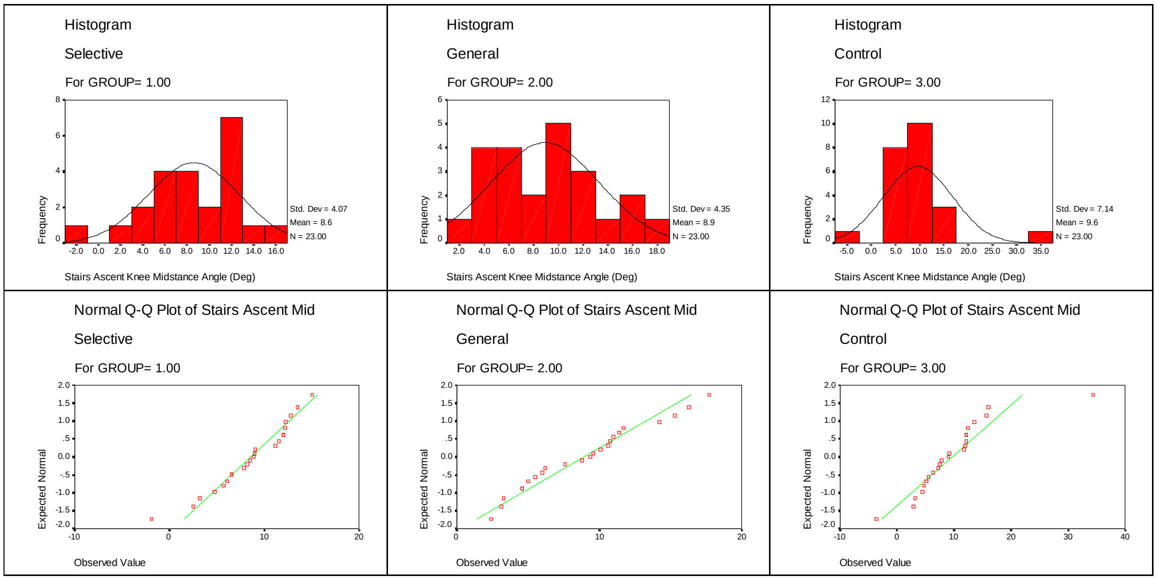
Graphs 16.47 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Maximum Knee Flexion Angle at Heel Strike (Degrees)



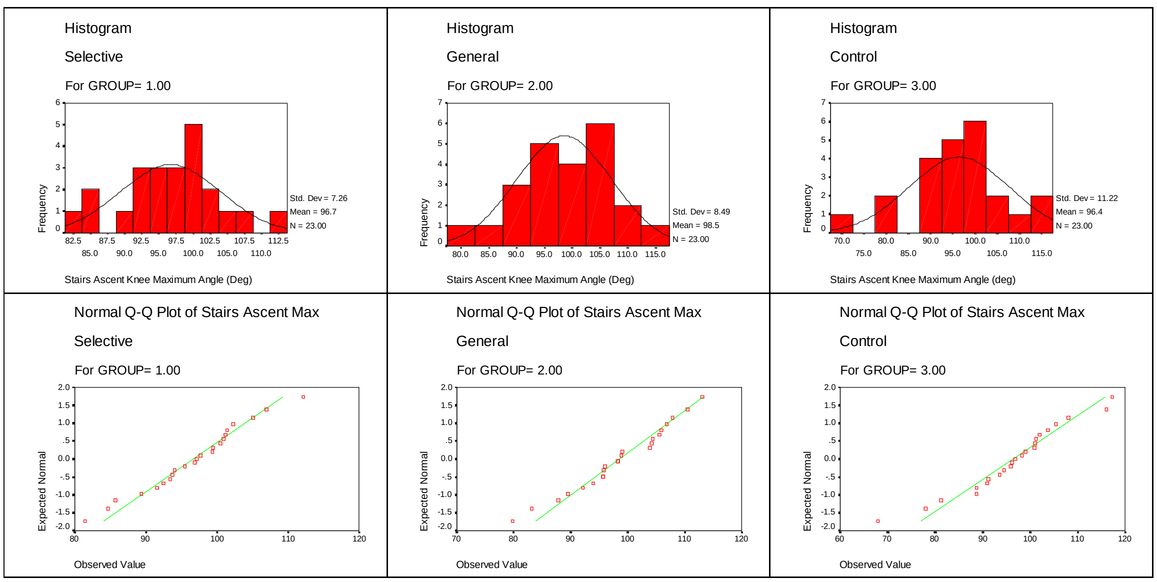
Graphs 16.48 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Minimum to Maximum Knee Excursion Angle (Degrees)



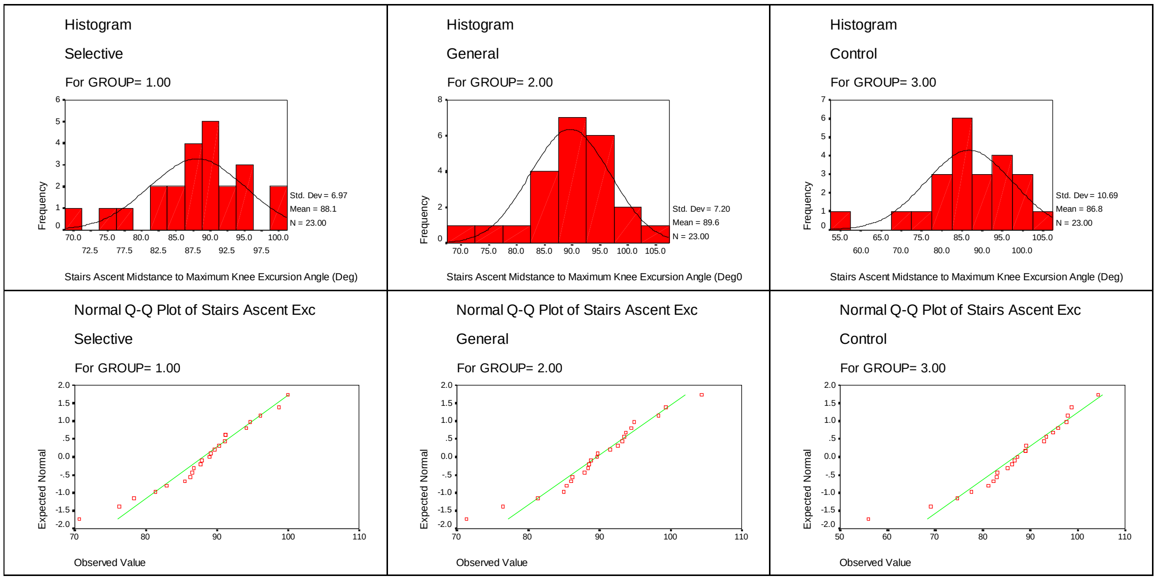
Graphs 16.49 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Minimum to Peak Midstance Knee Excursion Angle (Degrees)



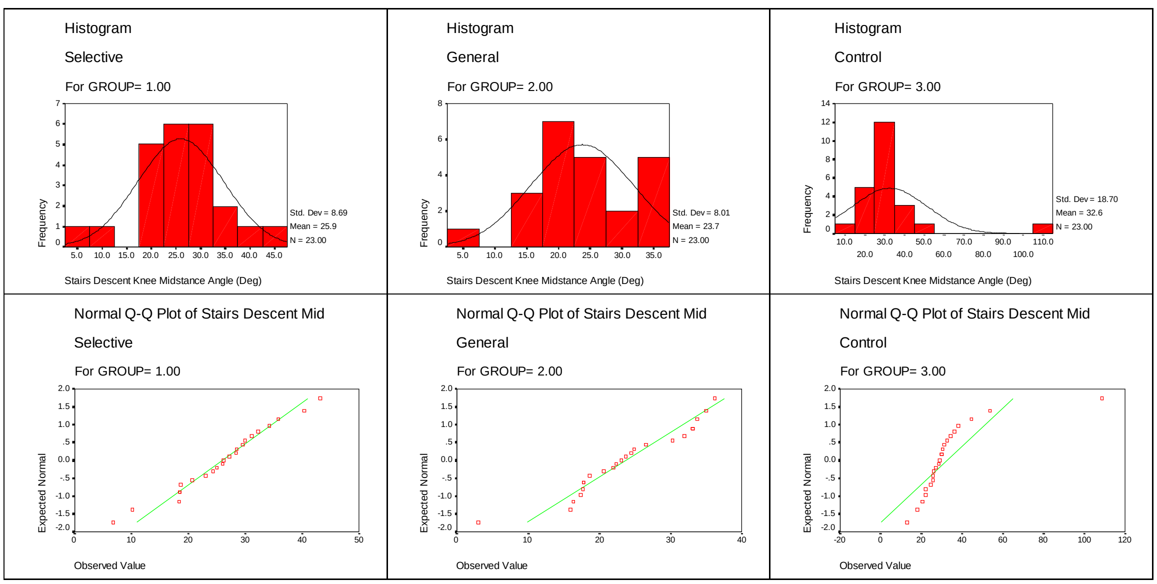
Graphs 16.50 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Ascent Knee Midstance Angle (Degrees)**



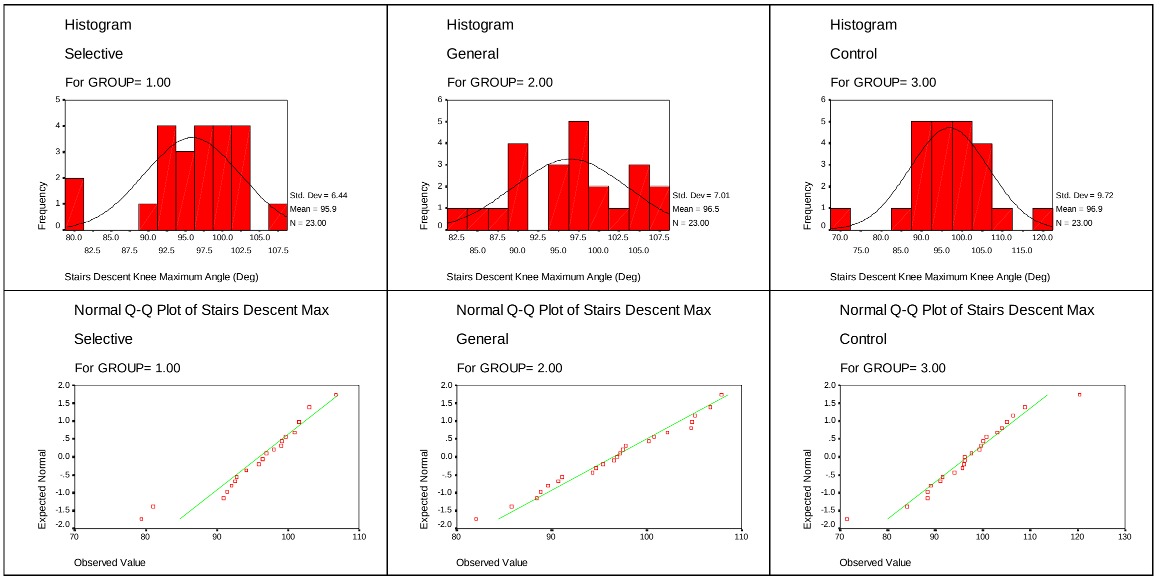
Graphs 16.51 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Ascent Knee Maximum Angle (Degrees)**



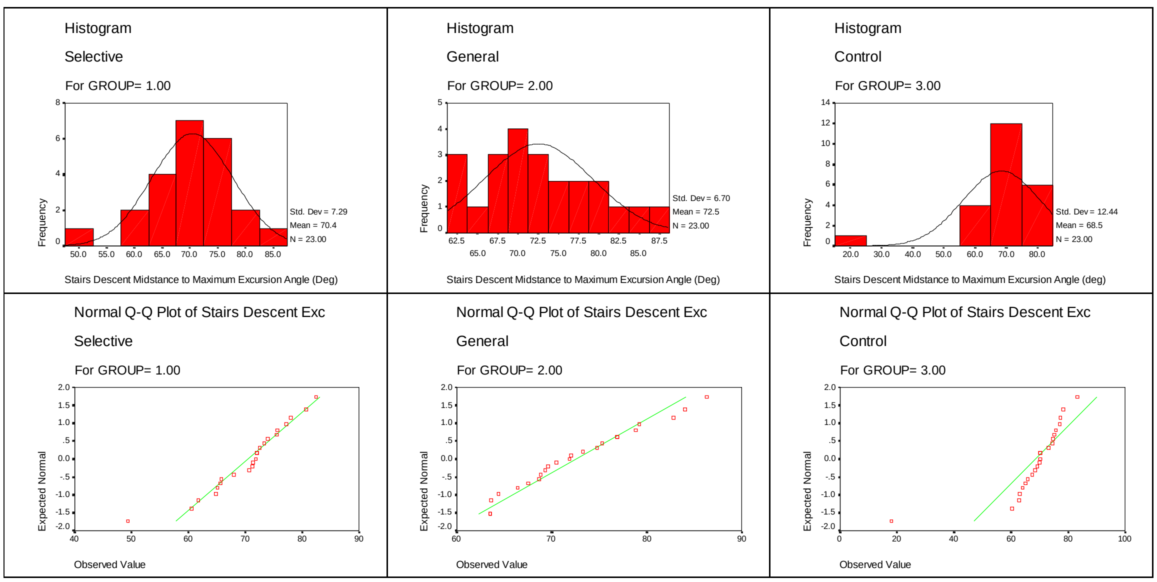
Graphs 16.52 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Ascent Midstance to Maximum Knee Excursion Angle (Degrees)



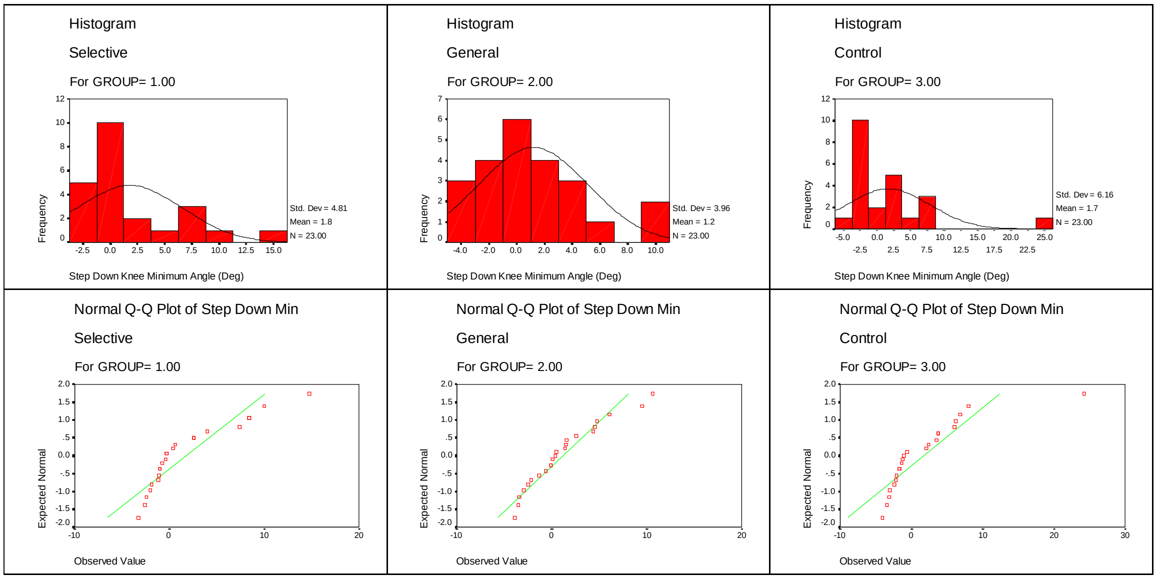
Graphs 16.53 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Descent Knee Midstance Angle (Degrees)



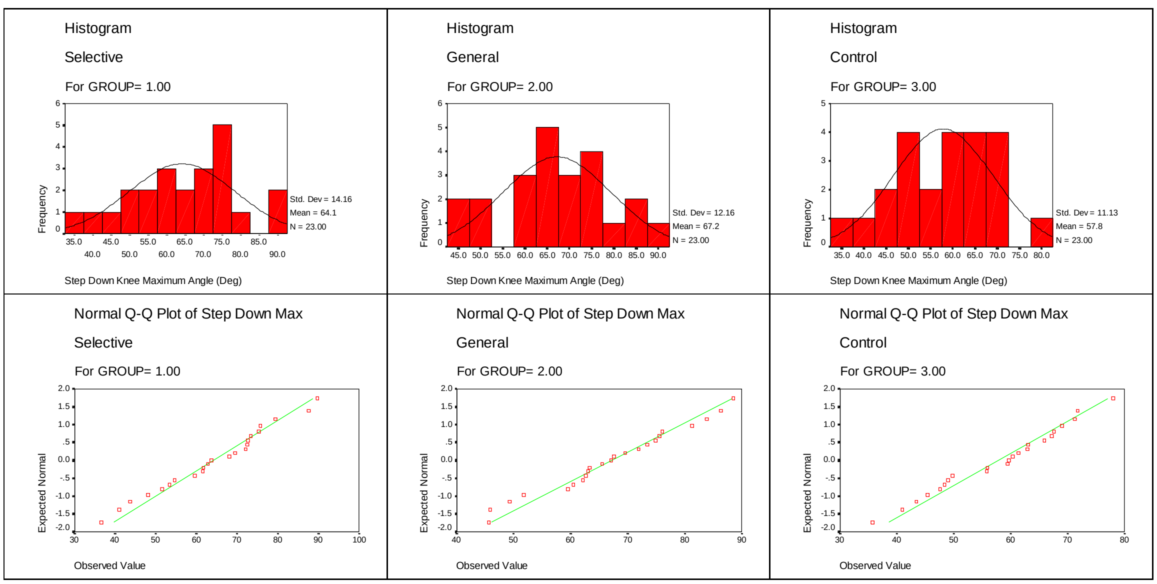
Graphs 16.54 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Descent Maximum Knee Angle (Degrees)**



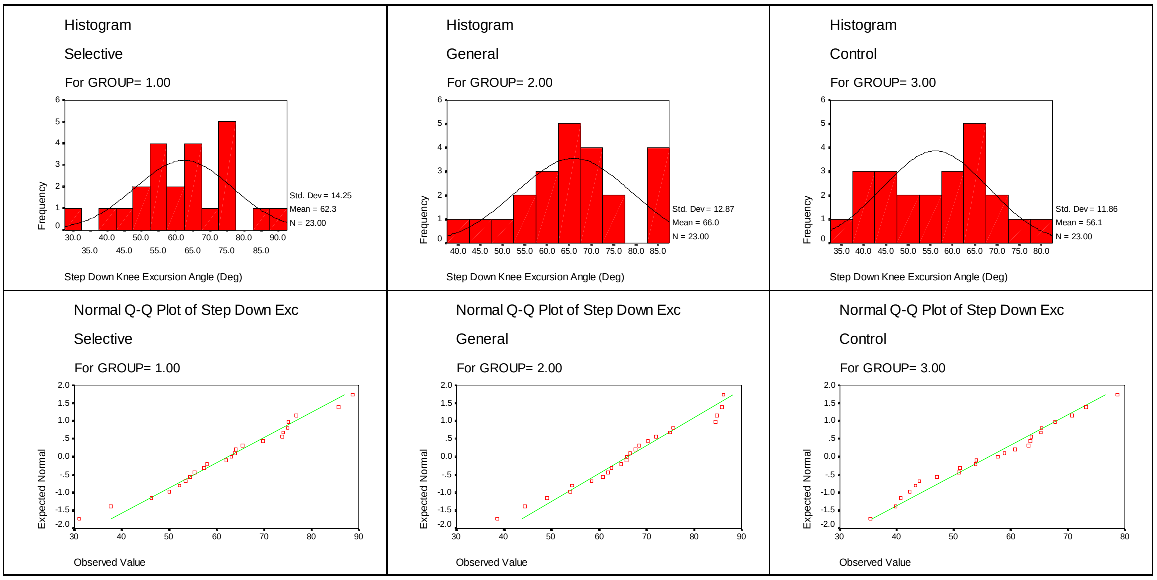
Graphs 16.55 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Stairs Descent Midstance to Maximum Knee Angle (Degrees)**



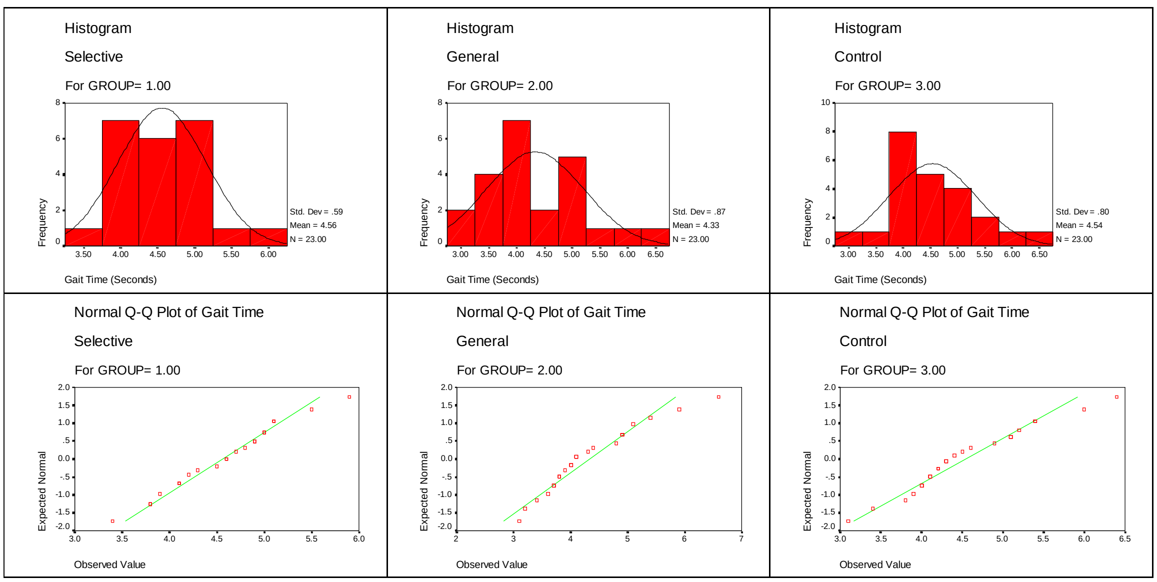
Graphs 16.56 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Step Down Minimum Knee Angle (Degrees)



Graphs 16.57 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Step Down Maximum Knee Angle (Degrees)



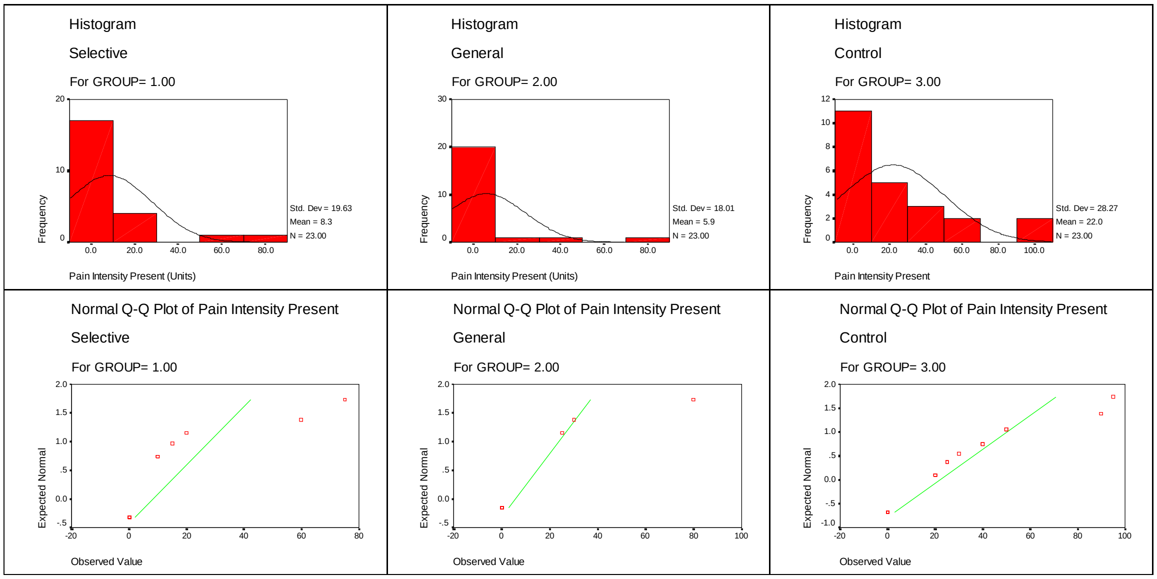
Graphs 16.58 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Step Down Knee Excursion Angle (Degrees)

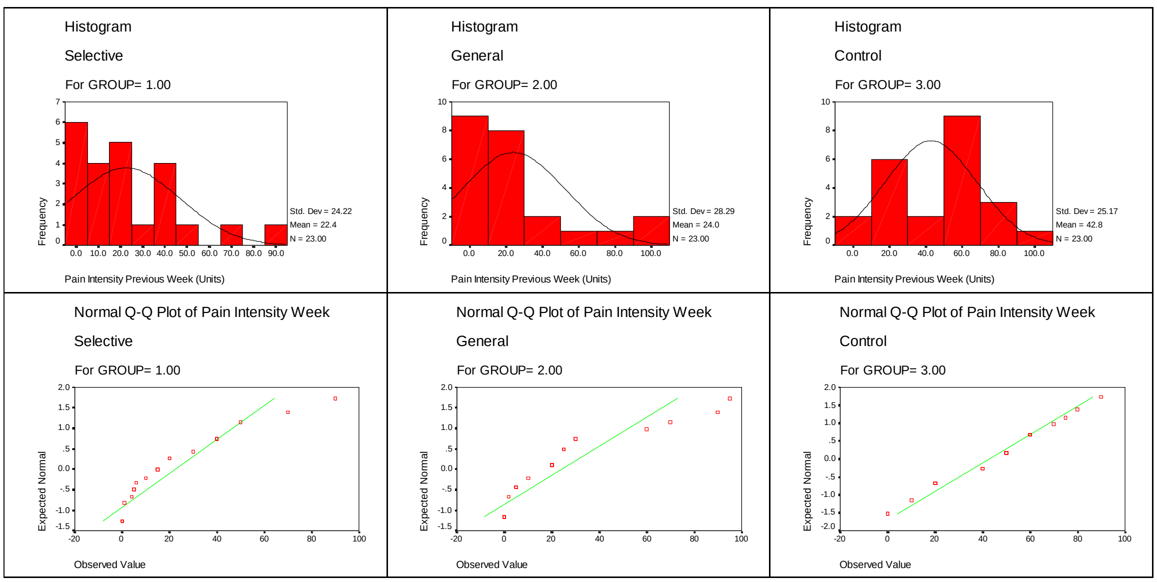


Graphs 16.59 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Level Walking Gait Time for 5 Metres (Seconds)

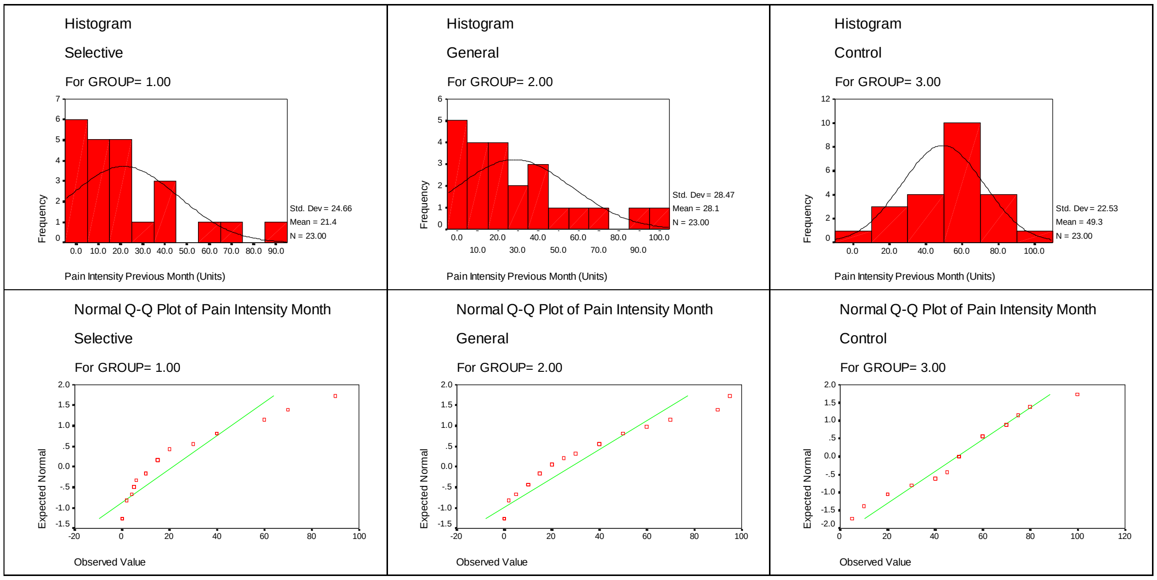
NUMERICAL PAIN RATING SCALES

Graphs 16.60 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Intensity (Units)

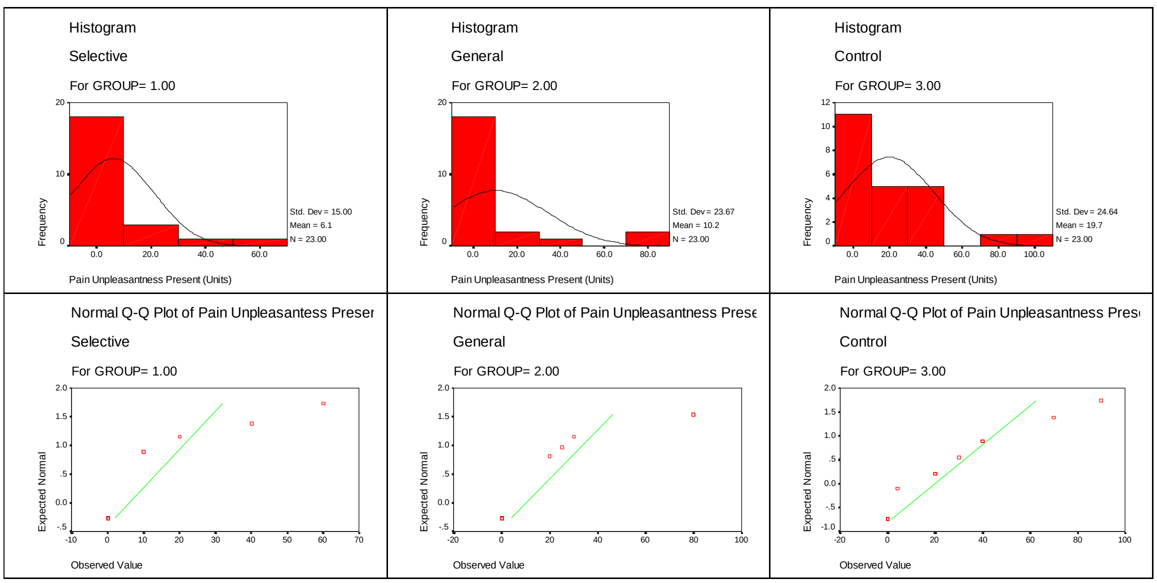




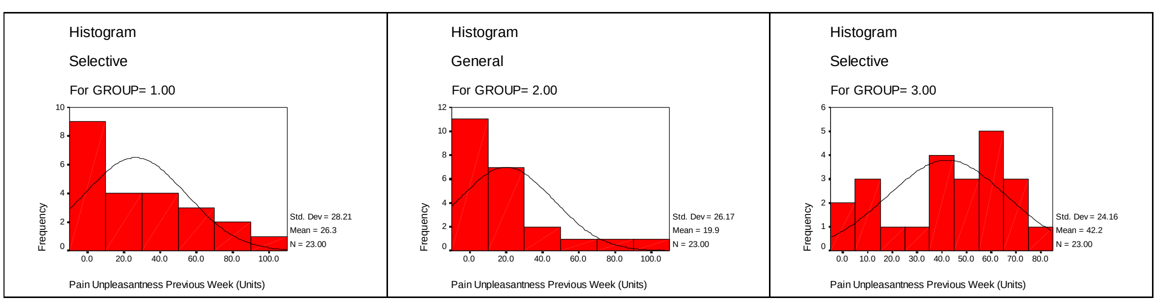
Graphs 16.61 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Intensity Previous Week (Units)

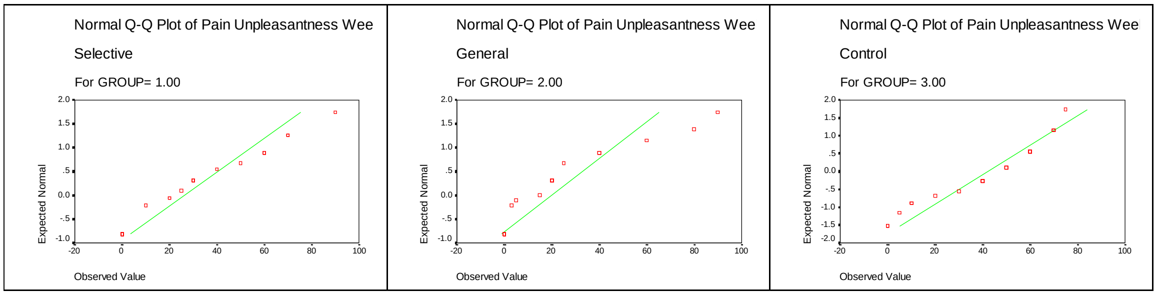


Graphs 16.62 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Intensity Previous Month (Units)

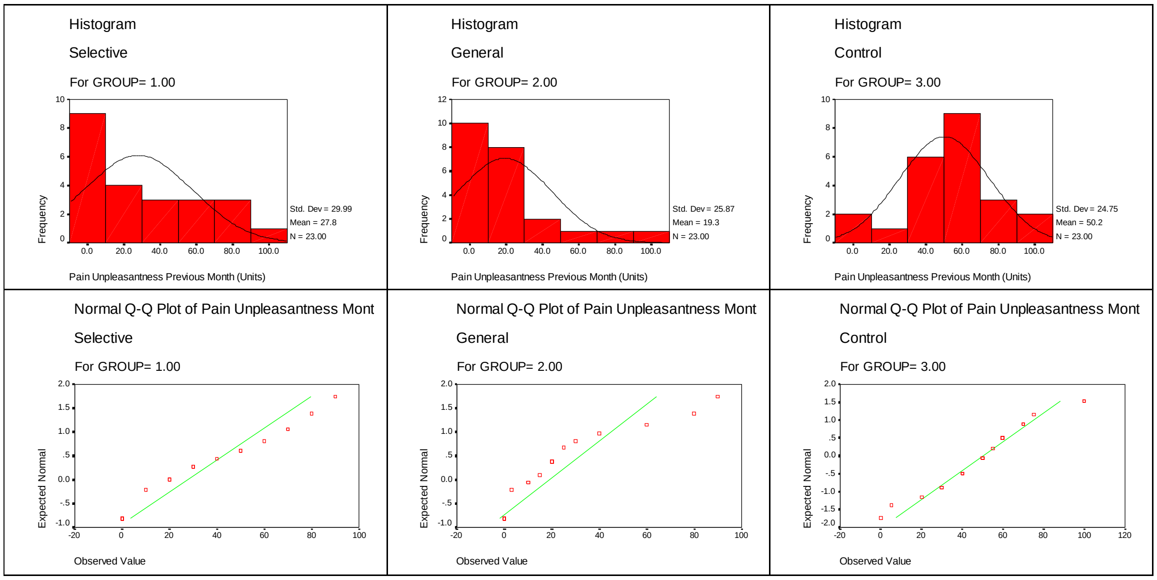


Graphs 16.63 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Unpleasantness Present (Units)

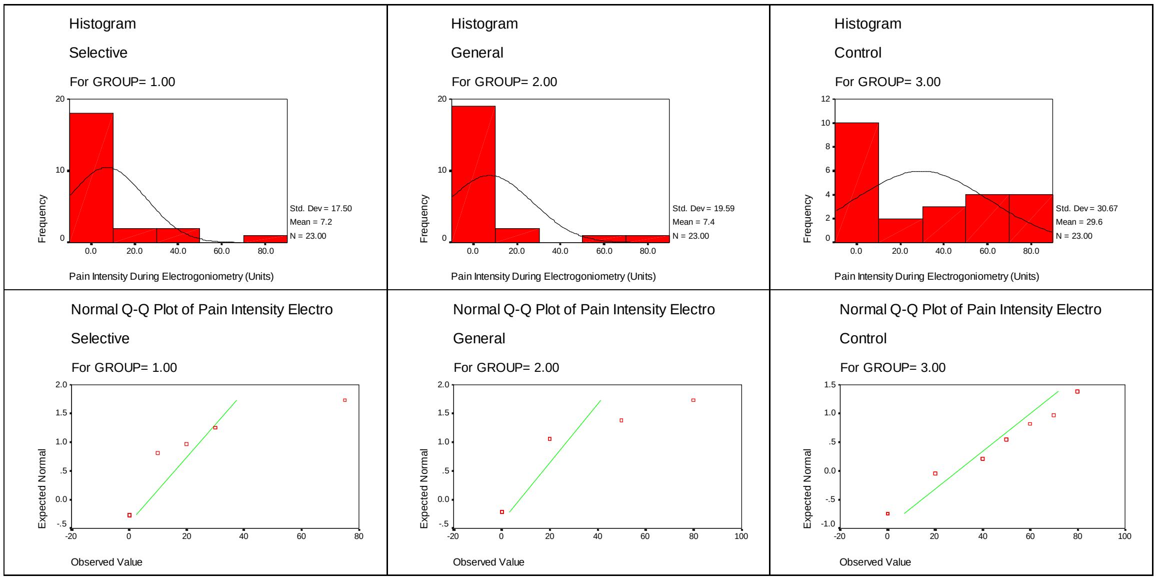




Graphs 16.64 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Unpleasantness Week (Units)

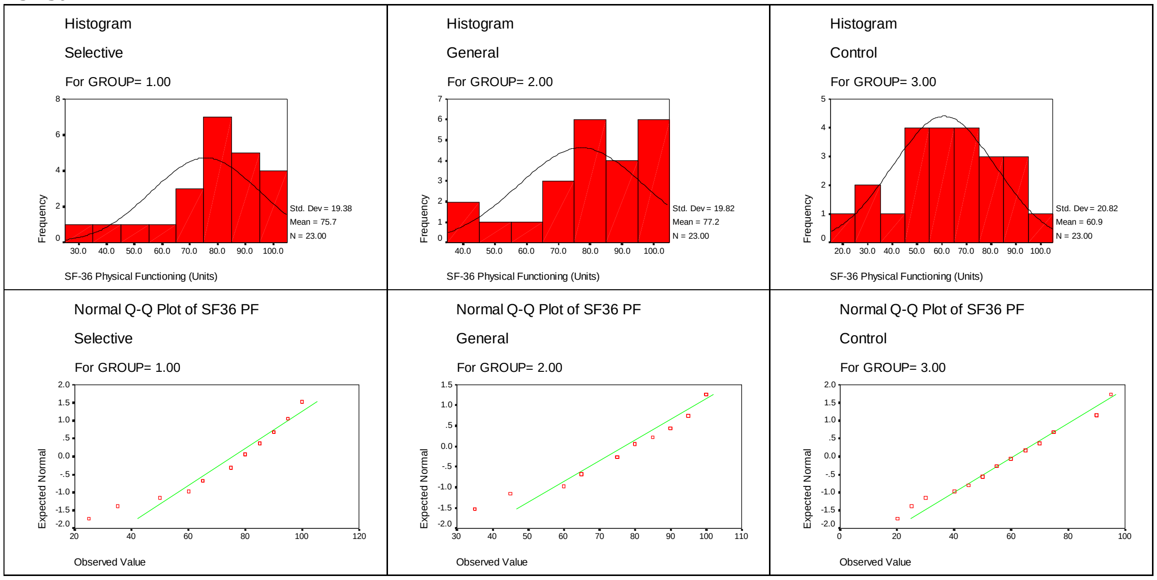


Graphs 16.65 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Unpleasantness Month (Units)

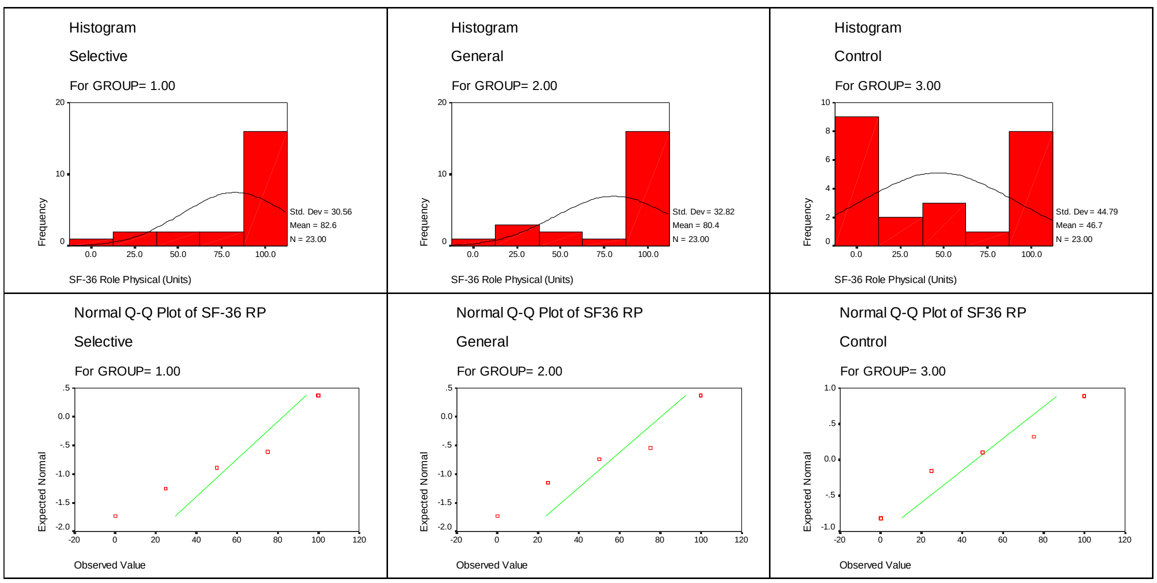


Graphs 16.66 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Numerical Pain Rating Scale Pain Intensity During Electrogoniometry (Units)

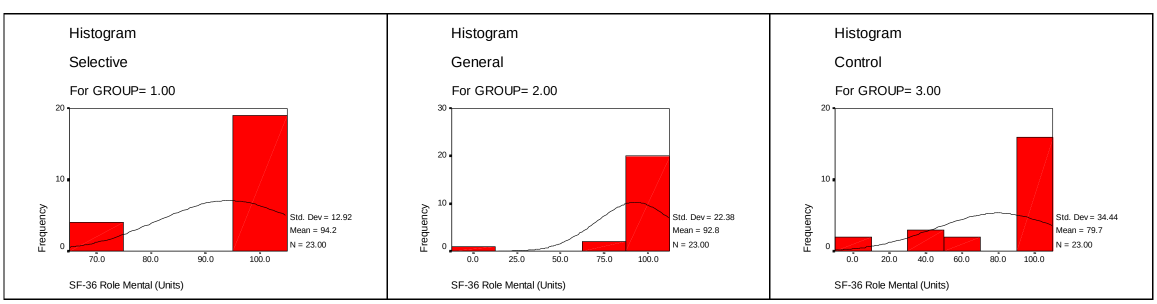
SF-36

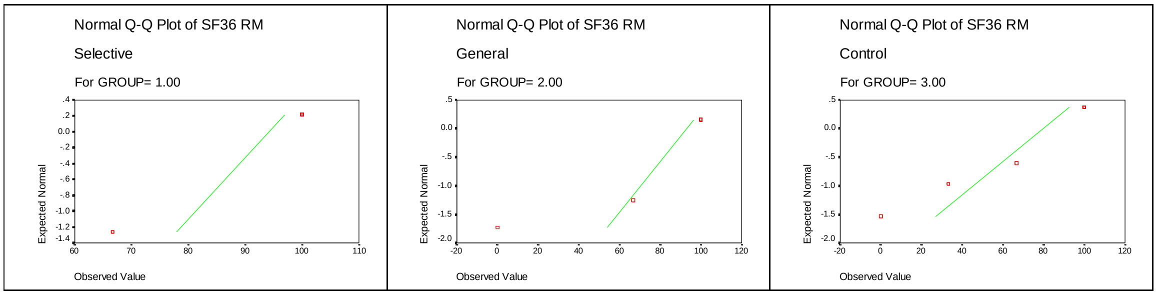


Graphs 16.67 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Physical Functioning (Units)**

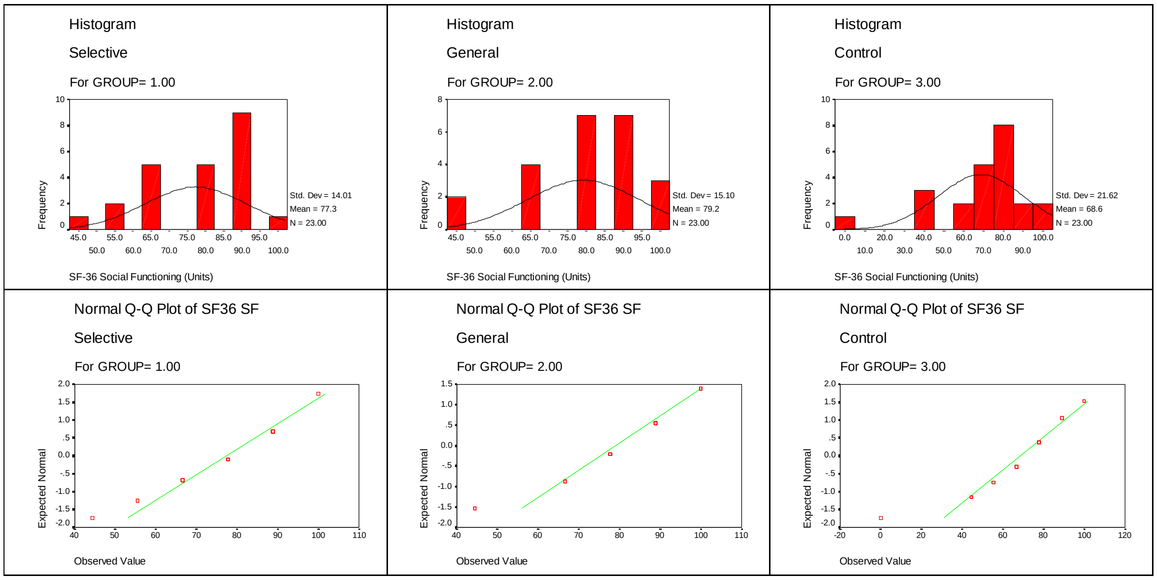


Graphs 16.68 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Role Physical (Units)**

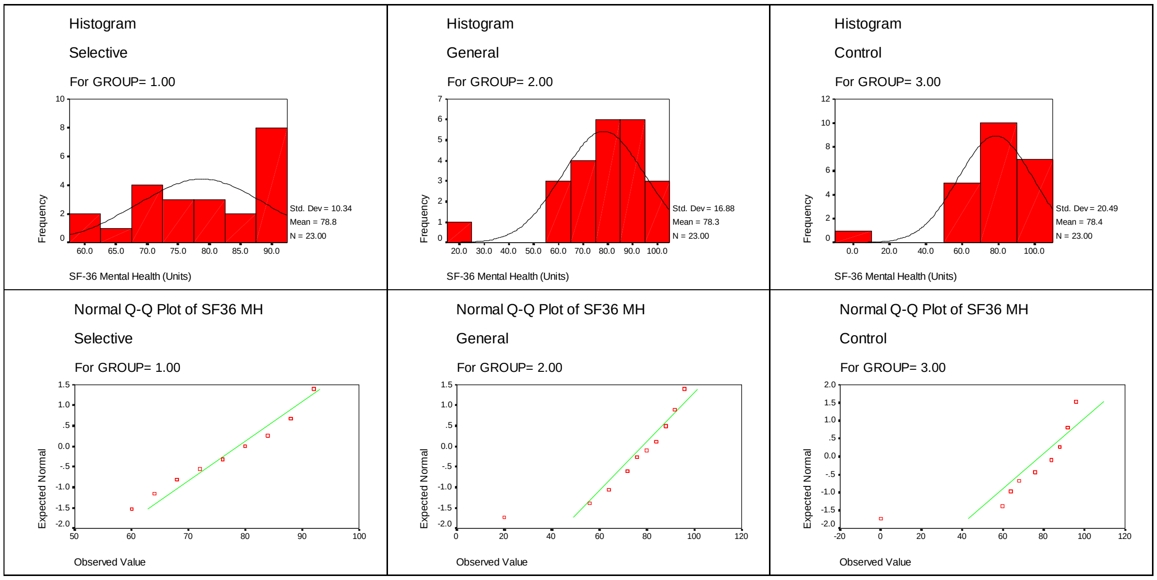




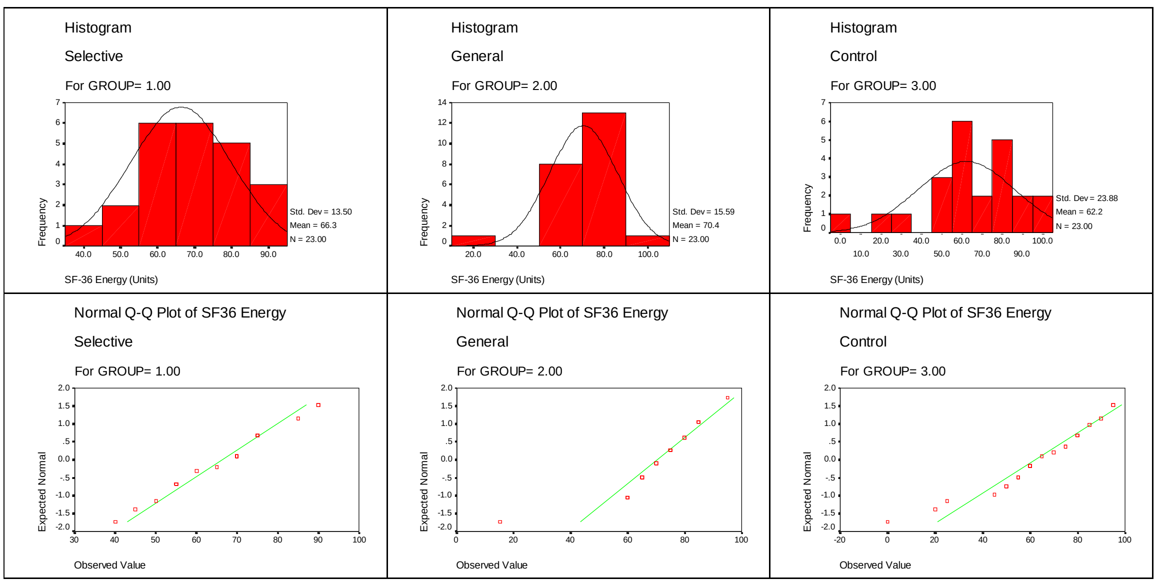
Graphs 16.69 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Role Mental (Units)



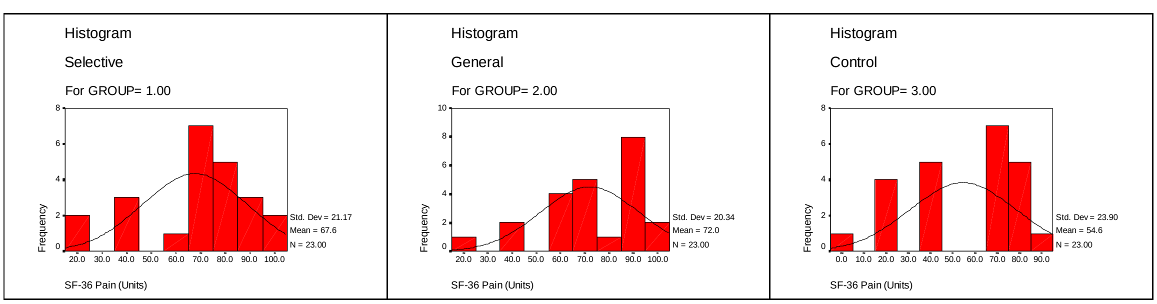
Graphs 16.70 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Social Functioning (Units)

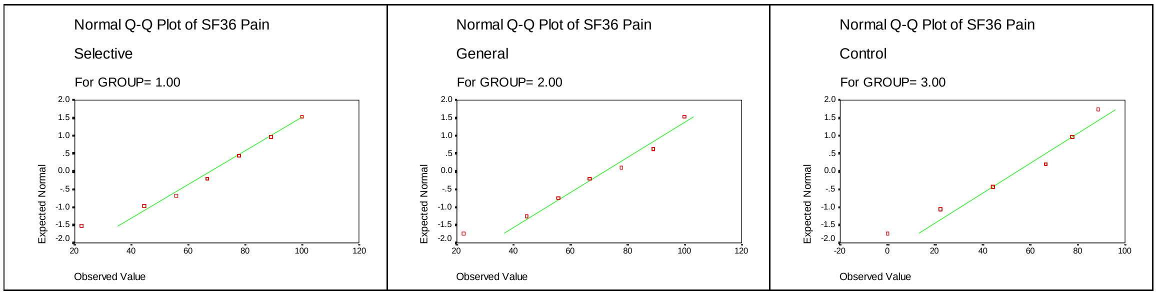


Graphs 16.71 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Mental Health (Units)**

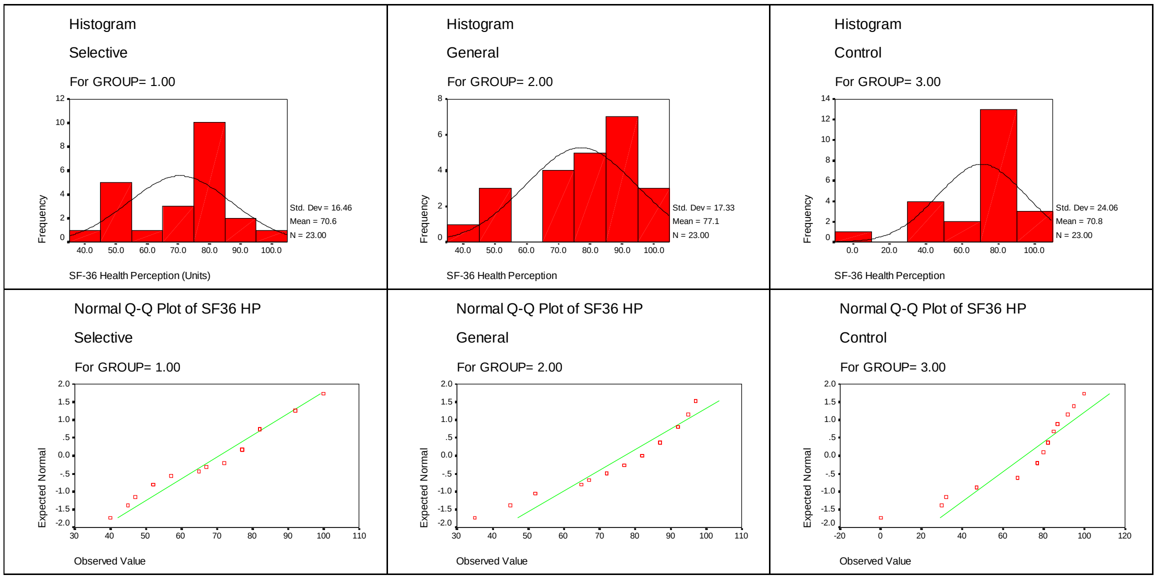


Graphs 16.72 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Energy (Units)**

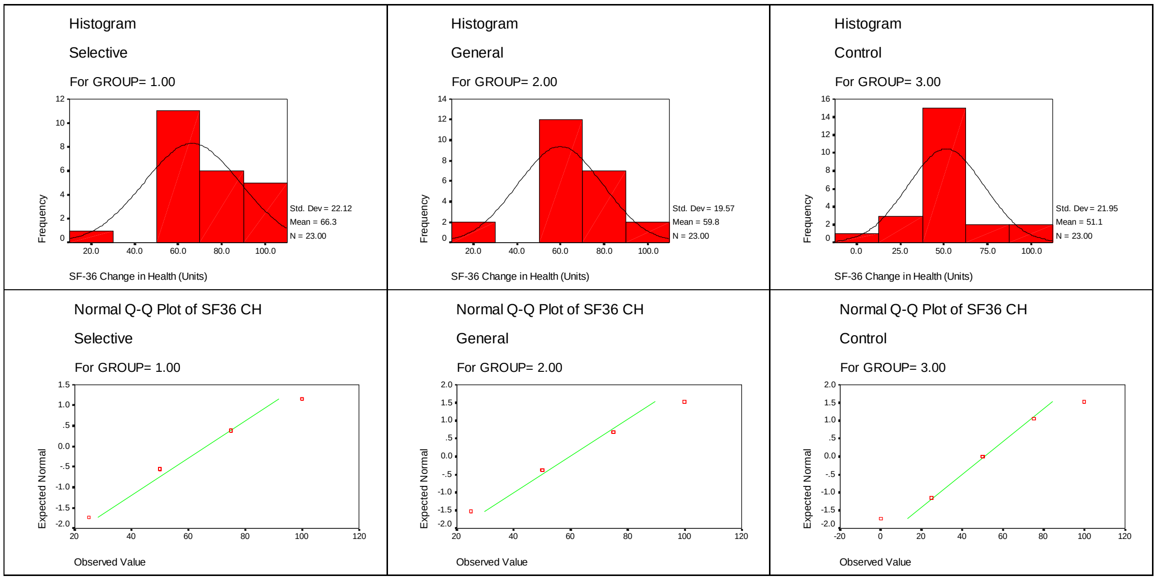




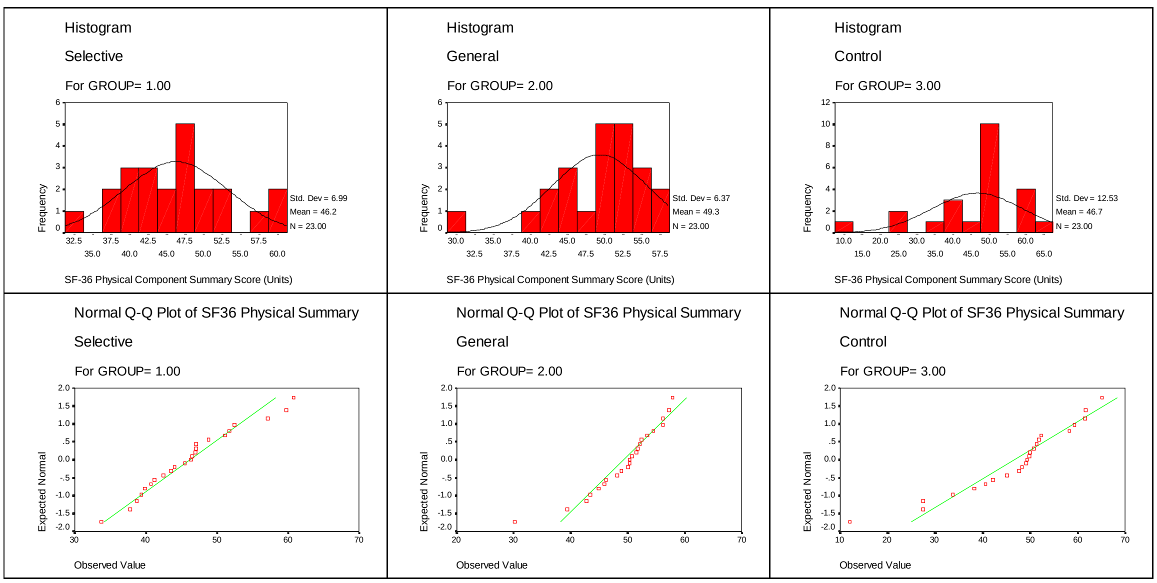
Graphs 16.73 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Pain (Units)**



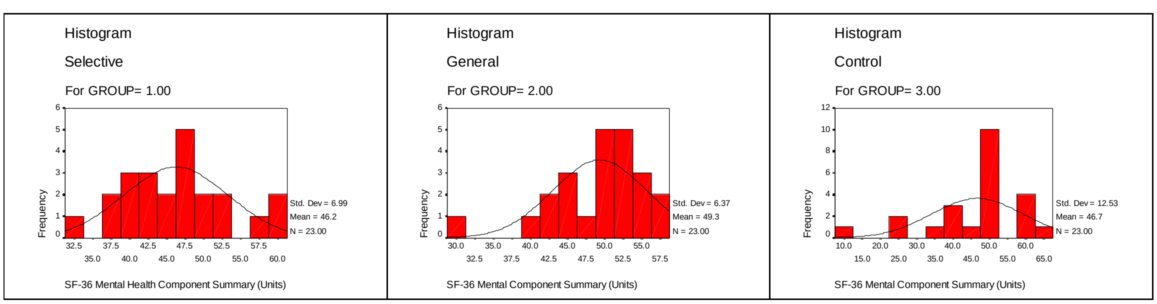
Graphs 16.74 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Health Perception (Units)**

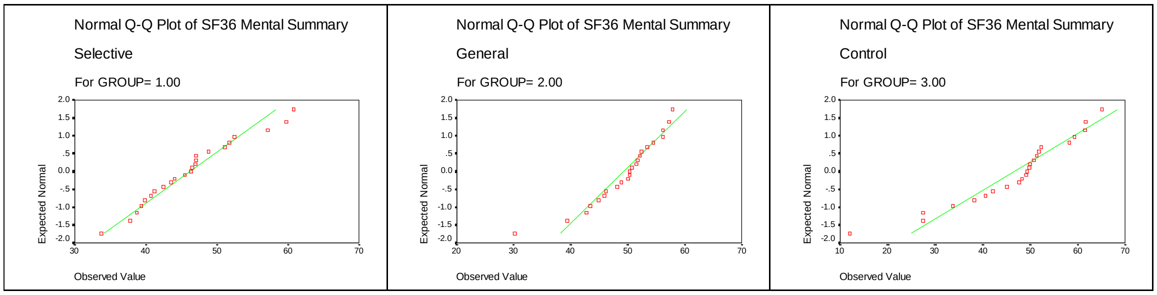


Graphs 16.75 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Change in Health (Units)**



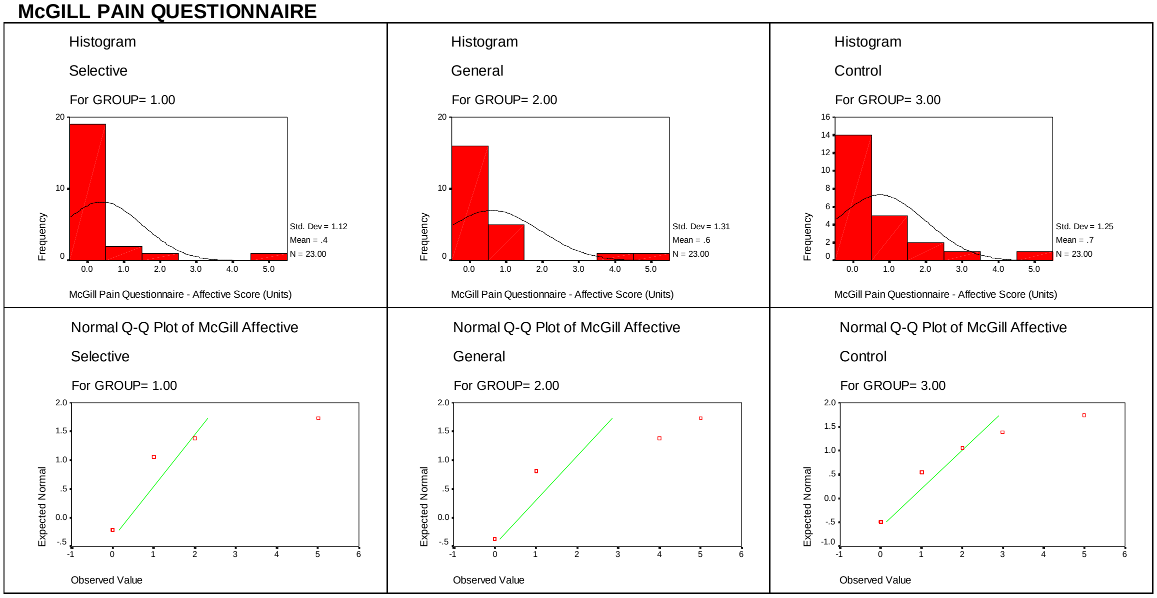
Graphs 16.76 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Physical Component Summary Score (Units)**



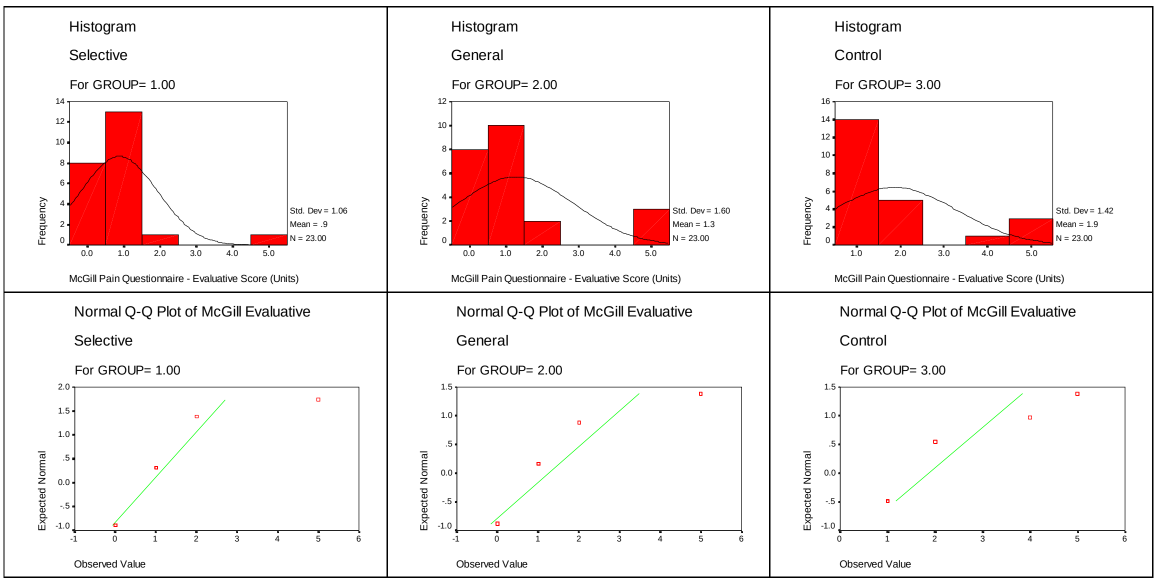


Graphs 16.77 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for SF-36 Mental Component Summary Score (Units)

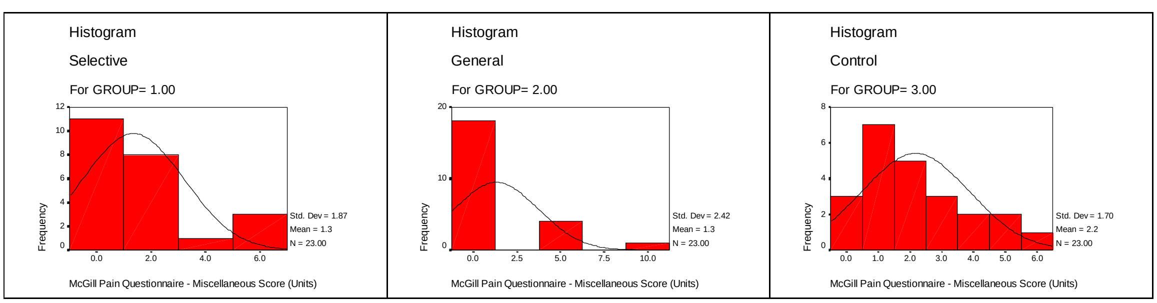
McGILL PAIN QUESTIONNAIRE

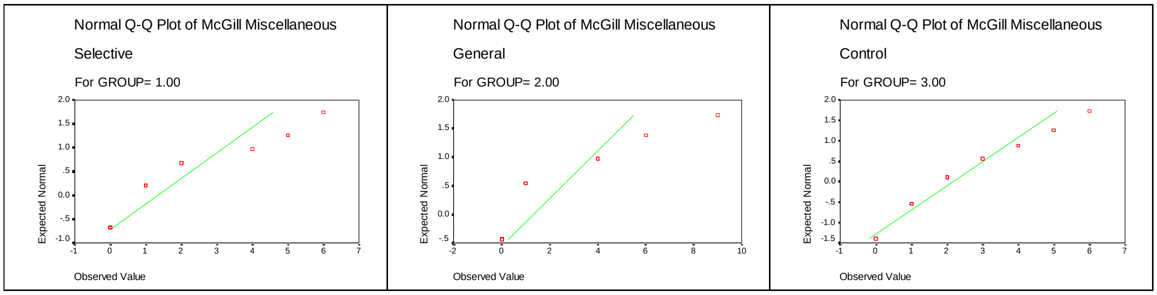


Graphs 16.78 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire - Affective Score (Units)**

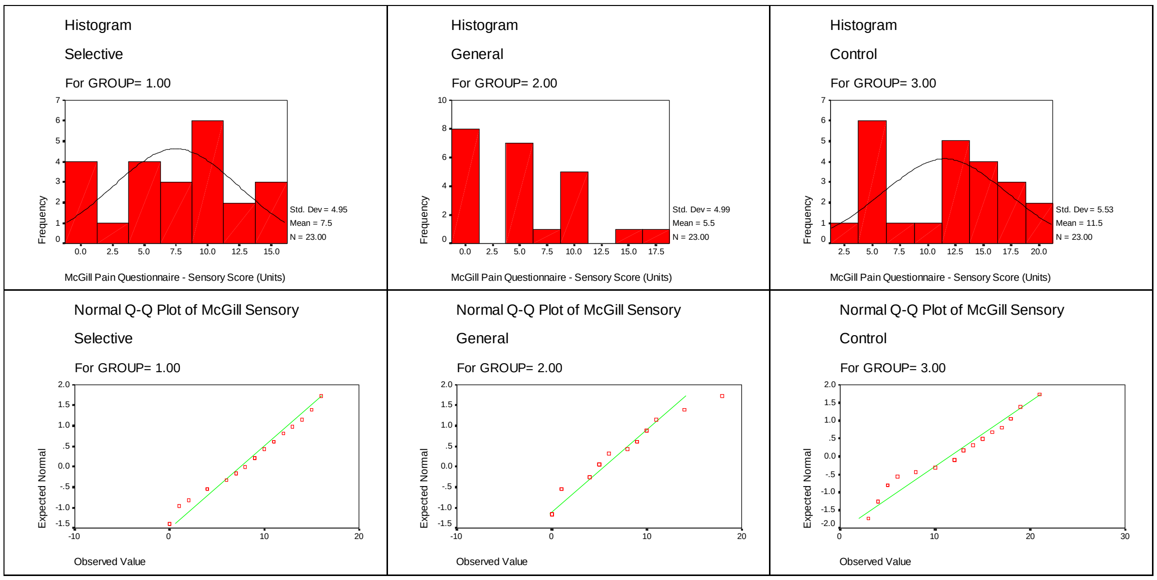


Graphs 16.79 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire - Evaluative Score (Units)**

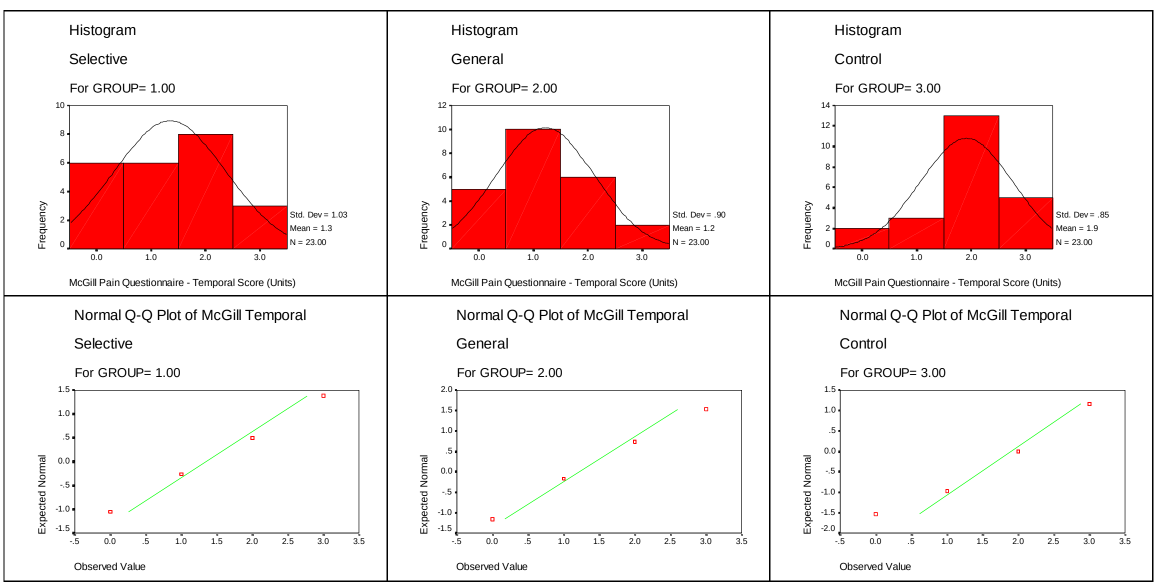




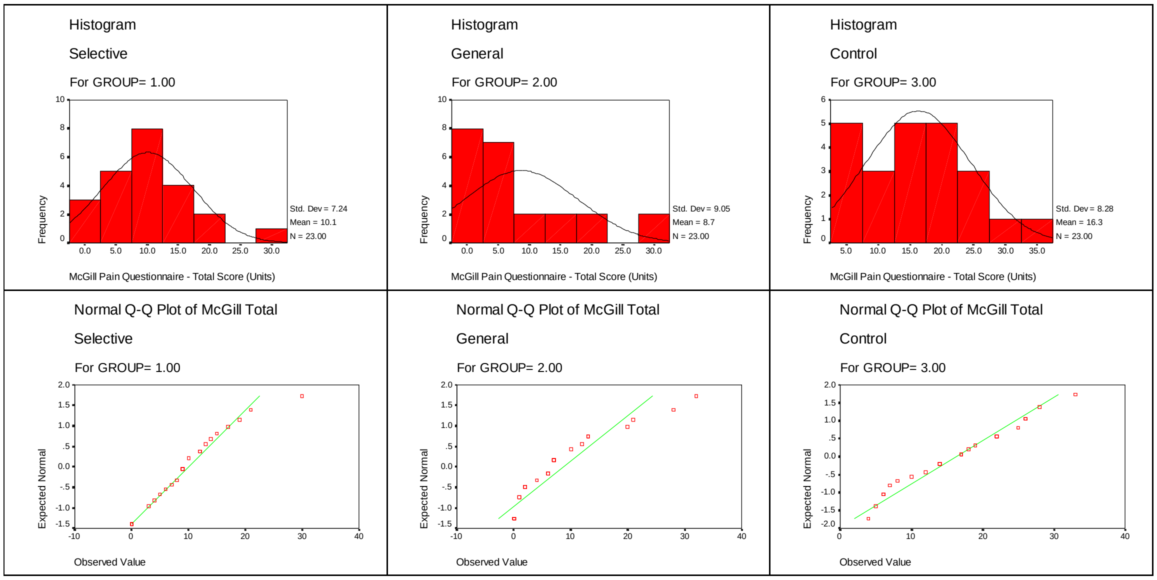
Graphs 16.80 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire - Miscellaneous Score (Units)



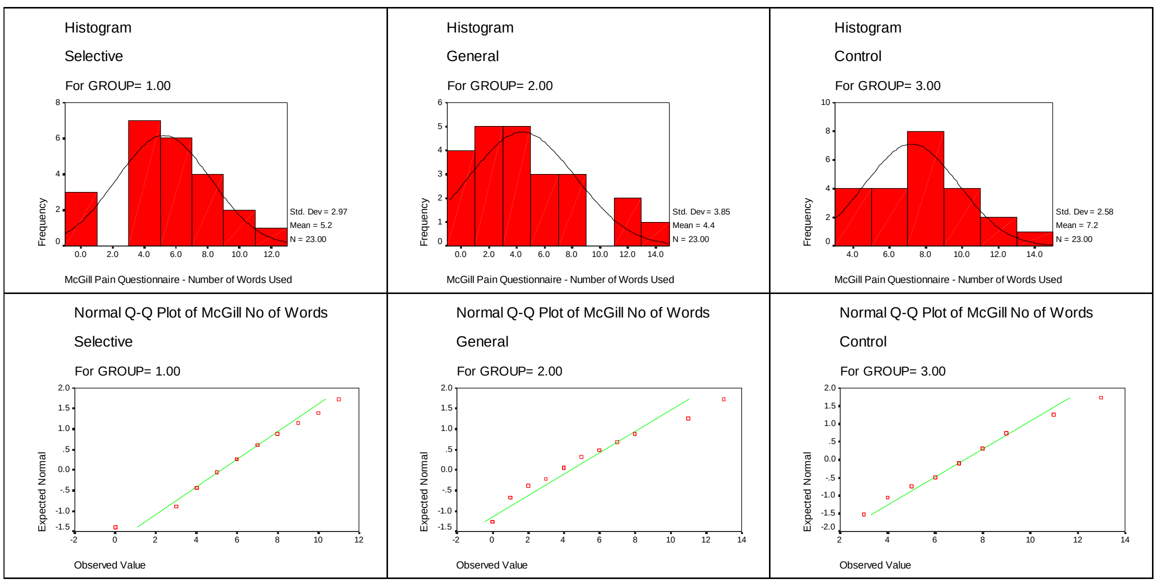
Graphs 16.81 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – Sensory Score (Units)



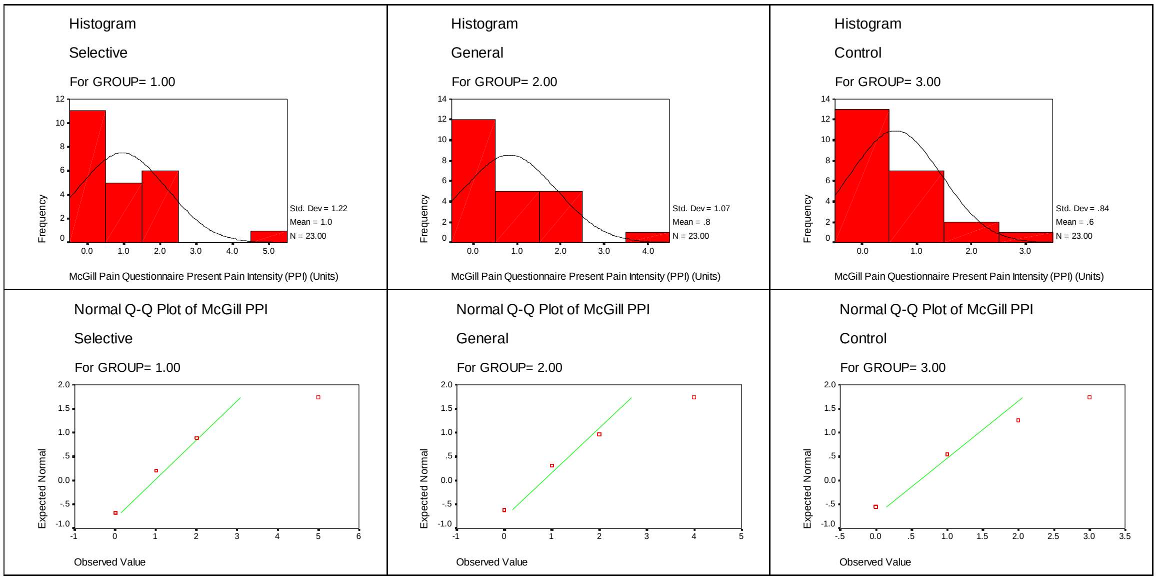
Graphs 16.82 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – Temporal Score (Units)



Graphs 16.83 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – Total Score (Units)

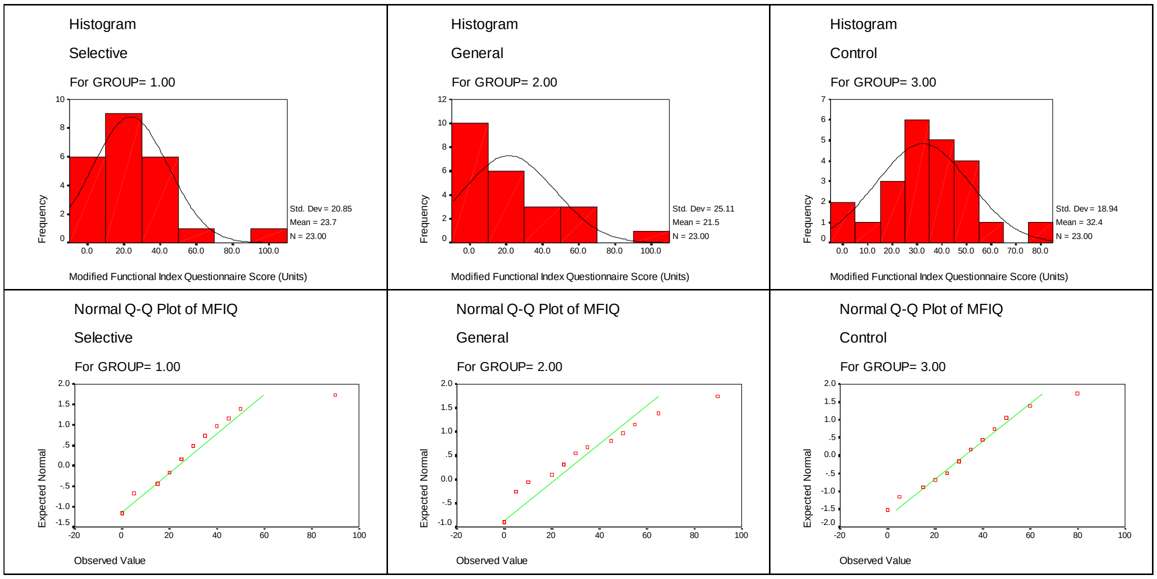


Graphs 16.84 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – Number of Words Used



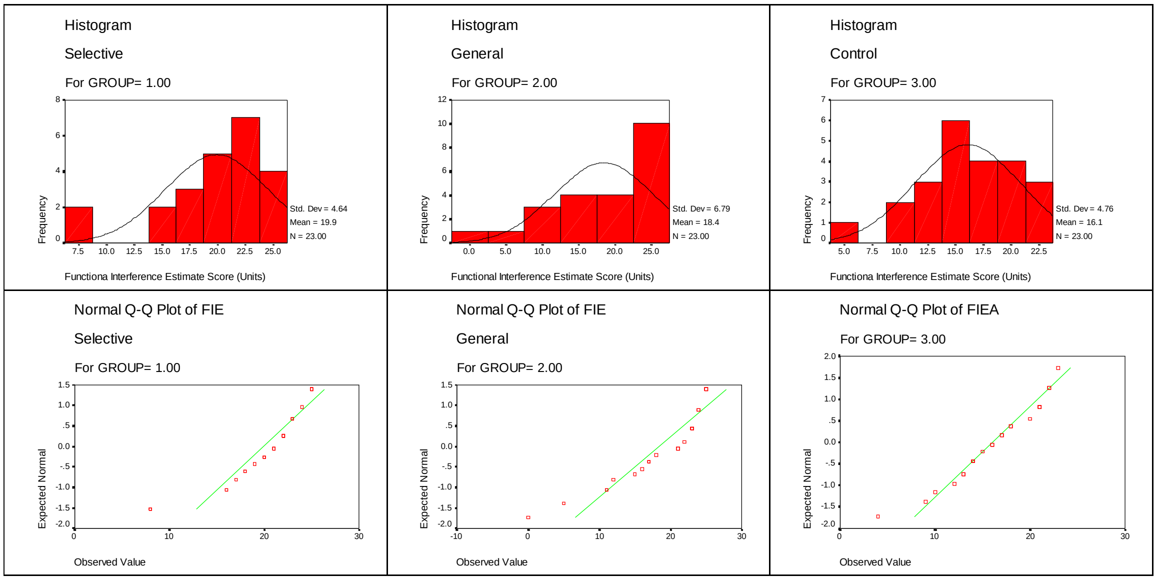
Graphs 16.85 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for McGill Pain Questionnaire – Present Pain Index (PPI) (Units)

MODIFIED FUNCTIONAL INDEX QUESTIONNAIRE (MFIQ)



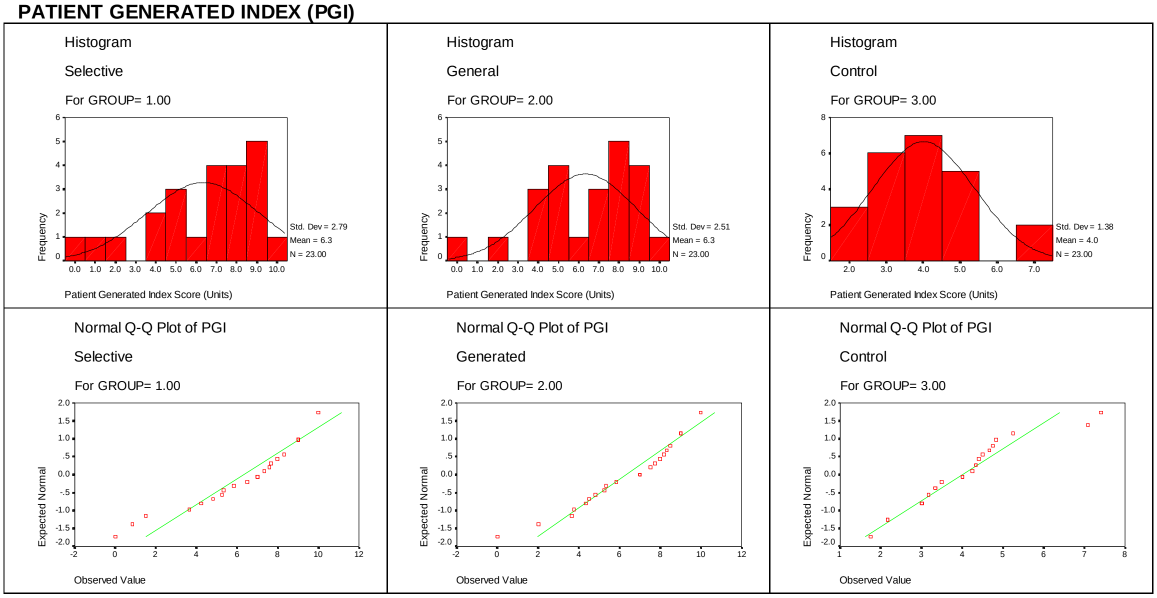
Graphs 16.86 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Modified Functional Index Questionnaire (MFIQ) Score (Units)

FUNCTIONAL INTERFERENCE ESTIMATE (FIE)

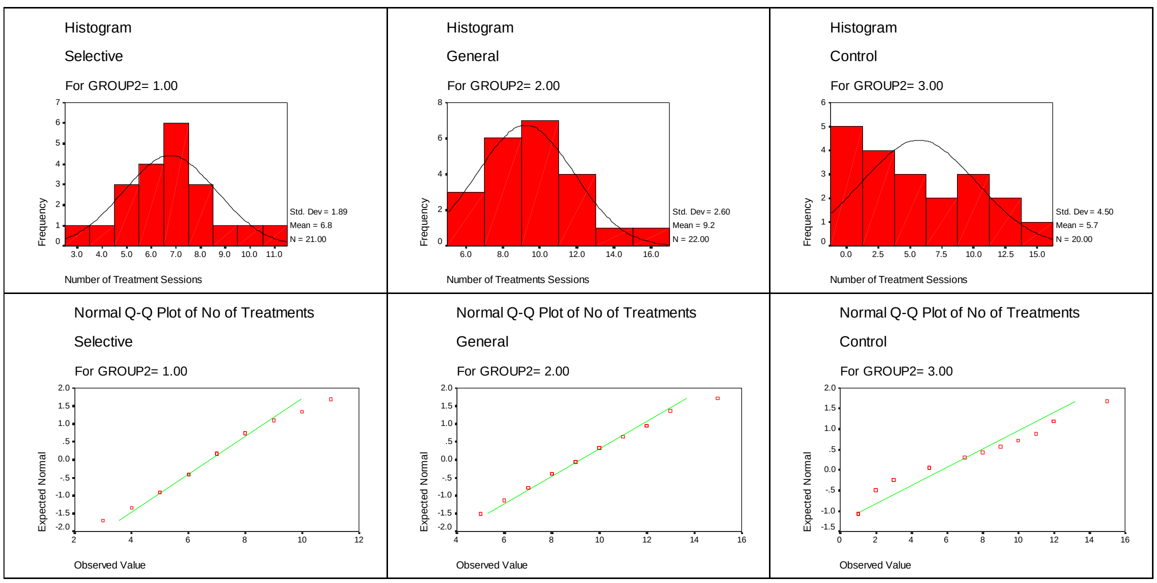


Graphs 16.87 Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Functional Interference Estimate (FIE) Score (Units)

PATIENT GENERATED INDEX (PGI)



Graphs 16.88 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Patient Generated Index (PGI) Score (Units)**



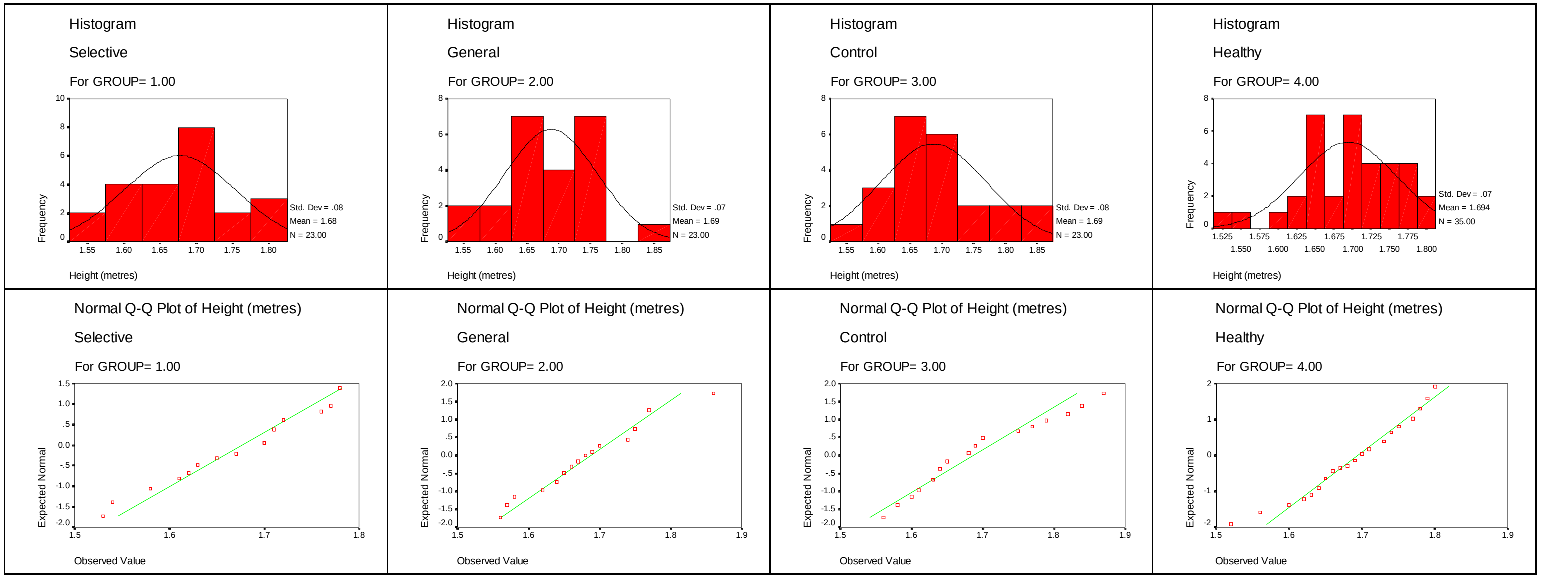
Graphs 16.89 **Histograms and Normal Q-Q Plots of Selective, General and Control Groups for Number of Treatment Sessions**

ELECTRONIC APPENDIX 17

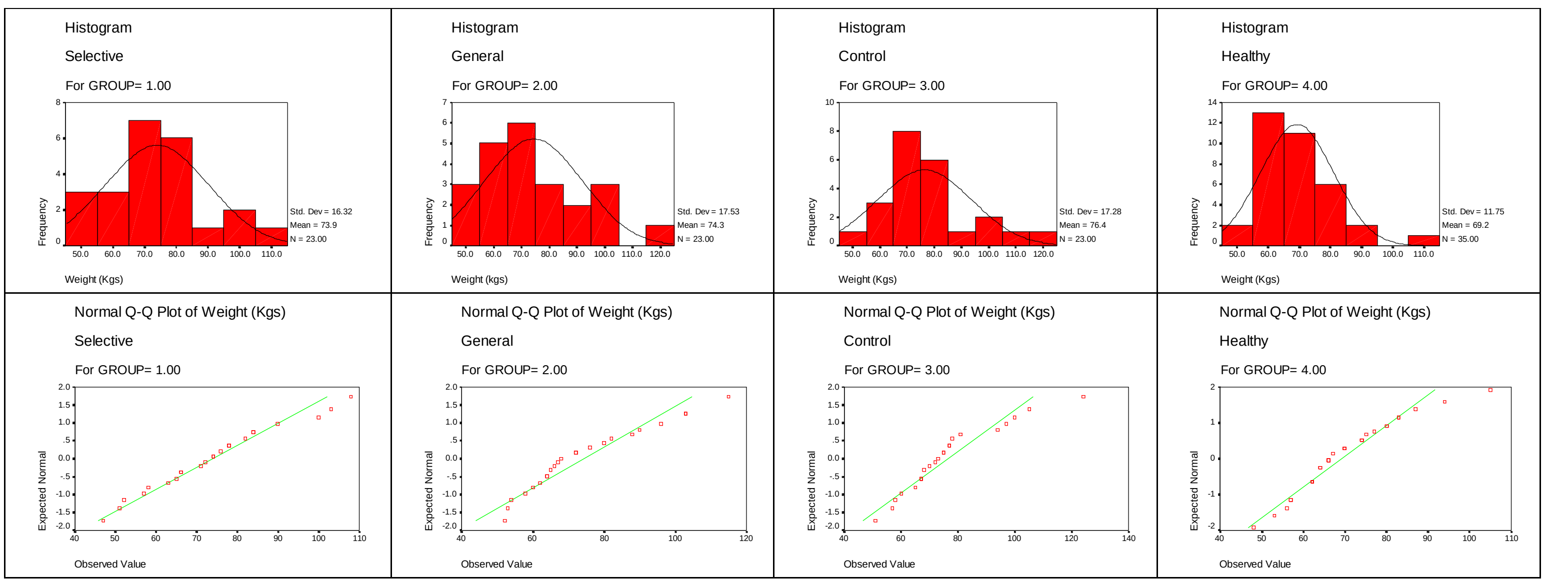
17.1 POST RCT PFPS PATIENTS vs. HEALTHY COMPARISON NORMALITY GRAPHS AND Q-Q PLOTS

ELECTRONIC APPENDIX 17

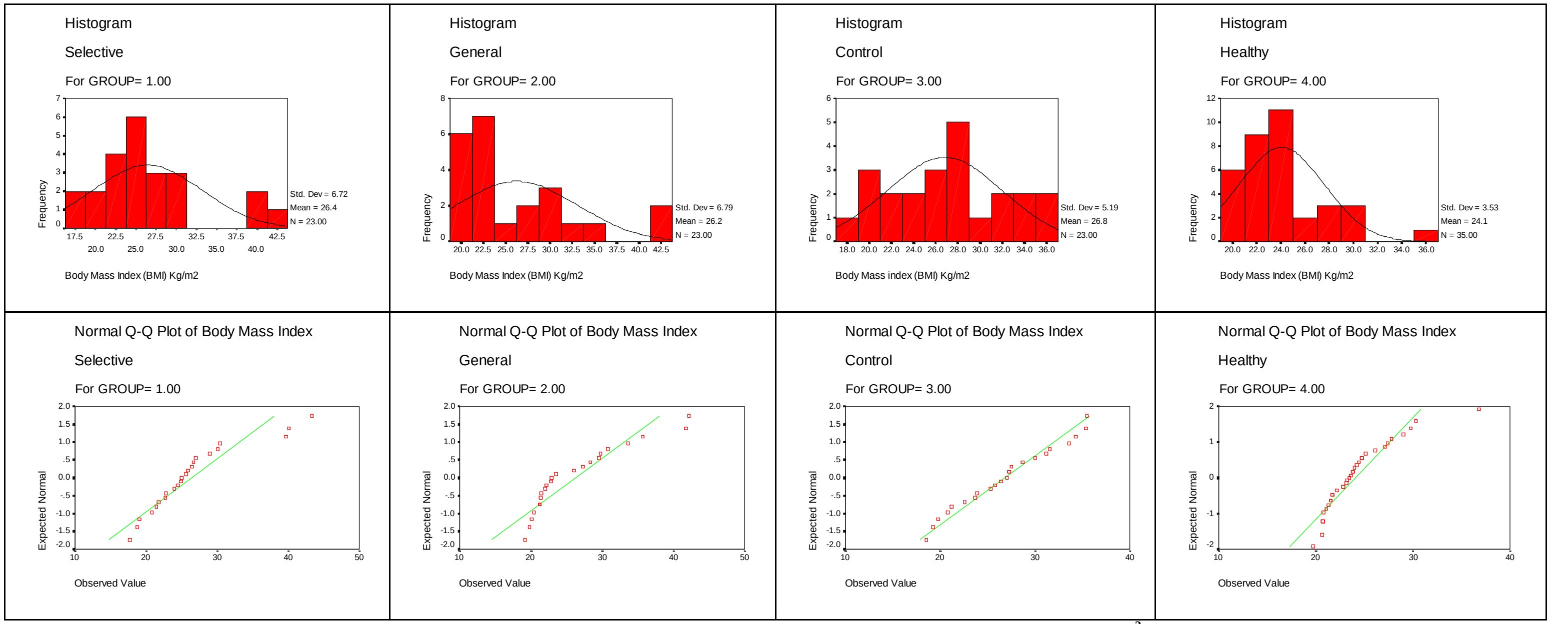
17.1 POST RCT PFPS PATIENTS VS. HEALHTY COMPARISON NORMALITY GRAPHS AND Q-Q PLOTS



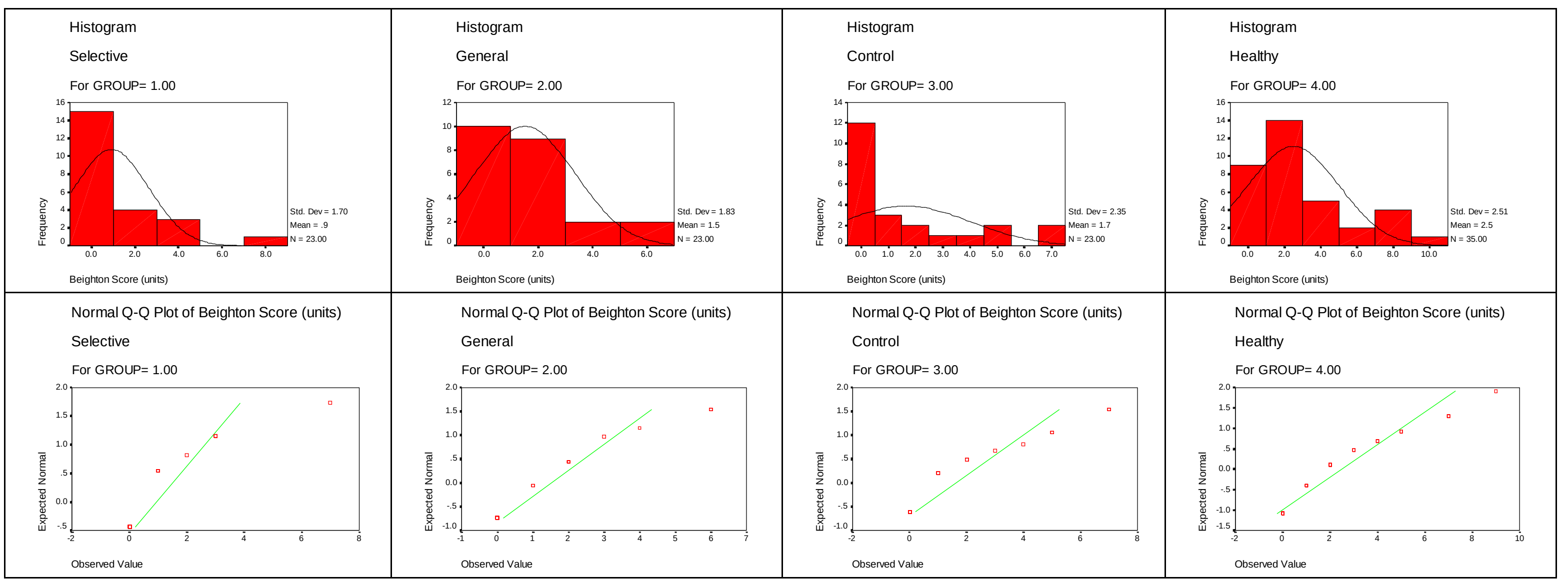
Graphs 17.1 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Height (Metres)



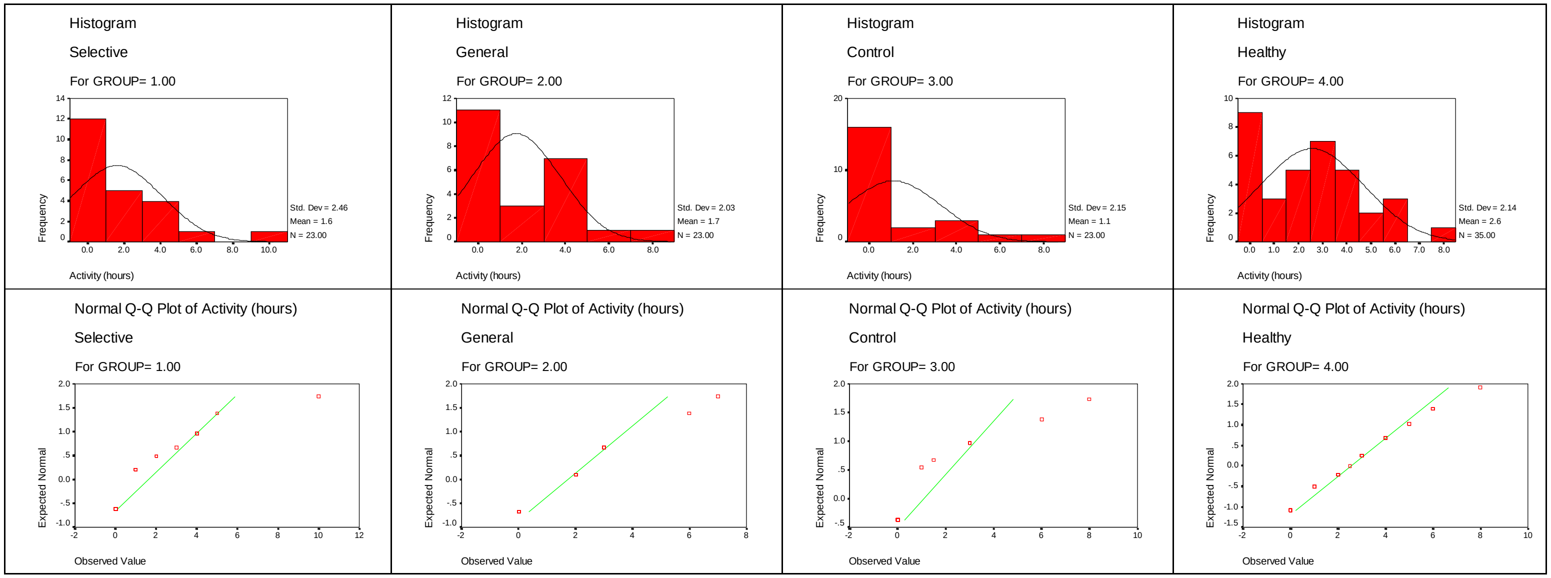
Graphs 17.2 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Body Mass (Kgs)



Graphs 17.3 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Body Mass Index (BMI) (Kg/m^2)

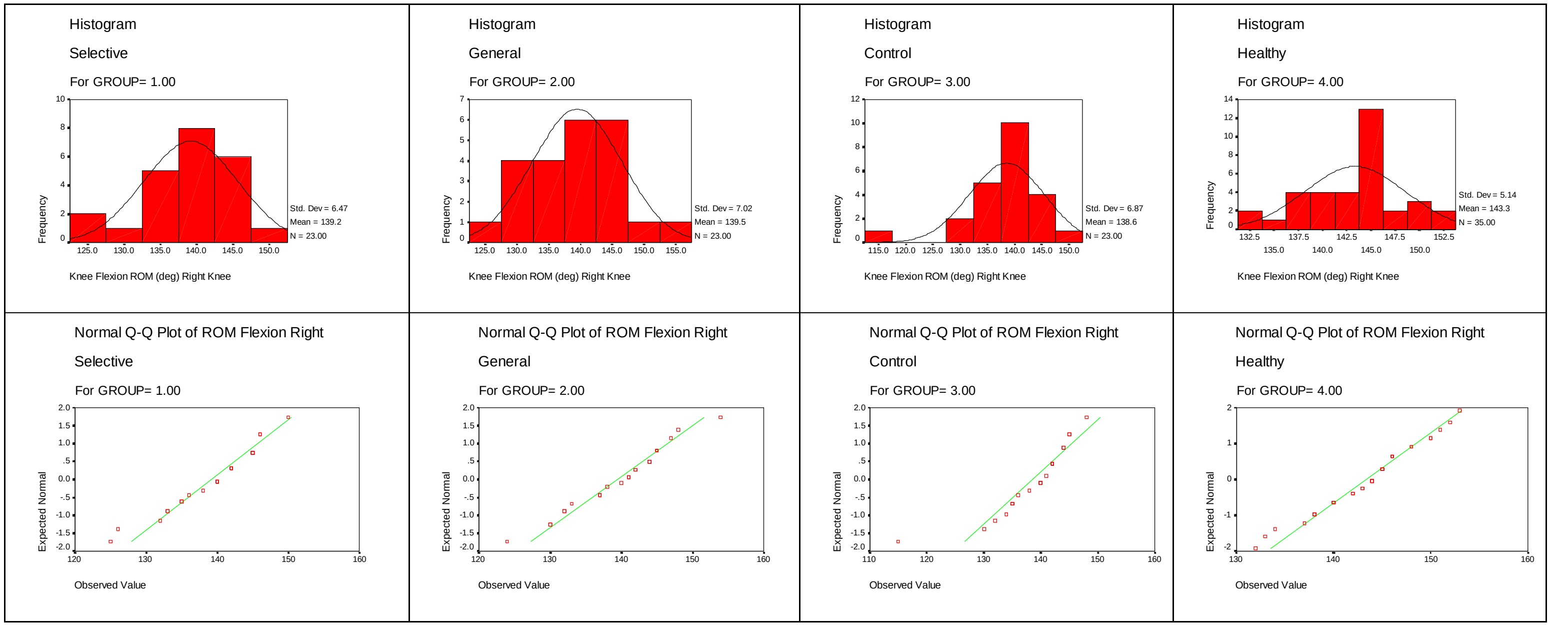


Graphs 17.4 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Beighton Score (Units)**

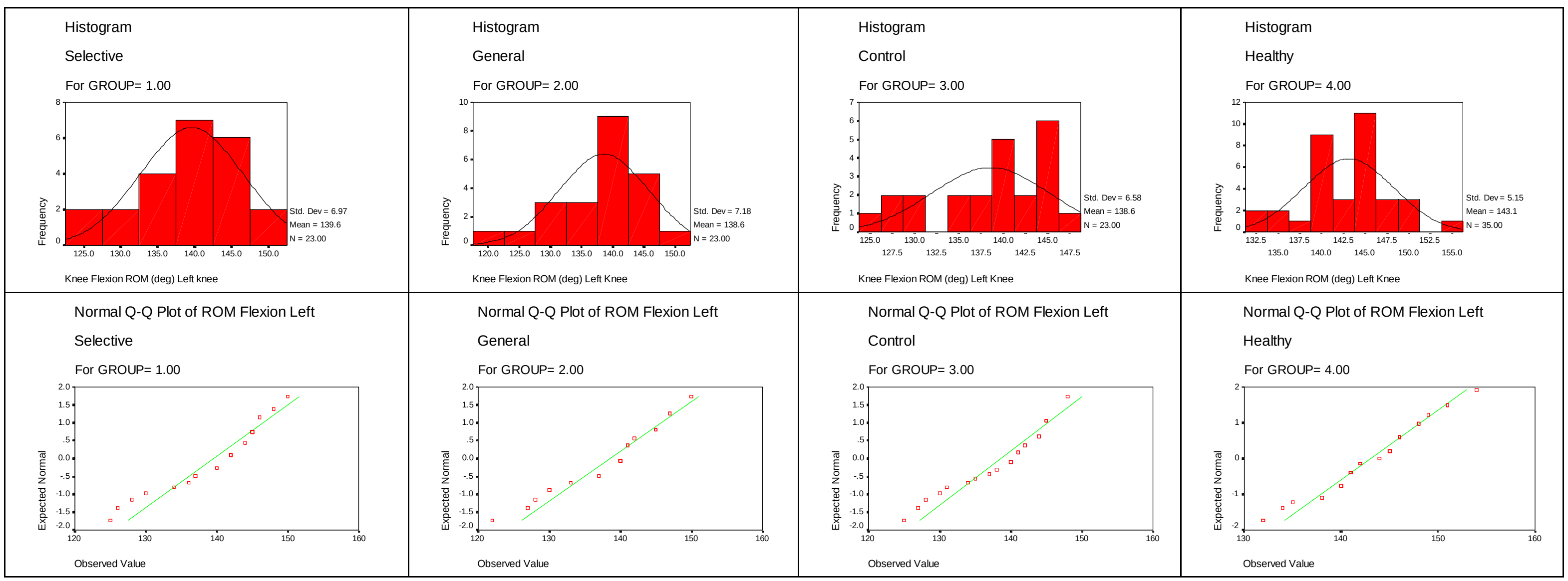


Graphs 17.5 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Activity (Hours)**

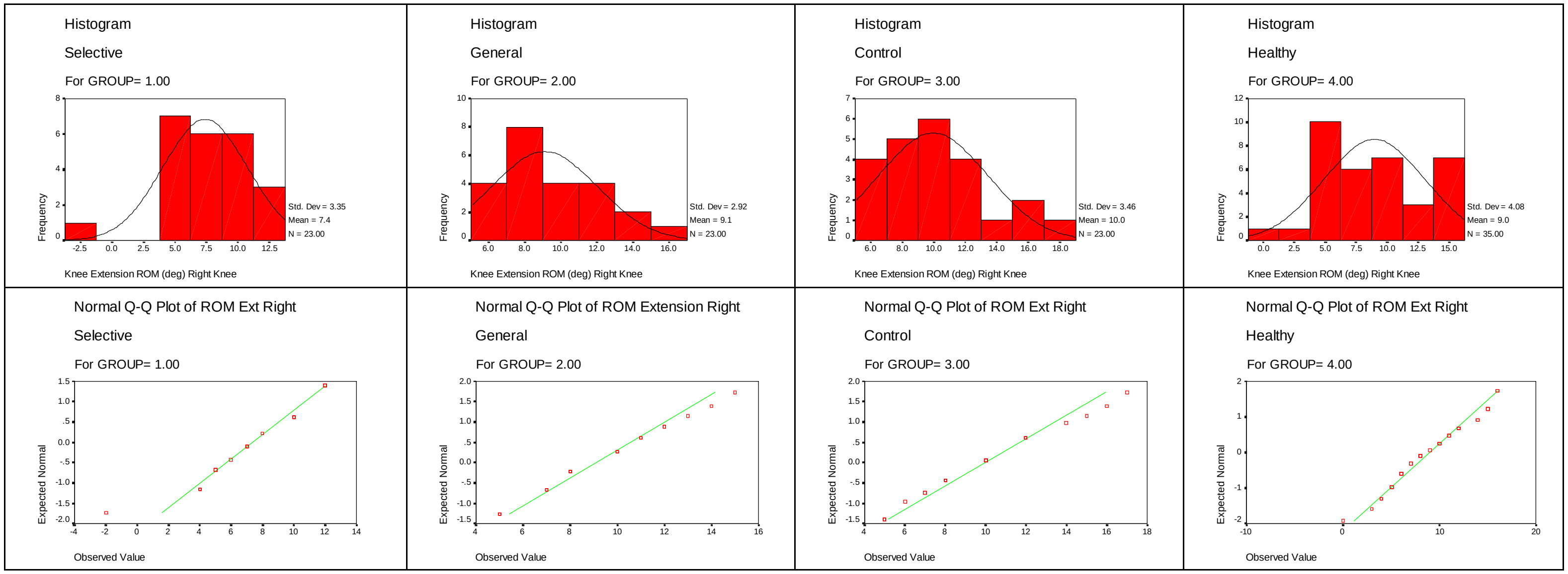
ANTHROPOMETRIC VARIABLES



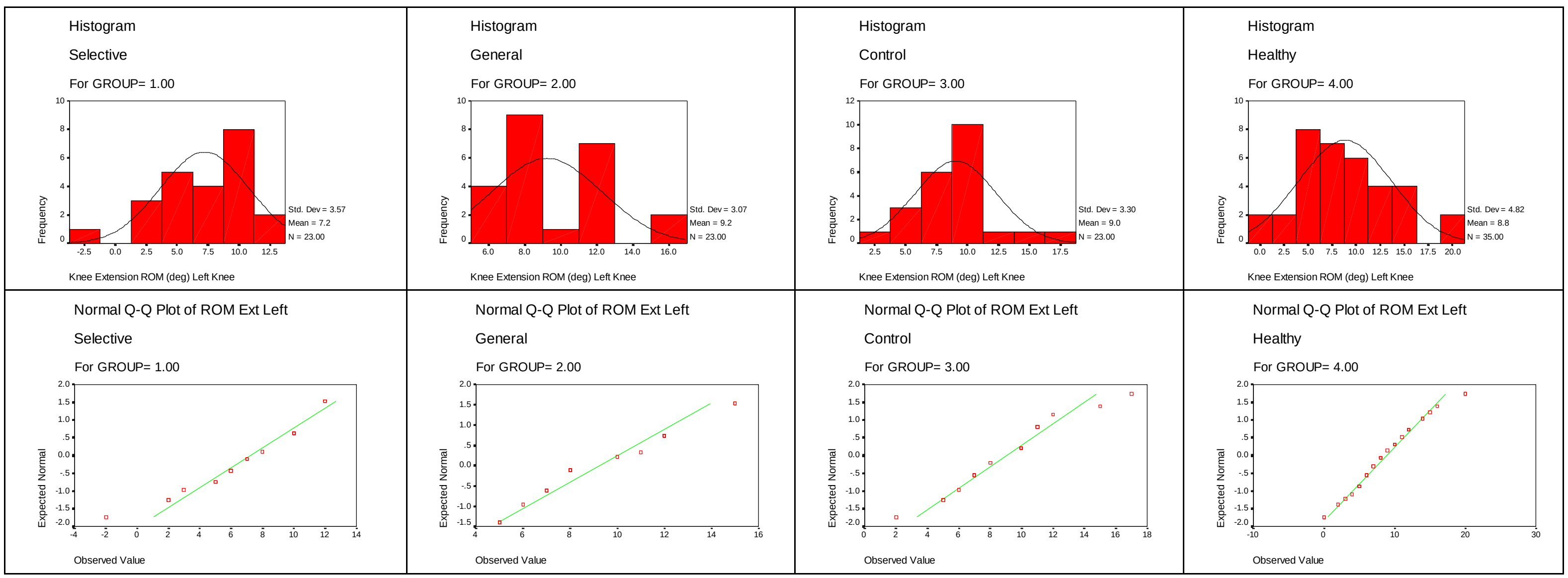
Graphs 17.6 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Flexion Range of Motion Right Knee (Degrees)**



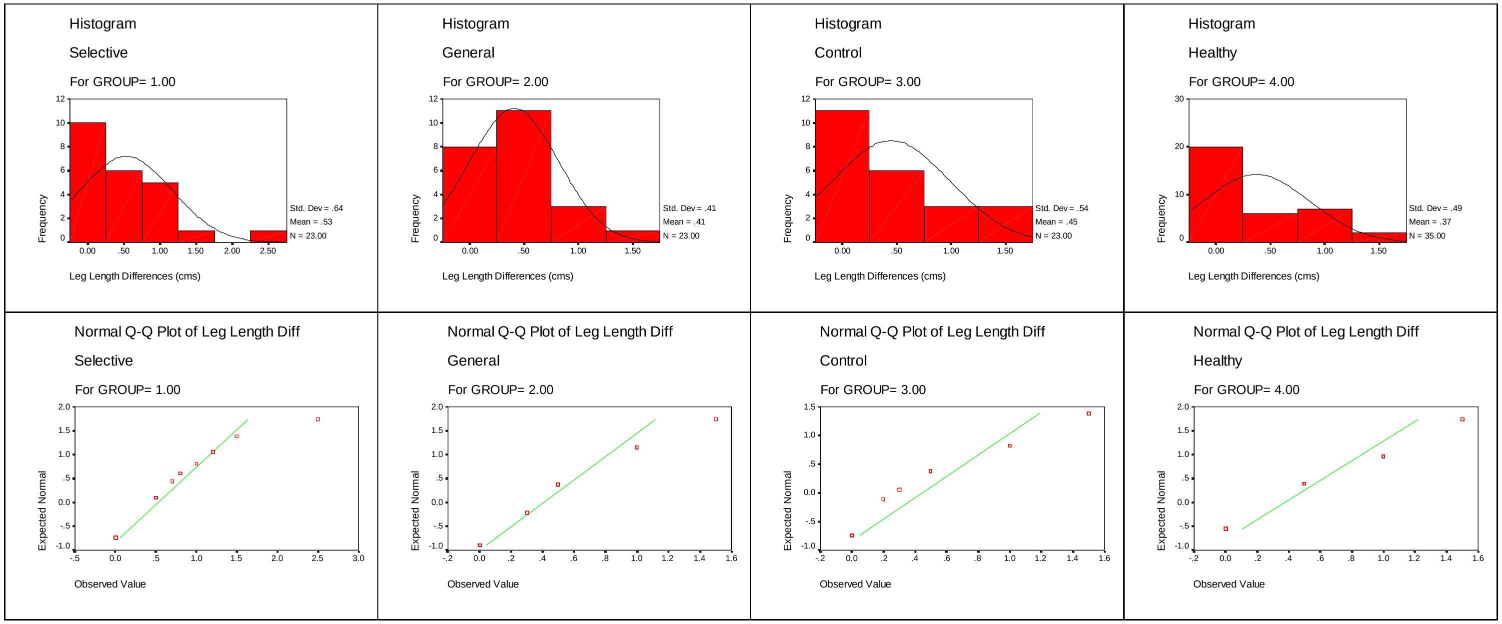
Graphs 17.7 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Flexion Range of Motion Left Knee (Degrees)**



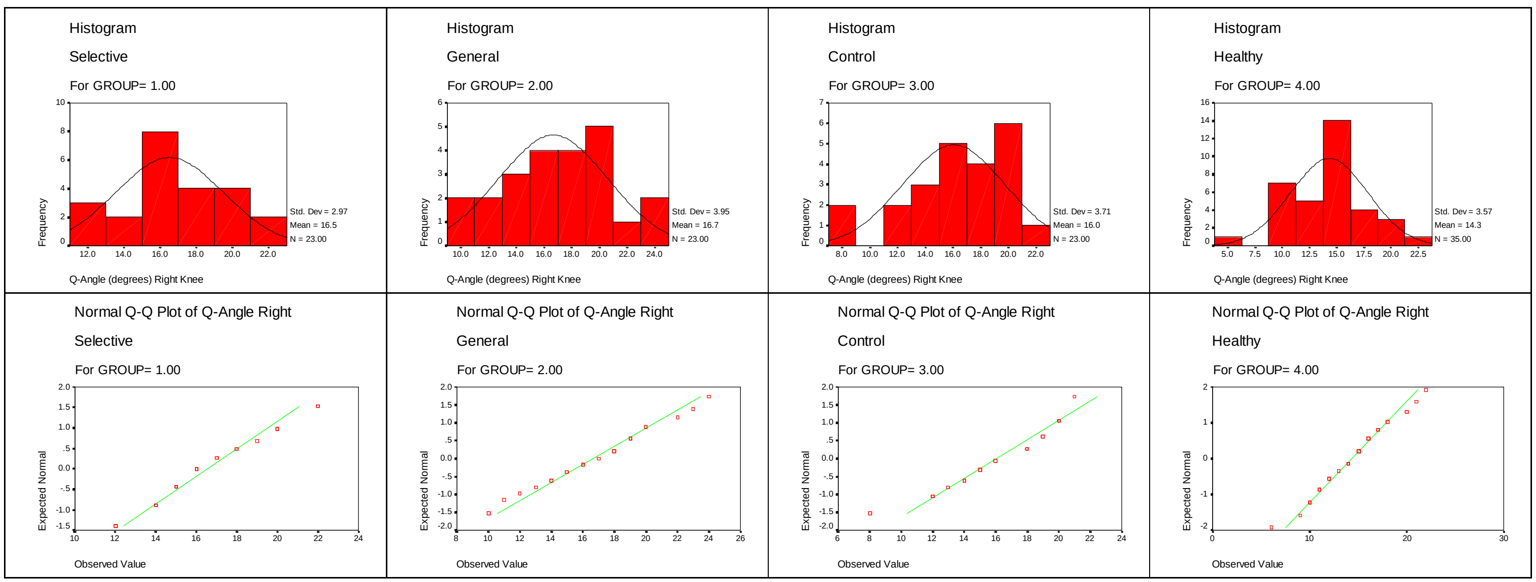
Graphs 17.8 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Extension Range of Motion Right Knee (Degrees)**



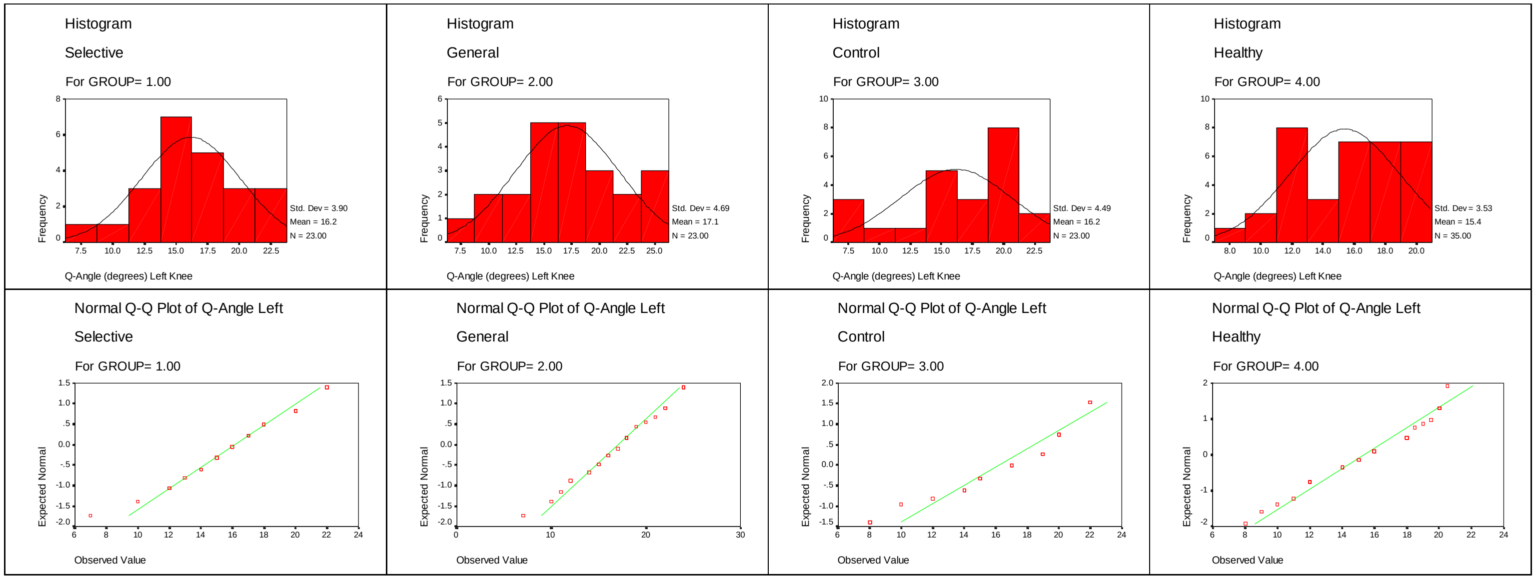
Graphs 17.9 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Extension Range of Motion Left Knee (Degrees)**



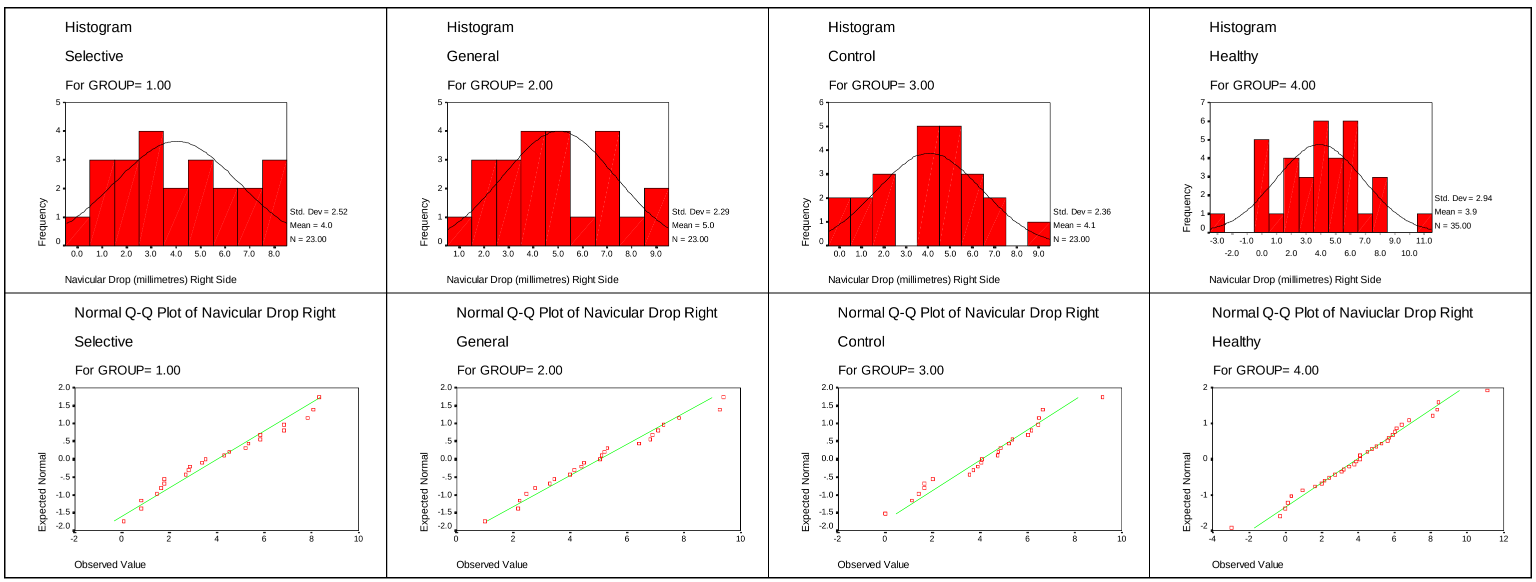
Graphs 17.10 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Leg Length Differences (Centimetres)**



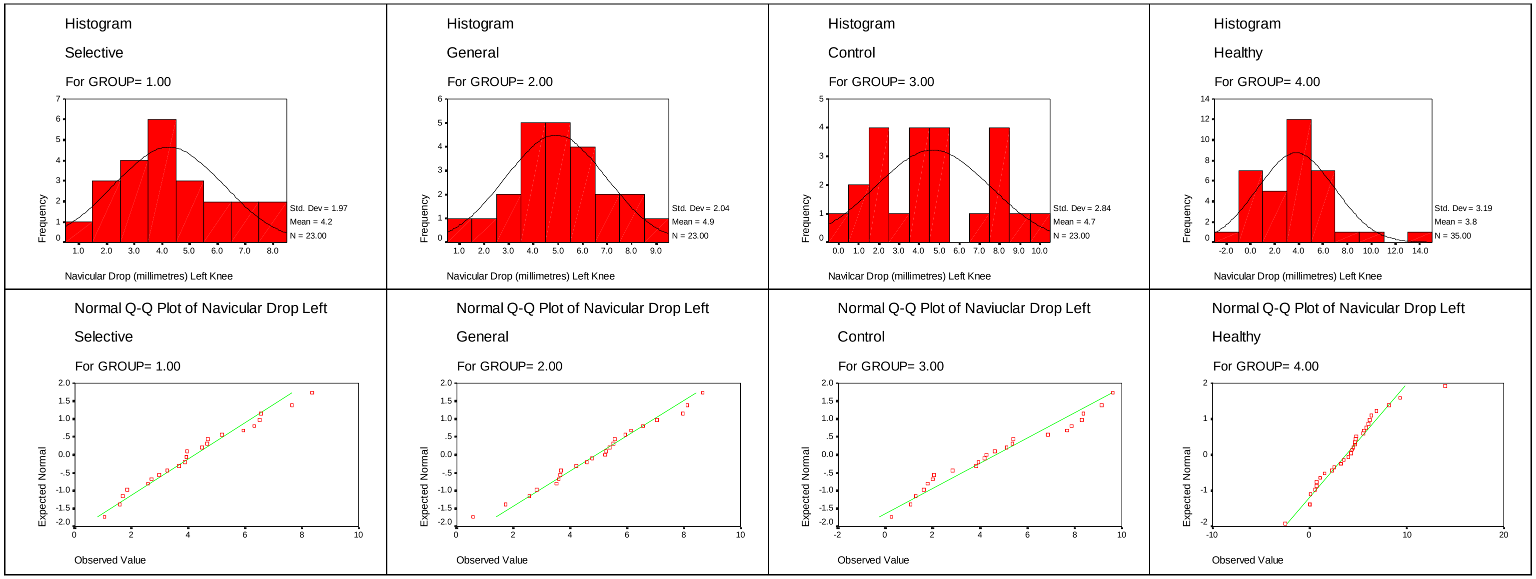
Graphs 17.11 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Q-Angle Right Side (Degrees)**



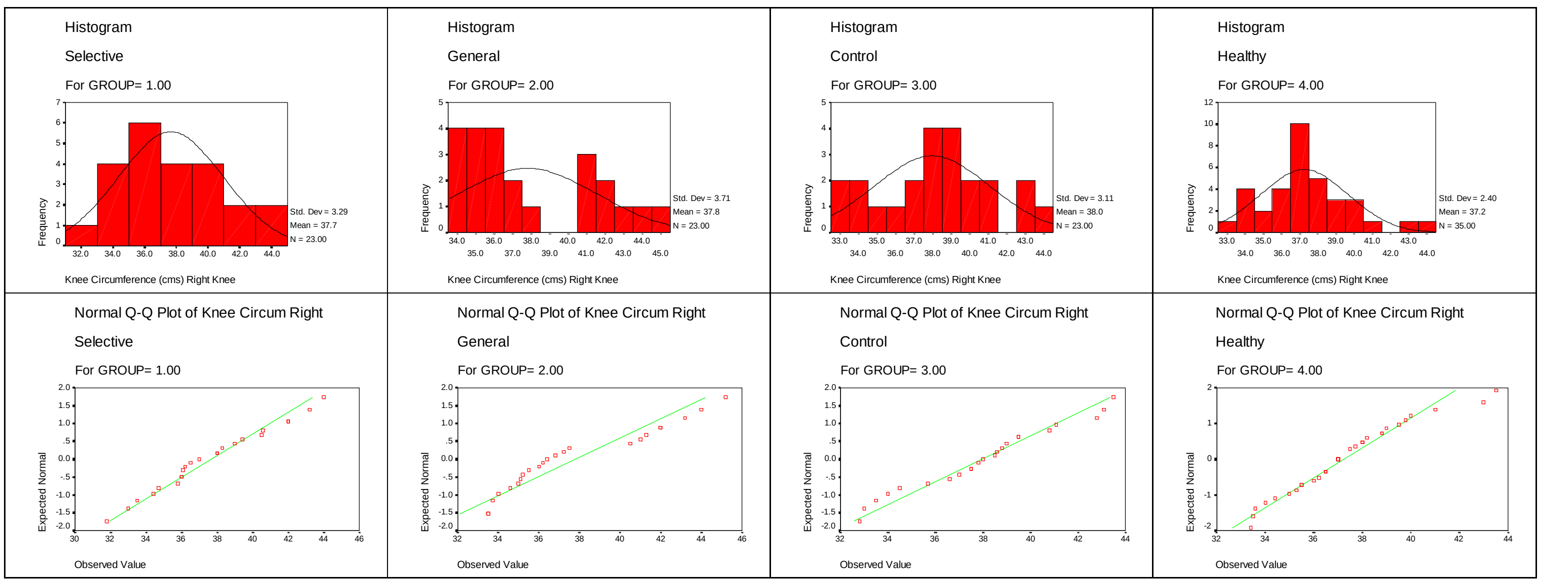
Graphs 17.12 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Q-Angle Left Side (Degrees)



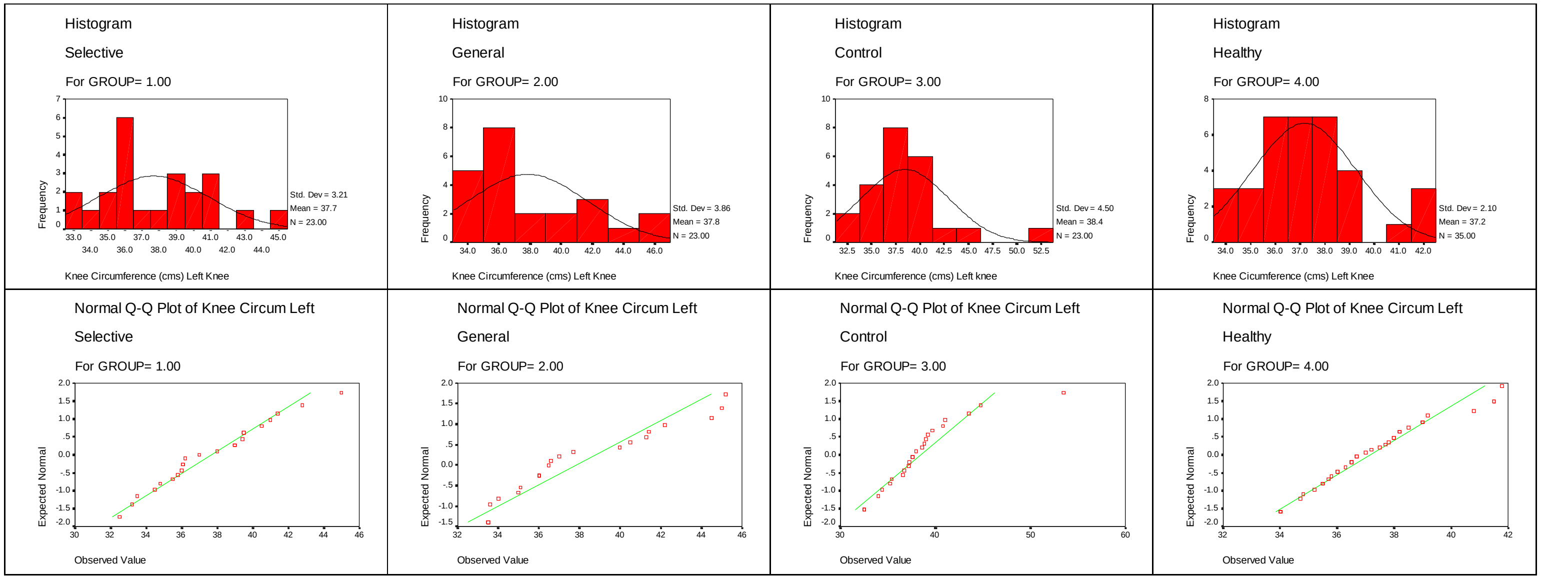
Graphs 17.13 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Navicular Drop Right Side(Millimetres)



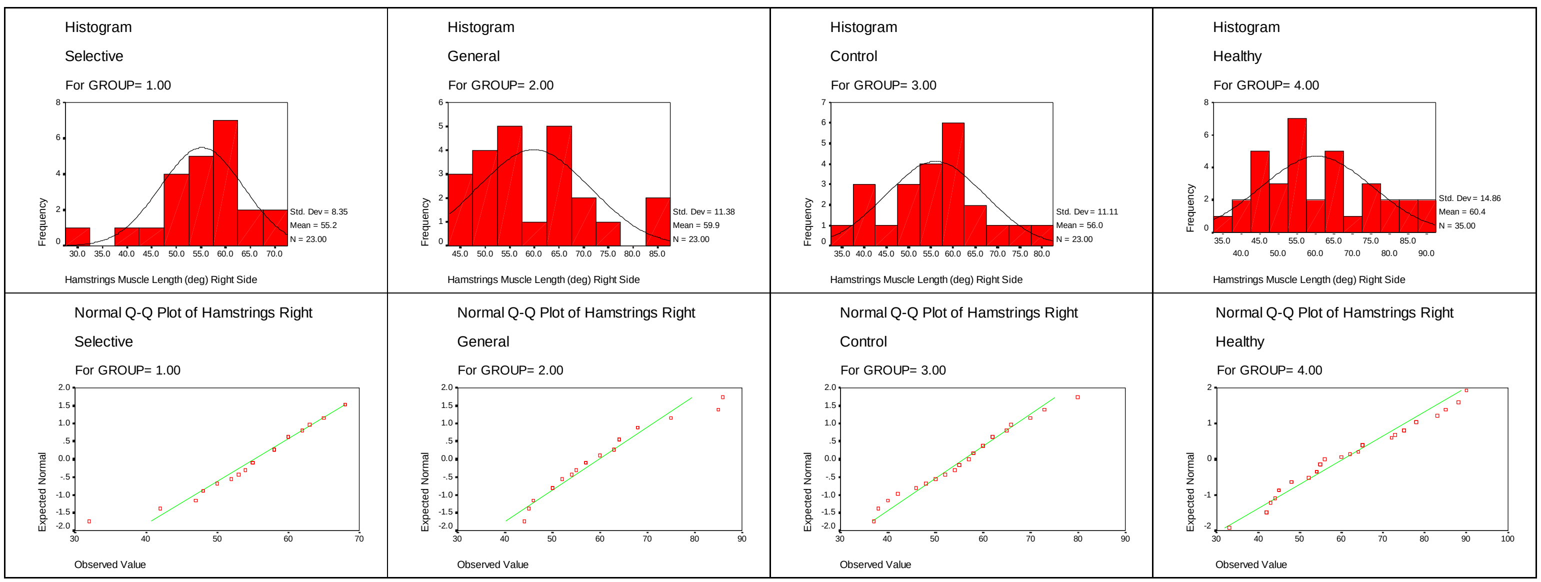
Graphs 17.14 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Navicular Drop Left Side (Millimetres)



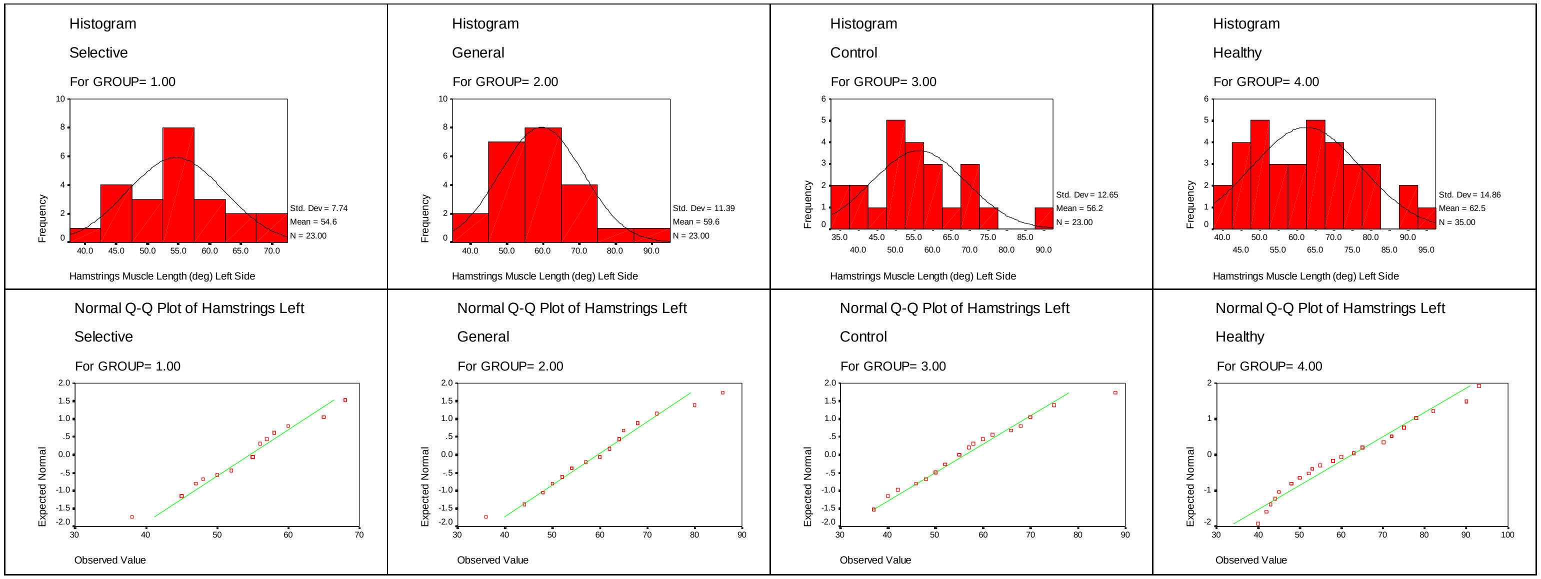
Graphs 17.15 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Circumferential Measurements Right Knee (Centimetres)



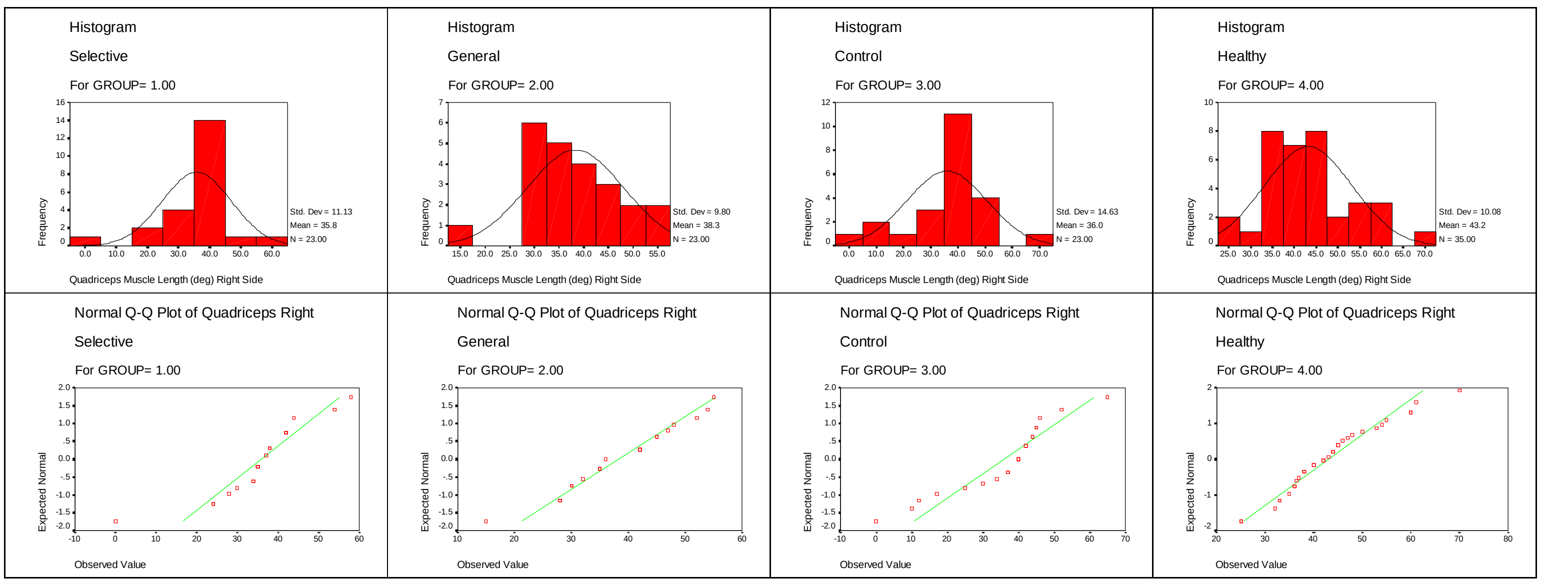
Graphs 17.16 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Knee Circumferential Measurements Left Knee (Centimetres)**



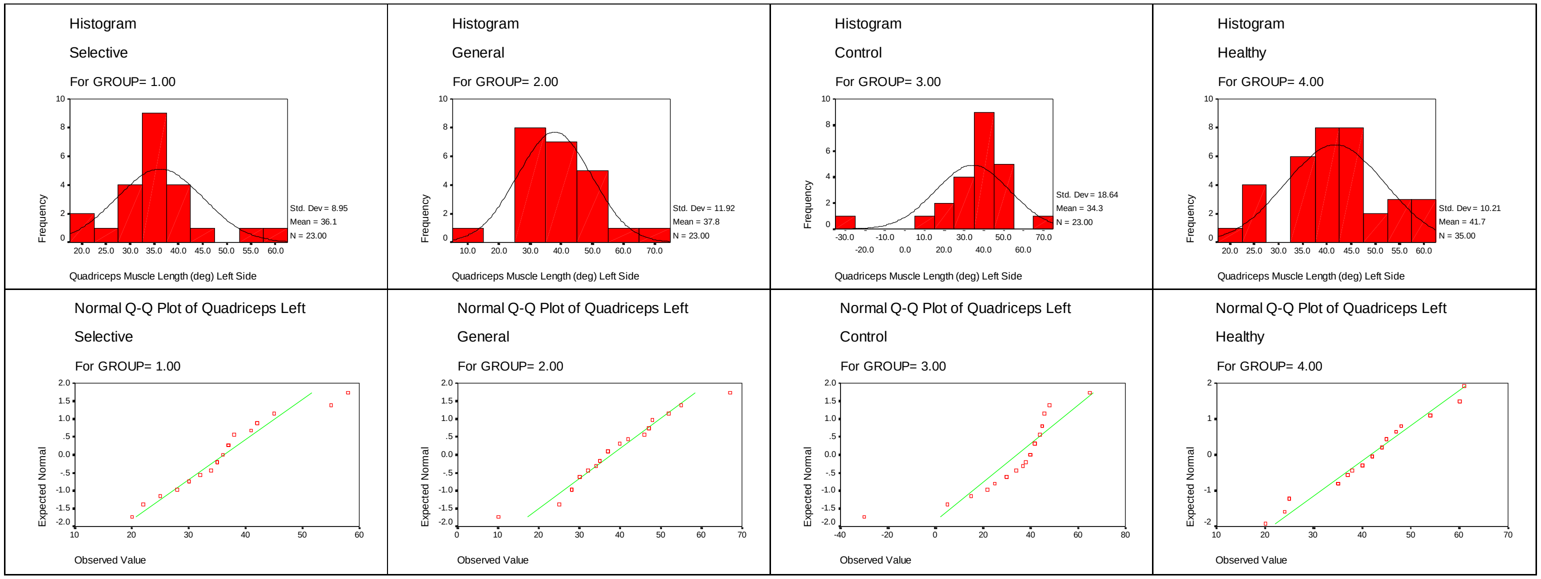
Graphs 17.17 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Hamstrings Length Right Side (Degrees)**



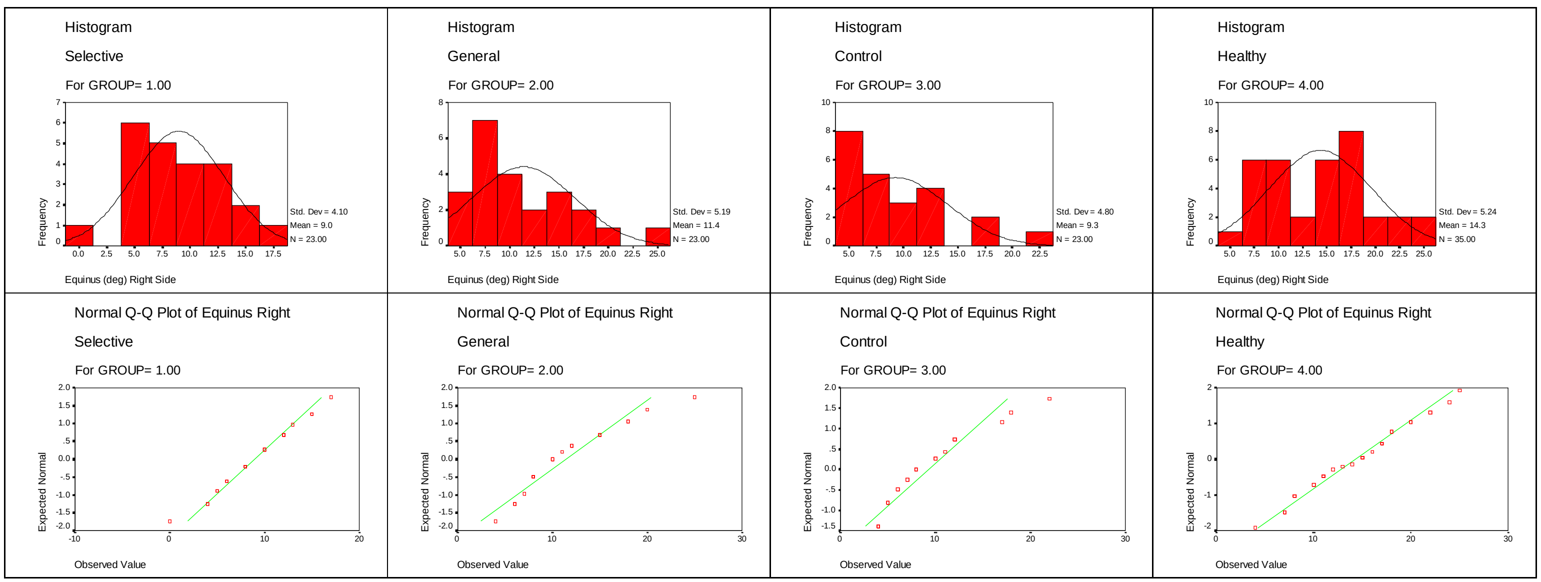
Graphs 17.18 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Hamstrings Length Left Side (Degrees)**



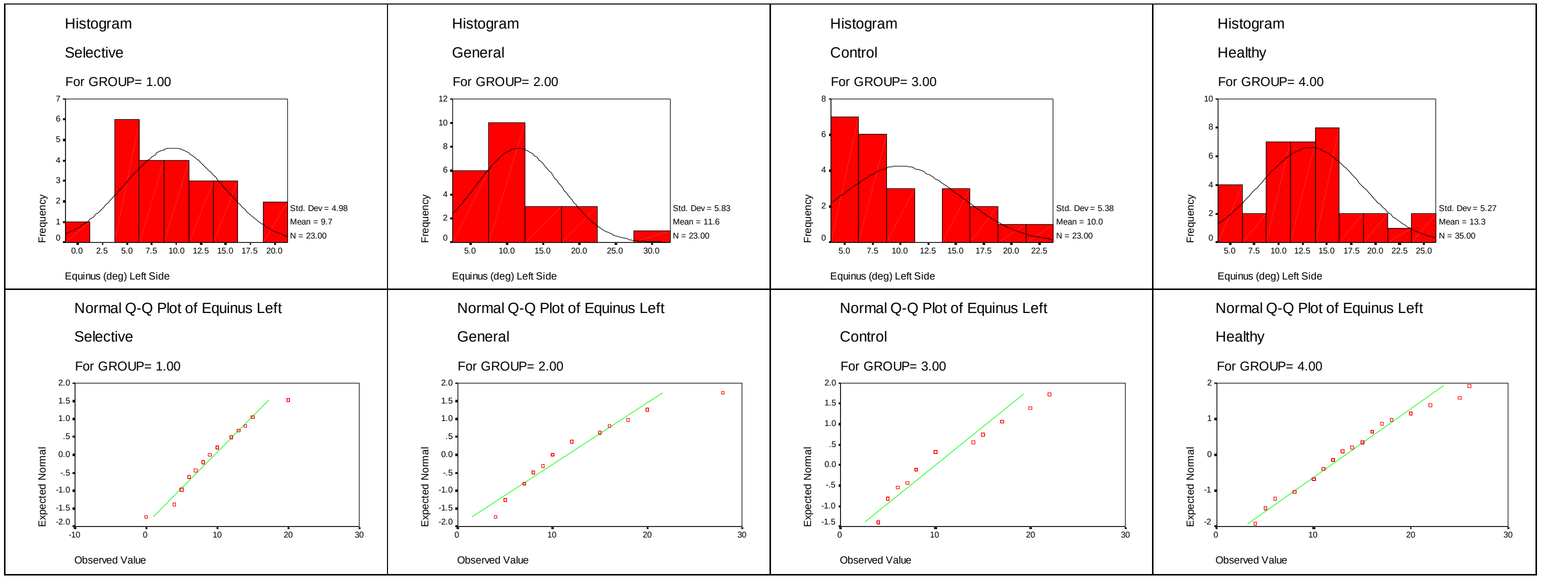
Graphs 17.19 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Quadriceps Length Right Side (Degrees)**



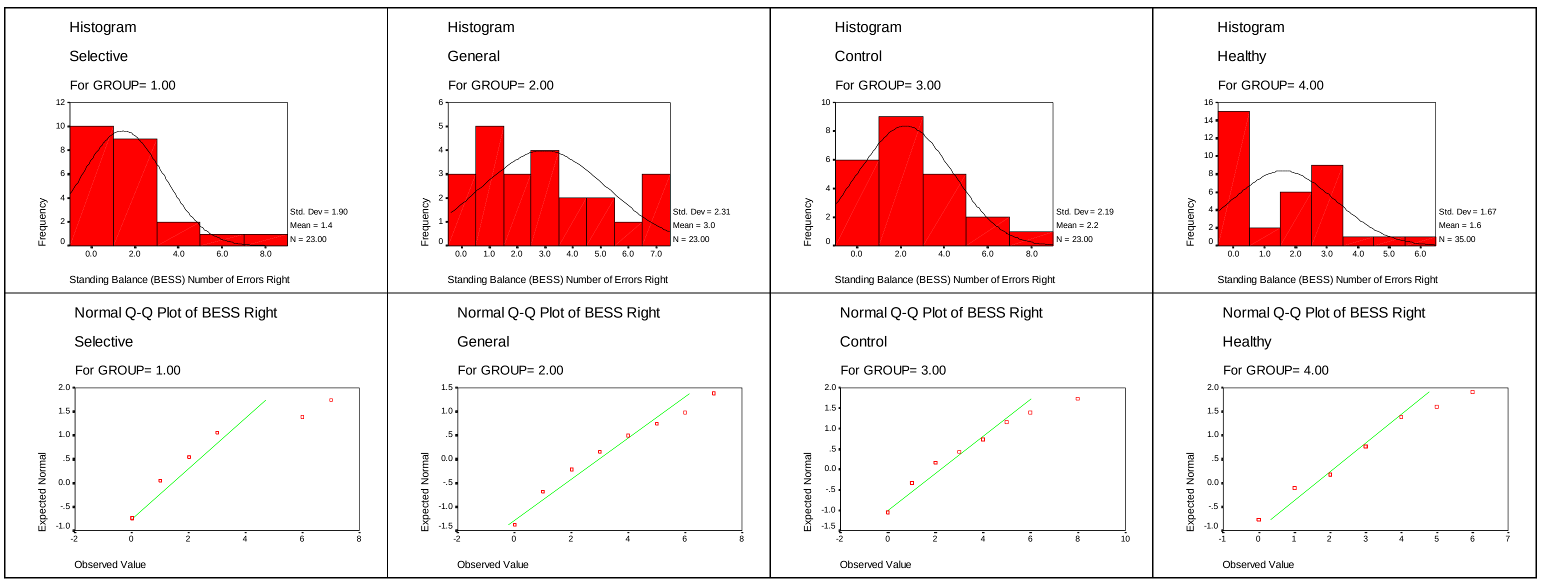
Graphs 17.20 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Quadriceps Length Left Side (Degrees)



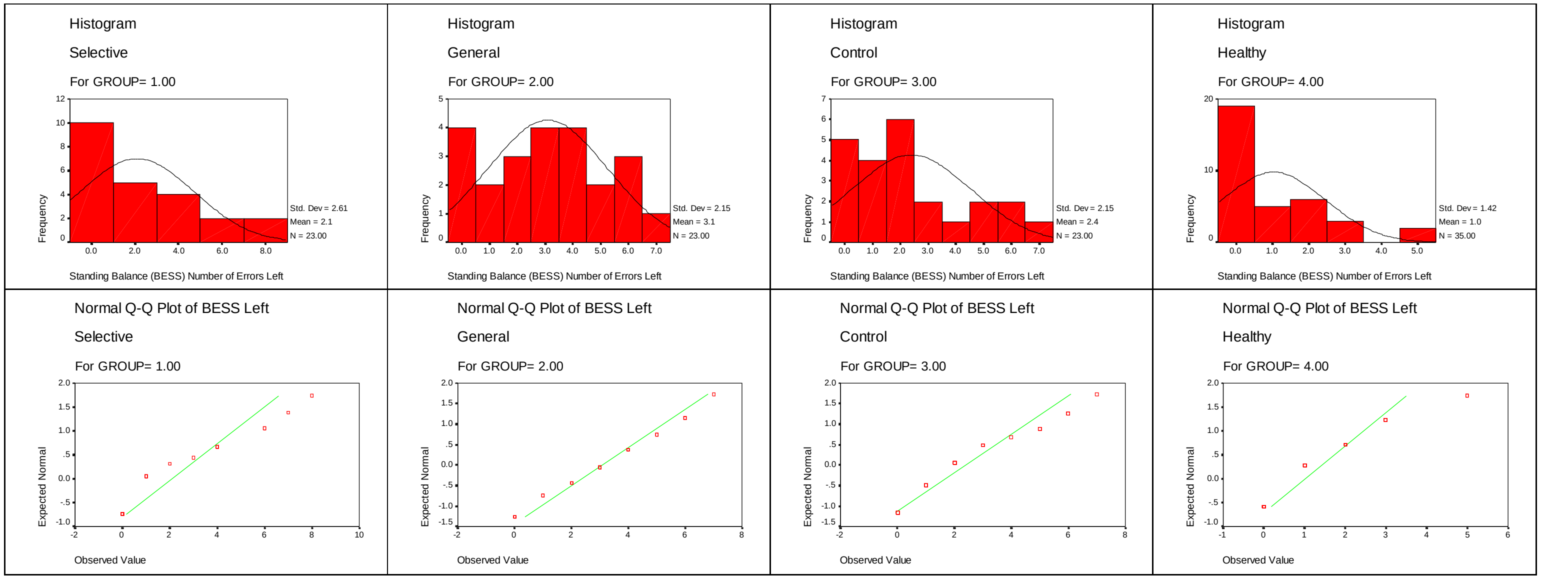
Graphs 17.21 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Equinus Right Side (Degrees)



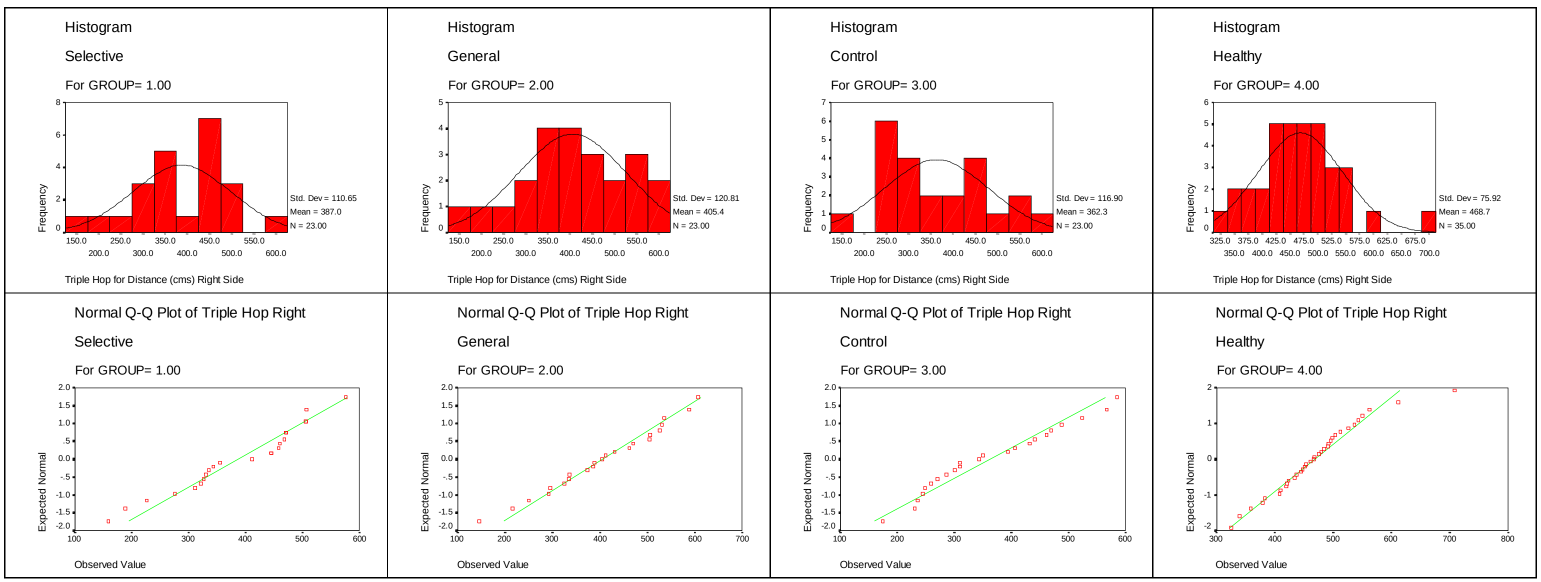
Graphs 17.22 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Equinus Left Side (Degrees)**



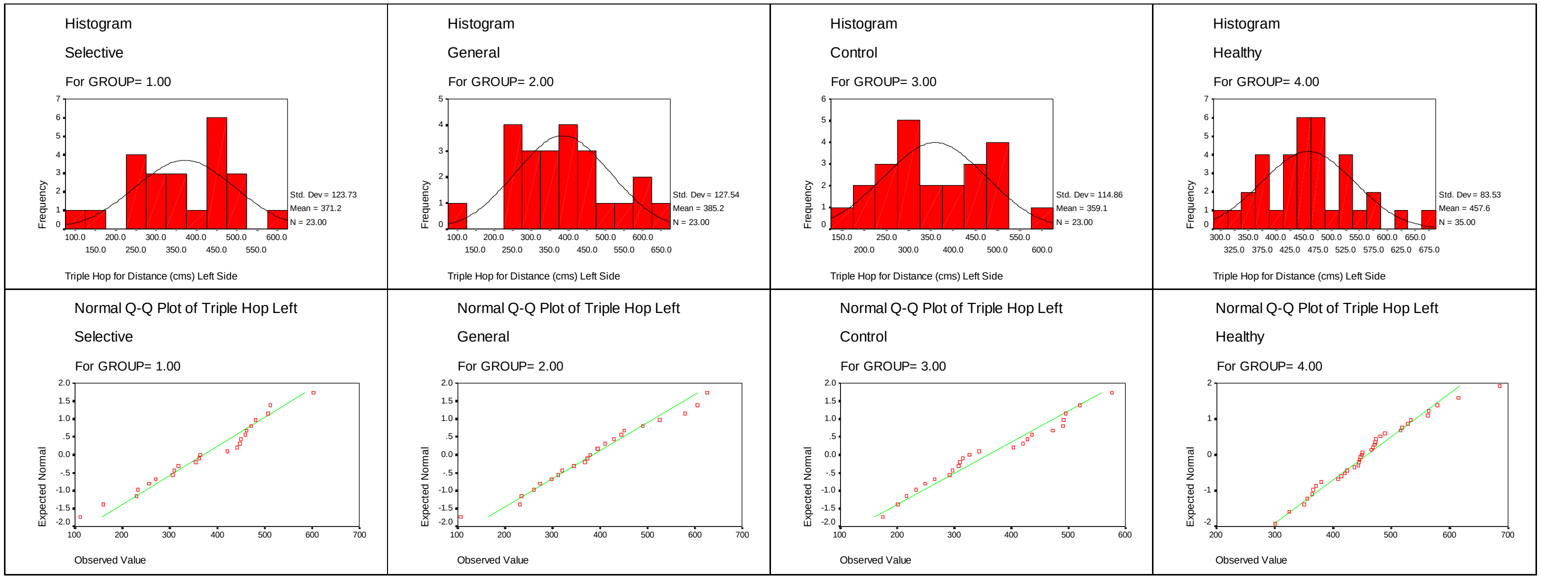
Graphs 17.23 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for BESS Test Right Side (Number of Errors)**



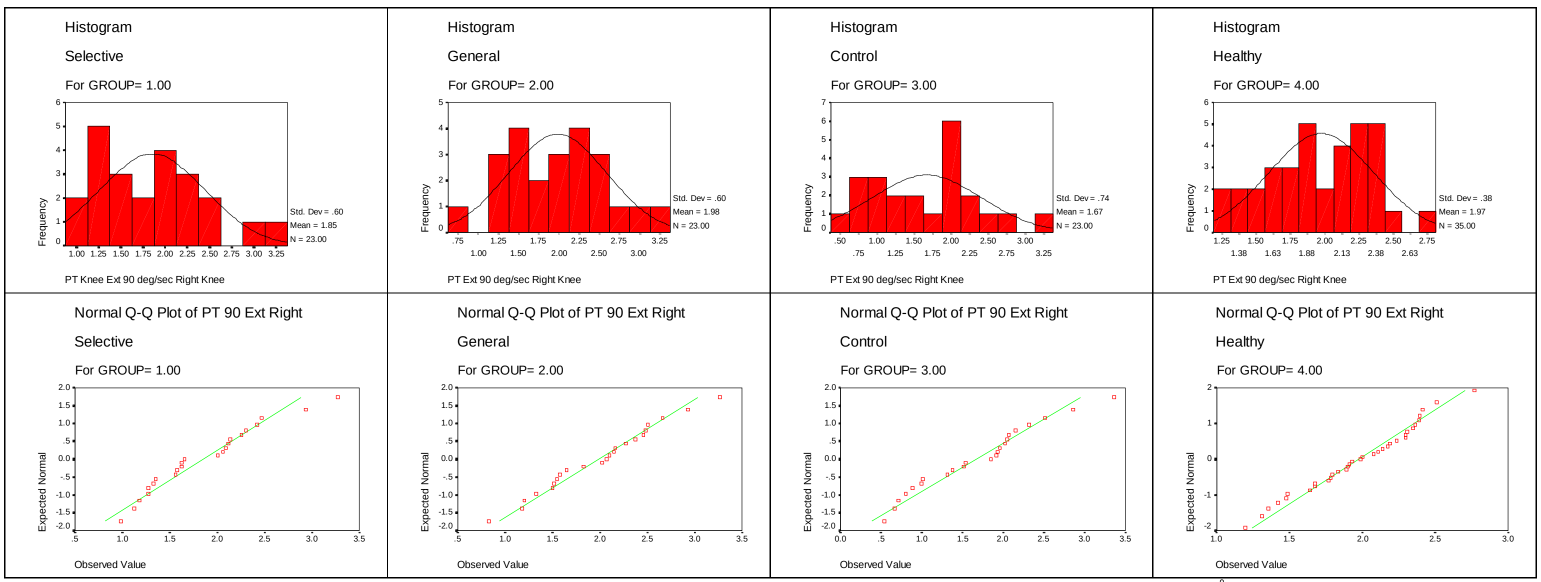
Graphs 17.24 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for BESS Test Left Side (Number of Errors)**



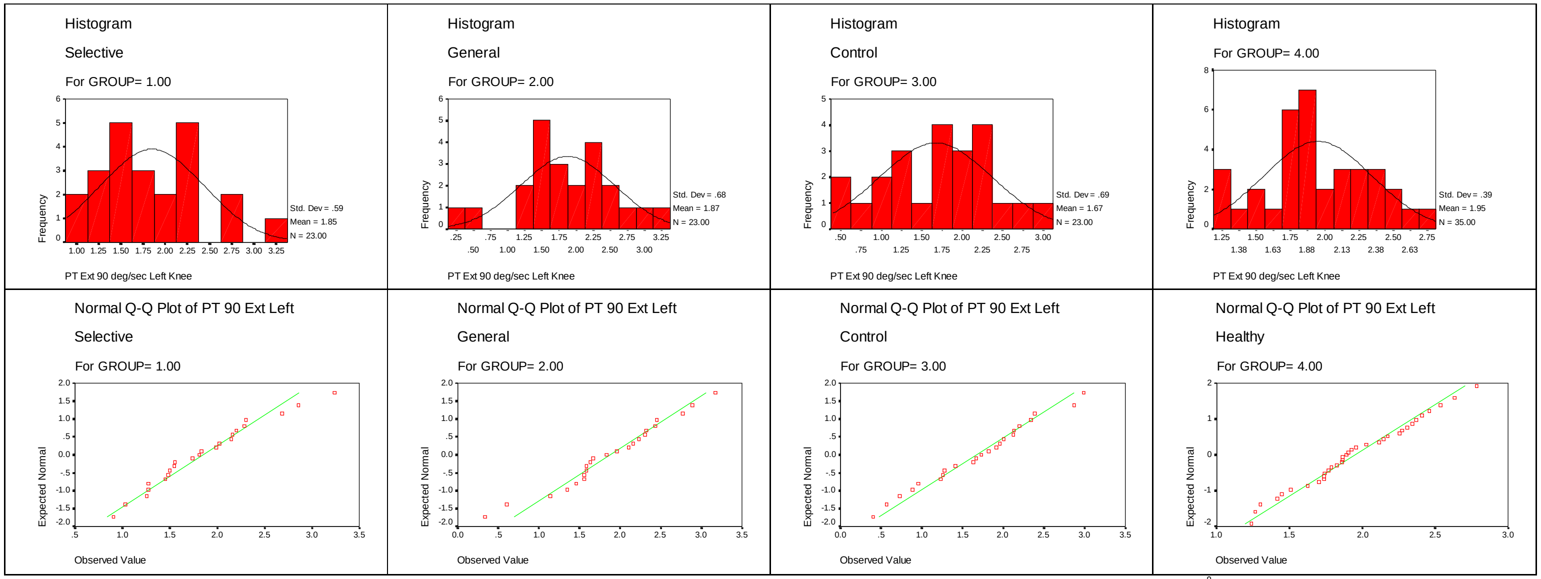
Graphs 17.25 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Triple Hop for Distance Right Side (Centimetres)**



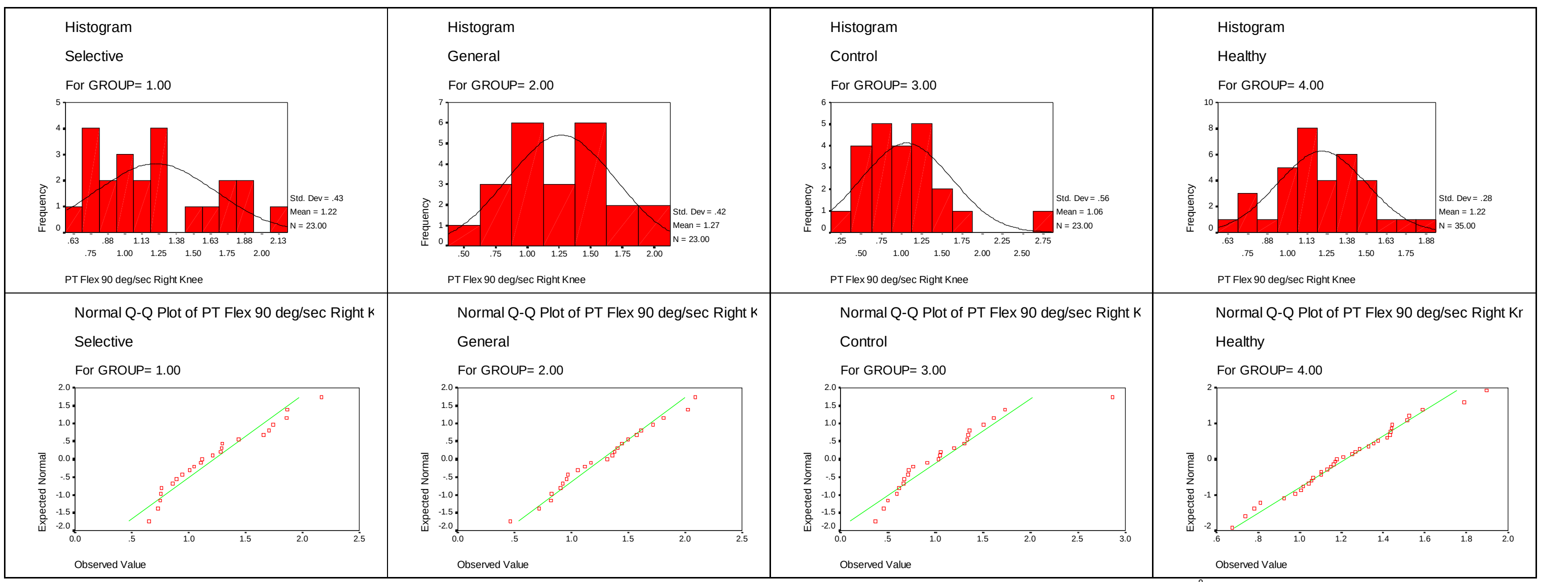
Graphs 17.26 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Triple Hop for Distance Left Side (Centimetres)**



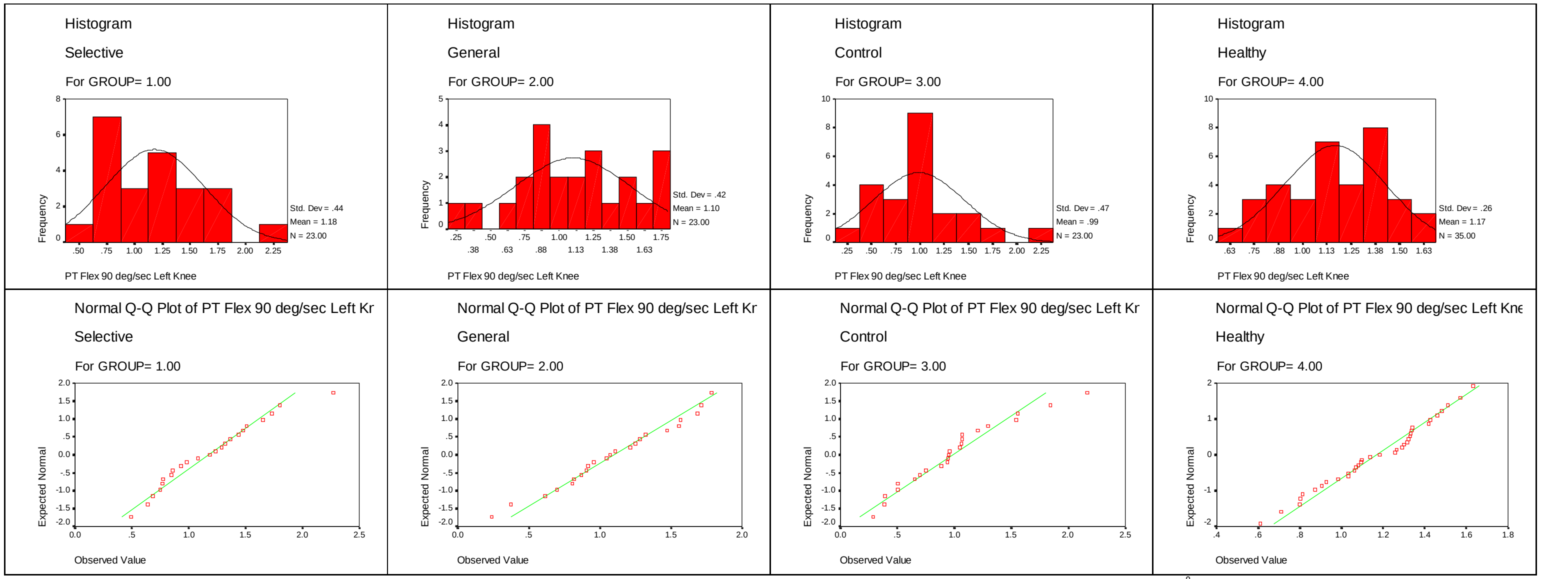
Graphs 17.27 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Extension Right Knee at 90°/s Nm/kg**



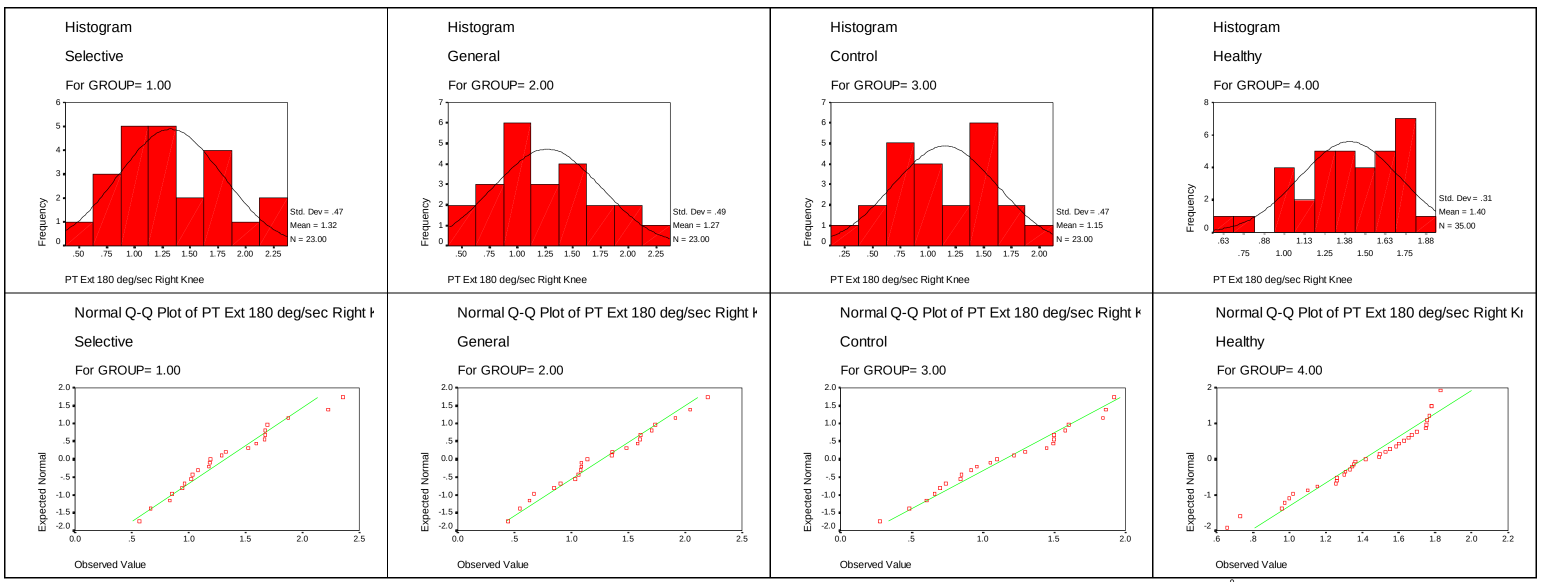
Graphs 17.28 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Extension Left Knee at 90°/s Nm/kg**



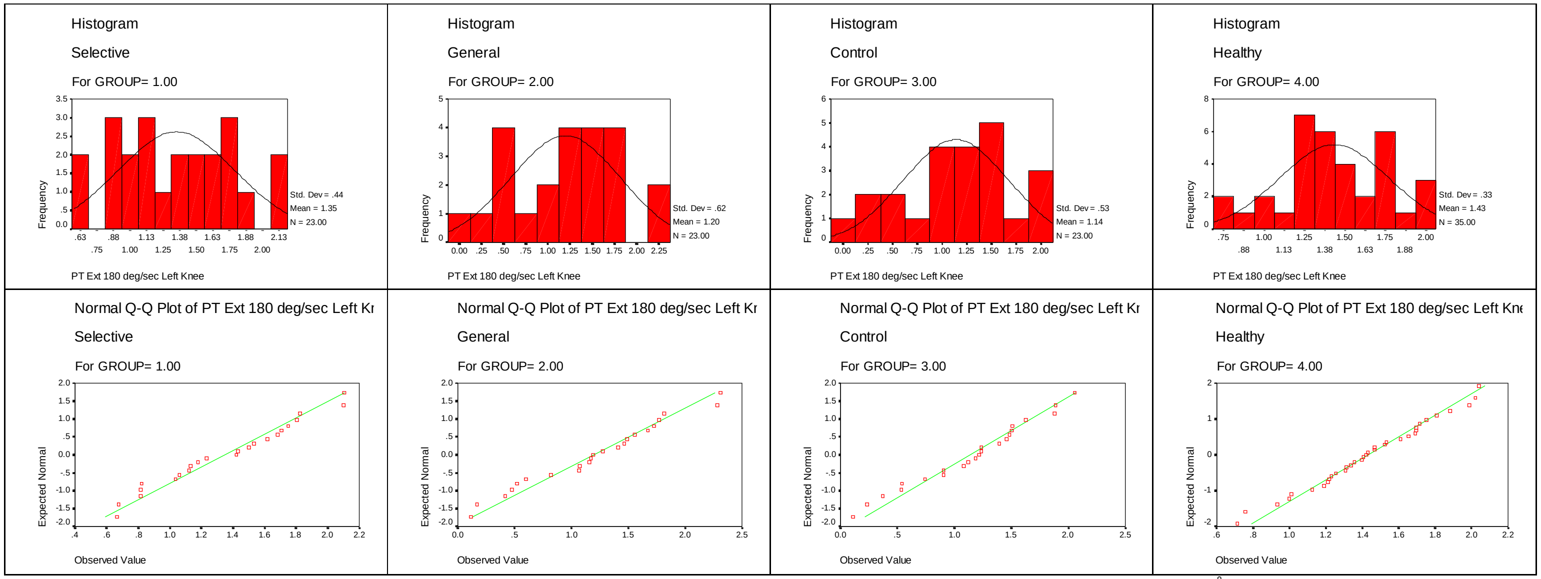
Graphs 17.29 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Flexion Right Knee at 90°/s Nm/kg**



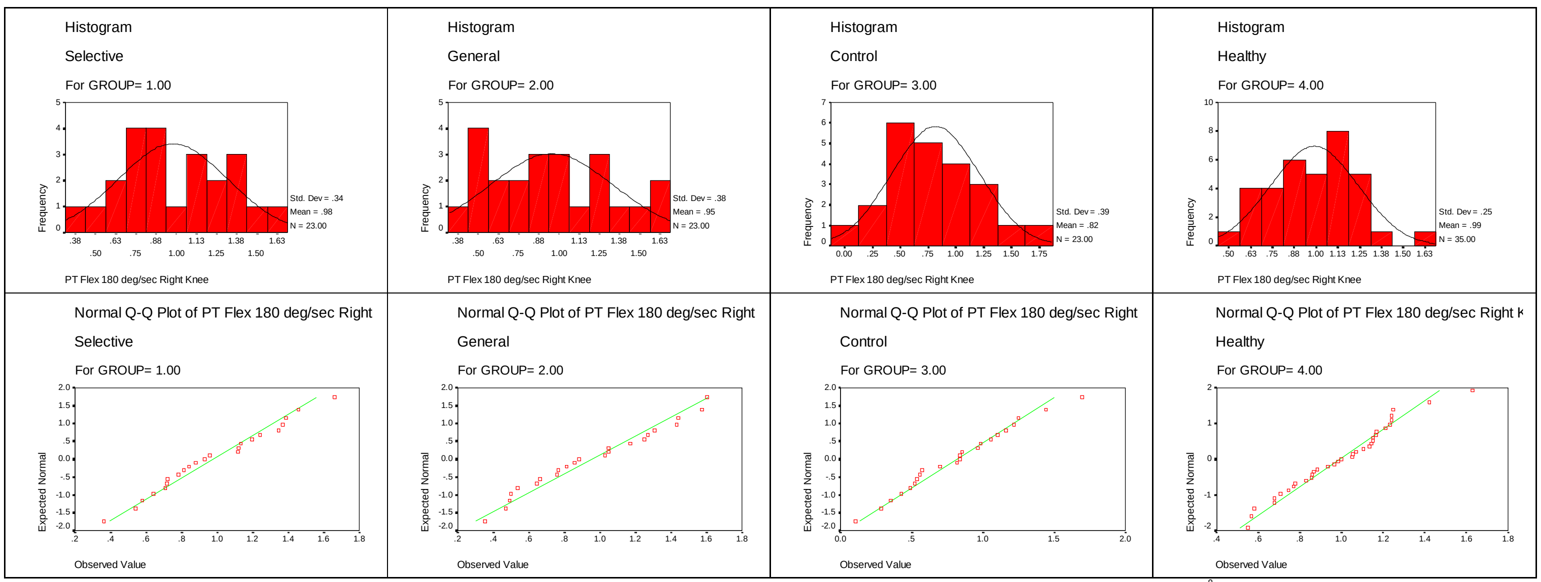
Graphs 17.30 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Flexion Left Knee at 90°/s Nm/kg**



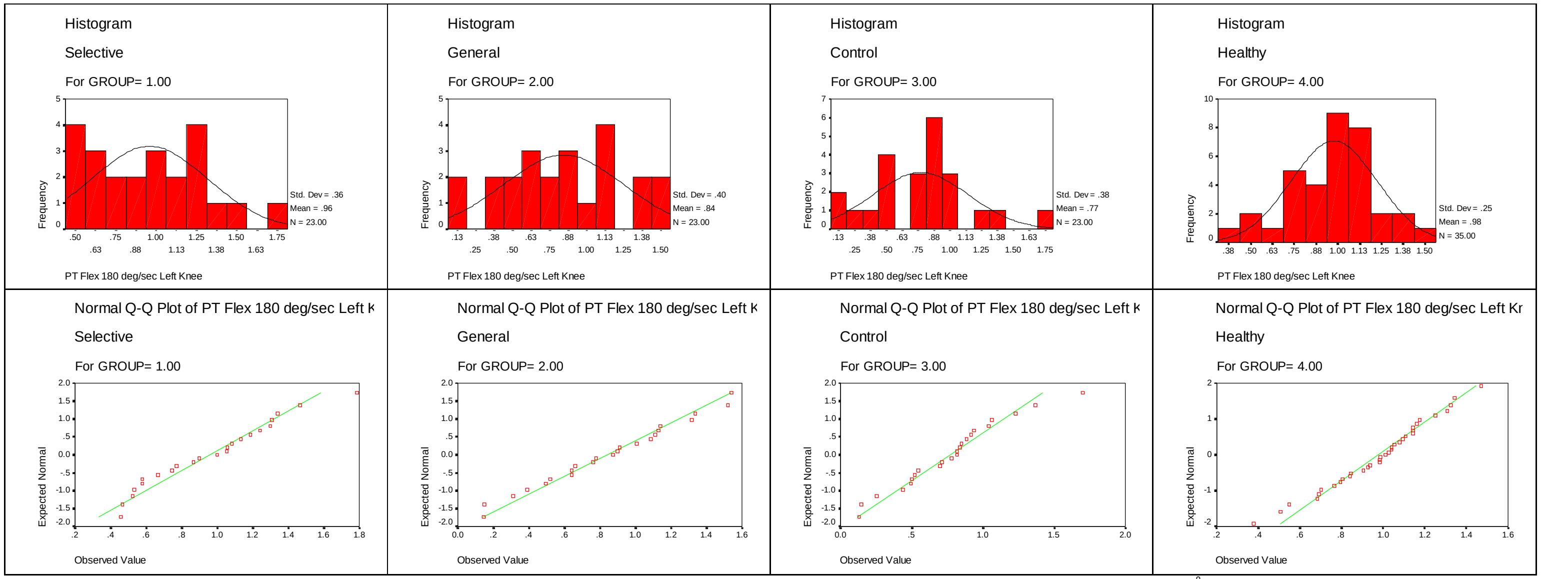
Graphs 17.31 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Extension Right Knee at 180°/s Nm/kg**



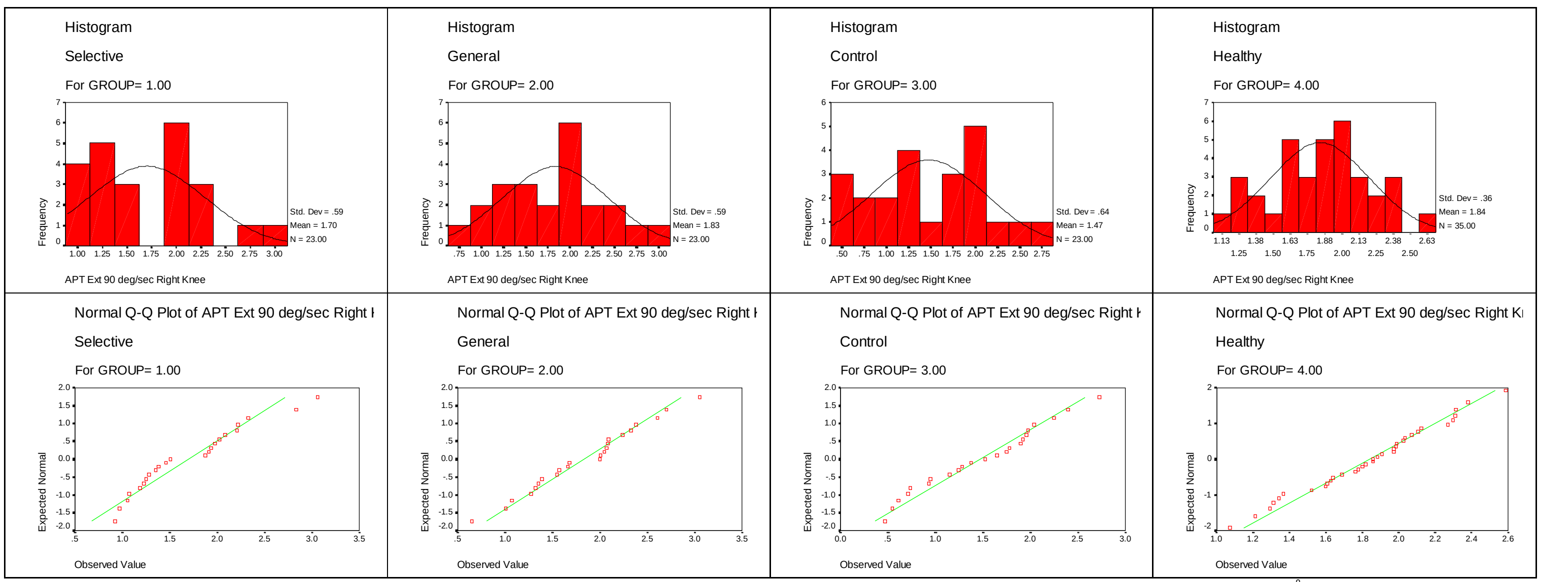
Graphs 17.32 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Extension Left Knee at 180°/s Nm/kg**



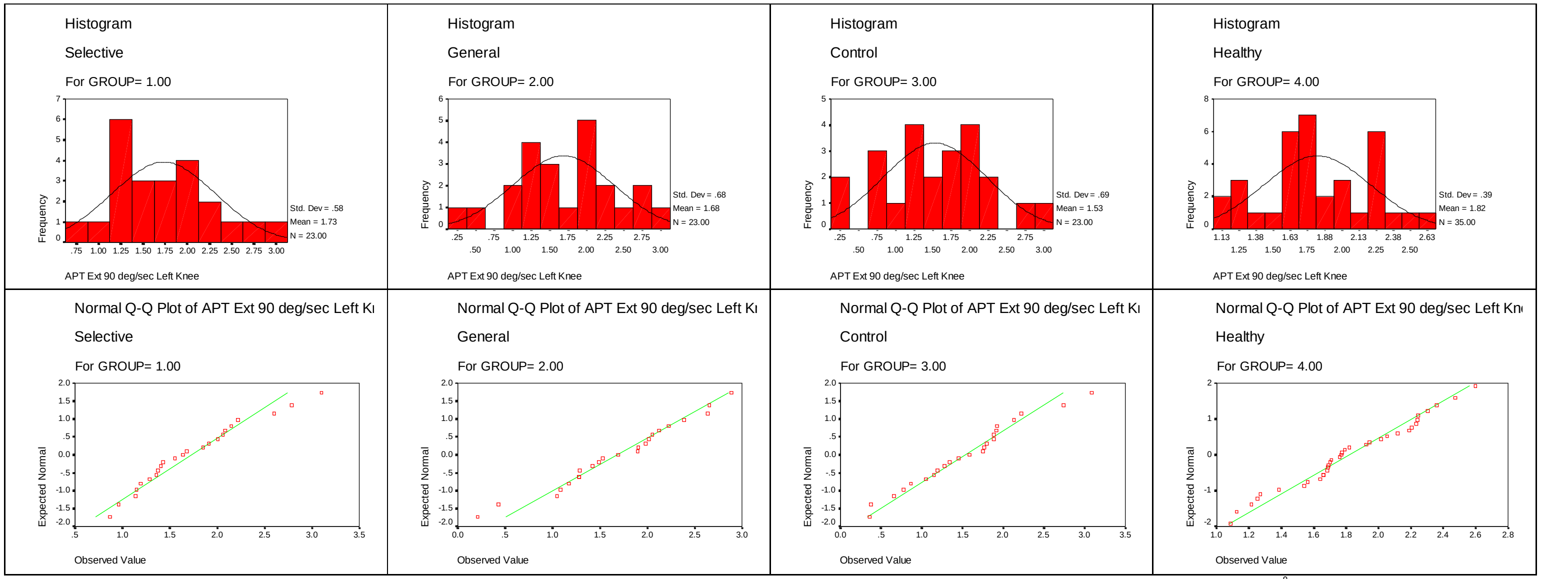
Graphs 17.33 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Flexion Right Knee at 180°/s Nm/kg**



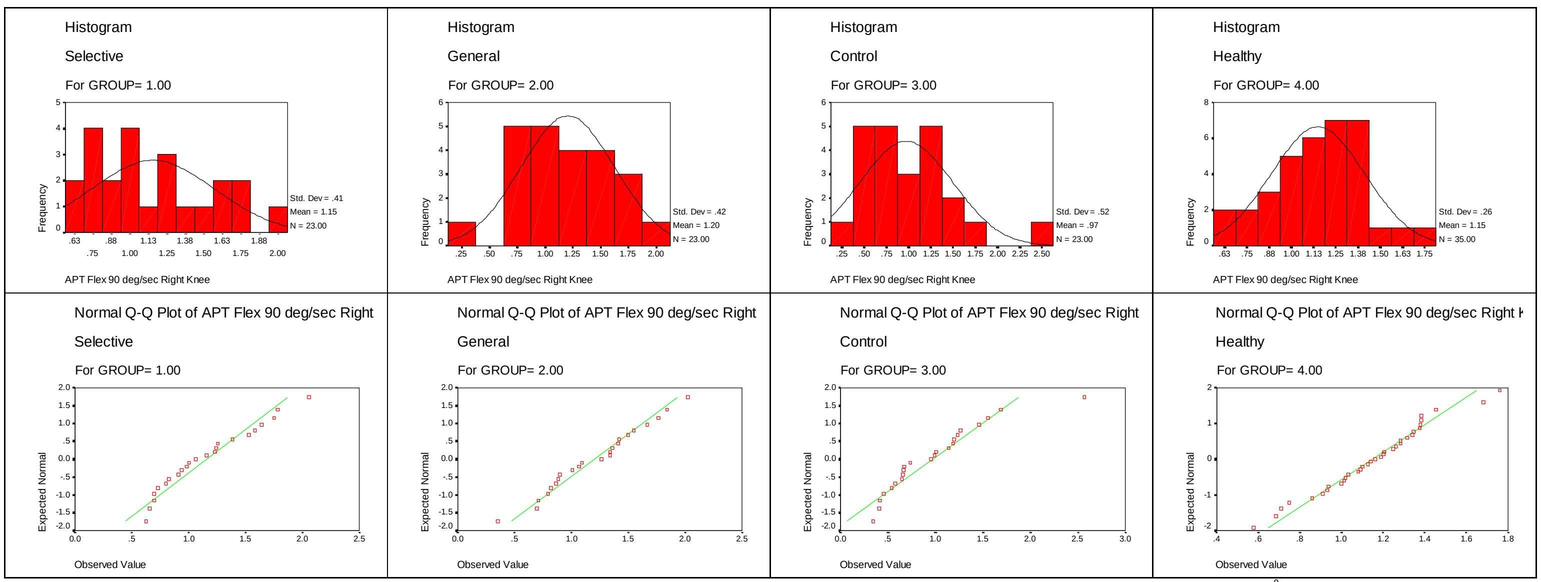
Graphs 17.34 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Peak Torque Flexion Left Knee at 180°/s Nm/kg**



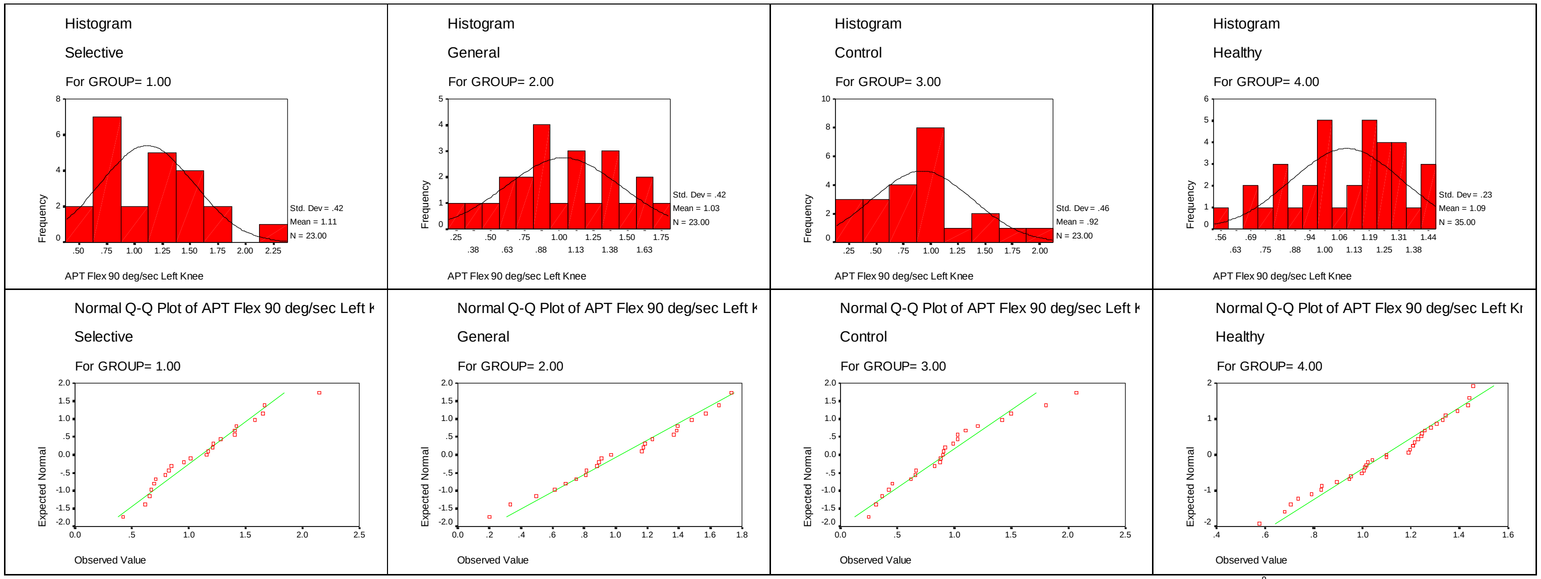
Graphs 17.35 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Extension Right Knee at 90°/s Nm/kg**



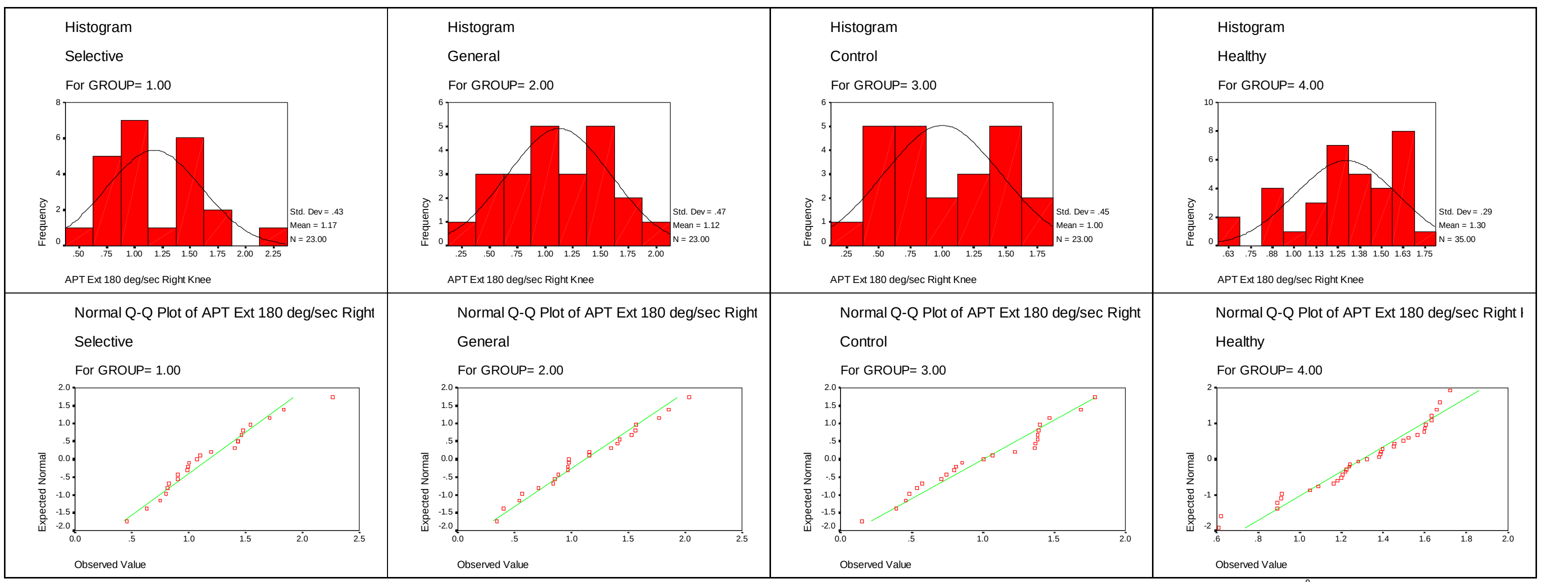
Graphs 17.36 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Extension Left Knee at 90°/s Nm/kg**



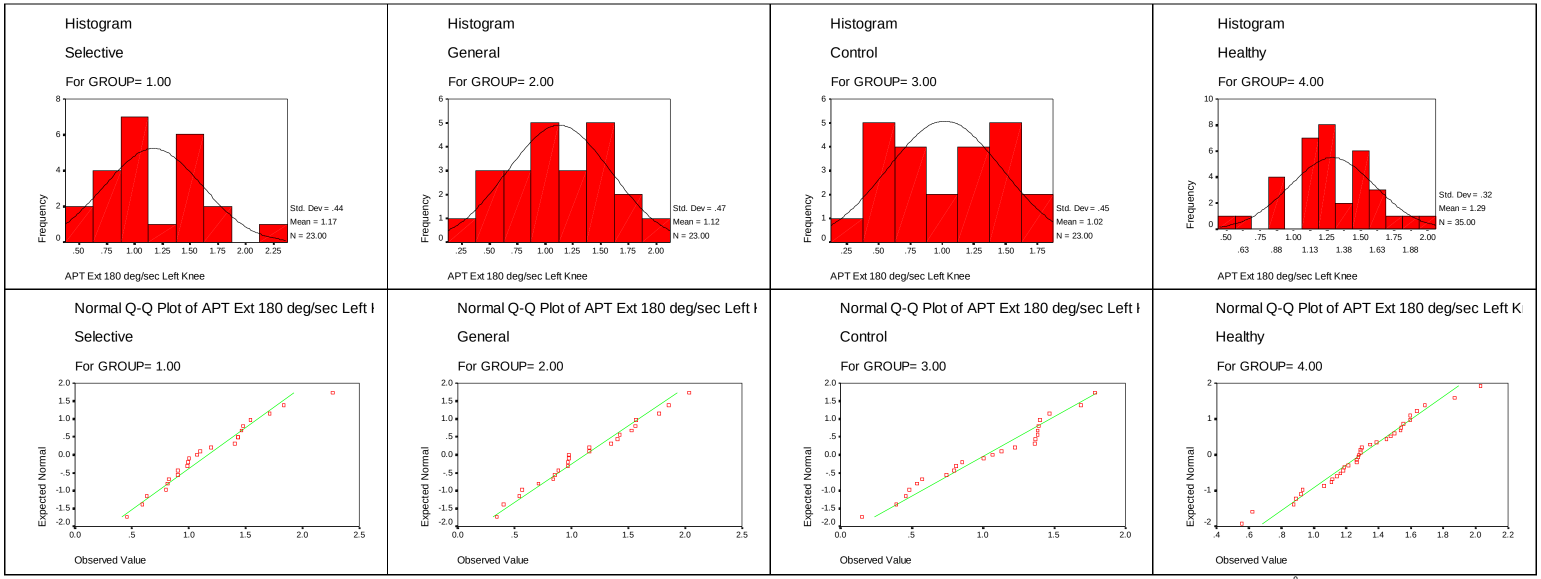
Graphs 17.37 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Flexion Right Knee at 90°/s Nm/kg**



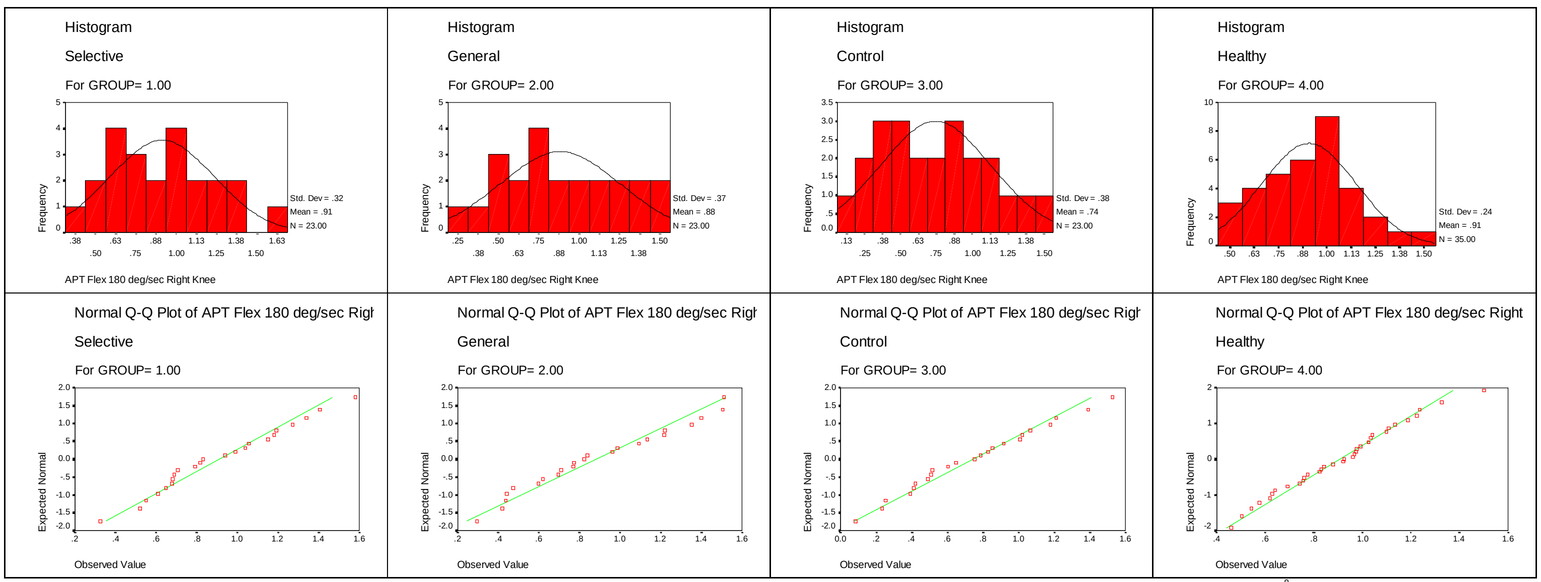
Graphs 17.38 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Flexion Left Knee at 90°/s Nm/kg**



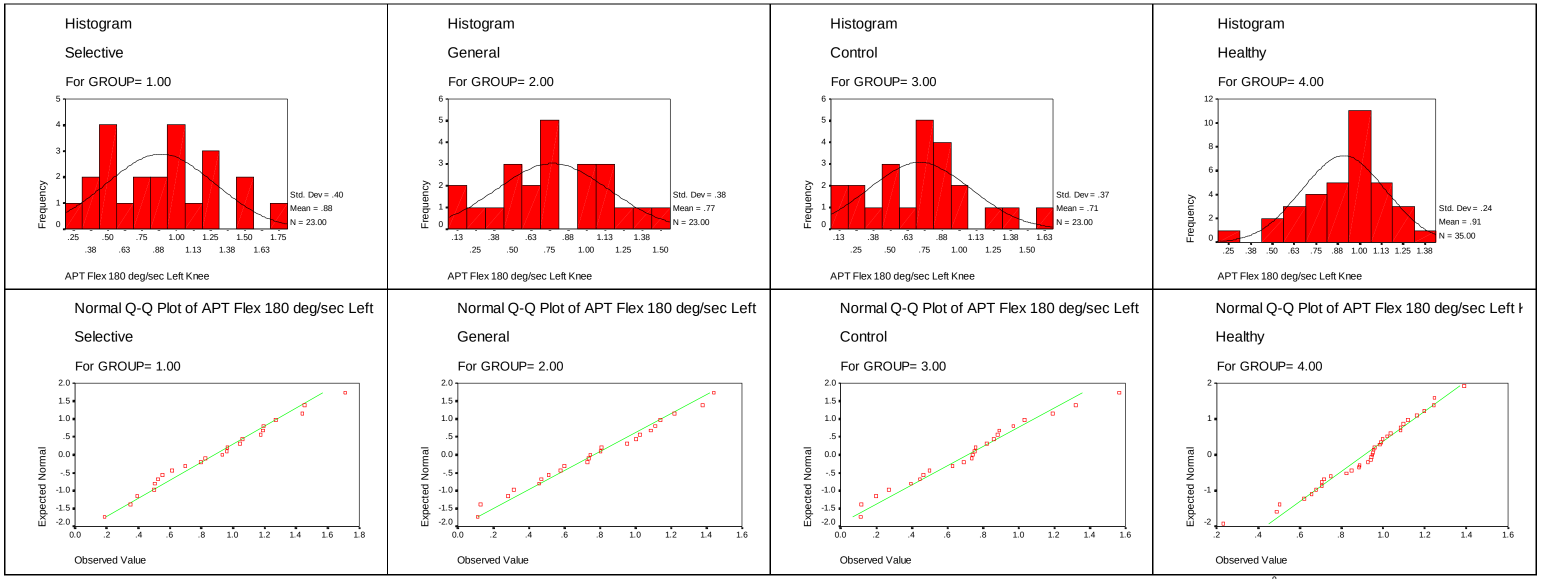
Graphs 17.39 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Extension Right Knee at 180°/s Nm/kg**



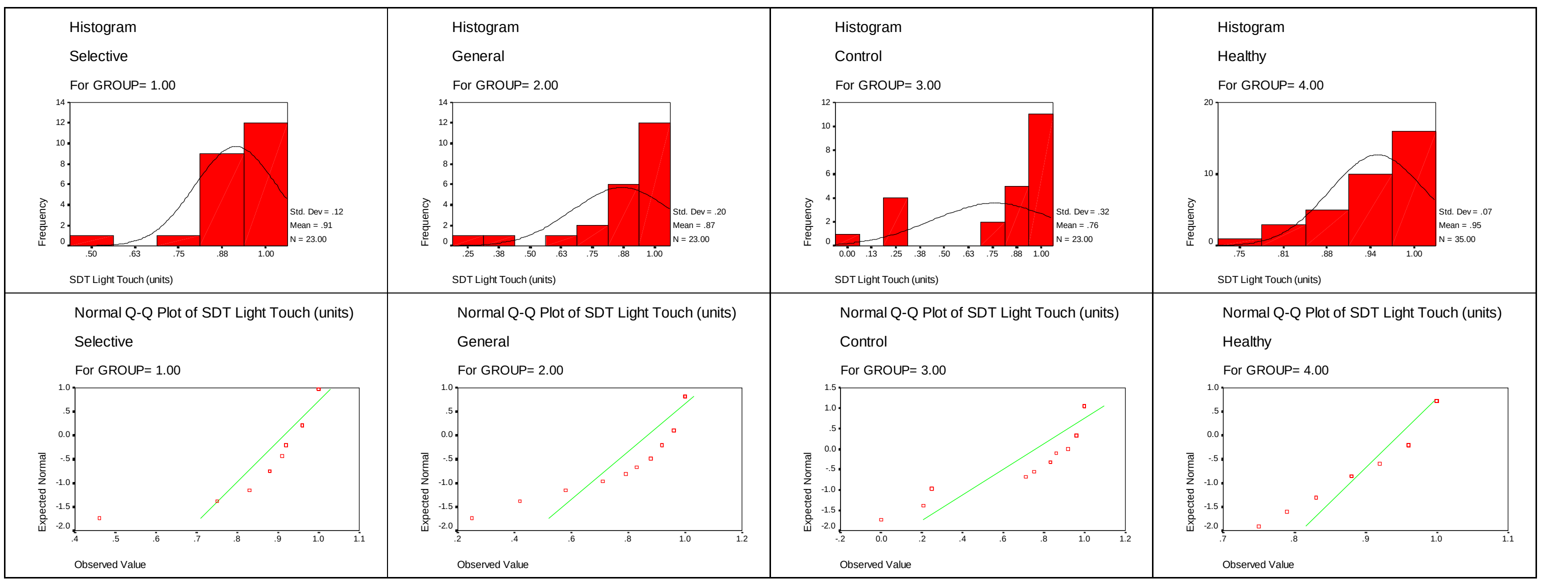
Graphs 17.40 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Extension Left Knee at 180°/s Nm/kg



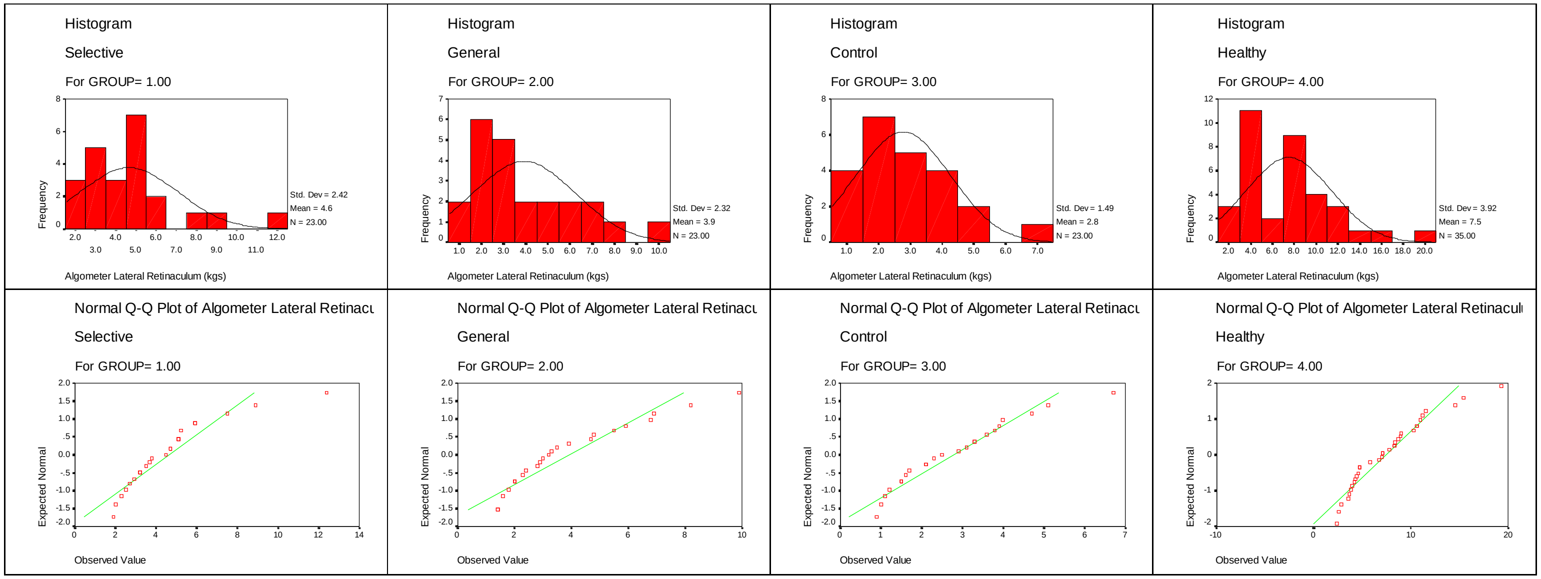
Graphs 17.41 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Flexion Right Knee at 180°/s Nm/kg



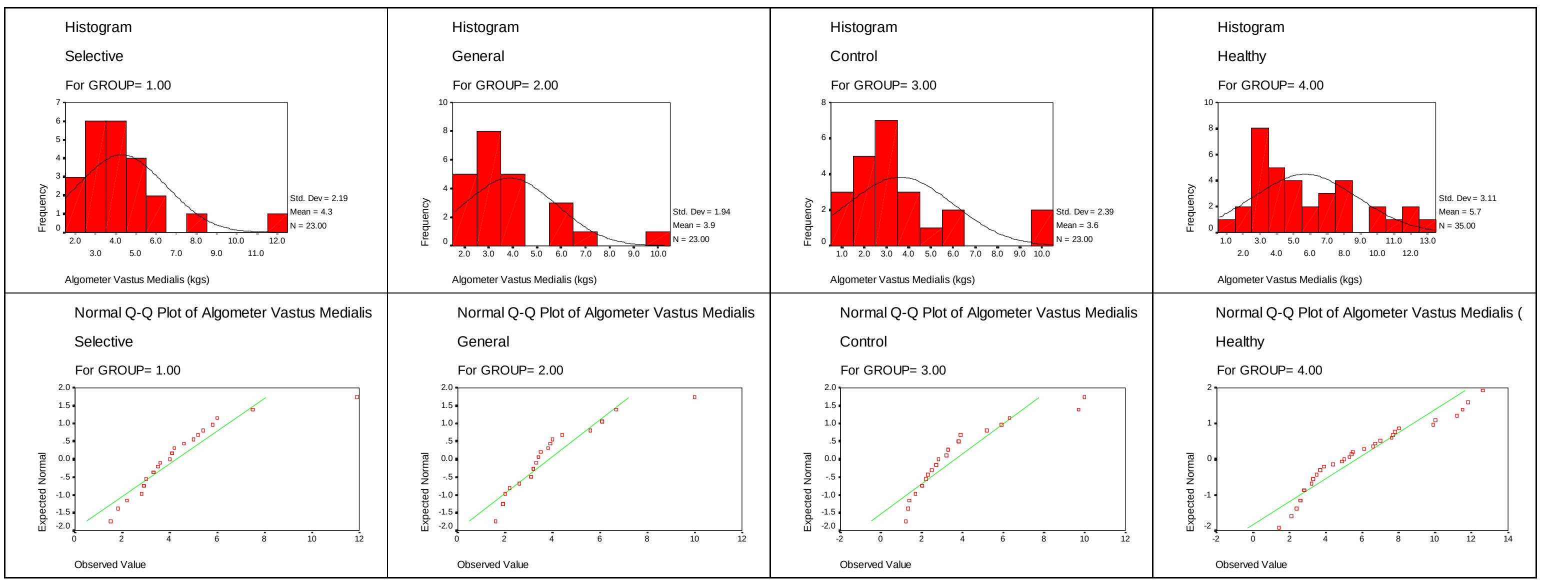
Graphs 17.42 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Average Peak Torque Flexion Left Knee at 180°/s Nm/kg**



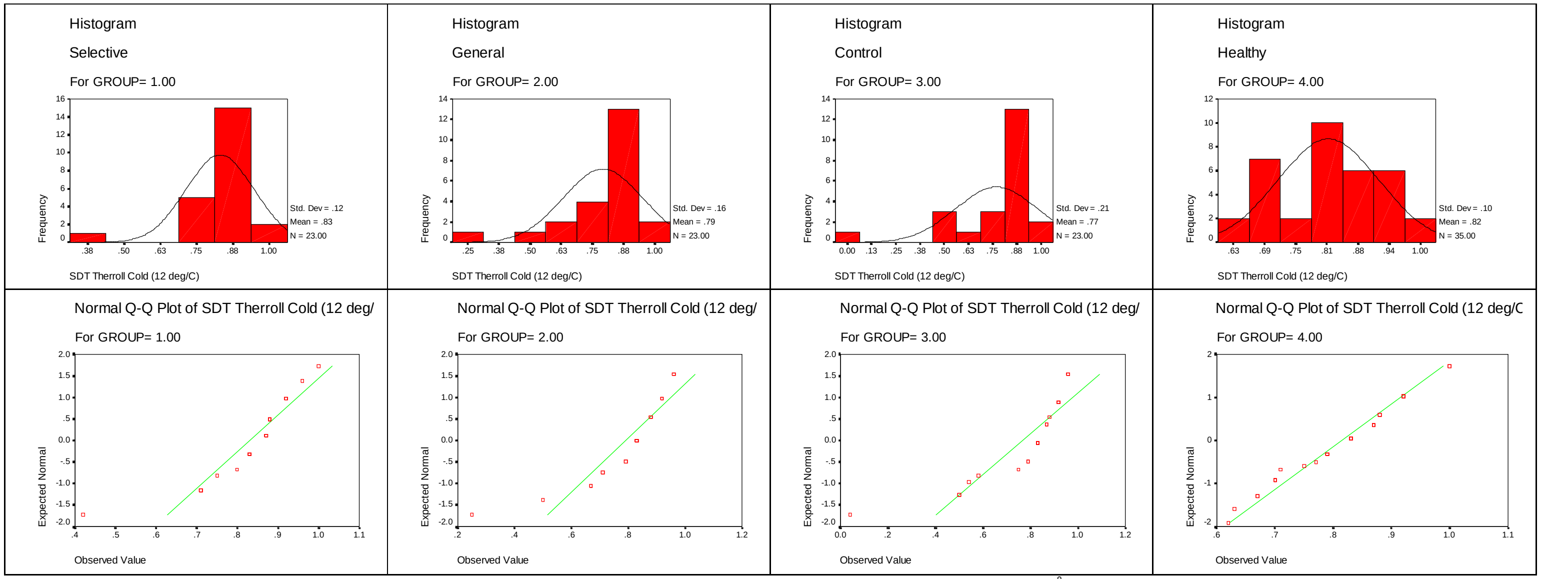
Graphs 17.43 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Light Touch SDT at Lateral Retinaculum (Units)**



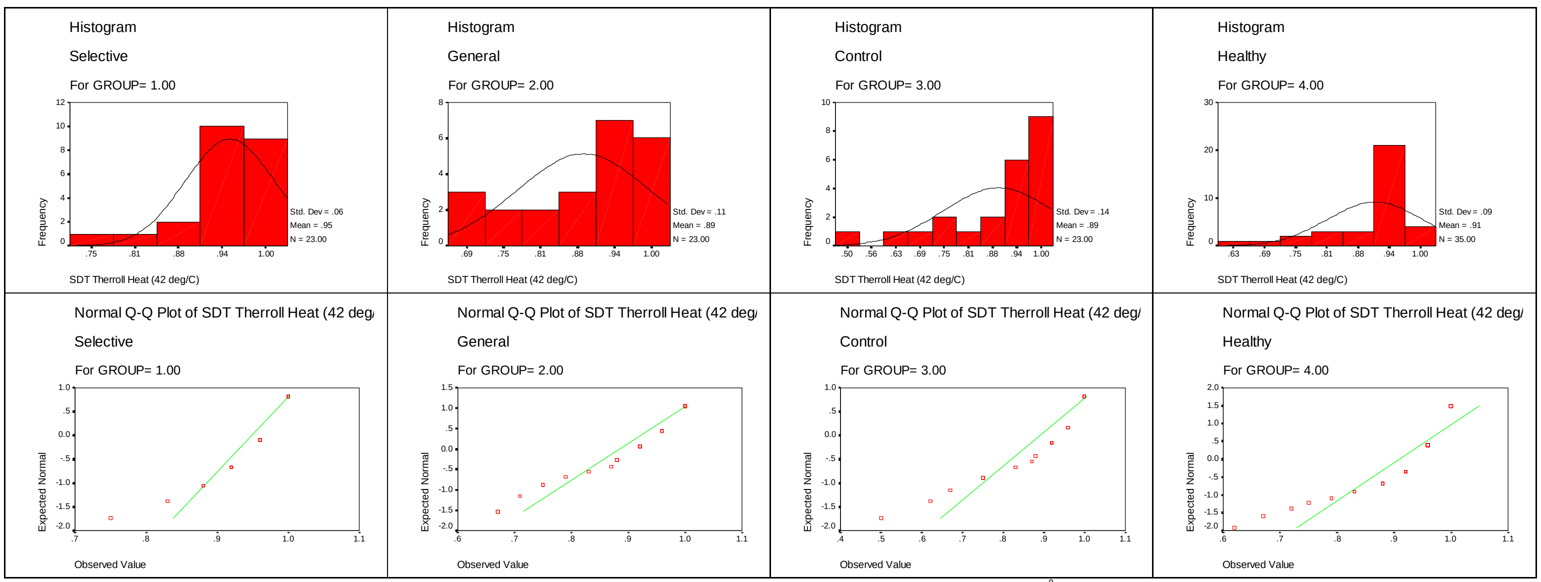
Graphs 17.44 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Algometer Measurements at Lateral Retinaculum (Kgs)



Graphs 17.45 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Algometer Measurements at Vastus Medialis Muscle (Kgs)



Graphs 17.46 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Therroll SDT Cold 12°/C (Units)**



Graphs 17.47 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Therroll SDT Hot 42°/C (Units)**

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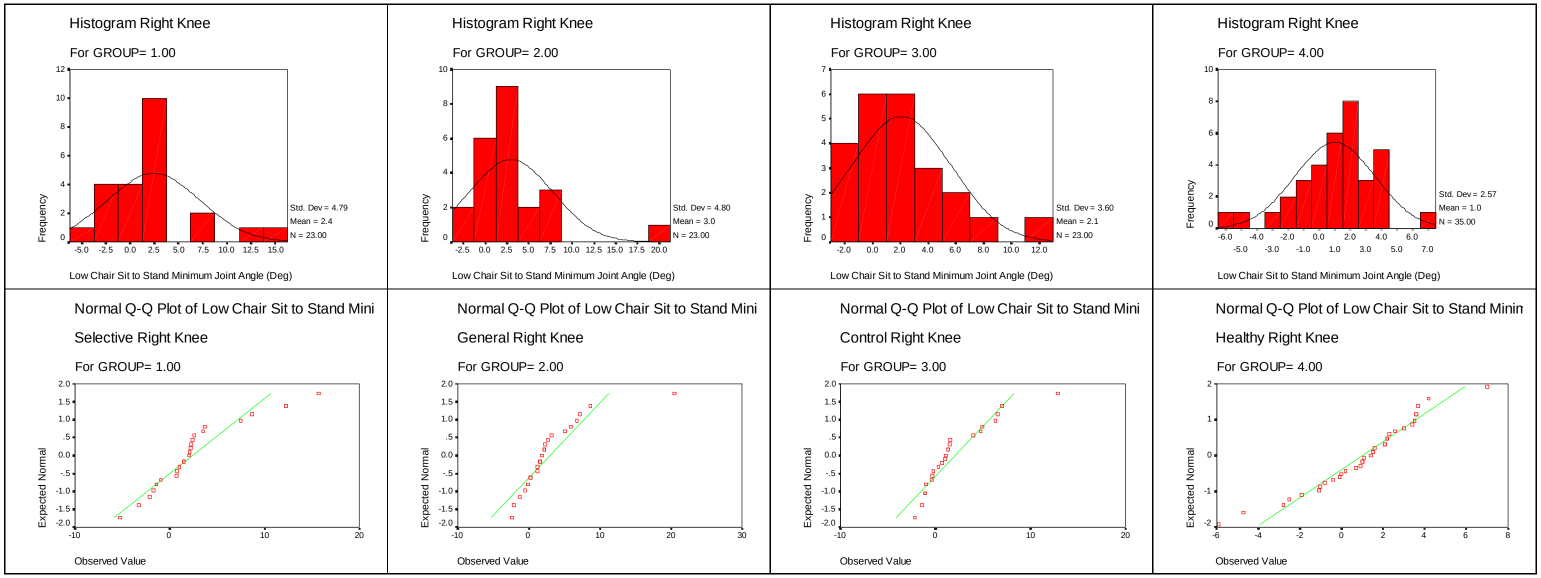
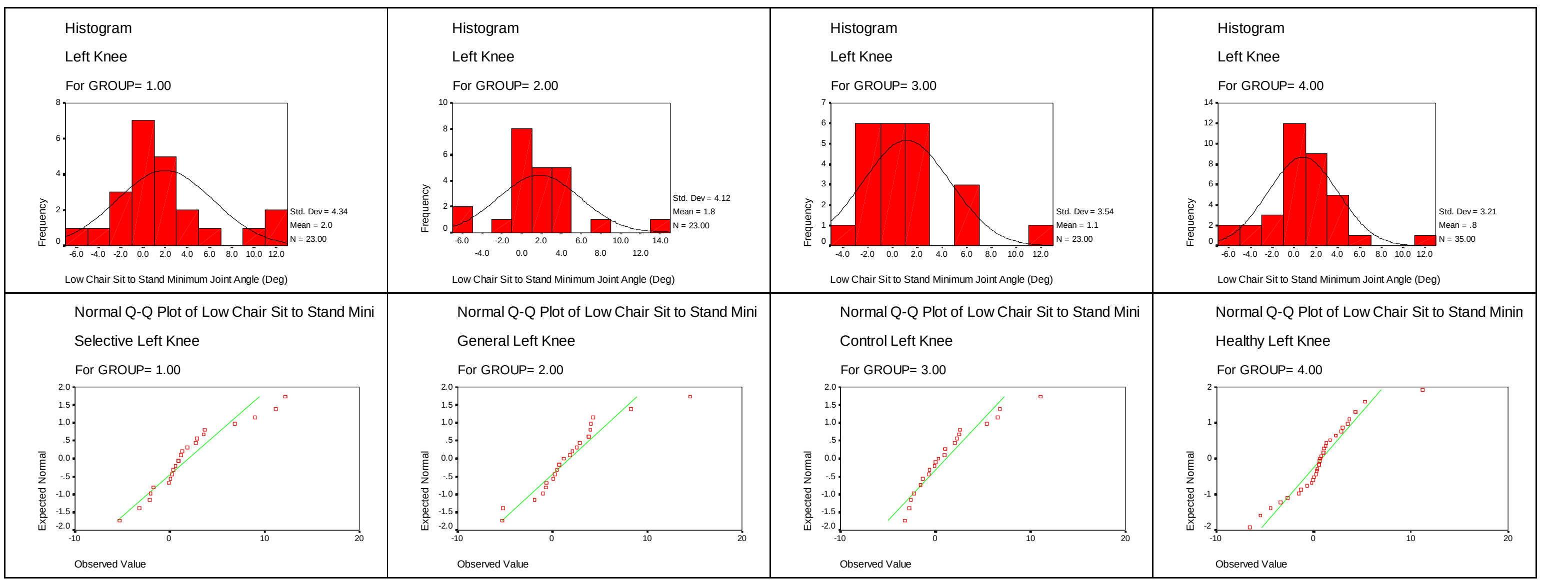
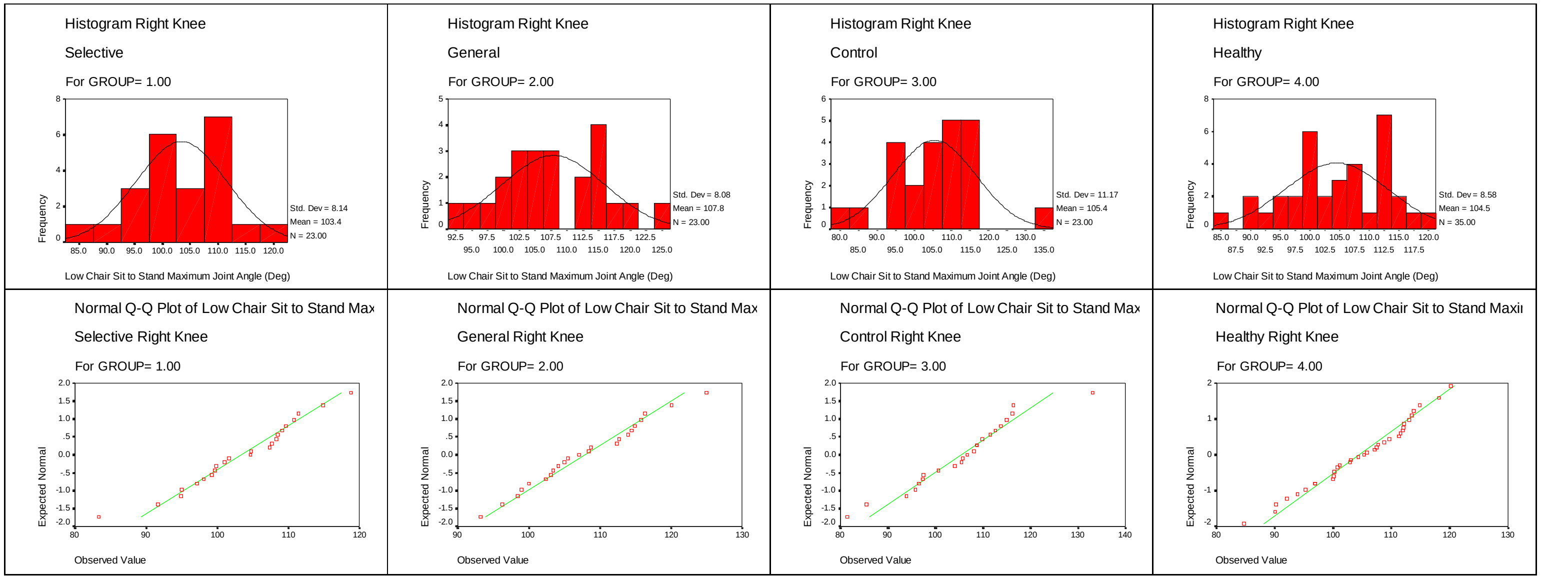


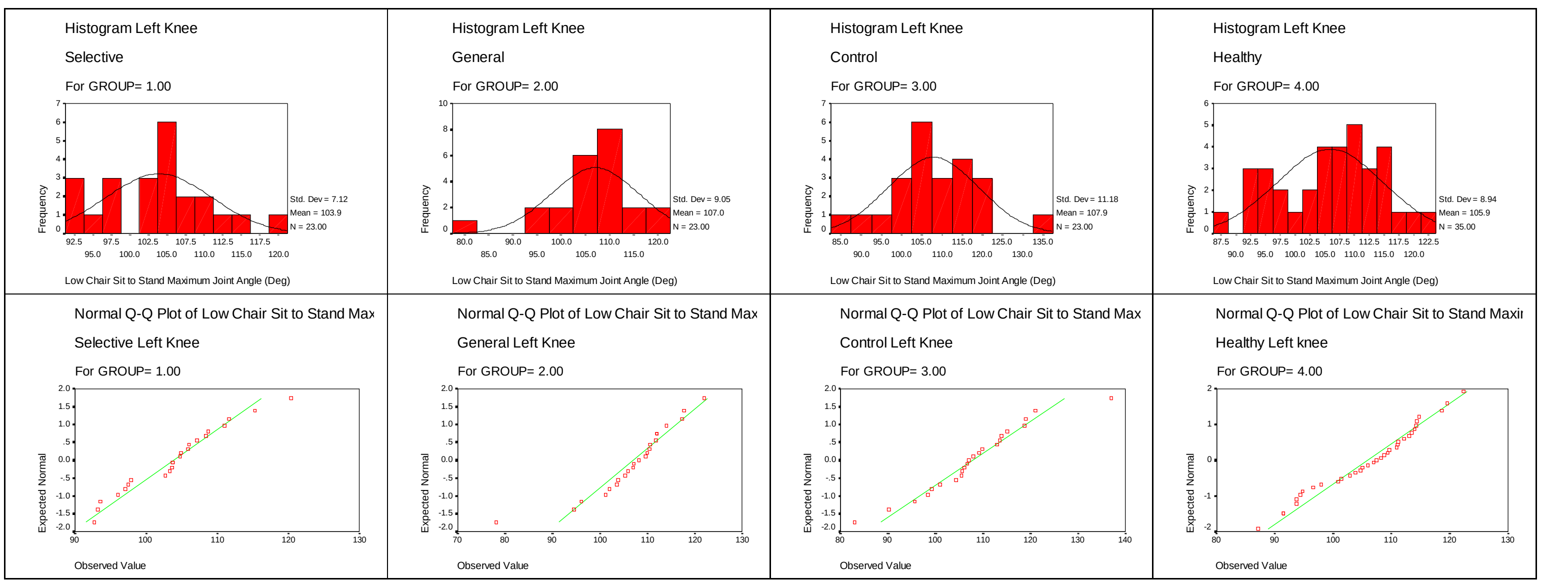
Graphs 17.48 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Minimum Right Knee Joint Angle (Degrees)**



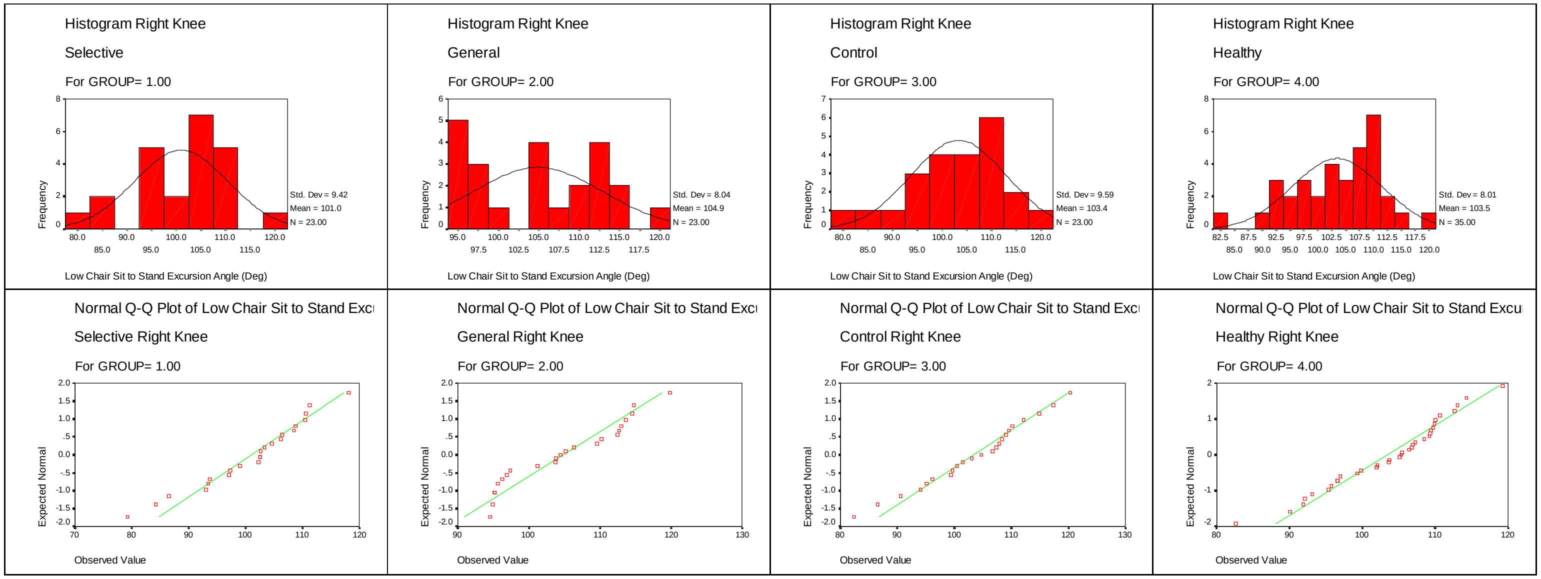
Graphs 17.49 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Minimum Left Knee Joint Angle (Degrees)**



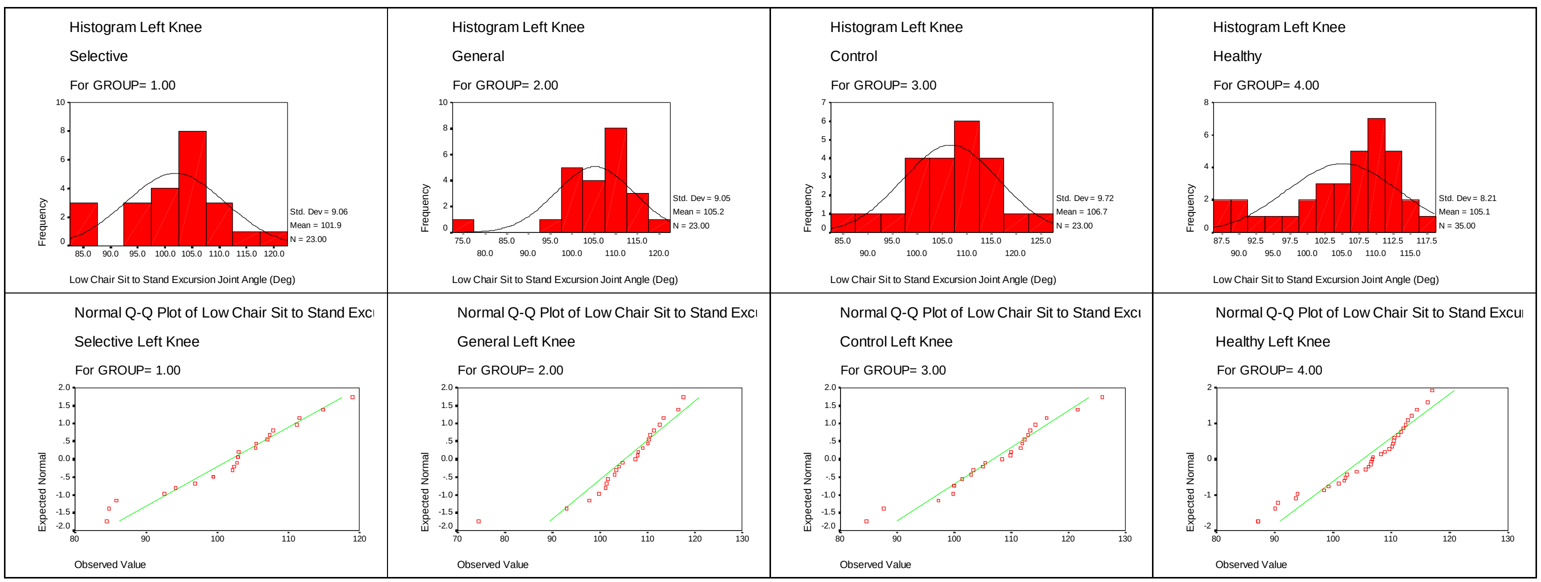
Graphs 17.50 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Maximum Right Knee Joint Angle (Degrees)**



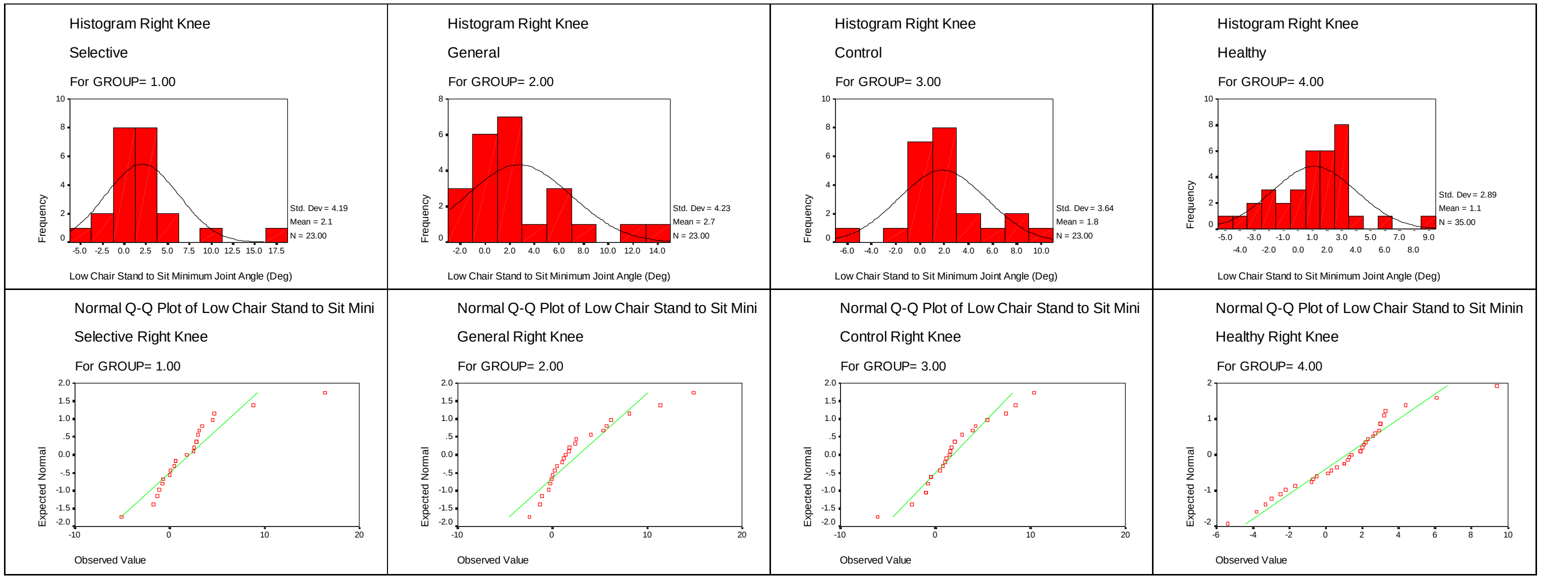
Graphs 17.51 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Maximum Left Knee Joint Angle (Degrees)**



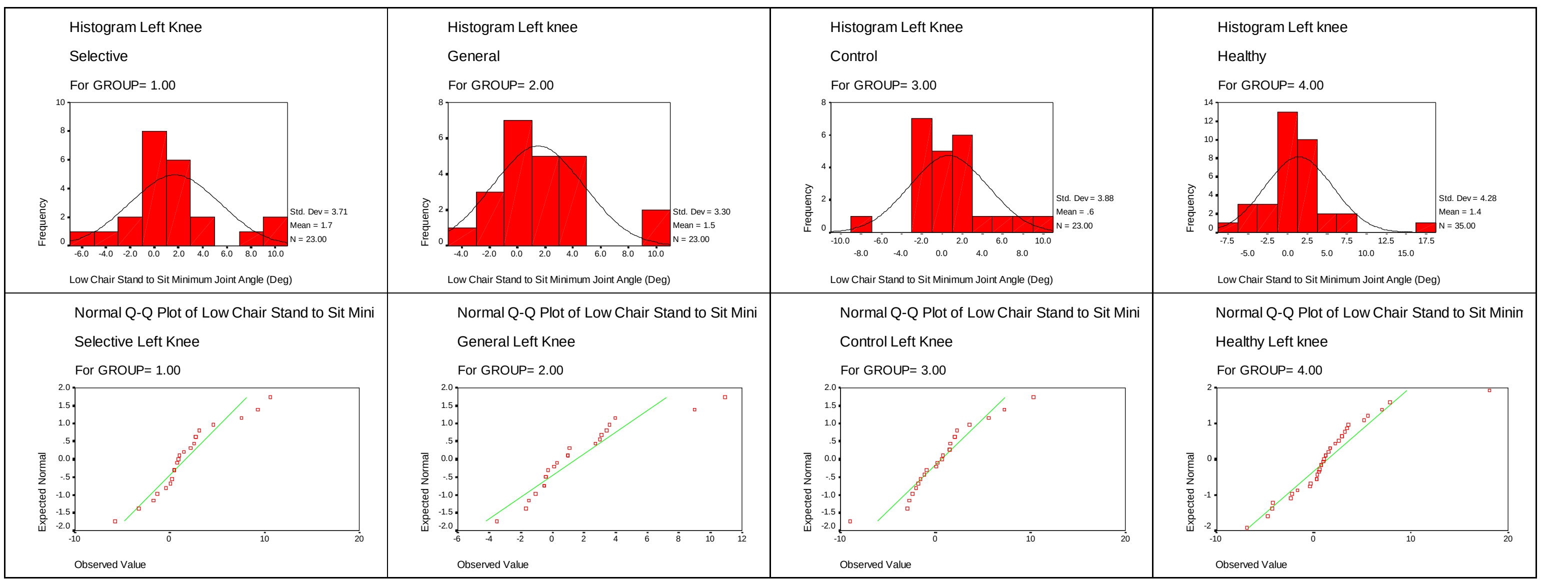
Graphs 17.52 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Right Knee Excursion Angle (Degrees)**



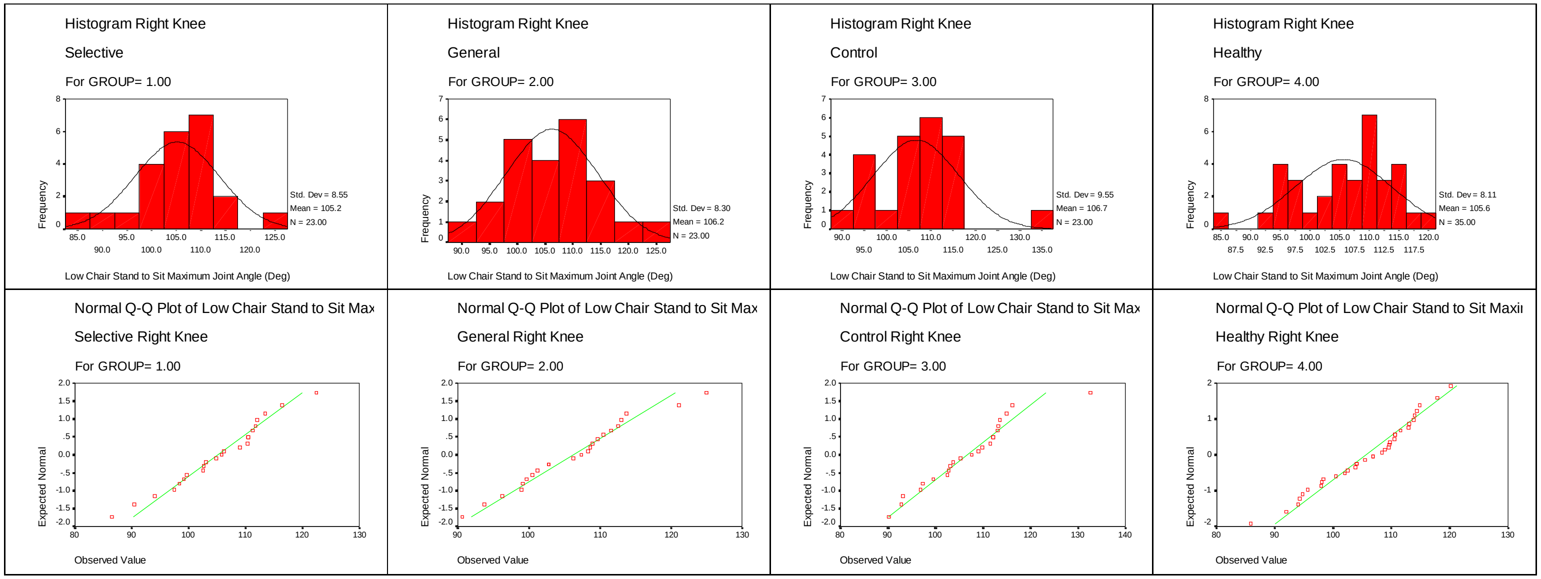
Graphs 17.53 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Low Chair Left Knee Excursion Angle (Degrees)**



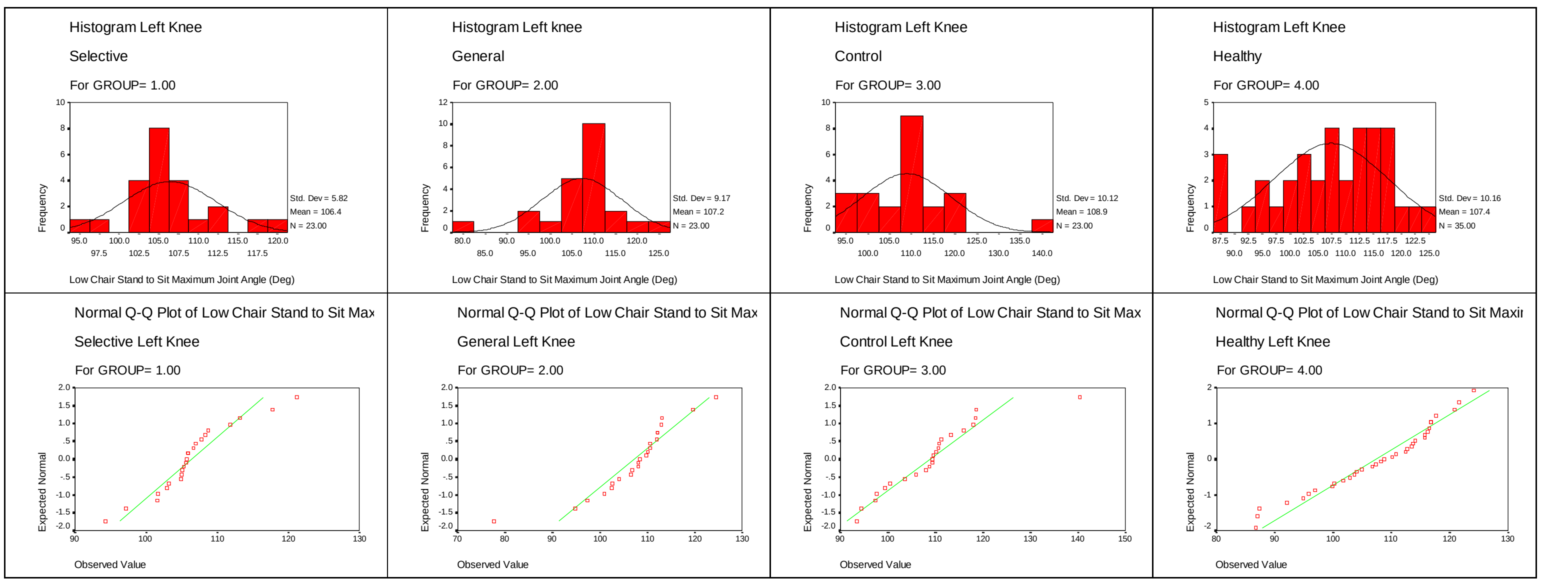
Graphs 17.54 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Minimum Right Knee Joint Angle (Degrees)**



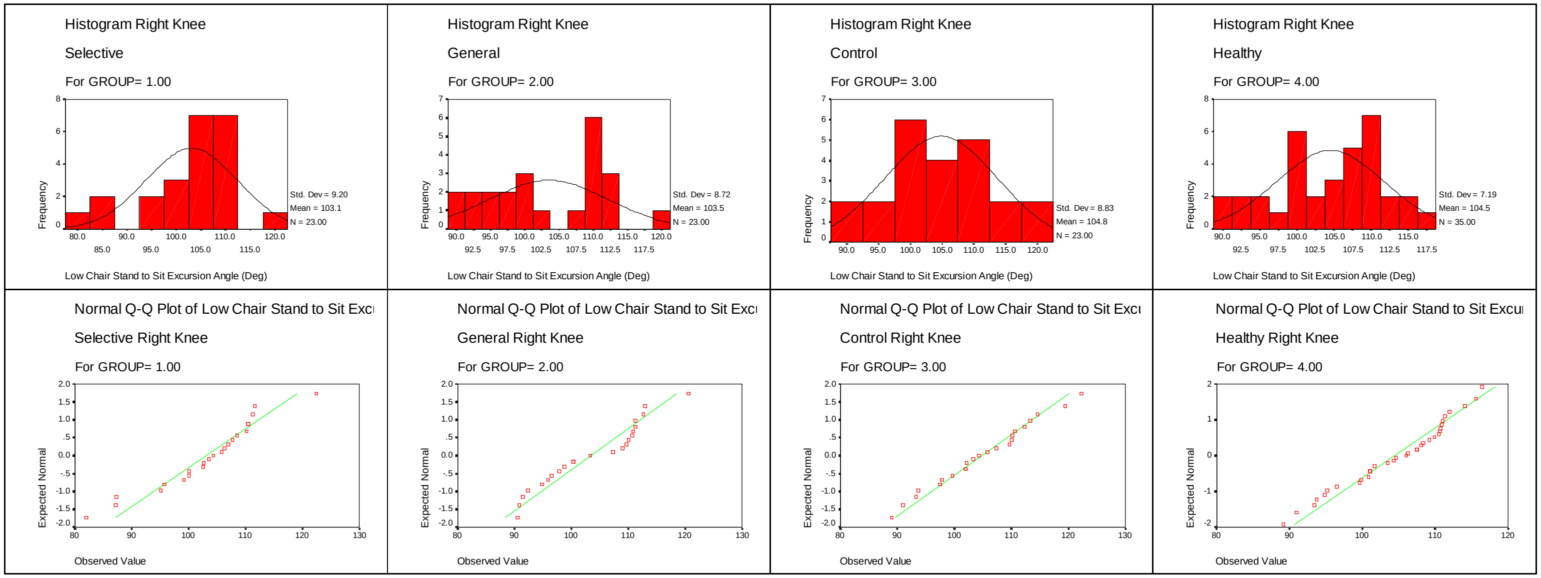
Graphs 17.55 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Minimum Left Knee Joint Angle (Degrees)**



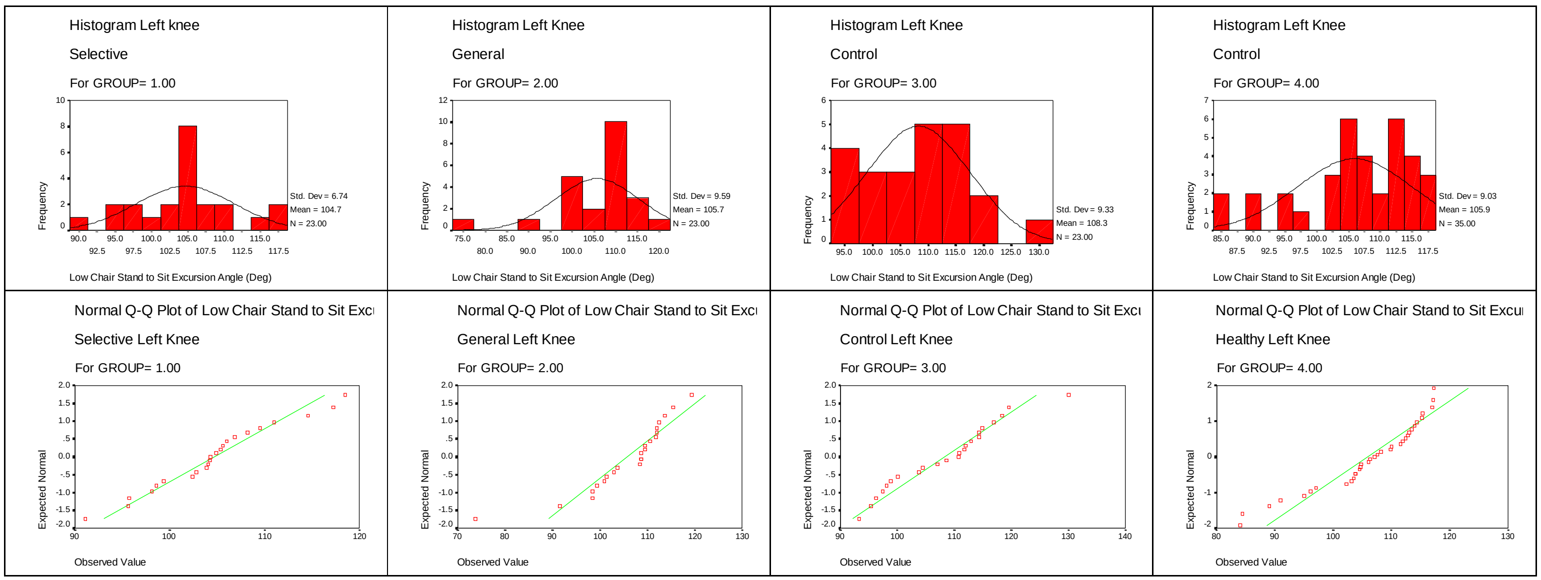
Graphs 17.56 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Maximum Right Knee Joint Angle (Degrees)**



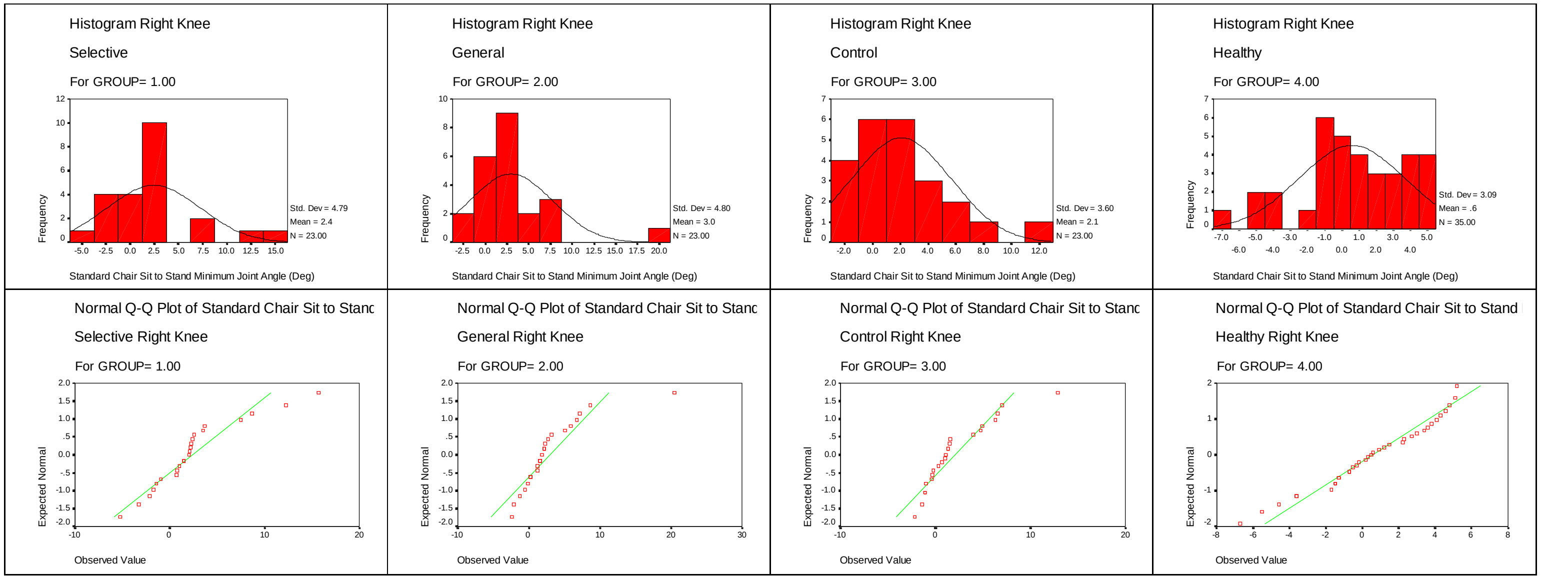
Graphs 17.57 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Maximum Left Knee Joint Angle (Degrees)**



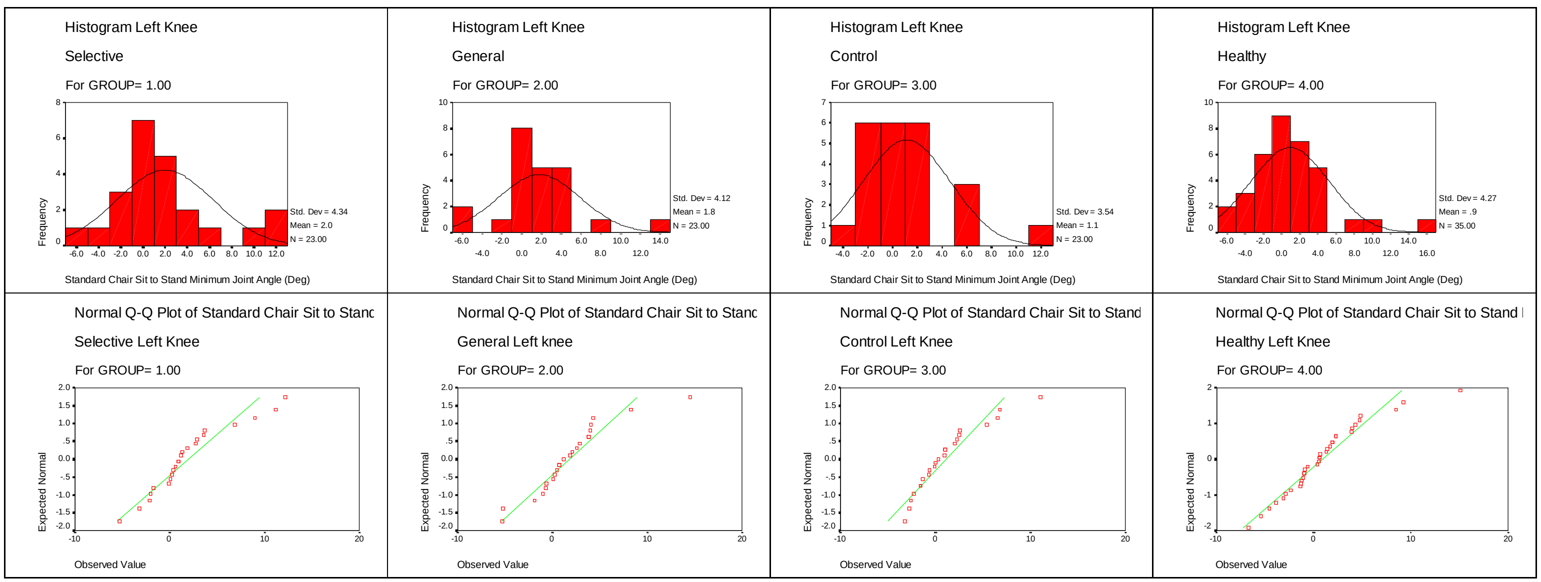
Graphs 17.58 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Right Knee Excursion Angle (Degrees)**



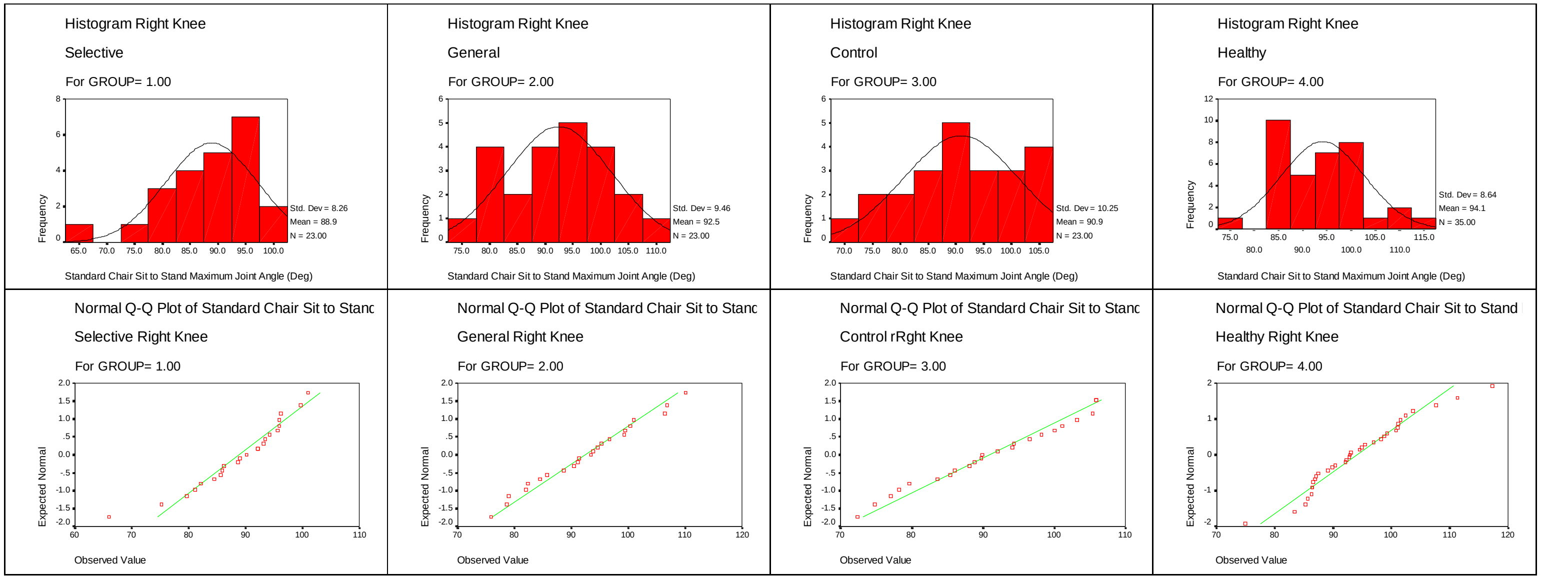
Graphs 17.59 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Low Chair Left Knee Excursion Angle (Degrees)**



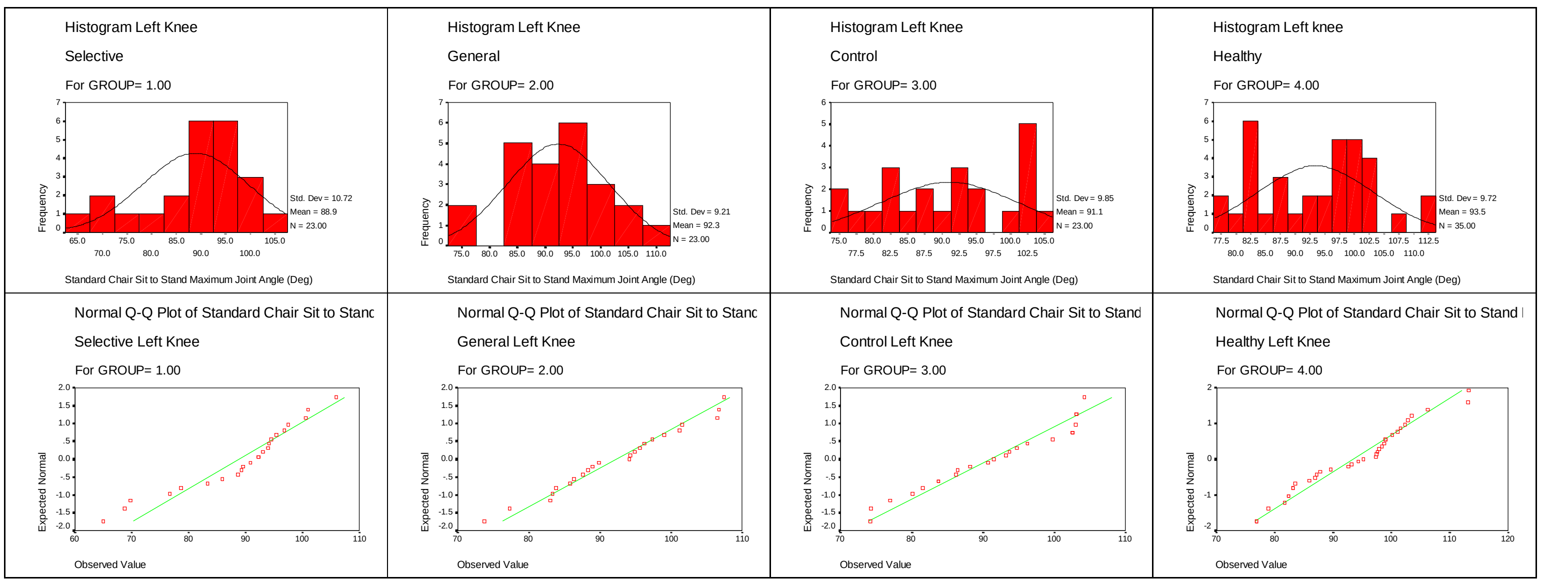
Graphs 17.60 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Minimum Right Knee Joint Angle (Degrees)**



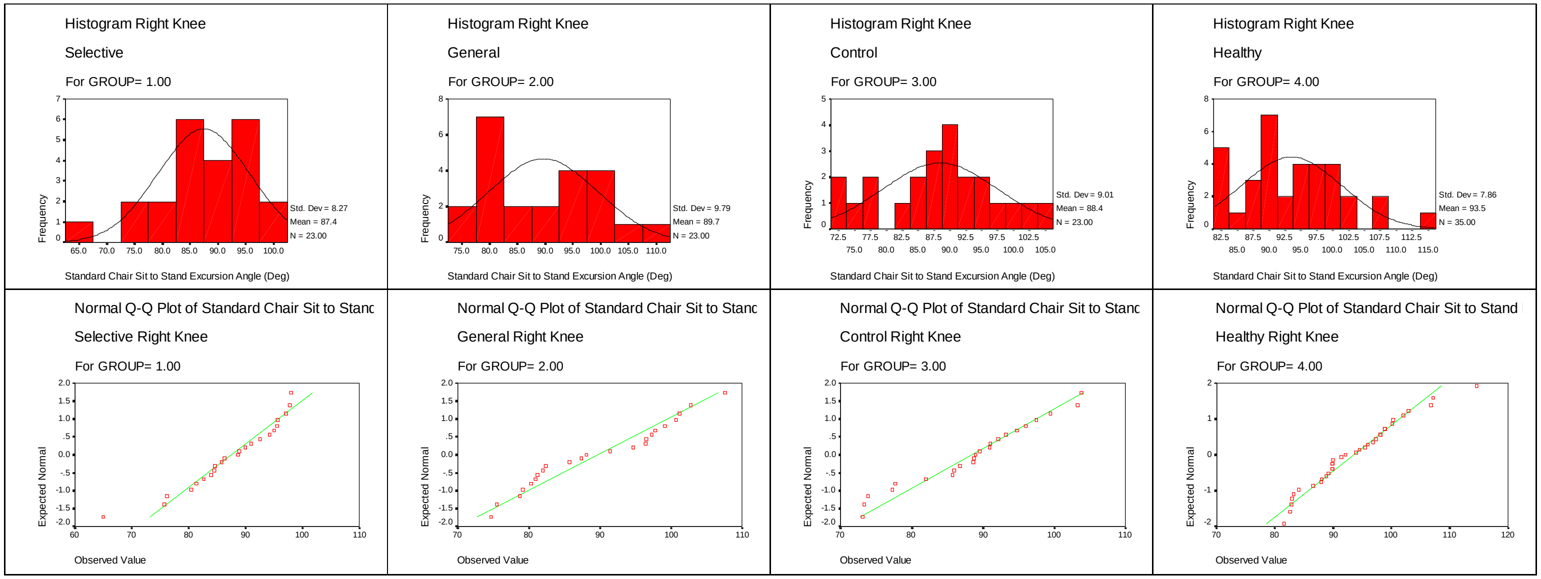
Graphs 17.61 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Minimum Left Knee Joint Angle (Degrees)**



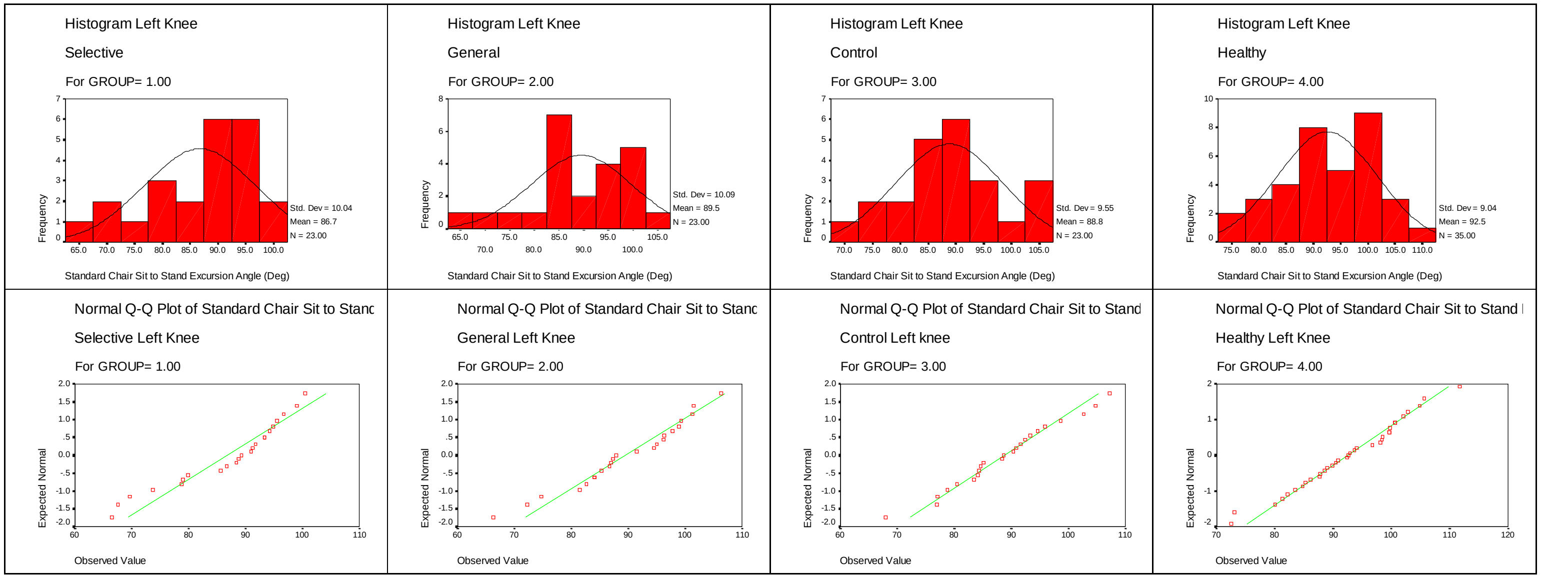
Graphs 17.62 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Maximum Right Knee Joint Angle (Degrees)**



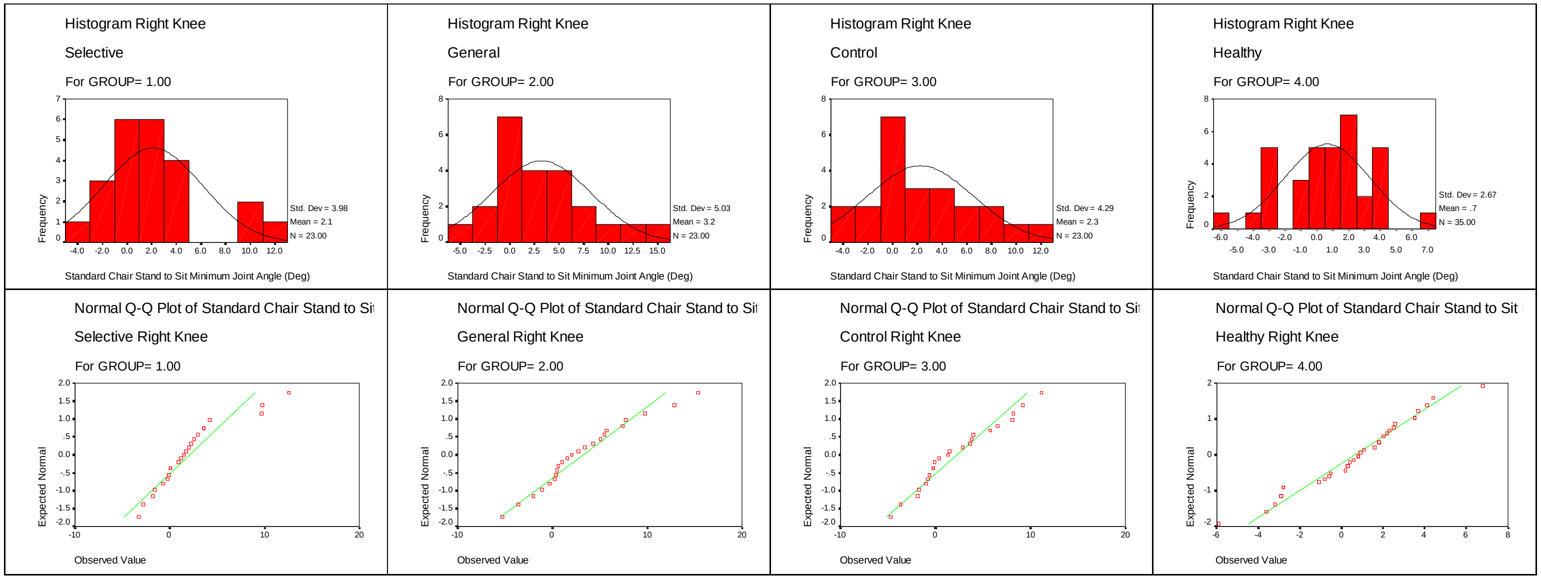
Graphs 17.63 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Minimum Left Knee Joint Angle (Degrees)**



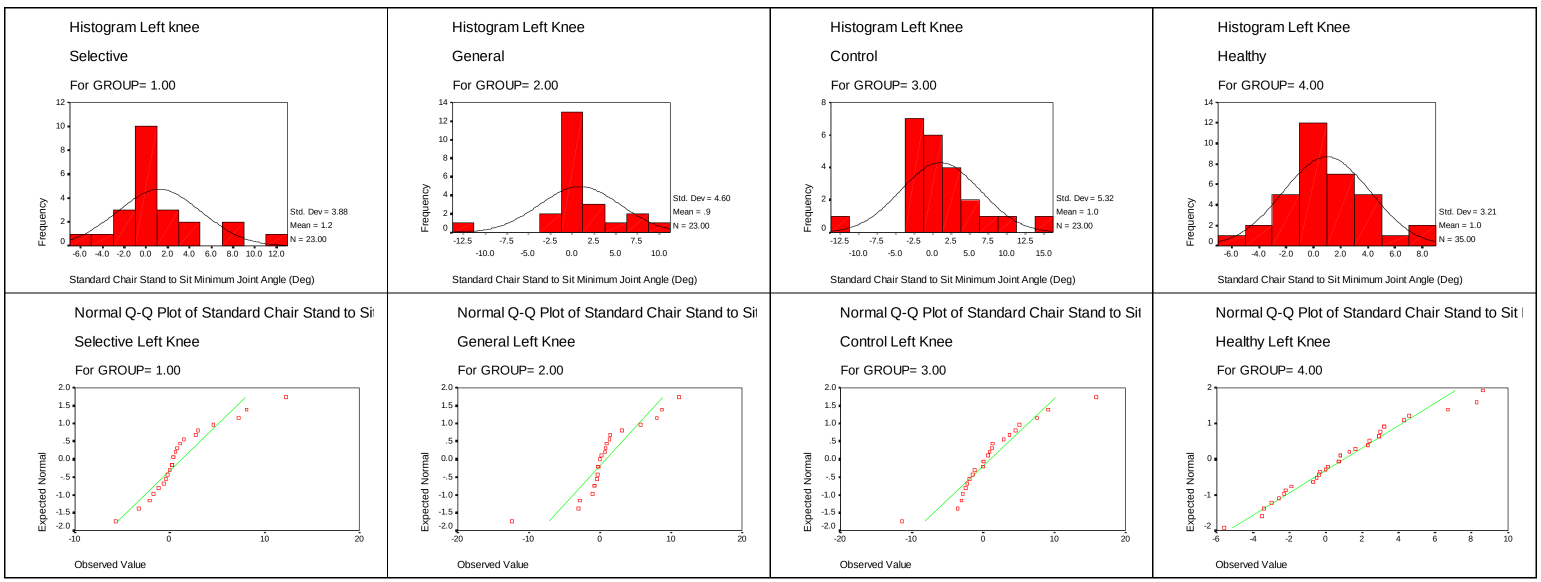
Graphs 17.64 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Right Knee Excursion Angle (Degrees)



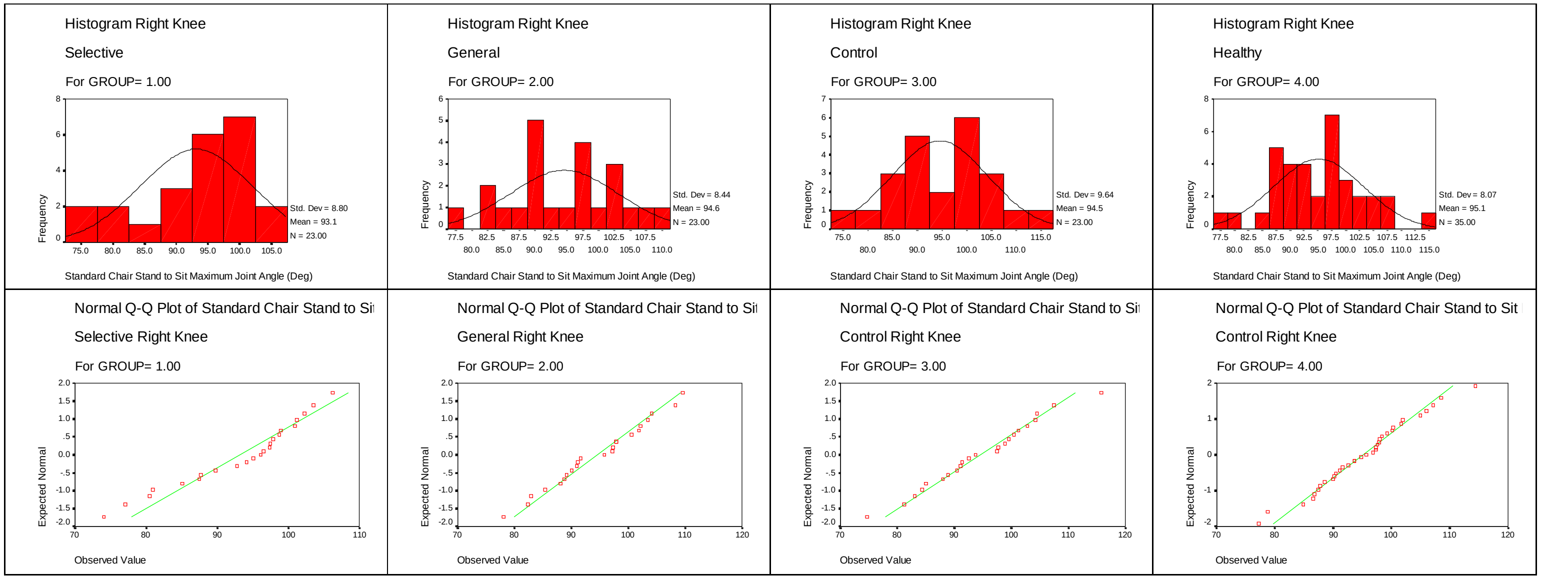
Graphs 17.65 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Left Knee Excursion Angle (Degrees)



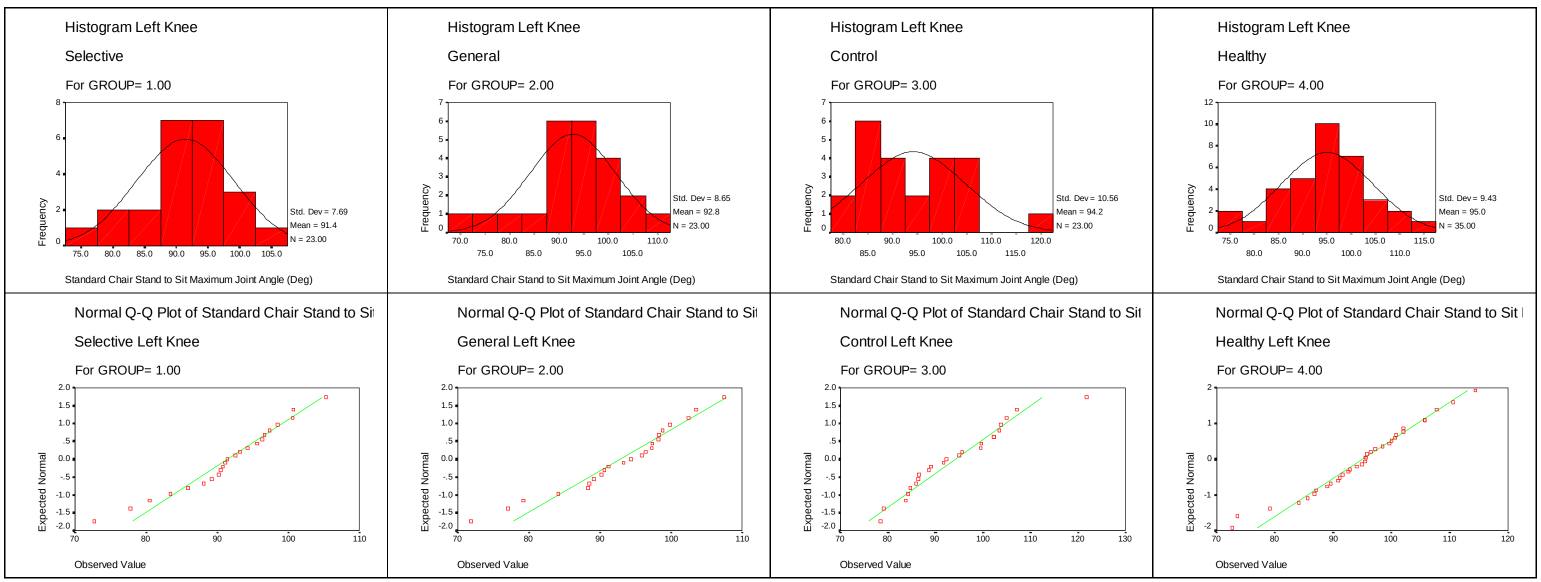
Graphs 17.66 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Standing to Sitting to a Standard Chair Minimum Right Knee Joint Angle (Degrees)**



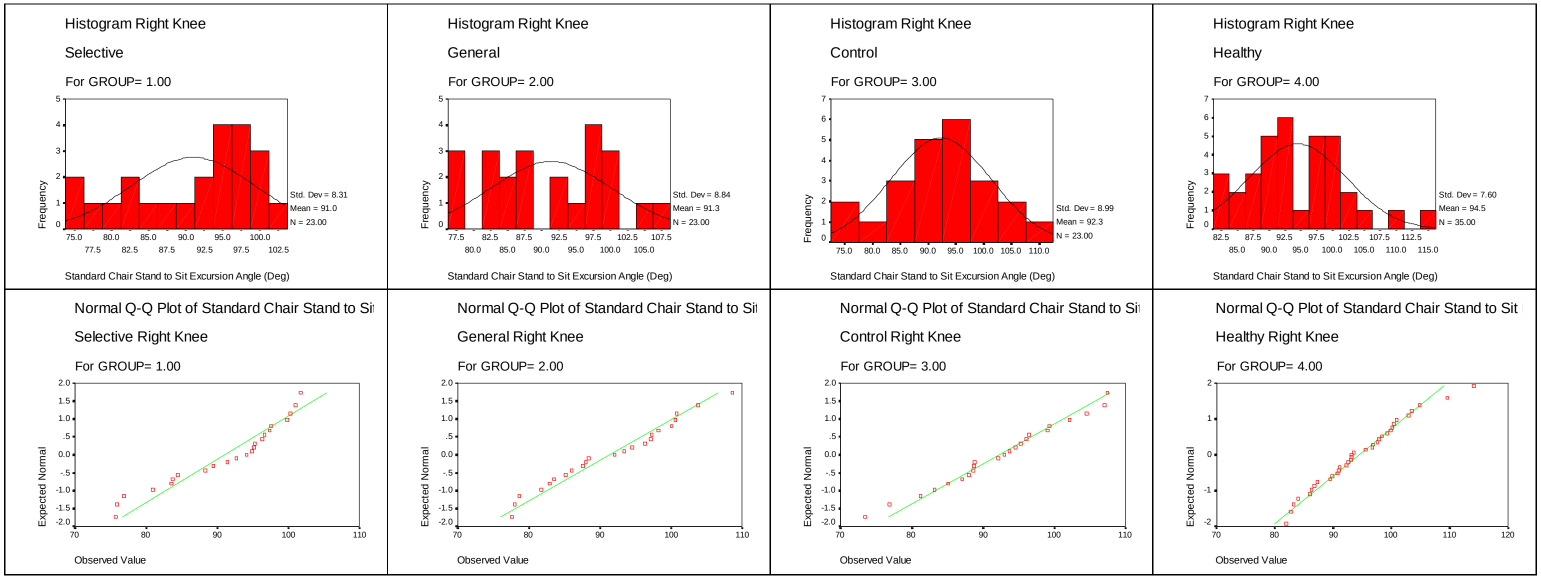
Graphs 17.67 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Minimum Left Knee Joint Angle (Degrees)**



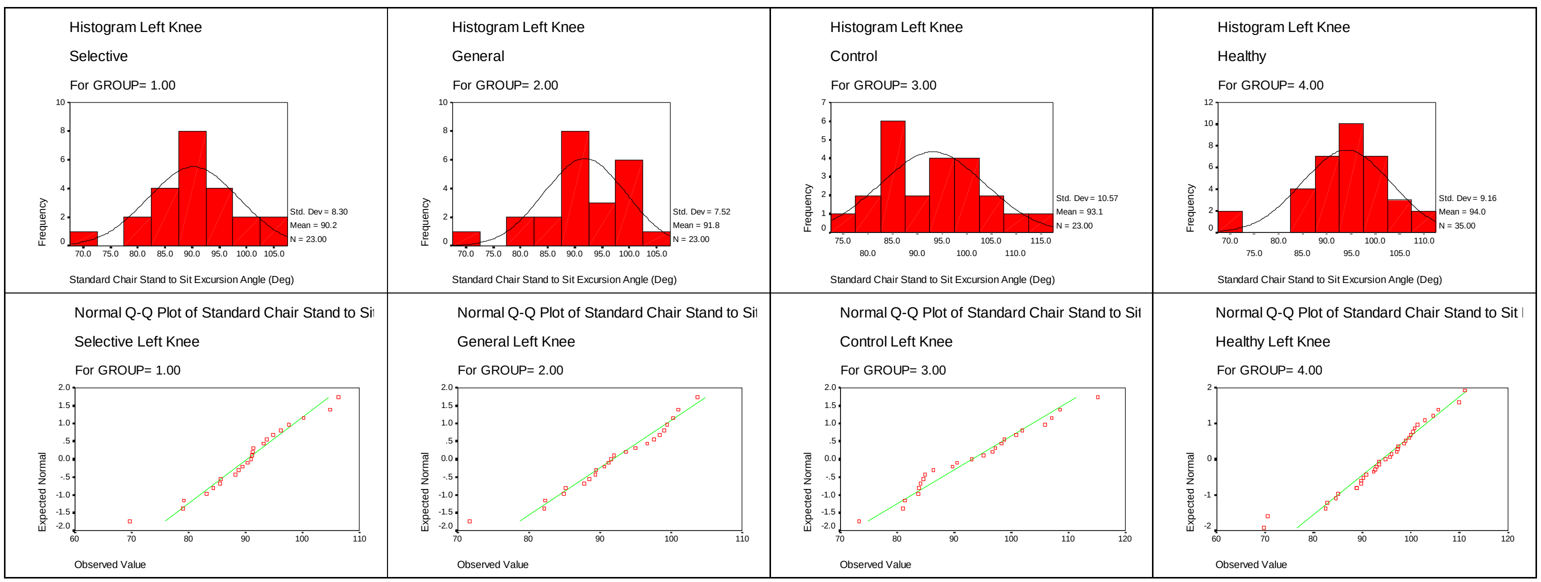
Graphs 17.68 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Maximum Right Knee Joint Angle (Degrees)**



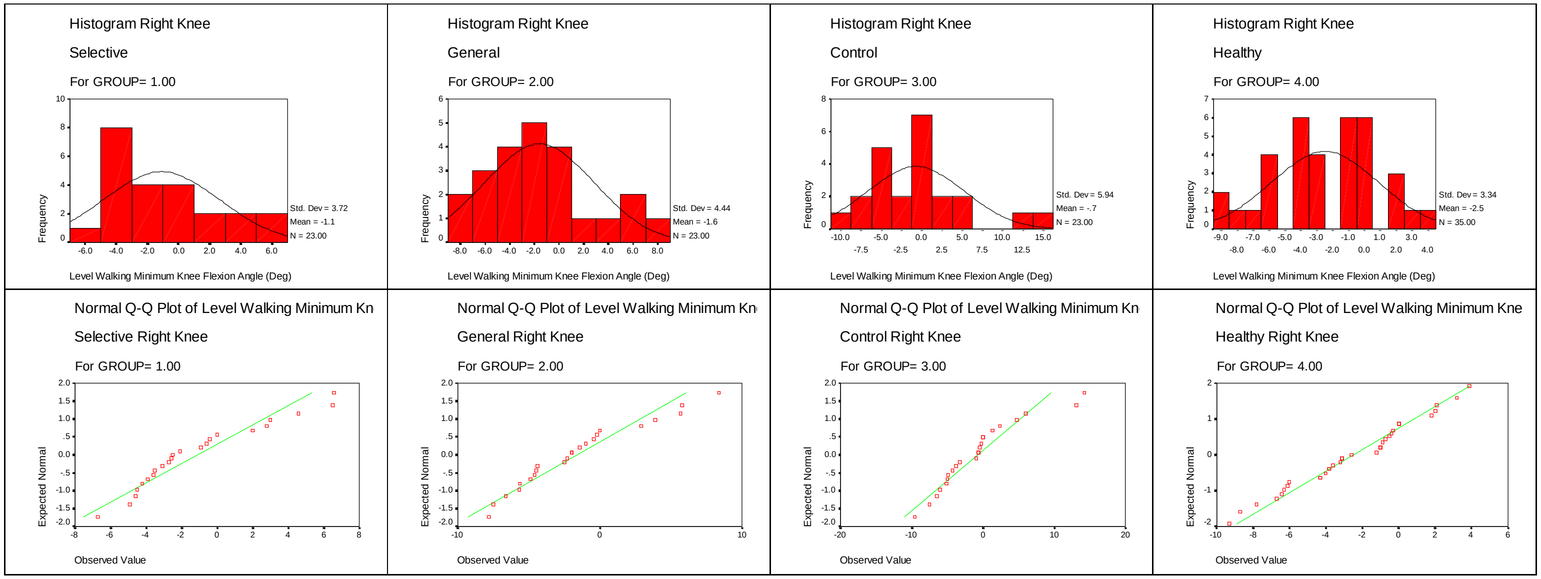
Graphs 17.69 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Maximum Left Knee Joint Angle (Degrees)**



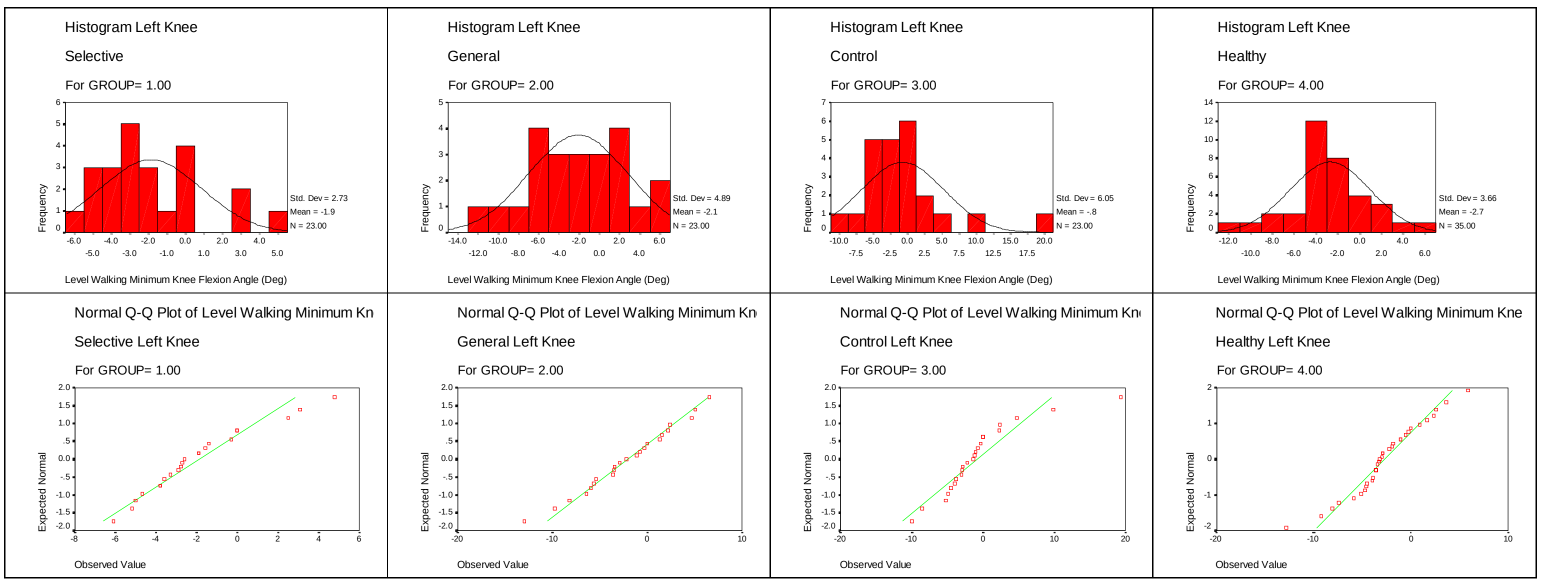
Graphs 17.70 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Right Knee Excursion Angle (Degrees)**



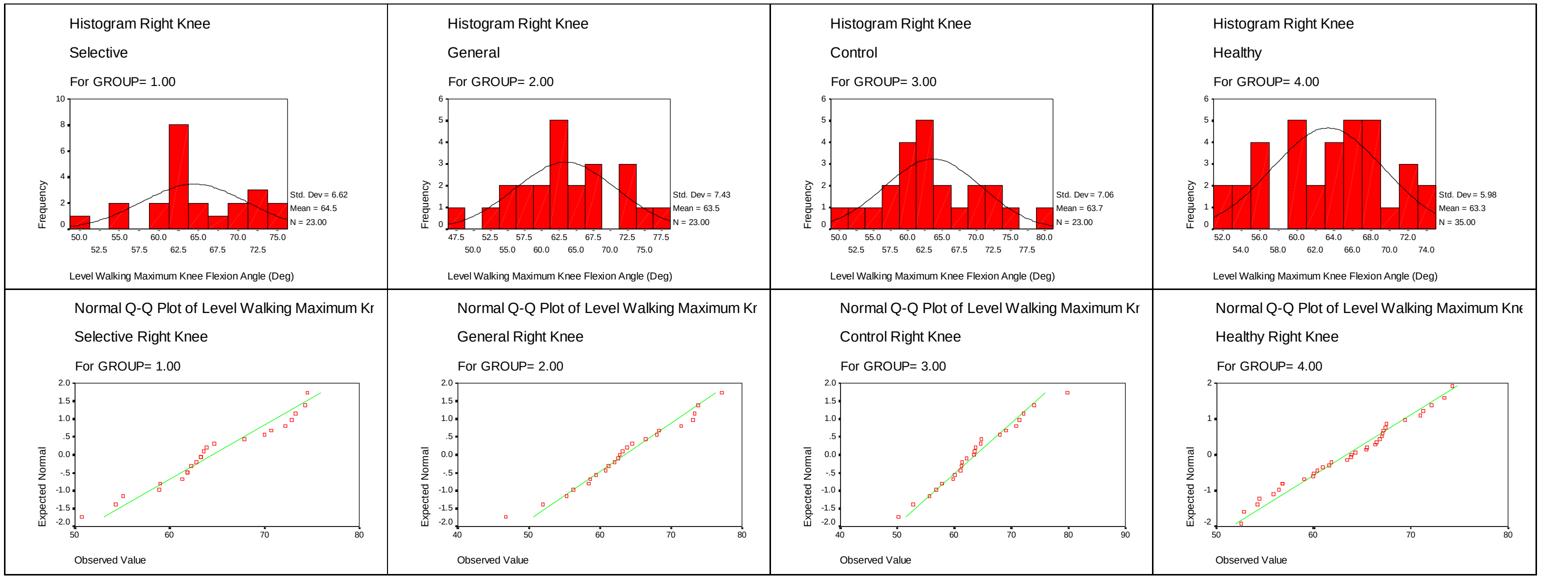
Graphs 17.71 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Sitting to Standing from a Standard Chair Left Knee Excursion Angle (Degrees)**



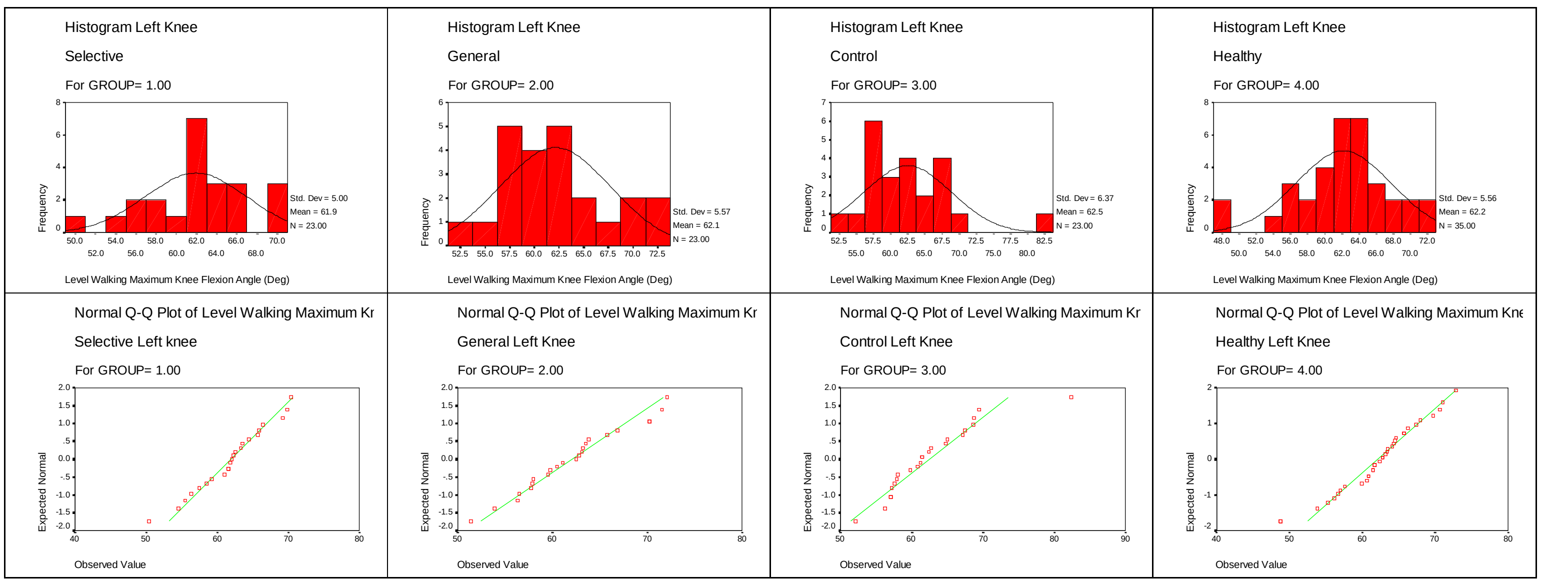
Graphs 17.72 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Minimum Right Knee Flexion Angle (Degrees)**



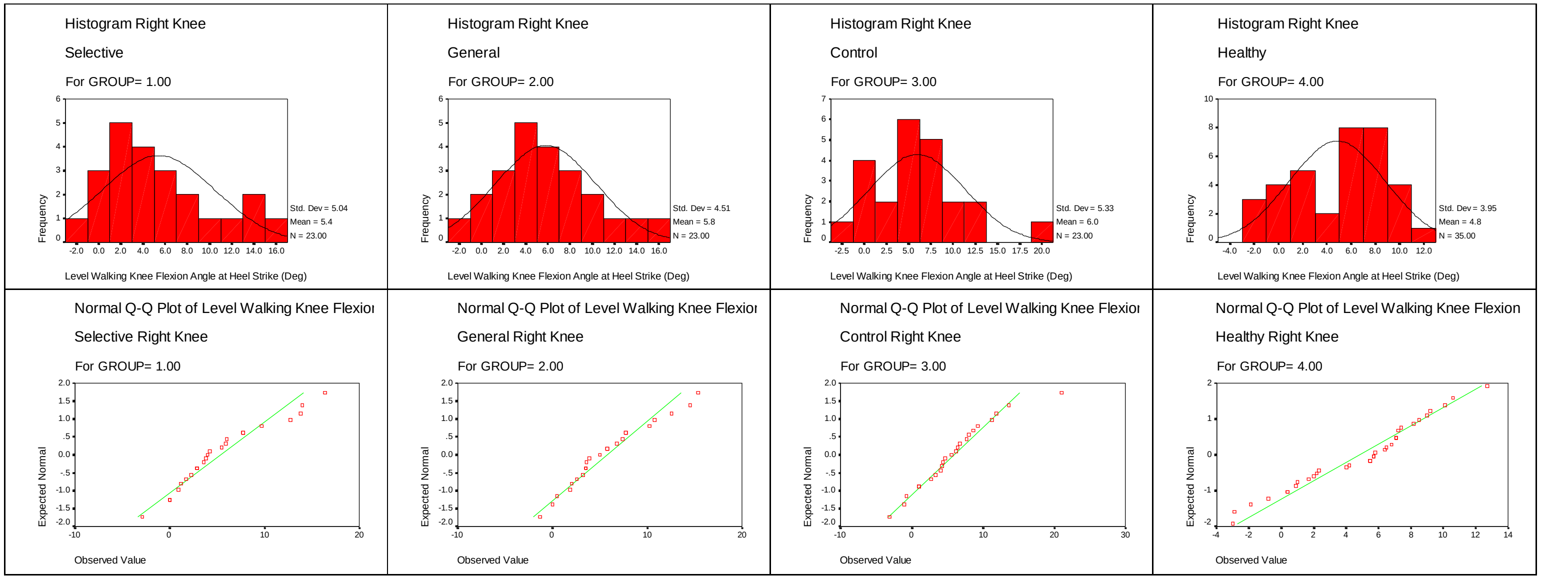
Graphs 17.73 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Minimum Left Knee Flexion Angle (Degrees)**



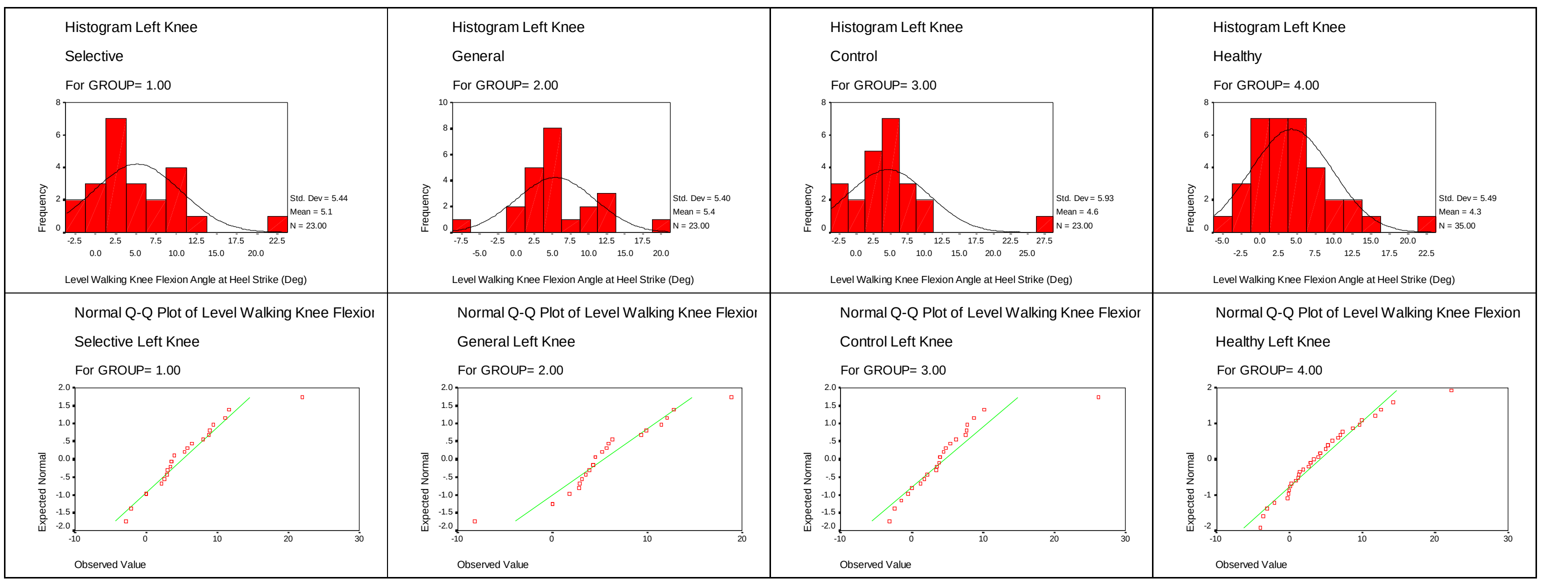
Graphs 17.74 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Right Knee Flexion Angle (Degrees)



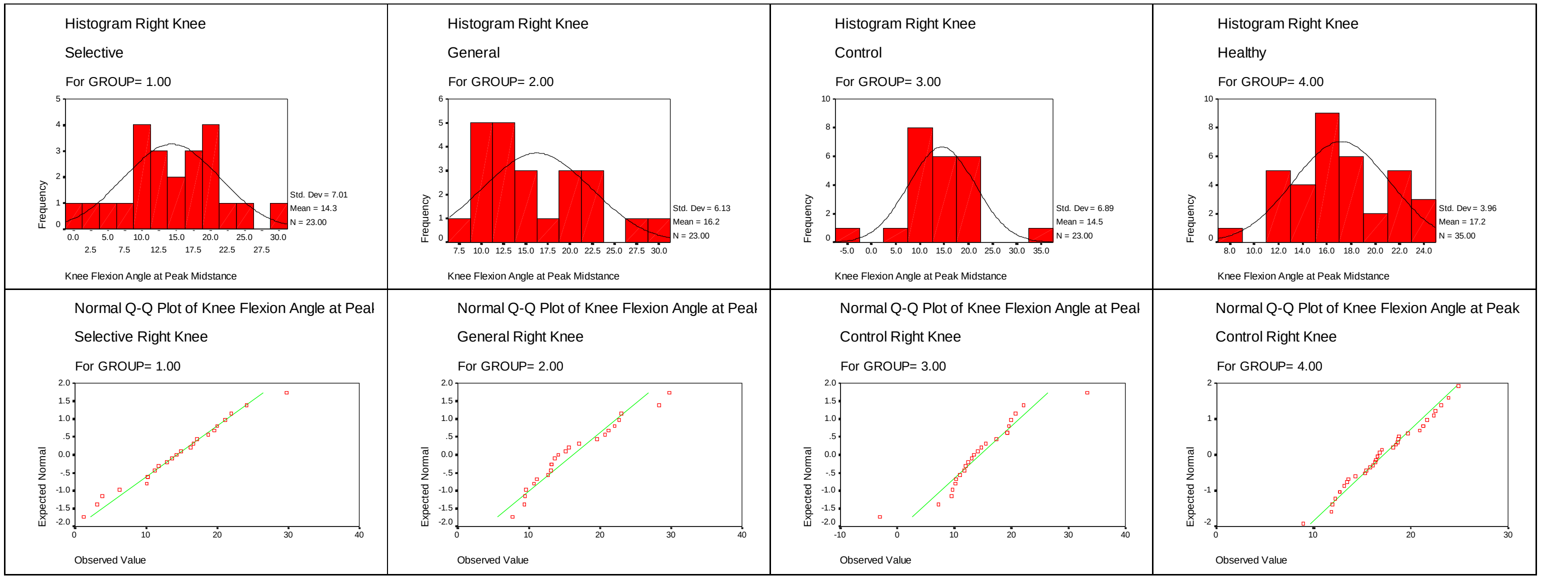
Graphs 17.75 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Left Knee Flexion Angle (Degrees)



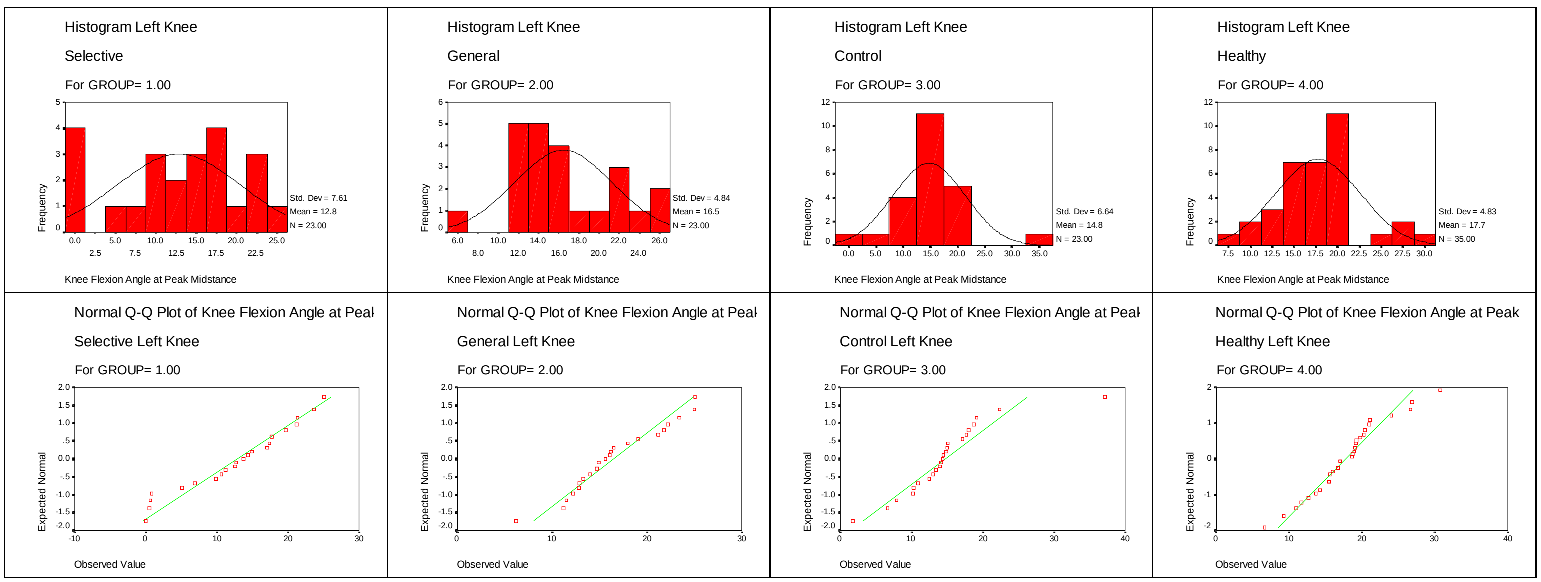
Graphs 17.76 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Right Knee Flexion Angle at Heel Strike (Degrees)



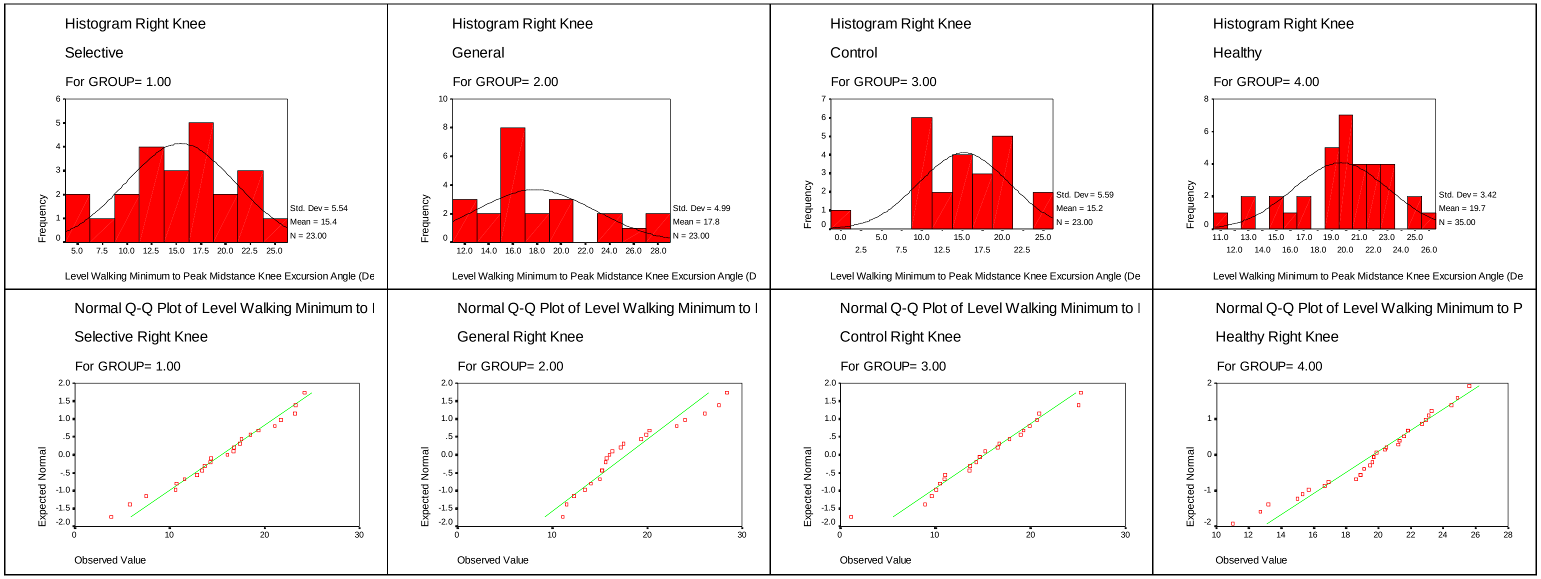
Graphs 17.77 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Left Knee Flexion Angle at Heel Strike (Degrees)



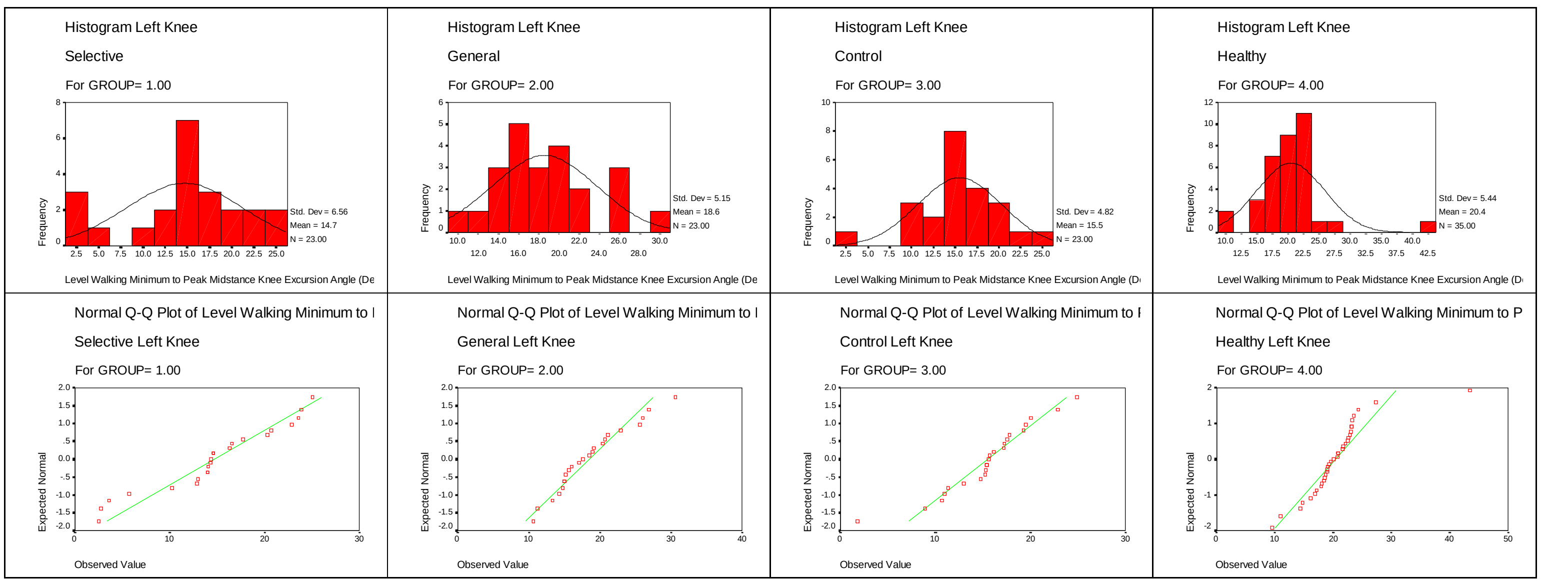
Graphs 17.78 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Right Knee Flexion Angle at Peak Midstance (Degrees)**



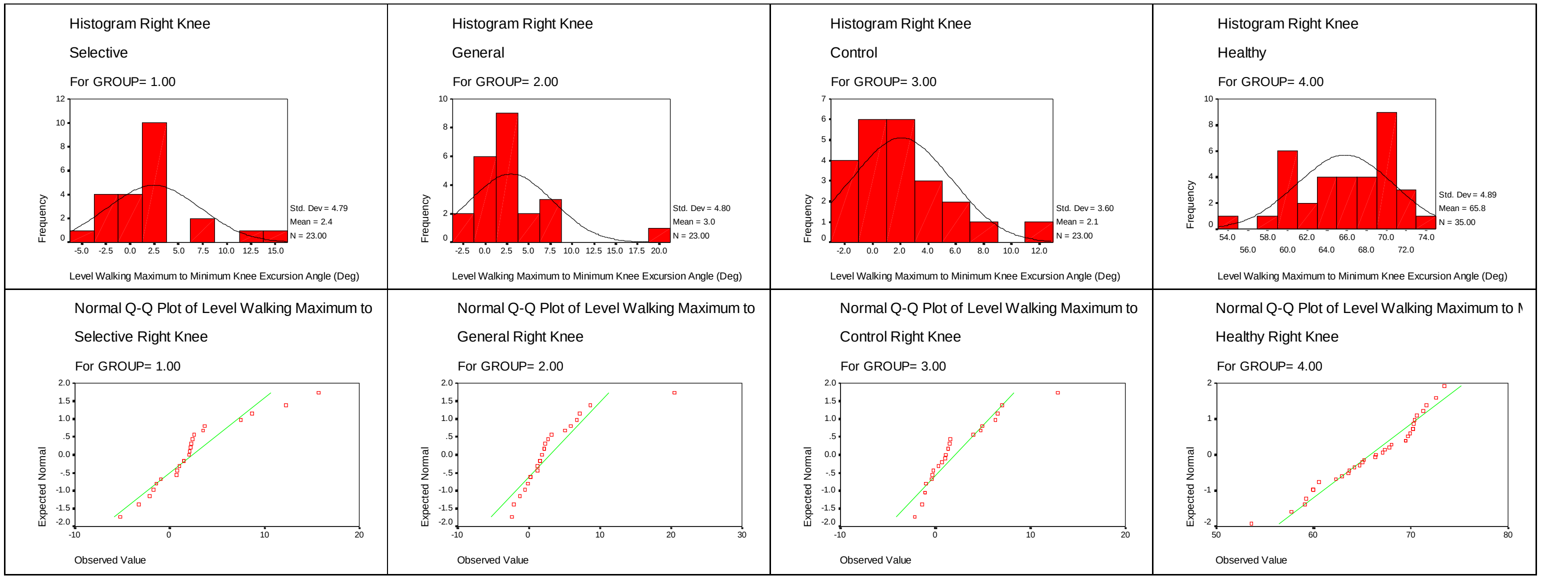
Graphs 17.79 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Maximum Left Knee Flexion Angle at Peak Midstance (Degrees)**



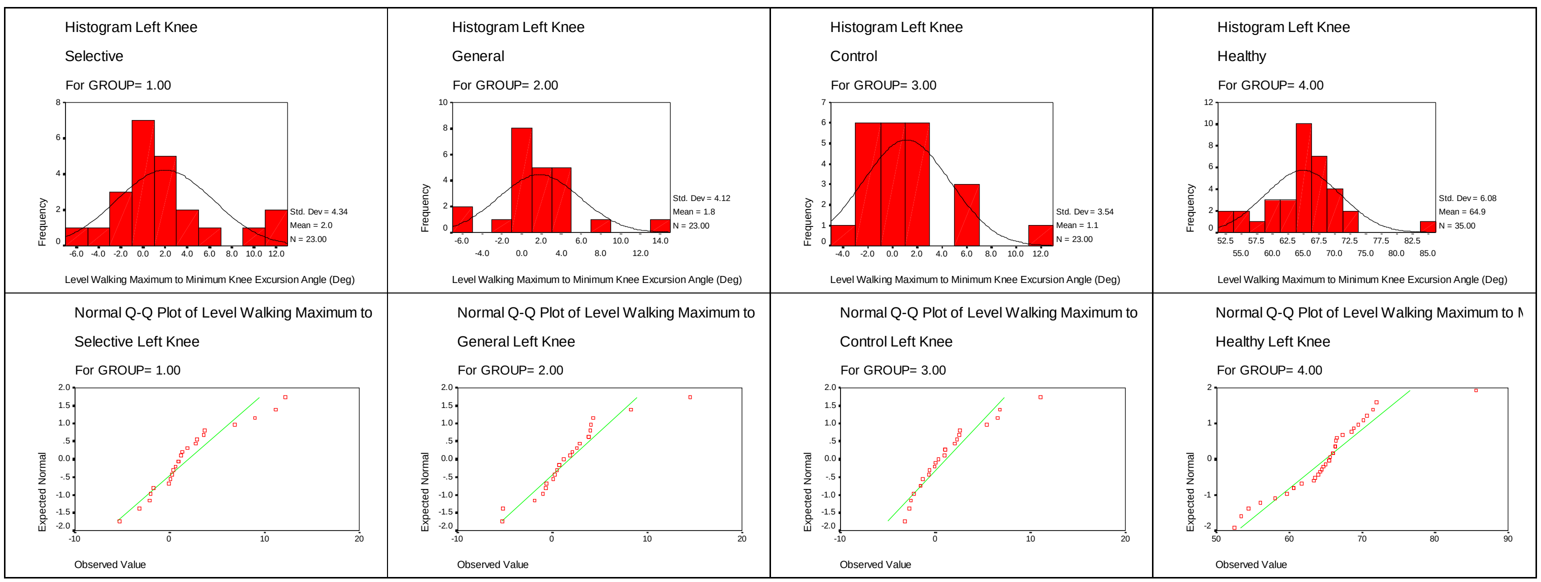
Graphs 17.80 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Right Knee Minimum to Maximum Excursion Angle (Degrees)



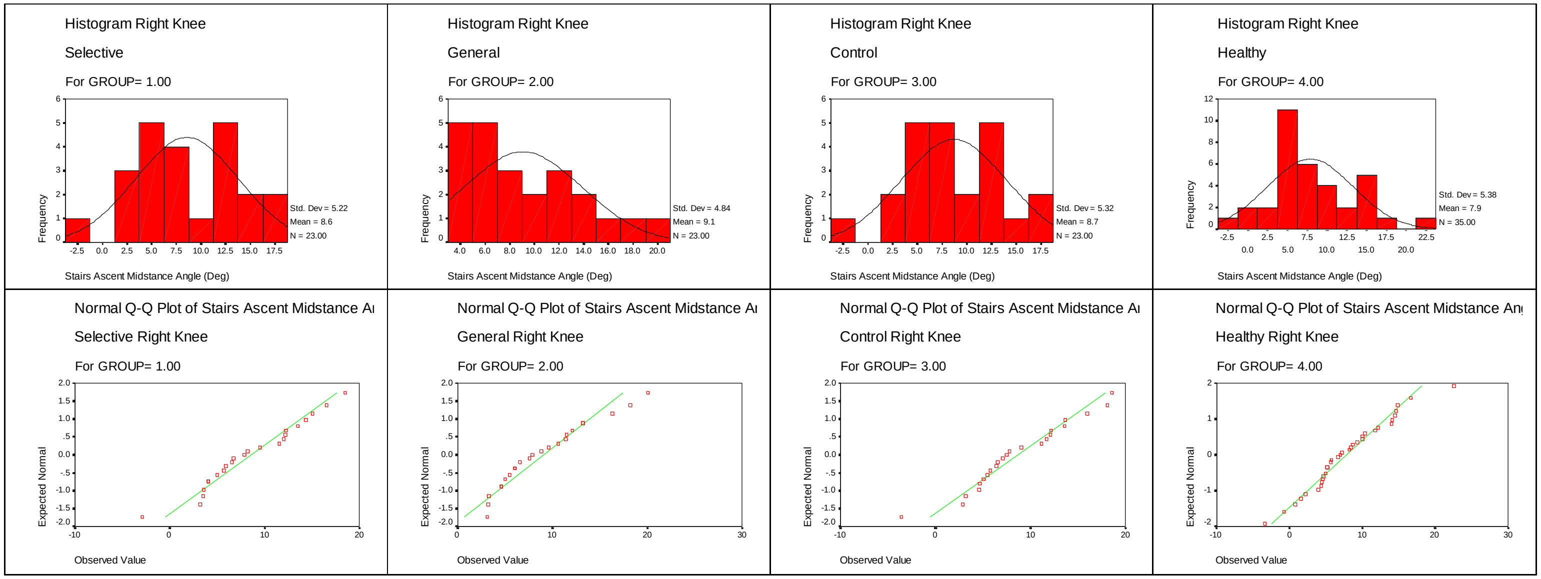
Graphs 17.81 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Left Knee Minimum to Maximum Excursion Angle (Degrees)



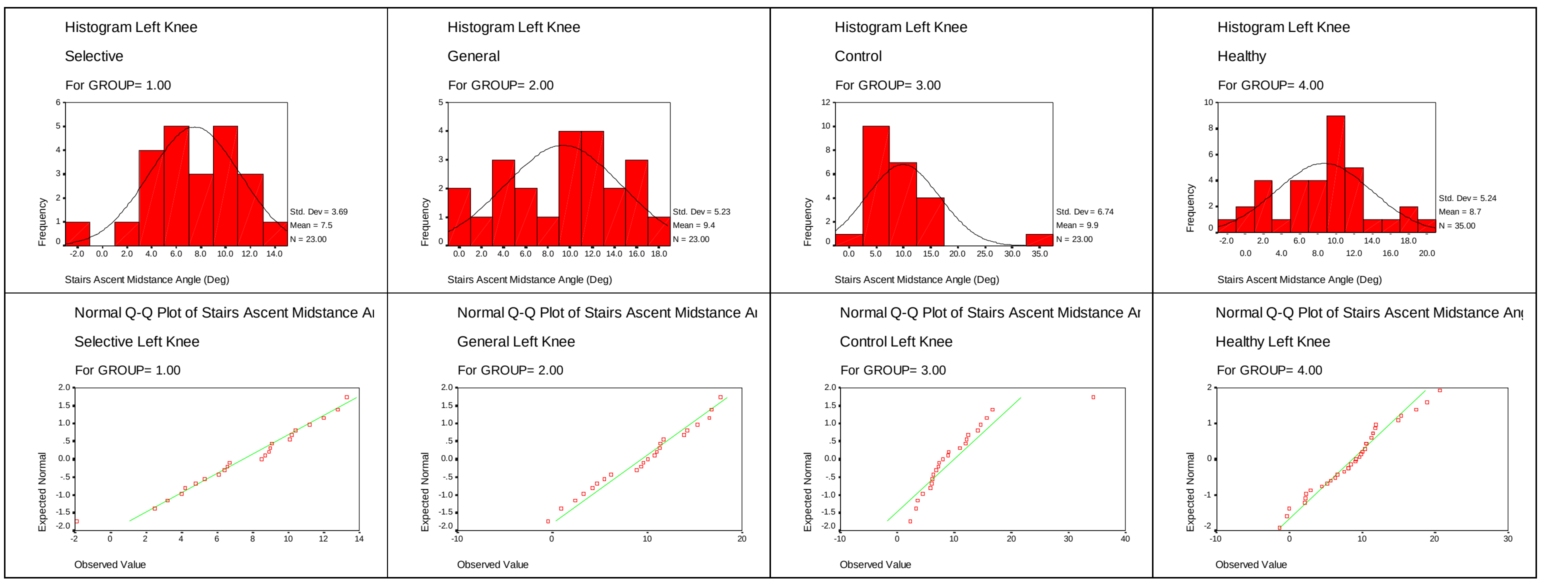
Graphs 17.82 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Right Knee Minimum to Peak Midstance Excursion Angle (Degrees)**



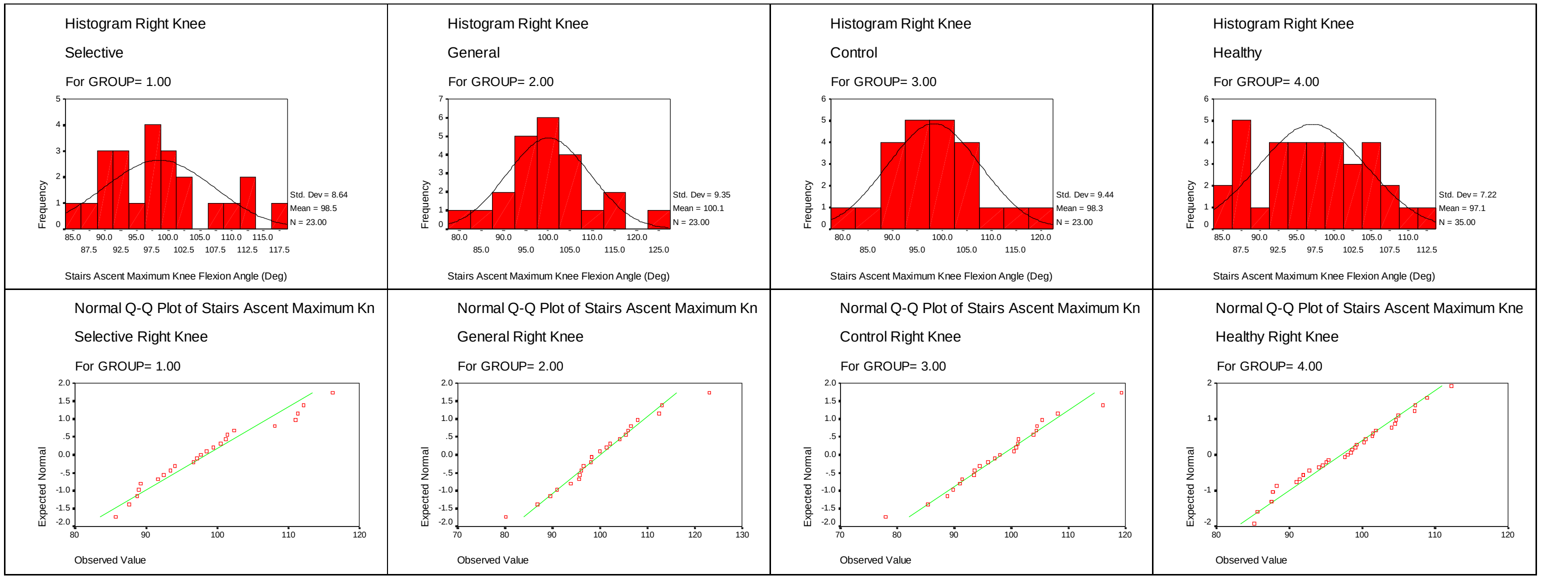
Graphs 17.83 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Left Knee Minimum to Peak Midstance Excursion Angle (Degrees)**



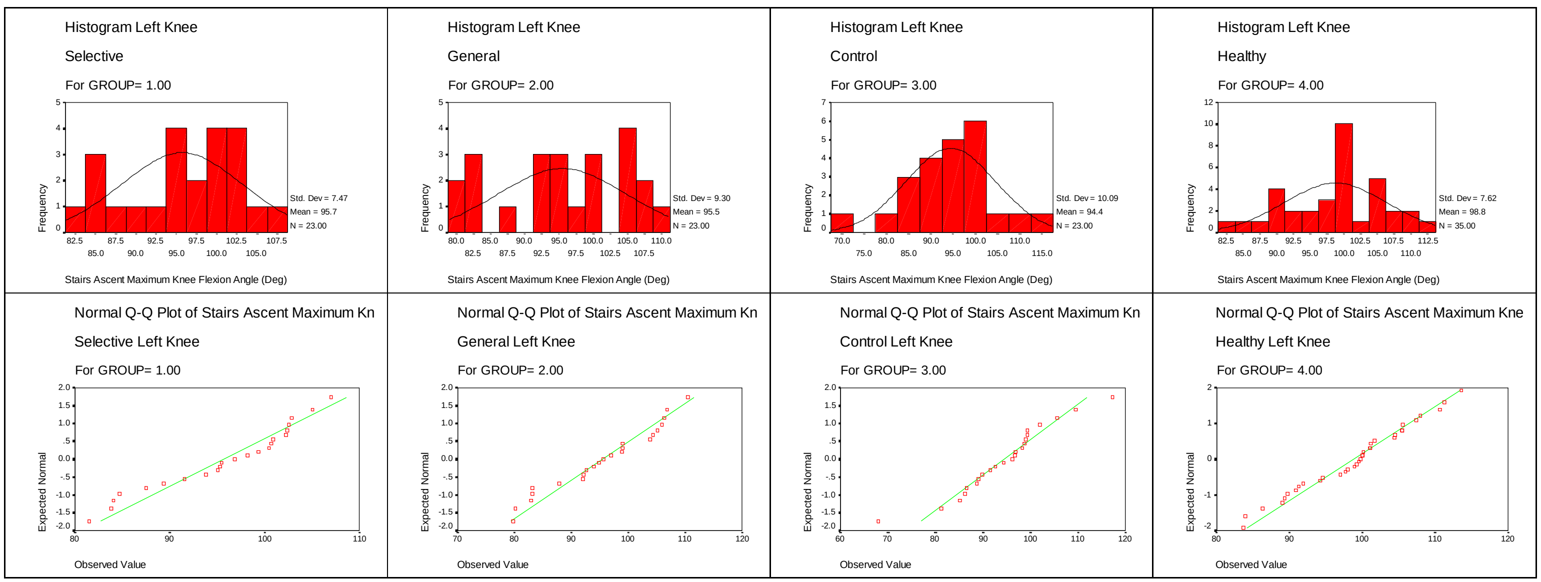
Graphs 17.84 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Right Knee Midstance Angle (Degrees)**



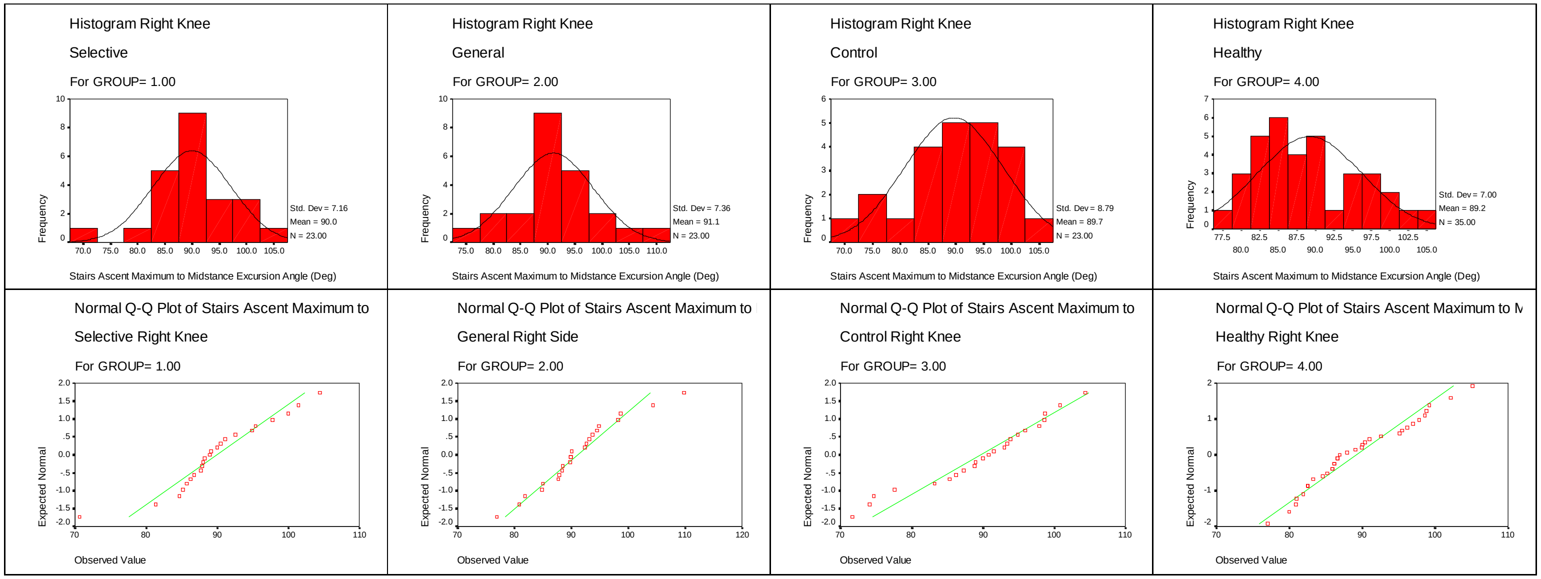
Graphs 17.85 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Right Knee Midstance Angle (Degrees)**



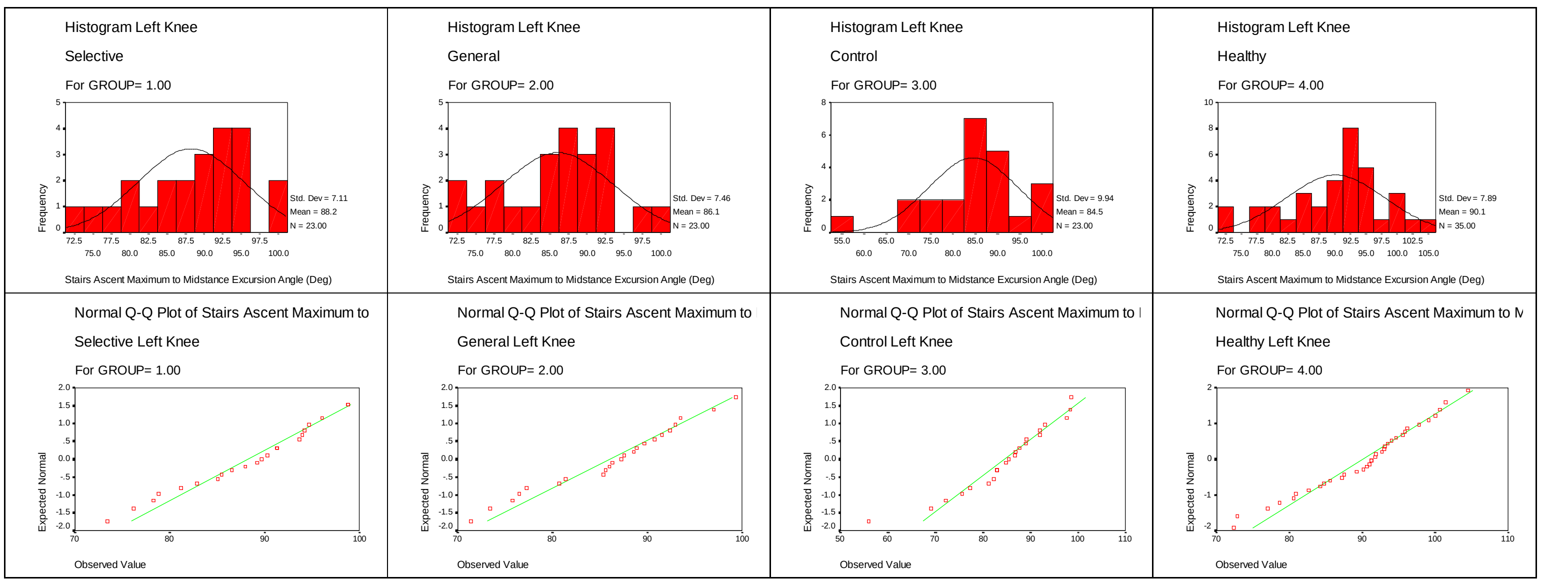
Graphs 17.86 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Right Knee Maximum Angle (Degrees)



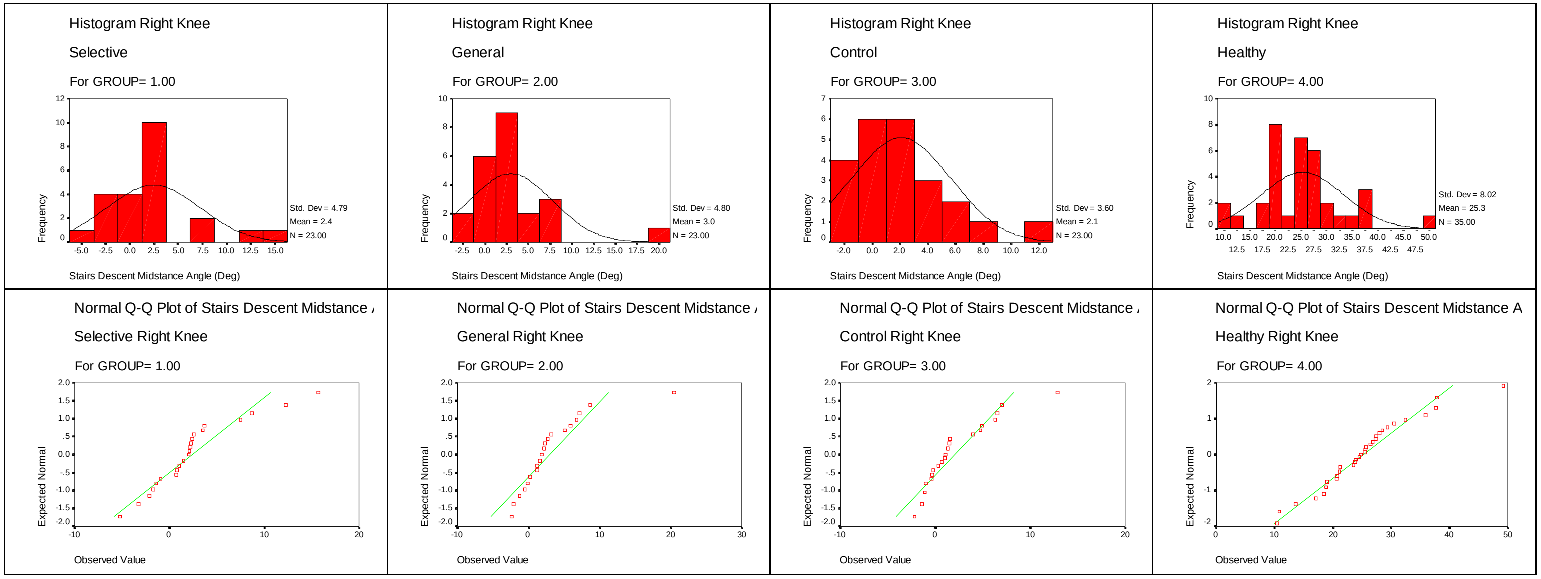
Graphs 17.87 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Left Knee Maximum Angle (Degrees)



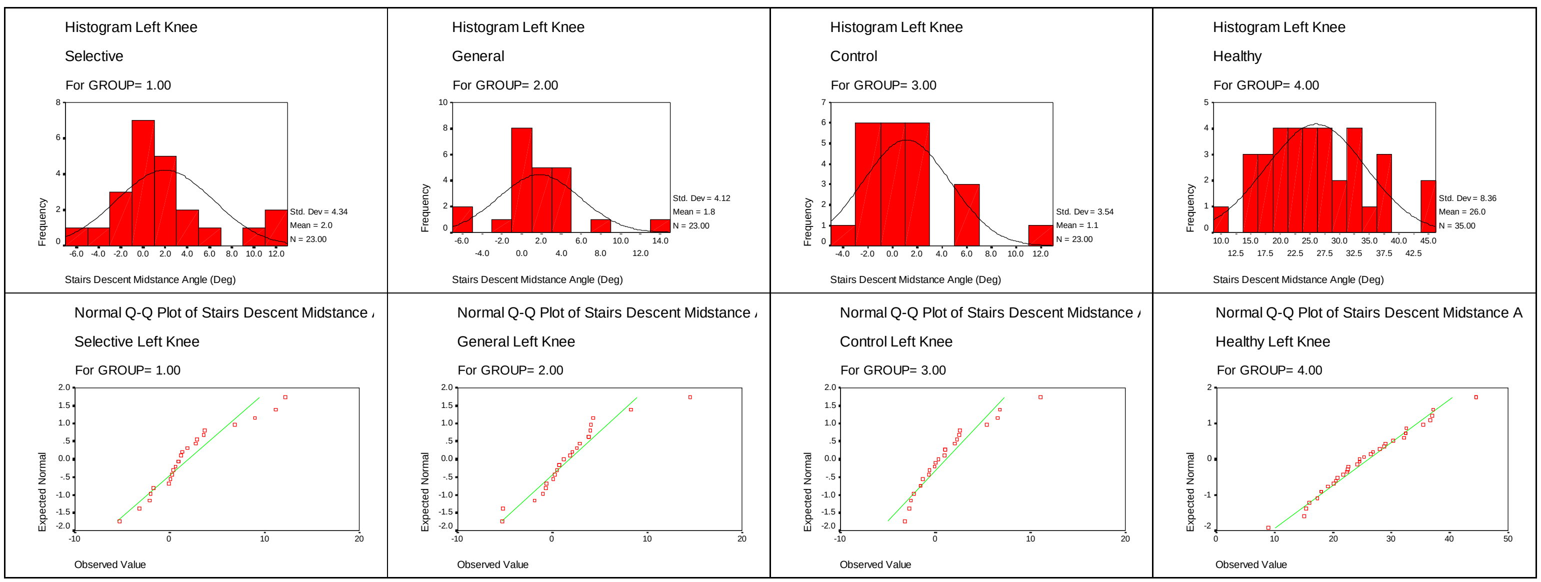
Graphs 17.88 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Right Knee Midstance to Maximum Excursion Angle (Degrees)**



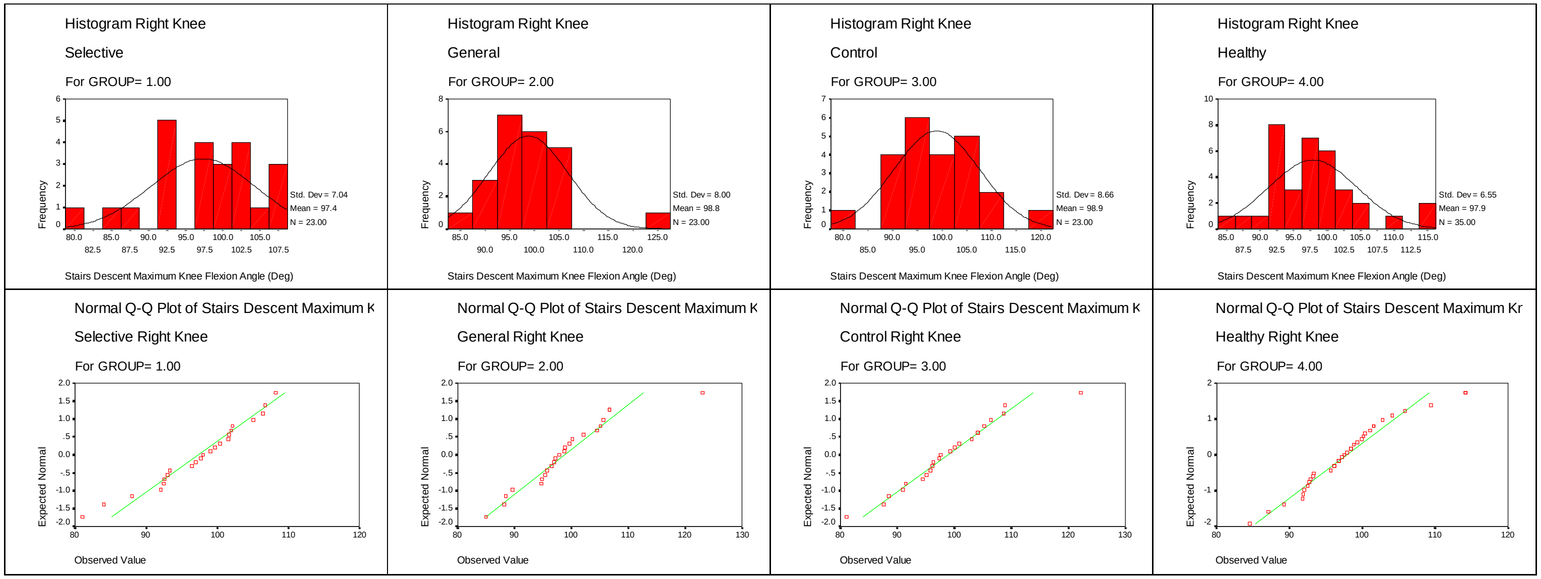
Graphs 17.89 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Ascent Left Knee Midstance to Maximum Excursion Angle (Degrees)**



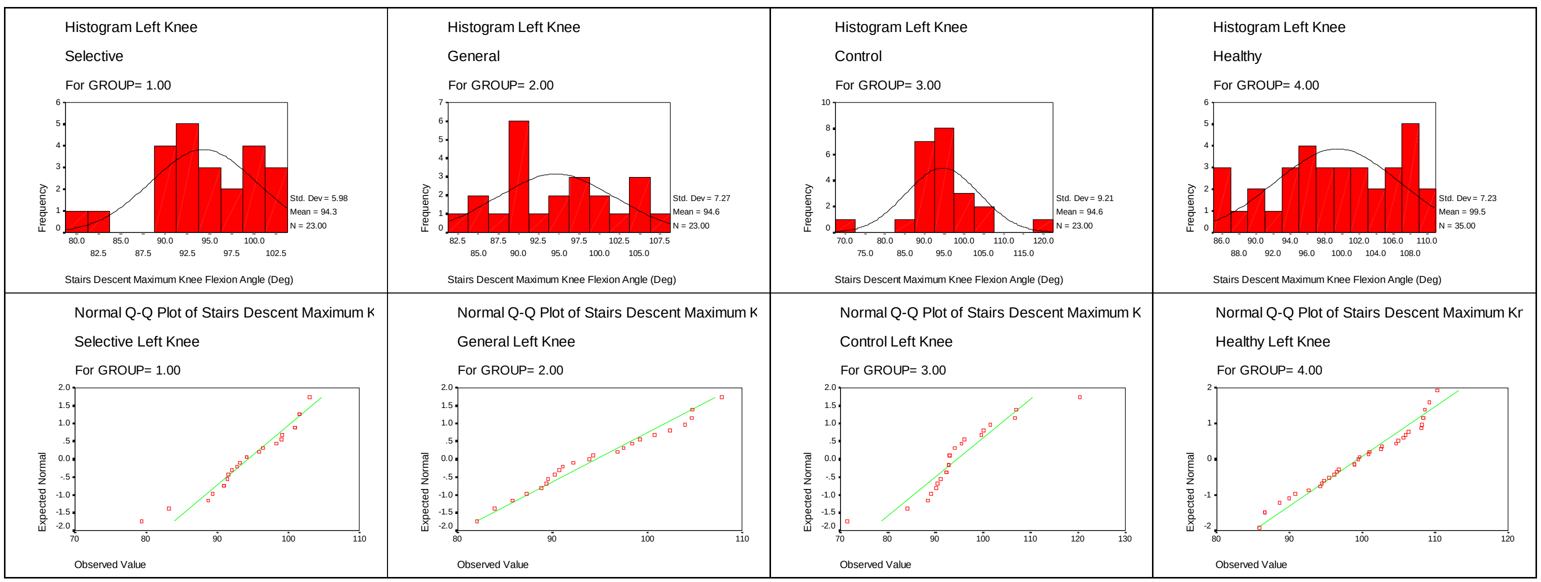
Graphs 17.90 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Right Knee Midstance Angle (Degrees)**



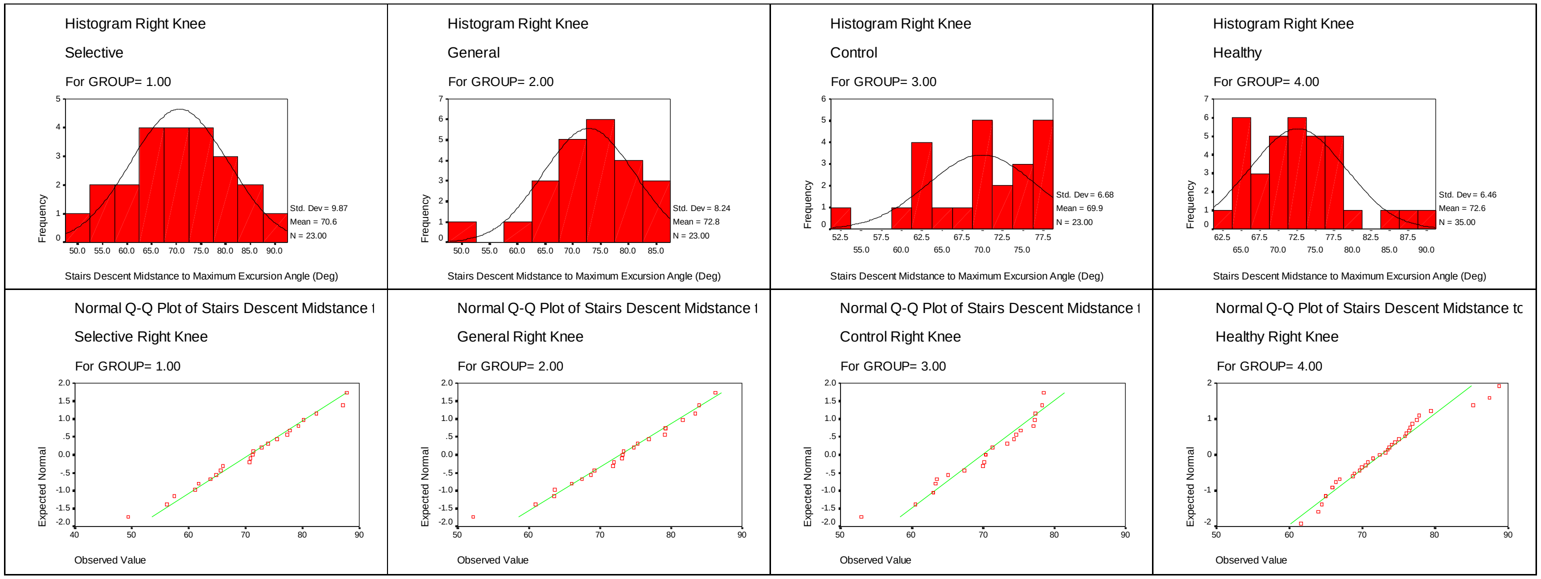
Graphs 17.91 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Left Knee Midstance Angle (Degrees)**



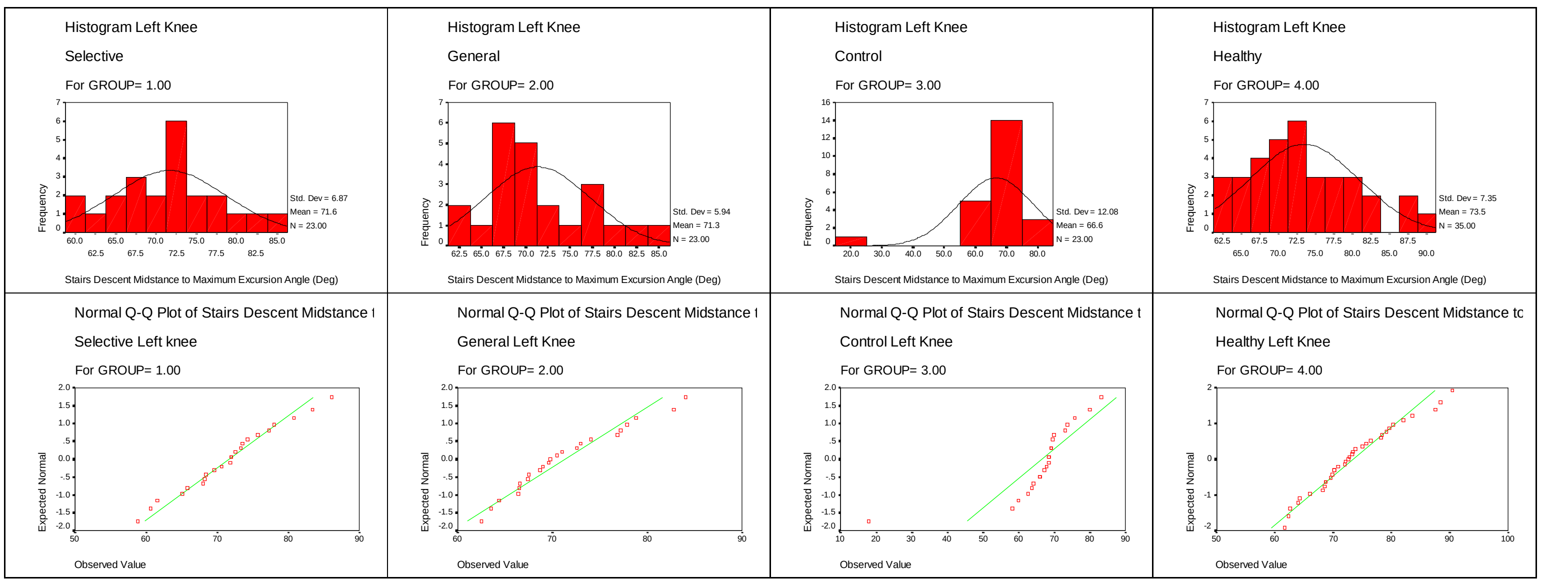
Graphs 17.92 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Right Knee Maximum Angle (Degrees)



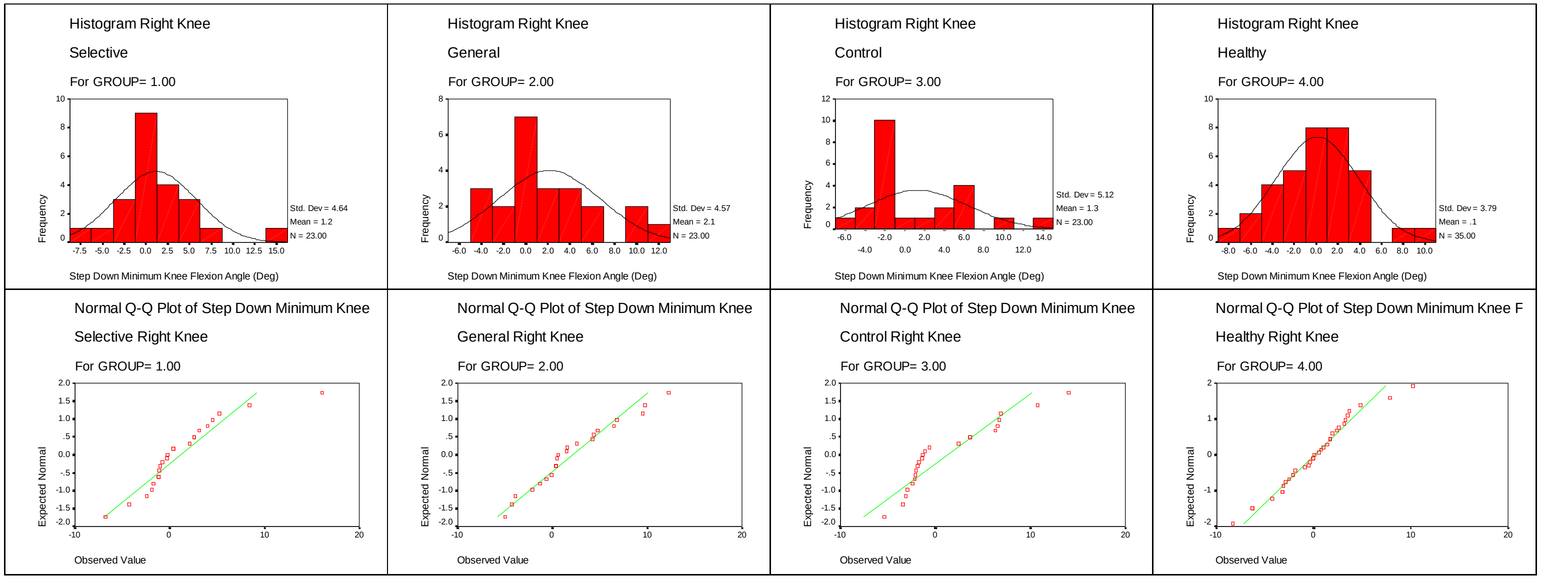
Graphs 17.93 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Left Knee Maximum Angle (Degrees)



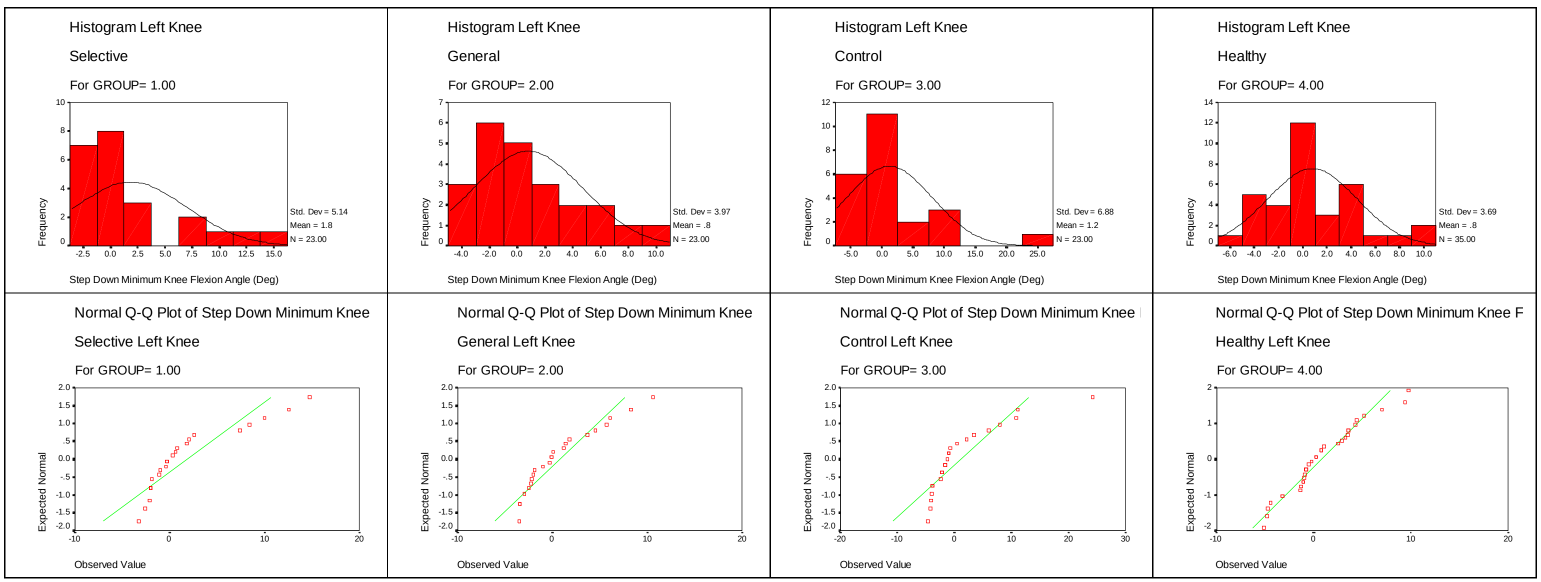
Graphs 17.94 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Right Knee Midstance to Maximum Excursion Angle (Degrees)**



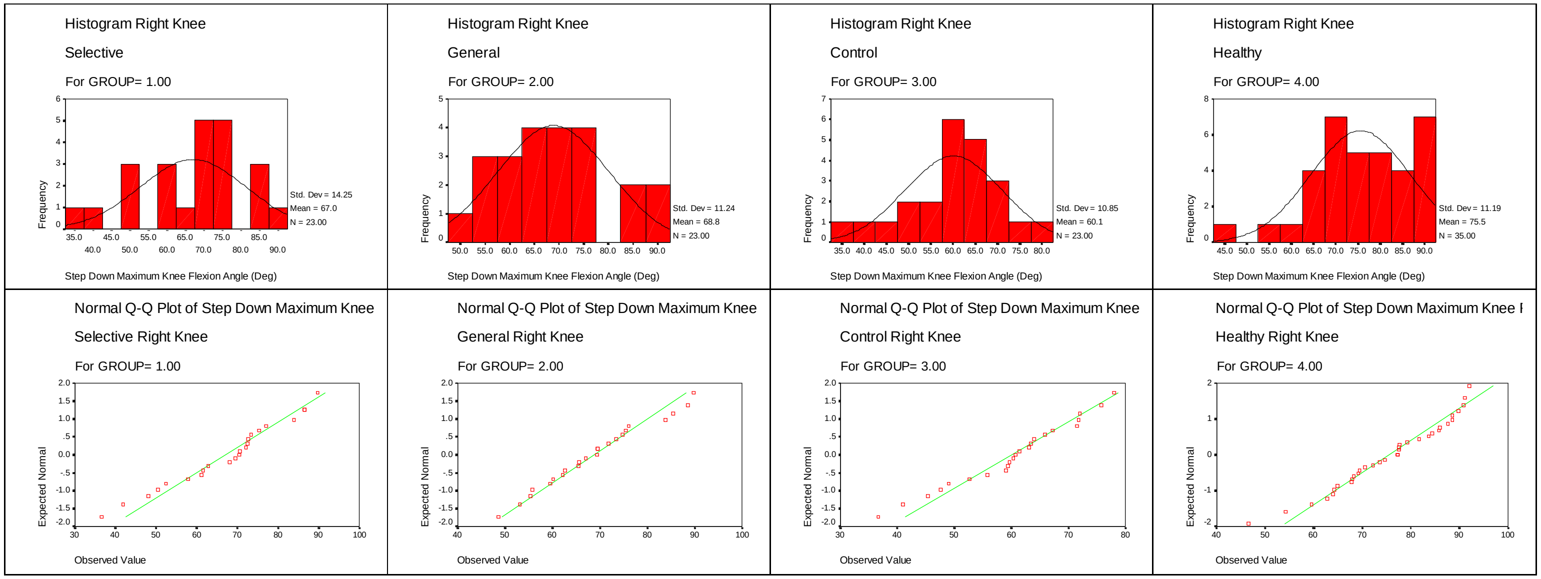
Graphs 17.95 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Stairs Descent Left Knee Midstance to Maximum Excursion Angle (Degrees)**



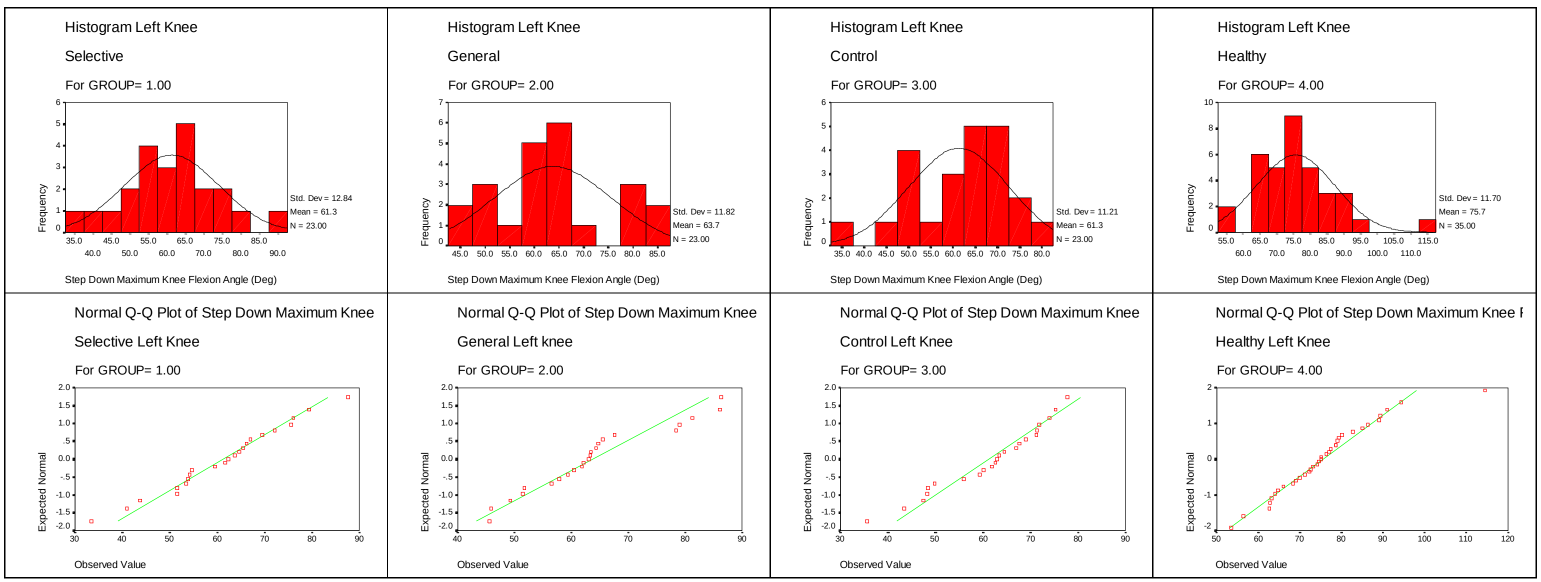
Graphs 17.96 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Minimum Right Knee Angle (Degrees)**



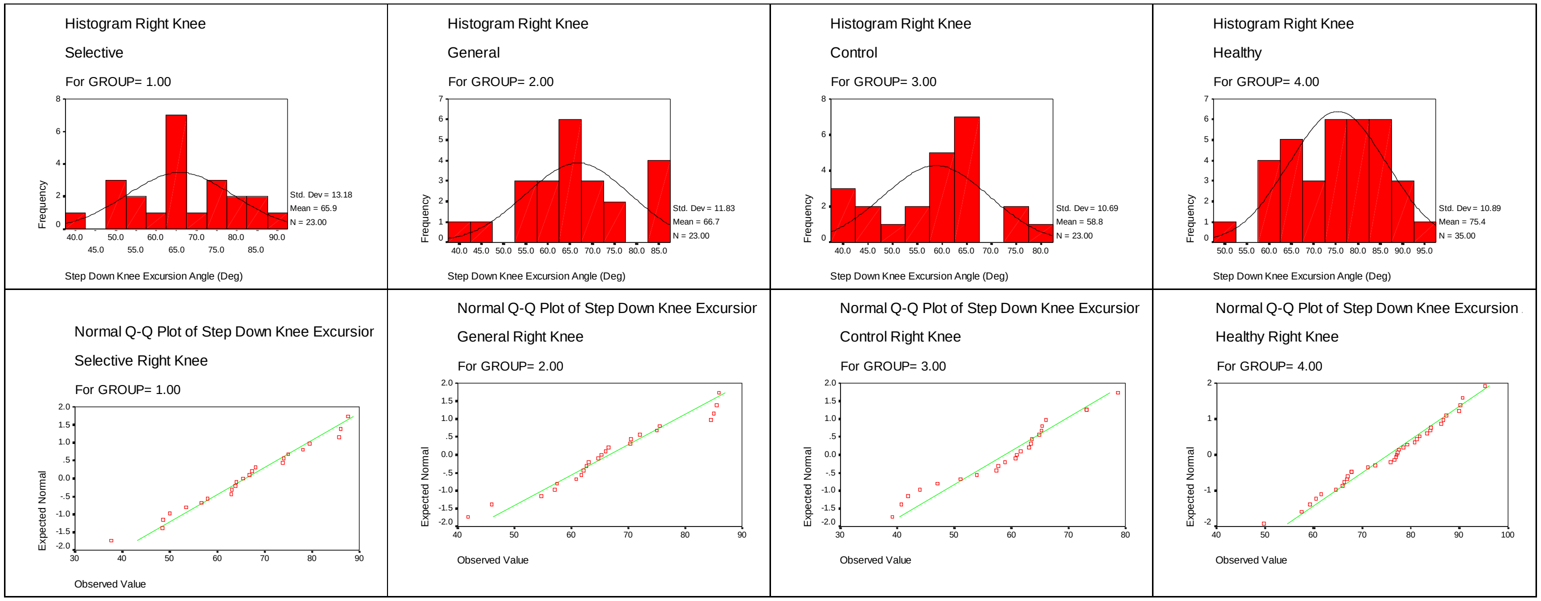
Graphs 17.97 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Minimum Left Knee Angle (Degrees)**



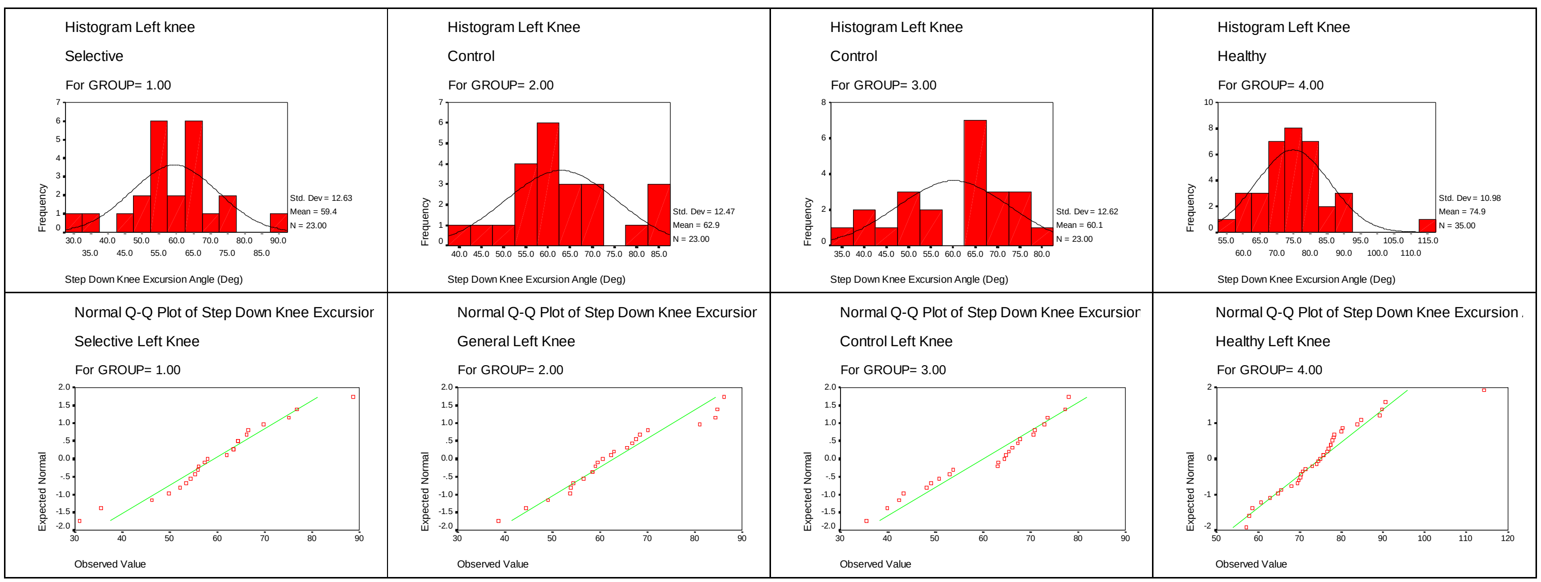
Graphs 17.98 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Maximum Right Knee Angle (Degrees)**



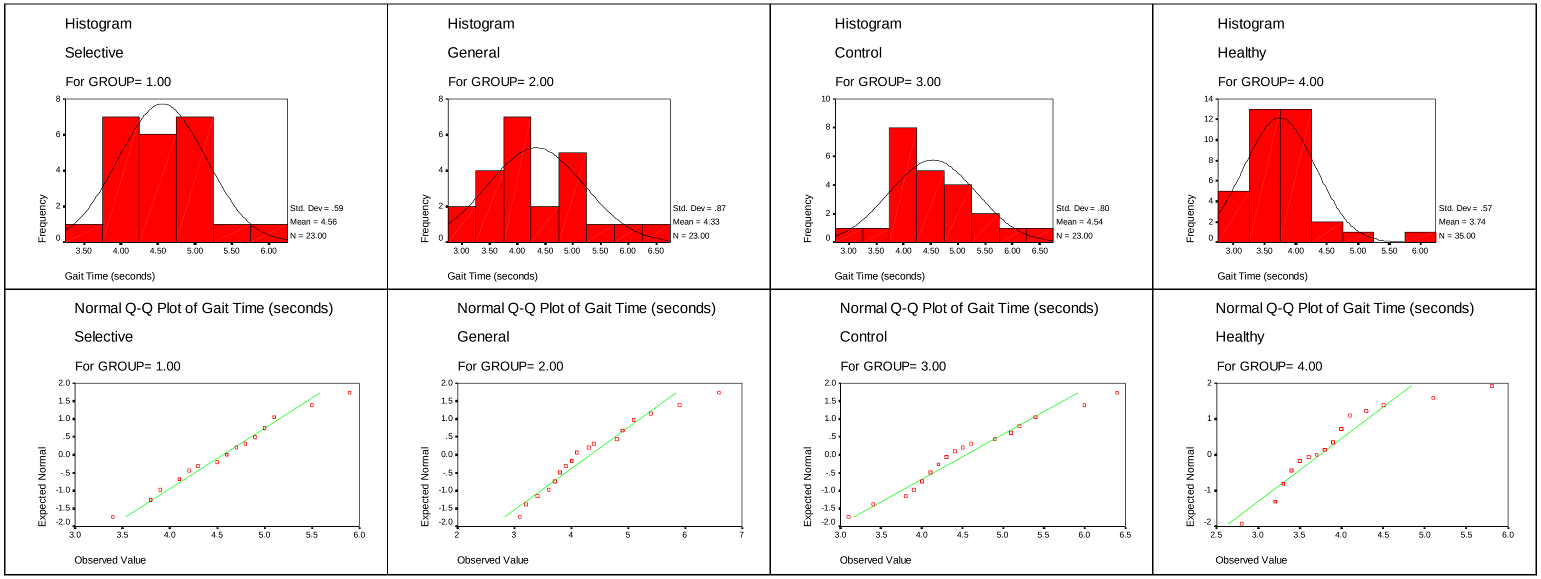
Graphs 17.99 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Maximum Left Knee Angle (Degrees)**



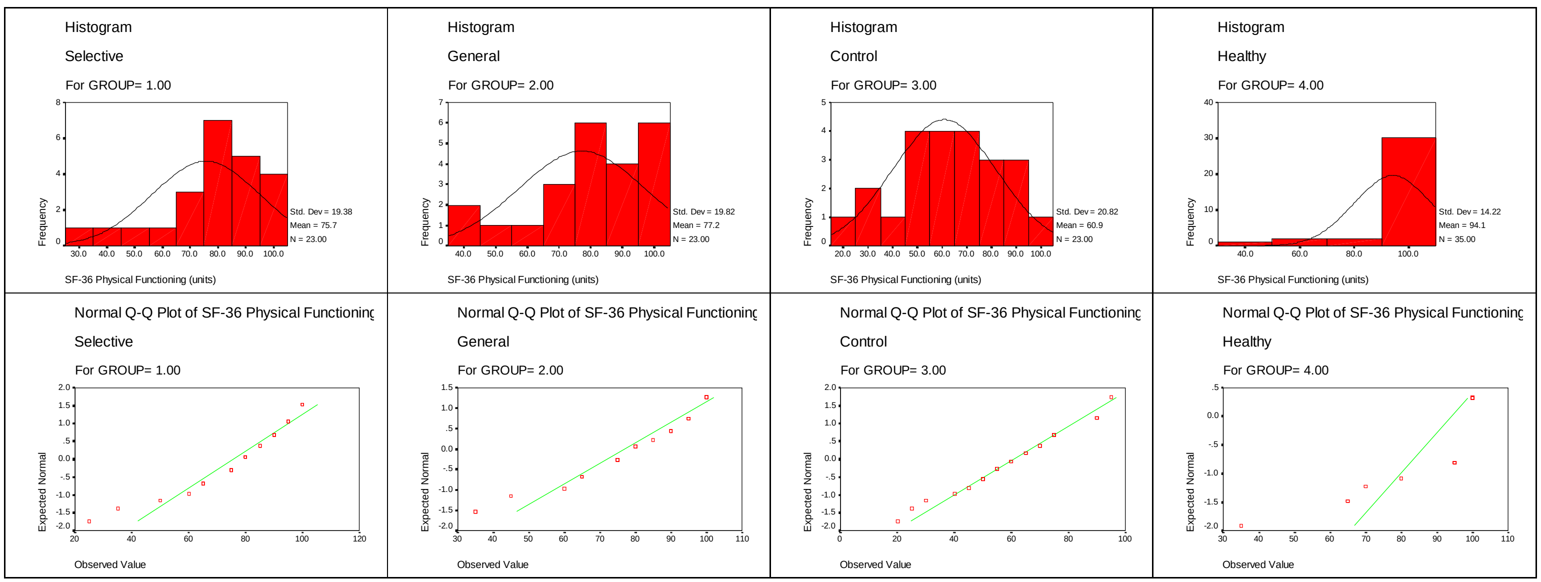
Graphs 17.100 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Right Knee Excursion Angle (Degrees)**



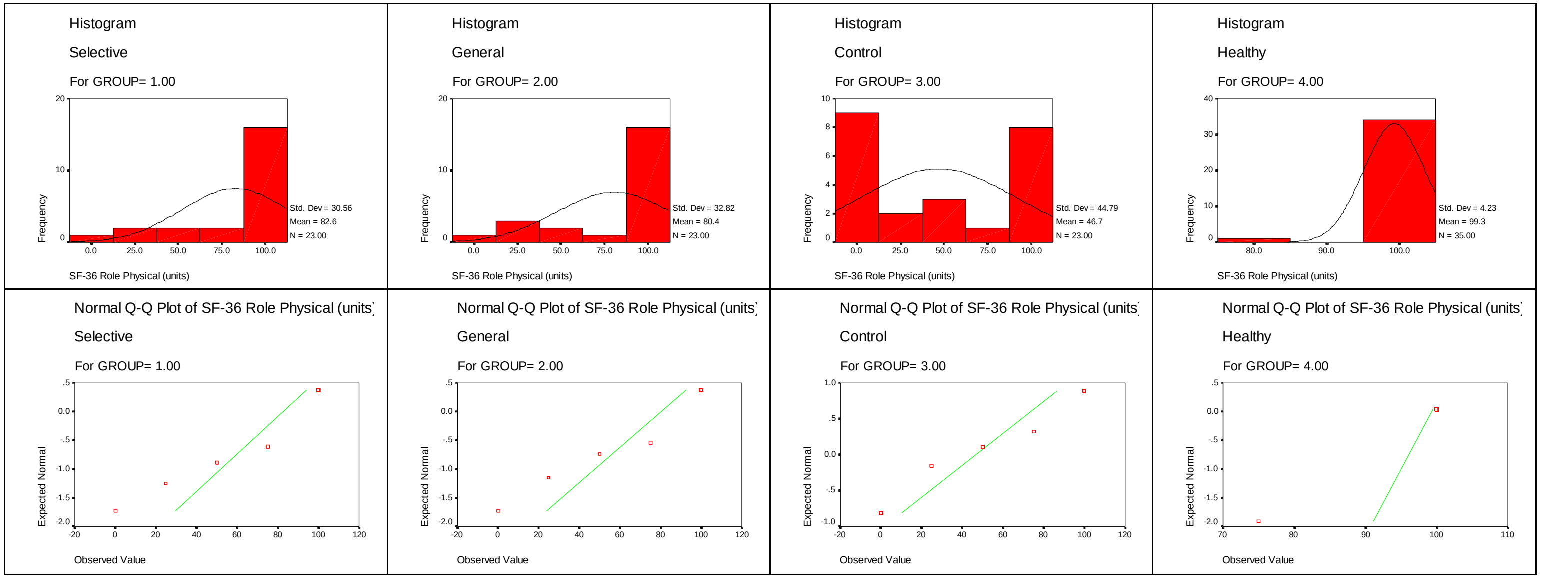
Graphs 17.101 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Step Down Left Knee Excursion Angle (Degrees)**



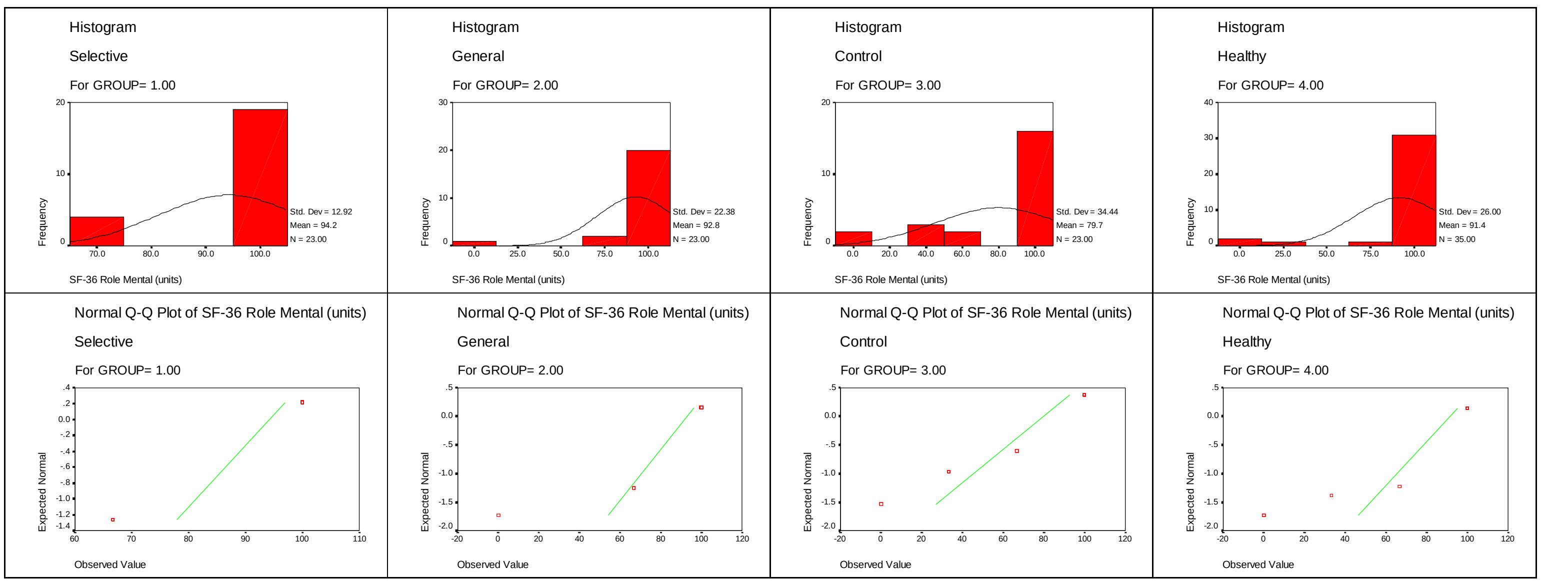
Graphs 17.102 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls for Level Walking Gait Time for 5 Metres (Seconds)**



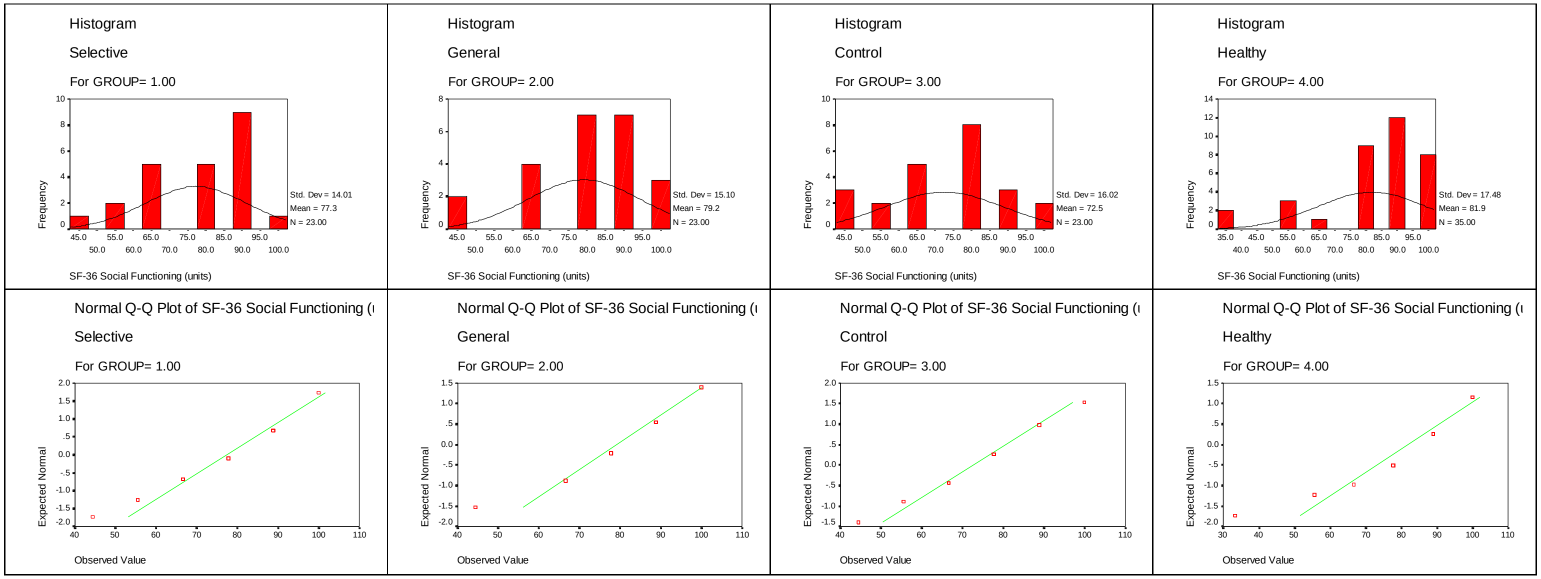
Graphs 17.103 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Physical Functioning (Units)**



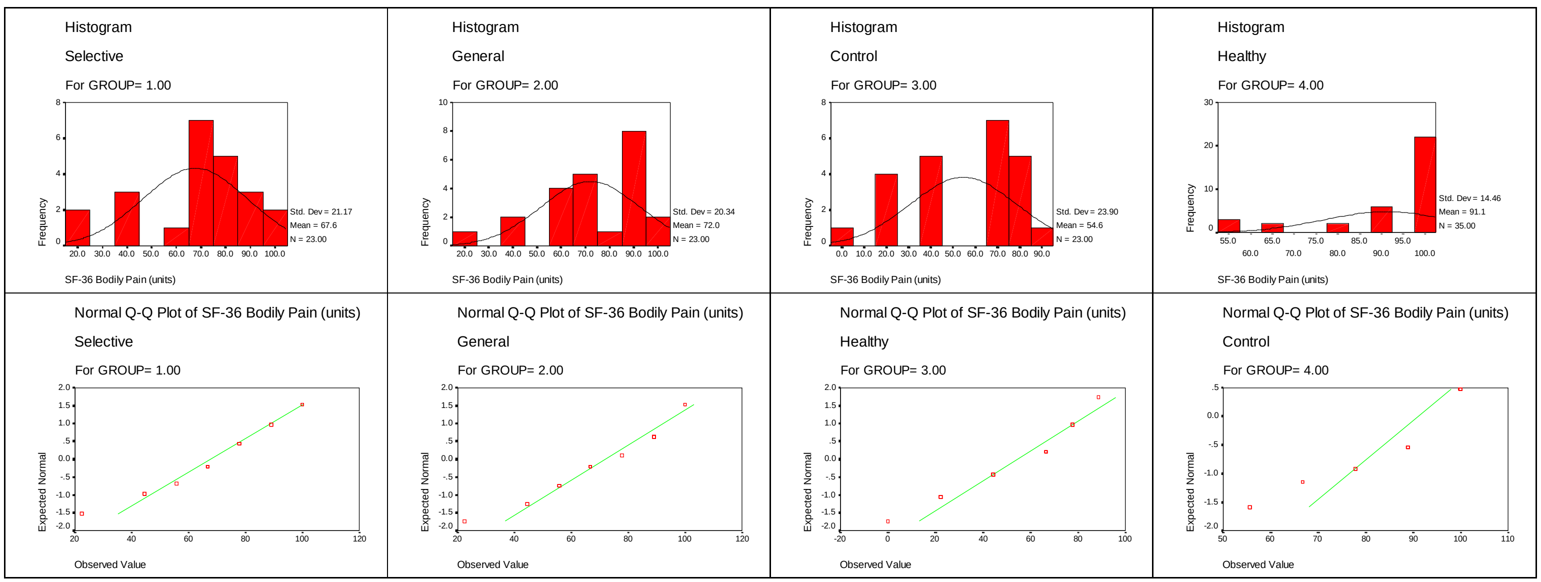
Graphs 17.104 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Role Physical (Units)**



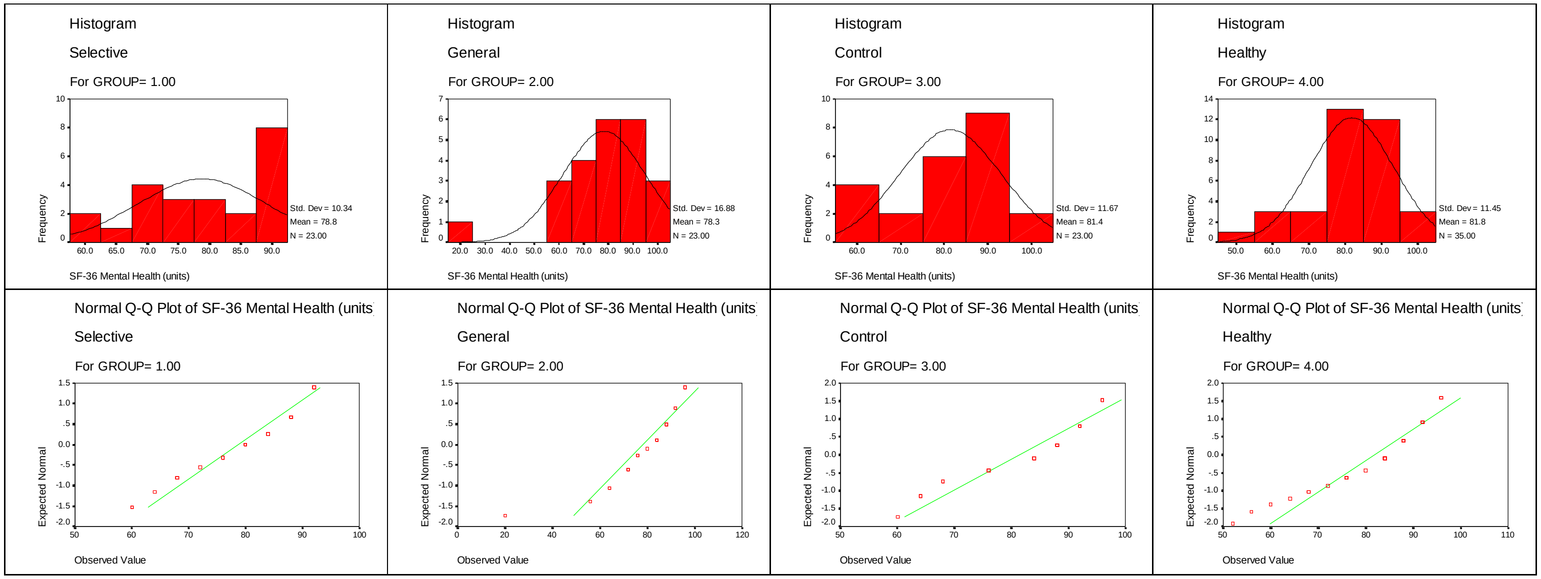
Graphs 17.105 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Role Mental (Units)**



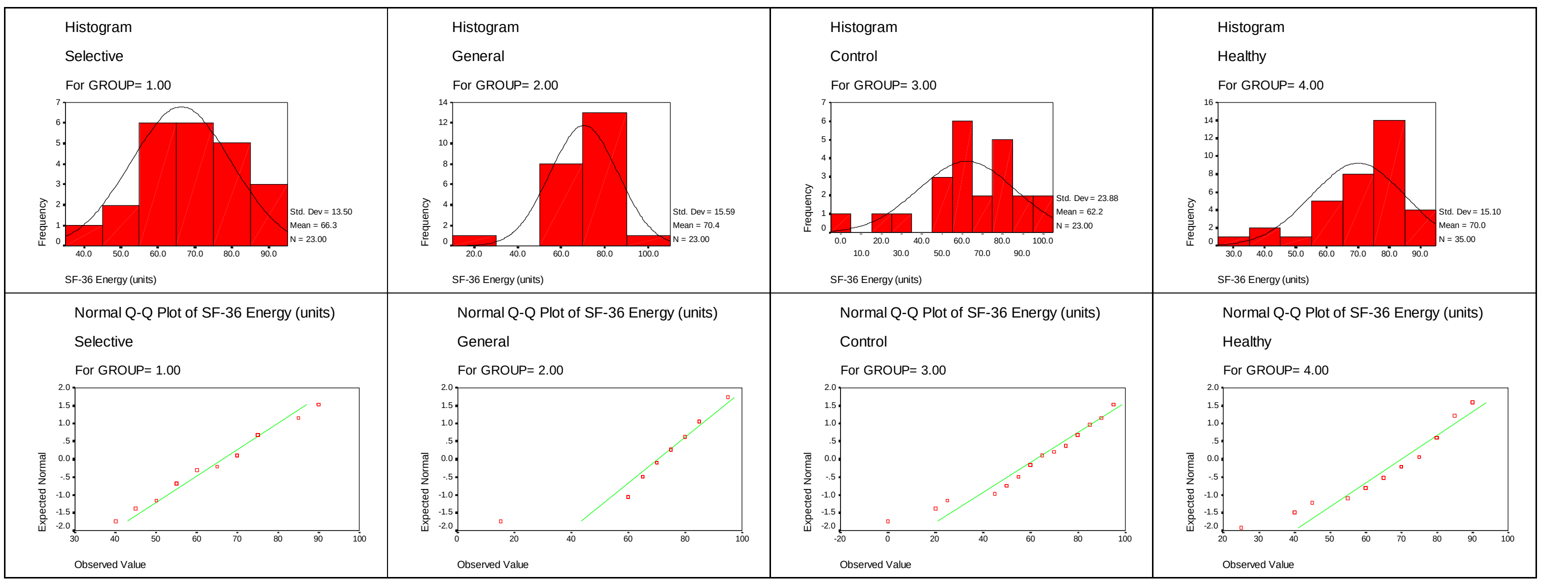
Graphs17.106 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Social Functioning (Units)**



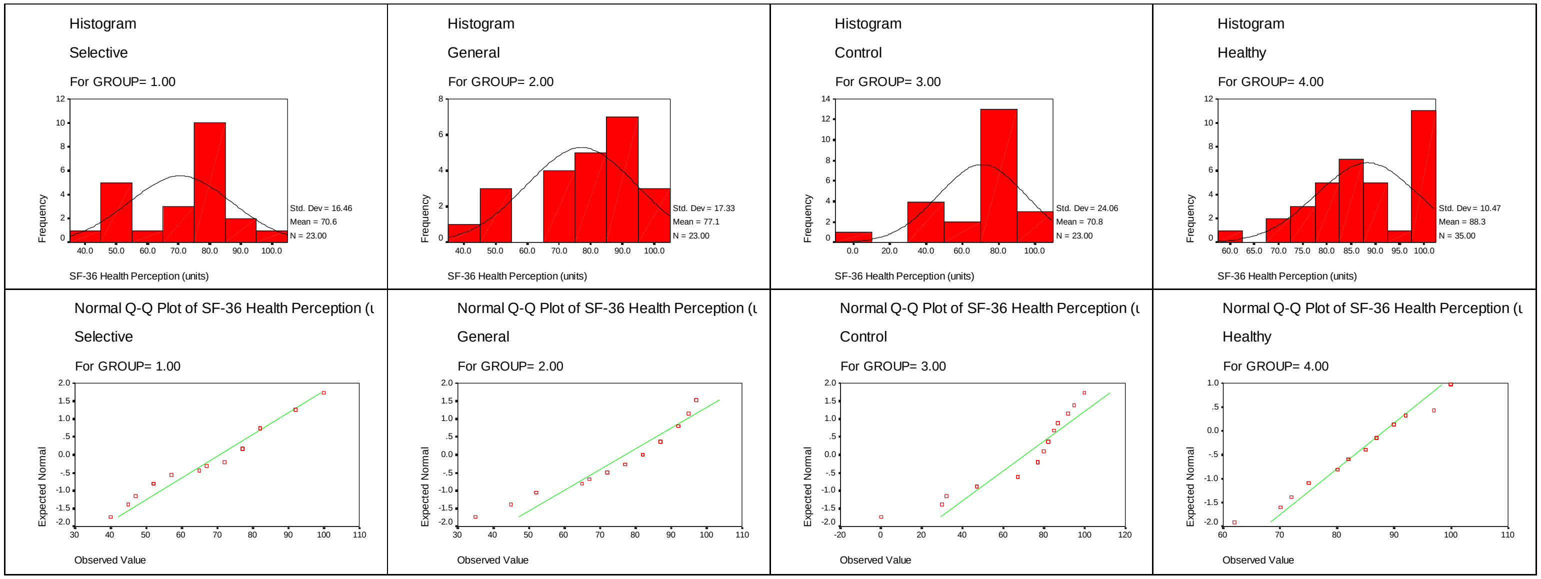
Graphs 17.107 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Pain (Units)**



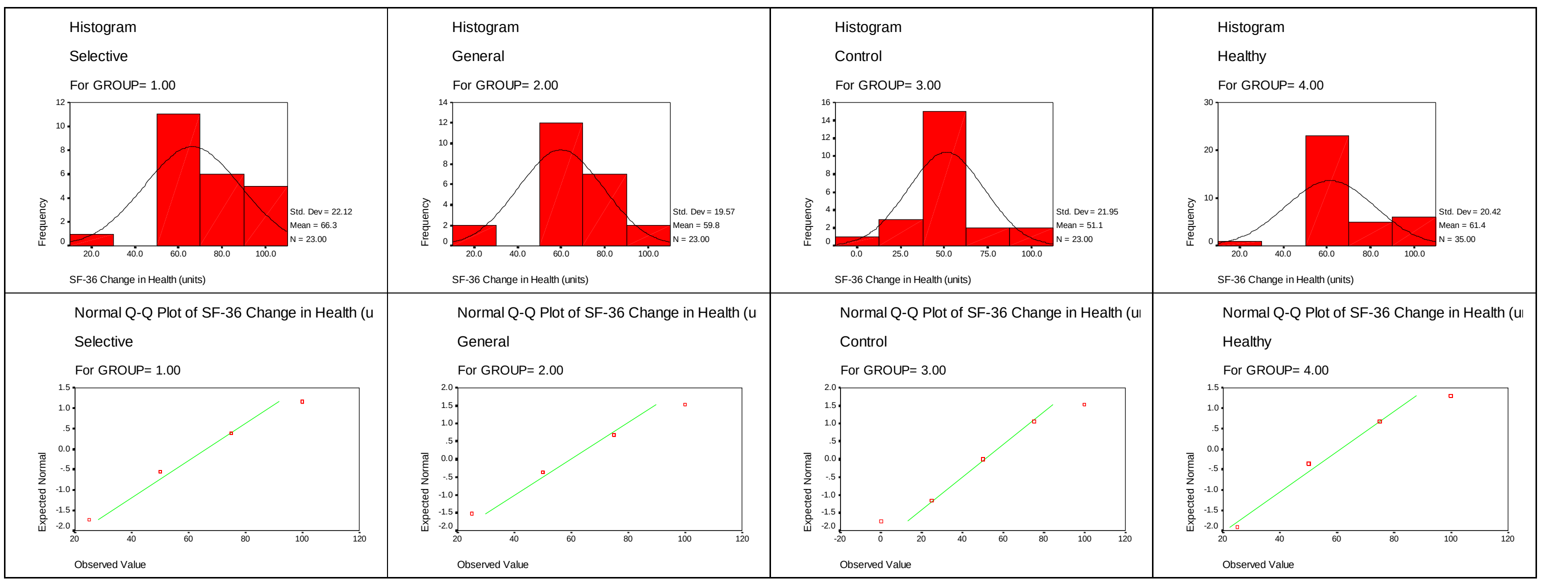
Graphs 17.108 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Mental Health (Units)**



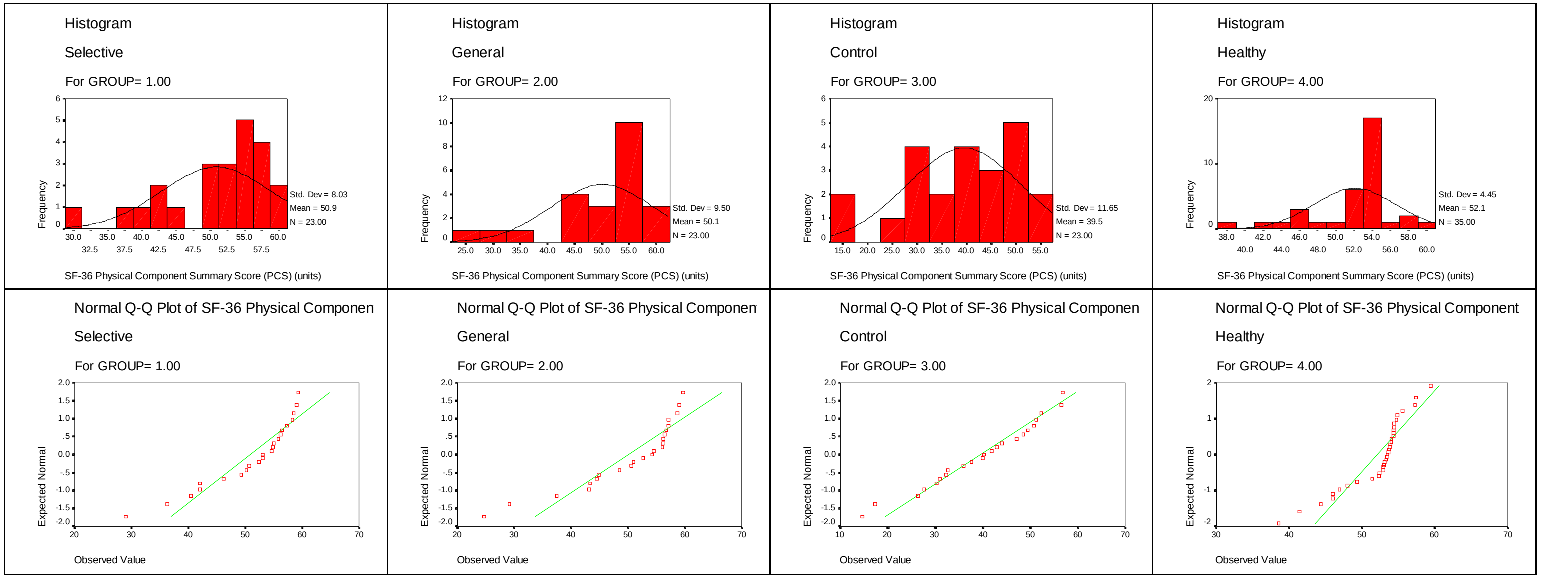
Graphs 17.109 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Energy (Units)**



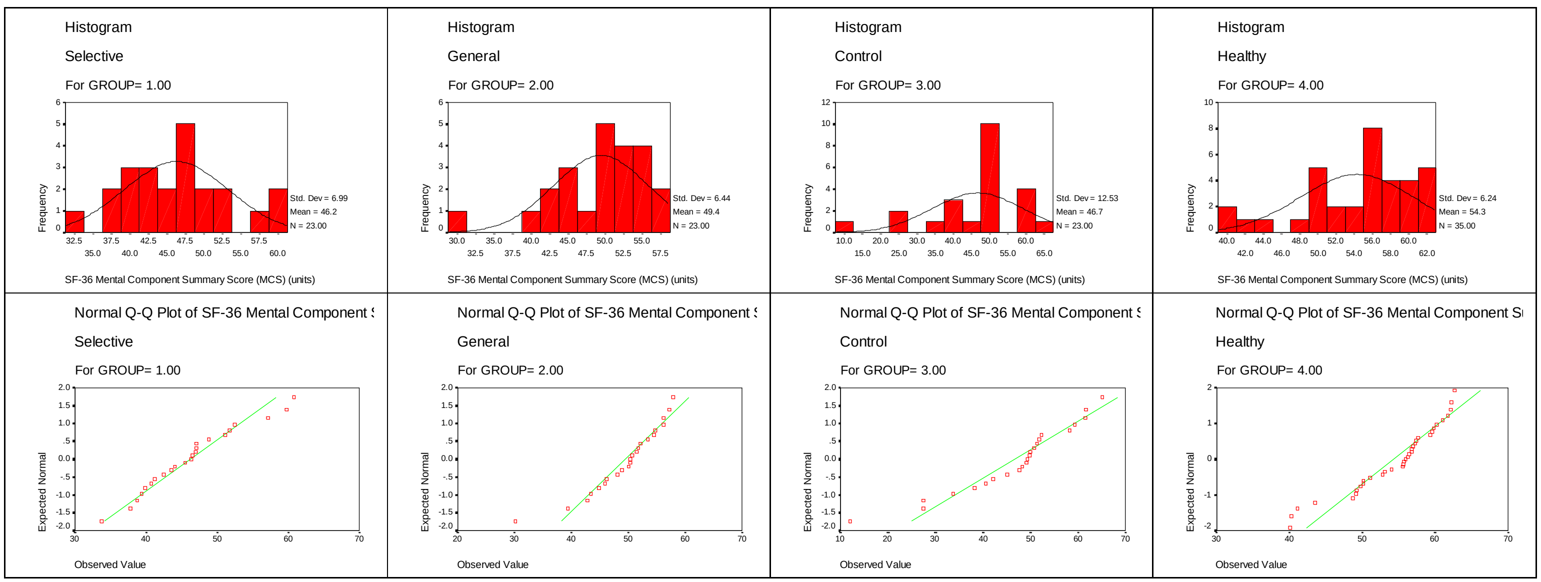
Graphs 17.110 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Health Perception (Units)



Graphs 17.111 Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Change in Health (Units)



Graphs 17.112 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Physical Component Summary Score (Units)**



Graphs 17.113 **Histograms and Normal Q-Q plots of PFPS Patients and Healthy Controls SF-36 Mental Health Component Summary Score (Units)**