1995

Long term restoration of peak torque, endurance and muscle activation post anterior cruciate ligament reconstruction

Darryl Alan Turner
Edith Cowan University

LONG TERM RESTORATION OF PEAK TORQUE, ENDURANCE AND MUSCLE ACTIVATION POST ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

By

Darryl Alan Turner

A thesis submitted in partial fulfilment of the requirements for the award of

Bachelor of Science (Sports Science) with Honours

at the Faculty of Science, Technology and Engineering, Edith Cowan University

Date of submission 9/11/95

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

ABSTRACT

In recent years, Accelerated Rehabilitation (A.R.) protocols have been used following Anterior Cruciate Ligament (A.C.L.) reconstructions, the longer term effects of these programs are seldom analysed. This study examined musculoskeletal mechanisms that might affect long term functional restoration,

The control subjects (n = 19) of mixed age and gender, had no previous knee deficiences and were recreationally fit. The experimental subjects (n = 17) had undergone intra-articular A.C.L reconstruction, using bone patellar-tendon bone grafts performed by the same surgeon and had also participated in the A.R. protocol, similar to that described by Shelbourne and Nitz (1990).

The experimental group attended Edith Cowan University (E.C.U.) research laboratory between 20-36 months post operation, where they participated in tests on a Cybex 6000 isokinetic dynamometer. Isokinetic knee extensions and flexions at 90, 180 and 300 degrees per second were performed, with torque output recorded from the hamstring and quadricep muscle groups, in the involved leg (I.N.) and in the uninvolved leg (U.N.) . To examine quadriceps inhibition, maximal isometric contractions with twitch super-imposition were analysed for each leg. Functional endurance was examined during repeated isokinetic contractions at 90 degrees per second for a duration of two minutes. To study muscle activation and co-activation, surface electromyography (S.E.M.G.) of the quadricep and hamstring muscle groups was recorded during all isokinetic contractions .

The results from this study indicate that A.R. does not fully restore all long term musculoskeletal mechanisms that influence function. Compared to those of the uninvolved leg, the involved quadriceps were significantly deficient, whilst the hamstrings/ quadriceps ratio increased since the hamstrings peak torque did not diminish as much as the quadriceps peak torque. This long term evaluation of muscle functions after A.C.L reconstructions, indicates a need for further research into surgical and rehabilitation procedures, that would enable complete restoration of all parameters and a return to maximal bilateral equality.

DECLARATION

I certify that this thesis does not incorporate without acknowledgment, any material previously submitted for a degree or diploma in any institution of higher education, and that to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text.

Date................9/11/1995................

ACKNOWLEDGMENTS

LIST OF FIGURES

LIST OF TABLES

Table

Page

Number

LIST OF CONTENTS

Appendices ·

CHAPTER ONE

INTRODUCTION

1.1 Background

Professional and recreational athletes of either gender can suffer anterior cruciate ligament (A.C.L.) damage during twisting or rapid change of direction. The higher the competitive pressure, the more intense the ligament stress and the more likely the need for reconstructive surgery.

Treatment of the A.C.L. for chronic deterioration or acute rupture can be conservative or surgical, but with recent advances in arthroscopic surgery, intra-articular reconstruction has become the most commonly used procedure (see Figure 1.1). The surgical choice determines the rehabilitation program, which aims to restore the knee to full function and bilateral equality with maximal strength, range of motion, endurance, agility and sensory feedback. These parameters decline before surgical intervention and are considerably deficient after the operation (Blackburn,1992). Post-operative rehabilitation programs vary considerably with current trends favouring aggressive accelerated protocols (McCarthy, Buxton, Hiller, Doyle & Yamada, 1994).

During rehabilitation, patients regain their musculoskeletal functions and these may be evaluated by isokinetic dynamometry but, more often by the therapist's subjective assessment. Rehabilitation continues post hospital with self administered therapy and weekly visits to the rehabilitation officer, until such time as the patient regains 80 per cent of bilateral functions. Previous studies (Shelbourne et al,1990, Blackburn,1992 and Yates, McCarthy, Hirsch & Pascale,1992) have reviewed the effects of accelerated protocols during the first 12 months. Although changes in muscle action can compensate for knee joint instabilities, it is uncertain whether these facilitate

maximal bilateral function and a full return to activity (Arvidsson, Eriksson, Haggmark and Johnson, 1981).

It is presumed that progressive recovery will continue however, scientific verification is required to understand the long term functional restoration of the knee and associated muscle parameters (Elmqvist, Lorentzon, Johansson, Langstrom, Fagerlund and Fugl-Meyer, 1989).

In support of long term evaluation is a case study of a college athlete who underwent A.C.L reconstruction with an accelerated rehabilitation program. He had enhanced knee extensor torque, diminished thigh girth atrophy and an early return to activity, however, anterior laxity and functional deficiency were apparent at 52 weeks (Nyland, Currier, Ray & Duby, 1993). A follow-up study by Arvidsson et al (1981) revealed muscle compensation and deficient torque outputs in the majority of the 80 subjects tested, 5-10 years post surgery.

Recently, there has been an increase in media reports on high profile athletes with A.C.L breakdowns, however the true extent of secondary or post-operative failures in the recreational athlete, are rarely reported. The surgical techniques are proven and fairly standard but rehabilitation protocols are still under scrutiny and require further long term evaluation.

```
                          ┌─────────────────┐
                          │   KNEE DAMAGE   │
                          └─────────────────┘

┌──────────────────────┐            ┌──────────────────────────┐
│   LIGAMENT DAMAGE    │◄──────────►│  MENISCUS / PATELLA      │
└──────────────────────┘            │  / OTHER DAMAGE          │
                                    └──────────────────────────┘

        ┌──────────────────┐        ┌──────────────────────────┐
        │   ACL DAMAGE     │◄──────►│  PCL / COLLATERAL /OTHER  │
        └──────────────────┘        └──────────────────────────┘

        ┌──────────────────┐        ┌──────────────────────────┐
        │  ACUTE TRAUMA    │◄──────►│  CHRONIC TRAUMA           │
        └──────────────────┘        └──────────────────────────┘

┌──────────────────────┐            ┌──────────────────────────┐
│  SURGICAL TREATMENT  │◄──────────►│  CONSERVATIVE TREATMENT   │
└──────────────────────┘            └──────────────────────────┘

┌──────────────────────────┐        ┌──────────────────────────┐
│ INTRA-ARTICULAR SURGERY  │◄──────►│  EXTRA-ARTICULAR SURGERY  │
└──────────────────────────┘        └──────────────────────────┘

┌──────────────────────────┐        ┌──────────────────────────┐
│ ARTHROSCOPIC TECHNIQUE   │◄──────►│  OPEN SURGERY             │
└──────────────────────────┘        └──────────────────────────┘

        ┌──────────────────┐        ┌──────────────────────────┐
        │   AUTOGRAFT      │◄──────►│  ALLOGRAFT                │
        └──────────────────┘        └──────────────────────────┘

┌──────────────────────────┐        ┌──────────────────────────┐
│ BONE PATTELAR-TENDON     │◄──────►│  ILLIOTIBIAL /            │
│ GRAFT                    │        │  SEMITENDINOSUS GRAFT     │
└──────────────────────────┘        └──────────────────────────┘

        ┌──────────────────┐        ┌──────────────────────────┐
        │  ACCELERATED     │◄──────►│  TRADITIONAL /            │
        │  REHABILITATION  │        │  REHABILITATION           │
        └──────────────────┘        └──────────────────────────┘

        ┌──────────────────┐        ┌──────────────────────────┐
        │  DAY 1 C.P.M.    │◄──────►│  IMMOBILISATION           │
        │  CLOSED CHAIN    │        │  BRACES                   │
        │  FULL R.O.M.     │        └──────────────────────────┘
        │  WEIGHT BEARING  │                    │
        └──────────────────┘                    ▼
                │              ┌──────────────────────────┐
                ▼             │ 12 MONTHS RETURN          │
┌──────────────────────────┐ │ TO FULL ACTIVITY          │
│ 6 MONTHS RETURN          │ └──────────────────────────┘
│ TO FULL ACTIVITY         │
│ 80-100% BILATERAL FUNCTION│
└──────────────────────────┘
                │
                ▼
┌──────────────────────────┐
│ >24 MONTHS               │
│ 100% BILATERAL FUNCTION ??│
└──────────────────────────┘
```

Figure 1.1 options for knee injuries

Legend
ACL- anterior cruciate ligament
PCL- posterior cruciate ligament
CPM- continuous passive motion
ROM- range of motion

3

1.2   Significance of the Study

Musculoskeletal function is dependant on muscular performance, neuromuscular co-ordination, joint motion and laxity, as well as intra-articular and extra-articular pathologies (Kannus,1994). An investigation was made for bilateral deficiencies in peak torque, muscle inhibition, activation and fatigability, which can affect normal function. Increased graft stresses after an accelerated return to activity could lead to long term instability or failure and it might be that complete and permanent restoration of the knee is not possible using these aggressive protocols.

The long term evaluation of musculoskeletal indices are necessary to verify complete recovery or indicate possible deficiencies, that may mask any surgical or rehabilitation inadequacies.

1.3   Definition of key terms in the study

Bilateral variance   : the difference between the uninvolved leg and
                                              the involved leg intra subject.

Difference in bilateral-   : the difference in bilateral-variance between the
variance   experimental group and the control group

Uninvolved leg (U.N)   : non operated contralateral leg.

Involved leg (I.N)   : reconstructed leg.

M.V.C.   : maximal voluntary contraction.

Isokinetic torque   : force produced about a joint's axis of
                                              rotation at a predetermined velocity

Isometric torque   : force produced about a joint's axis of
                                              rotation at zero velocity.

Peak torque (P.T)   : highest of four M.V.C torques

4

Accelerated rehabilitation(A.R.) : as described by Shelbourne et al (1990)

                                   (see Appendix D)

Long term   : greater than 20 months.

Quadriceps group   : synergistic Vastus Lateralis (V.L.), Vastus

                                   Medialis (V.M.) and Rectus Femoris (R.F)

Hamstrings group   : synergistic Semitendinosus (S) and Biceps

                                   Femoris (B.F.)

Endurance Ratio   : determined by the sum of the last five peak torques

                                   as a percentage of the sum of the first five peak

                                   torques, during a 2 minute isokinetic leg extension

                                   a flexion protocol, at 90 degrees per second as

                                   described by Kannus (1994)

Muscle Inhibition   : inability to maximally activate a muscle. A

                                   percentage of total activation during an M.V.C.

Hamstring / Quadriceps Ratio   : hamstrings peak torque during flexion divided by

                                   quadriceps peak torque in extension x 100

                                   No gravity correction

Hamstrings Antagonist   : peak amplitude and frequency unrectified

Co-activation E.MG.   E.M.G. waveform measured from the onset

activity   to conclusion during quadriceps extension

1.4   The purpose of the study.

The purpose of this study was the long term comparison between the uninvolved leg and the involved leg of reconstructed A.C.L subjects, whilst evaluating isokinetic concentric torque in the leg extensors/flexors at various angular velocities. Muscular endurance, during repeated maximal isokinetic leg extension/flexion, was analysed in terms of peak torque decline. To assess any central inhibition, the subjects performed maximal voluntary isometric contractions at 60 degrees flexion, whilst the twitch

interpolation technique was used to super-impose electrical twitches. Surface electromyographic activity (S.E.M.G). in the quadriceps and hamstring muscle groups was recorded during all isokinetic contractions to investigate any muscle activation after A.C.L. reconstruction Co-activated antagonistic activity from hamstring muscle group was indirectly measured with S.E.M.G. during leg extension. Data collected from the involved leg were compared to the uninvolved leg and bilateral-variance analysed by a paired t-test for significant differences (p less than .01). A group of 19 controls, with no prior knee problems underwent identical testing to examine normal dominant / non-dominant relationships. The differences between the experimental and control groups in bilateral-variance, were analysed by an independent t-test. Any significant differences between groups would demonstrate long term deficiencies of the reconstructed knee that might indicate the need for modification of surgical or rehabilitation procedures.

1.5 Hypotheses

In the long term (greater than 20 months) after A.C.L reconstruction and accelerated rehabilitation :

Peak torque

(1) There will be a significant difference between the experimental group and the control group in bilateral - variance of quadriceps peak torque during isokinetic leg extension, measured by Cybex dynamometry at (a) 90 degrees per second (b) 180 degrees per second and (c) 300 degrees per second.

(2) There will be a significant difference between the experimental group and the control group in bilateral - variance of hamstrings peak torque during isokinetic leg flexions, measured by Cybex dynamometry at (a) 90 degrees per second (b) 180 degrees per second and (c) 300 degree per second.

(3) There will be a significant difference between the experimental group and the control group in bilateral-variance of the hamstrings/quadriceps ratio during isokinetic leg extension / flexion, measured by Cybex dynamometry at (a) 90 degrees per second (b) 180 degrees per second and (c) 300 degrees per second.

Endurance ratios

(4) There will be a significant difference between the experimental group and the control group in bilateral-variance of the quadriceps endurance ratio during isokinetic leg extensions/ flexions, measured by Cybex dynamometry at (a) 90 degrees per second (b) 180 degrees per second and (c) 300 degrees per second.

(5) There will be a significant difference between the experimental group and the control group in bilateral-variance of the hamstrings endurance ratio during isokinetic leg extension / flexion, measured by Cybex dynamometry at (a) 90 degrees per second, (b) 180 degrees per second and (c) 300 degrees per second.

Inhibition

(6) There will be a significant difference between the experimental group and the control group in bilateral - variance of muscle inhibition during a 60 degree isometric maximal voluntary contraction, performed with Cybex dynamometry and utilising the percutaneous twitch superimposition technique.

E.M.G Activation

(7) There will be a significant difference between the experimental group and the control group in bilateral - variance in antagonistic hamstrings co-activation during leg extension, indirectly measured by E.M.G. activity during Cybex dynamometry at 90 degrees per second.

(8) There will be a significant difference between the experimental group and the control group in bilateral - variance of surface integrated E.M.G. activity during isokinetic leg extension / flexion performed with Cybex dynamometry at 90 degrees per second.

1.6 Variables

The independent Variable (treatment)

A.C.L reconstruction and accelerated rehabilitation:- Arthroscopic intra-articular surgery with a bone patellar-tendon (B.P.T.) bone graft and A.R. similar to that described by Shelbourne et al (1990) (see Appendix D).

The Dependant Variables

Force production:	Mean peak torque measured in Newton-meters as described by Perrin (1993)
Endurance Ratio:	Sum of the last five peak torques compared to the sum of the first five peak torques during a 2 minute protocol, expressed as a ratio, as described by Kannus (1994)
Muscle inhibition:	The percentage of inactivated muscle during a M.V.C. with twitch superimposition as described by Rutherford, Jones and Newham (1986).
Co-activation:	Hamstring co-activation during leg extension indirectly assessed by E.M.G. peak amplitude and frequency.
Muscle activation:	As measured by surface integrated electromyography as described by Gans (1992).

| Atrophy: | Assumed to be normalised and checked by girth circumference and limb weight |

The Controlled Variables

Surgeon:	The same surgeon performed all reconstructions.
Surgical method:	The identical method (arthroscopic intra-articular surgery with B.P.T. graft) was used for all reconstructions.
Accelerated Rehabilitation:	Similar to that described by Shelbourne et al (1990)
Fitness level:	A questionnaire established that subjects were recreationally fit athletes (someone who considered that they had participated on a weekly basis in a sporting activity, at least up until the injury.
Knee history:	No previous or subsequent knee trauma to either leg.

The Intervening Variables

Leg dominance:	Control legs assigned to match experimental groups involved leg dominance.
Gender:	Mixed groups used, experimental group (10 males - 7 females) control group (16 males - 4 females)
Age:	Experimental group (mean 25 years, range 18-47 years), control group (mean 25 years, range 18-46 years).
Right or Left Leg:	Randomised

1.7   Assumptions

1. Assumed Surgical success. -

Some operations are by nature more successful than others. This study has relied on the surgeon's competence and advice if the surgery was only partially successful. Three experimental subjects had other minor meniscus surgery at the time of the

9

reconstruction. The surgeon advised that these interventions would not affect musculoskeletal functions. It has been assumed this was true.

2. Motivation to fully activate during M.C.V.'s

It was explained to all subjects that the validity of the test depended on their motivation to produce maximal efforts in all protocols and on both legs. They were provided with visual feedback from the monitor and persistent verbal encouragement from the researcher to produce maximal efforts. It was assumed that they were fully motivated, and more importantly, equally motivated on both legs.

3. Clinical contra-indications

Any subjects who had health contra-indications, if recognised, were not included in the study, however it was assumed that neither the control or the experimental group had unknown knee deficiencies, other than the A.C.L reconstruction.

4. Subjects adherence to accelerated rehabilitation protocols

It was assumed that adherence to the rehabilitation program was neither excessive or non compliant. If there was inconsistent adherence to the prescribed rehabilitation, then any significant bilateral-variance cannot be attributed to the accelerated protocols.

5. Subsequent post rehabilitation activity

If exercise or activity, in the long interim period between completion of rehabilitation and the time of this study, was excessive, then further damage not attributable to the original reconstruction may have occurred. To the contrary, a lack of exercise since rehabilitation may have caused muscular weakness.

6. Psychological attitude

After injury and subsequent surgery, patients have a psychological hurdle to overcome. There are reservations as to the capabilities of the limb. This perceived disability could subconsciously prevent maximal effort even though there might be no clinical reason for deficient function. It was assumed the subjects no longer had reservations about the integrity of their knees.

7. Questionnaire reliability

It was assumed that all subjects had answered the questionnaire correctly and as indicated, were recreationally fit, at least up until the operation. Also that immediately prior to the test, that they had not participated in any excessive leg exercises.

1.8   Delimitations

1.   The results of this study were applicable to this particular surgical technique (arthroscopic intra-articular), graft (bone patellar-tendon bone), rehabilitation protocols (accelerated) and surgeon.

2.   Subjects were aged 18 years to 46 years, so these results would not necessarily apply to a younger or older population, who may have different regenerative characteristics.

3.   The testing protocols utilised concentric contractions of the leg muscles at velocities between 90-300 degrees per second, so these results might not apply to eccentric contractions or to velocities outside this range.

4.   The inhibition protocol examined maximal activation during a 60 degree isometric contraction, inhibition might be different isokinetically or at a different isometric angle, so these results would not apply.

5.   Isokinetic and isometric contractions on a dynamometer do not ideally replicate the functional stresses and movement patterns during intense twisting and turning. Hence the evaluations in this study are predictions of possible deficiencies or muscular attributes but, should not be used in isolation, to indicate 100 per cent recovery for intense activity.

1.9   Ethical Considerations

Confidentiality

The confidentiality of all subjects were maintained by assignment of numerical codes used throughout the data collection.   No information was personalised or made available to any other person, outside those specifically involved in the study, without written agreement from the subject.   On advice, it may be suggested that the subject consults and communicates these findings to his/her doctor.   All records were maintained secure and will not used for any other research purpose without prior consent.   Each session at the laboratory was private with only 1 subject being tested at a time

Consent

The enclosed form (see Appendix A) was issued to each proposed subject.   The implications, procedure and methodology of the study was fully explained to the subject prior to obtaining their written consent.   At any point before, during or post study, the subject could have withdrawn from participation or withdrawn the use of the data collected upon their efforts.   The entire procedure was explained prior to commencement of participation.

Approval

All subjects only participated with the authority of the acting medical surgeon or doctor, who explicitly indicated that the subject was fit, healthy and able to undergo the research without any foreseeable detrimental effect. Any and all contra-indications were referred to the doctor before any further participation.

Minors

No minors participated.

CHAPTER TWO

LITERATURE REVIEW

2.1   General Literature

2.1.1 Introduction

The knee, a hinge joint articulated by the distal femur and proximal tibia, allows flexion of the leg with internal tibial rotation and extension with external tibial rotation. Twelve muscles cross the knee joint, but the principal extensors are Vastus Lateralis (V.L.), Vastus Medialis (V.M.) , Rectus Femoris (R.F.) and flexors are Biceps Femoris (B.F) and Semitendinosus (Perrin,1994). The A.C.L., 31- 38 mm in length, consists of multiple longitudinal fascicles that insert proximally on the medial aspect of the lateral femoral condyle and distally on the anterior tibial plateau (see Figure 2.1). Blood supply for the synovial membrane around the ligament flows from the middle genicular artery that enters transversely then runs longitudinally and parallel to the collagen bundles (Smith, Livesay & Woo 1993; Hawkins, 1993). The knee joint is innervated by two groups of articular nerves, the posterior group consisting of branches of the tibial nerve and the obturator nerve, the anterior group consisting of branches of the femoral, peroneal and saphenous nerves (Barrack, Lund & Skinner, 1994).

The A.C.L is a tough connective ligament and functions to guide skeletal motion during low loads and limit motion in high loads, preventing subluxation of the tibia. Failure characteristics change depending on the direction of loading and the angle of knee flexion, loading capabilities decreasing with increasing flexion. Graft insertion sites and not the strain, may be the main determinant of failure after surgery (Hawkins, 1993). The changing elastic properties are very relevant to A.C.L

14

replacement, since graft is tendon and not ligament, thus tension alters with time. (Smith et al, 1993).
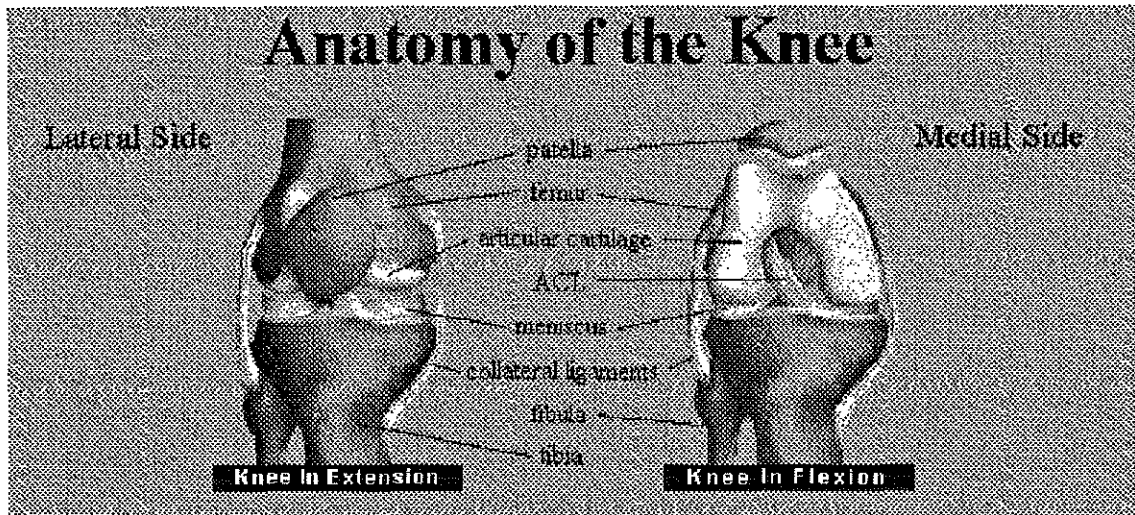
Figure 2.1   The Anatomy of the Knee

* Source: internet / yahoo http://www.sco1.com/knee anat.htm (1995)

Sensory information on joint position, motion and acceleration is communicated by the several A.C.L. mechanoreceptors that convert mechanical deformation into a series of nerve action potentials. Ruffini and golgi tendon organs are slowly adapting receptors that respond to motion throughout the knee joint abduction and extension. At the limit of full range of motion and rotational limits, their discharges increase and have been shown to generate reflex muscular contractions important in stiffening or stabilising the affected joint. Pacinian Corpuscles are also able to initiate protective reflexes (Barrack et al, 1994). Free nerve endings communicating pain are sparse or absent in knee ligaments and not active when mechanoreceptors are maximally stimulated.

Chronic injury to the A.C.L. is potentially crippling and if untreated, an active person will incur further damage and deterioration of the joint. However, for those willing to modify their activity and if there is no other structural damage, non-operative

15

conservative treatment is possible Functional training, bracing and education is used to re-establish maximal strength and muscle activation, with caution for patellar femoral symptoms (Irrgang, 1993; Blackburn,1992).

The injured A.C.L. is often treated surgically. This treatment allows greater option for activity and less subsequent degeneration. Surgical procedures are either extra-articular or intra-articular, the latter having more success for graft fixation using arthroscopically aided techniques (McCarthy et al, 1994). The intra-articular, autogenous, bone-tendon-bone graft has become widely used, reducing tissue morbidity and allowing early rehabilitation. Recovery is evaluated at 6 months and providing 80 per cent bilateral function has returned, the patient is allowed to return to normal activity. However, it is presumed that muscle strength and activation will continue to return to pre-injury levels although this is not usually assessed in the lo⹁ ·term, therefore full recovery is assumed. The aim of A.C.L surgical treatment is to restore joint stability within 2mm anterior laxity, assessed by the Lachman test, thus restraining anterior movement of the tibia (Irragang,1993; Smith et al, 1993; Carborn & Johnson,1993).

It is still suggested that adolescents with open epiphysial plates have extra-articular surgery using a strip of the illotibial band under the fibular-collateral ligament (Nisonson,1991).

Arthroscopic view of a healthy A.C.L
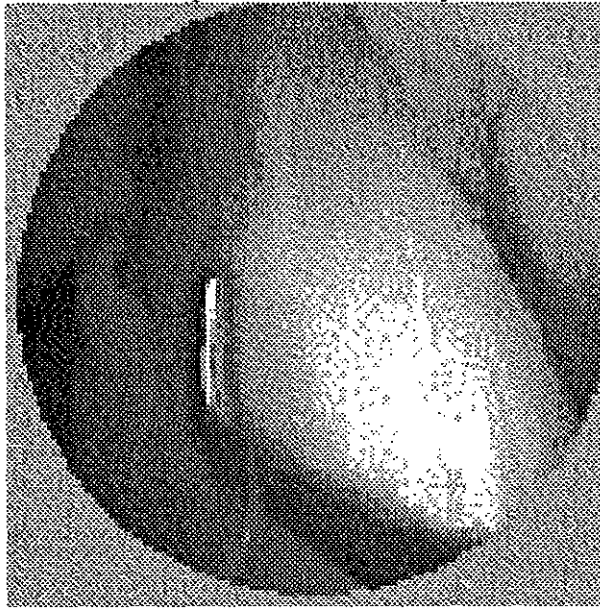
Arthroscopic view of a ruptured A.C.L
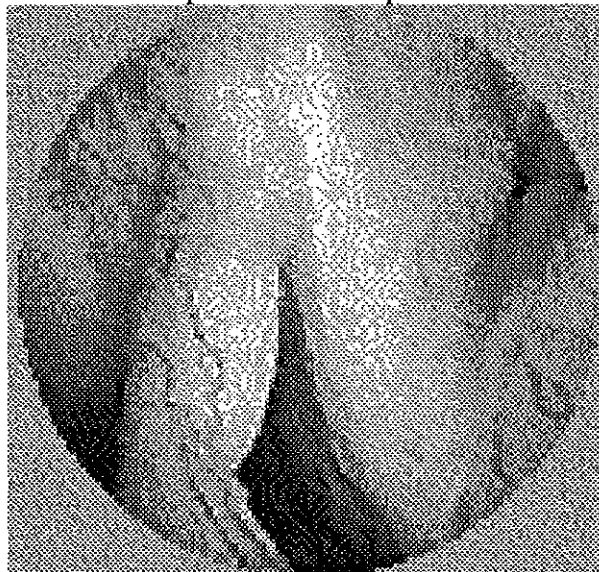
Figure 2.2   Comparison of a healthy and a ruptured A.C.L.

* Source: Internet / Yahoo http://www/sco1.com./acl.recon.htm. (1995)

Complications caused by immobilisation after reconstruction are associated with intra-articular adhesions, infra-patellar adhesions, patellar femoral crepitations, joint stiffness, range of motion and quadriceps atrophy (Frndak and Berasi, 1991). Arthrogenous muscle weakness may be due to atrophy or the inability to activate the muscle, atrophy of the vastus medialis being more common than the other quadriceps muscles and the quadriceps atrophying to a greater extent than the hamstrings. There is atrophy in both type I and type II muscle fibres suggesting strengthening at various intensities and velocities would be beneficial. Type I respond better to slow velocity training, whereas type II respond better to more intense, fast velocity training (Elmqvist et al, 1989). Joint pathology can inhibit muscle activity so causing weakness and wasting of muscle fibres which maybe caused by reflex inhibition, ischaemia, effusion or periarticular pathology (Elmqvist et al, 1989). Arthrofibrosis (joint stiffness) prevents the patient from gaining full range of motion, in particular, the terminal 5 degrees of full extension. A study by Shelbourne et al (1991) investigated the optimal time after acute A.C.L. injury, appropriate for reconstruction to minimise joint stiffness. They noted that in chronic A.C.L. reconstructions, there was less arthrofibrosis than after acute reconstruction and concluded that the optimal time for surgery was 3 weeks from the injury. This surgical delay, together with accelerated rehabilitation, cryotherapy, early muscle control and functional weight bearing exercise, produced the least arthrofibrosis (Noyes, Torvik and Hydee, 1984).
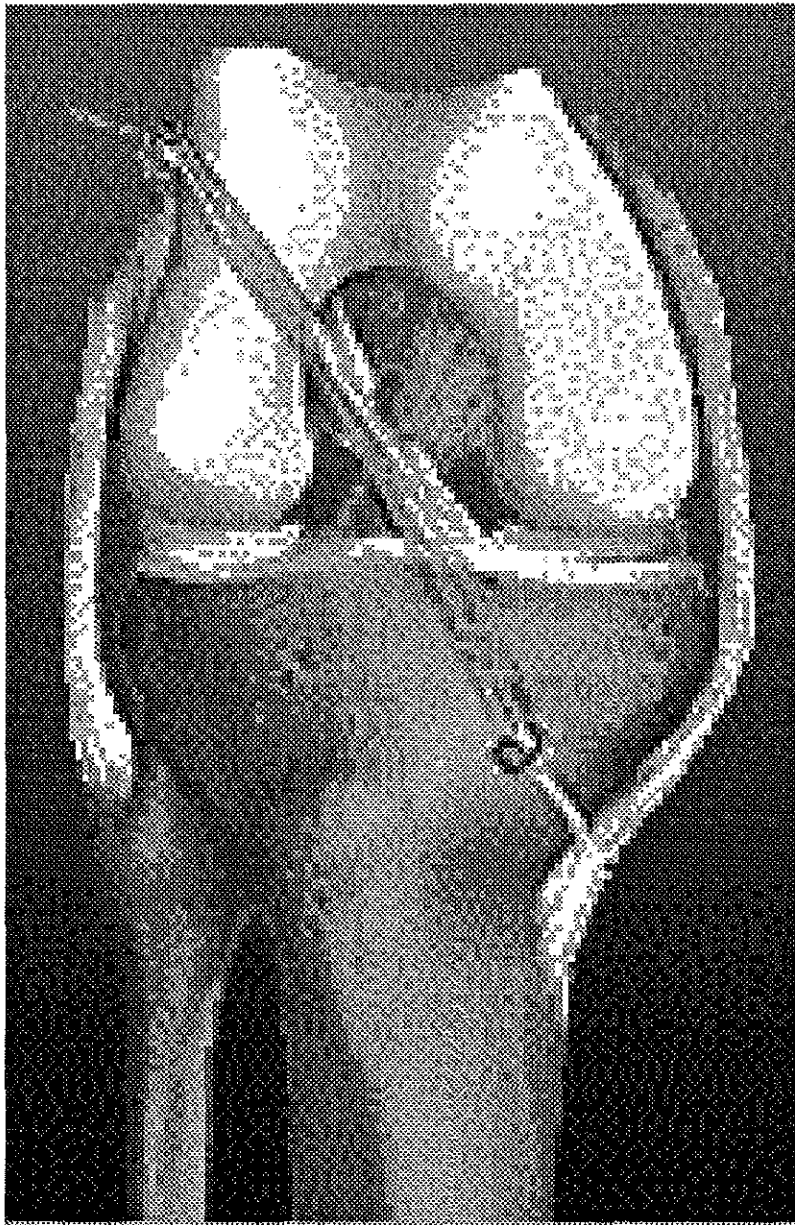
Figure 2.3   Placement of the new A.C.L graft

* Source: Internet / Yahoo http://www.sco1.com/acl.recon.htm. (1995)

Grafts used in A.C.L. reconstructions include semitendinosus, illotibial band and patellar tendon, the latter autografts have shown the best biomechanical properties and graft strengths allowing aggressive rehabilitation (Irrgang, 1993; Blackburn, 1992; McCarthy et al,1994). Knee laxity can be a problem due to inadequate graft tension and placement or excessive stress during rehabilitation. Graft failure can be a complication if the new graft does not restore passive stability of the knee or, is not strong enough to withstand physiological stresses. It must be permitted to heal in the desired position without disruption or displacement. Studies investigating the biomechanics of the knee demonstrate that passive positioning in the maximally flexed and extended position cause stresses on the A.C.L. by comparison to mid range position. Within 6 weeks of surgery, the fixation site is kept in position by bony or fibrous healing but revascularisation of the graft is a longer process which takes up to 6 months (Noyes,et al, 1984). Although the bone patellar-tendon bone autografts are considered 168 per cent as strong as healthy A.C.L's, activities should be controlled for the amount of stress on the grafts. Quadriceps contraction alone produces an anterior drawer force on the proximal tibia from 45 degrees to full extension, which can be neutralised by simultaneous co-contractions of the hamstrings or by restricting extension beyond 60 degrees (Frndak et al, 1991). The type of contraction and rate of force production placed on auto grafts, as well as age, ischaemic disease, steroids and vascular problems will all effect the healing rate (Blackburn,1992).

Until the 1980's, rehabilitation after A.C.L. reconstruction was conservative, time restraints for graft healing were imposed, range of motion was limited and full activity not permitted until 9-12 months (Blackburn, 1992). There were increased losses of proprioception, flexion contracture and articular damage due to lack of weight bearing exercise and immobilisation of the leg (Blackburn, 1992)

The accelerated approach initialised by Shelbourne et al (1990) (see Appendix D), featured early emphasis on restoration of full knee extension equal to the contra-lateral leg, closed kinetic chain exercises to improve muscle function and full activity by 4-6 months (Irrgan,1993; McCarthy et al, 1992). Continuous passive motion (C.P.M) was used to assist full range of motion without detrimental effect to graft laxity (McCarthy et al,1994; Yates et al, 1992). General encouragement for full and immediate range of motion became the accepted method of avoiding complications. After surgery, C.P.M. was restricted to ranges from 35-70 degrees flexion so as to avoid compressive forces. Problems were more related to range than velocity, the forces on the joint being greater at lower velocities.

The closed chain concept means overlapping segments connected by joints, both ends being connected to an immoveable framework thus preventing translation of either the proximal or distal joint centres. This creates a system where movement at one joint reduces movement at all other joints in a predictable manner. An open kinetic chain exists when the peripheral joint of the extremity can move freely such as a swinging hand or foot or as in isokinetic dynamometry (Palmitier, An, Scott & Chao 1991). The accelerated approach utilises closed chain activities within first post-operative week, ambulation in the brace (1 week) and subsequently without (4-6 weeks) allowing weight bearing exercises as can be tolerated. Functional activities are emphasised and neuromuscular control exercises with stabilising wobbleboards are progressed throughout rehabilitation (Irrgang,1993: Shelbourne et al,1990). Closed chain exercises reproduce co-activation of the hamstrings and quadriceps, found in normal squatting, walking and running activities, thus reproducing functional movement more precisely. Open chain exercises during rehabilitation are only performed safely in knee extensions, isometrically or isotonically, from 60-90 degrees of flexion or undue stress is placed on the graft (Irrgang,1993; Perrin,1994).

To prevent the quadriceps muscle atrophying and weakening during immobilisation after knee reconstruction, a research project by Sisk, Stralka, Deering & Griffin (1987) investigated voluntary isometric exercise and isometric exercise with electrical stimulation on the quadriceps. Although not conclusive, significant differences were found with isometric protocols and it was suggested that further studies of electrical stimulation during immobilisation might retard strength loss after A.C.L. reconstruction.

Although the surgical techniques have become fairly standard, the rehabilitation protocols still remain varied, demonstrating the need for further long term clinical research into programs that provide 100 per cent muscle function recovery (McCarthy, et al, 1994).

2.1.2 Force and Endurance Functions

To function with full range of motion, the muscles must be capable of producing forces about the joint's axis but after A.C.L. injury, maximal force production of the leg muscles deteriorate due to atrophy, inhibition or both. Immediately post operation, the force capabilities rapidly decline due to the knee pathology, however the surgeon, by using arthroscopic techniques, attempts to reduce the time of inactivity and subsequent muscle wastage, whilst the rehabilitation therapist attempts to restore the force functions as early as possible.

There are six major factors that influence the ability of skeletal muscle to produce power, these are muscle length, contractile velocity, cross sectional area, muscle architecture, muscle activation and previous muscle action (Gregor & Abelew, 1994). In functional activity after A.C.L. reconstruction, the muscle length of the quadriceps and hamstring groups are most relevant, as force production varies according to the biomechanical advantages attained through the range of motion (R.O.M.), thus testing for leg strength is attempted through the greatest range possible. Force

values can be compared when the R.O.M. is bilaterally equal or if a peak force value is taken. The force-velocity curve dictates, that force outputs should be compared only at equivalent velocities. For functional purposes, a slow velocity of 90 degrees per second will demonstrate higher strength capabilities, whereas 300 degrees per second will demonstrate the fast powerful moves of sprinting. Muscle architecture is dependent on fibre types and cross sectional area (C.S.A), the former being bilaterally matched, however after A.C.L. reconstruction, atrophied C.S.A. of muscle, is a main determinant of reduced force output. If the muscle is not atrophied it can still have a reduced ability to produce force, if the fibres cannot be fully activated. Thus inhibition through the neuromuscular system is a complication seen after surgery and will naturally affect force production and muscle function. Previous muscle action such as the stretch-shorten cycle or fatigue protocols will effect the leg force productions and therefore must be evaluated with identical muscle history. Isokinetic dynamometry is excellent for force analysis as it can control R.O.M. (length), velocity (0-500 degrees per second) and previous muscle history (repetitions, endurance protocols, rest periods and contraction types). Force can be measured during isometric, isokinetic (concentric and eccentric) or isotonic muscular contractions.

A comprehensive study by Shelbourne et al (1990) compared isokinetic strength of the quadriceps, range of motion, knee laxity and subjective patient assessment of 800 subjects. This investigation compared an accelerated rehabilitated (A.R.) group (n = 450) with the conservative rehabilitated group (n= 350), 12 months post surgery and found that both groups had 90 per cent quadriceps force of the uninvolved leg, during extension at 120 degrees per second. They indicated that some well motivated subjects in the A.R. group, reached 85-90 per cent bilateral equality as early as 10 weeks post operation. Elmqvist et al (1989) found knee extensor performance improved and stop deteriorating after 14 weeks post operation, however, after 1 year the injured leg was unequal to the normal leg but not

significantly. The researchers suggest that early loss of performance was caused by loss of muscle mass and that neuromuscular learning was an important factor in later recovery.

Fitts (1994) describes the ability to sustain force production over a period of time as the endurance factor of the muscle. Fatigue can be defined as a failure to maintain the required or expected power output and the factors involved are dependant on fibre type, intensity, type and duration of activity and the individual's fitness. Potential sites of central fatigue are, the excitatory input to higher motor sensors, the excitatory drive to lower motor neurons, the motor neuron excitability and neuromuscular transmission. The potential peripheral sites of fatigue are the sarcolemma excitability, the excitation contraction coupling, the contractile mechanism and the metabolic energy supply, including metabolite accumulation. There is considerable controversy over the mechanism of fatigue as to whether it is central, peripheral or both.

Snyder-Mackler, Binder, MacLeod & Williams (1993) examined eighteen patients with A.C.L. reconstructions who performed an electrically forced fatigue test. Contra-lateral legs were examined with stimulation set at 20 per cent M.V.C. of the uninjured leg. Unexpectedly the uninjured leg fatigued sooner than the reconstructed leg, indicating this was due to greater recruitment of type 1 fibres by stimulation or selective type II fibre atrophy in the reconstructed knee. The authors suggest that muscle activation can be inhibited by feedback loc$_{\mu}$ from the quadriceps to the hamstrings and is a major cause of diminished quadriceps performance, together with muscle atrophy. The super-imposition technique used in this study, assessed motor nerve and muscle independent of sensory feedback or the central nervous system and therefore evaluated a true loss of force producing capability within the muscle during endurance exercise.

Newham, McCarthy and Turner (1991) investigated the difference between isometric and dynamic contractions during fatiguing protocols. They found no evidence of greater failure at higher velocities but rather a force related mechanism as opposed to temporal. They concluded that brief, high intensity dynamic exercise can cause a considerable failure of voluntary activation, most marked during lower velocity contractions.

2.1.3 Hamstring Involvement

In functional lower body exercise, there is a co-activation of the hamstrings/ quadriceps during flexion and extension of the knee joint. Consequently there has been investigation into the benefits of hamstring training during rehabilitation and subsequent adaptions of the hamstrings/quadriceps ratio of force output and muscular activity. After A.C.L reconstruction, there is a need to actively exercise atrophied thigh muscles however, the action of isokinetic leg extensions draws the tibia out anteriorly in relation to the femur, before the ligament has matured. During dynamic motion the A.C.L. is the primary restraint to anterior tibial translation, however muscular co-contraction should neutralise the shear forces at the knee. In closed chain rehabilitation exercises, the cruciate ligaments act as passive guides to the femoral condyles on the tibial plateau and the hamstrings act to restrain the tibia, thus the strain on the A.C.L. would be no higher than during active range of motion.

During non-weight bearing exercise, co-contraction of the hamstrings appears to be quite small and relatively ineffective in decreasing A.C.L. strain whereas, in weight bearing exercises, like the squat, the contribution of the hamstrings is quite significant (Palmitier et al, 1991). During the simultaneous hip and knee extension when rising from a squat, the quadriceps and hamstrings are both active. As the hip extends, quadriceps lengthens while the hamstrings shorten, but as the knee extends, the quadriceps shortens as the hamstrings lengthen. This resultant contraction due to

25

simultaneous concentric and eccentric contractions at opposite ends of each muscle, is called "the concurrent shift". Three types of contractions (isometric, concentric and eccentric) occur during a concurrent shift kinetic chain exercise (Palmitier et al, 1991).

Electromyography (E.M.G) can reveal hamstring co-contraction in everyday functional activities. Some researchers have shown increased activity in vastus lateralis, biceps femoris and tibialis anterior in rehabilitated A.C.L. patients, suggesting that there was an alteration in muscle firing patterns to stabilise the knee (Barrack et al, 1994). Basmajian (1974), when investigating E.M.G. activity, found that the hamstring antagonists act as a reciprocal inhibitor during leg extension at the end of motion, when there is a short burst of activity in some antagonists to prevent damage to the joint. Low unsustained activity occurs in antagonists at slow speeds during voluntary flexion and extension whilst at high speeds, there is a partial overlapping of phasic activities in agonists and antagonists. It is not the speed of movement but the tension in the agonist that induces reflex activity during muscular recruitment, especially in extension movements.

A study by Kain, McCarthy, Arms, Pope, Steadman, Manske & Shively (1988) investigated the effects of transcutaneous electrical stimulation of the quadriceps and hamstrings on A.C.L deformation in Rhesus monkeys. At 45 degrees knee flexion, when the quadriceps were stimulated before the hamstrings, the A.C.L. lengthened, but when the hamstrings were fired before the quadriceps muscles and simultaneous contraction of both were sustained, A.C.L. shortening occurred. This suggested that optimal A.C.L protection may occur only if the hamstring muscles are voluntarily contracted before the quadriceps and that quadriceps contraction alone may cause injury at flexion angles, less than 45 degrees.

Renstrom, Arms, Stanwyck, Johnson and Pope (1986) examined removed knee specimens for hamstring / quadriceps activity both separately and simultaneously to test for A.C.L. strain through various angles of flexion. They concluded that isometric hamstring activity decreased A.C.L. strain in all positions and are therefore not detrimental after reconstructions. However, they also noted that the hamstrings cannot prevent potential harmful effects of simultaneous quadriceps contraction on reconstructed A.C.L.s unless the knee flexion angles exceeds 30 degrees. This is in agreement with other studies by More, Karras, Neiman, Fritschy, Woo & Daniel (1993), Yasuda and Sasaki (1987), and Renstrom et al, (1986) concluded that vigorous activity of the quadriceps at angles from 0 - 45 degrees flexion, produced strains on the A.C.L. which could damage the reconstructed knee.

Delitto, McKowen, McCarthy, Shively and Rose (1988) using electrical stimulation to produce co-contraction of the thigh and Kain et al (1988) using voluntary contractions, demonstrated reduced strain on the A.C.L. during co-contraction, especially when hamstring muscle contraction slightly preceded the quadriceps contraction. Delitto et al (1988) suggested that the co-contraction stimulation method would allow safe, aggressive quadriceps strengthening as early as 6 weeks after surgery. Activities such as squatting, stair climbing and rising from a chair, use hamstring muscle activity, functioning synergistically with the A.C.L. to prevent anterior tibial movement and tibial rotation, thus providing knee stability. A study by More et al (1993) used a cadaveric model during passive motion to examine graft tension during a simulated squat, this was found to be greatest at full extension. It was found that the addition of hamstrings load caused a significant decrease in the amount of femoral roll-back and tibial rotation. This study found that hamstrings load had no measurable effect on quadriceps force during a squat and did not significantly increase the flexion moment on the knee.

In agreement with Kain et al (1988) and Delitto et al (1988), More et al (1993) demonstrated that the hamstrings acting with the A.C.L., provide anterior stability.

The above studies and research by Baratta, Solomonow and Zhou (1988); Solomonow, Baratta, Zhou, Shoji, Bose, Beck and D'Ambrosia (1987) and Draganich and Vahey (1990) demonstrate that the hamstrings act as synergists with the A.C.L. during isokinetic quadriceps exercises, helping to limit anterior tibial displacement. In addition, More et al (1993) demonstrated that the A.C.L. graft load was also dependent on the technique of the A.C.L. reconstruction, and different tunnel hole placements which would alter the load / flexion angle curve.

2.1.4. Sensory Proprioception

Proprioception is the ability to sense position and movement of the limb, mechanoreceptors in the joint communicate sensory information through the central nervous system or by using the feedback loop. Subsequently, the mechanoreceptors initiate this feedback by muscle facilitation and inhibition that can protect the joints' integrity at the extremes of motion. Mechanoreceptors, are found near the tibial insertion and are often shown to be absent or non-functional in A.C.L reconstructed knees. The re-innervation process appears to be slow, taking anything from six months to a year in patellar tendon reconstructions and predispose the subject to further injury during rehabilitation. Proprioception also declines with age (Barrack et al, 1994). There are conflicting opinions as to the return of proprioception after A.C.L reconstruction, some studies showing improvement, some showing bi-lateral equality. Deficiencies in gait, reflexes and muscle activation are apparent and can be trained during rehabilitation protocols. Antagonist muscles such as the hamstring group have increased activity as a form of adaptation to these deficiencies (Barrack et al, 1994 and Irgang, 1994).

In a normal knee, the A.C.L which has sparse free nerve endings, is known to have important sensory functions, mechanoreceptors detect joint position as well as fast and slow position changes. This sensory neuromuscular function needs to be re-educated in the reconstructed knee. Although the hamstring reflex from the A.C.L may be damaged, the remaining proprioceptive structures in the knee and the proprioceptors in the new patellar tendon graft require training to assist the hamstring protection mechanism needed for stability (Draganich et al 1989).

Quickly adapting mechanoreceptors such as the pacinian corpuscles are very sensitive to changes in stimulation and are therefore thought to mediate the sensation of joint motion. Slowing adapting mechanoreceptors such as the ruffini corpuscles and the golgi tendon organs are stimulated by different populations at specific joint angles and thus a continuum of receptors is thought to mediate the sensation of joint position. Muscle receptors and joint receptors are probably complimentary components of an intricate afferent system in which each receptor modifies the function of the other. The threshold for the detection of passive motion or the ability to reproduce passive positioning are criteria for assessing deficits in proprioception. An increase in the threshold to detection of passive motion and a latency of the A.C.L hamstring reflex are correlated to the functional instability of A.C.L injured subjects. Any deficit may predispose subjects to re-injury. (Lephart, Kocher, Fu, Borsa & Harner,1992)

The fact that fatigue causes diminished proprioception is relevant to the athlete who has an early return to sport due to the susceptibility to further injury until complete return of sensory mechanisms (Loitzs and Frank, 1992 ; Barrack et al 1994).

Lephart et al (1992) studied kinesthetic awareness in patients 11-26 months post A.C.L reconstruction, revealing decreased awareness at near terminal range of motion. In addition to reflex pathways, joint mechanoreceptors have cortical

pathways that account for conscious appreciation of joint movement and position, especially at near terminal range of motion. This study concluded that kinesthetic deficits exist in the A.C.L reconstructed knee at the near terminal range of motion. Harter, Osternig & Singer (1992) found there were no significant differences in knee joint position sense, between the post surgical and normal contra-lateral limbs, suggesting that if knee joint position sense was disrupted by A.C.L injury and reconstructive surgery, related sensory mechanisms compensated for any proprioceptive loss, prior to the 2 year post surgical follow-up employed in their study. These results are not in agreement with Barrack et al (1989) who found that the A.C.L functions as a significant sensory organ providing proprioceptive information feedback, which is not replaced by other compensatory mechanisms in an A.C.L deficient knee.

Recently Barrack et al (1994), by using E.M.G. demonstrated that the quadriceps are inhibited and hamstrings stimulated when stress is put on the A.C.L., establishing the presence of a direct A.C.L muscle reflex. This response is also present in A.C.L deficient knees but is significantly slower, implying that a secondary reflex was initiated by capsular or other ligamentous receptors. Snyder-Mackler et al (1993) suggest that knee effusion also causes reflex inhibition of the quadriceps muscle, demonstrating that the fluid in the joint and not the tear of the A.C.L., leads to this reflex inhibition.

The hamstrings/quadriceps relationship is affected by sensory proprioception and feedback loops during functional activity, these appear to take a long time to restore and maybe the cause of further breakdown during stressful activity. Facilitation of the hamstrings and inhibition of the quadriceps action, act as a protective mechanism for the A.C.L during recovery. This neural input can not be rebalanced until proprioception and feedback loops are fully restored. Strengthening of the hamstring is important for A.C.L protection, but strengthening of the inhibited knee extensors is

also required for optimal knee recovery (Elmqvist et al,1989; Baratta et al, 1988 and Solomonow et al, 1987).

During daily functions of running and walking, the proprioceptive input would be sufficient to activate muscular stability. However, activity in contact sports often exceeds the maximal tolerance of the knee, even when fully activated, the proprioceptive input is inadequate to initialise protection (Barrack et al, 1994). Reflex inhibition is dependent on sensory stimuli from the joint which initiates inhibition of the quadriceps. This may also be caused by factors such as ischaemia, effusion or peri-articular pathology. Transcutaneous sensory nerve stimulation (T.N.S.) has been used for increasing motor neurone excitability and preventing activation of inhibitory synapse (Stokes & Young, 1984).

Proprioception was not examined in this investigation but has been shown by others, Barrack et al (1994), Lephart et al (1992), Harter et al (1992) to have a major involvement in muscle activation changes after knee reconstruction. The possible influence of sensory functions in the present study, will be discussed in the summary at the end of chapter 6.

2.1.5 Neuro-muscular Inhibition

Neuro-muscular activation is essential for force production, even in the absence of muscle atrophy. After A.C.L damage and subsequent reconstruction, the muscle's ability to activate the contractile mechanisms can be inhibited, which has been demonstrated in patients with muscle pain or joint pathology. Decreased activation shown by some patients may be caused by consciously not trying as hard as possible, thereby reducing pain, alternatively reflex inhibition from the affected joint may prevent maximum force production without any conscious perception or pain.

31

Skeletal strength can be increased in the absence of measurable hypertrophy, due to muscle activation and motor learning, especially during early rehabilitation, nevertheless, a strong relationship exists between absolute strength and cross sectional area of muscle. The activation level is the result of the interaction of both facilitatory and inhibitory phenomena known as neural factors. Moritani and de Vries (1979) describe the ratio of activation to the force produced, as electrical efficiency, which reflect genetic factors to do with the muscle mass, as well as fibre hypertrophy brought about by the amount and type of activity. These investigators suggest that neural factors account for the larger proportion of initial strength gains, whilst hypertrophy becomes the later dominant factor. Inhibition or inability to maximally activate during voluntary contractions has been examined by electrical stimulation techniques. Maximal torque output during a voluntary contraction can be compared to the torque output produced during electrically stimulated contractions. Direct femoral nerve innervation is relatively inaccessible and the generation of maximum tetanic force is an uncomfortable procedure. Workers (Rutherford et al 1986) have demonstrated that there is no significant difference in torque output during femoral nerve stimulation and percutaneous stimulation. The percutaneous technique (Chapman, Edwards, Greig & Rutherford, 1984) (described in 2.2.2.) is particularly useful for identifying inhibition in the absence of pain and can be used to distinguish between central and peripheral causes of weaknesses, however muscle inhibition variations may be due to a difference in the general pattern of use during daily functional activities (Belanger and McComas, 1981).

Recent inhibition studies have focussed on the percutaneous technique to investigate activation levels, such studies normally manage a stimulative level equivalent to 25 per cent of the individuals maximal voluntary contraction during transcutaneous neuromuscular electrical stimulation (T.N.E.S.) (Lieber and Keily, 1991)

2.1.6 Neuro-muscular Activation Patterns

Electromyographic (E.M.G.) studies can record changes in muscle activation through surface electrodes revealing the specificity of firing units according to movement patterns, activation of prime movers and changes in synergists and antagonists. The principle of E.M.G. is the recording of electrical potentials resulting from the flow of action currents from muscle fibres, through the impedance of adjacent tissues. Muscle fibres are sub-divided into spiking (twitch), which are commonly recorded as an E.M.G. and non-spiking (tonic) categories. The mechanical twitch of a muscle represents a unit of potential that when counted will estimate relative magnitude of muscle activation, however, activity does not necessarily correlate with force. Force assessment from E.M.G. is a problem due to absolute and relative change of muscle fibre length and arrangement of different fibre compositions. Repeated stimulation of fibres that have not relaxed will produce increased contraction force resulting in a tetanus. The flux or current density decreases with distance from the generating fibre and is additive in multiple fibres. The flux is greater measured along the length of the fibre of a single motor unit rather than perpendicular to it, thus the signal generated will differ depending on the location and orientation of the recording electrodes. The area of electrode, their impedance and the distance between tips will determine the sampling zone (Gans, 1992).

The more fully trained an athlete with a specific contraction, the greater the ability to fully activate and maintain motor unit firing for longer, compared to untrained subjects. Motor units are recruited by size and threshold, so fast twitch fibres are the last to activate and hence the most difficult to activate. There is also a variation in recruitment and firing rate specific to the muscle group and range of contraction. (Sale,1988).

Elmqvist et al (1989) investigated muscle function before and after reconstruction on 4 different occasions, using isokinetic measurements and electromyography. Force output at 90 degrees per second and fatiguability of the quadriceps muscles during 100 repetitions at 90 degrees per second, were recorded on various occassions up to 1 year after reconstruction. The E.M.G. signals were obtained from the superficial parts of the quadriceps and the signals were full wave rectified, low pass filtered and integrated with the results summed. Their findings revealed that after one year continued physical rehabilitation, the maximum performance of the quadriceps was statistically inseparable from that of the non-injured leg before the operation. However, the non-injured leg performance also increased, so that the two legs still exhibited a difference. Integrated E.M.G., indicated that the major factor for torque decrease was reduced central nervous drive, particularly from rectus femoris. They suggest this could be explained by reduced afferent input from knee joint receptors, and that neuro-muscular learning, which is normally considered in the early stages of strength improvement, is also a factor for late recovery after A.C.L reconstruction.

A study by Kostka, Costa & Cafarelli (1982) examined the effects of pH on integrated electromyograms during fatigue. They demonstrated reductions in maximal twitch tension observed at low pH, as well as E.M.G. activity increasing during fatigue as a result of either additional recruitment or increased firing frequency or both.

2.2 Literature of Methodology

2.2.1 Isokinetic Dynamometry Methodology

Earlier assessment of muscle forces used cable tensiometry, invasive measurements have been made using strain gauges and buckle type transducers implanted on the tendons and isotonic strength assessment has been measured dynamically using dumbbells and barbells (Gregor et al, 1994). However, the modern development of isokinetic dynamometers allow accurate measurement of force and angular movements at predetermined velocities (Perrin, 1993).

There is a learning curve with dynamometry that can affect testing, so subjects should familiarise themselves with trials at various angular velocities. Stabilising and positioning the body are critical to the reliability and validity of performance so that additional forces do not affect results. When assessing subjects for leg extensions/ flexions in the seated position during isokinetic dynamometry, the axis of the dynamometer should be aligned with the medial epicondyle of the femur, velcro straps should be placed proximal to the malleoli, proximal to the knee and across the hips for stabilisation. The vertical and horizontal positions of the dynamometer should be recorded to ensure identical placement during bilateral tests so that there is no change in biomechanical advantage (Arnold & Perrin, 1993).

Results can be affected by variations in velocity of movement, inertial forces during dynamic movements, impact artefact or torque overshoot, calibration, damping of the signal from the transducer, verbal encouragement and motivation. Significant artefact can be found at high velocities when measuring isokinetic muscle torque, as the lever arm is accelerated by the leg until it reaches the pre-set speed of the machine. The oscillating artefact is more prevalent at high angular velocities and it is not truly representative of muscle tension until the oscillations have ceased, dynamic

ramping lessens the impact (Arvidsson et al, 1981). The assessment of hamstrings and quadriceps function regarding peak torque produced and E.M.G. activity varies enormously according to hip position. The hamstrings / quadriceps ratio increases with increasing velocities and also in the seated position, since greater rotational torques are produced at 90 degrees of hip flexion as opposed to supine position (Smith, 1993).

Bilateral comparison must be made with identical test protocols, the range of motion may be restricted through injury but must be identical for both limbs, when assessing average torque or work values. A further consideration, is the influence of limb dominance or the effect of neuromuscular specificity in sport activity (Perrin,1993). Reciprocal muscle group comparisons must consider gravity correction or values will be artificially inflated or deflated, test velocity changes the ratio as quadriceps torque will decrease more than hamstrings torque, with increases in test velocity. Thus a lower hamstrings/quadriceps ratio will be found at slower test velocities. Eccentric contraction of the hamstrings would be more relevant to functional studies and thus a ratio between quadriceps concentric and hamstring eccentric could be beneficial (Kannus, 1994).

Barber, Noyes, Mangine, McCloskey and Hartman (1990) investigating functional and isokinetic testing methods, demonstrated in a population of 93 normal subjects, that there was no statistical significant difference found between right and left lower limb scores in the tests, as related to sports activity level, gender or dominant side. Thus, when using the opposite limb as the control, biological variability is avoided from one individual to another. This study substantiated that age, gender and sporting activity levels can be evaluated on an individual basis and be removed as confounding variables in studies of bilateral differences. In normal individuals, isokinetic bilateral imbalances in strength of less than 10 per cent can be considered normal, those greater than 20 per cent, probably abnormal. The ideal hamstrings/

quadriceps ratio of an injured extremity appears to be an equal ratio to the opposite healthy limb (Kannus, 1994; Perrin, 1993).

Isokinetic testing parameters include quantification of muscle functions such as peak torque, work, power, torque acceleration and various endurance indexes. They can be assessed isometrically at various angular positions and isokinetically with concentric and eccentric contractions, at various angular velocities. Peak torque (P.T), the most tested parameter, refers to the highest peak torque output of the joint, produced by muscular contraction, as the limb moves through the range of motion. Kannus (1994) says P.T. remains almost unchanged between angular velocities of 0 - 60 degrees per second and that with greater velocities there is almost a linear decline. At higher velocities, PT occurs later in the range of movement and observation and may not represent maximal torque capacity, as the limb may pass the optimal joint position for performance (Kannus, 1994).

Arnold et al (1993) tested the reliability of different methods of assessing quadriceps peak torque and angle specific torque using a Kin-Com isokinetic dynamometer. The methods tested were; averaging the first three contractions, averaging the first five contractions, taking the single best value of the first three contractions and taking the single best value of five contractions. Intraclass correlation co-efficient showed high correlation among all four methods. This supports their conclusion that different methods of calculating quadriceps peak torque had no effect on the reliability of the measures.

Muscular endurance can be defined as the ability of contracting muscles to perform repeated contractions against a load. Isokinetic endurance tests typically measure, either the number of repetitions of maximum effort, test movements that are necessary to reach a 50 per cent reduction in torque output, the percent decline in work or torque from the beginning to the end of a certain time period or after a

37

certain number of contractions. Thorstenson & Karlsson cited in Kanus, Cook and Alosa (1992) defined muscular endurance as a fatigue index. They expressed mean torques of the last three contractions as a percent of the mean torques of the initial three contractions. Kanus et al (1992) concluded that absolute endurance measurements of work performed during the last five repetitions and total work during 25 repetitions was consistent with peak torque values.

2.2.2 Stimulation Methodology

The interpolation of a single indirect stimulus to a muscle during the course of an attempted maximal voluntary contraction (M.V.C.) will demonstrate any incomplete motor activation and functional weakness (McComas, Kereshi & Quinlan, 1983). If motor units have not been recruited or are firing at sub-optimal rates for tension development, then a twitch response will be super-imposed on the voluntary torque recording, or if motor units are fully activated, then no super-imposition will occur. Different intensities of voluntary contractions will result in voluntary force increases and interpolated twitch declines. A superimposed twitch can be due to lack of voluntary effort or pyramidial or extra pyramidial activation disorder.

Lieber et al (1991) demonstrated that the electrical efficiency of stimulation is not dramatically changeable by using high stimulation currents or large electrode sizes, activation level being limited by subject tolerance and discomfort. The other variables controlling torque output during stimulation were current, voltage and impedance.

In a study by Rutherford et al (1986), percutaneous stimulation of lateral quadriceps, used unidirectional square wave pulses of 50 milli second duration, at 400 volts. The subjects relaxed their leg and three pre twitches were initiated to establish the amount of muscle activated. Then subjects performed three isometric M.V.C's, followed by

a further M.V.C. maintained for four seconds, during which twitches were superimposed. During maximum contractions, there were no extra forces generated by the twitch and in many cases, there was a momentary drop in force immediately after the stimulus. To investigate whether twitch potentiation was occurring during the contraction, twitch height was measured during a series of submaximal contractions. Twitch height is expressed as a percentage of the pre contraction height. Reduced activation was seen in those patients with muscle pain and joint pathology but not those with extensive loss of muscle tissue. These investigators found that the relationship between the extra force generated by a twitch and the level of voluntary contraction, was independent of the percentage of muscle stimulated, but Kain et al (1988) emphasised that differences in muscle bulk and the amount of adipose tissue as well as other anatomical variances of the muscle, can affect the sensitivity of muscle groups to neuromuscular stimulation.

Newham et al (1991) modified the established technique of superimposing twitches on voluntary contractions. Finding that the single twitches were too small and brief to be reliably detected when superimposed on a dynamic contractions, they used percutaneous tetanic stimulation with pulses of 50 milli seconds duration at 300-400 volts. During dynamic contractions, a train of stimuli at a 100 Hz was delivered for 250 milli seconds, generating forces that were 30-40 per cent of the isometric M.V.C. at that specific angle. Using this technique on fresh muscle, the subjects showed virtually full voluntary activation during isometric contractions and at two isokinetic velocities.

Various placements of electrodes have been used to find the association between torque, impedance, durability, comfort, skin response and ease of application on the quadriceps femoris muscle. The preferred approach is to place electrodes over the motor point or innervating nerve or both. Conduction is about four times better when the electrodes are placed longitudinally rather than transversely, facilitating the

excitation-contraction coupling mechanism of the muscle. Rectangular shaped electrodes may be placed closer together longitudinally and thus allow greater current density which subsequently would activate a greater number of motor units to produce more torque (Brooks, Smith and Currier,1990).

Ferguson, Blackley, Knight, Sutlive, Underwood and Greathouse (1989) investigating torque output with various electrode placement strategies, concluded that placement upon vastus medialis, vastus lateralis and rectus femoris, produced statistically identical quadriceps torque when expressed as a percentage of maximal voluntary isometric contraction. However, the proper anatomical placement of the electrical pads, used to stimulate muscle groups, is critical and can be extremely difficult to duplicate muscle stimulation and resultant muscular contraction can be technically difficult to control and consistently reproduce.(Kain et al, 1988)

Delitto et al (1988) used two pairs of gelled carbonised rubber 4.5 x 10 centimetres electrodes to provide stimulation during co-contraction of the thigh muscles. They found the optimal quadriceps femoris muscle electrode placement to be distally over the vastus medialis muscle and proximally over the vastus lateralis muscle, located through direct visualisation and palpitation .

2.2.3 E.M.G. Methodology

Potential differences are measured by recording and comparing the value of two local potential's relative to each other and to a relatively stable ground. Initial millivolts readings are amplified between 100 and 10,000 times resulting in signal values of 0.1 - 10 volts, which may be converted by an analog to digital converter and then stored on disk.

The electrode material is dependent on the absolute size, configuration and position of the muscles to be recorded. The surface of each electrode should be as close as possible to the tissues generating the signal, pairs of electrodes longitudinally placed, within one bi-polar (2-10mm) separation of the signal source, will register changes of potential. Surface electrodes are some distance from the muscles being sampled and are relatively non selective so they are best used over large muscle masses that tend to act in unison, being insensitive to individual motor units (Gans,1992). Electroplacement is selected by use of standard anatomical reference points supplemented by palpitation and isolated isometric contraction, after skin surface is shaved, cleaned and saturated with alcohol to reduce lead artefact. Care should be taken to the continued state of electrode attachment and raw data should be integrated after full wave rectification (Ysuda & Sasaki 1987).

When treating a signal, the background activity must be extracted and the amplification gain must be calibrated. Ideally a signal has a straight clean baseline and all deflections have experimental significance, or require explanation. In order to reduce electrical noise and motion artefact, the contacts need to be pressed to the skin by pressure contacts with gel. Wide band noise is intrinsic to the system and narrow band noise frequently comes from alternating current at 50-60 Hz through equipment and lights whilst biological noise derives from other organs and tissues. By keeping the electrode source impedance low relative to the amplifier input impedance, motion artefact may be avoided and any cross talk eliminated (Gans,1992). E.M.G. recordings with surface electrodes should be made at the same sensitivity throughout the whole period of experimentation.

E.M.G relies upon qualitative and quantitative evaluation, qualitative analysis requiring a suitably experienced worker to understand the complex intricacies. Quantitative reflection of the amount of muscular activity can involve counting the number of spikes, a summation of spikes, as well as height and type factors. The

sampling rates should be at least four to six times the upper frequency limit of the signal and at least one sample should occur at or near the peak. Fourier analysis may establish the distribution of frequencies within a full wave and rectified signal. Information maybe integrated or the spikes individually counted but failure to discriminate between artefacts and unit potential or comparison of different channels, can be a danger. Comparison can only be made within the integrated curve, however, integration outputs are convenient and provide immediate numerical read-outs which vary directly with the strength of a contraction in a muscle (Gans, 1992). A coupling interval needs to be established for correlation between E.M.G. and mechanical action because the signal predicts the force rather than responds to it. Correlation is difficult due to complexity of these muscle actions.

A study by Black, Woodhouse, Suttmiller and Sholl (1993) used integrated surface E.M.G. to examine output during isokinetic knee flexion. Their results showed E.M.G. activity was statistically significant for gender (males greater than females), muscle groups (quadriceps greater than hamstrings) and muscular contraction (concentric greater than eccentric). E.M.G. activity did not change during the sitting or supine position for either the hamstrings or the quadriceps.

2.3 Literature Summary

The A.C.L shows a poor capacity for healing due to complex geometry and poor regenerating capacity of the graft. A more aggressive rehabilitation program appears to minimise complications and optimise restoration of function, but it needs to be done so that inflammation and loss of motion are minimised by using sound rehabilitation principles. Functional outcome, stability, R.O.M., strength, muscle activation and proprioception must be researched further as the quest for accelerated recovery continues.

After reconstruction, quadricep muscles atrophy more than hamstrings muscles, with selective wasting of type II fibres. A possible cause of atrophy is reflex inhibition from the sensory feedback loop, in which hamstrings activation is facilitated and quadriceps activation is inhibited. Co-activation of the hamstring antagonists act synergistically with the A.C.L to prevent tibial subluxation during leg extension. The hamstring strength is often diminished in a reconstructed knee but to a lesser degree than the quadriceps, hence, there is adaptational change in the hamstring / quadriceps ratio, which appears to assist in A.C.L protection during functional activity. The mechanoreceptors are slow to establish in the new graft, so insufficient sensory input to the reflex loop, during extreme movements, puts the A.C.L at risk especially during fatiguing exercise when proprioception is further diminished, the quadriceps fatiguing quicker than the hamstrings. After 12 months rehabilitation, studies have examined peak torque and fatigue by using isokinetic dynamometry and have found 80- 90 per cent bilateral recovery. This methodology does not replicate or examine the "concurrent shift" that naturally occurs in weight bearing functional movements, but allows assessment of individual muscle groups, in a controlled environment. Percutaneous stimulation, using the superimposition technique can assess the amount of inhibition or the ability to voluntary maximal activate the muscle fibres which, can be a problem after surgery. Electromyography, utilised in many A.C.L studies, can reveal a change in activation patterns, twitch amplitude and twitch frequency which demonstrate muscle adaptions after reconstruction.

CHAPTER 3

THEORETICAL MODEL
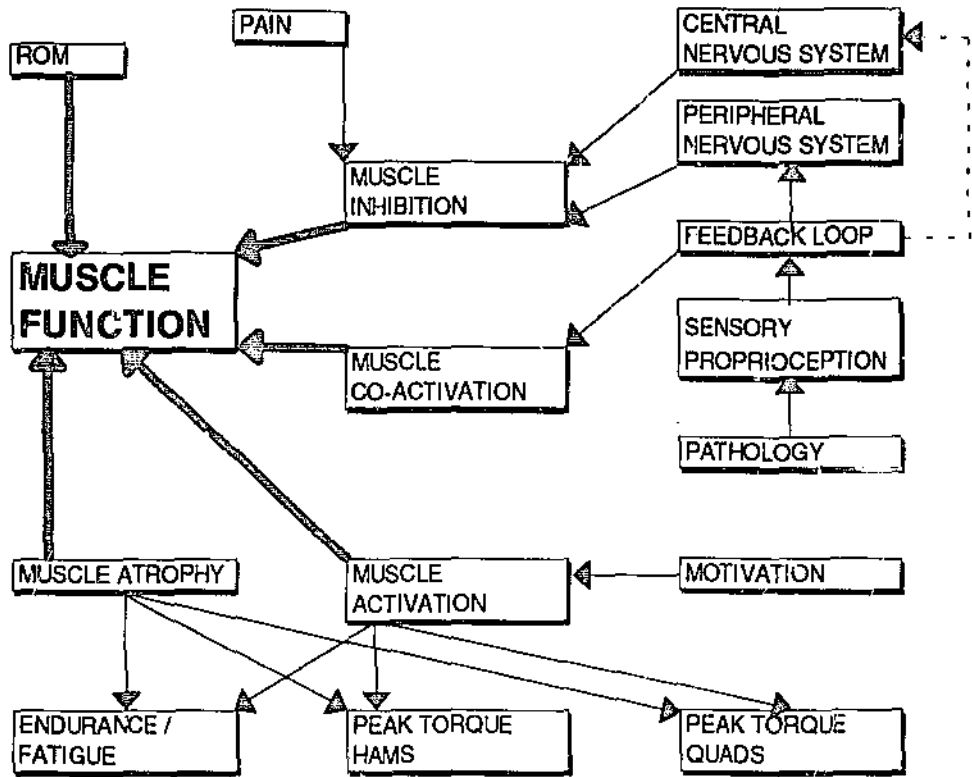
Figure 3.1 Theoretical Model of Muscle Function

Muscle function is affected by atrophy, activation, co-activation and inhibition, these subsequently affect the measurable parameters of endurance and strength, which are recorded as peak torque decline and peak torque, respectfully. Muscle inhibition and co-activation of the antagonist can be controlled by feedback loops that initiate reflex inhibition of the agonist or facilitate contraction of the antagonist, either through the peripheral or central nervous systems. These feedback loops rely on proprioception from the mechanoreceptors in the joint and ligament. Central nervous commands to activate muscle are also dependent on motivation to maximal stimulate motor units.

CHAPTER 4

METHODOLOGY

4.1 Subjects

The experimental group (n = 17), consisted of 10 males and 7 females, mean age 25 years and range 18-47 years. They had all undergone A.C.L reconstructions using bone patellar-tendon bone grafts performed with similar arthroscopic surgical techniques, and performed by the same surgeon between 20-36 months previously. Subjects who were considered rehabilitated and capable of participating in this study, were selected from a list supplied by the hospital's medical records department. From these records, all patients who had A.C.L reconstructions during that period were short-listed, of these, three had other simultaneous minor meniscus surgery. The surgeon indicated that this would have no effect on the reconstruction, rehabilitation or functional outcome and thus not influencing the study. The subjects were contacted by telephone, beginning with the most recently operated (20 months post operation). Apart from the operation date, the order for subject contact was entirely at random with regard to gender, age, dominant/non-dominant leg and right/ left handed leg. Communication was attempted with all subjects short listed (n=50), but due to change of address, telephone, unavailable time or no desire to participate, only 20 subjects agreed to testing. Of these, three possible subjects had further knee complications subsequent to the initial surgery and so were not suitable for the study. The remaining 17 subjects, considered themselves recreationally fit at the time of their operation, had all participated in the accelerated rehabilitation program at the hospital and were considered adequately bilaterally functional so as to return to normal activity.

The control group (n=20), consisted of 16 males and 4 females, mean age 25 years and range 18 - 46 years, were randomly selected from recreationally fit volunteers

45

from the local surf club and from Edith Cowan University. Thirty subjects who were within the experimental group age range and were recreationally fit (they trained at least once per week), were informed of the study and invited to participate. Three possible subjects declined, four were unable to attend due to commitments and three had previous knee injuries. The remaining twenty were of mixed gender but not equally matched to the experimental group for gender balance. None had any previously known knee damage and were still actively involved in sports. They were randomly selected, irrespective of leg dominance.

4.2 Design

The investigation was a quasi-experimental, quantitative research project using a post-test design with randomised subjects. Sensitivity was increased by assigning the control subjects dominant/ non-dominate leg to match the experimental subject's involved dominant / non-dominant leg. This was a "Solomon design 4" as described by Isaac and Michael (1981). Thus the variable of involved leg dominance was controlled.

In the experimental group, the involved leg was compared "within body" to the uninvolved leg, thus removing biological inter-subject differences. Normal pre-injury bilateral-variance was established by a control group with similar characteristics but unaffected bilateral legs. The mean bilateral -variances of the two groups were then compared for independent significant differences.

Experimental group involved leg	------	Accelerated program	----	Post-test.
Experimental group uninvolved leg	------	Normal Activity	----	Post-test.
Control group (dominant leg)	------	Normal activity	----	Post-test
Control group (non dominant leg)	------	Normal activity	----	Post-test.

4.3. Equipment

Cybex 6000 isokinetic dynamometer

Software version 4.04 operating system DOS 5.0

produced by Lumex Inc. New York

Thandor Stimulator

Model TG503 5mhz Pulse/Function Generator

Digitimer

Stimulator model DS7.

Supplied by Neomedixs Systems

Stimulator pads

Serial 800 made by Unipatch in U.S.A.

Self adhering re-useable electrode pads, 8" by 5" dispersive pad with pig-tail

pin conne

ctions.

Electromyographic apparatus

Nihon Kohden supplied by Medtel

2 channel bioelectric polygraph amplifier AB-621G

Model RMP - 6004M

Used with a BC output channel selector

Red Dot Electrodes (E.M.G.) surface receivers

I.B.M 486DX Computer

Software used Waveview for DOS 1.17 multiboard

(Supplied by Eagle Appliances 1994)

Analogue digital conversion   (PC 30 PGL card rev viii DX)

Electrical Junction Box - Cybex raw data/ E.M.G. signals/ computer

4.4 Procedure.

Subject pre- selection

Subjects (n=37) were selected (as described in 4.1) and invited to participate in the study. They were sent an abstract, a questionnaire (see Appendix B) and additional information of the test procedures, together with a consent form (see Appendix A). Testing was arranged at their convenience, in the case of the experimental group, at least 20 month post reconstruction ($\underline{m}$ = 24 months, range 20-36 months).

On the test day, the subjects were requested to refrain from any prior exercise and any medication. Contra-indications were discussed and evaluated. The subjects gave written permission for the described testing at this time during post rehabilitation.

Equipment Setup

An I.B.M. 486 DX computer with a 30 PGL card installed, was used as an analogue digital converter (A.D.C.). This was linked to the raw output of the Cybex 6000 isokinetic dynamometer and to the electromyograph (E.M.G.) two channel bioelectric amplifier, through an electrical connection box. A Thandor stimulator and digitimer were connected for delivery of electrical impulses.

The Cybex was put into power mode and ran through automatic check procedures and calibrated according to the Cybex manual instructions (Cybex, 1991). The Cybex raw data torque output was also calibrated to the A.D.C. voltage (see Appendix E). This was calculated by placing the Cybex arm horizontally, checked by

a spirit level, and by then loading a series of 10 kilogram Cybex calibration weights and recording the corresponding A.D.C. voltages. Three different torques were tabulated with the A.D.C. voltage to obtain a mean conversion figure. The calibration weights were also validated on a Mettler Platform scale made by F.S.E. and accurate to 1000th of a kilogram per gram. This calibration procedure was completed prior to testing.

Exercise protocols previously entered in the Cybex facility data bank, were recalled into the isometric mode, ready for the first test and the patient menu was programmed with subject details and entered into a file.

The stimulator was switched to zero voltage and zero current with the dial frequency set at 1.0 x 1 on the frequency multiplier. Pulse width range was set at five micro seconds x 100 in the normal pulse mode and the digitimer pulse width was set at 50 micro seconds. The Waveview software program was loaded on the A.D.C. and a preset protocol to sample channel zero for torque, channel two for E.M.G. one, channel four for E.M.G. two and channel six for angle. The sample frequency was set at 500Hz to record a maximum of 60,000 samples for two minutes duration. The electromyograph was set with direct current, a time constant of .003 seconds and a high cut frequency of 300 Hz. The sensitivity level of recording was 0.2 volts per division. These adjustments were found to be suitable for presenting good waveforms and were subsequently kept identical for all subjects.

Subject preparation

Immediately prior to testing, each subject had a five minute warm-up on a cycle ergometer at approximately 60 per cent VO2 max, adjusted according to perceived fitness. The subjects were measured with data recorded for mid thigh girths on both legs, using the mid point between the greater trochanter of the femur and the illiotibial plateau of the tibia. The circumference midpoint was marked anteriorly for

the quadriceps and posteriorly for the hamstrings before sitting the subject in the Cybex chair prepared for the un-involved leg. Two stimulating electrode pads were attached over the belly of the quadriceps muscle group, covering rectus femoris, vastus lateralis and vastus medialis. These pads were placed proximally and distally to the mid thigh mark, and connected to the electrical stimulation digitiser. The pads and leg were covered with a net stocking to ensure close contact and to protect wire connections.

The Cybex was adjusted to suit the subject's un-involved leg first, by altering seating angles to 90 degrees then , forward / aft position and dynamometer height. The knee's axis of rotation was aligned with the axis of the rotation arm on the Cybex, the lever length adjusted so that the lever pad was positioned on the anterior tibia, superior to the malleolus and the ankle strap being comfortably tightened. The subjects were firmly strapped in across the chest and hips so as to prevent any trunk movement. A further knee strap was put over the femur to restrict upper leg movement. The subjects were required to move their leg to 45 degrees for Cybex gravity correction and then to full flexion and extension for positioning the range of motion stops. All set-up data was recorded.

Stimulation Level

The stimulator levels were then set at 400 volts with a starting current of zero. The current was increased gradually at eight second intervals, whilst supplying a single 1 Hz, 50 micro second duration pulse to the subject's leg. This continued until the maximum of 1 amp was reached or when the subject registered discomfort. The final voltage and amperage was set and remained unaltered for the isometric contractions and twitch superimposition to follow.

Protocol One - Maximal Activation

Each subject raised their leg to a 60 degree flexion angle which was held by the pre-set Cybex arm, and performed three trial submaximal isometric contractions for a four second duration and then lowered and rested the leg for 60 seconds. The limb was again raised to the pre-set angle where the Cybex held the isometric position whilst the subject relaxed. The A.D.C. was set to record the torque data, whilst three stimulation impulses at a frequency of 1 Hz were delivered to the quadriceps muscle in the relaxed state. This was immediately followed by the subject's maximal voluntary isometric contraction, held for four seconds, during which three further twitches were super-imposed on the voluntary contraction. The subject then relaxed the muscle again while three further twitches were imposed at the pre-set level. After two minute rest, this process was repeated. The torque outputs were recorded from both contractions on each occasion. The A.D.C. was visually monitored to ensure a good recording had been attained and the Cybex computer data was also simultaneously saved.

E.M.G. Preparation

While the subject had a five minute rest period, the stimulator was switched off and the pads were removed, the skin was rubbed with abrasive wool, cleaned with an alcohol wipe and then wiped dry, ready for E.M.G. electrode placement. Two red dot E.M.G. electrodes were positioned longitudinally 10mm apart, mid quadriceps upon the belly of rectus femoris and a further electrode was placed upon the knee to act as the common ground. Additionally, two red dot electrodes were placed longitudinally 10mm apart mid hamstrings, on the belly of biceps femoris, and a third red dot attached at the greater trochanter of the hip. All electrode areas were abraded and cleaned to ensure less noise and impedance, the latter hamstring placements had some padding surrounding the electrodes to prevent excessive pressure from the leg affecting the E.M.G. data, during movement. The electrode placement was found by visual and palpitation of the muscle.

The E.M.G. electrodes were connected to the E.M.G. recorder. The electrodes and the protruding wires were covered with a leg stocking to reduce movement and noise.

Protocol Two - Isokinetic Peak Torque

The subjects were familiarised to the next protocol by a trial of eight repeated submaximal isokinetic leg flexions / extensions, through approximately 90 degrees and at an angular velocity of 90 degrees per second.

The subjects then performed four maximal voluntary contractions (MVC) at 90 degrees per second whilst torque, angle and E.M.G. data were recorded on the A.D.C. After a two minute rest, the procedure was repeated at an angular velocity of 180 degrees/second through the same range of motion and finally after a further two minutes rest, at an angular velocity of 300 degrees/second.

Protocol Three - Isokinetic Endurance

The Cybex facility menu was changed to the pre-set endurance protocol, and after a five minute interval, the subjects proceeded with as many MVC's in flexion and extension at 90 degrees per second that could be managed during a two minute period. They were encouraged and motivated to produce their best effort by visual feedback provided from the Cybex performance monitor and verbal feedback from the investigator.

This protocol stopped after two minutes, 60 repetitions or at the subjects own volition.

The complete procedure was repeated for the involved leg, with special consideration to the patients perceived pain or any contra-indications, that would indicate ceasing the study.

The control subjects were tested, using the assigned uninvolved leg first, irrespective of handedness, thus balancing any learning curve between groups. When both legs had been tested, subjects were offered water and monitored for five minutes, before being thanked and allowed to leave. They were told they would be informed of any significant deficiencies at a later date, when the data was analysed.

4.5 Data Analysis

Statistical independent t-tests were used to determine whether the difference between the means of the two samples was representative of the normal distribution. The sample size (n = 36) was sufficient for a statistical independent t-test. A conservative level of significance (alpha less than .01) was set because of the large number of t-test used on the same data. Levene's test for equality of variance analysed groups to show if there was a significant variance (p less than .01). If p was less that .01, then the variances are unequal, if p is greater than .01, then the variances are equal and the corresponding values were then used. Paired t-tests were used within the group to ascertain if there was a significant difference (p less than .01) between the uninvolved leg and the involved leg in the same subjects. This difference has been defined as bilateral-variance. All statistical analysis used a 2-tail test as they were non directional, since rehabilitation could increase the strength of the leg if successful or not increase the strength if unsuccessful.

1. Peak torque of quadriceps during isokinetic extension at 90 degrees, 180 degrees and 300 degrees per second.

The greatest peak torque value was recorded as raw voltage on the A.D.C. during four maximum voluntary contractions, at 90 degrees per second, for each subject and on both legs. Intra-subject bilateral-variance was analysed using a dependent paired t-test and the difference between bilateral-variance inter-group using an independent

t-test, at an alpha level p less than 0.01. The analysis was repeated for quadriceps in extension at 180 degrees/second and 300 degrees/second.

2. Peak torque of Hamstrings during isokinetic flexion at 90 degrees, 180 degrees and 300 degrees per second.

The greatest peak torque value was recorded as raw voltage on the A.D.C. during four maximum voluntary contractions, at 90 degrees per second, for each subject and on both legs. Intra-subject bilateral-variance was analysed using a dependent paired t-test and the difference between bilateral-variance inter-group using an independent t-test, at an alpha level p less than 0.01. The analysis was repeated for hamstrings in flexion at 180 degrees/second and 300 degrees/second.

3. The hamstring / quadriceps ratio

The hamstrings/ quadriceps ratio was calculated by the hamstring peak torque in flexion as a percentage of the quadriceps peak torque in extension, without gravity correction. Intra-subject bilateral-variance was analysed using a dependent paired t-test and the difference between bilateral-variance inter-group, using an independent t-test. The analysis was repeated at each angular velocity. Alpha level was set at 0.01.

4. Quadriceps Muscle endurance

The quadriceps peak torque of the last five extensions was taken as a percentage of the quadriceps peak torque of the first five extensions, to represent an endurance ratio. The intra-subject bilateral-variance of the endurance ratio as analysed, using a dependant paired t-test and the difference between bilateral-variance inter-group, was analysed using an independent t-test at an alpha level of 0.01.

5. Hamstring Muscle endurance

The hamstrings peak torque of the last five flexions was taken as a percentage of the hamstrings peak torque of the first five flexions, to represent an endurance ratio. The

intra-subject bilateral-variance of the endurance ratio as analysed, using a dependant paired t-test and the difference between bilateral-variance inter-group, was analysed using an independent t-test at an alpha level of 0.01.

6. *Muscle inhibition during a 60 degree quadriceps isometric contraction with superimposed stimulation*

The amount of muscle activated was calculated by the size of the pre-twitch compared to the isometric M.V.C. and recorded as a percentage. Muscle inhibition was calculated as the height of the superimposed twitch as a percentage of the height of the pre-twitch. Intra-subject bilateral-variance of inhibition was analysed using a dependent paired t-test. The difference between the bilateral-variance inter-group was analysed using an independent t-test at an alpha level of 0.01.

7. *Co-activation of the Hamstrings during quadriceps extension*

Due to the unavailable software program to analyse integrated E.M.G. data, it was decided to physically measure amplitude peaks and count the frequency of peaks in the hamstring co-activated wave form. Although not a reliable method, without considerable experience, the same investigator assessed these criteria on both legs. Thus any bilateral-variance would indicate E.M.G. activity differences both intergroup and intragroup but would not be valid to other populations using a different investigator.

The hamstring amplitude was recorded as the highest E.M.G. peak during a 90 degree per second quadriceps extension. The sample was taken after the onset of quadriceps extension and before the onset of hamstring flexion. This was analysed for bilateral variance in each group, using a dependant paired t test. The difference between the bilateral-variance of the experimental group and the control group was analysed using an independent t test at an alpha level of 0.01.

The hamstring frequency was recorded as the amount of unrectified positive peaks above the base line. The sample was taken after the onset of quadriceps extension and before the onset of hamstring flexion during a 90 degree per second quadriceps extension. The frequency was analysed for bilateral-variance in each group using a dependent paired t-test. The difference between the bilateral-variance of the experimental group and the control group was analysed, using an independent t-test at an alpha level of 0.01.

8. I.E.M.G.

Integrated electromyography during isokinetic contractions was not analysed due to circumstances outside the investigators control. The data has been saved on disk for later analysis when software programs are available.

9. Atrophy

Intra-subject bilateral girth variance was analysed using a dependant paired t-test, intergroup differences of bilateral-variance was compared using an independent t-test. An alpha level of 0.01 was set.

10. Appendix B Questionnaire - physical fitness

These questionnaires ascertained the subject's physical fitness characteristics that might have some implication to the results. The questionnaire enabled samples to be matched by dominant but not handed legs and was a subjective assessment by each individual.

4.6 Limitations

1. Quantification of Atrophy

This study examines peak torque and endurance related to muscle inhibition/activation. However, a difference in force and fatigue can also be

attributed to muscle atrophy. The accelerated rehabilitation program had attempted to reduce muscle atrophy whilst considering all other medical restraints. It is assumed that due to the long term nature of the research, atrophy would not be a cause of any functional deficit, however, girth measurements were taken to support this contention, although it is not the intention of this study to investigate atrophy

Unfortunately, due to budget and time restrictions, this method is not ideal for assessing muscle cross sectional area. Tomography would be the preferred technique to assess muscle wastage. The investigator utilised correct anthropometric procedures and all measurements were taken in an identical manner and by the same worker.

2.   Not being able to obtain a software program to analyse the E.M.G. data was a major limitation. The investigator endeavoured to physically count the unrectified twitch frequency during co-activation of the hamstrings and also physically measure the peak amplitudes of the wave form. This was far from satisfactory considering the lack of E.M.G. experience, but was statistically analysed to provide some indication of co-activation activity. The data has been stored for future evaluation.

3.   Integrated E.M.G. analysis could not be attempted due to the same limitation.

4.   The limitations of time did not allow previous full test trials with any of the subjects. This could have reduced the learning curve effect during isokinetic dynamometry. The subjects may have increased their output on the second leg as they learnt what was required. Trial efforts were allowed immediately prior to each test.

5.   Due to the required hospital formalities, there was a considerable delay in being able to contact A.C.L subjects. This unfortunately meant proceeding with many of

the control group prior to working with the experimental group. This had the effect of an unbalanced gender population and recreationally fitter control group. However, although not desirable, the literature (Barber et al, 1990) indicates bilateral variance is not dependent on gender and activity levels.

4.7. Validity and Reliability

Internal validity assesses whether the experimental treatment specifically caused a change in the dependent variables. Factors of subject history, such as subsequent knee injury are controlled by a questionnaire in this design. Maturation and pre-testing procedures had no influence and were not measured in this study. The measuring instruments and researcher influence remained unchanged and therefore did not affect the dependent variables. Selection of legs were biologically balanced within body design and also matched by dominance with the control group. The control group were selected on the basis of being recreational athletes similar to the experimental group prior to operation. There were no experimental mortalities in the study.

External validity demonstrates whether this phenomenon can be generalised to other populations. The experimental selection had no known bias, as the subjects randomly suffered A.C.L debilitation. They were recreational athletes, matched by age and of similar gender mix to the control group which would be representative of a similar population at large. Interaction of pre-testing did not apply in this study as all subjects had no prior experience with isokinetic dynamometry or stimulation procedures. Therefore effects of the procedure or any learning curve were similar between groups and limited to the trial efforts immediately prior to testing. There could be a reactive effect of experimental procedure as the effect of the first leg may confound either positive or negative feelings towards testing the second leg. In the control group, the assigned uninvolved leg was tested first irrespective of

58

handedness. In the experimental group, all subjects had the uninvolved leg tested first. Any reaction, negative or positive would depend on the subject's psychological makeup and would therefore be random. All subjects underwent the same sequence of events and there were no multiple treatment interferences. Although there were no pre-tests for the subjects, to ascertain previous bilateral-variance, the occurrence of A.C.L disability appears to affect recreational athletes at random. The independent t-test allows for the probability of these subjects having significant differences due to chance (Issacs and Michael, 1981).

Reliability refers to the accuracy, consistency and stability of measurement. The components of error of variance are

- A) response variation by the subject,
- B) the change of variation in the test situation
- C) change of variation in observation of results.

Regarding variations by the subjects, they were exhorted to produce their maximal efforts on both legs, all subjects indicating that they produced their best performance, so it can be concluded the scores were an accurate assessment of their maximal effort. The experimental situation remained identical during bilateral testing for both groups and therefore would not be a source of error in reliability. The equipment was calibrated prior to all testing sessions. The position of the subject and the Cybex arm length was kept constant between one leg and the other, for each subject. The same investigator recorded and examined all test data. Scores that were physically extrapolated from the A.D.C. displays used repeatedly consistent methods and with the same criteria. The investigator reliability was evaluated on three separate occasions with the same data displays to find the technical error of measurement (T.E.M.) which was found to be less than five per cent Girth measurement to assess atrophy had a similar tester reliability (T.E.M.) less than five per cent which

was considered accurate. Peak torque and endurance as measured by isokinetic dynamometry and A.D.C. computer equipment is a proven and reliable method of assessment (Kannus, 1994). Indirect co-activation measured by E.M.G. analysis is a reliable assessment of muscle activation in the leg (Basmajian, 1974; Gans, 1992).

A possible source of error could be the placement of E.M.G. electrodes, as this requires experience in muscle palpitation with many subjects of different musculature. The investigator took considerable time to ensure bilaterally similar electrode placement, but fully appreciates comparison is difficult between legs and invalid between subjects.

CHAPTER 5

RESULTS

5.1 Introduction

This chapter considers each hypothesis in the order in which they were posed, commencing with quadriceps and hamstrings peak torque, hamstrings / quadriceps ratio, followed by the quadriceps / hamstrings endurance ratio, quadriceps inhibition, hamstrings co-activation, muscle activation and finally, the atrophy results.

Each subsection begins with a statement of the hypothesis followed by a description of statistical tests performed and indication if the results are significantly different, by either rejection or support of the hypothesis.

Statistical details relevant to the argument are mentioned in the text and the reader is referred to the tabular presentations where necessary.

The statistical independent t-tests between the control and experimental groups, include mean and standard deviation values of bilateral-variance. These are presented in tabular form within the text.

Tables of paired t-tests of bilateral-variance between the involved and uninvolved legs, for each group separately, are to be found in Appendix C. A conservative level of significance was set at 0.01 because of the number of statistical tests performed on the same data. There are no figures in this section but some have been included in the discussion which may add clarity to the argument.

The chapter has a summary to emphasise the hypothesis findings.

5.2 Quadriceps Peak Torque

In the long term (greater than 20 months) after A.C.L reconstruction and accelerated rehabilitation :

Hypothesis 1

There will be a significant difference between the experimental group and the control group in bilateral - variance of quadriceps peak torque during isokinetic leg extension, measured by Cybex dynamometry at (a) 90 degrees per second, (b) 180 degrees per second and (c) 300 degrees per second.

An independent t-test (see table 5.1) revealed a significant difference between the experimental group and the control group, in quadriceps peak torque bilateral-variance (B.V.) at 90 and 180 degrees/second, during leg extension. However, this was not significant at 300 degrees/second ($p = .380$). The difference was greatest at the slowest speed (90 degrees/second) and least at the fastest speed (300 degrees/second).

Hypothesis 1 is supported at (A) 90 degrees/second and at (B) 180 degrees /second but is rejected at (C) 300 degrees/second.

Table 5.1.

Mean quadriceps peak torque bilateral-variance during leg extension at 90,180,300 degrees/second recorded in Newton-meters and compared between groups.

VARIABLE	CONTROL		EXPERIMENTAL		
	MEAN	(S.D.)	MEAN	(S.D.)	t(34)
Quads P.T. B.V @ 90 deg/sec	-3.57	(2.02)	24.45	(26.02)	-315.15*
Quads P.T. B.V @ 180 deg/sec	- .12	(10.50)	15.07	(16.16)	-273.13*
Quads P.T. B.V. @ 300deg/sec	7.04	(17.61)	11.51	(11.47)	-71.92

* Denotes significant differences at the 0.01 level

A paired t-test on the control group demonstrated no significant bilateral-variance at any velocities in quadriceps peak torque, between the uninvolved and the assigned involved leg. The greatest bilateral-variance in this group occurred at 300 degrees/second (see Table C.2 in Appendix C)

A paired t-test on the experimental group showed significant bilateral-variance in quadriceps peak torque at all velocities, revealing a substantial deficit in quadriceps strength in the A.C.L reconstructed leg. (see Table C.1 in Appendix C)

The mean values of the control group were higher than the mean values of the experimental group on both legs and at each velocity (see Table C.2, Table C.1 in Appendix C)

5.3 Hamstrings Peak Torque

Hypothesis 2

There will be a significant difference between the experimental group and the control group in bilateral - variance of hamstrings peak torque during isokinetic leg flexion, measured by Cybex dynamometry at (a) 90 degrees per second (b) 180 degrees per second and (c) 300 degrees per second.

An independent t-test (see Table 5.2) revealed no significant differences $(p < .01)$ in hamstrings peak torque bilateral-variance, at any velocities during leg flexion, between the experimental group and the control group. However, although not significant, the difference between the groups was greatest at 90 degrees/second $(p = .039)$ and at 180 degrees/second $(p = 0.89)$ and smallest at 300 degrees/second $(p = .684)$.

Therefore Hypothesis 2 is rejected.

Table 5.2

Mean hamstring peak torque bilateral variance during leg flexion at 90, 180, 300
degrees/second recorded in Newton-meters and compared between groups.

VARIABLE	CONTROL		EXPERIMENTAL		
	MEAN	(S.D.)	MEAN	(S.D.)	t(34)
Hams P.T. B.V. @ 90 deg/sec	- 2.52	(12.60)	6.69	(13.17)	-172.93
Hams P.T. B.V. @ 180 deg/sec	-1.06	(15.27)	6.06	(8.24)	-138.18
Hams P.T. B.V. @ 300 deg/sec.	6.44	(18.02)	4.25	(13.01)	33.13

* Denotes significant differences at the 0.01 level

A paired t-test showed no significant difference between legs in the control group at
any velocities, but a significant difference between legs in the experimental group at
180 degrees/second (see Table C.3 in Appendix C). At 90 degrees /second, although
not significant, the difference between legs was substantial. The mean hamstring
peak torques in the control group were higher than those in the experimental group,
on both legs and at each velocity (see Table C.4 and Table C.3 in Appendix C).

5.4 Hamstrings Quadriceps Ratio

Hypothesis 3

*There will be a significant difference between the experimental group and the
control group in bilateral - variance of hamstrings/ quad ratio during isokinetic
leg extension / flexion measured by Cybex dynamometry at (a) 90 degrees per
second, (b) 180 degrees per second and (c) 300 degrees per second.*

An independent t-test indicated no significant difference in bilateral-variance of the
hamstrings / quadriceps ratio between the experimental and the control group, at all
velocities (see Table 5.3). The difference between groups was greatest at the slowest
velocity (p = .048).

Therefore Hypothesis 3 is rejected.

Table 5.3

Mean hamstring/ quadriceps ratio bilateral-variance during leg extension/ flexion at 90, 180, 300 degrees/second recorded as percentage and compared between groups.

VARIABLE	CONTROL		EXPERIMENTAL		
	MEAN	(S.D)	MEAN	(S.D)	t(34)
Ham/Quad ratio @ B.V 90 deg/sec	-.16	(5.94)	-6.58	12.14	2.05
Ham/Quad ratio @ B.V 180 deg/sec	-1.37	(8.14)	-4.98	(12.05)	1.06
Ham/Quad ratio @ B.V. 300 deg/sec	-.04	(8.28)	-4.62	(14.35)	1.19

* Denotes significant differences at the 0.01 level

A paired t-test in both the experimental and the control group (see Table C.5 and Table C.6 in Appendix C) revealed no significant difference of hamstring/ quadriceps ratio between the involved leg and the uninvolved leg, at all velocities. The greatest bilateral-variance in the experimental group was at the slowest velocity (p=.040) and the least bilateral- variance at the fastest velocity (p = .203). The mean values of the hamstring / quadriceps ratio were greater in the involved leg than the uninvolved leg at all three velocities in the experimental group, thus indicating either greater hamstrings involvement, less quadriceps involvement, or both. The control group showed similar hamstrings/ quadriceps ratio in both legs and at all velocities.

5.5 Quadriceps endurance ratio

Hypothesis 4

There will be a significant difference between the experimental group and the control group in bilateral - variance of the quadriceps endurance ratio during isokinetic leg extension / flexion, measured by Cybex dynamometry at (a) 90 degree per second, (b) 180 degrees per second and (c) 300 degrees per second.

An independent t-test showed no significant difference in bilateral-variance of the quadriceps / endurance ratio, between the experimental group and the control group (see Table 5.4).

Therefore Hypothesis 4 is rejected.

Table 5.4

Mean quadriceps endurance ratio bilateral-variance during leg extension / flexion at 90 degrees/second for 2 minutes recorded as percentage and compared between groups.

VARIABLE	CONTROL		EXPERIMENTAL		
	MEAN	(S.D.)	MEAN	(S.D.)	t(34)
Quads. End Ratio B.V @ 90 deg/sec.	-1.39	(6.95)	-1.02	(10.33)	-.13
Hams. End Ratio B.V. @ 90deg/sec.	1.23	(9.29)	1.67	(12.46)	-.12

* Denotes significant differences at the 0.01 level.

A paired t-test showed no significant difference in bilateral-variance of the quadriceps endurance ratio in either the experimental group or the control group (see Table C.7 and Table C.8. in Appendix C). The mean ratio of both legs for the quadriceps endurance ratio were higher in the control group than the experimental group. Indicating the control subjects quadriceps had greater endurance than the experimental subjects

5.6 Hamstring endurance ratio

Hypothesis 5

There will be a significant difference between the experimental group and the control group in bilateral - variance of hamstrings endurance ratio during isokinetic leg extension / flexion, measured by Cybex dynamometry at (a) 90 degrees per second, (b) 180 degrees per second and (c) 300 degrees per second.

An independent t-test showed no significant difference in bilateral-variance of the hamstrings endurance ratio, between the experimental group and the control group (see Table 5.4).

Therefore Hypothesis 5 is rejected.

A paired t-test showed no significant difference in bilateral-variance of the hamstring endurance ratio in either the experimental group or the control group (see Table C.7 and Table C.8 in Appendix C). In the experimental group, the hamstring endurance ratio in the involved leg ($\underline{m}$ = 52.86 per cent), was slightly lower than the uninvolved leg ($\underline{m}$ = 54.54). The control group and the experimental group showed similar hamstring endurance ratios on both legs.

5.7   Muscle inhibition

Hypothesis 6

There will be a significant difference between the experimental group and the control group in bilateral-variance of muscle inhibition during a 60 degree isometric contraction, measured by Cybex dynamometry.

An independent t-test showed no significant difference in bilateral-variance of muscle inhibition between the experimental group and the control group (see Table 5.5).

Therefore Hypothesis 6 is rejected

Table 5.5

Mean quadriceps inhibition bilateral-variance during a 60 degree isometric contraction recorded as percentage of maximal voluntary contraction and compared between groups.

VARIABLE	CONTROL		EXPERIMENTAL		
	MEAN	(S.D.)	MEAN	(S.D.)	t(34)
Quads % Inhib B.V.	-5.40	(16.82)	2.62	(16.58)	-1.44

* Denotes significant differences at the 0.01 level

A paired t-test showed no significant difference in bilateral variance of muscle inhibition in either the experimental group or the control group (see Table C.9 and Table C.10 in Appendix C). The mean percentage inhibition in both legs of the experimental group ($\underline{m}$ = 19.65%, $\underline{m}$ =17.02%) were greater than the mean percentage inhibition in both legs of the control group ($\underline{m}$ =3.07%. $\underline{m}$ =8.47%). This indicated greater bilateral maximal activation in the control group than in the experimental group and thus greater bilateral inhibition in the experimental group than the control group.

5.8 Hamstrings / quadriceps co-activation.

Hypothesis 7

There will be a significant difference between the experimental group and the control group in bilateral - variance in antagonistic hamstrings co-activation during leg extension, indirectly measured by E.M.G. activity during Cybex dynamometry at 90 degrees per second.

An independent t-test showed no significant difference in bilateral-variance of E.M.G. activity (as demonstrated by amplitude and frequency) between the experimental group and the control group (see Table 5.6).

Therefore Hypothesis 7 is rejected

Table 5.6

Mean hamstring co-activation E.M.G. bilateral-variance during a 90 degree/second leg extension, frequency counted per contraction and peak amplitude measured in raw voltage output and compared between groups.

VARIABLE	CONTROL		EXPERIMENTAL		
	MEAN	(S.D.)	MEAN	(S.D.)	t(34)
E.M.G. frequency B.V.	-.15	(3.28)	-1.82	(4.20)	1.33
E.M.G. peak amplitude B.V	.03	(.17)	-.12	(.44)	1.39

* Denotes significant differences at the 0.01 level

A paired t-test showed no significant difference in bilateral-variance of E.M.G. activity (as demonstrated by amplitude and frequency) in either the experimental group or the control group (see Table C.11 and Table C.12 in Appendix C). However, the experimental group involved leg showed greater E.M.G. amplitude values than both legs of the control group. In the experimental group both legs showed lower frequency values than those of the control group.

5.9 Muscle activation

Hypothesis 8

There will be a significant difference between the experimental group and the control group in bilateral - variance of surface integrated E.M.G. activity during isokinetic leg extension / flexion during Cybex dynamometry at 90 degree per second

Due to circumstances outside the investigator's control, a computer analysis software program to analyze integrated E.M.G., was not available at the time of printing. The data collected was saved and will be analyzed in a later study.

5.10 Muscle atrophy

An independent t-test (see Table 5.7) showed no significant difference in bilateral-variance of girth measurements between the experimental group and the control group, but it should be noted that the difference between groups was substantial (p = .031) and demonstrated a mean girth deficit of .66 cms.

Table 5.7

Mean thigh girth bilateral-variance compared between groups recorded in cms.

VARIABLE	CONTROL		EXPERIMENTAL		
	MEAN	(S.D.)	MEAN	(S.D.)	t(34)
Girth	.33	.74	-.33	1.02	2.50

* Denotes significant differences at the 0.01 level.

70

The control group's age ($\underline{m}$ = 25.94 years, (S.D. 8.80) range 18 - 47) was similar to the experimental group's age ($\underline{m}$ = 25.00 years, (S.D. 6.91) range 18-46)

The majority of the control group were still recreationally active and training regularly compared to the experimental group who, since the operation, had participated less regularly and at a less intense level. A subjective assessment would suggest the control group were more capable and motivated to produce maximal efforts as opposed to the experimental group, who appeared to be more apprehensive towards maximal exertion on the involved leg.

5.11 Summary

Quadriceps peak torque bilateral-variance was found to be significantly different between groups at 90 and 180 degrees per second, but not at 300 degrees per second. This hypothesis was therefore partially accepted.

In all other hypotheses (hamstring, peak torque, hamstrings/quadriceps ratio, quadriceps endurance ratio, hamstring endurance ratio, quadriceps inhibition and hamstring co-activation), no significant differences in bilateral-variance, were found between the control group and the experimental group, at an alpha level of 0.01. These hypotheses were rejected. However, the analysis revealed that hamstring deficits were less than quadriceps and that the hamstrings/quadriceps ratio had changed in the experimental involved leg.

CHAPTER 6

DISCUSSION

6.1 Introduction

There are several factors that influence the ability of muscle to produce force, whilst acknowledging that muscle atrophy could be a main determinant of force deficiency. This study has focused on muscle activation and torque output during isokinetic contractions. Peak torque, reciprocal ratios, inhibition and muscle activation were examined in both legs of an experimental group who had a unilateral A.C.L. knee reconstruction and a control group who had bilaterally unaffected legs. This chapter discusses the results of this investigation in the order of the proposed Hypotheses, together with relevant literature on similar research. A summary of the discussion with a concluding statement and suggestions for future research, finalises this chapter.

6.2 Quadriceps Peak Torque

There was a significantly greater bilateral-variance in the quadriceps peak torque of the experimental group than in the control group, at both the slower velocities (90 and 180 degrees/ second) but, not at the fastest velocity (300 degree/second) (Figures 6.1, 6.2 and 6.3). The experimental group's paired t-tests showed significant bilateral-variance ($p=.001$) in quadriceps peak torque at all three velocities. In every case, the involved leg was inferior to the uninvolved leg, with the bilateral-variance being greater at the slower velocities. At 90 degrees/second, the experimental involved leg ($\underline{m} = 147.52$ Nm) was 85.8 per cent of the uninvolved leg ($\underline{m} = 171.98$ Nm).
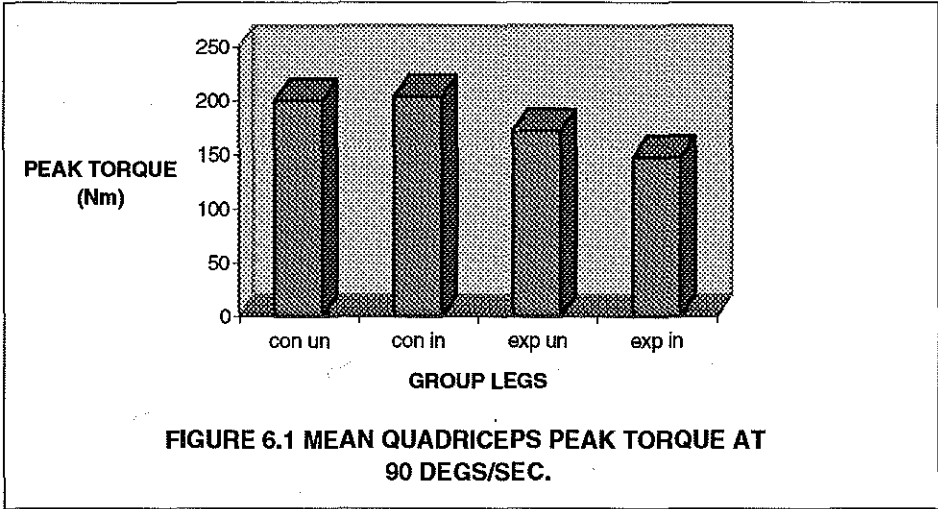
FIGURE 6.1 MEAN QUADRICEPS PEAK TORQUE AT
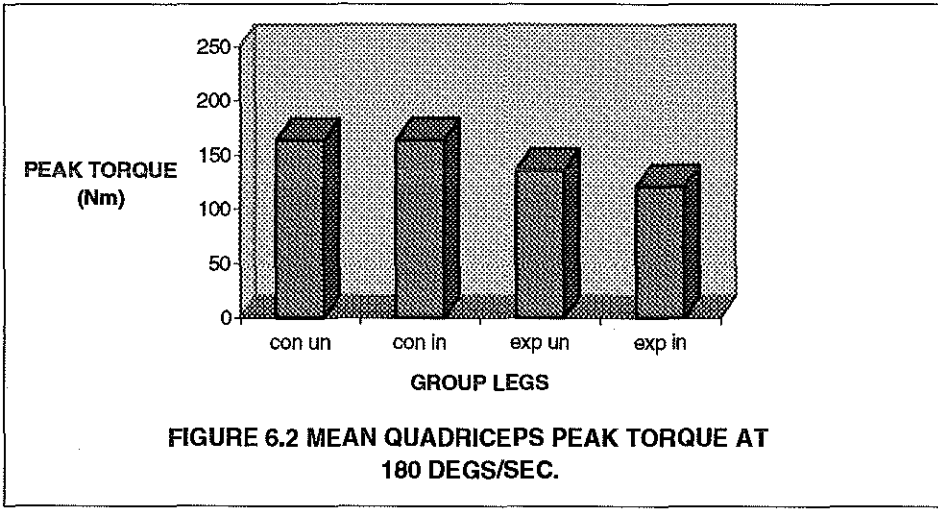90 DEGS/SEC.

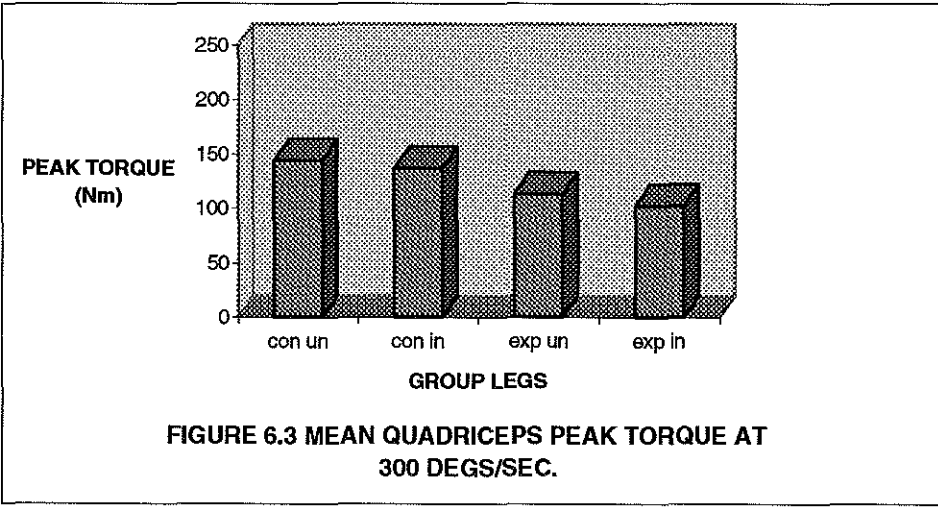FIGURE 6.2 MEAN QUADRICEPS PEAK TORQUE AT
180 DEGS/SEC.

FIGURE 6.3 MEAN QUADRICEPS PEAK TORQUE AT
300 DEGS/SEC.

73

An 85.8 per cent restoration of quadriceps bilateral values, found in the experimental group (more than 20 months post operation), was less than that found by Shelbourne et al (1990) at 10 weeks (85-90 per cent) and at 12 months (90 per cent), and notably less than Elmqvist et al (1989) who found the maximum performance of the quadriceps to be statistically inseparable between the involved and uninvolved legs 12 months after reconstruction. According to Kannus (1994) and Perrin (1993), less than 10 per cent imbalance is normal, and greater than 20 per cent, abnormal. The experimental group, in the current study would be considered to have a bilateral imbalance of quadriceps strength that is neither normal or abnormal. Considering the longterm nature of this investigation, the involved leg should have been fully rehabilitated and strength parameters completely restored, which was not the case.

Force studies, after A.C.L reconstruction are in abundance, however, few researchers have investigated the long term musculoskeletal functions. In a study by Arvidsson et al (1981), five to 10 years post reconstruction, a significant bilateral-variance (p less than 0.001)was found in extension strength with subjects ($\underline{n}$ = 38) who had some knee instability, pain under heavy stress and had slightly modified their sporting activity. This was less significant (p less than 0.01) at a faster velocity. These investigators also quantified subjective functional evaluation of the 80 subjects. Eight per cent were unable to participate in sport, 23 per cent had moderate pain and could not participate at intense twisting and turning activities, 43 per cent had pain under stress and consequently modified their activity and the remaining 26 per cent had no complaints and returned to full activity. It should be noted that some of the subjects who had poor muscle function, also showed reduced hamstring strength.

Gravity correction was not adjusted in the Cybex raw data analysis so, absolute values are not comparable to other studies. However, gravitational effects would not be significantly different between legs in any individual (bilateral-variance) unless there was a significant difference in atrophy. Legs were compared using the Cybex

software calculation for gravitational effect at 45 degrees and for girth differences using a constant tape measure, neither of which showed significant bilateral-variance. Therefore, any gravitational effects that would alter the reciprocal ratios or endurance ratios, would effect both legs intra-subject, equally. This study compared differences "within body" and not absolute ratios.

During the isokinetic protocols, especially at high velocities, significant artefact was observed, this was reduced by the Cybex dynamic ramping facility, but oscillations present were not representative of muscle tension. Hence careful consideration of the waveform was necessary to get a valid reading of peak torque (Arvidsson et al, 1981). At the higher velocities, peak torque occurs later in the range of movement, so if the limb passes the optimal position for performance, the peak torque observed may not represent maximal capacity (Kannus, 1994). Considering these confounding influences and that none of the subjects trained at high velocities, caution was applied to results at 300 degrees/second.

In the current study, the results of the quadriceps peak torque conform to the force-velocity curve which illustrates that when velocity increases, the potential force output declines (Fox, Bowers and Foss, 1989). Since the force at the high velocity end of the curve is of smaller absolute value than at the slower velocity end, the bilateral-variance in torque output at higher velocities was expected to be smaller too. In addition, during isokinetic quadriceps contraction, an increase in velocity caused a decrease in torque production, meaning that gravity would have an increasing negative effect on results. The increasing effect of gravity with increases in velocity would mean, group differences in quadriceps torque output would be minimised at higher velocities (Cybex 1991).
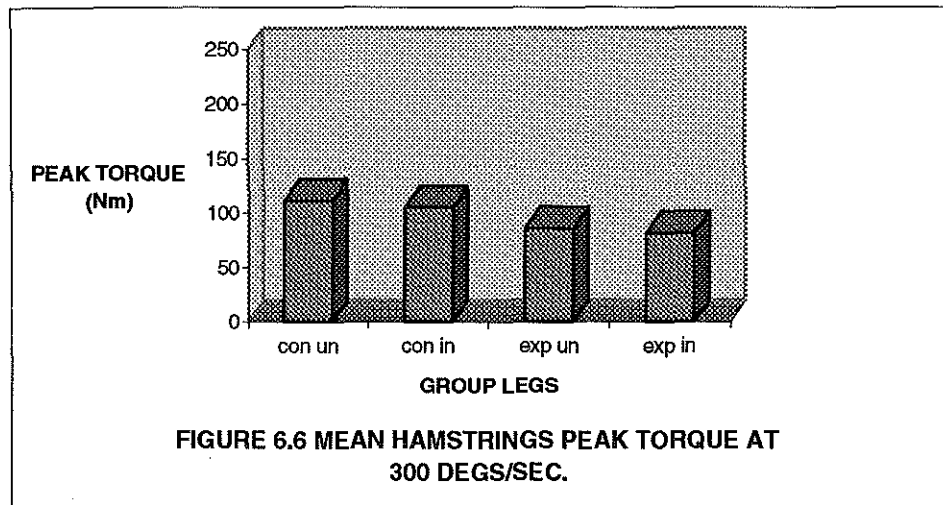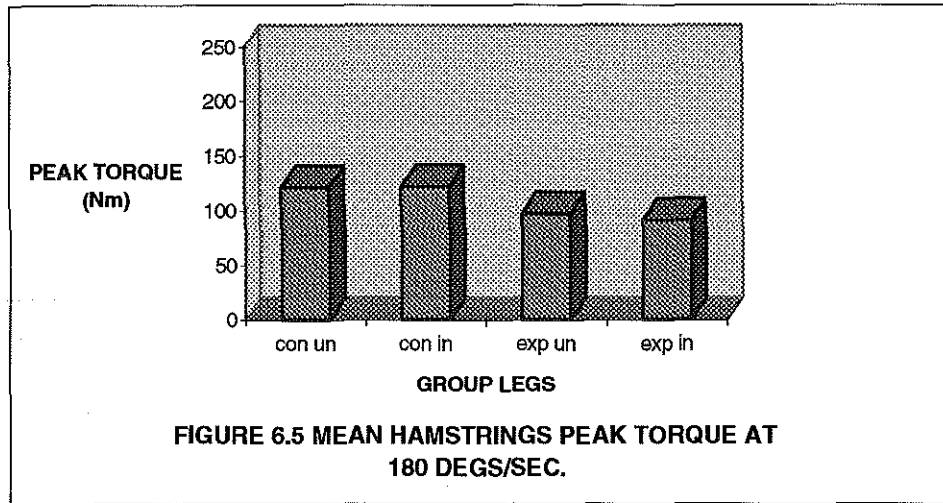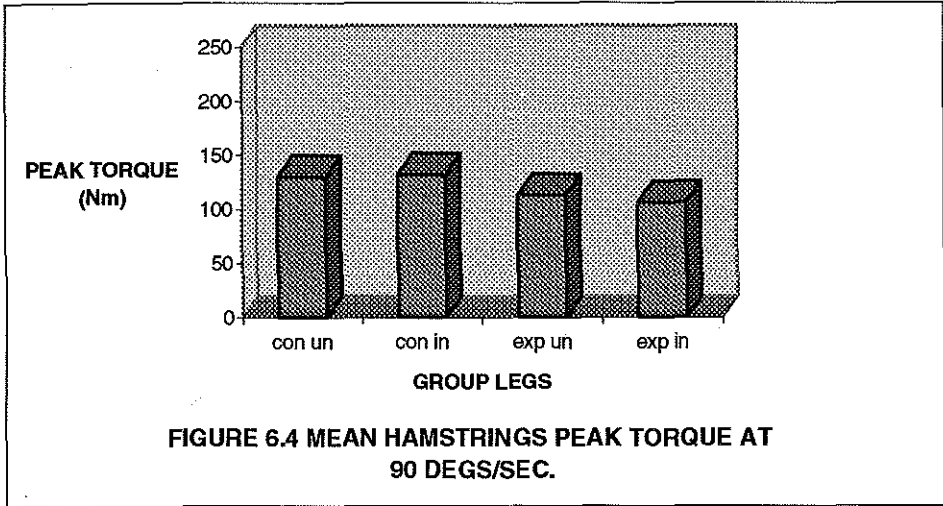
The control group showed an increase in bilateral-variance at 300 degrees/second. The ability to activate all motor units maximally at higher velocities, is partly

dependent on fibre type, fast twitch fibres being more capable of producing force quickly, and partly on specificity of training. Neither group of subjects were especially picked for fibre type or training characteristics, so a greater variance of force production would occur at the faster velocities (300 degrees/second), compared to the slower velocities. The scores of the uninvolved and involved legs in the control group were fairly consistent at 90 and 180 degrees/second.

It is noted that the mean quadriceps peak force of the control group (see Table C.2 in Appendix C) were, at all velocities, higher than those of the experimental group and on both legs. Both the experimental and control groups were questioned about their physical activity. The control group were considered recreational athletes who, in the majority, still played in competition and trained once or twice per week. This also applied to the experimental group but, only up until the time of injury, since then only a minority had returned to recreational activity at their previous level. All subjects in this group were functional in everyday duties but only a few still played and trained at their chosen sport. The subjects, who no longer participated at a relatively intense level, felt their involved leg was inferior to the contralateral leg and were apprehensive about a further occurrence of injury if the knee was put under stress. The experimental group's decline in activity during the previous 20-36 months, could explain the lower absolute values of both legs, compared to the control group. These lower mean torque values could also be attributed to gender influence, there being more males in the control group (males=15, females = 4) than the experimental (males=10, females=7). Although mean values revealed some difference in group strength, according to Barber et al (1990), this would have no influence on the subject's bilateral-variance. These workers found no significant difference between right and left legs intra-subject in a normal population, that was influenced by activity level, gender or leg dominance.

6.3 Hamstrings Peak Torque

The mean hamstrings peak torque in the experimental group was less than in the control group (see Table C.3 and Table C.4 in Appendix C). This would be for similar reasons as in the quadriceps mean peak torque (activity level and gender influence), but to a lesser extent due to the assisting effect of gravity during hamstring flexion. An independent t-test revealed no significant differences in bilateral-variance of hamstring peak torque between the control and experimental groups. However, as with the analysis of quadriceps peak torque, the differences were greater at the slower velocities and least at the faster velocities (see Figures 6.4, 6.5 and 6.6), gravity having an increasing effect on lower torque values. At 90 degrees/second the group differences in hamstrings bilateral-variance was notable (p = .039) although not significant. The experimental involved leg peak torque (m = 106.08 Nm) was 94.6 per cent of the uninvolved leg performance (m = 112.77 Nm) (see Table C.3 in Appendix C). The control group's hamstrings peak torque showed no significant bilateral-variance (see Table C.4 in Appendix C). The involved leg peak torque was less than 5 per cent different to that of the uninvolved leg, at all velocities. In the experimental group there was a significant difference in hamstring peak torque at 180 degrees/second between the involved leg (m = 91.08 Nm) and the uninvolved leg (m = 97.15 Nm) equivalent to 93.7 per cent. At 90 and 300 degrees/second, these values were not significantly different but were nevertheless substantial. It was unusual that bilateral- variance was significant, specifically at one velocity, 180 degrees/second, which was the most common functional movement velocity. It would be expected that the slower velocity would induce greater stresses, requiring greater strength output and therefore more likely to demonstrate any significant bilateral deficiencies. At faster velocities hamstring torque output was assisted by the effects of gravity so less bilateral-variance would be anticipated.

PEAK TORQUE (Nm)

**FIGURE 6.4 MEAN HAMSTRINGS PEAK TORQUE AT
90 DEGS/SEC.**

PEAK TORQUE (Nm)

**FIGURE 6.5 MEAN HAMSTRINGS PEAK TORQUE AT
180 DEGS/SEC.**

PEAK TORQUE (Nm)

**FIGURE 6.6 MEAN HAMSTRINGS PEAK TORQUE AT
300 DEGS/SEC.**

When evaluating the peak torque analysis in the current study, factors that influence performance should be considered. One such factor is the gravity effect that assists hamstrings flexion but has a negative effect on quadriceps extension. Thus in the presence of any leg weakness, there would naturally be a more pronounced difference in quadriceps absolute values than in the hamstring values. Another factor would be that testing was dependent on the subjects' ability to perform maximal voluntary contractions. A key confounding variable to this analysis would be the subjects' motivation in producing maximal efforts. It is possible that the control group, whilst still in training, were more motivated psychologically compared to the experimental group who, since the injury, may have been more apprehensive and less accustomed to maximal motivation. This study investigated concentric hamstrings contractions but Kannus (1994) suggests it would be more relevant to evaluate eccentric contractions, which are more significant to the functional action of muscle groups during walking, running and squatting activities. When evaluating isokinetic dynamometry performance, some investigators (Worrell, Perrin and Denegar,1989) suggest that results do not always correlate with functional capacity. These researchers demonstrated bilateral hamstrings equality in concentric and eccentric strength plus a bilaterally balanced hamstrings / quadriceps ratio (64 per cent), but a significant deficit in hamstrings functional flexibility. Thus caution must be used when assessing isokinetic force parameters and their relevance to musculoskeletal functions.
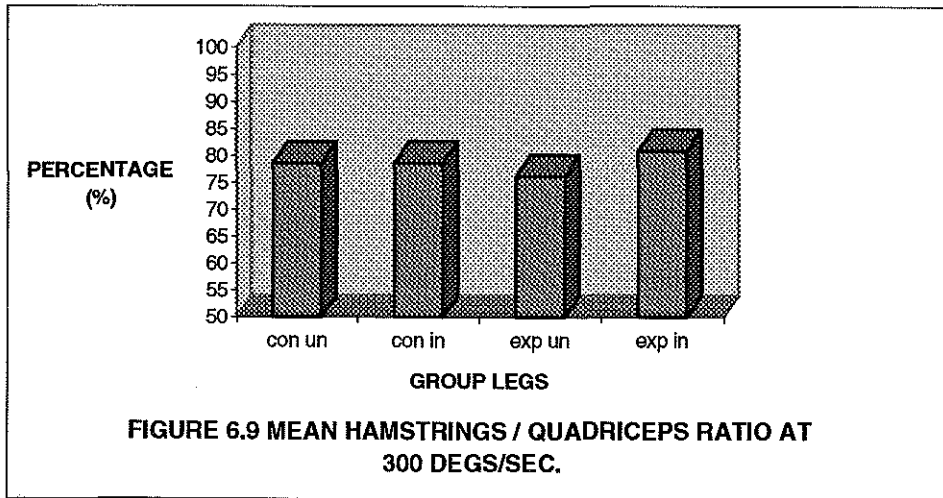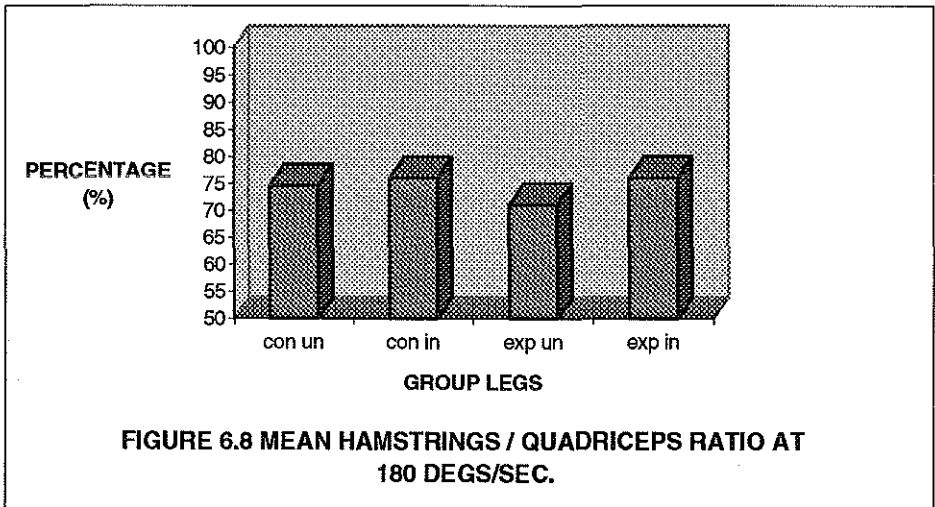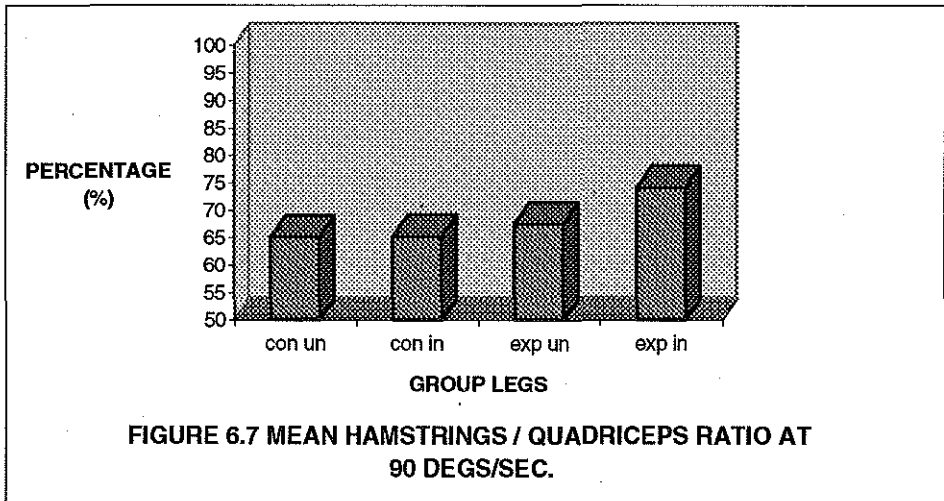
6.4 Hamstrings/quadriceps ratio

There was no significant difference in bilateral-variance of the hamstrings/quadriceps ratio between the experimental group and the control group at all velocities. However, the bilateral-variance was greatest ($m = -6.58$ per cent) at 90 degrees/second in the experimental group's involved legs (see Table 5.3). The experimental involved leg ($m = 74.14$ per cent) had a greater hamstrings/ quadriceps

ratio than the uninvolved leg (m = 67.56 per cent) at all velocities (see Figures 6.7, 6.8 and 6.9), which demonstrates either a greater hamstrings involvement or a lesser quadriceps involvement. The experimental group had a significant difference between the uninvolved and the involved quadriceps peak torque (see Table C.1 in Appendix C) but not in the hamstrings peak torque (see Table C.3 in Appendix C). Thus the hamstrings/quadriceps ratio would be greater in the involved leg compared to the uninvolved leg.

The hamstrings/quadriceps ratio of the experimental group's involved leg had an increasing value with increasing velocity, due to the gravitational effects aiding the hamstrings and negating the quadriceps forces. The weaker the subject's leg, the more the effect of gravity. However, the control group showed similar hamstrings/quadriceps ratios in both legs at each velocity.

Some researchers have indicated that muscle imbalance between legs or the ratio between hamstrings and quadriceps, are risk factors causing injuries, while others found no significant differences in the hamstrings / quadriceps ratio between injured A.C.L legs and uninjured contra-lateral legs (Van Mechelen, Hlobil, Rep, Strobos & Kemper, 1994). Kannus (1994), and Perrin (1993) have said the most ideal hamstrings/quadriceps ratio of an injured leg, would be equal to the ratio of the uninvolved leg. Subjective assessment in this study, revealed that subjects with the greater hamstrings/ quadriceps ratios, felt more functional and less apprehensive, than those with the lower hamstrings/quadriceps ratios.

FIGURE 6.7 MEAN HAMSTRINGS / QUADRICEPS RATIO AT
90 DEGS/SEC.

FIGURE 6.8 MEAN HAMSTRINGS / QUADRICEPS RATIO AT
180 DEGS/SEC.

FIGURE 6.9 MEAN HAMSTRINGS / QUADRICEPS RATIO AT
300 DEGS/SEC.

6.5   Endurance Ratio

An independent t-test showed no significant difference in bilateral-variance of the quadriceps endurance ratio between the experimental group and the control group (see Table 5.4).

In the experimental group (see Table C.8 in Appendix C), the involved leg (49.24 per cent) had slightly more quadriceps endurance than the uninvolved leg (47.84 per cent). This could be explained by the lower absolute forces produced by the involved leg at the onset of the protocol. Since the endurance ratio is the sum of the first five peak torques compared to the last five peak torques, the initial torque production is crucial to the ratio. The more maximal this initial torque, the more fast twitch fibres would be activated immediately, these fibres fatigue to a greater extent, than the slow twitch fibres activated in submaximal efforts. Hence the involved quadriceps with lower initial torque productions would not fatigue quite so quickly as the stronger uninvolved quadriceps, which have higher initial torque production.

The control group had a greater quadriceps endurance ratio in both the involved leg ($\underline{m}$ = 49.24 per cent) and the uninvolved leg ($\underline{m}$ = 47.84 per cent), than either the experimental involved leg ($\underline{m}$ = 43.38 per cent) or uninvolved leg ($\underline{m}$ = 42.36 per cent). Even though the experimental group demonstrated a lower initial torque output than the control group in both legs, they still fatigued to a greater extent than the control group (see Figure 6.10). The experimental group's fast twitch fibres fatigued very quickly and their slow twitch fibres, normally more endurable, were less able to sustain torque output than the control group. This endurance difference between groups, would be due mainly to the different current levels of training or inactivity.
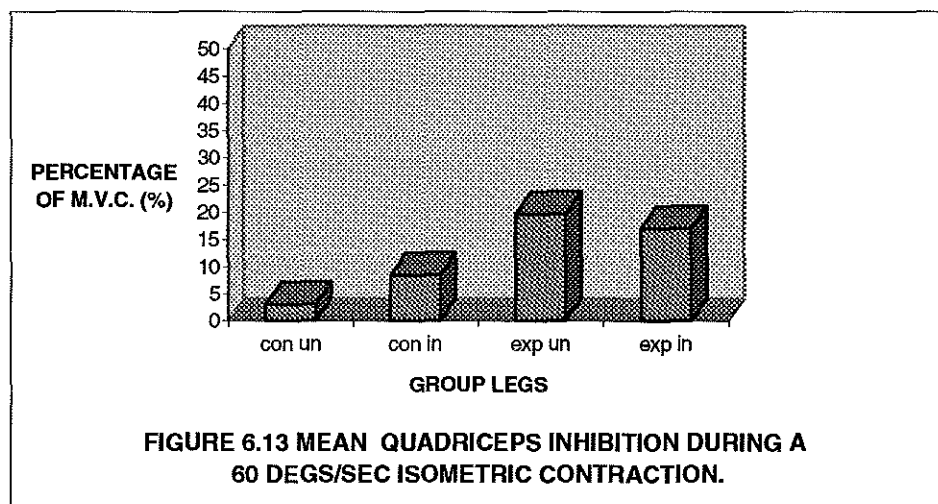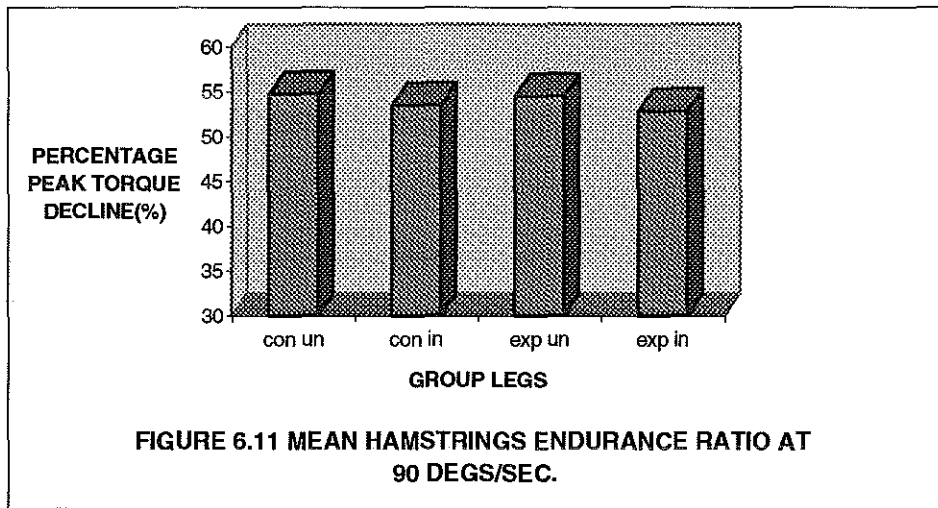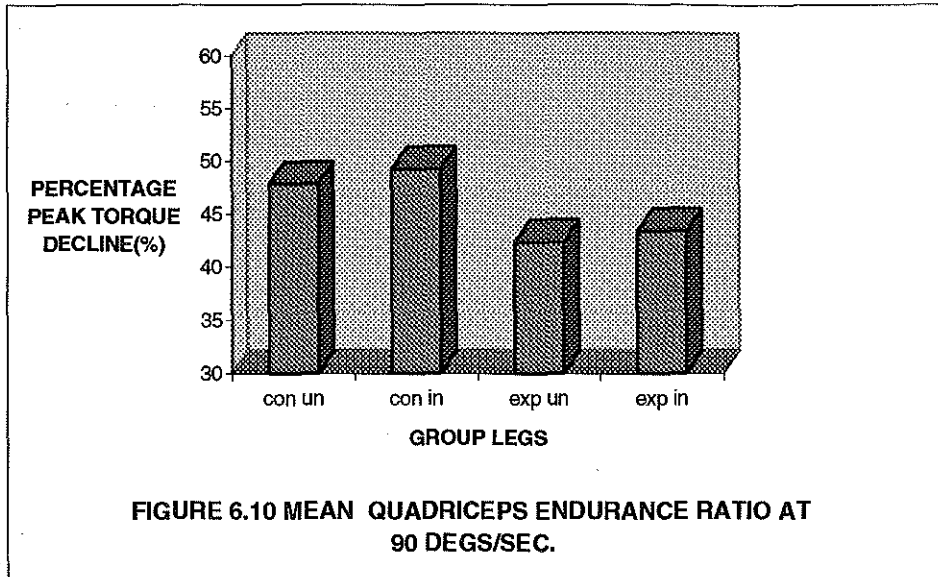
There was no significant difference in bilateral-variance of the hamstring endurance ration between the groups (see Table 5.4) although the experimental group ($\underline{m}$ = 1.67 per cent) had greater bilateral-variance than the control group ($\underline{m}$ = 1.23 per cent). Both legs in the experimental and control group showed very similar hamstrings endurance ratios (see Figure 6.11), all of which were higher than the corresponding quadriceps endurance ratios. As previously mentioned, the results were not corrected for gravitational effect, thus as fatigue increases during the two minute protocol, we would expect gravity to have a greater negative effect on the quadriceps and positive effect on the hamstrings. Bilateral atrophy and leg weight were not significantly different, so gravity would effect both legs equally. Both the control and experimental group had small (less than three per cent) bilateral-variance of girth circumference and limb weight.

The hamstrings endurance ratios in the experimental group were less than two per cent different to those of the control group, indicating an almost normalised endurance capability of this muscle group, albeit at a slightly lower torque output. It is evident therefore, that the involved hamstring endurance ratio was affected to a lesser extent than the quadriceps, in the experimental group. Elmqvist et al (1989) supports this observation in their study which indicated muscle weakness in both type I and type II fibres and to a greater extent, in the quadriceps than the hamstrings. Snyder-Mackler et al (1993) unexpectedly found that the involved quadriceps endured longer than the uninvolved quadriceps during an electrically elicited fatigue test. They concluded that possible selective atrophy of Type IIB fibres was greater than atrophy of fatigue resistant, Types I and IIA fibres which endured longer. Hence, as supported by the current study, although not significant, atrophy may selectively affect fast twitch fibres, allowing the reconstructed leg similar endurance capabilities as the normal leg. However, a confounding factor when comparing hamstrings to quadriceps endurance in the current study, was the gravitational effect which had opposite influences on the quadriceps endurance and the hamstrings

83

endurance. There was no attempt in the current study to examine the sites of fatigue during endurance protocols, probably these were both central and peripheral (Fitts, 1994). It was found during the electrical stimulation procedure, whilst performing a four second isometric contraction, that central inhibition was not significantly different between the involved and uninvolved legs, although this analysis does not necessarily apply to isokinetic endurance protocols.

6.6 Inhibition

Suprisingly, there was no significant difference in bilateral-variance of muscle inhibition between groups (see Table 5.5), however, the control group showed greater bilateral-variance of inhibition than the experimental group. Many of the control group demonstrated maximal activation with zero inhibition. This group's involved leg inhibition ($\underline{m}$ = 8.47 per cent) and uninvolved legs inhibition ($\underline{m}$ = 3.07 per cent), were quite low and within the expected normal population levels (McComas et al, 1983). Remembering that the control group legs were assigned to dominant/ nondominant equivalents in the experimental group, the control group bilateral-variance might well reflect non-dominant leg inhibition. It would be expected that the dominant leg in the control group should be more fully activated than the non-dominant leg. The control group's mean percentage inhibition was lower in both the involved leg and uninvolved leg, than the experimental group's involved leg ($\underline{m}$ = 17.02 per cent) and uninvolved leg ($\underline{m}$ = 19.65 per cent). A difference would be expected between active people currently training, and those who are less likely to maximally activate muscles regularly (Sale,1988). The unexpected result in the experimental group with no significant difference of inhibition between legs (see Figure 6.13), was not in agreement with Newham, Hurley and Jones (1989) who revealed bilateral inhibition differences ($\underline{m}$ = 20.1 per cent) in eleven subjects at ($\underline{m}$ = 11 months) post-operation during isometric contractions.

84

FIGURE 6.10 MEAN QUADRICEPS ENDURANCE RATIO AT 90 DEGS/SEC.

FIGURE 6.11 MEAN HAMSTRINGS ENDURANCE RATIO AT 90 DEGS/SEC.

FIGURE 6.13 MEAN QUADRICEPS INHIBITION DURING A 60 DEGS/SEC ISOMETRIC CONTRACTION.

Whilst using surface stimulation in this study, a greater percentage of the maximal voluntary force was stimulated in the experimental group (involved $\underline{m}$ = 31.50 per cent uninvolved, $\underline{m}$ = 30.17per cent) than the control group (involved $\underline{m}$ = 16.04 per cent, uninvolved. $\underline{m}$ = 14.97 per cent). Both groups were above the minimum stimulation level (10 per cent) that would produce valid results (Belanger et al, 1981), with the experimental group being more sensitive to stimulation. Lieber and Kelly (1991) managed stimulation of 25 per cent of maximal muscle activation, Belanger et al, (1981) managed seven to 28 per cent and Snyder-Mackler (1993) managed 20 - 34 per cent. The latter authors demonstrated there was little change in motor unit recruitment during stimulation of 20 - 50 per cent of maximal voluntary contraction.

McComas et al (1983) indicate that any superimposed twitch can be due to lack of voluntary effort, pyramidial or extra-pyramidial activation disorder whilst Rutherford et al (1986) say that loss of muscle tissue does not prevent maximal activation.

As previously mentioned, feedback loops in the leg are a major cause of inhibition and deficiency in quadriceps performance, however the super-imposition technique assessed motor nerve and muscle, independent of sensory feedback or the central nervous system (Snyder-Mackler et al, 1993). Thus the diminished quadriceps force in the current investigation is attributable to capacities within the muscle and not sensory feedback or central nervous communication.

Moritani et al (1979) indicated that initial strength gains came from neural factors or muscle activation and later gains through hypertrophy. Inhibition in the experimental subjects, although relatively high, was not significantly different between the involved and uninvolved leg, therefore, inhibition levels could not be attributed to the operation outcomes, or sensory feedback. The torque output curves appeared consistent, which indicated maximal efforts throughout the testing, in contrast to inconsistent curves with changing profiles, that would normally indicate lack of

maximal effort (Perrin 1993). The inability of the experimental group to maximally activate either leg could be due to lack of activities that would initiate full activation of all motor units. The rehabilitation protocol should address this issue.

6.7 Hamstrings Co-activation

It had been intended to indirectly measure the co-activated hamstring antagonist force by using I.E.M.G. The hamstring I.E.M.G.data would have been correlated with torque output during a 90 degrees/second flexion movement. Subsequently when I.E.M.G. data was recorded from the same muscle group during quadriceps extension, the antagonistic torque output of co-activated hamstrings, could have been assessed by using this correlation figure.

Due to circumstances beyond the investigator's control, computer software for analysing I.E.M.G.data was not available at the time of printing, so data collected will be computer analysed in a future study. To get a subjective assessment of hamstring co-activation during quadriceps extension at 90 degrees/second, the EMG graph was printed (see Appendix F) for each subject on both legs. The E.M.G. twitch representing an electrical motor unit potential may be counted to estimate relative magnitude of muscle activation, although this does not necessarily estimate force (Gans. 1992). Thus, by physically counting and measuring the hamstring's waveform, the E.M.G. peak amplitude and E.M.G. frequency per contraction, were ascertained. The amplitude was recorded as the single highest peak of the hamstring co-activated wave form, taken from the onset to the completion of the quadriceps concentric extension. The frequency of the unrectified peaks was assessed by their number above the baseline, from the onset to the completion of the quadriceps concentric extension. There are many confounding variables that invalidate a quantitative assessment, using this manual procedure, however, in the absence of adequate program analysis, it was decided to temporarily assess the amount of E.M.G. activity in the involved and the uninvolved legs, in both groups. The confounding variables to this procedure were the range of motion and time of

contraction, any unwanted noise received through the electrode wires and the need for identical electrode placement. Failure to discriminate between artefacts and potentials and comparison of different channels can be a danger, so integrated E.M.G. would have been preferable (Gans, 1992). E.M.G. results are significant for gender, muscle groups and contraction types, so when recording mixed gender groups or different muscle groups, the appropriate analysis must be used (Black et al, 1993).

Given the limitations of this assessment, it appears there was no significant difference in bilateral-variance of hamstring E.M.G. activity during leg extension, compared between groups. The control group (see Table C.12 in Appendix C) demonstrated slightly greater E.M.G. frequency per contraction, probably due to greater R.O.M. and a fractionally longer duration of contraction, than the experimental group. The experimental group had similar frequencies per contraction on both legs, however, the amplitude in the involved leg was slightly greater than the uninvolved leg.

The co-activation of the hamstrings in this research, examined isokinetic contractions on both legs, during which E.M.G. activity appeared to be bilaterally similar and relatively quite small. This observation is in agreement with Palmitier et al (1991) who purport that hamstrings act minimally during non-weight bearing exercise, but to the contrary, act quite significantly in normal weight bearing activity. This contention is fully supported by other researchers (Barrack et al, 1994 and Basmajian, 1974) who, demonstrated increased E.M.G. activity during functional movement and a change in muscle firing patterns. The assessment of E.M.G. activity in the current study did not reveal any bilateral-variation during isokinetic leg extension.

By using E.M.G. analysis Gans (1992) demonstrated that muscle firing patterns during co-activated muscular reflexes, showed inhibition of knee extension and facilitation of the medial hamstring flexor muscles. It is uncertain whether some impulses generated from the mechanoreceptors result directly in stimulation of alpha

motor neurones or whether the effect is primarily on the gamma efferent muscle spindle.

An increase in E.M.G. activity would have been expected in the reconstructed leg, especially at the slower velocities generating greater torque output (Basmajian, 1974). Kain et al (1988), Renstrom et al (1986) and More et al (1993) suggest that, adaptational activity by the hamstrings to protect the A.C.L., may occur only if contracted before the quadriceps and only at angles greater than 45 degrees flexion. This study has not been able to find significant E.M.G. co-activation adaptions in the hamstrings group, but given the limitations of the analysis method, it would be incorrect to disagree with the investigators cited. Perhaps the computer analysis of results will present different findings. However, the hamstrings peak torque and hamstrings/ quadriceps ratio results would support Barratta et al (1988), Solomonow et al (1987) and Draganich (1990) in their contention, that the hamstrings act as synergists with the A.C.L. during quadriceps extension and provide some protection to the ligament.

Sensory information to facilitate the hamstrings co-activation or inhibit the quadriceps, is communicated by either the central nervous system or feedback loop (Barrack et al 1994). This information is essential for position sense at the extremes of motion and to protect the reconstructed A.C.L. from further damage. Part of this sensory communication is initiated by the mechanoreceptors in the joint and in the A.C.L., which feedback the information causing a reflex action. These mechanoreceptors are found to take between six and twelve months to fully regenerate, which leaves the co-activation of the hamstring's in a protective role, somewhat deficient during intense or rapid movement. Hence Shelbourne et al (1992) and Dranganich et al (1989) have stated that it is essential to train hamstring activation during rehabilitation in order to get maximal protection. Subjects are predisposed to injury, especially if fatigued, until functional stability, proprioception and hamstring reflex loops are fully restored (Lephart et al, 1992).

Elmqvist et al (1989) suggested that reduced afferent input from the knee mechanoreceptors altered the central nervous drive and was a major cause of torque decline.

Surface integrated E.M.G. analysis was not attempted during any of the protocols, due to the unavailable software. The data collected has been stored for future analysis.

6.8 Atrophy

It was not the purpose of this study to examine atrophy of the reconstructed legs, although it is considered a main cause of reduced muscle function, however, it was presumed that in the longterm after rehabilitation, cross sectional muscle area would be bilaterally equal. To be able to investigate muscle activation, atrophy needed to be discounted as the major cause of functional weakness, hence subjects with obvious muscle wastage were not included. All subjects were examined for bilateral-variance in leg weight analysed by the Cybex computer software and girth size.

There was no significant difference in girth bilateral-variance between groups. The bilateral-variance in the control group (m = .33cms) was very similar to the experimental group (m = .34 cms). The bilateral-variance of leg weight was less than one Nm, which is considered normal and partly attributable to muscle relaxation during measurement (Cybex, 1991). Although girth measurement and limb weight are not wholly representative of muscle cross sectional area, ideally quantified by tomography, careful anthropometric measurement by a trained worker, is quite valid and reproducible. In both the control and experimental group, there were no significant signs of atrophy in either legs. However, there were two subjects within the experimental group who had some atrophy in the involved leg, with a one point five centimetre bilateral-variation. Eleven subjects in this group demonstrated slightly

smaller involved than uninvolved legs, and six subjects slightly larger. A study by Whitney et al (1995) found that by using a simple standardised procedure, girth measurements can be highly repeatable in experienced clinicians. In their study, mid thigh girth differences in the lower extremity were less than one point five centimetres and this was considered normal in people without prior injury or disease.

6.9 Summary

Musculoskeletal mechanisms that influence long term functions of the knee were examined in subjects with A.C.L. reconstructions. A control group also participated in identical testing protocols to establish normal dominant/nondominant relationships.

Quadriceps peak torque was found to be significantly deficient in the reconstructed leg, at 20-36 months post operation. Atrophy was not shown to be the major cause of this deficiency, but selective atrophy of Type IIB fibres have been shown by others (Snyder-Mackler et al, 1993) to be partly responsible for muscle weakness and this may not be revealed by girth or limb weight measurement. Sensory feedback loops initiate quadriceps reflex inhibition (Barrack et al, 1994), which prevent excessive quadriceps contractions that may damage the A.C.L. If the quadriceps are not adequately strengthened as the A.C.L. graft strengthens, then the feedback loops may continue to act protectively, inhibiting quadriceps contraction and preventing a return to maximal potential.

The feedback loops also facilitate hamstrings co-contraction during quadriceps extension, however this was not supported by the limited E.M.G. analysis in the current study, which showed no greater activation in the involved leg than the uninvolved leg. The involved hamstrings during flexion, although still bilaterally deficient, showed far better recovery than the involved quadriceps during extension. Consequently the hamstrings/quadriceps ratio increased in the involved leg compared

voluntarily maximally activate all muscle fibres, in particular, the recruitment of Type IIB. This approach may also alleviate apprehension and lack of motivation towards restoring the leg to former status.

Further investigation is required to look at the long term return of proprioception mechanisms whilst under the intense stresses of sporting activities. Sensory input together with adequate muscle strength and activation, are essential for complete functional restoration. An investigation into home programs for strength and conditioning, post physical therapy, would provide an insight into the 10 -15 per cent deficit of musculoskeletal parameters, that are presumed to return. Further areas that would benefit A.C.L. research are, twisting/turning ligament stresses and isokinetic assessment versus long term functional ability.

REFERENCES

Arnold, B.L & Perrin, D. (1993). The Reliability of Four Different Methods of Calculating Quadriceps Peak Torque and Angle-specific Torques at 30 deg, 60 deg, and 75 deg. Journal of Sport Rehabilitation. 2. 243-250.

Arvidsson, I., Eriksson, E., Haggmark, T. & Johnson, R.J. (1981). Isokinetic Thigh Muscle strength after Ligament Reconstruction in the Knee Joint: Results from a 5-10 year follow-up after Reconstructions of the Anterior Cruciate Ligament in the Knee Joint. International Journal of Sports Medicine. 2. 7-11.

Baratta, R., Solomonow, M., Zhou, B.H. (1988). The role of the Antagonist Musculature in maintaining knee stability. American Journal of Sports Medicine. 16. 113-122

Barber, S.D. Noyes, F.R., Mangine, R.E. McCloskey, J.W., & Hartman, W. (1990). Quantitative Assessment of Functional limitations in normal and anterior Cruciate Ligament - Deficient Knees. Clinical Orthopaedics and Related Research. 255. June 1990.

Barrack, R.L., Lund, P.J. & Skinner, H.B. (1994) Knee Joint Proprioception Revisited. Journal of Sport Rehabilitation 3, 18-42.

Basmajian, J.V. (1974). Muscles Alive: Their functions revealed by Electromyograph. (3rd Ed). Baltimore: Williams & Wilkins

Belanger, A.Y and McComas, J. (1981). Extent of motor unit activation during effort. The American Physiological Society. 51. (5). 1131-1135

Biewener, A.A. (1992). Biomechanics - Structures and Systems: A practical approach. Department of Organismal Biology and Anatomy. University of Chigcago.

Bigland-Ritchie, B., Johansson, R., Lippold, O.C. J. & Woods, J.J. (1983). Contracting Speed and E.M.G. Changes during Fatigue of Sustained Maximal Voluntary Contraction. The American Physiological Society. 50. 313-324

Bigland-Ritchie, B., Furbush, F & Woods, J.J. (1986). Fatigue of intermittent submaximal voluntary contractions: central and peripheral factors. The American Physiological Society. 61. 421-429

Black, S.J., Woodhouse, M.L., Suttmiller, S. & Shall, L (1993). Influence on hip position of Electromyographic & Torque productions in the knee. Journal of Sport Rehabilitation. 2, 26-34.

Blackburn, T.A. (1992). Rehabilitation of Anterior Instability of the knee. Journal of Sport Rehabilitation. 1, 132-145.

Brooks, M.E., Smith, E.M. & Currier, D.P. (1990). Effect of Longitudinal versus Transverse Electrode placement on Torque Production by the Quadriceps Femoris Muscle during Neuromuscular Electrical Stimulation. JOSPT. 11. (11) 530-534.

Carborn, D.N.M. & Johnson, B.M. (1993). The Natural history of the Anterior Cruciate Ligament - Deficient knee: A review. Clinics in Sports Medicine. 12, 4.

Chapman, S.J., Edwards, R. H. T., Greig, C. and Rutherford, O. (1984). Practical application of the twitch interpolation technique for the study of voluntary contraction of the quadriceps muscle in man. Journal of Physiology (London). 353. 3P.

Cybex 6000 Extremity Testing and Rehabilitation System Users Guide. Lumex Inc., Ronkonkoma, NY, U.S.A., 1991.

Daly, J.M., Brewer, B.W., Van Raalte, J.L., Petitpas, A.J. & Sklar, J.H. (1995). Cognitive Appraisal, Emotional Adjustment, and Adherence to Rehabilitation following Knee Surgery. Journal of Sport Rehabilitation. 4. 23-30.

DeCarlo, M.S., Shelbourne, K.D., McCarroll, J.R. & Rettig, A.C. (1992). Traditional versus Accelerated Rehabilitation following ACL Reconstruction: A One-Year Follow Up. JOSPT. 15 (6) 309-316

De-Carlo, M.S., Sell, K.E., Shelbourne, K.D. & Klootwyk, T.E. (1994). Current Concepts on Accelerated ACL Rehabilitation. Journal of Sport Rehabilitation. 3. 304-318.

Delitto, A., McKowen, J.M., McCarthy, J.A., Shively, R.A. & Rose, S.J. (1988). Electrically Elicited Co-contraction of Thigh Musculature After Anterior Cruciate Ligament Surgery. Physical Therapy. 68. 45-50.

Draganich, L.F., et al (1989). Co-activation of the hamstrings and quadriceps during extension of the knee. Journal of Bone and Joint Surgery. 71A. 1075-1087.

Draganich, L.F. & Vahey, J.W. (1990). An In-vitro study of anterior Cruciate Ligament strain induced by quadriceps and hamstrings forces. Journal of Orthopaedic Res. 8, 57-63.

Elmqvist, L., Lorentzon, R., Johansson, C. Fugl-Meyer, A.R. (1988). Does a torn anterior cruciate ligament lead to change in the central nervous drive of the knee extensors? European Journal of Applied Physiology. 58. 203-207.

Elmqvist, L,. Lorentzon, R., Johansson, C., Langstrom, M., Fagerlund, M. and Fugl-Meyer, A.R. (1989). Knee extensor muscle function before and after reconstruction of A.C.L Tear. Scandinavian Journal of Rehabilitation Medicine 21. 131-139.

Edwards, R.H.T., Young, A., Hosking, G.P. & Jones, D.A. (1977). Human skeletal muscle function: description of tests and normal values. Clinical Science and Molecular Medicine. 52, 283-290

Ferguson, J.P., Blackley, M.W., Knight, R.D., Sutlive, T.G., Underwood, F.B., & Greathouse, D.G. (1989). Effects of Varying Electrode site placements on the Torque output of an Electrically stimulated involuntary quadriceps femoris Muscle contraction. JOSPT. July 89. 24-29.

Fitts, R.H. (1994). Cellular Mechanisms of Muscle Fatigue. The American Physiological Society Reviews. 74 (1), 49-94

Fox, E.L., Bowers, R.W. and Foss, M.L. (1988). The Physiological Basis of Physical Education and Athletes. Dubuque, Iowa: Wm Brown Publishers.

Frndak, P.A. & Berasi, C.C. (1991). Rehabilitation Concerns Following Anterior
Cruciate Ligament Reconstruction). Sports Medicine 11 (6) 402-412

Fujie, H., Mabuchi, K., Woo, S.L-Y., Livesay, G.A., Arai, S. & Tsukamoto, Y.
(1993). The Use of Robotics Technology to study human joint kinematics: A new
methodology. Journal of Biomechanical Engineering, 115, 211-217

Gans, C. (1992). Electromyography in A.A. Biewener (Ed).Biomechanics -
Structures and Systems. New York: Oxford University Press.

Garland, S.J., Garner,S.H. & McComas, A.J. (1988). Reduced voluntary
electromyographic activity after fatiguing stimulation of human muscle. Journal of
Physiology. 401. 547-556

Geddes, L.A. (1987). Optimal stimulus duration for extracranial cortical stimulation.
Neurosurgery. 20. 94-99.

Grabiner, M.D., Coh, T.J. & Draganich, L.F. (1994). Neuromechanics of the
patello femoral joint. Medicine & Science in Sports and Exercise. 26. (1) 10-
21

Gregor, R.J. & Abelew, T.A. (1994). Tendon force measurement and movement
control: A review. Medicine Science in Sports & Exercise. 12 (11) 1359-1372.

Grigg, P. (1994). Peripheral Neural Mechanisms in Proprioception. Journal of
Sports Rehabilitation. 3. 2-17.

Harter, R.A., Ostelnig, L.R. & Singer, K.M. (1992). Knee Joint Proprioception Following Cruciate Ligament Reconstruction. Journal of Sport Rehabilitation. 1. 103-110.

Hawkings, D. (1993). In current issues in Biomechanics. Ligament Biomechanics. 5. 123-149

Holcomb, K.R., Skaggs, C.A., Worrell, T.W., DeCarlo, M. & Shelbourne, K.D. (1993). Assessment of knee laxity following anterior cruciate ligament reconstruction. Journal of Sport Rehabilitation. 2. 97-103.

Irrgan, J.J. (1993). Modern trends in anterior cruciate ligament rehabilitation: Non operative and post operative management. Clinics in Sports Medicine. 12 (4). 797-813

Irrgan, J.J., Whitney, S.L. & Cox. E.D. (1994). Balance and Proprioceptive Training for Rehabilitation of the Lower Extremity. Journal of Sport Rehabilitation. 3. 68-83.

Issac, S. and Michael, W.B. (1981), Handbook in Research and Evaluation. (2nd Ed.). San Diego, California: EdITS

Johansson, C., Lorentzon, R., Sjostrom, M., Fagerlund, M & Fugl-Meyers, A.R. (1987). Sprinters and marathon runners. Does isokinetic knee extensor performance reflect muscle size and structure? Acta Physiol Scand. 130. 663-669.

Jones, D.A. & Bigland-Ritchie, B. (1986). Electrical and contractile changes in muscle fatigue. Biochemistry of Exercise. International series of Sports Science. 16. 377-392.

Kain, C.C., McCarthy, J.A., Arms, S., Pope, M.H., Steadman, J.R., Manske, P.R. & Shively, R.A. (1988). An in vivo analysis of the effect of transcutaneous electrical stimulation of the quadriceps and hamstrings on anterior cruciate ligament deformation. The American Journal of Sports Medicine. 16. (2). 147- 152.

Kannus, P., Cook, L & Alosa, D. (1992). Absolute and Relative Endurance Parameters in Isokinetic Tests of Muscular Performance. Journal of Sport Rehabilitation. 1. 2-12

Kannus, P. (1994). Isokinetic Evaluation of muscular performance: Implications for muscle testing and rehabilitation. International Journal of Sports Medicine. 15, 511- 518.

Komi, P.V. & Tesch, P. (1979). E.M.G. Frequency spectrum, muscle Structure and Fatigue during Dynamic Contractions in Man. European Journal of Applied Physiology. 42. 41-50.

Kostka, C.E., Costa and Cafarelli, E. (1982). Effect of pH on sensation and vastus lateralis electromyogram during cycling exercise. The American Physiological Society. 1181-1185.

Lars-Gunnar, E., Lorentzon, R., Johansson, C., Langstrom, M., Fagerlund, M. & Fugl- Meyer, A.R. (1989). Knee extensor muscle function before and after reconstruction of anterior cruciate ligament tear. Scand J. Rehab Med. 21. 131- 139.

Lephart, S.M., Kocher, M.S., Fu, F.H., Borsa, P.A. & Harner, C.D. (1992). Proprioception Following Anterior Cruciate Ligament Construction. Journal of Sport Rehabilitation. 1. 188-196.

Lieber, R.L. & Kelly, M.J. (1991). Factors Influencing Quadriceps Femoris Muscle Torque Using Transcutaneous Neuromuscular Electrical Stimulation. Physical Therapy. 71. 10 October.

Loitz, B.J. & Frank, C.B. in Biology & Mechanics of ligament and ligament healing. McCarthy, M.R., Buxton, B.P. & Yates, C.K. (1992). Effects of Continuous passive motion on anterior laxity following A.C.L reconstruction with autogenous patellar tendon graphs. Journal of Sport rehabilitation. 1. 121-131.

McCarthy, M.R., Buxton, B.P., Hiller, D.B., Doyle, J.R. & Yamada, D., (1994). Current protocols and procedures for anterior cruciate ligament reconstruction and rehabilitation. Journal of Sport Rehabilitation. 3. 204-217.

McCormas, A.J., Kereshi, S., & Quinlan, J. (1983). A method for detecting functional weakness. Journal of Neurology, Neurosurgery and Psychiatry. 46. 280-282.

More, R.C., Karras, B.T., Neiman, R., Fritschy, D., Woo, S. L-Y. & Daniel, D.M. (1993). Hamstrings - an anterior cruciate ligament protagonist: An in vitro study. The American Journal of Sports Medicine. 21. 231-237.

Moritani, T. & deVries, H.A. (1979). Neural factor versus Hypertrophy in the time course of muscle strength gain. American Journal of Physical Medicine. 58. (3), 115- 130.

Newham, D.J., Hurley, M.V. and Jones, D.W. (1989). Ligamentous knee injuries and muscle inhibition. <u>Journal of Orthopaedic Rheumatology 2.</u> 163-173

Newham, D.J., McCarthy, T. & Turner, J. (1991). Voluntary activation of human quadriceps during and after isokinetic exercise. <u>Journal of Applied Physiology.</u> <u>71.</u> (6) 2122-2126.

Nisonson, B. (1991). Anterior cruciate ligament injuries conservative is Surgical treatment. <u>The physician and Sportsmedicine. 19. (5).</u> 82-85

Noyes, F.R., Torvik, P.J. and Hydee, W.V. (1984). Biomechanical analysis of human ligament grafts used in knee ligament repairs and reconstructions. <u>The Journal of Bone & Joint surgery 66A.</u> 344-352

Nyland, J.A., Currier, D.P., Ray, J.M. & Duby, M.J. (1993). A case study of an accelerate rehabilitation program on knee function following anterior cruciate ligament reconstruction. <u>Journal of Sport rehabilitation. 2.</u> 53-62

Palmitier, R.A., An, K-N., Scott, G. & Chao, E.Y.S. (1991). Kinetic Chain Exercise in Knee Rehabilitation. <u>Sports Medicine 11. (6).</u>402-412

Perrin, D.H. (1993). <u>Isokinetic Exercise and Assessment.</u> Champaign, Illinois: Human Kinetics Publishers.

Perrin, D.H. (1994). Open chain isokinetic assessment and exercise of the knee. <u>Journal of Sport Rehabilitation. 3.</u> 245-254.

Renstrom, P., Arms, S.W., Stanwyck, T.S., Johnson, R.J. & Pope, M.H. (1986). Strain within the anterior cruciate ligament during hamstring and quadriceps activity. The American Journal of Sports Medicine. 1. 83-87.

Rutherford, O.M., Jones, D.A. & Newham, D.J. (1986). Clinical and experimental application of the percutaneous twitch superimposition technique for the study of human muscle activation. Journal of Neurology, Neurosurgery and Psychiatry. 49. 1288-1291.

Safran, M.R., Caldwell, G.L. & Fu, F.H. (1994). Proprioception Considerations in Surgery. Journal of Sport Rehabilitation. 3. 105-115.

Sale, D.G. (1988). Neural adaptation to resistance training. Medicine and Science in Sports and Exercise. 20. 135-145.

Sapega, A.A., Moyer, R.A., Schneck, C. & Komalahiranya, N. (1990). Testing for Isometry during Reconstruction of the Anterior Cruciate Ligament. The Journal of Bone and Joint Surgery. 72.A. (2) 259-267.

Shelbourne, K.D. & Nitz, P. (1990). Accelerated rehabilitation after anterior cruciate ligament reconstruction. American Journal Sports Medicine. 18. (3). 292-299

Shelbourne, K.D., Wilckens, J.H., Mollabashy, A. & DeCarlo, M. (1991). Arthrofibrosis in acute anterior cruciate ligament reconstruction. The American Journal of Sports Medicine. 19. (4) 332-336.

Shelbourne, K.D., Klootwyk, T.E. & DeCarlo, M.S. (1992). Update on Accelerated Rehabilitation after Anterior Cruciate Ligament Reconstruction. JOSPT. 15 (6) 303-307.

Sisk,.T.D., Stralka, S.W., Deering, M.B., & Griffin, J.W. (1987). Effect of electrical stimulation on quadriceps strength after reconstructive surgery of the anterior cruciate ligament. The American Journal of Sports Medicine. 15. 3. 215-220.

Smith, D.D. (1993). Role of Body and Joint Position on Isokinetic Exercise and Testing. Journal of Sport Rehabilitation. 2. 141-149.

Smith, B.A., Livesay, G.A. & Woo, S.L-Y. (1993). Biology and biomechanics of the anterior cruciate ligament. Clinics in Sports Medicine. 12. (4).

Snyder-Mackler, L., Binder-Macleod, S.A. & Williams, P.R. (1993). Fatigability of human quadriceps femoris muscle following anterior cruciate ligament reconstruction. Medicine and Science in Sports & Exercise. 25. (7) 783-789.

Solomonow, M., Baratta, R., Zhou, B.H. Shosi, H. Bosew, Beck, C. D'Ambrosia,R. (1987). The synergistic action of the anterior cruciate ligament and thigh muscles in maintaining joint stability. American Journal of Sport Medicine. 15. 207-213.

Tovin, B.J., Tovin, T.S. & Tovin, M. (1992). Surgical and Biomechanical Considerations in Rehabilitation of Patients with Intra-Articular ACL Reconstructions. JOSPT. 15. (6) 317-322.

Van Mechelen, W. Hlobil, H., Rep, M.H., Strobos, W. & Kempter, H.C.G. (1994). Running injuries and hamstring and quadriceps weakness and balance: A case-control study in male runners. Sports Medicine Training and Rehabilitation. 5. 83-93.

Vandervoort, A.A, Sale, D.G. & Moroz, J. (1984). Comparison of motor unit activation during unilateral and bilateral leg extension. The American Physiological Society. 56. 45-51

Whitney, S.L., Mattocks, L., Irrgang, J.J., Gentile, P.A., Pezzullo, D. & Kamkar, A. (1995). Journal of Sport Rehabilitation. 4. 108-115

Worrell, T.W., Perrin, D.H. and Denegar, C.R. (1989). The influence of hip position on quadriceps and hamstring peak torque and reciprocal muscle group ratio values. Journal of Orthopaedic and Sports Physical Therapy. 11., 104-107.

Yates, C.K., McCarthy, M.R., Hirsch, H.S. & Pascale, M.S. (1992). Effects of continuous passive motion following A.C.L reconstruction with autogenous patellar tendon grafts. Journal of Sport Rehabilitation. 1. 121-131.

Ysuda, K. & Sasaki, T. (1987). Muscle exercise after anterior Cruciate Ligament reconstruction. Clinical Orthopaedics and Related Research. 220.

APPENDIX A

INFORMED CONSENT TO SUBJECTS

INFORMED CONSENT TO SUBJECTS

Research study: *Peak torque, fatigue and muscle activation 24 months post anterior cruciate ligament (A.C.L.) reconstruction with accelerated rehabilitation.*

This study will compare muscle functions in A.C.L reconstructed legs with the uninvolved leg and control subjects. Controls will be required to attend Edith Cowan University, Joondalup Campus, Research laboratory at their convenience and other subjects approximately 24 months post A.C.L reconstruction, in order to participate in isokinetic dynamometry tests.

The procedure involves sitting in a force chair whilst performing maximal voluntary contractions with each leg in extension/flexion, at fixed angular velocities. The forces are recorded on a computer together with surface electromyographic readings of muscle activation. The subject will have stimulating pads put on the muscle surface of the quadriceps and a twitch impulse will be applied. Initially this will be negligible and increased according to the subject's comfort and discretion Two isometric maximal voluntary contractions will be required with the agreed stimulation superimposed for 4 seconds. The final protocol (to examine muscle fatigue in each leg) involves repeated maximal voluntary contractions for approximately 120 secs or volitional withdrawal.

The only discomfort can come from muscle soreness (which may last for 24 hours) due to the contractions and a slight "cramp like" feeling due to stimulation which will last for 4 seconds on two occasions.

All subjects will be individually tested for a duration of up to 2 hours and on one occasion only.

The research data may well indicate muscular deficiencies in the reconstructed knee which could be of use in further rehabilitation. Further knowledge on long term muscular functions after accelerated rehabilitation and A.C.L reconstructions, in particular, muscle activation and sensory mechanisms, will benefit research in surgery and rehabilitation.

The subjects in this study are voluntary and may withdraw at any point during the procedures without any prejudice to further rehabilitation or services provided.

Any questions concerning this project entitled :_*Peak torque, fatigue and muscle activation, 24 months post A.C.L reconstruction with accelerated rehabilitation.* ; can be directed to Darryl Turner (Principal investigator), The Department of Human Movement, Edith Cowan University, Joondalup on 405 5868 or 307 6973.

I, (the participant) have read the information above and any questions I have asked have been asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time.

I agree that this research data gathered for this study may be published provided that I am not identifiable.

.... Date........................

Participant or authorised representative

.... Date........................

Investigator

APPENDIX B

SUBJECT CHARACTERISTICS AND HISTORY

SUBJECT CHARACTERISTICS AND HISTORY

NAME:

ADDRESS:

TELEPHONE NO:

DATE OF BIRTH:

AGE:

GENDER:

SPORT/ACTIVITY:

LEG DOMINANCE:

CONTRA- LEG ACTIVITY:

ATROPHY   RIGHT LEG:

                LEFT LEG:

OTHER PERMANENT LEG INJURIES:

OPERATION DATE:

SURGEON:

SURGICAL TECHNIQUE:

SURGICAL OUTCOME:

REHABILITATION PROTOCOL:

PERCEIVED TEST MOTIVATION:

APPENDIX C

CONTROL AND EXPERIMENTAL PAIRED T TESTS

CONTROL AND EXPERIMENTAL PAIRED T TESTS

Table C.1.
Mean quadriceps peak torque bilateral-variance during leg extension at 90, 180, 300degrees/second measured in Newton-meters, in the experimental group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	$t(16)$
Quads P.T. @ 90 deg/sec	171.98	(51.39)	147.52	(49.05)	-313.54*
Quads P.T. @ 180 deg/sec.	135.68	(38.46)	120.60	(37.41)	-311.11*
Quads P.T. @ 300 deg/sec.	113.19	(37.17)	101.67	(34.99)	-334.55*

* Denotes significant differences at the 0.01 level

Table C.2.
Mean quadriceps peak torque bilateral variance during leg extension at 90, 180, 300 degrees/second measured in Newton-metres, in the control group.

VARIABLE	UNINVOLVED	INVOLVED

Table C.3.

Mean hamstring peak torque bilateral variance during leg flexion at 90,180,300 degrees/second measured in Newton-meters, in the experimental group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(16)
Hams P.T. @ 90 deg/sec	112.77	(40.24)	106.08	(36.20)	-168.89
Hams P.T. @180 deg/sec.	97.15	(33.13)	91.08	(28.68)	-244.85*
P.T. Hamstrings at 300 deg/sec.	85.91	(29.33)	81.ι.,	(26.18)	-109.09

* Denotes significant differences at the 0.01 level

Table C.4.

Mean hamstring peak torque bilateral variance during leg flexion at 90, 180, 300 degrees/second measured in Newton-meters, in the control group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(18)
Hams P.T. @ 90 deg/sec	129.55	33.13	132.06	29.49	70.30
Hams P.T. @180 deg/sec.	121.23	32.64	122.29	24.24	24.24
Hams P.T. @ 300 deg/sec.	111.64	33.94	105.20	23.11	-126.06

* Denotes significant differences at the 0.01 level

Table C.5.

Mean hamstrings/ quadriceps ratio bilateral variance during leg extension / flexion at 90, 180, 300 degrees/second recorded as a percentage, in the experimental group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(16)
Ham / Quad Ratio @ 90 deg/ sec.	67.56	(28.49)	74.14	(23.75)	2.24
Ham / Quad Ratio @ 180 deg/ sec.	71.04	(10.14)	76.03	(11.53)	1.70
Ham / Quad Ratio @ 300 deg/ sec.	76.23	(11.42)	80.86	(11.62)	1.33

⌐enotes significant differences at the 0.01 level

Table C.6.

Mean hamstrings/ quadriceps ratio bilateral variance during leg extension / flexion at 90, 180, 300 degrees/second recorded as a percentage, in the control group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(18)
Ham / Quad Ratio @ 90 deg/ sec.	65.11	(4.90)	65.27	(6.78)	.12
Ham / Quad Ratio @ 180 deg/	74.63	(7.16)	76.01	(8.70)	.74
Ham / Quad Ratio @ 300 deg/	78.60	(8.29)	78.64	(8.86)	.02

* Denotes significant differences at the 0.01 level

Table C.7.

Mean quadriceps and hamstrings endurance ratio bilateral variance during leg extension / flexion at 90 degrees/second for 2 minutes, recorded as a percentage in the experimental group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(16)
Quads. End Ratio. at 90 deg/sec.	42.36	(9.99)	43.38	(13.27)	.41
Hams. End Ratio. at 90 deg/sec.	54.54	(10.32)	52.86	(14.05)	-.56

* Denotes significant differences at the 0.01 level

Table C.8.

Mean quadriceps and hamstrings endurance ratio bilateral-variance during leg extension / flexion at 90 degrees/second for 2 minutes, measured as a percentage in the control group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(18)
Quads. End Ratio. at 90 deg/sec.	47.84	(5.44)	49.24	(9.14)	.87
Hams. End Ratio. at 90 deg/sec.	54.76	(9.74)	53.53	(11.97)	-.58

* Denotes significant differences at the 0.01 level

Table C.9.

Mean quadriceps inhibition bilateral-variance during a 60 degree isometric contraction recorded as a percentage , in the experimental group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(16)
% Inhib of ...	19.65	(17.94)	17.02	(14.16)	-.65

* Denotes significant differences at the 0.01 level

Table C.10.

Mean quadriceps inhibition bilateral variance during a 60 degree isometric contraction recorded as a percentage, in the control group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(18)
% Inhib of M.V.C..	3.07	(6.08)	8.47	(15.19)	1.40

* Denotes significant differences at the 0.01 level

Table C.11.

Mean hamstring co-activation activity bilateral variance during a 90 degree/second leg extension, recorded as E.M.G. frequency per contraction and E.M.G. peak amplitude in raw voltage output, in the experimental group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(16)
E.M.G. freq/ contraction	28.12	(4.22)	29.94	(4.879)	1.79
E.M.G. amp/ voltage	.45	(.21)	.57	(.42)	1.14

* Denotes significant differences at the 0.01 level

Table C.12.

Mean hamstring co-activation activity bilateral variance during a 90 degrees/second leg extension recorded as E.M.G. frequency per contraction and E.M.G. peak amplitude in raw voltage output, in the control group.

VARIABLE	UNINVOLVED		INVOLVED		
	MEAN	(S.D.)	MEAN	(S.D.)	t(18)
E.M.G. freq/contraction	31.84	(2.63)	32.00	(3.77)	.21
E.M.G. amp / voltage	.49	(.17)	.46	(.19)	-.77

* Denotes significant differences at the 0.01 level

APPENDIX D

SHELBOURNE & NITZ (1990) PROTOCOL

SHELBOURNE & NITZ (1990) PROTOCOL

TABLE 2

Accelerated rehabilitation program, 1987 through 1988

Time after reconstruction	Rehabilitation program
Day 1	Continuous passive motion (CPM), rigid knee immobiliser in full extension for walking, weightbearing as tolerated without crutches
2-3 days	CPM passive range of motion (ROM) 0 deg. to 90 deg. (emphasis on full extension), weightbearing as tolerated without crutches
2-4 days	Discharge from hospital: CPM at home. *Note:* Prerequisite to discharge is 1) satisfactory pain management, 2) full extension symmetrical to non-operated knee, 3) able to do SLR for leg control and 4) full weightbearing with or without crutches
7-10 days	ROM terminal extension, prone hangs (2 pounds) if patient has not achieved full extension, towel extensions, wall slides, heel slides, active-assisted flexion, strengthening knee bends, step-ups, calf raises; weightbearing - partial to full weightbearing; gradual elimination of required use of knee immobiliser
2-3 weeks	ROM (0 deg to 110 deg), unilateral knee bends, step-ups, calf raises, StairMaster 4000, weight room activities; leg press, quarter squats and calf raises in the squat rack, stationary bicycling, swimming, custom-made functional knee brace with no present limits (to be used at all times out of the home for the next 4 weeks)
5-6 weeks	ROM (0 deg to 130 deg), isokinetic evaluation with 20 deg block at 180 and 240 deg/sec. When strength is 70% or greater than the opposite un-operated knee, the patient can begin lateral shuffles, cariocas, light jogging, jumping rope, agility drills, weight room activities, stationary bicycling and swimming. *Note:* Functional brace discontinued (except for sports activities) when muscle tone and strength are sufficient
10 weeks	Full ROM; isokinetic evaluation at 60, 180, and 240 deg/sec, KT-1000, increased agility workouts, sport-specific activities
16 weeks	Isokinetic evaluation, KT-1000, increased agility workouts
4-6 months	Return to full sports participation (*if* patient has met criteria or full ROM, no effusion, good knee stability, and has completed the running program)

Shelbourne & Nitz (1990),

APPENDIX E

CALIBRATIONS

CALIBRATIONS

Calibrations of the Cybex isokinetic dynamometer torque output in Newton-meters with raw data input to the Analogue Digital Converter (A.D.C.) in voltage.

Lever arm at 0 degrees (Horizontal)

Lever length = .338 meters

Acceleration due to gravity = 9.81

Normal Weight	Calibrated Weight	A.D.C. raw Voltage	Cybex Software Data
30 Kilogram	30.158	1.249	-
40 Kilogram	40.843	1.674	136 Nm
50 Kilogram	51.111	2.081	-
	122.112 Kilogram	= 5.004 Volts	

Therefore m value = 24.40 kilo per volt

24.40 x 9.81 = 239.39N per volt

239.39 N x .338 = 80.91 Nm per volt

A.D.C. voltage recorded multiplied by 80.91 for Newton-meter conversion.

APPENDIX F

E.M.G. GRAFT SAMPLES

E.M.G. Muscle Activation and Co-activation during

90 degrees per second isokinetic leg extension

Page	Code	Sample	IN/UN	Leg	Quad. Ext	Ham.Flex	H.Q. ratio
125	03JT	Con	UN	Right	2.179v	1.569v	72%
126	03JT	Con	UN	Right	(quads and angle trace removed)		
127	03JT	Con	IN	Left	2.099v	1.462v	69%
128	03JT	Con	IN	Left	(quads and angle trace removed)		
129	12AT	ACL	IN	Left	1.542v	1.381v	89%
130	12AT	ACL	IN	Left	(quads and angle trace removed)		
131	12AT	ACL	UN	Right	1.967v	1.249v	63%
132	12AT	ACL	UN	Right	(quads and angle trace removed)		
133	07PS	ACL	IN	Left	1.674v	1.168v	69%
134	07PS	ACL	IN	Left	(quads and angle trace removed)		
135	07PS	ACL	UN	Right	2.766v	1.674v	60%
136	07PS	ACL	UN	Right	(quads and angle trace removed)		

Twitch Superimposition during a 60 degree

isometric concentric quadriceps contraction

Page	Code	Sample	IN/UN	Leg
137	10PM	ACL	IN	Left
138	10PM	ACL	UN	Right
139	1PM	ACL	UN	Left
140	1PD	ACL	IN	Right

Waveform — Time (s) — Data set: 0 — — Torque — E.M.G.1 — E.M.G.2 — Angle

26/06/95

5,000.
3,838.
2,817.
1,894.
0,883.
-0,001.
-1,012.
-2,023.
-3,007.
-4,018.
-5,000.

18:59:40,152   18:59:40,350   18:59:40,548   18:59:40,746   18:59:40,944

26/06/95   Waveform -- Time (s) -- Data set: 0 -- -- Torque -- E.M.G.1 -- E.M.G.2
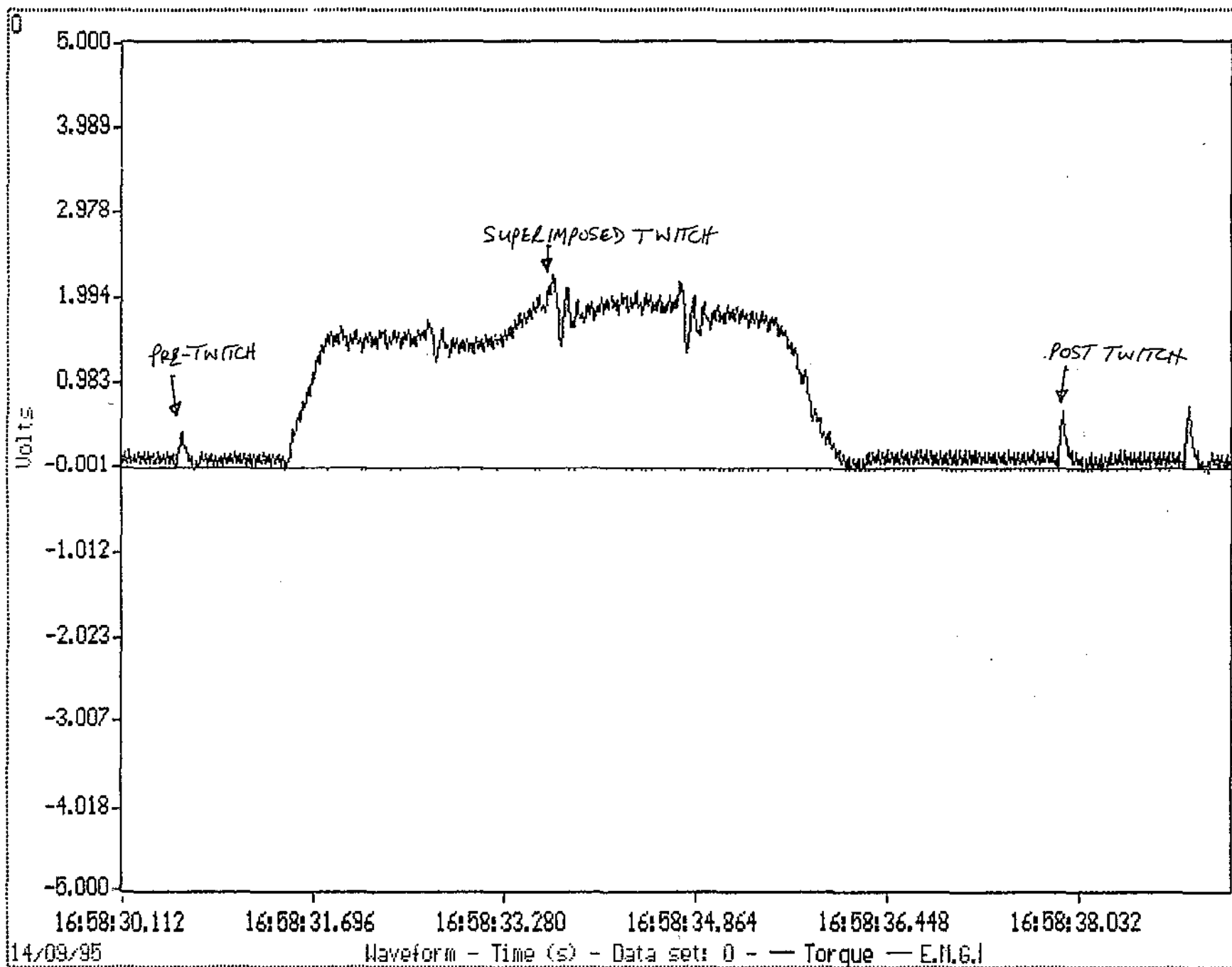
Waveform - Time (s) - Data set: 0 - — Torque — E.M.G.

Waveform — Time (s) — Data set: 0 — — Torque — E.M.G.|
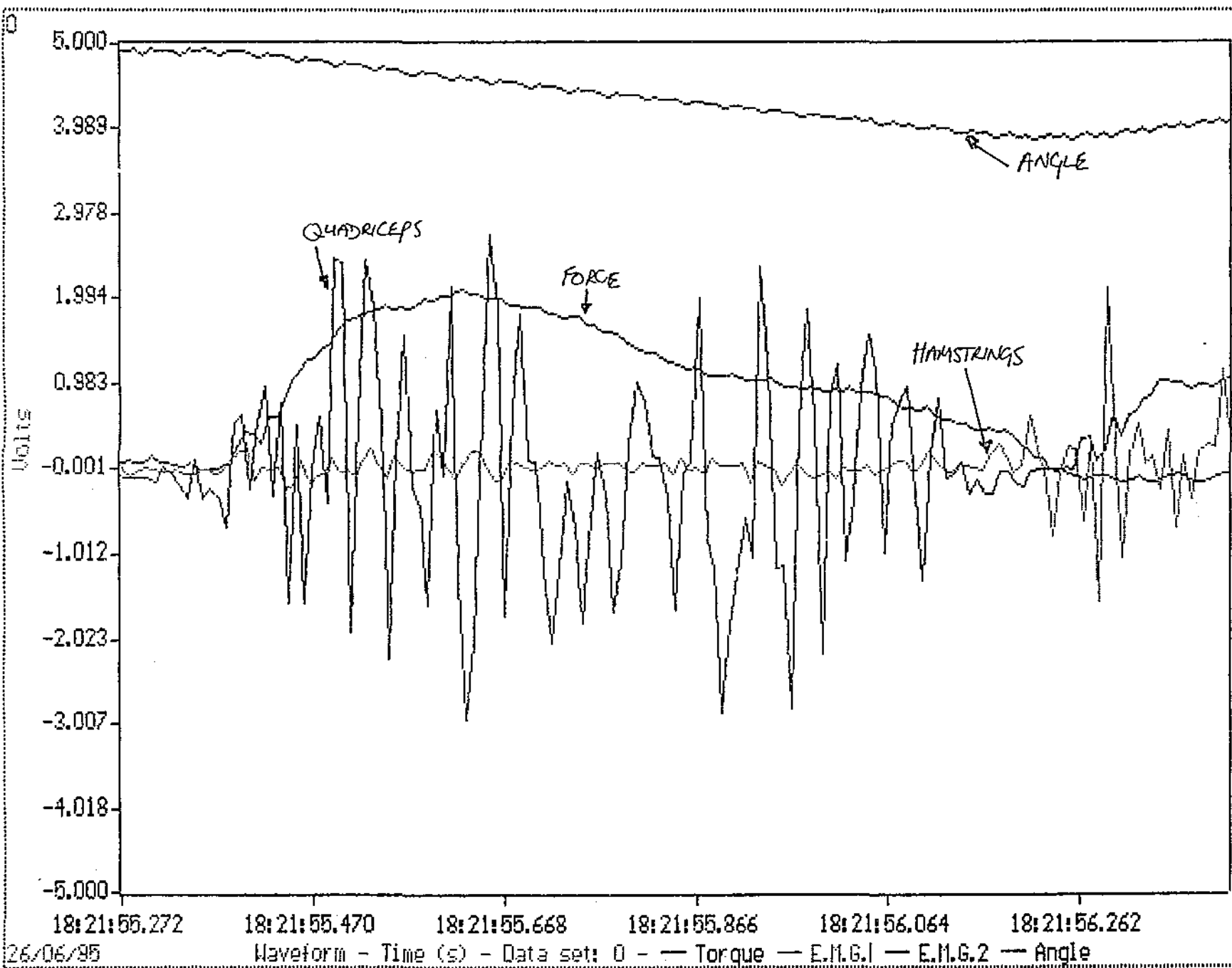
18/09/95
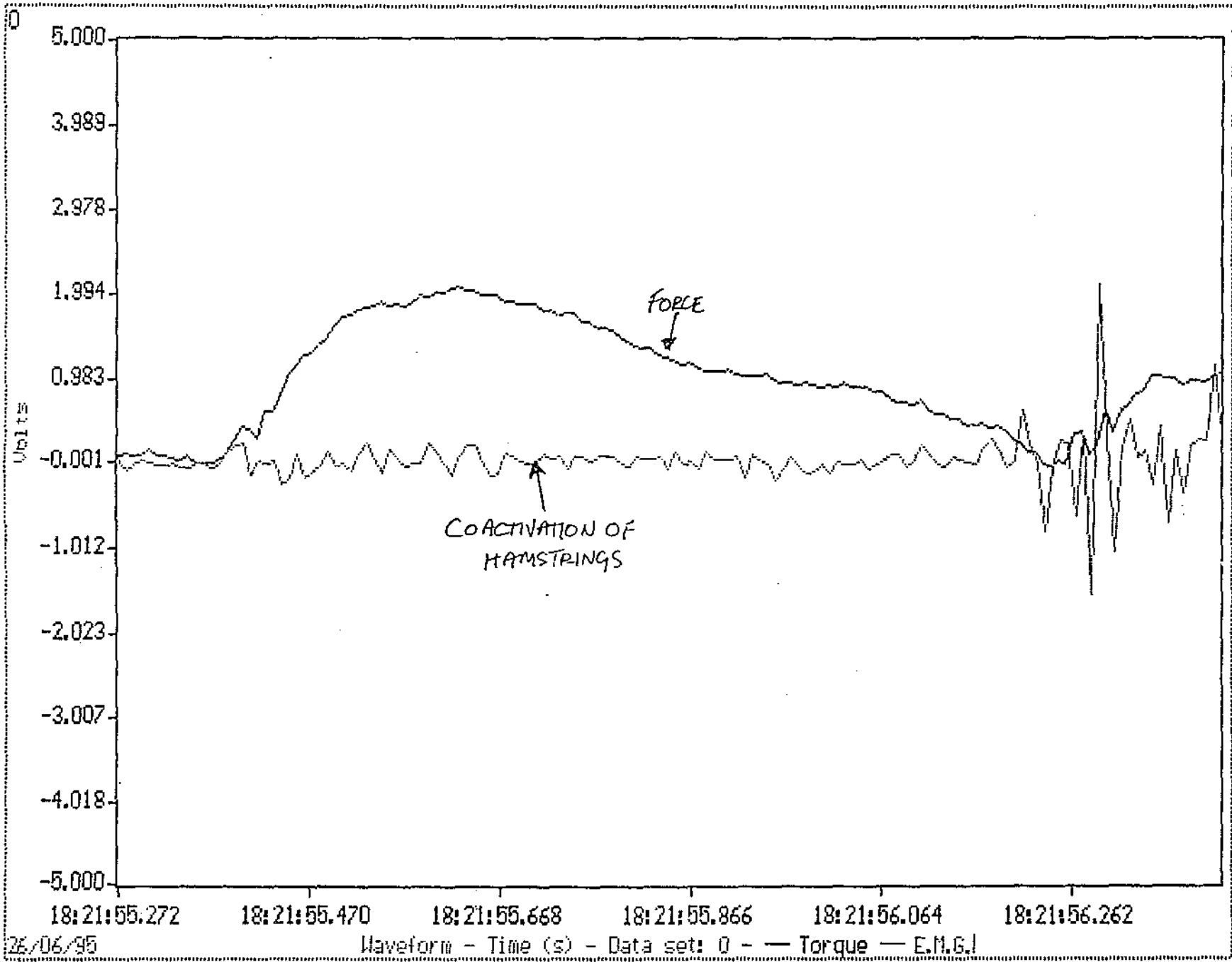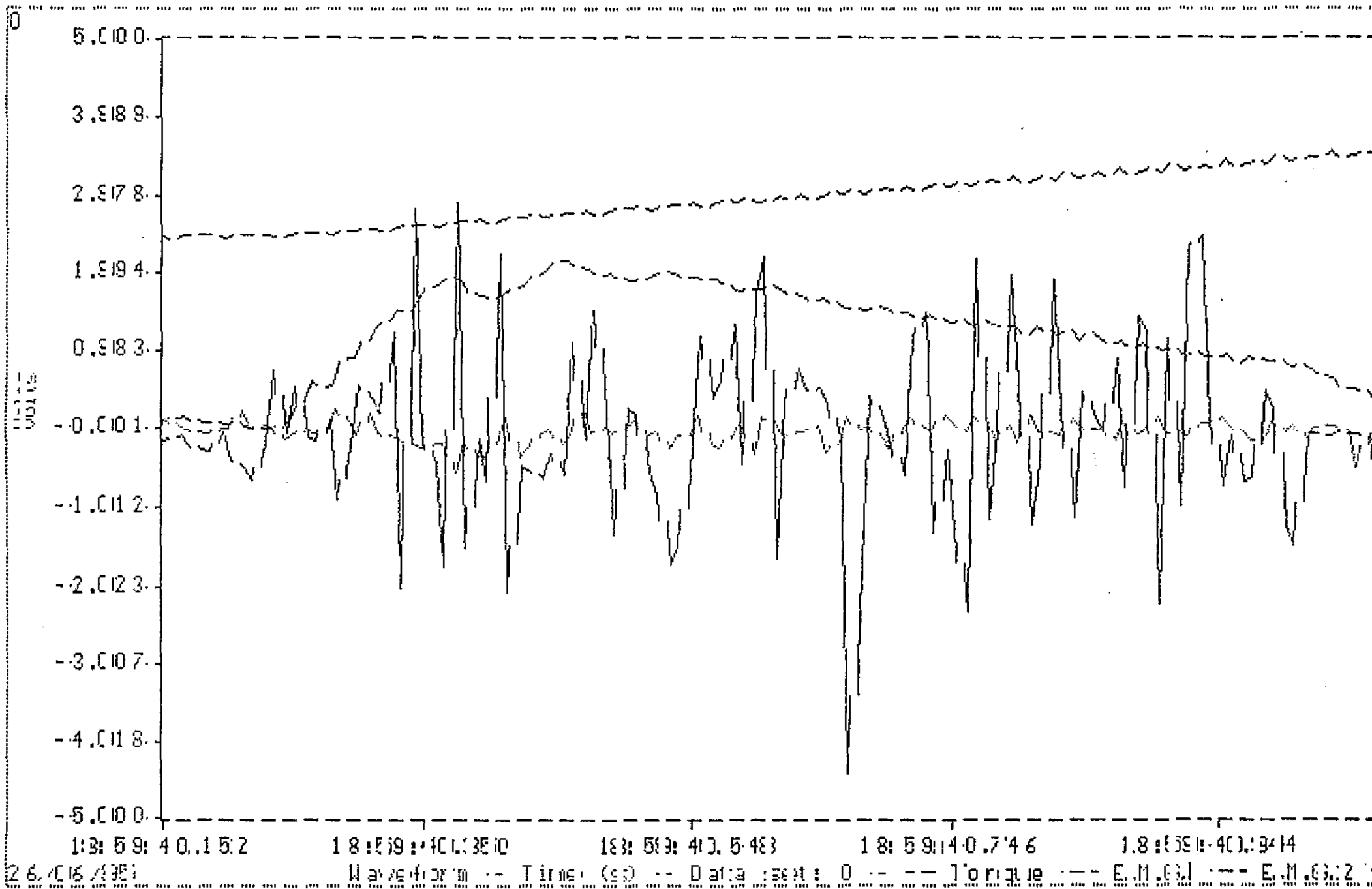
Waveform – Time (s) – Data set: 0 – — Torque — E.M.G.1 — E.M.G.2 — Angle
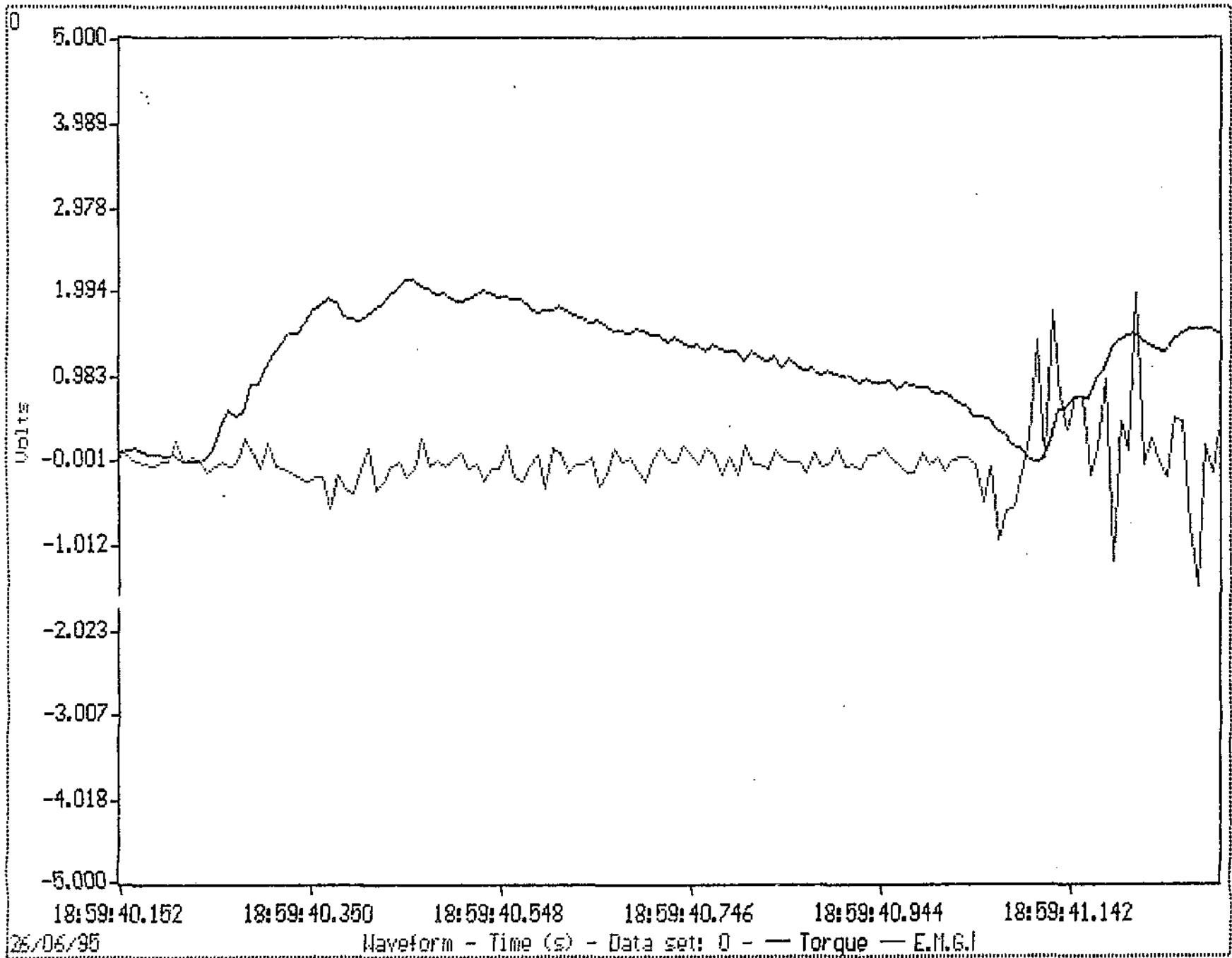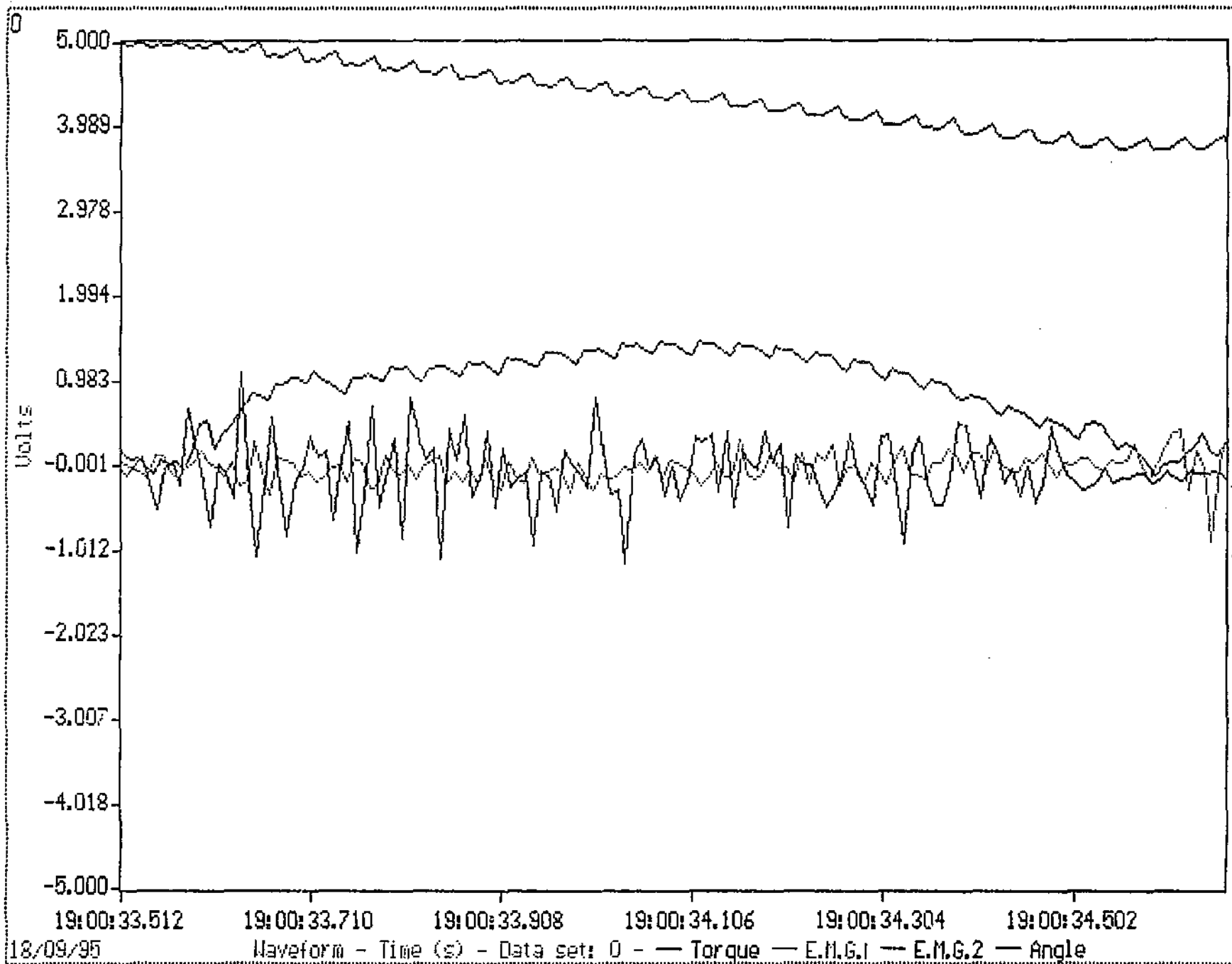
Waveform – Time (s) – Data set: 0 – — Torque — E.M.G.1 — E.M.G.2 — Angle

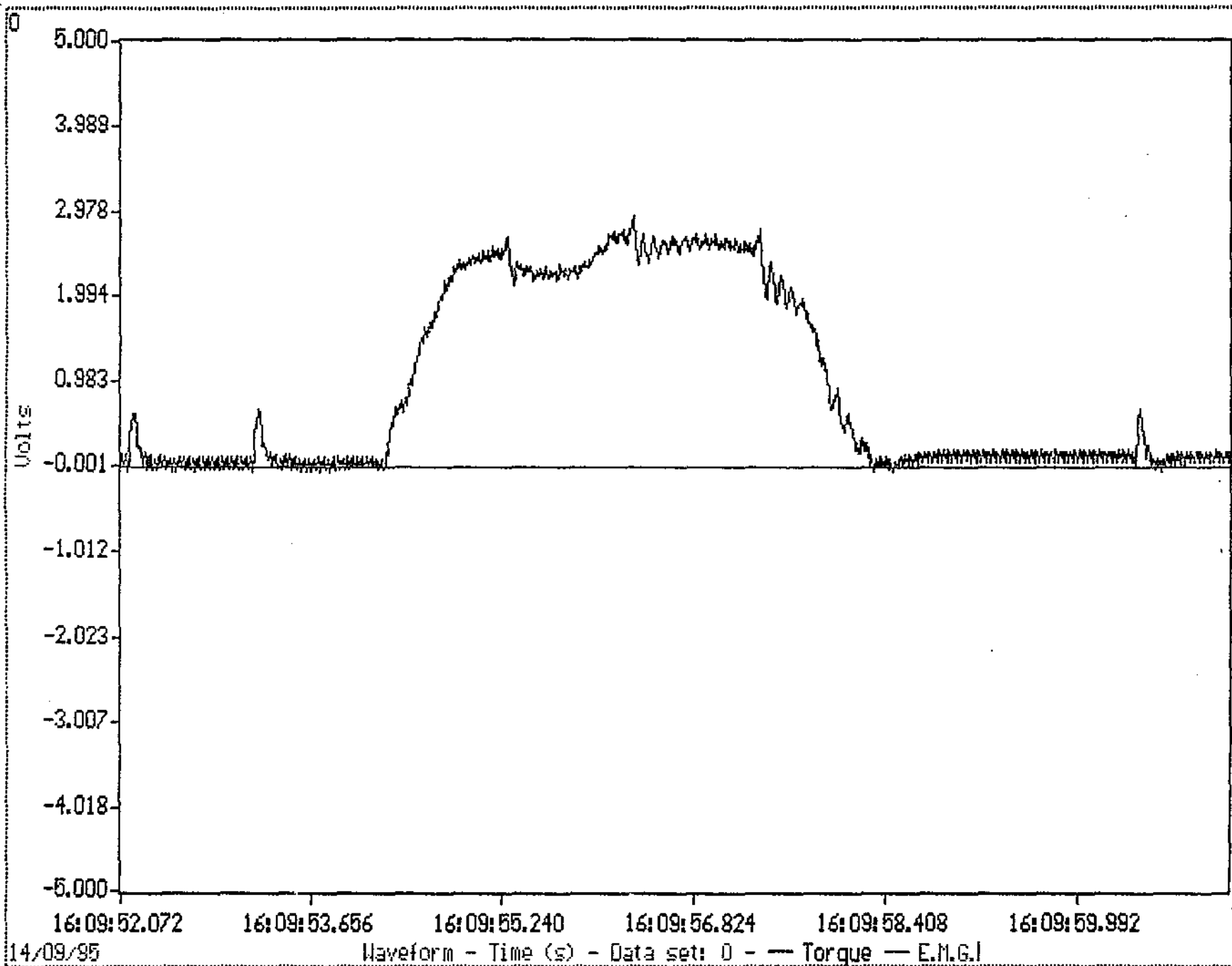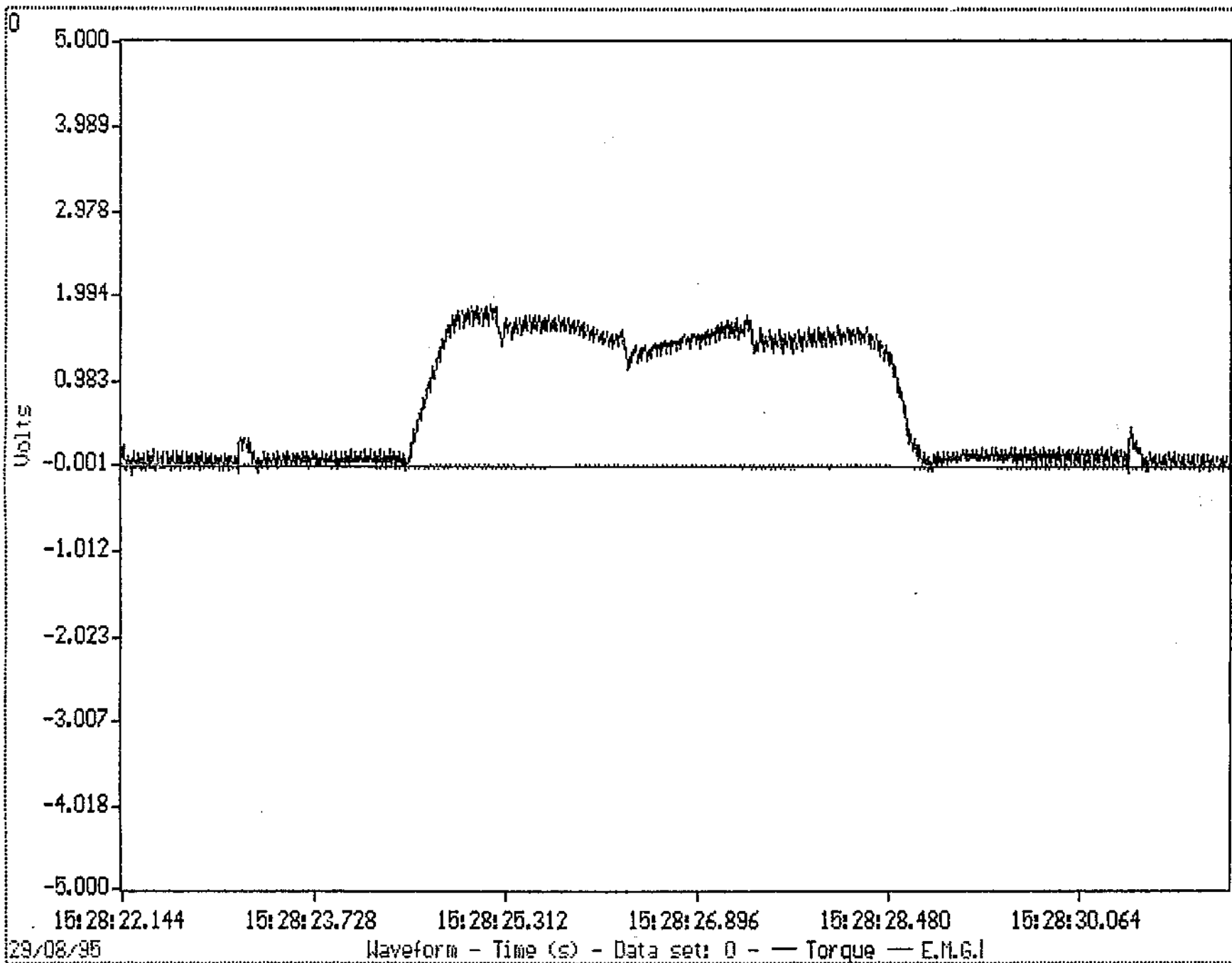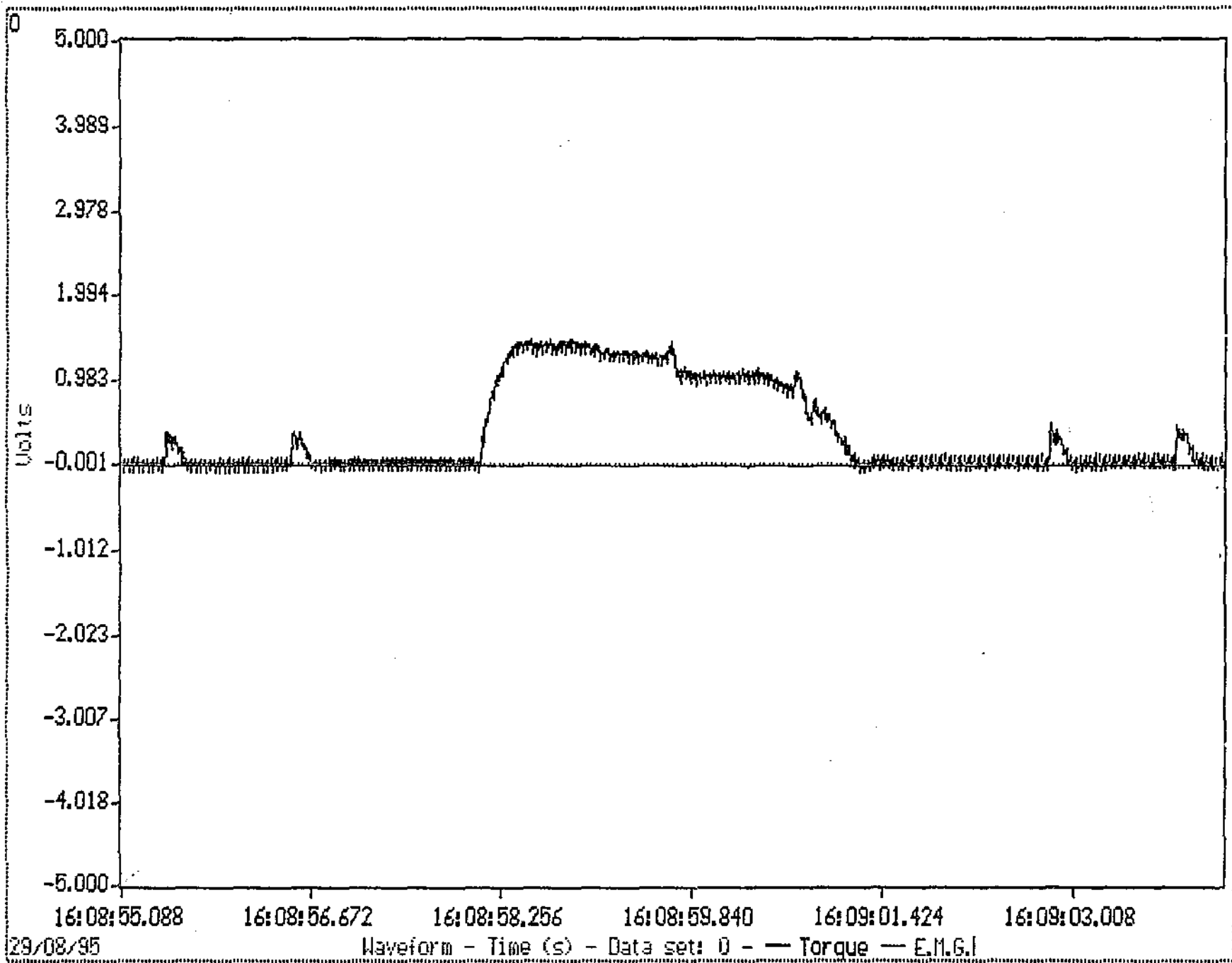13/09/95

Waveform - Time (s) - Data set: 0 - — Torque — E.M.G.I

13/09/95

Waveform - Time (s) - Data set: 0 - — Torque — E.M.G.I

13/09/95

Waveform – Time (s) – Data set: 0 – — Torque — E.M.G.l

Waveform - Time (s) - Data set: 0 - — Torque — E.M.G.1

29/08/95

Waveform - Time (s) - Data set: 0 - — Torque — E.M.G.

29/08/95