Spring 1992

The Effects of Orthopaedic Surgery and Dorsal Rhizotomy on Selected Gait Characteristics of Cerebral Palsy Children

Danielle M. Lanoue
Old Dominion University

THE EFFECTS OF ORTHOPAEDIC SURGERY AND DORSAL RHIZOTOMY ON SELECTED GAIT CHARACTERISTICS OF CEREBRAL PALSY CHILDREN

by

Danielle M. Lanoue
A.S. May 1984, Maria College
B.S. May 1987, Russell Sage College

A Thesis submitted to the Faculty of
Old Dominion University in Partial
Fulfillment of the Requirement for the Degree of

MASTER OF SCIENCE

PHYSICAL THERAPY

OLD DOMINION UNIVERSITY
May, 1992

Approved by:

Dr. John L. Echternach

Professor Evangeline Yoder

Professor Martha Walker

ABSTRACT

THE EFFECTS OF ORTHOPAEDIC SURGERY AND DORSAL RHIZOTOMY ON SELECTED GAIT CHARACTERISTICS OF CEREBRAL PALSY CHILDREN

Danielle Lanoue

Old Dominion University, 1992

Director: Dr. John L. Echternach

Surgical management of cerebral palsy children typically involves multiple orthopaedic surgeries in order to achieve and maintain the maximum functional level of ambulation. Orthopaedic intervention to address lower extremity spasticity often includes: muscle lengthenings, muscle releases and tendon transfers. The most recent advance in management of lower extremity spasticity has been through a neurosurgical approach; selective dorsal rhizotomy. The long term effects of dorsal rhizotomy are still being investigated. Through the use of instrumented gait analysis, the specific objective results of both of these types of surgeries can be investigated. The purpose of this retrospective study was to examine the effects of multiple simultaneous orthopaedic surgeries and selective dorsal rhizotomy on gait parameters of two groups of children with spastic diplegia cerebral palsy.

Nine subjects were included in this study. Four subjects had undergone multiple simultaneous orthopaedic surgeries, and five subjects had undergone selective dorsal rhizotomy. Both groups underwent gait analysis prior to surgery and approximately one year postoperatively using the Vicon five camera motion analysis system.

Data was collected on a total of nineteen variables. This included sagittal plane hip, knee and ankle joint rotation angles at initial contact, midstance and foot off; sagittal plane joint excursion at the hip, knee and ankle; average stride length; velocity; single limb support; and foot progression angle at initial contact.

Postoperative changes were averaged within each group and subjected to statistical analysis. Average changes were then compared between groups to determine statistically significant changes between the groups. The Wilkes-Shapiro Test determined appropriateness of statistical comparisons for either Student's t-Test or Wilcoxon Sign Test.

Statistical analysis revealed three variables of improvement in the orthopaedic group: knee joint rotation angles at initial contact, ankle joint rotation angles at initial contact and at midstance. The hip angle at foot off changed in a negative direction postoperatively.

In the dorsal rhizotomy group there were five variables improved postoperatively: knee and ankle joint rotation angles at initial contact and midstance, and overall hip excursion.

Variables of stride length, hip excursion and hip joint rotation angle at foot off were significantly more improved in the dorsal rhizotomy group postoperatively when compared to the orthopaedic group.

Overall, there was sagittal plane improvement at the knee and ankle in both groups with a higher amount of improvement in the dorsal rhizotomy group postoperatively. Three gait parameters were more improved in the dorsal rhizotomy group postoperatively when compared to the orthopaedic group.

ACKNOWLEDGEMENTS

I would like to gratefully acknowledge several people who have helped me considerably throughout this process. First, I would like to thank my primary advisor, Evangeline Yoder, for all of her assistance and input during the entire process of my thesis. I would also like to thank the other members of my advisory committee, Martha Walker and Dr. John L. Echternach, for all of their time and effort. Thanks also to Pat Sachon for her guidance during my first semester of graduate school.

I would like to thank the administration at Children's Hospital in Richmond, Virginia, for allowing me to utilized their resources and the Motion Analysis Lab for this study. I would especially like to thank Patty Payne for all of her insight and guidance in the field of motion analysis and cerebral palsy gait, and also for her friendship over the last year. Also, many thanks to George Masiello for his assistance in data collection.

I would finally like to thank my family for their support during my years of schooling in the field of physical therapy: my father for his constant inspiration, and my mother and sisters for their love, support, and sense of humor.

DEDICATION

To Ray, you have shared completely the last two years of graduate school with me. Dedication of this thesis represents our success in it's completion. My thanks and love to you always.

TABLE OF CONTENTS

LIST OF TABLES

TABLE

LIST OF GRAPHS

CHAPTER 1

INTRODUCTION

Multiple orthopaedic surgeries are a typical course of management for ambulatory children with cerebral palsy in order to promote maximal functional ambulation. Selective dorsal rhizotomy is a relatively new surgical procedure used to eliminate spasticity in the lower extremities and maximize gait efficiency. Outcome studies using objective measures to examine functional changes after multiple orthopaedic surgeries or selective dorsal rhizotomy are few in number. Objective measurements to substantiate the efficacy of both treatments for cerebral palsy are needed.

Instrumented gait analysis to obtain kinematic, kinetic, and electromyographic data has been used in research to provide objective measurement of gait parameters. [1,2] Reliability on normal subjects using these measurement techniques was reported on by Kadaba in 1989.[3] This objective data has been used with increasing frequency by surgeons in order to assist in surgical decision making on cerebral palsy children.[4,5,6] The data has also been used in measuring functional improvement after surgery.[5] Gait analysis provides three plane kinematic joint rotation angles, measurements of time and distance parameters, kinetic measures of ground reaction forces, and dynamic electromyographic information on selected lower extremity muscle groups. There are a few motion analysis labs that are also able to measure energy consumption.

Although data from instrumented gait analysis has been accumulated following multiple simultaneous surgeries and selected dorsal rhizotomy, sample sizes have remained small. No study to date has compared the objective gait analysis results obtained after orthopaedic surgeries and selective dorsal rhizotomy on children with spastic diplegia cerebral palsy.

Purpose

The purpose of this retrospective study was to examine the changes in selected gait parameters one year following surgery on two different groups of children with spastic diplegia cerebral palsy. An additional purpose was to compare and contrast surgical effects between the two groups using selected gait parameters. The first group consisted of children with spastic diplegia who had multiple simultaneous orthopaedic surgeries. The second group consisted of children with spastic diplegia who had selective dorsal rhizotomy.

Review of the Literature

The course of medical treatment of cerebral palsy patients may vary depending on the severity and nature of the problems that are manifested by the central nervous system damage. Orthopaedic surgeons have served as vital members of the medical team by attempting to manage the physical deformities that ensue in many cases of spastic cerebral palsy. Orthopaedic surgeons have been particularly active in treating ambulatory cerebral palsy patients in order to maximize their walking ability and decrease energy expenditure. Surgery often attempts to correct soft tissue and joint contractures, decrease the negative effects of spasticity, and to correct the bony deformity that can occur due to abnormal stresses on growing bones of the lower extremities.[7,8] Specific techniques utilized by orthopaedic surgeons include tendon lengthenings and recessions, muscle releases, tendon transfers, osteotomies, and arthrodesis.[9,10,11,12]

Orthopaedic surgical interventions are often required at repeated intervals during the growth years for children with cerebral palsy due to limited growth of muscle in relation to bone growth.[8,11] Surgery may be required at multiple levels of lower extremity joints since two joint muscles in the legs may cause compensatory abnormalities at both proximal and distal joint levels.[9,13] Many orthopedists advocate multiple simultaneous surgeries to address as many existing problems as possible at one time to avoid repeated "birthday surgeries" on growing children. [7,12,14]

Fasano in 1978 reported on selective dorsal rhizotomy as an improved neurosurgical technique to treat spasticity.[15] The technique used by Fasano was first described by Sherrington in 1898 following deafferentation research on cats.[16] The procedure was used by Foerester in 1908 for controlling spasticity in paraplegic patients.[17] Problems associated with ataxia and excessive hypotonia lessened the positive effects of the surgery. Several physicians following Foerester modified the technique to attempt to decrease the amount of sensory loss that accompanied the surgery. Fasano modified the surgical procedure to include a knowledge of functional anatomy of the dorsal rootlets with an intra-operative selection of the specific rootlets to be cut.[15] The procedure was further modified by Peacock in 1982 by raising the spinal incision level from the conus medularis to the cauda equina region.[18]

Spasticity is a motor disorder characterized by a velocity-dependent increase in muscle tone secondary to an upper motor neuron lesion. It results from hyperexcitability of the stretch reflex and loss of control of voluntary movements.[19] Spasticity is accompanied by hyperactivity of the stretch receptors which is demonstrated by clonus, the clasp-knife phenomenon, increased phasic tendon reflexes, abnormal tonic vibration reflex, the presence of tonic neck reflexes and Babinski sign.[20]

Spastic types of cerebral palsy are believed to result from damage to the inhibitory pathways of cerebral cortex.[15,18] The cerebral cortex is viewed as the inhibitory part of the balance mechanism at the motoneuron pools in the spinal cord. The dorsal afferent sensory fibers from the periphery are conduits for facilitory input on the motoneuron pools in the spinal cord. Cerebral cortex damage reduces central inhibition to the motoneuron pool. Therefore, damage to the upper motor neurons of the cerebral cortex causes an imbalance between the facilitory and inhibitory input at the spinal cord level. This is manifested in the extremities by an increase in tone.[15,21]

Selective dorsal rhizotomy involves cutting selected afferent sensory fibers that cause an abnormal tonic contraction of muscles when they are electrically stimulated intra-operatively at the dorsal root.[15,18,22] Fasano and Peacock have reported reduction in spasticity with preservation of sensation using this intra-operative selection process.[15,18]

Since 1982, selective dorsal rhizotomy has been used more frequently in managing the spastic cerebral palsy patients. Reports in the literature have favorably supported use of the procedure although the number of subjects that have undergone objective, reliable measurements for improvement have been small.

Normal Gait

Human locomotion involves a complex system of internal neuromuscular and biomechanical changes in relation to external forces on the body. Saunders et al[23] describe fundamental locomotion as the translation of the center of gravity through space with the least amount energy expenditure. Many researchers have discussed the functional requirements of normal gait[2,10,24]

Gage[10] states that the three necessities for normal ambulation include a stability in stance, a means of progression, and the necessity for energy conservation. According to Gage, stability in stance is achieved by maintaining the body's balance over the base of support. Forward progression is accomplished by the forward fall of the body from single limb support to double limb support which creates kinetic energy. Energy conservation occurs by minimizing excursion of the center of gravity, controlling momentum and transferring energy between body segments.[10]

Perry [24] describes three functional tasks that are accomplished during gait. The first is a mechanism of forward progression that includes propulsion, control of momentum and control of shock absorption. The second is alternately balancing the body over one limb and then over the other limb. The third task is repeated adjustment of the relative limb length.[24]

The dynamic mechanical changes that occur within this intricate system have been studied extensively. [23,24,25,26] Sophistication of gait analysis methods has improved over the last century. Both clinicians and engineers now analyze gait with computer systems, force plates, dynamic electromyography, and video analysis. Saunders et al[23] published the major determinants of gait after several years of research at the Biomechanics Laboratory in San Francisco. Through the use of various techniques such as interrupted light photography, motion pictures, force plates, glass walkways and electromyography, six determinants of normal gait were described.[23]

1. Pelvic rotation in the horizontal plane. This prevents the center of mass of the body from falling.

2. Pelvic list opposite to the weight bearing side in the coronal plane. This lowers the body's center of mass.

3. Knee flexion at the beginning and end of stance to allow for smooth change in center of mass.

4. Knee flexion, ankle plantarflexion and foot pronation at initial contact to decelerate the limb.

5. Knee extension with ankle plantarflexion and foot supination at the end of terminal stance to lengthen the limb and allow for smoothness in the passage of the center of mass.

6. Lateral displacement of the body, including the shoulders and thorax, and the

rotation of the thigh, leg and ankle/foot complex to allow for smooth forward progression of the body forward.[23]

Based on multiple research studies, normal gait has been divided into two major phases of stance and swing, with eight subphases to describe important events within the gait cycle.[10,27] Accepted terminology for the eight phases and their duration during one cycle are:[10,27]

Stance Phase:

1. Initial contact (IC)- Occurs at 0% of the gait cycle and is the moment the foot comes in contact with the ground.

2. Loading response (LR)- 0-10% of the gait cycle and is the deceleration of the limb which occurs as the foot becomes planted on the ground and the knee flexes as a shock absorber.

3. Midstance (MST)- 10-30% of the gait cycle; the body is progressing forward over the foot and the center of mass is at its highest point.

4. Terminal stance (TST)- 30-50% of the gait cycle; the center of mass continues to move in front of the base of support and the heel begins to rise off the floor.

5. Pre-swing (PSW) 50-60% of the gait cycle in which the limb is preparing for swing with knee flexion and plantarflexion of the ankle. Swing Phase:

6. Initial Swing (ISW)- 60-70% of the gait cycle; the limb is flexing at the hip and the foot begins to dorsiflex for foot clearance.

7. Mid-Swing (MSW)- 70-85% of the gait cycle; the limb continues to cross in front of contralateral stance limb with the hip flexing and the foot held in dorsiflexion.

8. Terminal swing (TSW)- 85-100% of the gait cycle in which the limb prepares for initial contact with knee extension and neutral position of the ankle.[27]

From researchers such as Inman[1], Winter[28], Sutherland,[2] Gage,[10] and Perry,[24] the important kinematic, kinetic, and electromyographic events that occur during one gait cycle have continued to be investigated as the sophistication of gait analysis has improved. Sagittal, transverse, and frontal plane joint rotations at the pelvis, hip, knee and ankle have been calculated by many researchers and used for comparison of pathological gait.

Researchers have broken down the kinematic events into many important components in order to further understand normal gait and assist in treatment of pathological gait. The "ankle rocker" is a system of three significant occurrences at the ankle during stance that contribute to the efficiency of gait.[10]

In normal gait the first ankle rocker occurs during loading response in which the anterior tibialis eccentrically decelerates the foot as it moves into plantarflexion and into a foot flat position. The second rocker occurs during midstance through terminal stance in which the gastrocsoleus complex eccentrically controls tibial rotation over the fixed foot. The third rocker occurs at pre-swing when the gastrocsoleus contracts concentrically and pushes the foot off the floor. According to Gage,[10] if the first or second rocker is pathological, then the mechanism is disrupted and push off is inappropriate.

Development of Gait

Factors such as age and neuromuscular development of gait patterns in children are essential for comparison of gait information. Ogg published data on stride length, dynamic base of support, angle of foot placement and step distance on thirty-three normal children ranging in age from two to fifteen years of age.[29]

Sutherland expanded upon this information using instrumented gait analysis on 186 children between the ages of one and seven. According to Sutherland's group, the previous criteria of a "mature" gait with reciprocal arm swing and heel strike patterns is usually present by the age of eighteen months.[2] The authors then investigated other gait parameters and decided upon five parameters that were more specifically indicative of a "mature" gait pattern. These parameters change until the age of seven years when they become most like adults.

The five indicators of "mature" gait are:

1. Duration of single limb stance
2. Walking velocity
3. Cadence
4. Step length
5. Ratio of pelvic span (width between ASIS) and ankle spread

Sutherland further elaborated on this information with 486 children and published age matched values for children ages one to seven on these five gait parameters and other parameters of gait such as stride length, opposite toe off, opposite foot contact, cycle time, and toe off.[30] According to Sutherland, sagittal plane joint rotation angles in adults during walking differ only slightly from children after age two.[2]

Cerebral Palsy Gait

Cerebral Palsy (C.P.) is a term that includes a group of disorders characterized by maldevelopment of the immature brain. Maldevelopment is due to a brain lesion that occurs in utero, during birth or in the early years of childhood.[31] It is a nonprogressive disorder that results in abnormal motor behaviors, often accompanied by sensory and perceptual disturbances.[31,32] Classifications of cerebral palsy generally describe the type of motor impairment that predominates and the distribution of the body parts affected.[33]

Moore[32] classifies motor impairment of C.P. into three major types. They are:

1. Spastic which involves damage to the cerebral cortex of the central nervous system and/or the subcortical nuclei. It is characterized by hypertonia, rigidity, and pathological reflexes, involuntary movement disorders, and may be associated with mental retardation.
2. Athetoid which involves damage to the caudate nucleus and putamen of the basal ganglia and/or the thalamus. It is characterized by unstable movement, purposeless involuntary movement with fluctuating tone from hypotonia to spasticity. It may also be associated with mental retardation, speech and swallowing difficulties.
3. Ataxic which involves damage to the cerebellum and/or major nuclei associated with cerebellar function. It is characterized by disturbances in coordinated or

synergistic movement, intention tremors, fluctuating tone and may be associated with varying degrees of mental retardation.

Minear's[33] classification of C.P. also involves topographical distribution as well as the tone and movement disorder. Topographical distributions of spasticity along with common pathologies are described by Moore.[32]

1. Diplegia: Total body involvement with the greater involvement of the trunk and lower extremities, usually associated with premature birth.

2. Quadriplegia: Total body involvement with the upper extremities more or equally involved as the trunk and lower extremities. These cases are usually the result of asphyxia in term infants or intraventricular bleeding in the immature infant.

3. Hemiplegia: Unilateral involvement of upper and lower extremity. These are usually associated with head trauma to term infant or child.

Spastic diplegia is a classification of cerebral palsy that denotes motor impairment with hypertonicity predominantly in the lower extremities with lesser upper extremity motor dysfunction.[11] These individuals will often exhibit loss of control of the lower extremities, abnormal tone, and an imbalance between agonistic and antagonistic muscles.[10]

Saunders views pathological gait as an attempt to preserve energy consumption by exaggerating motions at unaffected levels.[23] The information on pathological gait has been collected by researchers to include electromyographic, kinetic and kinematic data on spastic cerebral palsy gait.[6,10,34,35] Some common deviations in gait of spastic C.P. have also been identified through observational and instrumented gait analysis.

Bobath observed two major gait patterns in the spastic diplegia patient.[36] The first is termed the "pigeon gait" and is identified by the backward tilt of the trunk to advance the lower extremities during swing and then the forward thrust of the head to initiate the forward progression of the body.

The second gait pattern identified by Bobath involves excessive lateral flexion of the trunk to advance "stiff" legs with an increased lumbar lordosis due to spasticity around the hips. Bobath also observed that most spastic diplegia children walk on their toes which often results in an equinovarus or equinovalgus of the feet.[36]

A "crouch" gait pattern is often described in the literature. This pattern of gait is denoted by sustained knee flexion of more than 30 degrees and excessive dorsiflexion throughout stance phase.[37] This pattern may be associated with knee flexion contractures, hip flexion contractures, spastic hamstrings or overlengthened achilles tendon.[8,9,37]

Bleck describes characteristics of spastic diplegia lower extremities as hips in flexion, adduction and internal rotation spasm or contracture, excessive femoral anteversion, knees with flexor or extensor spasticity predominating and ankles in equinus and feet in valgus.[7]

A "stiff knee" gait is commonly described in the literature of cerebral palsy gait and is characterized by spastic quadriceps muscles resulting in decreased knee flexion during swing.[8,38]

"Scissoring" gait refers to excessive adduction of the lower extremities during swing with a narrow base of support.[12]

Instrumented gait analysis has elaborated on the pathomechanics involved in spastic gait patterns. In 1976 Aptekar et al[39] used sequential photography with lightbulbs over bony landmarks on children to record gait patterns. They reported on the typical gait patterns of spastic patients as having tight tendo calcaneus with detectable contracture of the triceps surae (gastrocsoleus complex), absent heel contact to the floor, jerky head and shoulder movements to retain balance and elbow held in a flexed position.

Winters et al[40] investigated typical patterns of spastic hemiplegic cerebral palsy using computerized gait analysis and identified four distinct patterns of walking in a population of forty-six children. Kinematic, kinetic and electromyographic studies of this nature are ongoing in a group of spastic diplegia cerebral palsy, however, results have not been published to date.[41]

Through gait analysis the patterns that are typically observed in the spastic diplegia patient are analyzed with the kinetic, kinematic and electromyographic data to allow for critical analysis of the pathomechanics involved with each child. DeLuca[9] makes reference to two children who have similar gait patterns on visual analysis but have very different pathomechanics on evaluation. Because of the individuality of the cases, gait analysis has been coupled closely with surgical decision making in order to alleviate the subjective interpretation of a "typical" gait pattern that dictates a specific surgery.

Instrumented Gait Analysis In Surgical Decision Making

The use of instrumented gait analysis has been an essential part of surgical decision making. Electromyographic (EMG) data assists surgeons in clarifying which muscles are inappropriately active or inactive during a particular phase of gait. This has assisted in planning tendon transfers, muscle releases and lengthenings.[5,42,43]

The use of electromyography in pre and postoperative analysis of specific orthopaedic surgeries has been well documented in the literature. In 1977 Perry et al[42] described use of EMG data for determining surgical technique in equinovarus deformity with good results when comparing surgical outcome. Multiple other studies have elaborated on the use of EMG in surgical decision making.[44,45,46]

The use of gait analysis has also contributed to clinical research of effectiveness of surgery by providing objective data from which to compare pre and postoperative gait measures of joint rotation angles and temporal distance parameters. Gage et al[43] used computerized gait analysis in determining surgical treatment of stiff knee gait with rectus tendon transfer in conjunction with hamstring lengthening with improved knee flexion during swing phase gait when compared with distal hamstring lengthening only.

Shapiro et al[47] investigated the effects of surgical correction of equinus deformity on children with C.P.. These authors found that time and distance parameters were reliable objective evaluation criteria of gait improvement after surgical correction using tendo-achilles lengthening.

Gage et al[5] in 1984 studied a group of children with spastic diplegia who underwent computerized gait analysis before and after surgery to assist in surgical planning preoperatively and to measure postoperative changes on gait. Variables of stride length, velocity, estimated external work of walking, and rotation angles of pelvis, hip, knee, ankle and foot were examined. Improvement was based on an overall change of greater than ten percent. Thirteen of twenty children who had undergone multiple simultaneous surgeries on the lower extremities had improved according to the criteria used. Specific areas of statistically significant improvements included increased knee extension during stance, increased ankle dorsiflexion during swing, stride length and velocity. The only adverse change noted was a decrease in knee flexion during swing. Nineteen of the twenty children were considered to be improved when subjectively evaluated by physicians and parents. The implication from Gage et al was that the gait analysis imposed more stringent criteria for improvement postoperatively.[5]

The use of gait analysis has been used more recently to not only assist the medical team in surgical decision making, but to also provide objective measurement of postoperative changes following a surgical intervention such as dorsal rhizotomy.

Vaughen et al[48] studied fourteen cerebral palsy children who underwent gait analysis prior to dorsal rhizotomy and at one and three years postoperatively. Vaughen found a statistically significant increase in stride length, knee range of motion and hip range of motion postoperatively. Cahan et al[49] studied fourteen subjects prior to rhizotomy and approximately one year postoperatively and found statistically significant improvements in velocity, stride length, duration of EMG in the hamstrings, quadriceps and calf muscles, and joint rotation angles of the hip, knee and ankle at "critical arcs" during the gait cycle.

Summary

The use of EMG and clinical gait analysis in surgical decision making has been well documented in the literature. Multiple level orthopaedic surgeries on cerebral palsy children are a typical course of surgical intervention, with few objective studies to document the effects postoperatively. Dorsal rhizotomy is a relatively new procedure with objective results of effectiveness on cerebral palsy children limited to only a few studies. Establishing functional outcomes is essential to provide physicians, parents and therapists with an adequate knowledge base to decide which children may be appropriate for this surgery.

With the availability of computerized gait analysis systems, outcome following orthopaedic surgeries and dorsal rhizotomy can be investigated objectively. Accumulation of objective data following both types of surgeries continues to be ongoing with the need for larger sample sizes of both groups.

Research Questions

The purpose of this study was to investigate the effects of dorsal rhizotomy and multiple orthopaedic surgeries on selected gait characteristics of spastic diplegia cerebral palsy children. Three questions were generated at the outset of this investigation.

1. Is there an improvement in selected gait parameters after simultaneous multiple orthopaedic surgeries performed on a population of children with spastic diplegia C.P.?

2. Is there an improvement in selected gait parameters after selected dorsal rhizotomy on a population of children with spastic diplegia C.P.?

3. Is there a statistically significant difference in the postoperative changes on selected gait parameters between the two surgical groups?

Hypotheses

Four hypotheses were generated for this study.

1. Multiple orthopaedic surgeries on a population of children with spastic diplegia will result in improved time and distance gait parameters and foot progression angle one year after surgery.

2. Selected dorsal rhizotomy in a population of children with spastic diplegia will result in improved time and distance parameters of gait and joint rotation angles in the lower extremities one year postoperatively.

3. There will be a greater amount of improvement in the hip, knee and ankle joint

rotation angles and an increase in joint excursions in the hip and knee in the dorsal rhizotomy group when compared to the orthopaedic group one year postoperatively.

4. There will be a greater amount of improvement in the foot progression angle in the orthopaedic group when compared to the dorsal rhizotomy group.

CHAPTER 2

METHODS

Selection Of The Sample

The sample was selected from a group of children that had undergone surgery and instrumented gait analysis at Children's Hospital in Richmond, Virginia between the years 1988 and 1991.

Subjects selected for this retrospective study were chosen from a group of children with spastic diplegia C.P. that had undergone instrumented gait analysis prior to either selective dorsal rhizotomy or simultaneous multiple orthopaedic surgeries, and had a repeated instrumented gait analysis test at approximately one year postoperatively.

Instrumentation

Pre-surgical and post-surgical tests included a physical therapy evaluation, collection of kinematic data, and dynamic electromyography of lower extremity muscle groups. In some cases kinetic data was collected on the subjects if his/her step length was adequate to perform this part of the test.

The physical therapy evaluation included goniometric range of motion testing, manual muscle testing, muscle tone assessment, flexibility tests, musculoskeletal assessment, and neurological assessment.

Kinematic joint rotation angles of the pelvis, hip, knee and ankle in the sagittal, frontal and transverse plane were collected using the Vicon five camera video based computerized motion analysis system. Please refer to appendix A for detailed description of the Vicon motion analysis system. Each subject walked barefoot at his/her self selected speed. If the subject used a particular assistive device for functional ambulation, the assistive device was used during the testing. Three dimensional kinematic data was recorded from passive reflective markers using five infrared cameras. Thus joint rotation angles could be graphed in the sagittal, frontal and transverse plane on the pelvis and lower extremity joints. Stance and swing phases of the gait cycle were separated and the three dimensional joint rotations were recorded and graphed during one complete gait cycle (0-100%).

All of the subjects completed gait trials were averaged for parameters of velocity, cadence, single limb support, double limb support, stride length, opposite foot strike, and opposite foot off. Subjects had a range of five to eight gait trials used for these calculations.

Dynamic electromyographic data was collected using surface electrodes over lower extremity muscle groups. Several subjects had fine wire electromyographic data collected on the iliopsoas and the posterior tibialis if was requested by the referring physician.

Kinetic calculations of ground reaction forces and joint moments were derived from data collected by Advanced Mechanical Technology Instruments (AMTI) force plates. Only those subjects with a step length that allowed one foot to land on each force plate had this data collected.

A video of the subjects walking was also recorded for subjective review by the physical therapist to correlate results of the test with the clinical picture of the child.

Operational Definitions

1. Stride Length: The distance from initial contact of one foot to the following initial contact of the same foot.[28]

2. Velocity: The average horizontal speed of the body along the plane of progression measured over one or more strides. It is represented as distance per unit of time.[28]

3. Single Limb Support: The period of time when only one foot is in contact with the ground, approximately 10-50% of the cycle during stance.[1]

4. Total Joint Excursion: Total range of motion of a joint achieved during one stride. (Operational Definition)

5. Foot Progression Angle: The number of degrees the foot is rotated from the direction of forward progression.[29] It is expressed as the relative angle of rotation in the transverse plane of the pelvis, hip, knee and ankle in relation to the direction of progression.(Operational Definition)

6. Hip Angle: The angle formed between the lateral midline of the pelvis and the lateral midline of the femur (using the lateral epicondyle of the femur for reference) with the axis of the hip joint at the level of the greater trochanter.[50]

7. Knee Angle: The angle formed between the lateral midline of the fibula (using the lateral malleoli for reference) and the lateral midline of the femur (using the greater trochanter for reference) around the axis of the knee joint at the level of the lateral epicondyle of femur.[50]

8. Ankle Angle: The angle formed between the lateral midline of the fibula and the lateral aspect of the fifth metatarsal around the axis of the ankle joint at the level of the lateral malleoli.[50]

9. Sagittal Plane: The vertical plane that divides the body into the right and left parts.[28]

10. Initial Contact (IC): The instant the foot or shoe comes in contact with the ground.[28]

11. Midstance (MST): The point during the gait cycle when there is reversal of the fore-aft shear over the stance limb, as measured by force plates.[51] The midpoint of single limb support of reference limb (Operational Definition).

12. Foot Off (FO) : The moment that the reference limb leaves the ground. Defines end of stance in normal gait.[28]

13. Stance Phase (ST): The period of time when the foot is in contact with the ground. In normal gait this represents approximately 60% of the gait cycle.[2]

Procedure

Collection of the data from the test records by this reviewer included the preoperative and postoperative average values of velocity, single limb support and stride length of both extremities collected off the subjects computer print out of all gait trials.

Overall joint excursion during one stride of the hip, knee and ankle in the sagittal plane was measured for each extremity from preoperative and postoperative joint rotation curves obtained from the medical record. Joint excursion was measured using the highest and lowest peaks of the joint rotation curve in the sagittal plane for the respective joints.

Joint rotation angles of the hip, knee and ankle were measured from joint rotation curves in the sagittal plane. These three joints were measured at three points during stance. The three points were initial contact, midstance and foot off for each subject. The left and right leg were measured for each subject.

Foot progression angle was measured for the left and right extremities by measuring the relative rotations of the pelvis, hip, knee and ankle in the transverse plane at initial contact. The sum of these four measurements represents the relative rotation of the limb at that point in the gait cycle.

All variables were measured and recorded from the subjects preoperative and postoperative motion analysis tests. Each subjects test was measured on two separate occasions by the examiner and then compared to ensure reliable recording of the data.

Data Analysis

Data for nineteen variables for each subject was collected. The mean, standard deviation, and range for each variable in each group was calculated. Each subjects postoperative change for each variable was described as positive if the change resulted in a value closer to normal values. The number of subjects that improved postoperatively relative to each variable was recorded.

The amount of change in each variable that occurred between the preoperative and postoperative test was calculated and used for statistical analysis within each group. The mean change between the two surgical groups was then compared for each variable measured.

Variables of velocity, stride length and duration of single limb support were normalized using age appropriate normal values recorded by Sutherland.[51] The measured values were then expressed as a percent of normal preoperatively and postoperatively. The difference between the two tests was calculated for each limb. The difference postoperatively for each subjects left and right extremities was averaged for the variables of stride length and single limb support.

Total joint excursion during one complete gait cycle at the hip, knee, and ankle was recorded for both tests. The difference between the two tests was used for statistical comparisons.

Total joint excursion at each lower extremity joint was also calculated to represent the amount of postoperative change that occurred in the direction of normal joint excursion values. This was calculated by measuring the difference that occurred in the direction of normal joint excursion at the respective joint and then measuring the amount of change that occurred away from normal values. A change toward normal values was given a positive number, and a change away from normal was given a negative number. Adding these two numbers together calculated the overall change toward normal values. These values were then statistically compared within each group and then between the two groups.

Joint rotations angles of the hip, knee and ankle at the three defined points during stance phase of gait were also measured by assigning a positive number to the amount of change that occurred postoperatively in the direction of normal lower extremity angles recorded at the same three points during gait. A negative number was assigned to the amount of change that occurred away from normal joint rotation angles at each joint. Normal values used for comparison were taken from the Helen Hayes Hospital software protocol collected by Kadaba et al[3,52] and used at Children's Hospital in Richmond. Each joint had left and right extremity values. These two values for each subject were compared together in each group with a total of eight measurements for each joint in the orthopaedic group and ten measurements for each joint in the dorsal rhizotomy group.

Statistical analysis was done on each of the two surgical groups using average difference between the two tests. Each variable was first screened using the Wilkes-Shapiro Test to determine appropriateness of parametric or non-parametric statistical analysis. When the Wilkes-Shapiro Test had a p value of $\leq .05$, the variable was compared using the Wilcoxon Sign Test. When the Wilkes-Shapiro Test had a p value of $> .05$ the Student's t-Test was used to determine if there was statistical significance.

Comparison between the two groups was done by using the average differences within both groups and by performing a Student's t-Test on each of the nineteen variables. The confidence level of alpha was set at .05 for all statistical comparisons.

CHAPTER 3

RESULTS

Demographics

A total of nine subjects was included in this study with an age range of four years to seventeen years. There were five subjects in the dorsal rhizotomy group (four male and one female; age range 5-10 years; average age 7.2; standard deviation 2.59). The average postoperative gait analysis was 13.5 months after the original surgery with a range of 13 months to 14 months. Three subjects used the same assistive device for both tests and two subjects walked independently for both tests.

Four subjects underwent multiple simultaneous orthopaedic surgeries(two males and two females; age range 4-17 years; average age 9.5; standard deviation 5.45). The average postoperative gait analysis was 12.5 months after surgery with a range from 7 months to 19 months. One subject used a different assistive device on the two tests, two subjects walked independently, and one subject used the same assistive device on both tests.

The orthopaedic surgeries included bilateral rectus femoris transfers from the patellar tendon to the gracilis tendon, bilateral percutaneous medial hamstring lengthening, bilateral extra-articular subtalar fusion, and tendo-achilles lengthening performed bilaterally and unilaterally.

The subjects in the dorsal rhizotomy group underwent the procedure similar to the procedure outlined in the literature review.

Of the nine subjects in this study, three subjects in the orthopaedic group and one subject in the dorsal rhizotomy group had undergone some type of orthopaedic surgery prior to participation in this study. Refer to Table 1 for description of surgical procedures and surgical histories for all nine subjects.

Results

The results of the statistical analysis are presented under each research question generated for this study.

1. Is there an improvement in selected gait parameters after simultaneous multiple orthopaedic surgeries performed on a population of children with spastic diplegia C.P.?

An analysis of the data revealed that statistically significant improvement occurred postoperatively in three variables: sagittal plane knee rotation at initial contact, ankle rotation at initial contact, and ankle rotation at midstance.

Sagittal plane joint rotation angle of the knee at the point of initial contact improved significantly postoperatively. A total of eight extremities were measured with six of the eight extremities improving one year after surgery in the direction of normal. Refer to Table 2 for average change, test statistics and group comparisons.

Six of the eight extremities significantly improved postoperatively in sagittal plane joint rotation angle of the ankle at initial contact. Refer to Table 3 for a summary of results for this variable.

Sagittal plane joint rotation angle of the ankle at midstance also improved postoperatively. Six of the eight measured extremities improved in the direction of normal. These results are given in Table 4.

There were was one variable that had a statistically significant adverse change from normal values. This was sagittal plane joint rotation angle of the hip at foot off. Postoperatively seven of eight extremities moved in the direction opposite of normal hip rotation at the point of foot off. Refer to Table 5.

2. Is there an improvement in selected gait parameters after selected dorsal rhizotomy in a population of children with spastic diplegia C.P.?

Five variables improved at statistically significant levels postoperatively: knee rotation at initial contact and midstance, ankle rotation at initial contact and midstance, and overall hip excursion.

Sagittal plane joint rotation angle of the knee at initial contact improved significantly after surgery. Of the ten extremities measured, nine extremities were closer to a normal position at the knee. Refer to Table 2.

Sagittal plane joint rotation angle of the knee at midstance significantly improved with ten extremities closer to a normal position postoperatively. Refer to Table 6.

Sagittal plane joint rotation angle of the ankle at initial contact statistically improved. Eight of ten extremities were closer to a normal angle postoperatively. Refer to Table 3.

Sagittal plane joint rotation angle of the ankle at midstance significantly improved postoperatively. Six of ten extremities were closer to normal values postoperatively. The average improvement and summary is in Table 4.

The overall change in sagittal plane hip joint excursion increased significantly after surgery. Two of the five subjects had a postoperative change that was in the direction of normal. This variable had statistical significance with regard to overall change between the two tests, but there was no statistically significant improvement occurring in the direction of normal. Results are given in Table 7.

3. Is there a statistically significant difference in the postoperative differences on selected gait parameters between the two surgical groups?

Of the nineteen variables measured, three variables significantly improved in the dorsal rhizotomy group when compared to the orthopaedic group: stride length, hip rotation at foot off, and hip excursion.

The improvement in stride length postoperatively was higher in the dorsal rhizotomy group when compared with the orthopaedic group. All five subjects who underwent dorsal rhizotomy had bilateral increases in stride length postoperatively. Refer to Table 8 for average changes in both groups.

The sagittal plane position of the hip at foot off as measured by the joint rotation angle at the hip at foot off was closer to normal in the dorsal rhizotomy group after surgery. In the dorsal rhizotomy group six of ten extremities improved closer to a normal range while seven of eight extremities in the orthopaedic group moved away from normal range of the hip at foot off postoperatively. Results are given in Table 5.

The overall increase in sagittal plane hip excursion increased in the dorsal rhizotomy group with a significantly higher change postoperatively. Table 7 lists the results for both groups.

A summary of the calculated differences between the two groups used for statistical analysis for the remaining variables are given in Tables 8-20 with mean change, standard deviation, test statistic and level of significance. Graphs of the normalized time and distance parameters are also provided with preoperative and postoperative values given for each subject in Graphs A-F.

CHAPTER 4

DISCUSSION

The aim of this study was to critically examine the surgical effects of selective dorsal rhizotomy and multiple combined orthopaedic surgeries on gait in a group of children with cerebral palsy. The parameters that were selected to measure improvement were chosen to reflect quality of walking patterns in the two groups in addition to overall efficiency of gait.

Orthopaedic Group

In the orthopaedic surgical group, it was hypothesized that there would be measurable improvement in time and distance gait parameters and foot progression angle one year postoperatively. In this group of four subjects, there was limited statistical improvement in the gait parameters measured.

The variables of stride length, velocity and single limb support did not improve postoperatively. The lack of significant improvement in orthopaedic surgical group is in disagreement with Gage et al[5] who had found increases in stride length postoperatively after multiple simultaneous orthopaedic surgeries. Other researchers have investigated the results of specific surgeries on mixed populations of children with hemiplegic, diplegic and quadriplegic spastic cerebral palsy. They have often included subjects who had undergone simultaneous procedures at other lower extremity joints.

Thometz et al[53] found no difference in stride length, velocity or cadence after hamstring lengthening on thirty-one subjects. Fourteen of the thirty-one subjects had undergone simultaneous surgeries at other lower extremity joints. Thometz's group normalized these parameters to age matched normal children for statistical comparisons and found no significant changes. This is an important factor to consider in interpreting the results of this study. The lack of significant change may be related to the normalization process. The normalization to age matched subjects may be inappropriate for cerebral palsy children who usually begin walking much later in life than normal children.

The mixed results noted in the literature reflect the need for controlled selection of subjects into specific research groups in order to limit the variables that could effect outcome. There is also the need to determine what statistical comparisons are appropriate for variables that are expected to change over a predetermined period of time. This will assist in interpreting postoperative effects that can be attributed to the surgical procedures versus changes in age.

Foot progression angle did not show significant change in the orthopaedic group. Four of eight extremities in the orthopaedic group showed an overall improvement in the foot progression angle that resulted in a foot closer to a normal range of 8-16 degrees of external rotation. This normal range is based on the absolute foot progression angle used in the Helen Hayes Software protocol of 12 degrees external rotation $\pm$ 4 degrees. The standard deviation was included in this measurement of "normal" for pre and postoperative comparisons of foot progression angle. Previous research has found a high degree of variability in the foot progression angle in children. Scrutton found marked differences between left and right extremities in children.[54] It is important to note that Scrutton's study did not use instrumented gait analysis. Therefore, the changes may not be directly comparable to this measurement system that investigated the specific lower extremity segments that contribute to the overall rotation at the limb.

In this study, the statistical improvements that occurred in this surgical group were joint rotation angles measured against normal joint rotation angles in the lower extremity joints at three defined times during stance phase gait. Previous researchers have correlated improvement based on the entire curve of the joint during stance phase or swing phase gait.[5,53] Because of the different measurement methods, direct correlations are difficult to make with previous studies. However, certain similarities are worth noting.

The area that did demonstrate improvement in this group were the positions of the knee and ankle during stance. The changes that occurred in the orthopaedic group at the knee were increased extension of the knee at initial contact. This supports previous research by Gage et al[5] and Thometz et al.[53] These authors measured overall sagittal plane knee joint curves and found an overall increase in knee extension during stance. Gage's group investigated multiple simultaneous surgeries and Thometz's group looked at medial hamstring releases in which many subjects had multiple simultaneous procedures.

The improvement at the ankle at initial contact and midstance in the orthopaedic group does not correlate directly with previous research measuring joint rotation angles in the manner in which they were measured for this study. Previous research has identified subjects as independent versus assisted walkers and toe walkers versus heel contact walkers postoperatively in addition to stride parameters as a measurement of success.[47,55]

The joint rotation angles of the orthopaedic group at the hip at foot off changed in an negative direction postoperatively into a more flexed position. Previous research by Sutherland et al,[56] investigated the position of the hip at terminal stance after rectus transfers and found that there was no significant change at the hip in the sagittal plane. Sutherland's group only evaluated rectus transfers without simultaneous hamstring lengthenings. In this study, all eight extremities underwent rectus femoris transfers and six of the eight extremities underwent rectus transfers in conjunction with hamstring lengthenings. All six of the extremities had a postoperative change away from normal, in addition to one of the two remaining extremities that did not have simultaneous hamstring lengthenings. Gage et al[43] found that after rectus transfers in conjunction with hamstring releases that there was significant improvement in flexion at the knee, however, the hip and pelvis were not investigated. Hsu and Li[57] in 1991 studied hamstring lengthening on forty-nine subjects with spastic C.P. and found an increase in hip flexion with and increased lumbar lordosis. The authors attributed this finding to weakened hip extension secondary to the hamstring releases. Further research is indicated to examine the position of the hip along with the pelvis after these surgeries to determine if these changes are representative of a larger population of spastic diplegia gait patterns.

Sagittal plane joint excursion measurements did not yield significant improvement in this surgical group. Previous research by Gage et al[43] found statistically significant improvements in sagittal plane knee excursion following rectus femoris transfer on a group of children with spastic cerebral palsy that were diagnosed with a "stiff knee" gait and abnormal activity of the rectus femoris during swing phase of gait.[43] The surgical group in Gage's study had specific criteria for surgery that included restriction of knee motion of at least twenty per cent (less than 45 degrees of knee flexion extension on dynamic motion curves), and abnormal rectus femoris activity found on dynamic EMG during swing phase gait.

The orthopaedic group in this study had no significant changes in joint excursion following surgeries. These differences may be related to different criteria used for surgical intervention in this group that did not match the criteria used by Gage et al[43]. One of the four orthopaedic subjects had in excess of 45 degrees of knee motion preoperatively and may have affected the overall outcome of the statistical analysis.

Dorsal Rhizotomy Group

In the dorsal rhizotomy group, it was hypothesized that there would be statistically significant increases in time and distance parameters of gait and joint rotation angles one year postoperatively. There were five variables that significantly changed after surgery in this particular group of children with spastic diplegia.

The increase in hip excursion in this group is consistent with results reported by

Vaughen et al in which hip excursion significantly increased in excess of normal after the surgery.[48] Vaughen also found in the three year postoperative follow up study that overall lower extremity joint excursion had a tendency to become closer to normal.[58] The significant increase in knee excursion that was found by Vaughen's group was not found in this study.

Boscarino et al[59] reported preliminary results on a sample of seven children and found significant increases in knee excursion following dorsal rhizotomy. Peacock and Staudt[60] also reported improvement in the thigh and knee ranges on gait analysis after dorsal rhizotomy.

The lack of significant improvement in knee excursion in this study may have been related to the range that was available at the knee preoperatively in the sample. Two of the ten extremities had knee motion in excess of 50 degrees on dynamic motion curves that may have limited the statistical changes postoperatively in this small group.

Analysis of the data reveal that most of the statistically significant changes in the dorsal rhizotomy group occurred at the knee and ankle during initial contact and midstance. These changes correlate with research done by Cahan et al[49] who found significant improvements in sagittal plane joint rotation angles at the knee and ankle at these same points during stance.

In this dorsal rhizotomy surgical group, there was also limited statistical improvement in the time and distance parameters of stride length, velocity and single limb support. A previous study published by Cahan's group found statistically significant changes in velocity and stride length, with no significant changes in single limb support, stance or swing ratio.[49]

Vaughen et al[48] found improvement in stride length following dorsal rhizotomy, but no significant improvement in velocity at one year postoperatively.[44] Boscarino's group found no statistically significant changes in the stride parameters based on their preliminary results.[59] The inconsistencies documented in these studies should be further investigated.

Foot progression angle was not statistically improved after dorsal rhizotomy. Five of ten extremities in the dorsal rhizotomy group improved postoperatively closer to a normal range of 8-16 degrees of external rotation.

Comparison Between Groups

It was hypothesized that postoperatively there would be differences in foot progression angle and joint rotation angles between the two groups. Differences were demonstrated in stride length, overall hip excursion, and the hip angle at foot off. All three variables were more improved in the dorsal rhizotomy group postoperatively.

There appeared to be improvement in the sagittal plane variables in both groups, with little statistical improvement in the stride parameters of gait. A factor which may account for this lack of statistical change in the time and distance parameters of gait may be related to the subjects performance with orthotics versus barefoot trials. Seven of nine subjects in this study wore some type of orthotic around the ankle and foot complex appeared to have improved gait that was not measured in this study.

There was more sagittal plane improvement in the dorsal rhizotomy group with five sagittal plane variables improved compared to three sagittal plane variables improved in the orthopaedic group.

It was hypothesized that the orthopaedic group would demonstrate more improvement in the foot progression angle postoperatively because of the ability of orthopaedic surgery to specifically address the rotational deformities in this population. The lack of significant change in this group may be related to the limited sample size and the limited surgical procedures that were specifically utilized in this group that attempted to alter rotation. Two of the four subjects in the orthopaedic group underwent subtalar fusions. This surgical procedure directly alters the foot position to a more neutral position, and should therefore change the overall direction of the limb in the transverse plane. This did not appear to be the case with these two subjects as only one of the subjects had an improvement closer to a normal range of foot progression. The other subject had a reverse in the direction of foot progression from excessive external rotation to excessive internal rotation, with no effective change in the direction of the limb in the transverse plane. Oppenheim[61] pointed out that dorsal rhizotomy and orthopaedic surgeries should be used in combination in order to effectively address all planes of motion and pathology. Further research into transverse plane foot progression angle may support this opinion.

Implications For Future Research

As was noted in the discussion, further research could be done to investigate the findings of this study. This should include increasing the sample sizes and including specific populations of children with more similar gait patterns. Establishing criteria by specific pathological gait patterns may yield interesting results regarding both surgeries and the effects on gait.

Research that examines the transverse and frontal plane changes in addition to the sagittal plane at the pelvis and lower extremity should be included. Stance and swing phase gait should also be included in order to thoroughly examine the surgical effects of both surgeries. Normal gait is a dynamic activity in which the limbs alternate between stance and swing phase. Many of the problems that occur during stance may be related to problems during swing. This study was limited to examining joint rotation angles during stance phase of gait, however, in order to fully understand the outcome of these surgeries, swing phase joint rotation angles should also be examined. The primary goals of swing phase gait are to clear the foot from the ground, control the momentum of the limb and conserve energy, and to position the limb for initial contact.[10] A good understanding of the postoperative changes during swing in these two surgical groups may provide additional insight into the lack of significant improvement of the time and distance variables. Also including the electromyographic changes and the kinetic changes that occurred postoperatively in both groups may assist with interpreting the implications for the specific surgical interventions.

The area of adverse change in the orthopaedic group should be further investigated by examining the rectus transfers with and without medial hamstring releases. This type of study should include the effects on the pelvis and lower extremity joints throughout stance and swing.

An area to further investigate would be the changes that occurred postoperatively with orthotics. Both surgeries did not result in "normal" gait parameters, however, most subjects had additional improvement in gait efficiency with orthotics that were not measured in this study. Correlating specific gait patterns with a specific surgery that creates a more optimal position of the lower extremity for bracing would assist in appropriate selection of orthotic and surgical intervention.

In the dorsal rhizotomy group, postoperative changes that did not correlate with previous studies may be related to different surgeons performing the surgeries. Because of the selection process intra-operatively, there may be differences between surgeons regarding which rootlets are cut and how many are cut. An investigation that collected data from multiple surgeons may yield more accurate data for generalizability of the surgical effects.

An area of potential differences between groups of subjects undergoing dorsal rhizotomy that could be investigated in future studies are the differences in the selection process of candidates for dorsal rhizotomy. According to Peacock and Ariens, maximum benefit is achieved from subjects who have "a certain amount of voluntary muscle" before the surgery.[18] Coiffi and Gaebler-Spira[62] qualify the selection process to include spastic diplegia or quadriplegia with Fair to Good underlying muscle strength. The importance of assessing adequate strength for potential candidates is difficult due to the presence of spasticity. Many hospitals are organizing criteria for assessing strength and underlying motor control. As these criteria are being developed, appropriate research should be done to determine if the criteria are reliable indicators for a successful rehabilitation after surgery.

Further research should include the types and amount of therapeutic intervention that the subjects received during the twelve months between surgery and the second gait analysis. Subjects that underwent dorsal rhizotomy at Children's Hospital participated in an established preoperative selection procedure and postoperative therapy protocol. This may have accounted for the positive outcome on gait parameters following surgery in the dorsal rhizotomy. This type of study may provide for more effective treatment programming and justification for therapeutic intervention.

Continued research in this area can assist with determining what type of surgical intervention is appropriate for specific gait pathology. By comparing the pre and postoperative results from each classification of cerebral palsy, results can be accumulated and compared between the surgeries. The diversity of problems that are manifested in cerebral palsy make a true homogeneous sample impossible, however by limiting the sample to include those children that could be treated by either surgery, the risk of a heterogeneous sample will be minimized.

Measurements of energy consumption would provide additional insight into the changes in gait efficiency in both groups. Reliable measurements of energy consumption could provide evidence for one or both of the surgical interventions.

CHAPTER 5

CONCLUSIONS

Instrumented gait analysis revealed statistically significant changes after dorsal rhizotomy in hip excursion, knee rotation angles at initial contact and midstance and ankle rotation angles at initial contact and midstance. There were statistically significant changes in the orthopaedic group at the knee at initial contact and the ankle at initial contact and midstance. In comparing the orthopaedic group and the dorsal rhizotomy groups, there were significant differences in postoperative changes in stride length, sagittal plane hip excursion, and the position of the hip at foot off. All three variables had more improvement postoperatively in the dorsal rhizotomy group when compared to the orthopaedic group.

Overall, there was improvement in both groups, with a greater amount of sagittal plane variable changes in the dorsal rhizotomy group.

1. Inman VT, Ralson HJ, Todd F. *Human Walking*. Baltimore,Md: Williams & Wilkins,1981.

2. Sutherland DH, Olshen R, Cooper L, Woo SL. The Development of Mature Gait. *J Bone Joint Surg*. 1980;62-A:336-353.

3. Kadaba MP, Ramakrishnan HK, Gainey J, Gorton G, Cochran GVB. Repeatability of Kinematic, Kinetic and Electromyographic Data in Normal Adult Gait.*J Ortho Res*.1989;17:849-860.

4. Perry H, Hoffer M, Antonelli D, Plut H, Lewis G, Greenberg R. Electromyography Before and After Surgery for Hip Deformity in Children with Cerebral Palsy. *J Bone Joint Surg*.1976;58-A:201-208.

5. Gage JR, Fabian D, Hicks R, Tashman S. Pre- and Postoperative Gait Analysis in Patients with Spastic Diplegia: A Preliminary Report.*J Pediatr Orthop*.1984;4:715-725.

6. Perry J, Hoffer MM, Giovan P, Antonelli D, Greenburg R. Gait Analysis of the Triceps Surae in Cerebral Palsy: A Preoperative and Postoperative Clinical and Electromyographic Study. *J Bone Joint Surg*. 1974;56:511-520.

7. Bleck, E. *Orthopaedic Management of Cerebral Palsy*. Philadelphia, Pa: WB Saunders Co;1979.

8. Rang M. In:Morrissey RT,ed. *Lovell and Winters Pediatric Orthopaedics.3 ed.* Philadelphia, Pa: J.B. Lippincott Co; 1990: Chapter 13.

9. DeLuca, PA. Gait Analysis in the Treatment of the Ambulatory Child with Cerebral Palsy. *Clin Orthop*.1991;262:65-75.

10. Gage, JR. An Overview of Normal and Cerebral Palsy Gait. *Neurosurgery: State of the Art Reviews*.1989;4:379-401.

11. Drennan, JC. *Neuromuscular Disorders*.Philadelphia, Pa:J.B. Lippincott Co; 1983.

12. Sage, FP. In:Crenshaw, AH ed. *Campbell's Operative Orthopaedics. 7 ed.* St.Louis, Mo: C.V.Mosby Co;1987:4:Chapter 65.

13. Smith JT, Stevens PM. Combined Adductor Transfer, Iliopsoas Release, and Proximal Hamstring Release in Cerebral Palsy. *J Pediatr Orthop*.1989;9:1-5.

12. Okawa A,Kajiura I, Hiroshima K. Physical, Therapeutic and Surgical Management in Spastic Diplegia.A Japanese Experience. *Clinical Orthop Rel Res.* 1990;253:38-44.

15. Fasano VA, Broggi G, Barolat-Ramana, Squazzi A. Surgical Treatment of Spasticity in Cerebra Palsy. *Child's Brain.*1978:4;289-305.

16. Sherrington S. Decerebrate Rigidity and Reflex Coordination of Movements. *J Physio (London).* 1898;22:319-337.

17. Foerester O. On the Indications and Results of the Excision of Posterior Spinal Nerve Roots. *Med Surg Gynecol Obstet.*1913;16:474-494.

18. Peacock WJ, Arens LJ. Selective Posterior Rhizotomy for the Relief of Spasticity in Cerebral Palsy. *Sa Mediese Tydskrif Deel.* 1982; 62:119-124.

19. Lance JW: Symposium synopsis. In: Feldman RG, Young RR, Koella WP. eds. *Spasticity: Disordered Motor Control.* Chicago, Il: Yearbook Medical;1980:485.

20. Carr JH, Shepherd RB. Physiotherapy in Disorders of the Brain . Aspen Publishers Inc; London, 1980:258-263.

21. Guiliani, CA. Dorsal Rhizotomy for Children with Cerebral Palsy: Supports for Concepts of Motor Control. *Phys Ther.* 1991;71:248-259.

22. Laitinen LV, Nilsson S, Fugl-Meyer, AR. Selective Posterior Rhizotomy for Treatment of Spasticity. *J Neurosurg.* 1983;58:895-899.

23. Saunders JB, Inman VT, Eberhart HD. The Major Determinants in Normal and Pathological Gait. *J Bone Joint Surg.* 1953;35-A:543-558.

24. Perry, J.The Mechanics of Walking. A Clinical Interpretation. *Phys Ther.* 1967;47:778-801.

25. Murray MP, Drought AB, Kory RC. Walking Patterns of Normal Men. *J Bone Joint Surg.* 1964;46-A:335-360.

26. Aptekar RG, Ford F, Bleck EE. Light Patterns as a Means of Assessing and Recording Gait.I: Methods and Results from Normal Children. *Dev Med Child Neurol.* 1976;18:31-36.

27. Ounpuu, S. Terminology Used in Gait Analysis. Presented at 3D Clinical Gait Analysis: Methods and Data Interpretation; April 17;1991.Newington, Ct.

28. Winter, DA. *The Biomechanics and Motor Control Of Human Walking*. Waterloo, Ontario: University of Waterloo Press;1987.1-20.

29. Ogg, M. Measuring and Evaluating Gait Patterns of Children. *J AM Phys Ther Assoc.*1963;43:717-720.

30. Sutherland, DA. *Gait Disorders in Childhood and Adolescence*. Baltimore: Williams & Wilkins;1984.

31. Bobath K, Bobath B. In:Pearson PH, Williams CE, eds. *Physical Therapy Services in the Developmental Disabilities*. Springfield, Il: Charles C Thomas; 1972: Chapter 3.

32. Moore J. In: Selected Proceedings from Barbro Salek Memorial Symposium. NDTA, Inc. 1984:53-58.

33. Minear WL. A Classification of Cerebral Palsy. *Pediatrics*. 1956; 18:841.

34. Sutherland, DA. Gait Analysis in Cerebral Palsy. *Dev Med Child Neurol.* 1978;20:807-813.

35. Perry,J. In:Samilson Rl, ed. *Orthopaedic Aspects of Cerebral Palsy*. Philadelphia, Pa: J.P. Lippincott Co;1975:Chapter 4B.

36. Bobath K. *The Motor Deficits in Patients with Cerebral Palsy*. William Heinemann Medical Books Ltd and The Spastics Society Medical Education and Information Unit. 1966

37. Sutherland DH, Cooper AS. The Pathomechanics of Progressive Crouch Gait in Spastic Diplegia. *Orthop Clinics of North America.* 1978;9:143-154.

38. Perry J. Distal Rectus Femoris Transfer. *Dev Med Child Neurol.* 1987;29:153-158.

39. Aptekar RG, Ford F, Bleck EE. Light Patterns as a Means of Assessing and Recording Gait. II: Results in Children with Cerebral Palsy. *Dev Med Child Neurol.* 1976;28:37-40.

40. Winters TF, Gage JE, Hicks RA. Gait Patterns in Spastic Hemiplegia in Children and Young Adults. *J Bone Joint Surg*. 1987;69-A:437-441.

41. Kadaba MP. Quantitative Clinical Gait Analysis: A Philosophical Perspective. Presented at the East Coast Clinical Gait Laboratory Conference;Nov 2, 1991;Richmond, Va.

42. Perry J, Hoffer MM. Dynamic Electromyography as an Aid in Planning Tendon Transfers in Children with Cerebral Palsy. *J Bone Joint Surg*. 1977;59-A:531-537.

43. Gage JR, Perry J, Hicks RR, Koop S, Werntz, VR. Rectus Femoris Transfer to Improve Knee Function of Children with Cerebral Palsy. *Dev Med Child Neuro*. 1987;29:159-166.

44. Hoffer MM, Reiswig JA, Garrett AM, Perry J. Split Anterior Tibial Tendon Transfer in Treatment of Spastic Varus Hindfoot of Children. *Orthop Clin North Am*. 1974;5:31-38.

45. Brunt D, Scarborough N. Ankle Muscle Activity During Gait in Children with Cerebral Palsy and Equinovarus Deformity. *Arch Phys Med Rehabil*. 1988;69:115-117.

46. Sutherland DH, Schottstaedt ER, Larsen LG, Ashley RK, Callander JM, James PM. Clinical and Electromyographic Study of Seven Spastic Children with Internal Rotation Gait. *J Bone Joint Surg*. 1969;51-A:1070-1082.

47. Shapiro A, Susak Z, Malkin C, Mizrahi J. Preoperative and Postoperative Gait Evaluation in Cerebral Palsy. *Arch Phys Med Rehabil*. 1990;71:236-240.

48. Vaughen CL, Berman B, Staudt LA, Peacock WJ. Gait Analysis of Cerebral Palsy Children Before and After Rhizotomy. *Pediatr Neurosci*. 1988;14:297-300.

49. Cahan LD, Adams JM, Perry J, Beeler LM. Instrumented Gait Analysis After Selective Dorsal Rhizotomy. *Dev Med Child Neurol*. 19909;32:1037-1043.

50. Norkin CC, White DJ. *Measurement of Joint Motion: A Guide to Goniometry*. Philadelphia, Pa:F.A. Davis Co.;1985.

51. Sutherland DH, Olshen, Biden, Wyatt. *The Development of Mature Walking*. London, Eng:MacKeith Press;1988.17.

52. Kadaba MP, Ramadrishnan HK, Wooten ME. Measurement of Lower Extremity Kinematics During Level Walking. *Orthop Res*. 1990;8:383-392.

53. Thometz J, Simon S, Rosenthal R. The Effect on Gait of Lengthening of the Medial Hamstrings in Cerebral Palsy. *J Bone Joint Surg*.1989;71-A:345-353.

54. Scrutton,DR. Footprint of Normal Children Under Five Years Old. *Dev Med Child Neurol*.1969;11:44-53.

55. Stretcker WB, Via MW, Oliver SK, Schoenecker PL. Heel Cord Advancement for Treatment of Equinus Deformity in Cerebral Palsy. *J Pediatr Orthop*. 1990;10:105-108.55.

56. Sutherland DH, Santi M, Abel M. Treatment of Stiff Knee Gait n Cerebral Palsy: A Comparison by Gait Analysis of Distal Rectus Femoris Transfer versus Proximal Rectus Release. *J Pediatr Orthop*.1990;10:433-441.

57. Hsu LCS, Li HSY. Distal Hamstring Elongation in the Management of Spastic Cerebral Palsy. *J Pediatr Orthop*. 1990;10:378-381.

58. Vaughen CL, Berman B, Peacock WH. Cerebral Palsy and Rhizotomy: A Three Year Follow Up Evaluation with Gait Analysis. *J Neurosurg*. 1991;74:178-184.

59. Boscarino L, Ounpuu S, Gage JR. The Effects of a Selective Dorsal Rhizotomy in Children with Cerebral Palsy. In: Proceedings From the East Coast Clinical Gait Conference; West Haverstraw, N.Y. Abstract.

60. Peacock WH, Staudt LA. Functional Outcomes Following Selective Posterior Rhizotomy in Children with Cerebral Palsy. *J Neurosurg*. 1991;74:380-385.

61. Oppenheim,WL. Selective Posterior Rhizotomy for Spastic Cerebral Palsy. A Review. *Clinical Orthop Rel Res*. 1990;253:20-29.

62. Coiffi M, Gaebler-Spira DJ. Selective Posterior Rhizotomy and the Child with Cerebral Palsy. *Topics in Pediatrics*.1990: American Physical Therapy Association.Lesson 10, pages 1-14.

TABLE 1

SUMMARY OF SUBJECTS SURGICAL INTERVENTIONS

CASE	AGE	PREOP SURGERIES	SURGERIES
1	8	B Med Hams Rel B Adductor Rel	B Subtalar Fusions B Rectus Fem Transfers B Percutaneous TAL
2	17	B Med Hams Rel	B Rectus Fem Transfers B Percutaneous Hams Rel
3	9	B TAL	B Rectus Fem Transfers Right TAL
4	4	None	B Rectus Fem Transfers B Med Hams Rel B TAL B Subtalar Fusions
5	5	B Add Tenotom B Iliospoas Rel B Gracilis Rel	Dorsal Rhizotomy
6	5	None	Dorsal Rhizotomy
7	6	None	Dorsal Rhizotomy
8	10	None	Dorsal Rhizotomy
9	10	None	Dorsal Rhizotomy

B=Bilateral; Med= Medial; Rel= Releases; Hams= Hamstring; TAL= Tendo-Achilles Lengthening; Fem=Femoris; Add= Adductor; Tenotom= Tenotomies.

TABLE 2

CHANGE IN KNEE ROTATION ANGLES AT INITIAL CONTACT TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	16.2 deg (14.3)	10.3 deg (6.4)
TEST STATISTIC (within group)	3.565826	4.539571
p-VALUE (within group)	.006*	.003*
TEST STATISTIC (between groups)	-1.1728	
p-VALUE (between groups)	.26	

* significant at $p \leq .05$

@ Normal= 3 degrees flexion

TABLE 3

CHANGE IN ANKLE ROTATION ANGLES AT INITIAL CONTACT TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	7.9 deg (8.1)	11.3 deg (13.7)
TEST STATISTIC (within group)	3.067592	2.324676
p-VALUE (within group)	.01*	.05*
TEST STATISTIC (between groups)	.6467	
p-VALUE (between groups)	.53	

* significant at $p \leq .05$

@ Normal= 0 degrees dorsiflexion/plantarflexion

TABLE 4

CHANGE IN ANKLE ROTATION ANGLES AT MIDSTANCE TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	7.1 deg (10.1)	13.9 deg (14.1)
TEST STATISTIC (within group)	2.224429	2.774133
p-VALUE (within group)	.05*	.03*
TEST STATISTIC (between groups)	1.1867	
p-VALUE (between groups)	.25	

* significant at $p \leq .05$

@ Normal= 9 degrees dorsiflexion

TABLE 5

CHANGE IN HIP ROTATION ANGLES AT FOOT OFF TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	1.6 deg (8.3)	-5.9 deg (6.1)
TEST STATISTIC (within group)	.607449	-2.71161
p-VALUE (within group)	.56	.03*
TEST STATISTIC (between groups)	-2.1162	
p-VALUE (between groups)	.05*	

* significant at $p \leq .05$

@ Normal= 0 degrees flexion/extension

TABLE 6

CHANGE IN KNEE ROTATION ANGLES AT MIDSTANCE TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	12.0 deg (14.3)	7.9 deg (9.7)
TEST STATISTIC (within group)	2.656845	2.285465
p-VALUE (within group)	.03*	.06
TEST STATISTIC (between groups)	-0.6956	
p-VALUE (between groups)	.50	

* significant at $p \leq .05$

@ Normal= 0 degrees flexion/extension

TABLE 7

CHANGE IN TOTAL HIP EXCURSION

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	5.4 deg (7.9)	-3.9 deg (7.2)
TEST STATISTIC (within group)	4 #	-9 #
p-VALUE (within group)	.02*	.17
TEST STATISTIC (between groups)	-2.5657	
p-VALUE (between groups)	.02*	

* significant at $p \leq .05$

# Indicates Wilcoxon Sign Test Statistic used based on the results of the Wilkes-Shapiro Test.

TABLE 8

CHANGE IN STRIDE LENGTH

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	17.4% (15.1)	-3.8% (5.4)
TEST STATISTIC (within group)	7.5 #	-1.37892
p-VALUE (within group)	.06	.26
TEST STATISTIC (between groups)	-2.6353	
p-VALUE (between groups)	.03*	

* significant at $p \leq .05$

# Indicates Wilcoxon Sign Test Statistic used based on the results of the Wilkes-Shapiro Test.

TABLE 9

CHANGE IN TOTAL HIP EXCURSION TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	-1.5 deg (7.2)	2.0 deg (6.1)
TEST STATISTIC (within group)	-0.65744	2.5 #
p-VALUE (within group)	.53	.69
TEST STATISTIC (between groups)	1.0905	
p-VALUE (between groups)	.29	

# Indicates Wilcoxon Sign Test Statistic used based on the results of the Wilkes-Shapiro Test.

@ Normal= 43 degrees flexion/extension

TABLE 10

TOTAL CHANGE IN KNEE EXCURSION

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	12.7 deg (21.1)	-0.4 deg (26.5)
TEST STATISTIC (within group)	1.902599	5.5 #
p-VALUE (within group)	.09	.48
TEST STATISTIC (between groups)	-1.1669	
p-VALUE (between groups)	.26	

# Indicates Wilcoxon Sign Test Statistic used based on the results of the Wilkes-Shapiro Test.

TABLE 11

CHANGE IN KNEE EXCURSION TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	8.8 deg (17.3)	6.8 deg (10.8)
TEST STATISTIC (within group)	1.602031	1.764507
p-VALUE (within group)	.14	.12
TEST STATISTIC (between groups)	-0.2908	
p-VALUE (between groups)	.78	

@ Normal= 57 degrees flexion/extension

TABLE 12

CHANGE IN ANKLE EXCURSION

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	-5.8 deg (26.7)	-12.9 deg (16.9)
TEST STATISTIC (within group)	-0.93166	-2.15717
p-VALUE (within group)	.38	.07
TEST STATISTIC (between groups)	-0.6501	
p-VALUE (between groups)	.52	

TABLE 13

CHANGE IN ANKLE EXCURSION TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	9.2 deg (20.7)	4.6 deg (6.3)
TEST STATISTIC (within group)	10 #	2.091364
p-VALUE (within group)	.33	.07
TEST STATISTIC (between groups)	-0.6787	
p-VALUE (between groups)	.51	

# Indicates Wilcoxon Sign Test Statistic based on the results of the Wilkes-Shapiro Test.

@ Normal= 26 degrees dorsiflexion/plantarflexion

TABLE 14

CHANGE IN HIP ROTATION ANGLES AT INITIAL CONTACT TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	2.0 deg (8.9)	2.1 deg (8.0)
TEST STATISTIC (within group)	3 #	.748902
p-VALUE (within group)	.74	.48
TEST STATISTIC (between groups)	0.0309	
p-VALUE (between groups)	.98	

# Indicates Wilcoxon Sign Test Statistic based on the results of the Wilkes-Shapiro Test.

@ Normal= 36 degrees flexion

TABLE 15

CHANGE IN HIP ROTATION ANGLES AT MIDSTANCE TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	2.2 deg (13.0)	.5 deg (10.2)
TEST STATISTIC (within group)	.534698	.1390589
p-VALUE (within group)	.61	.89
TEST STATISTIC (between groups)	-0.3024	
p-VALUE (between groups)	.77	

@ Normal= 9 degrees flexion

TABLE 16

CHANGE IN KNEE ROTATION ANGLES AT FOOT OFF TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	4.2 deg (13.9)	5.3 deg (8.9)
TEST STATISTIC (within group)	.957518	1.669916
p-VALUE (within group)	.36	.14
TEST STATISTIC (between groups)	0.1852	
p-VALUE (between groups)	.86	

@ Normal= 39 degrees flexion

TABLE 17

CHANGE IN ANKLE ROTATION ANGLES AT FOOT OFF TOWARD NORMAL@

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	10.4 deg (18.0)	13.4 deg (18.9)
TEST STATISTIC (within group)	1.825717	2.002638
p-VALUE (within group)	.10	.09
TEST STATISTIC (between groups)	0.3408	
p-VALUE (between groups)	.74	

@ Normal= 12 degrees plantarflexion

TABLE 18

CHANGE IN VELOCITY

	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	4.0% (12.7)	-6.6 % (24.4)
TEST STATISTIC (within group)	.702327	-0.5411
p-VALUE (within group)	.52	.62
TEST STATISTIC (between groups)	-0.8505	
p-VALUE (between groups)	.42	

TABLE 19

CHANGE IN SINGLE LIMB SUPPORT TOWARD NORMAL

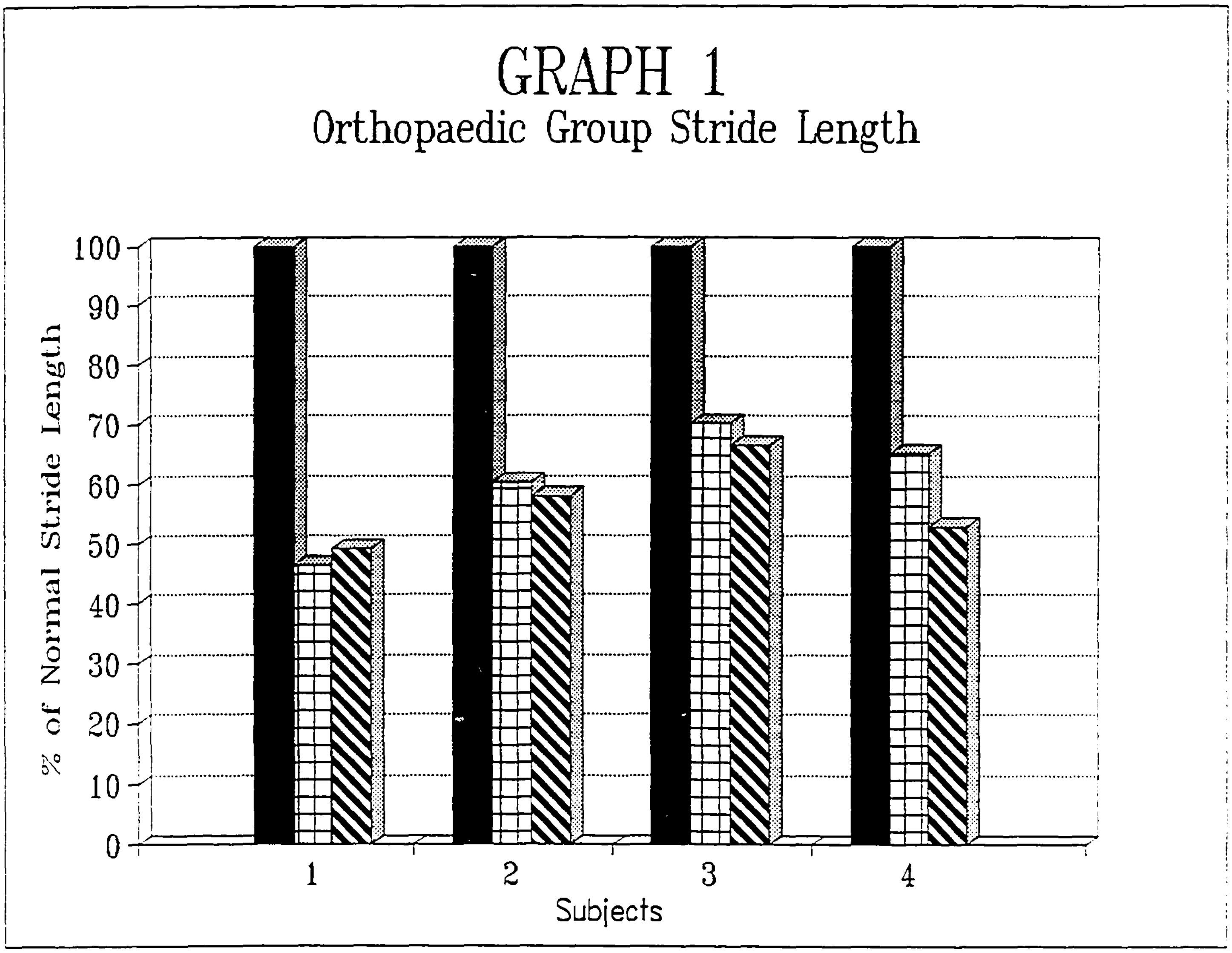
	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	1.5 % (23.9)	-14.4 % (12.3)
TEST STATISTIC (within group)	0.140894	-2.33378
p-VALUE (within group)	.90	.10
TEST STATISTIC (between groups)	-1.1955	
p-VALUE (between groups)	.27	

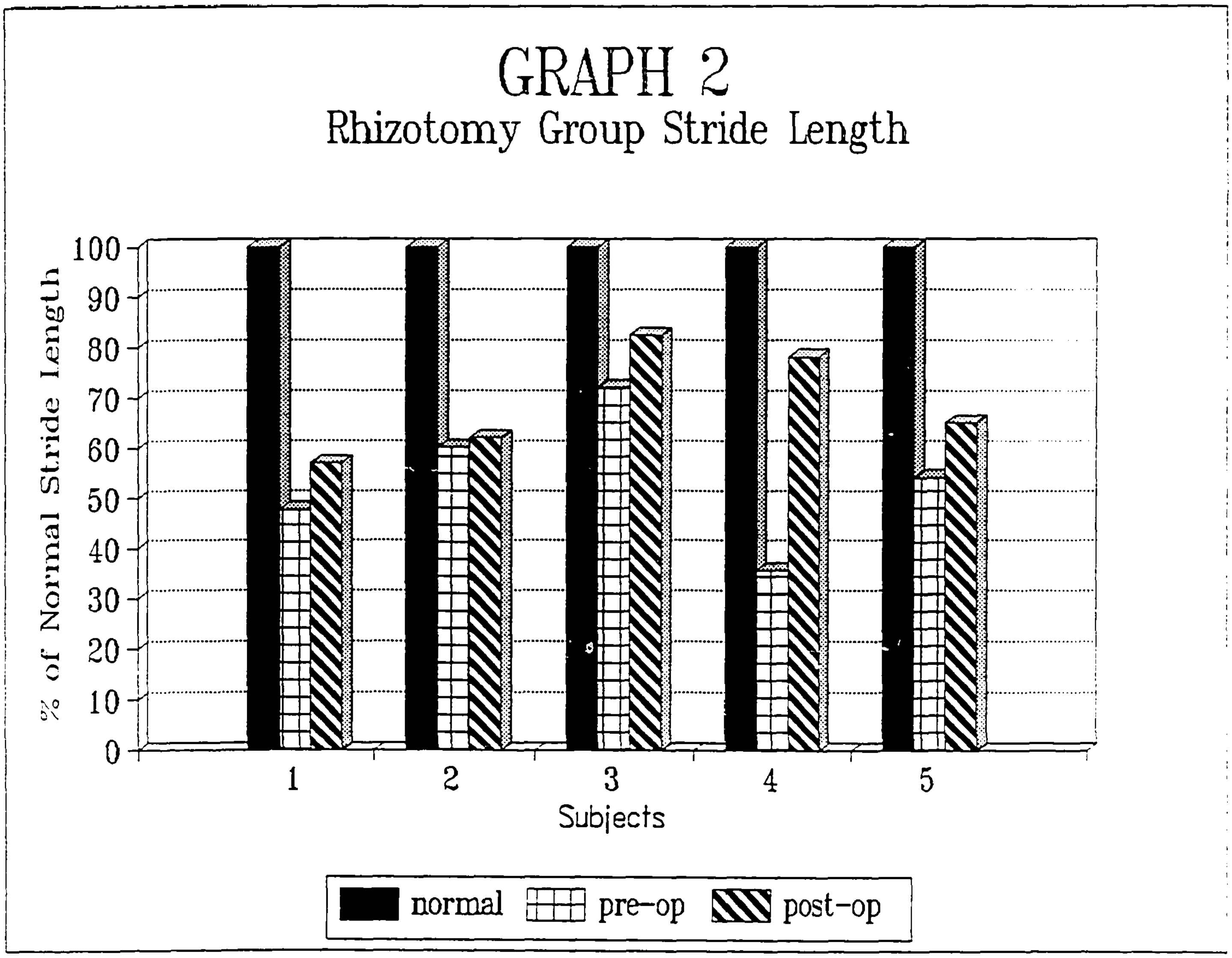
TABLE 20

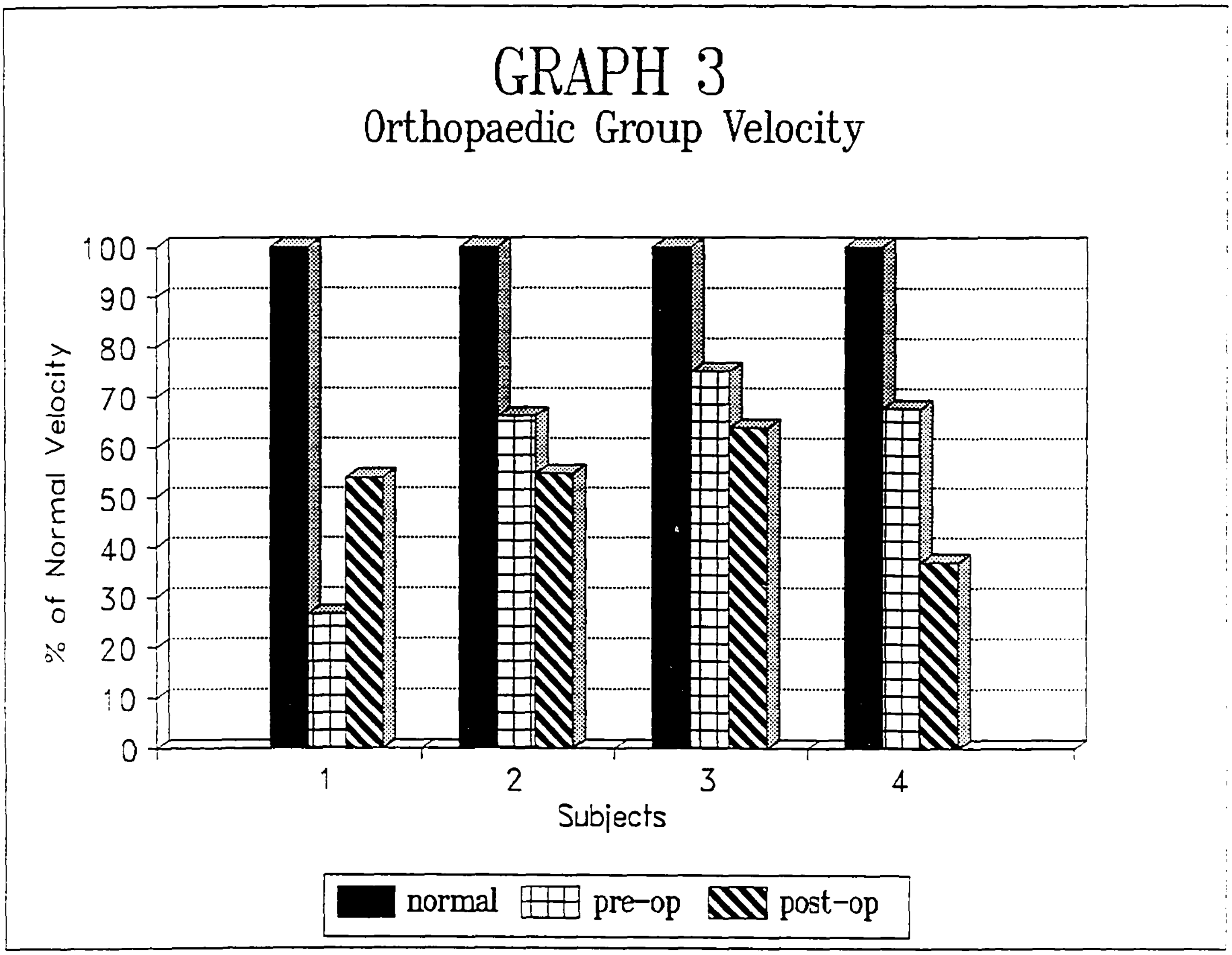
CHANGE IN FOOT PROGRESSION ANGLE TOWARD NORMAL@

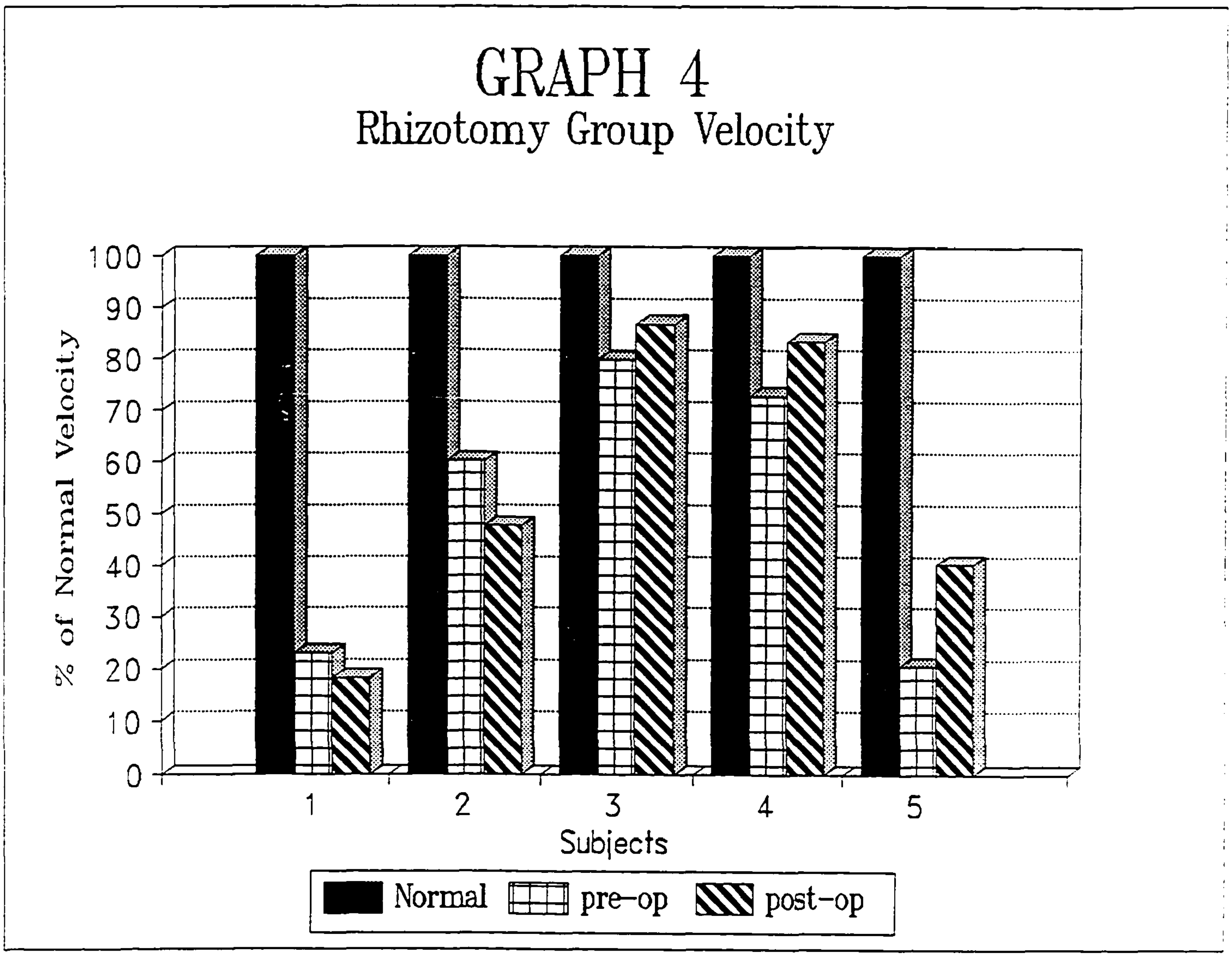
	RHIZOTOMY GROUP	ORTHOPAEDIC GROUP
MEAN CHANGE (±SD)	8.6 deg (19.8)	4.9 deg (12.4)
TEST STATISTIC (within group)	1.369245	1.107589
p-VALUE (within group)	.20	.30
TEST STATISTIC (between groups)	-0.4614	
p-VALUE (between groups)	.65	

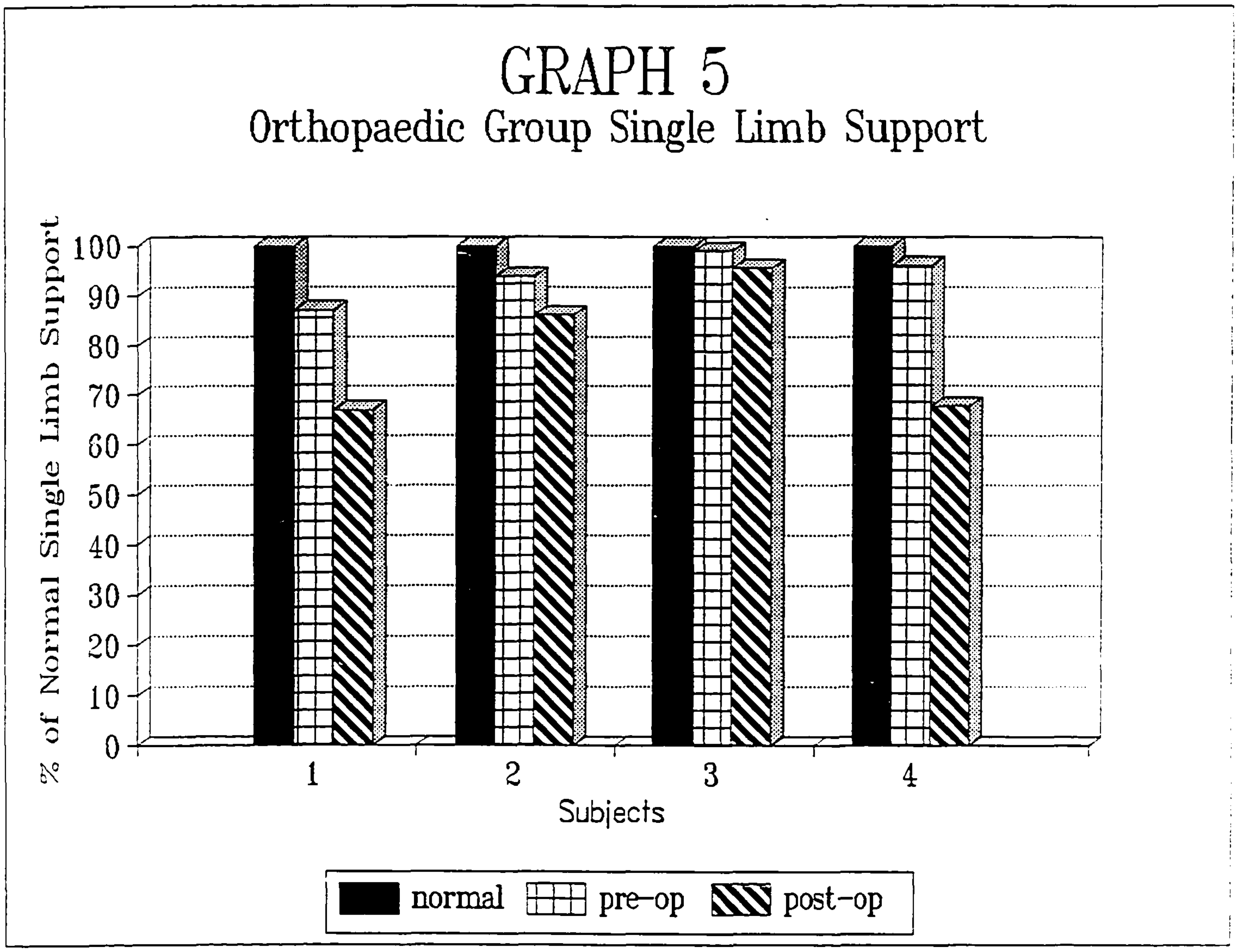
@ Normal= 8-12 degrees of external rotation

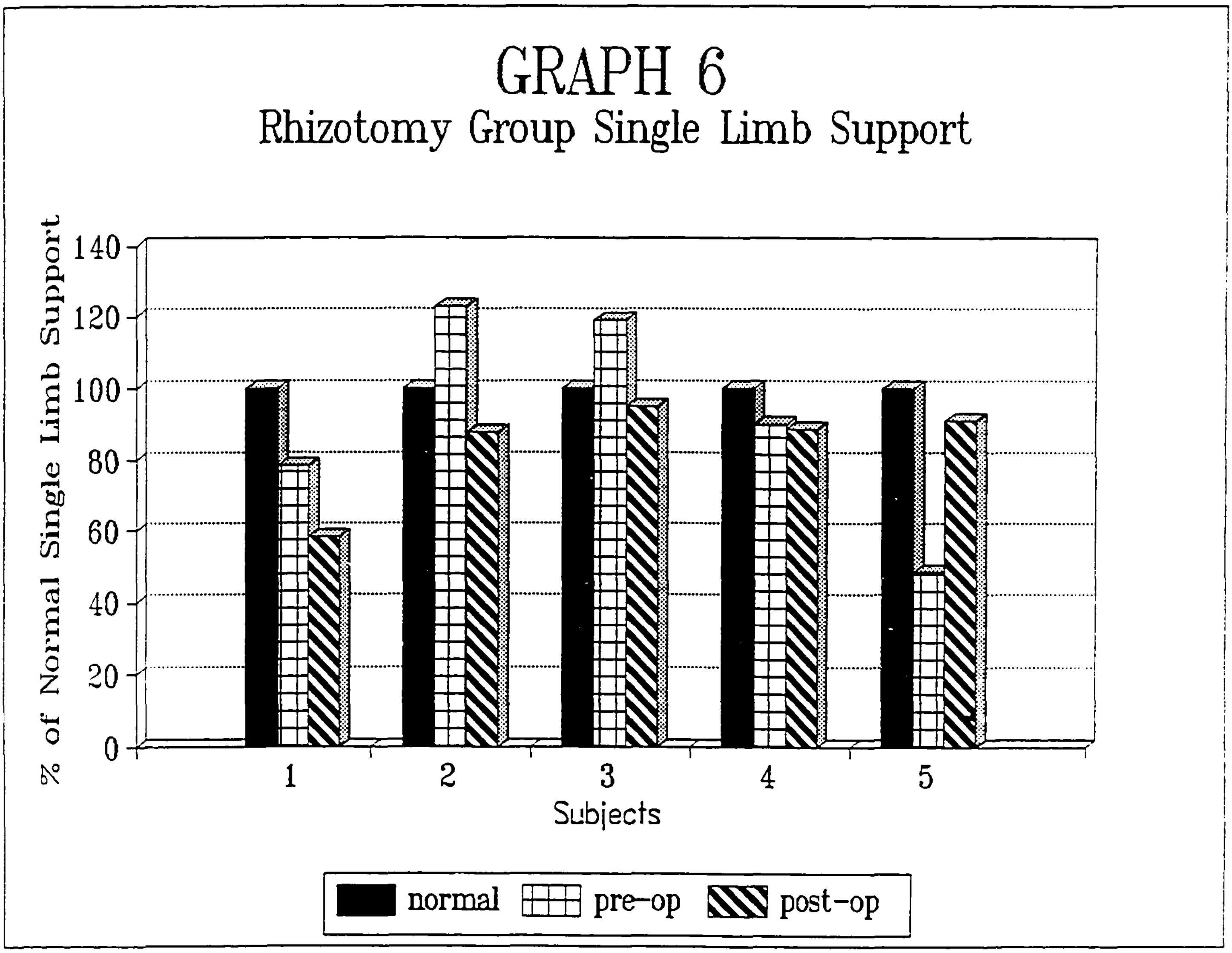

GRAPH 1
Orthopaedic Group Stride Length
100
90
80
70
60
50
40
30
20
10
0
% of Normal Stride Length
1
2
3
4
Subjects


GRAPH 2
Rhizotomy Group Stride Length
% of Normal Stride Length
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
Subjects
normal
pre-op
post-op


GRAPH 3
Orthopaedic Group Velocity
% of Normal Velocity
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
Subjects
normal
pre-op
post-op


GRAPH 4
Rhizotomy Group Velocity
100
90
80
70
60
50
40
30
20
10
0
% of Normal Velocity
1
2
3
4
5
Subjects
Normal
pre-op
post-op


GRAPH 5
Orthopaedic Group Single Limb Support
% of Normal Single Limb Support
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
Subjects
normal
pre-op
post-op


GRAPH 6
Rhizotomy Group Single Limb Support
% of Normal Single Limb Support
140
120
100
80
60
40
20
0
1
2
3
4
5
Subjects
normal
pre-op
post-op

APPENDIX A

VICON FIVE CAMERA MOTION ANALYSIS SYSTEM

Vicon Five Camera CCD motion analysis system is an optical tracking system with computer interfaced CCD-Based cameras that track the displacement of passive retroreflective markers simultaneously.

Five cameras are positioned around a 10 meter walkway.
Limb segment markers are placed on the pelvis and lower extremities at specific anatomical positions.
As the subject walks strobbed infrared light is reflected off of markers and transferred into the controlling computer.
After the anatomical landmarks have been identified for the computer, three-dimensional marker coordinates are computed and the rotation angles are caculated.

Along with this kinematic information, ground reaction forces are calculated from force plates embedded in the floor in addition to simultaneous electromyographic information from selected muscle groups.

* Vicon is produced by Oxford Metrics Ltd., Oxford, England

APPENDIX B

ORTHOPAEDIC GROUP

Variable:	X Preop	X Postop	p value	NL
stride length	61% NL	57% NL	.26	100%
s l s	94% NL	79% NL	.10	100%
velocity	59% NL	52% NL	.62	100%
hip excursion	46 deg	42 deg	.17	43 deg
knee excursion	40 deg	40 deg	.48	57 deg
ankle excursion	34 deg	21 deg	.07	26 deg
hip IC	47 deg	45 deg	.48.	36 deg fl
hip MS	21 deg	21 deg	.89	9 deg fl
hip FO	9 deg	15 deg	.03	0 deg fl
knee IC	38 deg	27 deg	.003	3 deg fl
knee MS	18 deg	17 deg	.06	6 deg fl
knee FO	27 deg	40 deg	.14	39 deg fl
ankle IC	12 deg PF	1 deg DF	.05	0 deg DF
ankle MS	8 deg PF	12 deg DF	.03	9 deg DF
ankle FO	26 deg PF	5 deg PF	.09	12 deg PF
foot angle	17 deg ER	9 deg ER	.30	8-16 deg ER

X=mean; NL=normal; deg=degrees; SLS=single limb support; IC=initial contact; MS=midstance; FO=foot off; foot angle=foot progression angle; fl=flexion; DF=dorsiflexion; PF=plantarflexion; ER=external rotation.

APPENDIX C

RHIZOTOMY GROUP

Variables	X Pre op	X Post op	p value	NL
stride length	54 % NL	69% NL	.06	100%
s l s	92% NL	84% NL	.90	100%
velocity	51% NL	55% NL	.52	100%
hip excursion	44 deg	50 deg	.02	43 deg
knee excursion	37 deg	50 deg	.09	57 deg
ankle excursion	38 deg	32 deg	.38	26 deg
hip IC	40 deg	42 deg	.74	36 deg fl
hip MS	17 deg	14 deg	.61	9 deg fl
hip FO	11 deg	9 deg	.56	0 deg fl
knee IC	41 deg	24 deg	.006	3 deg fl
knee MS	21 deg	8 deg	.03	6 deg fl
knee FO	35 deg	38 deg	.36	39 deg fl
ankle IC	1 deg DF	1 deg DF	.01	0 deg DF
ankle MS	7 deg DF	10 deg DF	.05	9 deg DF
ankle FO	9 deg PF	13 deg PF	.10	12 deg PF
foot angle	8 deg ER	11 deg ER	.20	8-16 deg ER

NL=normal; deg=degrees; SLS=single limb support; IC=initial contact; MS=midstance; FO=foot off; foot angle=foot progression angle; fl=flexion; DF=dorsiflexion; PF=plantarflexion; ER=external rotation.

APPENDIX D

NORMAL JOINT ROTATION CURVES