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The effects of selective dorsal rhizotomy and intensive rehabilitation training on the gait pattern of children with spastic diplegia

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November 1995

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements of the degree of Master of Science in Rehabilitation Science

ISBN 0-612-12280-8

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Abstract

Selective dorsal rhizotomy (SDR) has recently been used to improve function in children with cerebral palsy who have spasticity as a major handicapping condition. The primary purpose of this study is to describe the changes in the gait patterns of six children with spastic diplegia prior to and six months following SDR and intensive training intervention. Gait parameters (stride length, velocity, and cadence) and angular displacements (hip, knee, and ankle) as well as, muscle activation patterns of four lower extremity muscles, and movement skills were measured using kinematic, electromyography (EMG), and the Rusk Rhizotomy Evaluation Form respectively. Major results of this study were increased stride length, decreased velocity, and decreased cadence. Abnormal walking patterns as recorded by EMG remained relatively stable. The results of this study further support the efficacy of SDR and intensive training in young children by improving certain gait parameters.

Résumé

La radicellectomie dorsale sélective (RDS) a été utilisée récemment pour améliorer la fonction chez des enfants avec la paralysie cérébrale dont le principal facteur de handicap était la spasticité. Le but premier de cette étude était de décrire les changements dans le patron de marche de six enfants avec diplégie spastique avant, et six mois après la RDS et un entraînement intensif. Les paramètres de marche (longueur du pas, vitesse, et cadence) et les déplacements angulaires (hanche, genou, et cheville), ainsi que le patron d'activation de quatre muscles du membre inférieur et les habiletés de mouvement ont été mesurés a l'aide de la cinématique, L'électromyographie (EMG) et le "Rusk Rhizotomy Evaluation Form" respectivement. Les principaux résultats de cette étude étaient l'allongement de la longueur du pas, la réduction de la vitesse, et la diminution de la cadence. Le patron de marche anormal, tel qu'enregistré à l'aide de L'EMG, est resté relativement stable. Les résultats de cette étude supportent l'efficacité de la RDS combinée à un entraînement intensif chez des jeunes enfants en améliorant certains paramètres de marche.

Acknowledgments

I am greatly indebted to the Shriner's Hospital for Crippled Children in Montreal for its cooperation, particularly Dr. Jean-Pierre Farmer for providing me with subjects for this project. As well, this research was supported in part by a grant provided by the Shriner's Hospital for which I wish to express my unending gratitude. Additional thanks to Dr. Farmer and Dr. Ken Silver for their participation in the examining committee for this thesis. I wish to extend my appreciation to Joanne Gibis for her support and in providing me with a study leave without which completing this project would have been difficult.

In addition, I gratefully acknowledge the contributions of my supervisors, Dr. Annette Majnemer and Dr. Hugues Barbeau, whose invaluable input, support and academic leadership made this project possible. As well, I would like to thank Joanne Gibis, Luba Glasa, Eileen Kennedy, Michel Ladouceur, Shuk Man Poon, Kathleen Norman and André Pépin for their assistance in data collection and analysis.

I am also thankful to my family, Lewis, Julian and Dustin Gitelman for their continued understanding and encouragement throughout this research. Lastly, I would like to thank Jacqueline Durand and Lewis Gitelman for their assistance in document preparation.

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Abbreviations

2D	Two dimensional
3D	Three dimensional
CNS	Central nervous system
CP	Cerebral palsy
CPG	Central Pattern Generator
EMG	Electromyography
GA	Gastrocnemius
MH	Medial hamstrings
OT	Occupational therapy
PT	Physiotherapy
ROM	Range of motion
SDR	Selective dorsal rhizotomy
TA	Tibialis anterior
VL	Vastus lateralis

Objectives

The objectives of this descriptive study were to describe the changes in the locomotor patterns in six children with spastic cerebral palsy pre and 6 months post SDR. Gait parameters such as stride length, walking velocity, and cadence were evaluated to best describe the gait changes. Alterations in ankle, knee and hip angular displacements at heel contact, mid stance, toe off, and the following heel contact were analyzed. Gait EMG patterns of the gastrocnemius (GA), tibialis anterior (TA), vastus lateralis (VL), and medial hamstring (MH) muscles were described for two cases. In this analysis, the muscle activation timing and co-contraction on the locomotor pattern pre and post SDR was described.

Qualitative improvement in function, tone and range of motion have all been demonstrated post SDR. However, quantitative evaluation of the pre and postoperative gait patterns of patients undergoing SDR is important to establish the efficacy of this surgery in the treatment of patients with cerebral palsy.

Literature Review

Cerebral Palsy

Clinical Features

The overall incidence of CP is approximately 2 per 1000 live births with spastic CP being the most frequent type (Paneth & Kiely, 1984). With a prevalence of approximately 400,000 living affected children, CP is currently the most common childhood handicapping condition in the United States (Lord, 1984).

Static encephalopathy, or CP, is a non-progressive disorder of movement which can be due to central nervous system injury occurring prenatally, perinatally, or postnatally (Bleck, 1987). Individuals with this disorder exhibit a variety of motor impairments such as spasticity, rigidity, dystonia, tremor or ataxia. Persistent primitive reflexes and problems in balance, strength, selective motor control and coordination are usually present in varying degrees (McDonald, 1991; Peacock & Staudt, 1990).

Generally, there are four types included in this disorder: dyskinetic, ataxic, spastic, or mixed cerebral palsy. Of interest to this study is the spastic type which is subdivided according to the pattern of spasticity and includes: spastic diplegia (involvement in all four limbs, lower extremities more than upper extremities), spastic paraplegia (involvement of the lower extremities), spastic hemiplegia (asymmetrical involvement frequently manifested as bilateral hemiplegia), and spastic quadriplegia (involvement in all four limbs with the arm involvement equal to or exceeding the leg involvement) (Ingram, 1984). Children with spastic CP often have hypertonia, hyperreflexia, abnormal movement patterns, decreased movement speed, and poor coordination (Giuliani, 1991). Spastic diplegia is frequently associated with premature birth, while all of the spastic subgroups are associated with low birth weight.

Motor Impairment in Cerebral Palsy

Spasticity.

Spasticity is often exhibited by individuals with CP and is characterized as a velocity-dependent increase in tonic stretch reflexes and exaggerated tendon jerks resulting from increase of the stretch reflex (Lance, 1980; McDonald, 1991). When a spastic muscle is stretched, afferent signals from the muscle spindle travel up group 1a afferents and through the posterior roots of the spinal cord. At the segmental level 1a afferents make direct connections with alpha motor neurons and interneurons (Baldissera et al., 1981). The interneuronal pool also receives afferent input from flexor reflex afferents, secondary muscle afferents, joint receptor afferents, cutaneous afferents, and descending fibers. The interneurons modulate spinal cord reflexes and this interneuronal pool is, in turn, modulated by spinal segmental afferents and collateral propriospinal fibers that travel to distant segments and also by the brain via descending fiber tracts (McDonald, 1991).

There are several possible neurophysiological mechanisms for spasticity. Spasticity in CP is believed to result from a defect in the descending central interneuronal control acting on the group 1a afferents (McDonald, 1991). That is, descending tracts are damaged thus reducing the central inhibition to the motorneurons. When group 1a afferents are unopposed alpha-motoneuron overactivity is produced segmentally and suprasegmentally via monosynaptic and collateral propriospinal pathways (Ashby et al., 1974). The result is a spreading activation of muscle contraction in response to afferent stimuli. This spreading is reinforced via afferent gamma loop impulses from muscle spindles in antagonistic muscles that are undergoing progressive stretching. The pattern and degree of hypertonicity is a function of the location and extent of the central nervous system lesion (Abbott et al., 1989). Abnormal recurrent inhibition and renshaw cell inhibition may play minor roles in the mechanism of spasticity (McLaughlin et al., 1994).

Whenever the CNS is damaged two types of signs and symptoms emerge: positive and negative ones (Young, 1989). The negative ones include fatiguability, paralysis, weakness and loss of dexterity. This may be due to either a disconnection of the lower motor neurons in the brainstem and spinal cord from the cerebral motor system, or destruction of the neurons themselves. The second type of signs and symptoms are positive. These include excessive involuntary motor activity otherwise known as spasticity and are usually associated with macroscopic lesions of the central nervous system. Spasticity is often a dramatic symptom in CP children. However, according to Young and Wiegner (1987), even if there were a treatment to eliminate spasticity, one would not expect it to restore function in most patients. Landau and Hunt (1990) report that even when spasticity was reduced by SDR surgery or spasticity reducing drugs, there was no evidence of improved function. This finding suggests that tone and spasticity alone cannot totally explain movement dysfunction in children with cerebral palsy Problems with range of motion, postural control, coordination, and decreased strength are characteristic of children with CP (Giuliani, 1991). Spasticity is likely only one component of the upper motor neuron syndrome (Damiano, 1993; Richards & Malouin, 1992). According to Giuliani (1991), the belief that problems of movement control in children with CP are the result of a release from inhibitory supraspinal control is at best an oversimplification of the complexities of the disorder. Giuliani states that spasticity is not the cause of movement dysfunction, but rather that the mechanisms associated with spasticity and voluntary movement control are interactive.

Abnormal Spinal Circuitry.

There is mounting evidence that secondary changes in spinal circuitry take place in the child with CP (Mykelbust et al., 1982). Mykelbust et al. (1982) defines CP as damage to immature supraspinal structures that imposes a secondary disorder on a developing spinal cord. Their conclusions are based on observations of abnormal muscle responses

during reflex testing as well as during voluntary movements. Abnormal patterns of reciprocal excitation, reciprocal innervation and changes in agonist control have been reported in children with CP (Kundi et al., 1989; Mykelbust et al., 1982). These findings provide evidence for the hypothesis that CP may be a disorder of spinal as well as cerebral circuitry. However, future studies are needed to confirm this as an important mechanism in abnormal motor control in CP children.

Weakness.

Weakness of the agonist in children with CP has traditionally been attributed to spasticity of the antagonist producing a type of disuse syndrome. Disuse alone does not account for changes observed in muscles of subjects with CP (Giuliani, 1991). Milner-Brown & Penn (cited in Giuliani, 1991) reported reduced number and size of both type I and II muscle fibres in children with CP.

Abnormal Muscle Coordination.

Patients with CP often activate muscles in abnormal sequences and are unable to provide compensatory postural adjustments (Giuliani, 1991; Perry, 1975; Sutherland, 1984). These abnormal patterns may result from co-contraction of the agonist and antagonist (Sutherland, 1984) and can be explained according to Perry (cited in Sutherland & Davids, 1993) by the persistence of primitive muscle synergy that is only incompletely replaced by normal selective muscle control. This lack of muscle control is often attributed to problems of spasticity. However, there is evidence (Sahrmann & Norton, 1977) that the primary impairment of movement in subjects with hemiplegia is due to limited and prolonged recruitment of agonist muscles and the delayed cessation of agonist contraction at the end of movement. Inappropriate overflow and sustained contraction of the agonist muscles was demonstrated during reciprocal type movement. Other investigators (Cahan et al., 1990) demonstrated a persistence of abnormal timing of muscle activation in the gait pattern of CP children post SDR. Other evidence points to abnormal coactivation of

antagonists as a key factor in the motor disorder of CP. Knutsson (1980) observed that activation of muscles occurred in the wrong phase of the gait cycle and that misdirected coactivation of muscles could cancel the action of each other.

In conclusion, several problems involving motor control are assumed responsible for motor disturbances in spastic cerebral palsy. The use of SDR as a neurosurgical treatment to decrease spasticity in spastic CP children provides a rare opportunity to examine to what extent spasticity contributes to the abnormal locomotor pattern.

Gait of "Normal" Children

It is essential to have normative data for gait patterns in children in order to describe abnormal gait patterns and assess the effectiveness of a wide range of treatments offered to children with motor disabilities. A child's walking pattern is gradually modified with maturation until it resembles an adult pattern like gait. It has been shown by several authors using a variety of techniques (Richards et al., 1987; Statham & Murray, 1971; Sutherland et al., 1980) that the most dramatic changes occur between 1 and 2 years of age, and that by approximately the age of 2 an adult gait pattern is attained. Sutherland et al. (1980) described the kinematic patterns of normal children during gait and is summarized below. These values were taken at a comfortable walking speed of normal children which is different than the comfortable speed of abnormal children. Speed can vary the kinematic patterns and must be considered when comparing abnormal kinematic patterns to those from normal children.

Sagittal plane movement of the hip is a very simple progressive flexion during swing phase and extension during stance. The change occurs during opposite foot strike; thus flexion begins at second double support. Peak flexion occurs at eight-five percent of the cycle and diminishes by five degrees by heel strike. The dynamic range of motion for the one and two year olds is nine degrees less than for older children. There are two knee flexion waves in the adult gait. The first is a result of an eccentric contraction of the

quadriceps muscle during the early part of stance. This eccentric contraction acts as a shock absorber as the leg accepts weight. As well, it gradually elevates the body's center of mass and reduces the energy requirement for walking (Inman, 1973). The second knee flexion wave is a lot stronger and starts well before toe-off in order to advance the limb and clear the ground. In the one year old child there is only a hint of the first knee flexion wave. By three or four years old this motion is better developed. At two years old the second knee flexion wave during swing is indistinguishable from the adult form. Ankle motion in the adult gait pattern is characterized by two peaks and two valleys each representing dorsiflexion and plantarflexion respectively. The first valley is attributed to ankle plantarflexion immediately after foot strike.

EMG phasic activity of four lower limb muscles (TA, GA, VL and MH) has been described by Sutherland et al. (1980) and are discussed individually in the following sections.

Tibialis anterior

In adult gait tibialis anterior works concentrically to lift the foot during swing phase and eccentrically to decelerate the foot from heel strike to the foot flat position. The one year old infant's lack heel strike, landing foot flat and present with prolonged tibialis anterior activity during stance phase. As well, these children show a delay in the onset of swing phase activity. By 2 to 7 years of age the EMG phasic activity demonstrates an adult pattern with onset of tibialis anterior at just before toe off and continues until approximately 40% of stance phase.

Gastrocnemius/soleus (g/s)

The mature pattern of g/s muscle activity is confined to the single limb stance portion of stance phase. The function of g/s muscle is to decelerate the tibia during the first part of a single limb stance working eccentrically. This muscle complex then stops

dorsiflexion and subsequently accelerates the ankle joint prior to toe off, working concentrically.

Obvious differences are noted between the pediatric population and the adult group. G/s activity which is not usually present in the adult group is particularly noted during swing phase in the younger groups. Two distinct g/s patterns have been found. The first is the 'immature' pattern (also known as the wrap around pattern). It occurs in a very large percentage of the 12 to 18 month old infants and in approximately one-quarter of the subjects in the remaining age groups (18 months to 7 years). The EMG activity begins near the middle of swing phase and ends with opposite foot strike. In the second of these patterns (the "mature" pattern) the EMG activity is confined to the single stance portion of stance phase and resembles the mature pattern.

Vastus medialis

The function of the vastus medialis in mature walking is to prepare the lower extremity to bear weight in late swing phase and to act as a shock absorber in early stance phase (eccentric action). Again, the major maturational differences are evident in the 12 to 18 month old age group. These children show prolonged activity in early swing phase. In the 1 - 2 1/2 year old age groups slightly prolonged activity is seen during stance phase. By the age of 4, mature muscle activity pattern emerges where vastus medialis begins in late swing (approximately 60% of the gait cycle) and stops at approximately 35% of stance phase.

Medial hamstrings

In the mature gait pattern hamstrings act to decelerate the swinging limbs (working eccentrically) during swing phase. This usually begins at 50% of swing and continues until 55% of stance phase where it stabilizes the hip joint. In the 1 year old age group prolonged activity of the medial hamstrings is noted during the stance phase. There may be

two reasons to explain this. Firstly, due to poor balance, increased muscle firing is necessary to maintain an upright position. Secondly, the control system is poorly developed resulting in less precision of movements (Sutherland et al., 1988).

In summary, Sutherland et al. (1988) suggest that mature gait patterns are attained approximately at the age of two. They state the three basic indicators of mature gait are reciprocal arm swing, heel strike and two distinct knee flexion waves. Moreover, they find striking differences when the g/s EMG activity in the normal pediatric gait pattern is compared to the normal adult gait pattern. G/s activity (not usually noted among adults during swing) is commonly noted during swing phase in the pediatric cycle. This quantitative data on children's gait patterns is important for understanding pathological gait.

Gait Patterns in Spastic Cerebral Palsy

There are several gait patterns characteristic of different forms of CP with variation within each pattern. Of interest to this study are the common gait deviations of the spastic diplegic child. Many children with spastic diplegia have limited mobility in their trunk (lumbar spine), pelvis and hip joints and show limited and asymmetric pelvic tilt or pelvic rotation during gait. To compensate for this decreased movement, these children shift their weight and maintain their balance by excessive movement in the upper trunk, head and upper extremities (Bobath & Bobath, 1962).

The hips are flexed in stance, and usually adducted and internally rotated during ambulation. In severe cases, the children's knees touch medially during the gait cycle. Depending on the function of the pelvic, lumbar, ankle, and knee musculature, the knees may be either hyper-extended or kept in a flexed position. The ankles may be in equinus and lie close together or in valgus with the feet outside the base of the trunk and the knees touching medially (Tecklin, 1989). As well as, increased lateral side flexion of the trunk and small stride lengths may be noted (Peacock et al., 1987). The child may use an

assistive device such as a walker, rollator, quad canes, ankle/foot orthosis or shoe inserts to improve balance, thus facilitating independent ambulation.

Quantitative Characteristics of Spastic CP Gait

The characteristic electrophysiological features of immature gait are: 1) coactivation of antagonistic leg muscles during stance (similar to that found in newborn stepping) (Forssberg & Wallberg, 1980); 2) enhanced monosynaptic stretch reflexes; and 3) reduced plantar flexion EMG (Berger et al., 1984).

Spastic CP children have all of the above immature electrophysiological characteristics of gait (Berger et al., 1984). In addition, these children also demonstrate changes in the mechanical properties of the muscle tendon system (Berger et al., 1984; Dietz et al., 1981).

During the second year of life these features of immature gait in normal children evolve into: 1) reciprocal activation; 2) suppression of the excessive monosynaptic reflexes; and 3) an increase of gastrocnemius EMG activity.

According to Csongradi et al. (1979) two general patterns of activation were found with respect to the quadriceps, hamstrings and rectus femoris in CP children. The first pattern is prolonged activation (twice the average normal duration for quadriceps and almost double for the hamstrings) of the muscles in seventy-three percent of their patients. The remaining subjects exhibited abnormal timing.

The major components so far theoretically described (and further categorized by Crenna et al., 1992) as pathophysiological factors contributing to abnormal locomotion in CP children are: 1) nonselective activation of antagonistic muscles with loss of reciprocal inhibitory pattern (cocontraction component); 2) abnormal velocity dependent EMG recruitment during muscle stretch attributed to an increase in the monosynaptic stretch reflex (spastic component); 3) defective recruitment of motor units (paretic component); and

4) changes in the mechanical properties of the muscle tendon systems (non neural component).

It cannot be assumed that spasticity in these children masks good voluntary control. Given the heterogeneity of the CP population, it is logical to assume that pathophysiological factors mentioned above (i.e. cocontraction, spasticity, paresis or non neural factors) collectively may contribute to disturbed motor control (Richards & Malouin, 1992). Appreciating the key elements of poor motor control in each patient using objective measures is critical to the choice of therapeutic intervention.

Control of Locomotion

Neural control of walking involves control signals to initiate the rhythmic, alternating movements of the limbs and in turn, is closely regulated by signals relaying the current state of the limbs (Schotland, 1992). In one theoretical approach, the rhythmic alternating movements of the limbs are largely coordinated by specialized networks of neurons located in the spinal cord. Because these neuronal networks are capable of generating complex patterns of motor activity and because of their localization within the central nervous system, they have been referred to as central pattern generators (CPG) (Schotland, 1992). The 'network of neurons' constituting the locomotor CPG of the lumbar spinal cord is comprised of the interneurons interposed between afferent and efferent systems (Schotland, 1992). Although CPGs can be generated solely by spinal networks (in the absence of afferent input) (Grillner, 1988), these networks are believed to be activated by descending signals from higher levels of the nervous system.

According to Shik et al. (1966), tonic stimulation of a specialized region of the brain stem known as the mesencephalic locomotor region causes normal walking on a treadmill in decerebrate cats. As well, stimulation of brain stem reticulospinal neurons in the isolated brain stem spinal cord preparation of the lamprey leads to rhythmic locomotor patterns (McClellan & Grillner, 1984). These and other studies provide evidence that

CPG's exist. In the intact animal, all types of sensory information such as visual, auditory, somatosensory, and vestibular, have access to spinal locomotor networks through descending inputs. In mammals these signals are transmitted to spinal networks via three major descending motor systems; the ventromedial, dorsolateral and corticospinal pathways. In addition to these three major descending pathways, the output of spinal CPG circuitry is also influenced by the cerebellum and basal ganglia and by secondary motor cortical areas (Schotland, 1992).

Contrary to this view of locomotion (i.e.; existence of an innate human spinal locomotor program - CPG), Thelen (1992) suggests a less deterministic mechanism than this traditional account. She describes the process of learning to walk by a dynamic system's approach. One of the most important assumptions of the dynamic system is that motor patterns are softly assembled in the central nervous system. Soft assembly implies that the actual trajectories of movement are determined by several factors; the patterns of neural firing, the elastic qualities of the muscles, anatomical properties of the bones and joints, passive and mechanical forces acting on the body, and the energy delivered to the moving limbs and segments (Thelen, 1992). Movement patterns are assembled 'on-line' in reference to and in continual interaction with the intention of the subjects, their perception of the task at hand, and the physical properties of their bodies and the environment.

Thelen speculates that the locomotor pattern is slowly carved into the system through practice. In other words, as infants move, the perceptual and motor consequences of their actions are used by the central nervous system (CNS) to form continually more adaptive motor patterns and finally, the most efficient and stable motor pattern.

A dynamic systems view has profound implications for therapy (Thelen, 1992). CP patients with a damaged nervous system have much tighter constraints on movement and perception of movement, and their system is much more limited in their ability to explore and discover efficient movement solutions.

A cycle can be established where dysfunctional patterns are recruited, much like new walkers finding opportunistic solutions to their instability. Over time these abnormal patterns may become self sustaining and reinforced by care-giving practices. Thelen stresses the importance of early intervention while the system is still molding and before motor patterns become stable maps in the brain. Current research in brain plasticity supports this approach (Bach-y-Rita, 1980).

These two approaches are not incompatible. There is evidence to support the existence of an innate spinal locomotor program, i.e. CPG's. This view together with a central nervous system which is continually monitoring and adapting motor patterns until the most efficient and stable motor patterns emerge are complimentary and require further research to confirm these merging theories. If the motor patterns do evolve over time, then earlier implementation of an invasive surgery such as SDR, which eliminates spasticity and thereby changes the constraints placed on that motor system, the earlier that system can carve out a more normal motor pattern.

These concepts will need to be considered when analyzing the changes observed in the subjects post SDR as they may contribute to our understanding of the underlying mechanisms responsible for these changes. Specifically, a persistence of abnormal patterns that is characteristic of spastic diplegic children (Cahan et al., 1990) may explain the limited gains that may be found post SDR, suggesting the need for earlier surgical intervention and/or perhaps different therapeutic strategies after SDR surgery.

Treatment Modalities for Spasticity

According to Massagli (1991), the literature is replete with studies of treatments for spasticity which, may reduce spasticity, but do not produce a substantial improvement in function. Common treatment options include physical modalities, medications, neurosurgical and orthopedic procedures.

One of the physical modalities used is prolonged stretching of the involved muscle (Kottke, 1982). Tremblay et al. (1990) report a decrease in spasticity, as recorded by EMG, of the triceps surea muscle for 35 minutes post cessation of prolonged muscle stretch. However, the capacity to activate the dorsiflexors is apparently not affected. It therefore remains to be determined whether repeated sessions of prolonged muscle stretch can induce a long-lasting improvement in motor function in children with CP (Tremblay et al., 1990).

There are other methods used in conjunction with stretching to alleviate spasticity temporarily, which are either, not practical for day to day use, or have not yet been shown to improve functional outcome (Massagli, 1991). These treatments include high frequency vibrations (>70 Hz) applied to the antagonists (Giebler, 1990) as well as local application of ice (Lehman et al., 1982).

There is some success reported with the use of biofeedback in children with CP. In one study, children over 4 years of age with dynamic equinus deformity achieve heel strike after using biofeedback (Bleck, 1987).

One of the most prevalent treatment approaches currently used by physiotherapists involves neuromuscular facilitation also known as neurodevelopmental treatment (NDT). NDT is based on the therapeutic approach developed by the Bobaths (Bobath and Bobath, 1962). This treatment is driven by the belief that abnormal motor patterns and the persistence of primitive reflexes are at the root of the movement problem. They theorize that these abnormal movement patterns are later used to perform functional activities. The Bobath method involves prevention of abnormal reflex postures by physically positioning a child in inhibitory primitive reflex postures. While the child is held in a reflex inhibiting position, overall muscle tone improves, thus facilitating the child's ability to move in a more normal fashion. This technique requires highly skilled therapists and demands intensive parent involvement (Lord, 1984). Studies documenting the long term benefit of

NDT with regards to volitional motor control or prevention of contractures have been inconclusive (Mayo, 1991; Palmer et al., 1988; Piper et al., 1985).

The most commonly used medications for treatment of spasticity are baclofen, dantrolene and diazepam (Massagli, 1991). Generally, these drugs tend to show greater improvements in spasticity than in overall function (Whyte & Robinson, 1990). Moreover, many of these children become so lethargic that they cannot participate in the classroom or family activities (Denhoff et al., 1975). Side effects include overall muscular weakness, drowsiness and nausea (Lord, 1984).

Recently the infusion of baclofen directly into the subarachnoid space by a programmable pump has decreased the dosage needed to 100 times less than that given orally thereby decreasing the side effects and increasing the positive effects of baclofen on spasticity (Young, 1989). However, pump malfunction, infections, possible drug overdose and damage to the nervous tissue limit the more widespread use of this mode of therapy (Young, 1989). According to Pape et al., 1990 (cited in Massagli, 1991) the efficacy of this new technique in spastic CP awaits the results of further experimental trials. Improved functional outcome has been described but remains controversial, especially for those who rely on their spasticity for mobility (Penn, 1989).

Botulinum toxin is routinely used in several spasmodic disorders, focal dystonias or tremors. When injected close to the main area of nerve arborisation within a muscle the toxin is selectively taken up by cholinergic nerve terminals and blocks neuromuscular transmission for between two and four months until new terminals grow. Recent reports of its use in the cerebral palsies are encouraging but require further clinical study (Neville, 1994). Neville (1994) states that Botulinum toxin is not a cure for CP but may become one modality in the integrated management of the cerebral palsies.

Orthopedic procedures are the most widely used invasive technique to control the effects of spastic CP (Sutherland, 1984). Various surgical procedures can be used to

correct problems such as forearm pronation, hip subluxation, spinal deformities (e.g. scoliosis), knee flexion contractures, and spastic equinus deformities of the foot and ankle complex (Vaughan et al., 1989). These procedures include muscle lengthening, tendon transfers (commonly performed when useful voluntary motor activity is present) (Bleck, 1987) and osteotomies. Indication for surgery may be improvement of function, prevention or correction of deformity, facilitation of positioning or hygiene and cosmesis (Bleck, 1987). However, the orthopedic surgeon corrects developing deformities at the musculoskeletal level and does not effect the primary lesion which lies in the central nervous system (Vaughan et al., 1989).

A surgical technique used to decrease spasticity in the past involved total transection of dorsal roots (Young, 1989). Selective dorsal rhizotomy is a modification of this approach. In this operative procedure, the surgeon preferentially transects afferent input from nocicepters and muscle spindles at the entry zone, thereby eliminating flexor reflexes and muscle stretch or tendon reflexes without causing complete deafferentation to the limbs (Sindou & Jeanmonod, 1989). This approach has recently become very popular and is being used in many centers (Abbott et al., 1989; Arens et al., 1989; Berman et al., 1989; Cahan et al., 1990; Fasano et al., 1978; Peacock & Arens, 1982; Vaughan et al., 1988, 1991).

Selective Dorsal Rhizotomy

Surgical Technique

SDR, an operative procedure to decrease spasticity, has evolved considerably over recent years. Saving some of the afferent fibres to avoid the difficulties of sensory ataxia and stasis ulceration has become paramount (Abbott et al., 1989). After Gros in 1973 (cited in Abbott et al., 1989) demonstrated that these side effects could be avoided with only partial sectioning of the roots, several authors such as Fraioli & Guidetti, as well as Ouakine published reports of technical modifications that sought to differentiate between

normally and abnormally processing afferents (cited in Abbott et al., 1989). Fasano et al. (cited in Abbott et al., 1989) presented the technique of monitoring the pattern of muscle response to stimulation of afferent inputs, so as to differentiate rootlets with normally functioning activity from those with abnormal modulation. This technique forms the basis for the surgical procedure used today.

The surgical procedure is performed under general anesthetic in a manner that preserves a muscle's ability to contract in response to motorneuron action potentials (Abbott et al., 1989; Peacock & Staudt, 1990). The preferred site for the operation is the cauda equina as it ensures positive identification of the roots at the point of exit from the dural sleeve (Abbott et al., 1989). A midline laminectomy or laminotomy is performed from L2 - L5 (Peacock & Staudt, 1990) or from L1/L2 to S1 (Abbott et al., 1989).

Individual nerve rootlets constituting each root are individually stimulated with single pulses to determine the threshold, followed by trains of stimuli at a frequency of 50 Hz for 1 second (Peacock & Staudt, 1990). Threshold values obtained at the outset are typically between 6-10 mA (Abbott et al., 1989).

Rootlets are either spared or divided depending on the muscular response (Peacock & Staudt, 1990). Characteristic EMG patterns that are associated with incremental, clonic, multiphasic or sustained responses are abnormal and are therefore divided. Responses that spread proximally, distally or contralaterally are also considered to be abnormal (Peacock & Staudt, 1990).

It is not uncommon to find most rootlets behaving abnormally (Abbott et al., 1989). Foerster noted that he could safely lesion two adjacent levels without creating a sensory deficit (Fasano et al., 1979). Abbott et al. (1989) will only do a partial rhizotomy (≤ 50% of rootlets cut) at a level adjacent to two levels which have received complete sensory rhizotomy. Using this as a guide, they witnessed a demonstrable sensory loss

(S1 dermatome unilaterally) in only 1 out of 120 patients. This remains controversial and should be addressed.

Effectiveness of the SDR Procedure

Function and Tone

Over the past decade several investigators have evaluated the efficacy of the SDR procedure (Abbott et al., 1989; Arens et al., 1989; Berman et al., 1989; Cahan, 1988; Cahan et al., 1989, 1990; Fasano, 1978; Fasano & Broggi, 1989; Giuliani, 1991; Peacock & Arens, 1982; Peacock & Staudt, 1990; Peacock et al., 1987; Vaughan et al., 1988, 1989, 1991). However, only in recent years have quantitative assessments been applied to SDR studies. Assessment of an individual's functional abilities is difficult since an objective, standardized grading system is lacking to quantify the subtle changes seen. Therefore, the literature surrounding the rhizotomy procedure primarily summarizes qualitative or informal observations. Improvement in functional skills, such as sitting, standing, and walking (Fasano et al., 1978) and crawling, walking, upper extremity use, and speech (Peacock et al., 1987) was documented in two studies using a rating of visual inspection at 3 year follow-up. Longer follow-up of 3-7 years on 53 patients from the same cohort revealed that functional outcome improved and were maintained in 82% of the cases (Arens et al., 1989).

In one study, kinematic analysis on 11 patients' crawling patterns was collected (Vaughan et al., 1988). Crawling stride length and average speed of crawling was found to increase after rhizotomy ($p = 0.08$). This was theorized to be due to an increase in the joint range of motion (ROM), primarily at the hip.

Peacock et al. (1987) reported that patients whose function improved most were purely spastic diplegic, of normal intelligence, had some degree of forward locomotion and could side-sit independently. Therefore the authors concluded that an appropriate selection

process for SDR candidacy is essential to ensure the beneficial effects of the procedure. Moreover, most studies (Abbott et al., 1989; Peacock et al., 1987) found that intensive physiotherapy following SDR was integral to a positive functional outcome.

There is general concensus that tone improves post SDR, however the methodology used to measure or evaluate this has varied (Abbott et al., 1989; Arens et al., 1989; Fasano et al., 1978; Peacock & Arens, 1982; Peacock et al.,1987). Unfortunately, in all studies a subjective grading of muscle tone was used which reflects the current lack of standardized tone assessment scales that use objective instruments (Abbott et al., 1989).

Tone was evaluated quantitatively using EMG by Cahan et al. (1990). The duration of EMG response to quick manual stretch was recorded postoperatively (mean post-op evaluation 8.3 months). The duration of EMG response was identified as: normal <250 ms, prolonged >250 ms, clonic 5-8 Hz signal or absent. A significant reduction in EMG response in the VL, GA, and MH muscles was documented in this group of 14 CP children ranging from 4.6 to 23.5 years.

Hypotonia and hyperesthesia have been reported as problems in the active period postsurgery and long-term sensory loss or weakness have been reported in a few cases (Abbott, 1992). Because deafferentation of the bladder is avoidable using careful intraoperative identification of the sacral roots (S2 and below), few long term bladder problems have arisen (Montgomery, 1992).

Spinal deformities related to the extensive laminectomy L2 - L5 or S1 are a lingering concern. Some neurosurgeons suggest using osteoplastic laminotomy in an effort to minimize the risk of spinal deformities (Park et al., 1993). However, according to Park et al. the long term consequence of extensive laminotomy is also not known. They suggest a L1/L2 laminectomy to diminish the risk of long term spinal deformities such as spondylolisthesis or scoliosis. Spondylolisthesis was reported in 14% of 80 children who underwent SDR and only 2% in a CP control group (Park et al., 1993).

There has been recent controversy on whether intraoperative monitoring EMG improves the efficacy of the SDR procedure. Weiss and Schiff (1993) have suggested that the inconsistency in EMG responses negates the need for intraoperative EMG during rhizotomy. However, Peacock et al. (1994) question the validity of this conclusion based on the quality of their recordings and interpretation of the EMG responses they obtained.

Reduction of spasticity may be achieved by random division of rootlets which may make the procedure easier for the surgeon but may not protect the patient or provide the best possible reduction of spasticity, without unnecessary or excessive division of sensory rootlets (Peacock et al., 1994). Caution must be taken when critically reviewing the literature on the efficacy SDR patient due to the varying surgical strategies used at the different centers. No outcome studies relating the number or distribution of rootlets sectioned to either positive or negative sequelae have been published (Montgomery, 1992)

Secondary gains with respect to upper extremity function and trunk control have also been reported (Beck et al., 1993; Berman et al., 1989; Kinghorn, 1992). Berman et al. (1989) concluded that when a child is able to sit with greater stability, upper limb function may become more efficient.

Gait

In a study by Vaughan et al. (1988) two dimensional (2D) kinematic gait of 14 children with CP revealed a statistically significant improvement in range of motion (ROM) of the knee and thigh, and increased stride length 9 months post rhizotomy. It should be noted that 2D analysis does not only measure sagittal plane motion as rotational movement also contributes to the movement of gait (Vaughan et al., 1988). In a 3 year follow-up of their patients, Vaughan et al. (1991) found a further significant improvement, again in ROM of the knee and thigh, also in stride length, and in velocity of walking. The authors suggested that changes in ROM are probably attributed to a reduction in spasticity, however no measure of spasticity was recorded. To measure the degree of strength and

stability a patient exhibited during gait. Vaughan analyzed mid-range points. The initially increased value of the knee mid-range point after the first year postsurgery was indicative of a more flexed standing posture, likely due to weakness or lack of stability of the calf musculature. The subsequent improvement in knee posture at three years post rhizotomy (indicated by a lower knee mid range value or less flexion) suggested development of better strength and motor control.

Recent studies by Cahan et al. (1990) using instrumental gait analysis of patients undergoing rhizotomy have shown similar improvements in range of motion, stride length and velocity. The improvements recorded in velocity were more than twice the changes expected due to maturation as reported by Sutherland et al. (1988). However, caution should be used in interpreting the modest increase in velocity postoperatively since walking speed is highly dependent on an individual's motivation or compliance and can therefore vary considerably (Vaughan et al., 1989). Kinematic analysis of these children showed a smoother gait with less hip flexion at the onset of the stance phase (i.e. less of a crouched gait), as well as increased knee and hip ranges (Cahan et al., 1990).

At 5 year follow-up, Arens et al. (1989) identified 15 community walkers (for example, able to walk at least 5 minutes outdoors) whereas there were only 4 prior to surgery. Twelve out of the 15 demonstrated an increase in stride length due to an increase in knee extension. Of the 8 dependent ambulators (those requiring an assistive device), 5 became independent. One child experienced a decline in his ambulatory function as his spasticity had helped him maintain an erect posture. Improvement in locomotor status was described qualitatively and no statistical analysis was performed.

As well, Fasano et al. (1978) reported at three year follow-up, a qualitative improvement in their patients' walking abilities. They were assessed by visual observation only. In most patients, the lower extremities were no longer scissoring and a more appropriate stride was accomplished with full knee movement rather than by hip rotation.

Furthermore, all patients who walked on tiptoes prior to surgery were said to have full plantar support post rhizotomy.

To date, only Cahan et al. (1990) evaluated on/off EMG during the gait cycle pre and post rhizotomy and compared the findings to published normative data (Sutherland et al., 1980, 1988). They investigated 14 subjects with spastic diplegia ranging from 4.6 to 23.5 years of age. Postoperatively, they found that abnormal timing of muscle activity persisted in five lower extremity muscles (hamstrings, quadriceps, the hip adductors, tibialis anterior and gastrocnemius). The clonic activity of the calf muscle during stance disappeared in one patient out of 14. They found that rhizotomy diminished spasticity and thereby improved the functional gait pattern. However, rhizotomy did not change or improve the aberrant sequencing of muscle action as was revealed by the persistence of primitive locomotor synergy patterns. They concluded as did Perry (1975) that CP is not only a disorder involving spasticity but also a disorder of motor control. As a result, these children cannot execute the proper sequence of muscle action. However this study only presented one figure of raw EMG for one patient's TA and GA muscles for three consecutive steps therefore it is difficult to assess the consistency or variability of these results.

In summary, studies to date have demonstrated improvements in tone, function, and gait, however, quantitative measures have not, for the most part, been paramount to the methodology. Despite growing support for SDR as an effective intervention for spastic diplegic cerebral palsy, lack of control groups, selection bias, subjective outcome measures and variable intraoperative techniques limit the conclusions that can be drawn from these investigations (Landau & Hunt, 1990). Moreover, measures of functional abilities should be representative of tasks required of the child in a natural environment. Montgomery (1992) suggests improved posture in static positions such as long sitting, side sitting and kneeling may be an indication of improved biomechanical status achieved through

improved range of motion rather than an indication of improved motor control. Gait analysis which incorporates dynamic EMG recordings and kinematic analysis, may be useful in objectively quantifying changes in gait post SDR (McLaughlin et al., 1994).

Rationale

SDR is increasingly becoming an alternative to conventional interventions in children with cerebral palsy. The literature suggests that SDR can benefit selected patients with spasticity but is obviously not a panacea for cerebral palsy (Cahan et al., 1990). Studies to date examining the efficacy of SDR suggest that SDR decreases spasticity and improves motor performance. However, most of these studies are descriptive. To date, only two centers have reported on the effects of SDR using motion analysis to describe quantitative variables of gait and provide support that SDR can improve some aspects of gait by reducing spasticity (Cahan et al., 1990; Vaughan et al., 1988). Interestingly, Cahan et al. (1990) found a persistence of abnormal movement patterns post SDR using kinematic and EMG analysis. No other studies to date have reported on dynamic EMG patterns in this population. The lack of objective and reliable outcome measures for motor function and gait has prevented the accurate documentation of the effectiveness of SDR for CP (McLaughlin et al., 1994). Further studies are necessary to quantify the changes reported postoperatively given that SDR is invasive and permanent. Gait analysis enables investigators to analyze outcomes objectively with precision and to gain additional insight into pathophysiology, results of treatment, and perhaps optimizes therapeutic strategies offered postoperatively.

In this study, 2-D gait analysis was used in a group of young children with spastic diplegia to measure changes six to nine months following SDR coupled with six months of intensive therapy. Gait parameters.angular displacements, and timing of muscle activation were measured using kinematic and EMG analysis. Functional improvements in gait pattern were also evaluated using a formal clinical assessment scale. Analyzing the results of these outcome measures may increase our understanding of the functional improvements seen following SDR, and of the underlying mechanisms that contribute to disturbed motor control.

Statement of Null Hypotheses

There will be no measurable change in :

a) the gait parameters such as stride length, velocity and cadence in six children with spastic diplegia tested pre and six months post SDR coupled with intensive therapy;

b) the angular displacements of the ankle, knee and hip joints during gait in these children; and

c) the pattern of muscle activation (on/off EMG) during the gait cycle in two of these children tested pre and six months post SDR with intensive therapy.

Research Design

In 1991 the Montreal Children's Hospital and Shriner's Hospital for Crippled Children first began a rhizotomy treatment program to decrease spasticity for spastic CP children. Once subjects met selection criteria for the rhizotomy program, as determined by the team consisting of a neurosurgeon, neurologist, orthopedic surgeon, physiotherapist, and occupational therapist, the neurosurgeon referred the subjects for recruitment into this study.

The child's cognitive level and motivation were assessed by the team and had to be age appropriate in order to ensure adequate involvement in the post surgical rehabilitation program. As well, the child had to have exhibited a plateau in the acquisition of their motor milestones. This plateau in motor development was evaluated by the neurosurgeon, neurologist, orthopedic surgeon, physiotherapist and occupational therapist prior to acceptance into the treatment program and subsequently into this study. Upon evaluation and review of the medical chart, team members ascertained that there had been at least 6 months of no new gains in motor skills (these include clinical observations with respect to functional development, mobility or gait changes).

The children enrolled in the rhizotomy treatment program were obliged to participate in an intensive in-patient rehabilitation program for 2 months post rhizotomy surgery at the Shriner's Hospital. They were required to continue physiotherapy on an outpatient basis, two to three times a week, up to one year postsurgery.

In the first postoperative week the children remained at the Montreal Children's Hospital (for acute care). Individualized physical and occupational therapy programs were initiated as soon as the children were admitted to the Shriner's hospital on the seventh postoperative day. As in-patients for the next two months, physiotherapy was carried out three hours/day; ie. one hour in the pool, one hour of individual exercises with the

therapist, and one hour of either riding a bicycle or ambulating. Occupational therapy sessions ranged from 2-5 hours a week and consisted primarily of fine motor skills, dressing and trunk control training. For the next ten months, the children were scheduled to receive approximately three hours of physiotherapy per week in the community. Physiotherapy consisted of range of motion, muscle strengthening, ambulation training and postural control exercises.

The treatment condition, or independent variable, introduced in this study consisted of selective dorsal rhizotomy plus two months of intensive physiotherapy. The dependent variables measured included the following gait characteristics: 1) temporal distance parameters; 2) kinematic variables; 3) EMG patterns; as well as 4) functional outcome as measured by a portion of the Rusk Institute Rhizotomy Evaluation Form. As part of this "within subject" design, the subjects underwent two preoperative evaluations (1 to 2 weeks before selective dorsal rhizotomy surgery). The first evaluation took place at the Shriner's Hospital during the subject's regular rhizotomy clinic visit and was performed by a physiotherapist. The examiner used the Rusk Institute Rhizotomy Evaluation Form. The second preoperative evaluation took place at the McGill University Gait Laboratory where kinematic data and EMG patterns of overground locomotion were recorded by the author. These clinical and electrophysiological evaluations were repeated approximately 6 months postsurgery using the same testing procedures.

Method and Procedures

Subjects

Posterior rhizotomy is referred to as selective for two reasons. Firstly, only those dorsal rootlets associated with an abnormal EMG response to intraoperative stimulation are selectively divided. The number of affected rootlets may vary from 25% to 80% (Pape, 1990). Secondly, only selective individuals with spasticity are carefully chosen to undergo this procedure. There are two broad categories of candidates (Peacock & Arens, 1982). The first category consists of high functioning children who have adequate underlying muscle strength, motor control, balance, and freedom from fixed contractures and are therefore expected to improve once the spasticity has been alleviated (Peacock & Staudt, 1990). The second group of children best suited for this procedure are those that are nonambulatory. Their spasticity interferes with sitting, positioning, bathing and general personal care. In this group, the procedure improves the ease in which the caretaker can care for the child.

Inclusion Criteria

The candidates considered eligible for this study had spastic CP and were between 3 and 6 years of age. As well, the children included in this study had a primary diagnosis of spastic diplegia, were high functioning, had adequate motor control, balance and freedom from fixed contractures. They must have demonstrated spasticity (defined by increased hyperactive tendon reflexes), and ambulatory disability. As well, they required enough strength to maintain and subsequently improve their level of function once their spasticity was to be eliminated by the SDR procedure. Strength was determined to be ample if the child was able to do seven squat to stands (Abbott et al., 1989). As well, the candidate must have been able to ambulate either independently or with an assistive device.

Exclusion Criteria

Any subject requiring physical assistance from the experimenter while ambulating was not included in the study. Children demonstrating other types of cerebral palsy (e.g. dyskinetic, ataxic, or mixed) were excluded as many authors report less favorable response to the surgery in these individuals (Abbott et al., 1989; Fasano et al., 1978; Peacock & Arens, 1982; Peacock et al., 1987).

Locomotor Kinematic and EMG Evaluations

Preparation

The subjects' parents were given an information sheet (see Appendix A and B) by the neurosurgeon or physiotherapist at the Shriner's Hospital during the selection process. This sheet helped to familiarize the parents and the subject with what the "walking test" would involve. The subject was called by the author or the secretary at the Shriner's Hospital. The subject's parents were informed that they had the option to participate or not in the study and that no obligation to participate was imposed. If the parents agreed to have their child participate in the study a convenient time was arranged in order to do the "walking test" at McGill University's gait laboratory where the temporal distance parameters, kinematic and EMG data of overground locomotion would be recorded. The consent form was signed when the family arrived at McGill for the evaluation (see Appendix C). The child was shown around the laboratory and familiarized with the equipment, especially the electrodes. They were shown the overground walkway and were allowed to walk several times on it before the electrodes and reflective markers were attached to them. An age appropriate video was available for viewing during the preparation if the child so desired to watch. The parents were asked to remain in the room with the child at all times to help make the child feel comfortable and secure. The child was placed in a reclined position in order to make the preparation easier for the evaluator as well as for the child.

Reflective markers were affixed to anatomical landmarks on the acromion process, greater trochanter, lateral tibial condyle, lateral malleolus, lateral heel, and 5th metatarsal-phalangeal joint. Bipolar surface electrodes were placed over the muscle belly of the GA, TA, VL and MH muscles following conventional skin preparation.

Recording

The child walked overground at their own comfortable walking speed. The child walked, if possible, independently or with any assistive or orthotic appliance normally employed. The child was asked to walk on a 10 foot long overground walkway approximately 10 times to ensure collection of ten consecutive steps.

The gait cycle was defined as the period from initial foot floor contact (0%) to the subsequent foot floor contact (100%). The stance and swing duration was defined as the period extending from heel contact to toe off, and from toe off to the subsequent heel contact respectively. The gait cycle was defined by signals from electronic foot switches taped to both shoes under the heel, 5th metatarsal, and big toe of the subject's shoe. The footswitch data provided temporal distance parameters of gait, such as : 1) stride length; 2) velocity; 3) cadence; and 4) stance/swing ratio.

Kinematic data was collected from the side which displayed greater gait abnormality. The subjects were videotaped as they walked overground using two rotary shutter video cameras at 60 fields/second on 1/2 inch tape. Only the sagittal plane was analyzed from this 3-D recording. However, using the 3-D recording setup results in a sharper resolution and a more accurate 2-D kinematic analysis. A time code was recorded both on FM magnetic tape and videotape allowing for synchronization of muscle activity with mechanical events. This enabled the EMG recordings of lower extremity muscles to be synchronized with the kinematic data recorded by the video camera. The angular displacements were automatically captured by digitizing the reflective markers using Peak

Performance software. Ten representative gait cycles (the same ten cycles used for EMG analysis) were analyzed and normalized to the gait cycle.

Electromyographic patterns were recorded from the GA, TA, VL and MH muscles of one leg, as well as, the contralateral GA and TA. The more severely involved leg was the one evaluated in more detail. The EMG signals were differentially preamplified, amplified, band passed at 10-1000 Hz, and were recorded on a 14 channel FM tape recorder.

Analysis

Four methods of descriptive analysis of the locomotor pattern were employed to summarize the gait changes pre and post SDR for all six subjects.

1) A variety of temporal distance parameters were derived from the displacement data which included: 1) Stride length (the distance in meters from foot contact to the subsequent ipsilateral foot contact). 2) Velocity (the average distance travelled per second; which was calculated by dividing stride length by cycle time). 3) Cadence (the number of steps per minute; there are two steps per stride). 4) Stance/swing ratios.

2) Angular displacement of the hip, knee and ankle were identified at key points in the gait cycle (initial contact, mid stance, and terminal stance) and evaluated to best describe the gait changes pre and post SDR and allow for within subject comparisons. These key points were chosen in direct response to the kinematic characteristics of the CP gait. At initial contact, children with cerebral palsy usually contact the ground in plantarflexion rather than the normal zero degrees (0°) of dorsiflexion, therefore making this an important point to measure. Mid stance and terminal stance were significant points to monitor as well because generally children with CP walk in a triple crouched position (i.e. hip, knee and ankle flexion) and therefore any increase in extension at these key points in the gait cycle would indicate a straighter and more normal posture.

3) The recorded data was played back to select portions of the representative EMG and video sequences that were free from artifacts. The selected sequences were digitized at a sampling rate of 1200 Hz and data analysis was processed on a PC computer using Datapac waveform software. The EMG signals were passed through a digital filter (20-400 Hz) and then full wave rectified. EMG of the GA, TA, VL, and MH muscles was analyzed one cycle at a time in order to take into account the irregularity of gait in spastic CP children (Berger et al., 1984). The ambulatory EMG phasing regarding onset and offset of muscle activity was compared pre and postoperatively and was also compared to the normal pattern (Cahan et al., 1990; Sutherland et al., 1988). Means and standard deviations for the quantifiable variables of the temporal distance parameters and kinematic values were calculated.

Functional Evaluation

The Rusk Institution Rhizotomy Evaluation Form

Functional measures that evaluate quality of movement are lacking for young children. Some researchers have used norm referenced scales such as the Peabody Developmental Motor Scales or the Bruininks-Oseretsky Test of Motor Development to measure motor changes following specific interventions. However, these assessments are standardized on able bodied children and were intended as diagnostic assessments. They are not sensitive to longitudinal changes in the function of disabled children (Rosenbaum et. al, 1990, cited in McLaughlin et al., 1994). As well, it is important to examine if there are any functional gains, particularly in pre-requisite movements to ambulation. The Rusk Institute Rhizotomy Evaluation Form was developed by a team of physiotherapists at New York University Hospital to describe the physical status of children with spastic cerebral palsy who were undergoing selective dorsal rhizotomy surgery. It is a criterion referenced evaluative assessment tool designed to measure change in gross motor skills in children. It was designed specifically for this pediatric population and one portion assesses specific motor

skills which are pre-requisites for ambulation. This portion of the Rusk Evaluation form has been evaluated for test-retest and inter-rater reliability (Johann-Murphy et al., 1993).

The full Rusk evaluation form was performed on all subjects at the Shriner's Hospital prior to surgery. For the purposes of this study only a portion of the items on the evaluation form were analyzed (see Appendix D). Those items and scales include specific motor skills which are pre-requisites for ambulation. The scales that were used in this study were the transition and assistance scales. The grading for the transition and assistance scales is also found in Appendix D. Both scales demonstrated good to excellent percent match agreement (68% - 100%) and kappa scores for interrater (0.54 - 1.0) and test-retest reliability (0.74 - 0.95) (see Appendix E). The transition scale describes how a child gets into a position. The assistance scale describes how a child stays in the position. These two scales were used to evaluate seven positions of the motor development sequence and have at least five grades for each item. These seven positions include long sit, short sit, right and left side sit, right and left half kneel and standing. No equipment other than a small bench is required to perform this evaluation. The items were evaluated in order of least difficult task such as long sitting, to most difficult such as standing.

Results

From June 1993 to January 1995 twenty one patients were referred for gait analysis pre and post SDR of whom seven did not fit the inclusion criteria of this study. Of the remaining fourteen, one subject was deemed uncooperative by the treating physiotherapist and two subjects' parents refused to return for the six month follow-up evaluation. Difficulty in scheduling the evaluation became a problem in 3 subjects, precluding participation in the study. Technical breakdown within the gait laboratory resulted in partial data of two subjects to be lost.

In addition, three of the above subjects were referred by the neurosurgeon several months prior to surgery so that two baseline evaluations could be performed. This would have provided a means of comparing the stability of recordings and could have determined if the gait pattern had plateaued. Unfortunately, of these three subjects, one refused to be tested twice before surgery, one was nine years old and did not fit our inclusion criteria. The other was deemed uncooperative by the testing therapist and would not have tolerated the testing situation. To this date, data from six children have been analyzed.

The subjects' ages varied from three years two months to four years eleven months. There were five males and one female. Post operative evaluations took place on average at seven months post SDR surgery. All the children received treatment for CP in infancy. All the subjects received physiotherapy (PT) 1 - 2 times per week prior to surgery and occupational therapy (OT) approximately once a week. One child had undergone achilles tendon lengthening several years earlier.

All subjects were able to walk postoperatively. Two subjects (S_1 and S_2) who walked independently preoperatively, continued to walk independently postoperatively. Two subjects (S_3 and S_4) who had previously used a rollator walker continued to use this assistive device postoperatively. However, out of 2 subjects (S_5 and S_6) who used

Rollator Walkers presurgery, one required less assistance than previously and used quad canes postoperatively (S_5) and one became independent (S_6).

Therefore, the subjects were divided into 3 groups. The first group consisted of the *Independent Walkers*. The second group was named *Rollator Walkers* and the third group was named *Progressors* (Table 1 summarizes the age, sex and level of independence in these groups). Temporal distance parameters, kinematic analysis and a functional evaluation were performed on all six subjects. Of the six subjects studied, four did not change postoperatively in terms of the amount of external assistance required to walk. However, two of the subjects progressed from reverse rollator walker to either, walking with quad canes, or, to independent walking. Kinematic analysis, as well as gait EMG were analyzed in detail on two subjects, one who did not progress in terms of external assistance required and one who did progress.

Temporal distance parameters

Stride length improved in all subjects. The range of improvement was from 0.05 m. to 0.23 m. with an average improvement of 0.12 m. Average stride length pre and postsurgery was 0.49 m. and 0.61 m. respectively. Normal stride length for a four year old is 0.77 m. (Sutherland 1988) and for a 5 year old according to Sutherland (1988) is 0.84 m. See Table 2 for temporal distance parameters on all six subjects.

Velocity increased in only one subject (S_3). This subject walked with a rollator walker pre and post SDR. There was little or no change in velocity in two other subjects (S_4 and S_6) who walked with a rollator preoperatively, however their stride length improved by 0.23 m. (S_3) and 0.12 m. (S_4 and S_6) concomitant with a considerable decrease in cadence. One subject's (S_5) walking velocity decreased by 0.38 m/s. This subject walked with a rollator walker prior to surgery and with quad canes postsurgery thus slowing down her gait significantly. Two other subjects' (S_1 and S_2) walking velocity decreased by 0.12 m/s and 0.10 m/s postsurgery. These subjects walked independently pre and postsurgery. These last three subjects' cadence decreased dramatically postsurgery.

DESCRIPTION OF AMBULATORY ASSISTIVE DEVICE PRE AND POSTSURGERY

Table 1

SUBJECT	SEX	PRE-OPERATIVE AGE	PRE-OPERATIVEI STATUS	POST-OPERATIVE STATUS
		INDEPENDENT WALKERS		
S_1	M	4 yrs. 10 mos.	Independent	Independent
S_2	M	3 yrs. 7 mos.	Independent	Independent
		ROLLATOR WALKERS		
S_3	M	4 yrs. 11 mos.	Reverse Rollator Walker	Reverse Rollator Walker
S_4	M	3 yrs. 3 mos.	Reverse Rollator Walker	Reverse Rollator Walker
		PROGRESSORS		
S_5	F	3 yrs. 5 mos.	Reverse Rollator Walker	Walks with Quad Canes
S_6	M	3 yrs. 5 mos.	Reverse Rollator Walker	Independent

TEMPORAL DISTANCE PARAMETERS

Table 2

SUBJECT	PRE-OPERATIVE / SD	POST-OPERATIVE / SD	CHANGE
	STRIDE LENGTH (m.)		
S_1	0.67 / 0.17	0.75 / 0.19	+0.08
S_2	0.54 / 0.07	0.59 / 0.14	+0.05
S_3	0.40 / 0.06	0.63 / 0.23	+0.23
S_4	0.42 / 0.05	0.54 / 0.12	+0.12
S_5	0.44 / 0.05	0.54 / 0.09	+0.10
S_6	0.48 / 0.07	0.60 / 0.12	+0.12
Average (S_1 - S_6)	0.49	0.61	+0.12
Normal (4 years old)	0.77		
	VELOCITY (m. / sec.)		
S_1	0.79 / 0.19	0.69 / 0.19	-0.10
S_2	0.59 / 0.16	0.47 / 0.13	-0.12
S_3	0.36 / 0.12	0.58 / 0.18	+0.22
S_4	0.38 / 0.14	0.38 / 0.13	0.00
S_5	0.57 / 0.11	0.19 / 0.03	-0.38
S_6	0.74 / 0.15	0.71 / 0.22	-0.03
Average (S_1 - S_6)	0.66	0.50	-0.07
Normal (4 years old)	0.99		
	CADENCE (steps / min.)		
S_1	141	110	-31
S_2	131	95	-36
S_3	108	110	+2
S_4	108	84	-24
S_5	155	42	-113
S_6	185	142	-43
Average (S_1 - S_6)	138	97	-41
Normal (4 years old)	152		
	STANCE / SWING RATIO		
S_1	63 / 37	62 / 38	
S_2	52 / 48	55 / 45	
S_3	66 / 34	66 / 34	
S_4	52 / 48	60 / 40	
S_5	67 / 33	82 / 18	
S_6	54 / 46	61 / 39	
Average (S_1 - S_6)	59 / 41	64 / 36	
Normal (4 years old)	60 / 40		

SD = standard deviation

Kinematic Analysis

The angular displacements for the hip, knee and ankle at the key points of the gait cycle for all 6 subjects are presented in Table 3. As well, the angular displacement for the *Independent Walkers* (Figure 1), the *Rollator Walkers* (Figure 2) and the *Progressors* (Figure 3) is presented by joint for 100 percent of the gait cycle. At the hip, extension at terminal stance improved by an average of 13° in 5 subjects (S_2 to S_6). The sixth subject's (S_1) extension at terminal stance decreased by 12°. This subject's flexion at initial contact increased by almost 9° thereby keeping the total ROM at the hip basically constant. Overall, there was an average of only 1.3° change in the amount of hip flexion at initial contact. Therefore most of the increase in stride length may be attributed to increased hip extension at terminal stance. As well, the average hip extension preoperatively at terminal stance was found to be -2.2° whereas postoperatively it was -10.9° (i.e. very similar to the normal hip extension of -10° found at this point of the gait cycle — see Table 3).

The average hip extension at mid stance for the two (S_1 and S_2) independent subjects increased from 5° preoperatively to 11.4° postoperatively, moving further away from the normal value of 0°. However, for the four other subjects, the *Rollator Walkers* and *Progressors* (S_3 to S_6), average hip extension at mid stance decreased slightly from 1.9° to -1.4° postoperatively staying close to the normal value of 0°.

The average knee flexion at initial contact was 50° preoperatively and 38.1° postoperatively whereas normal value should be 0°. Moreover, the average knee flexion at mid stance was 30.5° preoperatively and 22.1° postoperatively, whereas normal values again should be 0°. Therefore knee flexion decreased by an average of 12° at initial contact and by 8.4° at mid stance. Excessive knee flexion which was evident in all subjects preoperatively was reduced at initial contact and at mid stance. However most of the subjects continued to walk in knee flexion throughout stance and none of them achieved normal knee movement of 0°. When we remove the two *Independent Walkers* from the scores, the subjects (S_3 to S_6) average knee flexion at initial contact improves even more, from 49° preoperatively to 30° postoperatively, and at mid stance from 29° to 11.0°. This is closer to the normal value of 0° (i.e. knee flexion decreased by an average 19° at initial contact and 18° at mid stance). These subjects all had external walking aids to help support their body weight.

SAGITTAL ANGULAR EXCURSIONS FOR THE HIP, KNEE AND ANKLE AT KEY POINTS DURING THE GAIT CYCLE

In degrees (°)

Table 3

SUBJECT	HEEL CONTACT		MID STANCE		TERMINAL STANCE		TOTAL MAXIMAL RANGE	
	pre-op	post-op	pre-op	post-op	pre-op	post-op	pre-op	post-op
HIP								
S_1	26.5	35.4	1.0	10.6	-10.9	1.1	37.4	34.3
S_2	32.9	38.2	9.0	12.3	-4.9	-9.5	37.8	47.7
S_3	33.6	30.2	6.3	-7.0	2.9	-19.4	30.7	49.6
S_4	27.4	24.5	-2.3	-6.8	12.5	-12.4	14.9	36.9
S_5	30.2	29.8	-3.5	-9.8	-9.4	-17.5	39.6	47.3
S_6	27.5	27.9	1.6	0.5	-3.5	-7.7	31.0	35.6
Average	29.7	31.0	2.0	0.0	-2.2	-10.9		
Normal	30		0		10			
KNEE								
S_1	42.7	45.9	18.8	39.9				
S_2	58.8	60.1	50.3	50.0				
S_3	44.3	33.3	25.0	9.9				
S_4	48.4	24.9	35.1	6.7				
S_5	58.3	38.6	34.0	15.2				
S_6	47.7	25.9	19.8	10.7				
Average	50.0	38.1	30.5	22.1				
Normal	0		0					
ANKLE								
S_1	-14.3	4.1	-6.7	15.0	-20.0	-2.3		
S_2	14.0	18.9	12.8	26.7	-3.9	25.4		
S_3	-25.1	-2.3	-31.2	-5.2	-44.7	-29.5		
S_4	3.0	3.7	7.8	10.6	-3.9	16.4		
S_5	11.7	11.2	10.4	19.3	-25.3	3.9		
S_6	20.6	3.6	16.0	4.2	13.5	4.3		
Average	1.6	6.5	1.5	11.8	-14.1	3.0		
Normal	0		10		0			

positive number = flexion
negative number = extension
op = operative

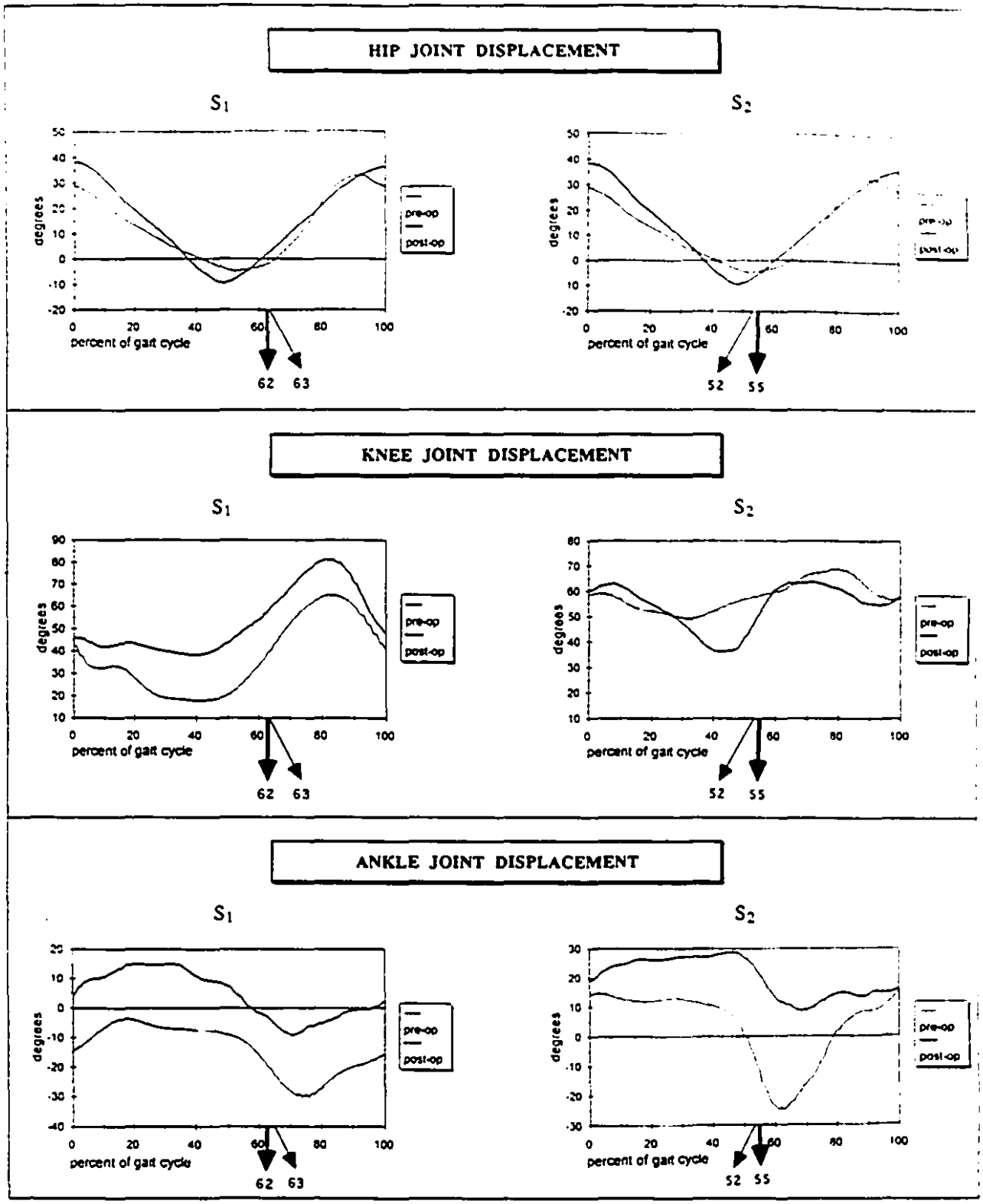


Figure 1 Hip, knee and ankle joint displacement of the two independent walkers (S_1 and S_2) pre and post surgery. The thin arrow is pre-op stance/swing ratio and the thick arrow is post-op stance/swing ratio.

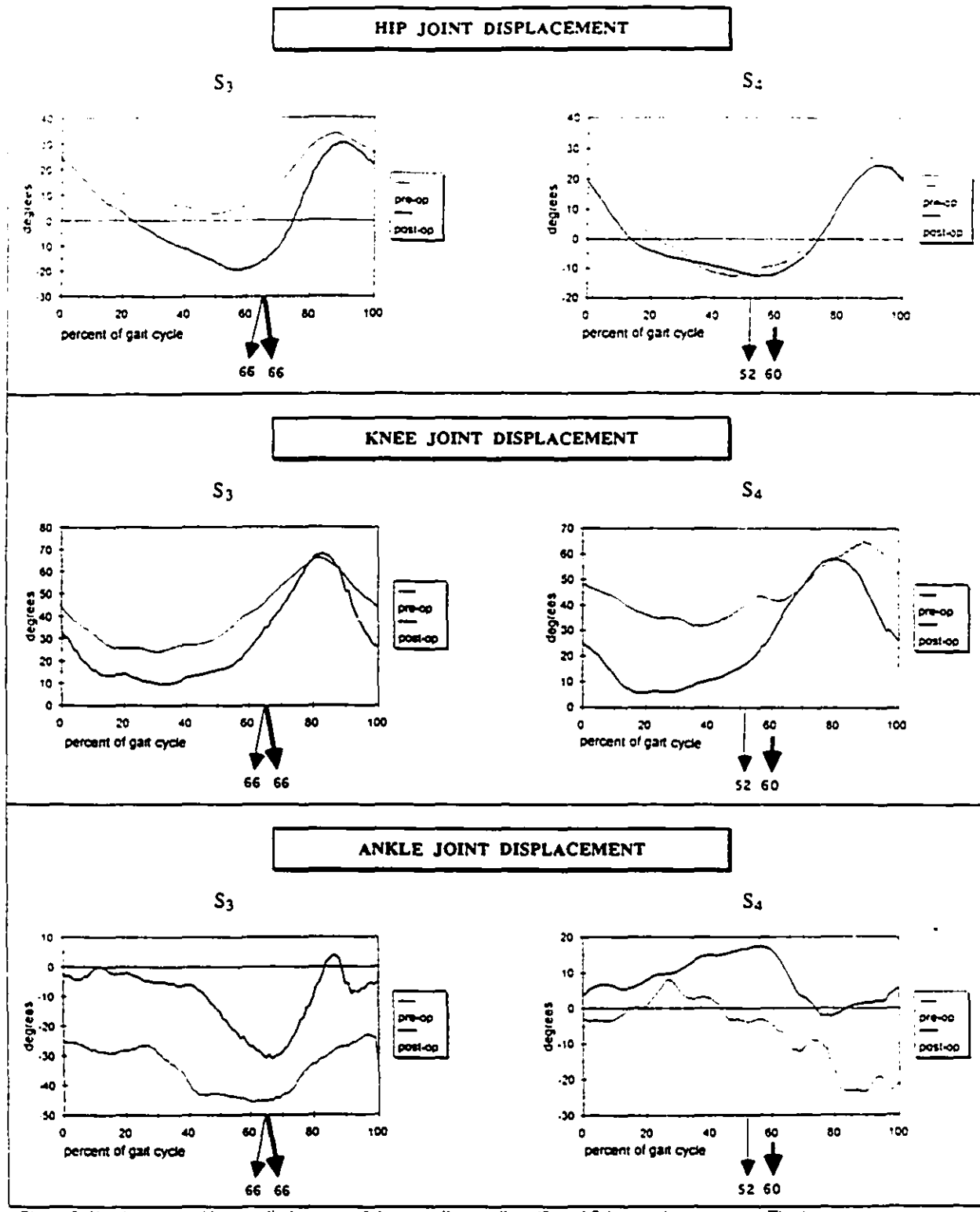


Figure 2 Hip, knee and ankle joint displacement of the two rollator walkers (S_3 and S_4) pre and post surgery. The thin arrow is pre-op stance/swing ratio and the thick arrow is post-op stance/swing ratio.

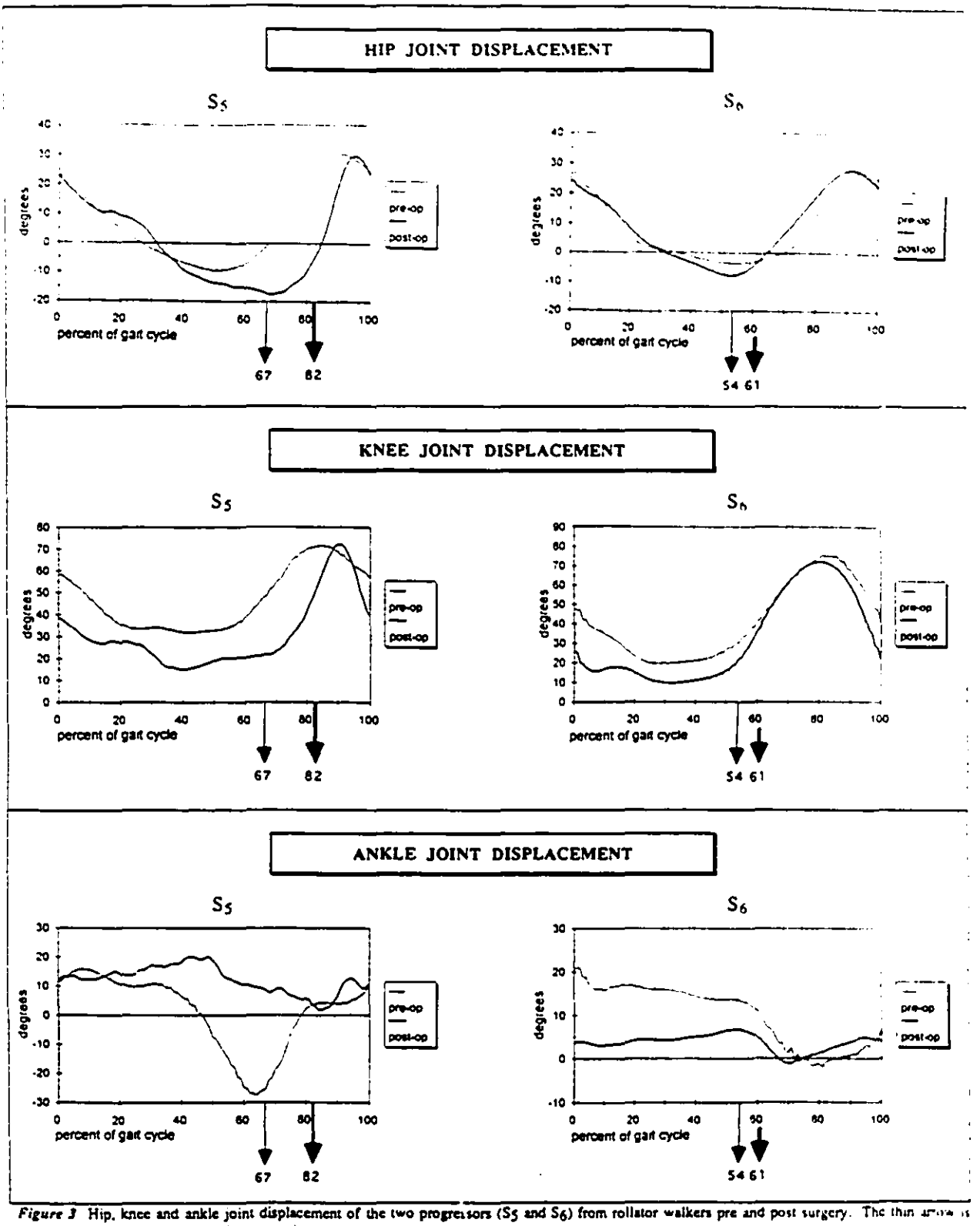


Figure 3 Hip, knee and ankle joint displacement of the two progressors (S_5 and S_6) from rollator walkers pre and post surgery. The thin arrow is op stance/swing ratio and the thick arrow is post-op stance/swing ratio.

Ankle angle at initial contact approached more normal values (0°) or remained status quo in five out of six patients. One subject's (S_2) ankle angle became more flexed by 4.9° at initial contact. As well, this subject had increased dorsiflexion during mid stance and terminal stance postoperatively. Ankle dorsiflexion approached the more normal value of 10° during mid stance as it went from an average of 1.5° preoperatively to 11.8° postoperatively. Ankle dorsiflexion was improved by an average of 17.1° at terminal stance as the average value for terminal stance went from -14° to 3° and approached the more normal value of 0°.

Functional evaluation

The clinical measure used to evaluate function was the Rusk Institute Rhizotomy Evaluation Form. A change of one on a score from one to five on any item was judged to be a clinically important change by the physiotherapist. In general, all scores improved by one to two grades or maintained status quo for the seven positions whether grading was on transition or assistance. More specifically, it was the more difficult functional positions that revealed the most dramatic improvements such as half kneeling, side sitting and standing as other functional positions were already achieved in most cases. Half kneeling was evaluated to be most difficult, even more difficult than standing in the majority of cases. S_2 to S_6 improved their scores on half kneeling by either one, two or even three grades depending on the side of the kneeling and depending on whether or not it was a transition or assistance that was being graded. In the half kneeling position when grading transition (describes how a child gets into a position), most of the subjects (i.e. S_3 to S_6) were only capable of a grade of two prior to surgery which corresponds to "child cannot observably participate in transition - therapist completes entire movement". Postsurgery all but one subject reached a grade of four or higher which corresponds to "child completes limb movement but requires therapist, furniture to push/pull self into position". In half kneeling position when grading assistance (describes how a child stays in a position), S_2 to S_6 were capable of a grade of one or two prior to surgery. Postsurgery they attained grades of three or four. Frequency distributions of pre and postoperative scores for each subject are presented (see Figures 4 to 7).

Figure 4

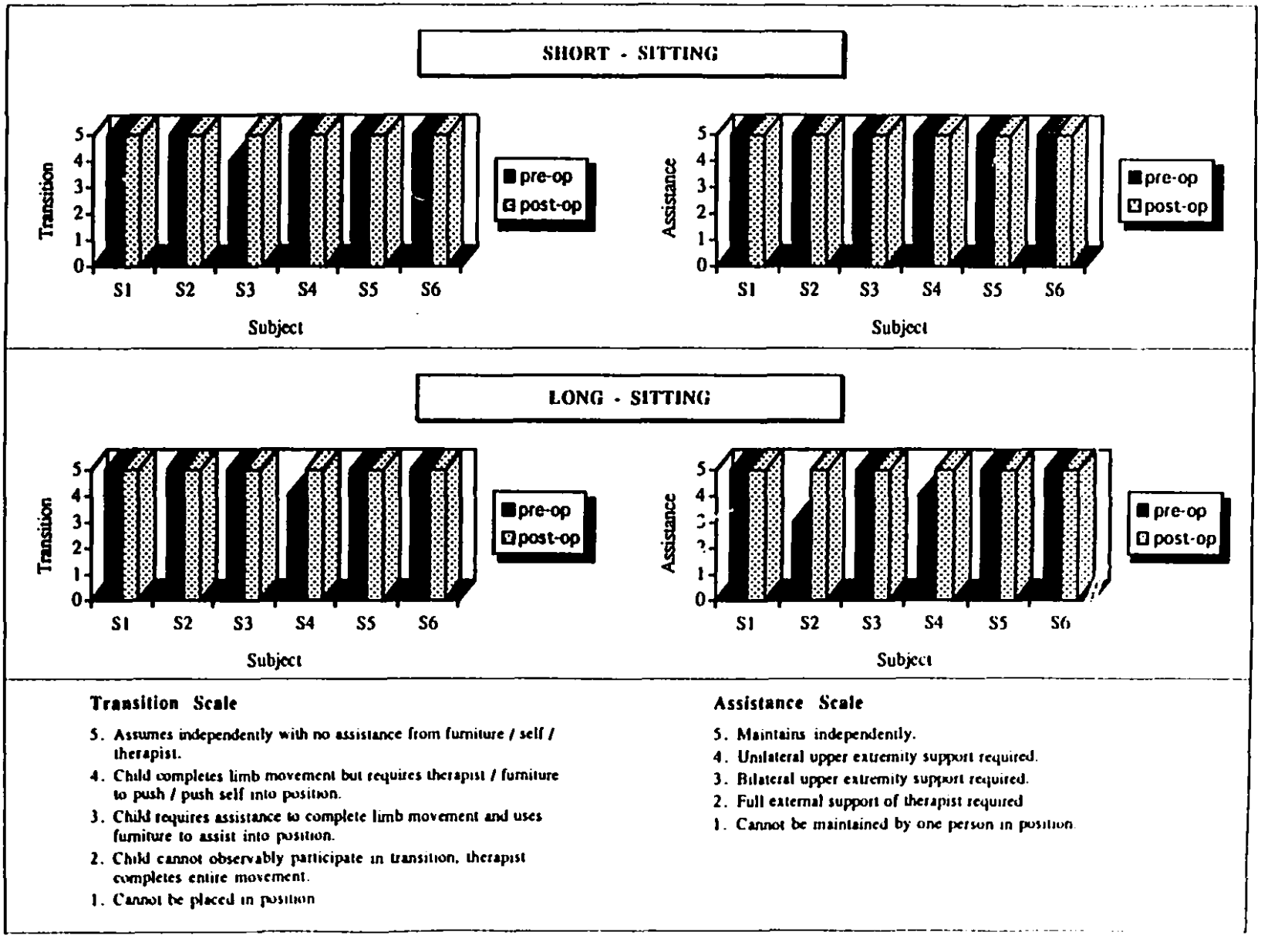
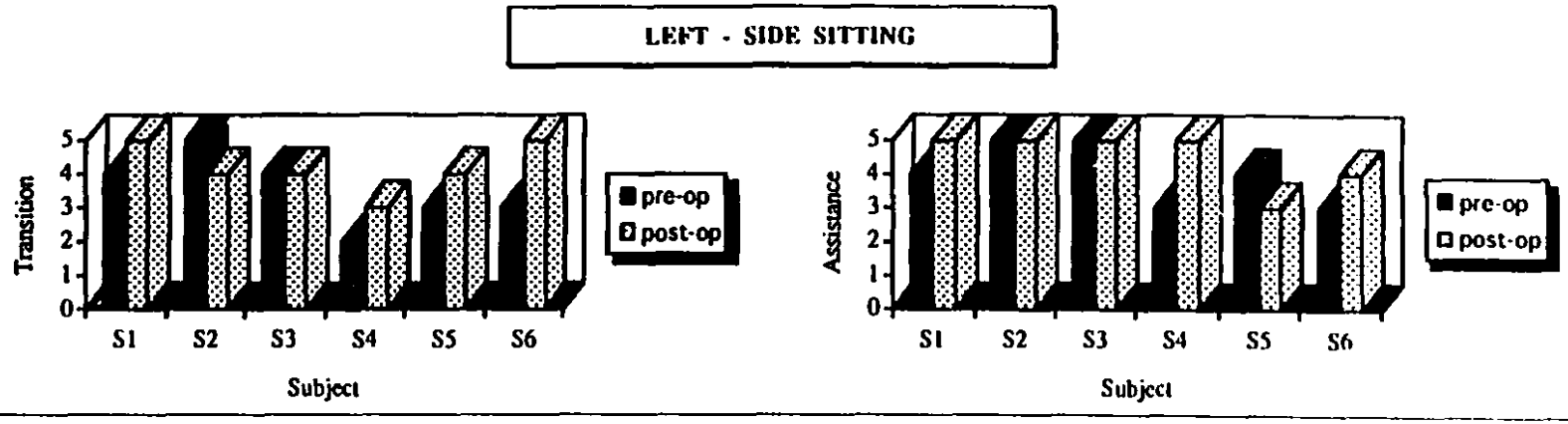
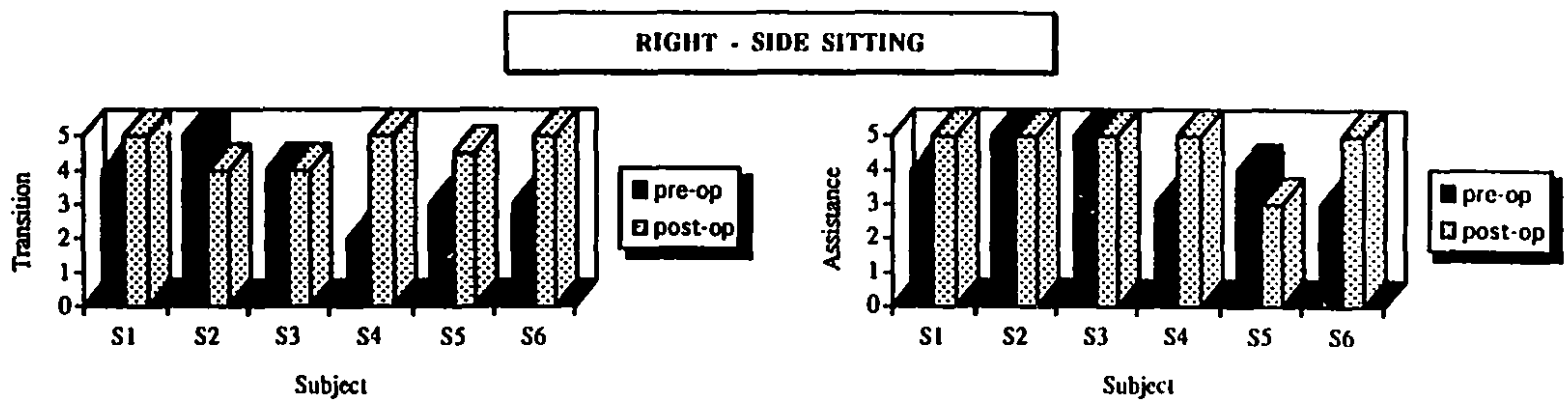

SHORT - SITTING
Transition
Assistance
pre-op
post-op
S1
S2
S3
S4
S5
S6
Subject
LONG - SITTING
Transition
Assistance
pre-op
post-op
S1
S2
S3
S4
S5
S6
Subject
Transition Scale
5. Assumes independently with no assistance from furniture / self / therapist.
4. Child completes limb movement but requires therapist / furniture to push / push self into position.
3. Child requires assistance to complete limb movement and uses furniture to assist into position.
2. Child cannot observably participate in transition, therapist completes entire movement.
1. Cannot be placed in position
Assistance Scale
5. Maintains independently.
4. Unilateral upper extremity support required.
3. Bilateral upper extremity support required.
2. Full external support of therapist required
1. Cannot be maintained by one person in position.

Figure 5





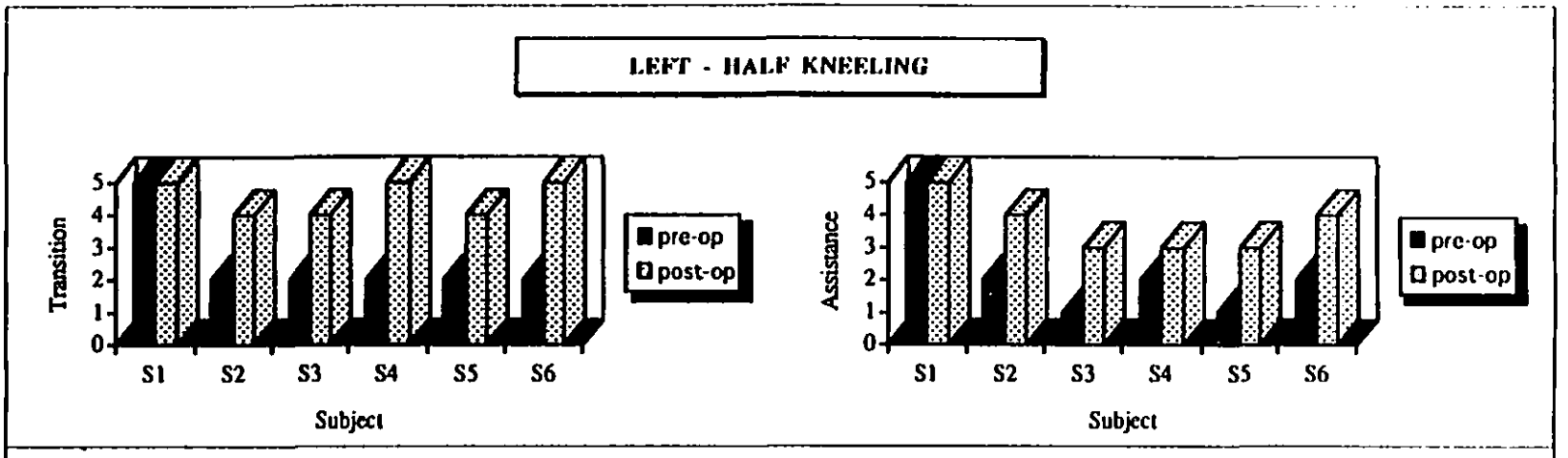
Transition Scale

5. Assumes independently with no assistance from furniture / self / therapist.
4. Child completes limb movement but requires therapist / furniture to push / push self into position.
3. Child requires assistance to complete limb movement and uses furniture to assist into position.
2. Child cannot observably participate in transition, therapist completes entire movement.
1. Cannot be placed in position.

Assistance Scale

5. Maintains independently.
4. Unilateral upper extremity support required.
3. Bilateral upper extremity support required.
2. Full external support of therapist required.
1. Cannot be maintained by one person in position.

Figure 6



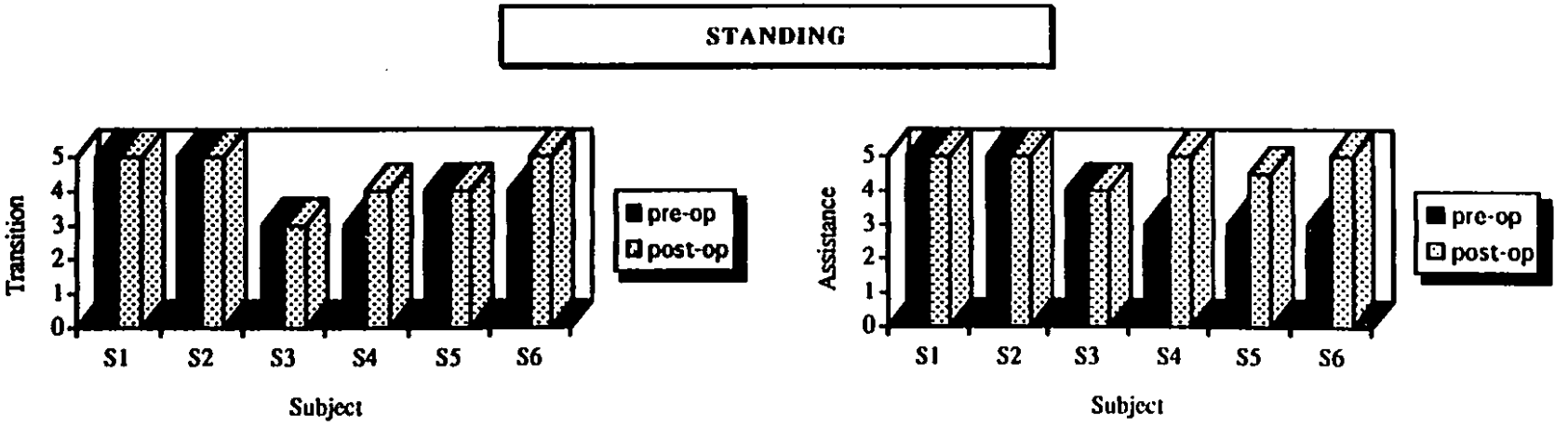
Transition Scale

5. Assumes independently with no assistance from furniture / self / therapist.
4. Child completes limb movement but requires therapist / furniture to push / push self into position.
3. Child requires assistance to complete limb movement and uses furniture to assist into position.
2. Child cannot observably participate in transition, therapist completes entire movement.
1. Cannot be placed in position.

Assistance Scale

5. Maintains independently
4. Unilateral upper extremity support required.
3. Bilateral upper extremity support required.
2. Full external support of therapist required.
1. Cannot be maintained by one person in position.

Figure 7



Transition Scale

5. Assumes independently with no assistance from furniture / self / therapist.
4. Child completes limb movement but requires therapist / furniture to push / push self into position.
3. Child requires assistance to complete limb movement and uses furniture to assist into position.
2. Child cannot observably participate in transition, therapist completes entire movement.
1. Cannot be placed in position.

Assistance Scale

5. Maintains independently.
4. Unilateral upper extremity support required.
3. Bilateral upper extremity support required.
2. Full external support of therapist required.
1. Cannot be maintained by one person in position.

Subject 3
(4 1/2 year old boy who continued to use a rollator reverse walker)

Temporal Distance Parameters

Stride length increased by 0.23 m. and attained a value of 0.63 m. Postoperatively it approached the average five year old group value of 0.84 m. (Sutherland et al., 1988). The stance/swing ratio in this case remained unchanged pre and postoperatively at 66/33 and he continued to use a reverse rollator walker. His walking velocity increased by 0.22 m/s (from 0.36 to 0.58 m/s). Average value at this age is 1.08 m/s. Part of this slower walking speed (compared to normal children) can be attributed to the use of an assistive device. Cadence remained relatively stable from 108 preoperatively to 110 steps/min postoperatively. Normal cadence for this age group is 154 steps/min (Sutherland et al., 1988). His walking velocity increased due to the longer stride length, however he was not able to progress to using less external assistance as the control and balance required was not present (Giuliani, 1991).

Kinematic Analysis

Hip joint displacement

The major improvement seen at this joint was an increase in hip extension at terminal stance by 22.3° thus allowing for a greater stride length. Total hip range increased by 18.9°.

Knee joint displacement

Excessive flexion during stance is evident preoperatively. Postoperatively he achieves 10° more flexion at initial contact and 15.1° more flexion at mid stance. The

persistent knee flexion may be related to weakened plantar flexors which were unable to control forward tibial advancement caused by momentum and anterior displacement of body mass. The eccentric contraction of the calf muscle places the muscles at a constant stretch. Consequently, the presence of spasticity is a major deterrent to the progression of gait (Cahan et al., 1990). Therefore, postoperatively strengthening of the gastrocnemius muscle especially eccentrically would likely benefit this patient.

Ankle joint displacement

Preoperatively the dominant ankle pattern was forefoot contact. During mid stance to terminal stance forefoot contact continued and flatfoot stance was never achieved. During swing there was a tendency to dorsiflex but this remained unsuccessful throughout swing.

Postoperatively at initial contact he gained a more neutral position of the ankle and remained in this near neutral position during mid stance. He exhibited premature heel rise in mid to late stance, however much less so than preoperatively. He achieved dorsiflexion past neutral in late swing to prepare for the next heel contact.

EMG Analysis

Preoperatively, a primitive locomotor pattern of abnormal phasing as described by Sutherland et al. (1988) was identified for all four muscle groups. GA/TA muscle activity preoperatively was characterized by some cocontraction, especially in the GA muscle with some bursts of activity by TA in the swing phase. All the cycles were quite variable. Preoperatively VL and the MH have no consistent firing pattern and there is cocontraction throughout the cycles.

Postoperatively however, we see more organized burst of muscle activity in all of the four muscle groups. The timing however, cannot be described as normal. Gastrocnemius reveals bursts of activity in all five cycles at approximately push off (60% of the gait cycle) and continues abnormally into the beginning and mid point of swing. At the same time though, TA is silent and becomes active only once GA turns off. However, TA activity is also not considered normal as it starts late in swing (instead of early) and continues throughout stance. Of importance, is the decrease of cocontraction postoperatively between agonist and antagonist as compared to preoperatively (see Figure 8).

Furthermore, postoperatively the VL/MH complex shows less variability between cycles. There is a more organized pattern where VL is active in mid to late swing to stabilize the knee for weight acceptance. VL remains active into mid stance. This pattern is nearer to the normal standard seen at this age. MH also reveals more consistent and organized on/off patterns where it is active in mid to late swing and then however, continues with prolonged activation until the end of stance. In summary, the pattern is not normal and reveals prolonged activation, however it does show less cocontraction and more consistency than it did preoperatively.

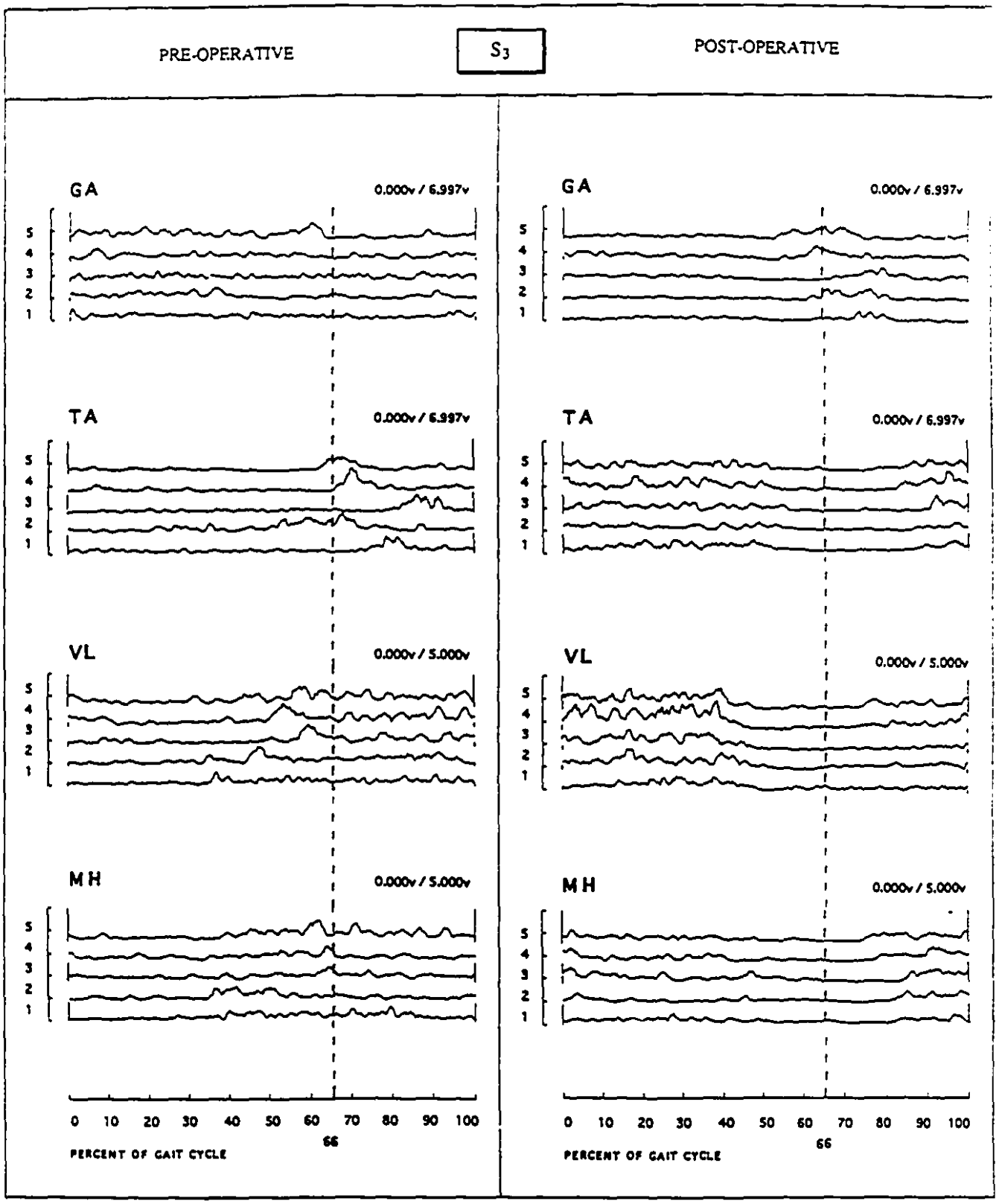


Figure 8 EMG phasic activity of 5 cycles for gastrocnemius (GA), tibialis anterior (TA), vastus lateralis (VL) and medial hamstrings (MH) of S_3 pre and post SDR during normal walking. The dotted line is the average stance/swing ratio.

Subject 5
(3 1/2 year old girl who progressed from a rollator reverse walker to quad canes)

Temporal distance parameters

Stride length increased from 0.44 m. preoperatively to 0.54 m. postoperatively. The stance/swing ratio as a percentage of the gait cycle changed from 67/33 to 82/18. This significant lengthening of the stance cycle postoperatively is due to the use of quad canes, whereas, preoperatively she used a backward rollator walker. Walking velocity decreased from 0.57 m/s to 0.19 m/s. Cadence decreased from 155 steps/min. to 42 steps/min.

Kinematic Analysis

Hip joint displacement

This subject achieved 8° more hip extension at terminal stance postoperatively which is reflected in a greater stride length. Total hip range also increased by almost 8°. All of the increased range may be attributed to increased hip extension.

Knee joint displacement

Excessive flexion is evident preoperatively throughout stance. She achieved 20° less knee flexion at initial contact and 19° less flexion at mid stance postoperatively.

Ankle joint displacement

Pre and postsurgery the ankle at initial contact was quite similar, 11.7° and 11.2° respectively. The major difference occurred at mid stance to mid swing. Preoperatively she pushed off and attained -28° just before toe off. Postoperatively she barely achieved any pushoff which may be caused by weakened plantar flexors. At toe off postoperatively (82% cycle), she exhibited dorsiflexion to clear the foot for swing.

EMG Analysis

Preoperatively, early gastrocnemius activation was evident in all cycles examined. The cycles had little variability in the more distal muscles and slightly more variability in the proximal muscles as is found in normal adults, (Winter & Yack, 1987). With respect to timing, the TA muscle contracted quite normally, just before swing, however, the eccentric contraction normally seen in the first half of stance was hardly evident. VL was active in the last third of swing as in normal three year olds, however, it revealed prolonged activation throughout stance. MH showed quite normal muscle activity timing except for a short activation at the end of stance which was evident in most of the trials. In general the timing of the four muscles was somewhat prolonged however the muscles appeared to be working as a unit with little cocontraction (see Figure 9).

Postoperatively, the timing is quite similar in all trials as compared to preoperatively, taking into consideration the much larger stance/swing ratio after surgery due to the new adaptive equipment (quad canes) being used.

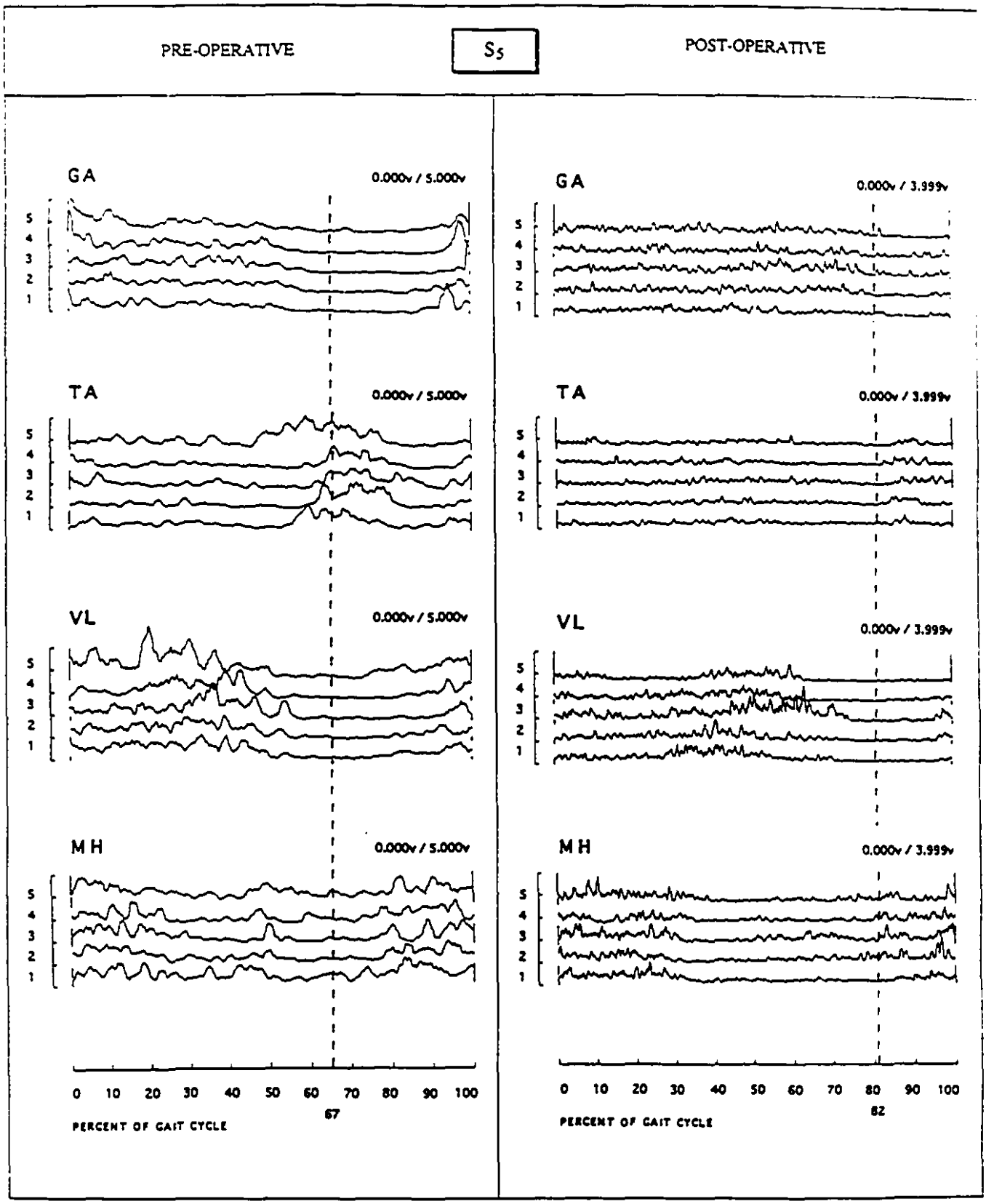


Figure 9 EMG phasic activity of 5 cycles for gastrocnemius (GA), tibialis anterior (TA), vastus lateralis (VL) and medial hamstrings (MH) of S_5 pre and post SDR during normal walking. The dotted line is the average stance/swing ratio.

Summary of Results

Six subjects' walking patterns were analyzed by temporal distance parameters and kinematic analysis. The major results found in this study were increased stride length in all 6 subjects, decreased walking velocity in all but one subject, and decreased cadence. Hip extension at terminal stance improved in five out of six subjects. Less knee flexion and ankle dorsiflexion at initial contact and mid stance were found in the *Rollator Walkers* and *Progressors*. However, increased knee flexion and ankle dorsiflexion were observed in the *Independent Walkers*. Out of the six subjects, EMG on two subjects were analyzed to further detail their walking patterns. Abnormal walking patterns as noted by EMG of 4 muscle groups remained relatively stable post SDR. The EMG analysis revealed a difference in the amount of cocontraction and abnormal timing present in these 2 subjects pre as well as postoperatively. Interestingly S_5 who progressed in her walking aids more quickly than S_3, had better timing prior to surgery (however not normal) than S_3.

The functional evaluation's most important finding was improvement in the half kneeling position postoperatively, both in how the child gets into the position (transition), as well as how the child stays in the position (assistance). This is important in that it demonstrates an improvement in the ability to dissociate between total flexion and total extension patterns.

Discussion

Selective dorsal rhizotomy is a neurosurgical procedure designed to reduce spasticity and improve function by selective division of sensory rootlets in the cauda equina of the spinal cord. Dorsal roots or rootlets that are determined by electrical stimulation to be abnormal are cut. This surgical approach has primarily been used for selected children with spastic cerebral palsy. Decreased spasticity, increased ROM and improved motor skills such as ambulation and upper extremity function have been reported in patients with cerebral palsy after SDR (Abbott et al., 1989; Fasano et al., 1978; Peacock et al., 1987). Despite growing support for SDR as an effective intervention, efficacy studies are lacking. The lack of objective and reliable outcome measures for motor function and gait have limited the conclusions that can be drawn from previous studies (McLaughlin et al., 1994).

Vaughan et al. (1988) and Cahan et al. (1990) are the only two studies that have quantitatively investigated gait characteristics with SDR. Both groups have found significant improvements in ROM, stride length and velocity during gait post SDR. Both studies have ascertained from kinematic analys's that there was less hip flexion at the beginning of stance as well as increased knee and hip ranges throughout gait. This study's finding of increased stride length further supports these results. This increased stride length may be attributed to increased hip extension that was recorded in 5 out of the 6 subjects at terminal stance. This finding is significant in that it confirms what therapists have described clinically as a more extended hip position during gait. Instead of these subjects walking in a continually flexed position, postoperatively they achieve more extension at the end of stance and therefore look more normal.

Improved stride length found in this study however did not translate into increased velocity as was found in the two other studies cited above. Both reported modest increases in velocity postoperatively. This should be interpreted with caution as walking speed is highly dependent on an individual's motivation or compliance and can vary considerably

(Vaughan et al., 1989). Furthermore, both of these studies included subjects that were up to 14 years of age which differs significantly from the present study where the oldest child was only 5 years old. In this study, walking velocity improved in only one subject (S_3). He was one of two subjects who continued to use a rollator walker postoperatively. The other subject (S_4), in this category (*Rollator Walkers*), had a stable walking velocity. Walking velocity in all the other subjects decreased. This may be explained in terms of gaining control. The increased stride length created the need to learn a new walking pattern. In order to adapt to this new ambulation behavior, velocity and cadence may have decreased to ensure better control and stability. Different strategies seem to have emerged in different subjects. As the motor learning theory states, when one begins to learn new skills there is variability and flexibility in the way in which these skills are achieved (Poole, 1991). S_3 increased his stride and velocity and maintained a stable cadence. This may be because he continued postoperatively with the walker and was not ready for a progression with respect to his assistive device. He had attempted to use quad canes in therapy and was able to use them with moderate to maximal assistance but was not able to use them independently or functionally. S_5 however, progressed to quad canes from the reverse rollator walker, improving her stride length but decreasing or sacrificing her walking velocity and cadence, and perhaps exhibiting improved control with use of the new adaptive equipment, but this requires further investigation. The two subjects who did not upgrade their adaptive assistive devices could maintain or even increase their velocity with this new stride length. The *Independent Walkers* (S_1 and S_2) and *Progressors* (S_5 and S_6) whose velocity decreased were those who upgraded their ambulatory status with respect to assistive device. Those who were already independent prior to surgery (S_1 and S_2) were included because they also progressed in terms of control. From the videos preoperatively, it appears that these two subjects are chasing their center of gravity. However, postoperatively they have increased stride lengths and compensate by slowing down (both velocity and cadence) in order not to lose their balance. They appear to be relearning how

to walk with new walking parameters (decreased spasticity and increased ROM of the hip extensors).

Another major finding in this study was the improved hip and knee extension during mid stance. According to Vaughan et al. (1988), the mid stance angle of the hip, knee and ankle provide insight into the degree of strength and control a subject exhibits during gait. In agreement with Cahan et al. (1990), a more extended position at the knee was found in four out of six subjects, reflecting a more upright position and perhaps more control at the knee. As well, a more extended hip angle at mid stance was found in all subjects and indicates a more upright position. Contrary to this, Vaughan et al. (1988) found their subjects to be more crouched at 6 months than they were prior to surgery but more extended at one year postsurgery than they were presurgery. They suggest that this indicates a temporary weakness postsurgery which improves with time. All four of our subjects with more extended knees and hips at mid stance walked with some type of assistive device, thus any decrease in strength encountered post SDR may be masked by the assistive device which provides support of their weight. On the other hand, the two subjects who walked independently prior to surgery walked with more knee flexion during stance postoperatively as did Vaughan's subjects, probably because of weakness of the quadriceps muscle and loss of spasticity that was helping them preoperatively to stand up more rigidly (Abbott et al., 1989). Therefore, it is necessary to follow S_1 and S_2 (those who walked independently pre and postsurgery) at one year in order to determine whether the knees became more extended at mid stance indicating improving strength over time.

With respect to strength at the ankle, this study found on average an increase of 10 degrees of dorsiflexion at mid stance probably reflecting decreased strength of the gastrocnemius muscle post SDR. Clinically the children are found to crouch at the ankle post SDR and so they are required to use ankle foot orthosis in order to keep the ankle in a neutral position. When the gastrocnemius muscle (which is a two joint muscle) is weak it

does not fulfill its role which is to prevent forward displacement of the tibia. According to Giuliani (1991), this decrease in strength may have been present preoperatively and may have been masked by spasticity. It is of interest to follow these children long term in order to evaluate whether this decreased strength improves over time. In this light, therapeutic strengthening exercises are of great importance in the rehabilitation of these children.

We see from the present EMG study there are differences in the two subjects' muscle firing patterns during gait prior to surgery. S_3 revealed a paucity of normal muscle activity timing which may be reflective of the immature pattern described by Hirschfield and Forssberg (1988). According to these authors, the normal infant gait pattern is characterized by a high degree of agonist/antagonist muscle coactivation. There is no push off and no preactivation of any musculature to decelerate the limbs. Frequently there are mass on/off synergies with extensor muscle activation for stance and flexor activation for swing. This type of activity is related to a deficit in voluntary motor control which is distinct from spasticity (Cahan et al., 1990). Contrary to S_3, S_5 revealed good muscle activity timing preoperatively as well as postoperatively. That is, the spasticity that she demonstrated prior to surgery probably masked good underlying voluntary control. Therefore, she was able to improve functionally (progressing from rollator walker to quad canes) more readily than her counterpart who remained a rollator walker. However, only minor spasticity is actually noted in S_5's EMG analysis prior to surgery and therefore perhaps some of her improvements are due to the intensive rehabilitation training received following surgery. Interestingly, Leonard et al. (1988) note there is a gradual progression from muscular cocontraction to reciprocal activation in normal children at about 2 years of age. As well, the amount of cocontraction during gait in children with CP tends to decrease with time and varies among individuals. Postoperatively, S_3 revealed a decrease in cocontraction between agonist and antagonist as compared to preoperatively. Therefore it cannot be ruled out that this decrease in cocontraction postoperatively may be independent

of the SDR surgery. It should be noted that S_3 has gone on to independent walking one year postsurgery. It would therefore be interesting to reanalyze the phasic muscle activity in this subject and see whether the timing has improved or not.

To date, only Cahan et al. (1990) evaluated on/off EMG during the gait cycle pre and post rhizotomy. The investigators found that rhizotomy did not alter the abnormal sequencing of muscle action as was revealed by a persistence of primitive locomotor synergy patterns. They concluded as did Perry (1975) that CP is not only a disorder involving spasticity but also a disorder of motor control. From Cahan's results, we would assume S_3's muscle timing would not have changed at one year following surgery, when he started to walk independently. However, if muscle timing does change gradually then perhaps this can be explained by his young age and the adaptability of the nervous system. The level of maturation may contribute to control of locomotion. Perhaps S_3 was young enough to take advantage of Thelen's (1992) less deterministic view of locomotion. She states that motor patterns during gait are only softly assembled in the central nervous system. Movement patterns are assembled "on line" in reference to and in continual interaction with the physical properties of the body and the environment. Therefore, as we mature even one alteration in a component of S_3's ambulatory behavior such as stride length may in turn affect the wiring of the muscle firing patterns during gait. Due to S_3's young age at the time of surgery, his motor patterns during gait may not have been completely hard wired and he would have been able to learn more normal muscle patterns after spasticity was removed by SDR. These trends need to be confirmed on larger numbers and therefore ongoing recruitment of patients, follow-up and analysis of kinematic and EMG findings are in progress. Longer follow up evaluation are also needed to follow the changes through time particularly for the children with more severe impairment in motor control. This may enhance our ability to select candidates most suitable for this procedure.

In summary, the existence of abnormal motor patterns preoperatively may explain the slower gains that may be found post SDR, suggesting the need for perhaps earlier surgical intervention and/or perhaps different therapeutic strategies after SDR surgery. Whether or not the abnormal movement patterns improve, the principles of motor learning as a treatment approach appear to be important in the comprehensive rehabilitation of children undergoing SDR. As we change some gait parameters in these subjects following SDR intervention (for example, increased stride length or decreased velocity) they may learn new walking patterns to adjust to these changes. They can learn poor patterns or more appropriate patterns. Therapists use the principles of practice, positive and environmental feedback, as well as ROM and strengthening exercises to teach these "more normal" walking patterns. These principles, long used by physiotherapists and occupational therapists, have been supported by the recent research in motor learning theory. Intensive rehabilitation is a part of most SDR programs in North America and are felt it to be integral to a positive outcome (Abbott et al., 1989; Peacock et al., 1987). Children who can practice appropriate patterns of movement using a range of functional activities, first within a controlled environment, will likely learn and maintain these more normal patterns of movement.

These children need to unlearn these abnormal muscle firing sequences and replace these strategies by learning more functional movement patterns. Most CP children move in total flexor or extensor patterns and often have difficulty dissociating these two movement patterns. Gait is one example where flexion is required at one hip and extension is required at the other, making this activity very difficult for the child with CP. The half kneeling position is another example which demands hip flexion on one side and hip extension on the contralateral side. This increased ability to dissociate from a total flexor pattern is evident in all of the subjects as measured by the half kneeling position in the Functional Evaluation in this study. It was found to be the most difficult position evaluated in the

functional evaluation preoperatively, even more difficult than standing. Moreover, the greatest amount of improvement was found in this half kneeling position where most subjects had a baseline grade of 2 and attained a grade of 4 postsurgery. The half kneeling position was the most sensitive measure of change in the functional evaluation. Future studies need to include a wider range of functional indicators which would include the basic half kneeling position and ending with a gamut of functional activities in the standing position during gait. The positions evaluated in this study using the Rusk assessment tool were too simple (except for half kneeling) for the subjects and therefore did not reflect the change in function post SDR.

Motor function changes that should be investigated in the future can include activities such as walking and stopping to pick up an object, stopping and turning, or stepping over an object. These can all be captured with kinematics and are thus quantifiable. These are all significant functional activities that will enable the child to be more adaptable and mobile, and be able to participate in more activities that are typical of their age group, thus enhancing their quality of life.

Many questions remain to be answered. Although recent literature suggests that SDR is efficacious or improves function, because no studies have controlled for the direct effects of intensive therapy confounding motivational effects or maturational changes in young children with CP (McLaughlin et al., 1994). According to McDonald (1991), it also remains to be determined that any positive effects are long lasting and better than traditional forms of treatment (cited in McLaughlin et al., 1994).

In summary, this study examined the gait patterns of six individual children with CP and found: 1) improved stride length; 2) decreased walking velocity suggesting improved control; 3) improved hip and knee angles at mid stance indicating less of a crouched gait for the rollator walkers; 4) increased dorsiflexion which may be attributed to decreased strength of the gastrocnemius muscle (thus requiring ankle foot orthosis); and

5) a persistence of abnormal muscle firing during gait. It was found that more abnormal firing patterns were noted in S_3 than S_5 preoperatively and perhaps can explain why S_3 took longer to progress from a rollator walker (i.e. he started with less voluntary motor control).

Limitations

The small number of patients as well as the variable nature of gait patterns in cerebral palsy limit the interpretation and generalization of the findings regarding the effects of SDR on locomotor function (Csongradi et al., 1979; Sutherland & Davids, 1993). It has been suggested that several pathophysiological factors may contribute to abnormal locomotion in children with CP and each patient has a distinct gait profile (Berger et al., 1984; Crenna et al., 1992). This indicates there is consistent intersubject variability even within the same clinical group and emphasizes the precluding of pooling results. It is for this reason that each subject was studied individually.

The gait analysis procedure took approximately two hours to complete, including preparation and execution time. The long preparation time prior to gait analysis made some of the children irritable and tired. In order to pass the time in a more eventful way, age appropriate videos were shown, and arts and crafts material were made available. Attrition was another limiting factor to this study as some parents found the procedure excessive. Adequate rest periods (with snacks) throughout the testing procedure were used to ensure reliable data collection and hopefully limited the drop-out rate.

Although it would have been desirable to test all subjects at least 6 months prior to surgery in addition to the preoperative assessment to ascertain that gait was indeed stable, many subjects underwent this surgical procedure very soon after the selection process. Moreover, because gait analysis is a lengthy procedure it was not realistic to expect participation of these young children in the research protocol beyond two experimental sessions. As described earlier, the team clinically determined that each subject's functional

status had plateaued within the last 6 month period before surgery. Significant gains in locomotor function due to maturation was therefore not anticipated. It should be noted that although these children may show stability over a six month time span, slow gains over several years are still possible. Therefore, the effect of maturation could not be excluded completely. To better control for maturation, a randomized approach would have been ideal in comparing those who meet the criteria for SDR and have the surgery, and those who have a delay in surgery. Ideally, this design approach could be implemented if a large waiting list for this surgery existed. This study was limited in that it could not look at the effects of SDR alone. A similar randomized approach could be used to examine effects of SDR and intensive training versus intensive training alone. Intensive training, which was a part of the SDR intervention may have had an impact on the gait changes found postoperatively.

Although spasticity was not evaluated in this study using a quantifiable tool, spasticity was a necessary criterion in order for the child to be recommended for the SDR program. However, the degree of improvement following SDR with respect to spasticity, was not specifically documented.

Ethical Considerations

The major ethical consideration in this study was the fatiguing nature of the laboratory testing procedure. It was hoped that entertainment, refreshments, collection of data at a comfortable speed, and sensitivity to the children's needs would alleviate this problem.

The removal of EMG electrodes and skin tape caused minor discomfort. Every effort was made to remove these carefully and slowly.

Significance

Studies to date have demonstrated that SDR can improve gait. Both Cahan et al. (1990) and Vaughan et al. (1988) found improved stride length and velocity. This study reinforces the finding of increased stride length post SDR. However, with respect to velocity a decreased walking speed was found in most cases. This decrease may be indicative of improved control and should be substantiated by further studies that would evaluate balance, as well as, synergic activation of appropriate muscle groups. As well, this study found better hip and knee extension during stance phase signifying a more erect posture. This increased stride length, better control and increased hip extension during walking is functionally significant in that the children look more like their normal peers. Looking more normal may have an impact on peer relationships and societal acceptance which may also translate into improved self esteem. Quality of life issues such as integration into the community and peer relationships are important factors which need to be investigated. These children who walk "better" post SDR may also be able to take part in more leisure and sport activities, and may be less of a burden on their caretakers. These specific outcome measures need to be applied to this population of interest to determine if minimizing their disabilities translate into enhanced quality of life.

This study demonstrates that SDR and intensive therapy have altered several parameters in the children's walking patterns. These children have novel motor characteristics and traditional neurodevelopmental therapeutic approaches may no longer be valid (Giuliani, 1991). Traditionally, therapists have not included strengthening exercises as part of the regimen of physiotherapy intervention in children with CP. It was generally understood that the spasticity would interfere with the strengthening process. However, some of the children in this study demonstrated an underlying muscle weakness which became more apparent following SDR. It was shown in this study that the children are able to dissociate more easily between flexion and extension (as seen in the improved half

kneeling position) and achieved longer stride length (demonstrating flexion / extension dissociation). It appears that post SDR children may be better able to isolate movements (example: increased hip extension at end of stance). This new ability makes strengthening a more feasible treatment objective; and therapists may now consider concentrating on strengthening exercises. One of the challenges that rehabilitation professionals address is the new gait parameters observed following SDR. The children need to unlearn abnormal muscle firing sequences and replace these strategies by learning more functional patterns. Principles such as feedback, practice and cueing, which are all a part of the motor learning theory, appear to address these needs.

This study is unique in examining muscle timing during the gait cycle preoperatively, and the relationship between preoperative muscle activation and degree of improvement documented postoperatively. Trends in two subjects have demonstrated that the more abnormal the timing or degree of voluntary control, the slower and more limited the progress after SDR. There was a difference in the quality of movement control preoperatively between S_3 and S_5, and this may explain, in part ,why S_5 could improve her gait parameters more quickly than S_3. Preoperative voluntary control as recorded by the EMG analysis may be a useful indicator in determining before surgery degree of improvement following intervention. This may enhance our ability to select candidates most suitable for the procedure. Only one other study reported on abnormal muscle timing which persisted post SDR but the subjects in that study were older (age range from 4.6 to 23.5 years) than in the present study. The children in this study were very young, therefore age variation was less confounding to the results than in the study by Cahan et al., 1990 . As well, in the study by Cahan et al. (1990), the EMG findings were summarized generally and the variability between subjects preoperative were not described.

In summary, the results of this study signify: 1) a more normal looking gait pattern is achieved and may therefore translate into other social and functional gains; 2) traditional neurodevelopmental therapeutic approach may need to be replaced by a motor learning approach to rehabilitation; and 3) preoperative EMG patterns may be helpful in predicting degree of improvement in the SDR candidates.

Future directions

Although results presented here are encouraging, there are many more questions that need to be answered. Other gait parameters such as trunk posture and double support time (an indicator of balance skills) could also be measured as part of gait analysis in these children following SDR. The use of varied functional activities during gait such as start and stop time, picking up or carrying objects while walking, turning or going over obstacles as functional outcome measures should be recognized as important. The relationship between functional gains and quality of life issues need to be addressed. As well, future studies could also assess energy costs and endurance post SDR. In time, long term studies of this nature will hopefully provide evidence of the functional benefits of selective dorsal rhizotomy (see limitations section).

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Appendix A

Walking test: Information Sheet

McGill University, in cooperation with the Montreal children's Hospital and Shriner's Hospital are conducting electromyographic and kinematic analysis of the children who are scheduled for the selective dorsal rhizotomy surgery.

What is electromyographic (EMG) analysis?

EMG is the electrical activity produced by a muscle. The EMG of several muscles of your child's legs will be recorded while he/she is walking.

How will the recording be done?

Small electrodes are taped to your child's skin in order to record muscle activity for later analysis.

Does it hurt?

Not at all! However, removing the tape is like removing a band-aid.

What is Kinematic analysis?

It is the study of movement. Small neon stickers are taped to your child's body (foot, ankle, knee, hip and soulder points). He/she is then videotaped while walking.

How long will the test take?

The test generally required forty minutes of preparation time, e.g., taping on electrodes. The child is then asked to walk for approximately 10 minutes over a span of approximately forty-five minutes. The child can rest for as long as needed.

The test will be repeated six months after surgery.

Why is this testing important?

The analysis obtained from these tests will provided valuable information about the children's walking pattern before and after surgery.

Who will get in touch with me about the test?

Debbie Teitelbaum will call you to arrange an appointment for the test.

Where will the test take place?

The test will take place at McGill University, 3630 Drummond. If you have any questions fell free to call Debbie at (514) 696-8121.

Appendix B

Information concernant le test de démarche

L'université McGill mène, conjointement avec l'hôpital de Montréal pour enfants et l'hôpital Shriners pour l'enfant informe, une étude /lectromyographique et kinématique sur les enfants qui doivent subir une rhizotomie dorsale sélective.

Qu'est-ce qu'une analyse électromyographique (EMG)?

L'EMG mesure l'activité électrique produite par un muscle. L'EMG de plusieurs muscles des jambes de votre enfant sera enregistrée pendant qu'il/qu'elle marche.

Comment s'effectue l'enregistrement?

De petites électrodes sont appliquées sur la peau de votre enfant pour permettre d'enregistrer l'activité musculaire en vue d'une analyse ultérieure.

Est-ce douloureux?

Non, pas du tout! Cependant enlever la bande adhésive revient à enlever un pansement adhésif de type "band-aid".

Qu'est-ce que l'analyse kinématique?

Il s'agit de l'étude du mouvement. De petits collants au néon sont collés sur le corps de votre enfant (à l'articulation des pieds, des chevilles, des genoux, des hanches et des épaules). Il/elle est filmé/e sur vidéo pendant qu'il ou qu'elle marche.

Combien de temps dure le test?

Le test exige 40 minutes de préparation pour coller les électrodes et les collants. On demande ensuite à l'enfant de marcher pendant dix minutes sur une période totale de 45 minutes. L'enfant peut se reposer à tout moment et aussi longtemps qu'il le souhaite.

Le test sera repris six mois après l'opération.

En quoi ce test est-il important?

Ces tests permettront de recueillir de l'information utile sur les démarches des enfants avant et après l'opération.

Qui communiquera avec moi à propos du test?

Debbie Teitelbaum vous appellera pour vous fixer un rendez-vous.

Où s'effectuera le test?

Le test se fera à l'universit/ McGill, 3630, rue Drummond. Si vous avez des questions n'hésitez pas à appeler Debbie au (514) 696-8121.

Appendix C

Shriner's Hospital for Crippled Children
Montreal Children's Hospital
&
Rehabilitation Science
Physical and Occupational Therapy
McGill University

The Use of Kinematic and Electromyographic Measures to Describe the Effects of Selective Dorsal Rhizotomy and Intensive Therapyon the Locomotor Pattern of Cerebral Palsy Children

Informed Consent Form

The purpose of this study is to investigate if Selective Dorsal Rhizotomy improves the ability to walk in children with cerebral palsy.

I agree to have my child evaluated at the Human Gait Laboratory at McGill University, 3630, Drummond, Room 105, Montreal, once prior to the surgery and then again after surgery, 6 months, and possibly one year following surgery.

The Electromyographic (EMG) activity of several lower limb muscles will be measured with surface electrodes.Reflective skin markers will be placed on my child's shoulder, hip, knee, ankle, and foot. There will also be footswitches taped to my child's shoes while she/he walks overground.

The procedure is in no way painful or harmful to my child. My child or myself may stop the procedure at any time. It will take approximately 45-60 minutes to tape the electrodes, attach joint markers, and foot switches to my child's skin and clothing. If my child has a significant amount of hair on her/his legs it may be necessary to shave the immediate area. My child may get a rash on her/his skin from the electrode gel or tape. My child will be asked to walk overground for approximately fifteen minutes. Analysis of my child's walking pattern will take approximately 2 hours to complete. As this may be tiring, my child will be allowed to rest whenever she/he requires it. I may insist on rest periods whenever I feel it necessary. I understand that parents are to be in attendance at the time of the evaluation.

The findings of this analysis will be related to the findings from the clinical evaluation done by the physiotherapist pre and postoperatively.

I understand that my participation in this research project is voluntary and that I may withdraw my child from this study at any time without prejudice to myself or my child. My child will receive surgery and treatment whether or not she/he partakes in this research study. Any treatment my child is currently receiving or will receive will not be affected by my decision to participate or not in this study. The evaluations in this study do not constitute treatment.

I understand that any inquiries I may have about this study will be answered. I also understand that the data gathered may be the subject of scientific publications. Nonetheless, my child's anonymity will be respected at all times.

The investigators thank you. If you have any questions please feel free to contact Debbie Teitelbaum at the Shriner's Hospital, 842-4464, ext. 126, or Dr. A. Majnemer at the Montreal Children's Hospital at 934-4400, ext. 2902, or Dr. H.Barbeau at McGill University at 398-4519.

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Shriner's Hospital for Crippled Children
Montreal Children's Hospital
&
Rehabilitation Science
Physical and Occupational Therapy
McGill University

The Use of Kinematic and Electromyographic Measures to Describe the Effects of Selective Dorsal Rhizotomy and Intensive Therapyon the Locomotor Pattern of Cerebral Palsy Children

Informed Consent Form

I the undersigned, understand the procedures, effects of participation and withdrawal involved with this research study and am aware that any inquiries that I may have will be answered by researchers, and I agree to participate in this research study.

_____

Signature of participant's parent or legal guardian.

_____

Witness.

_____

Date.

I hereby certify that I have explained to the above mentioned participant the nature of the research study, and that the participant has the option of withdrawing from the study at any time without prejudice to him/herself.

_____

Signature of investigator.

_____

Date

Appendix D

Rusk Institute Rhizotomy Evaluation Form

(Functional Assessment Portion)

	Transition		Assistance	
	Pre	Post	Pre	Post
Long Sit				
Short Sit				
R Side Sit				
L Side Sit				
R Half Kneel				
L Half Kneel				
Standing				

Transition Scale

5. Assumes independently with no assistance from furniture /self / therapist.
4. Child completes limb movement but requires therapist / furniture to push / push self into position.
3. Child requires assistance to complete limb movement and uses furniture to assist into position.
2. Child cannot observably participate in transition, therapist completes entire movement.
1. Cannot be placed in position.

Assistance Scale

5. Maintains independently.
4. Unilateral upper extremity support required.
3. Bilateral upper extremity support required.
2. Full external support of therapist required.
1. Cannot be maintained by one person in position.

Appendix E

Results of Interobserver and Test-retest Reliability Studies of the Rusk Institute Rhizotomy

	Inter rater		Test-retest	
	% Match	Weighted Kappa	% Match	Weighted Kappa
Transition	68% - 96%	0.54 - 0.95	85% - 100%	0.74 - 1.00
Assistance	76% - 100%	0.68 - 1.00	81% - 96%	0.75 - 0.95
Alignment	48% - 79%	0.37 - 0.64	56% - 85%	0.28 - 0.75
Protective Sitting	57% - 65%	0.42 - 0.57	70% - 84%	0.54 - 0.78
Protective Standing	87% - 96%	0.57 - 0.85	83% - 88%	0.59 - 0.73
Half heel to Standing	88%	0.81	91%	0.86