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Outcomes of Selective Percutaneous Myofascial Lengthening Surgery (SPML) In Children with Lower Extremity Spasticity

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Outcomes of Selective Percutaneous Myofascial Lengthening Surgery (SPML) In Children with Lower Extremity Spasticity

by

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Dedication

To my husband, Steve, who always supports and encourages me in whatever I do. Without his understanding of my goal and willingness to allow me to spend hours on end upstairs on the computer, I would have never made it. To my daughters, Kendall and Lindsay, who suffered through "every man for themselves" dinners and a sometimes stressed out mom. To my family and friends who offered patience, assistance, and advice throughout this endeavor.

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Outcomes of Selective Percutaneous Myofascial Lengthening Surgery (SPML) In Children with Lower Extremity Spasticity

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Cerebral palsy (CP) is a neurodevelopmental condition defined as a disorder of posture and movement that is caused by a nonprogressive abnormality of an immature brain which can result in spasticity (Paneth, 2006; Pelligrino, 2002). Children with spastic CP usually present with muscle stiffness which eventually leads to decreased range of motion (ROM) in the knee and ankle joints interfering with gait and functional mobility (Graham, 2003). The purpose of this study was to assess changes in dynamic ROM of the knee and ankle and functional mobility following Selective Percutaneous Myofascial Lengthening Surgery (SPML) in a group of children with spastic CP. SPML is a minimally invasive surgical procedure designed to lengthen tight muscles of the lower extremity. Subjective and objective measures were obtained from medical records and video tapes of gait. Pre-operative and follow–up videos of gait for 31 children with CP who underwent SPML surgery from 2006 to 2008 were evaluated retrospectively. The outcome measures considered for this study included sagittal plane kinematic parameters of the knee and ankle joint, gait speed, and functional mobility. Mixed model for repeated measures for the knee and ankle joint parameters were used to estimate the change in ROM. Statistically significant differences in ROM were found for most joint measurements at $p<0.05$ in pre and post-operative comparisons, except for plantarflexion at toe-off. There was no difference in gait speed. FMS ratings improved by 1 level at 5 m, 50 m, and 500 m distances. The results of this study indicate that the SPML surgery, can positively affect dynamic ROM of the knee and ankle during gait, as well as improve functional mobility at 5 m, 50 m, and 500 m. This study provides information regarding a minimally invasive surgical option for children with spastic CP.

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Chapter 1: Introduction

Cerebral Palsy (CP) is the most common motor disorder in children (Howle, 1999). It is a neurodevelopmental condition, which causes difficulty with posture and movement. The prevalence of CP ranges from 1.5-2.5 per 1,000 live births (Paneth et al., 2006). It is estimated that the lifetime cost for someone with CP in the United States is close to $1 million (Honeycutt et al., 2004).

Most children with CP present with spasticity. Spasticity results in an abnormal sensitivity to muscle stretch. This abnormal sensitivity leads to stiffness of the muscles, especially in the legs. By limiting the degree to which the child can straighten their knee or bend the ankle, this stiffness can hamper a child's ability to move around in the environment and participate with peers.

For the child with spastic CP, body functions/structure impairments may include tightness of the hamstring and gastrocnemius muscles due to the effect of spasticity on the neuromuscular system. The tightness/stiffness of muscles interferes with the ability to fully straighten the knee or flatten the foot during walking. This impairment may lead to an activity limitation in the ability to stand and walk in the community. Finally, this impairment may result in a restriction in a child's ability to participate with peers at the neighborhood park or go on evening walks with family. Physical therapists are involved with the prevention of secondary impairments due to spasticity in children with CP. Some common goals for physical therapy are to increase functional abilities and skills by helping to increase range of motion and decrease energy expenditure.

Treatment for CP may be aimed at managing the spasticity and lengthening the shortened muscles either by stretching, casting, injections, or intensive neurological and orthopedic surgical procedures. These procedures can be extremely time-consuming and painful, with limited long term success. Physical therapists are directly involved in stretching and casting and indirectly involved in the injections and surgical procedures by providing care prior to the procedures as well as follow up care. Therapists answer questions and provide families with information to help them determine the best options for their child. It is important for the therapist to be knowledgeable not only of the options available for treatment, but also the follow up care and possible complications. Because family compliance is essential for the success of any treatment, realistic goals should be set after a thorough evaluation. A discussion of the expectations and limitations of the family must be considered. The expected functional gains after any procedure or treatment must be thoroughly and realistically presented. The potential consequences and time commitments involved should be discussed prior to initializing therapeutic activities. The final goal in intervention for children with CP is for them to grow, develop, and participate while attempting to minimize physical limitations.

The central goal of this project was to examine the outcomes of a minimally invasive surgical procedure, Selective Percutaneous Myofascial Lengthening (SPML) surgery, designed to lengthen tight muscles of the lower extremity in children with spastic CP. This project specifically focused on the change in functional range of motion of the knee and ankle joints during gait, gait speed, and the overall change in functional mobility after the SPML surgical procedure.

1.1 The Specific Aims:

1. Estimate the changes in range of motion of maximum knee flexion in the swing phase of gait cycle in children with spastic CP after SPML surgery, using video graphic analysis.

Hypothesis 1: There will be a change in range of motion of maximum knee flexion in the swing phase of the gait cycle after SPML surgery.

2. Estimate the changes in range of motion of maximum knee extension at terminal swing phase of gait cycle in children with spastic CP after SPML surgery, using video graphic analysis.

   Hypothesis 2: There will be a change in range of motion of maximum knee extension at the terminal swing phase of the gait cycle after SPML surgery.

3. Estimate the changes in range of motion of maximum knee extension at midstance of the gait cycle in children with spastic CP after SPML surgery, using video graphic analysis.

   Hypothesis 3: There will be a change in range of motion of maximum knee extension at midstance phase of the gait cycle after SPML surgery.

4. Estimate the changes in range of motion of plantarflexion at toe off in the gait cycle in children with spastic CP after SPML surgery, using video graphic analysis.

   Hypothesis 4: There will be a change in plantar flexion at toe off (pre-swing) in the gait cycle after SPML surgery.

5. Estimate the changes in range of motion of maximum ankle dorsiflexion in swing phase of the gait cycle in children with spastic CP after SPML surgery, using video graphic analysis.

   Hypothesis 5: There will be a change in maximum ankle dorsiflexion in swing phase of the gait cycle after SPML surgery.

6. Estimate the changes in range of motion of maximum dorsiflexion in the midstance phase of the gait cycle in children with spastic CP after SPML surgery, using video graphic analysis.

   Hypothesis 6: There will be a change in maximum ankle dorsiflexion in the midstance phase of the gait cycle after SPML surgery.

7. Estimate the changes in gait speed after SPML surgery in children with spastic CP. Gait speed will be evaluated using video graphic analysis.

   Hypothesis 7: There will be a change in gait speed after SPML surgery.

8. Estimate the changes in functional mobility in children with spastic CP after SPML surgery to lengthen lower extremity muscles via the Functional Mobility Scale (FMS).

   Hypothesis 8: There will be a change in FMS in children with CP after SPML surgery.

9. Using video analysis, estimate the relationship between a measure of functional status and range of motion measures of the lower extremity using the FMS and

range of motion measurements of the knee and ankle in children with spastic CP after SPML surgery.

Hypothesis 9: Increased FMS will be associated with increase in range of motion of knee extension in swing and stance phase of gait.

The hypotheses of this study were that Selective Percutaneous Myofascial Lengthening Surgery (SPML) of the lower extremities in children with Cerebral Palsy will change range of motion of the knee and ankle during specific phases of gait, change gait speed, and change in functional mobility as measured by the Functional Mobility Scale (FMS).

Chapter 2: Background and Significance

2.1 Historical perspective

William John Little, a prominent British orthopedic surgeon, was the first to describe a condition that would later be called cerebral palsy (Kavcic, 2005; Raju, 2006). He described children with stiff spastic muscles in their legs which interfered with crawling and walking (Raju, 2006). In October 1861, based on birth histories of the children he was treating, he hypothesized that this stiffness of the muscles (spastic diplegia) was due to difficult labor, mainly asphyxia at the time of birth (Little, 1862). In early publications, spastic diplegia is sometimes referred to as "Little's Disease." Some 30 years later, Sir William Osler, a neurologist, introduced the term 'cerebral palsy' to describe children with a non progressive neuromuscular disease (Raju, 2006). Osler agreed that the etiology appeared to date from birth, but stressed that the cause of CP was impossible to fully articulate (Raju, 2006).

Sigmund Freud, more famous for his contributions to the field of psychiatry, was also a talented neurologist. He published several articles on the topic of neurologic problems in children, namely spastic diplegia (Longo & Ashwal, 1993). In some respects, he disagreed with Little's explanation for the cause of spastic diplegia. He agreed that asphyxia and birth trauma could lead to damage to the brain, but felt that the difficult birth was merely a symptom of deeper effects and possible problems with brain development in the womb (Freud, 1968; Raju, 2006). Little had focused on the motor deficits, and in contrast Freud also included other manifestations of CP such as mental retardation, visual, and hearing deficits. Until recently, the medical community did not fully accept Freud's explanation for the possible etiology of CP and for many years continued to believe that CP was due to birth complications (Kavcic, 2005; Raju, 2006).

2.2 PREVALENCE

Among most western nations, the prevalence of CP ranges from 1.5 to 2.5 per 1000 live births (Paneth et al., 2006). It is difficult to know the real numbers because of the vague diagnostic criteria and the lack of CP registries in the United States, unlike European and Scandinavian countries which have had CP registries since the 1950s (Paneth et al., 2006). The only registry type program in the United States is the Autism and Developmental Disabilities Monitoring Network (ADDM) sponsored by the Centers for Disease Control and Prevention (CDC) (Arneson et al., 2009). The ADDM is a multi site collaboration population-based surveillance in Alabama, Georgia, and Wisconsin. The latest report for the United States in 2004 showed the average prevalence among 8 year old children across all sites to be 3.3 per 1,000. The same report noted gender differences with an overall 1.4 to 1 ratio male/female, ranging from 2.5 to 1 in Wisconsin to 1.3 to 1 in Alabama and Georgia. (Arneson et al., 2009). Spastic CP was the most common subtype, ranging as high as 89% in Alabama and Wisconsin (Arneson et al., 2009). Due to the nature of the data collection, the ADDM numbers are really point prevalence numbers meaning they identify the number of persons with CP at a specified point in time, specifically 2004. Work currently is being done for the 2006 and 2008 data (Arneson et al., 2009).

It appears that the trend for children born with CP was fairly stable until the last decade of the 20th century when an increase was noted, possibly due to the increase in very low birth weight (VLBW) infant survival who are at great risk for neurological complications (Keogh & Badawi, 2006; Paneth et al., 2006; Robertson et al., 2007). Winter et al. (2002) also found a modest increase in prevalence of CP from 1975 to 1991. In contrast to Paneth’s explanation for the increase, they found the increase in infants of normal birth weight (Winter et al., 2002). Differences in the two studies could be explained by the denominator used in the 2002 report. The data from the later years was based on live births and earlier year's data were based on an estimated denominator for infant survivors. The higher infant mortality rates in the earlier years may mean the increase is just an artifact (Winter et al., 2002).

2.3 DEFINING CP

The contributions of Little, Osler, and Freud started the journey to define CP. Several definitions of CP can be found in the literature (Mutch et al., 1992; Paneth et al., 2006; Pelligrino, 2002), but there is little consensus on the definition or classification of CP. Consequently, the inconsistency of the case definition for CP makes research and communication between clinicians and scientists difficult.

There are multiple definitions of CP. In the literature CP is described as a neurodevelopmental condition defined as a disorder of posture and movement that is caused by a nonprogressive abnormality of an immature brain which can result in spasticity (Panethet al., 2006; Pelligrino, 2002). It has also been defined as a nonprogressive brain abnormality resulting in spasticity, ataxia, or involuntary movements arising in the early stages of development (Kuban, 1994). This condition leaves the child with a permanent impairment of motor control.

Considering the knowledge and emerging understanding of the development of the brain as well as the adoption of the World Health Organization International Classification of Functioning Disability and Health (ICF) model for research and practice, health professionals and researchers agreed that the description of CP was lacking clarity, confusing, and needed refinement. In 2005, an International Workshop on Definition and Classification of Cerebral Palsy was held in Bethesda, Maryland for the purpose of updating the definition and classification of CP (Bax et al., 2005). The updated definition is as follows:

> *Cerebral palsy (CP) describes a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception and/or a seizure disorder.*

This revision of the definition CP has been proposed, but it is still not the definition typically found in the professional literature. However, in current definitions, there are common themes. Most definitions include the fact that CP is non-progressive occurs in the immature brain and leaves the child with a permanent motor impairment (Bax et al., 2005; Mutch et al., 1992; Paneth et al., 2006, Pelligrino, 2002). Even with all of the disagreement regarding the definition of CP, motor disability is the hallmark of CP.

2.4 Classifying CP by Motor Abnormality

CP has many different subtypes, further adding to the confusion of classifying and categorizing children. Since CP is a broad term that encompasses a range of clinical presentations and varying degrees of activity and participation restriction, further categorization/classification is necessary in order to ensure the most effective description of the person with CP. The American Academy of Cerebral Palsy and Developmental Medicine has classified the types and topographic distribution of movement impairments. This classification provides common terminology and descriptions of CP for clinicians, parents, and physicians. In the literature, the clinical types of CP are described as: spastic (hypertonic), dyskinesia (athetosis), ataxia, and sometimes hypotonia (Bax et al., 2005; Esscher et al., 1996; Guyton & Hall, 1996; Howle, 1999; Scherzer, 2001).

Considered the most common type of CP, spastic CP is characterized by muscle stiffness with velocity-dependent resistance to passive movement. According to the literature, it makes up approximately 75% of all children who have CP (Bax et al., 2005; Esscher et al., 1996; Miller, 2005; Scherzer, 2001). The stiffness of the muscle leads to joint restriction as well as muscle weakness. White matter infarct in the periventricular area of the brain appears to be associated with spastic diplegia CP (Scherzer, 2001; Tang-Wai et al., 2006).

Dyskinesia is the group of disorders in which movements appear uncontrolled and involuntary. They include athetosis, rigidity, and tremor. Athetosis involves movements that are abnormal in timing, direction, and coordination. Rigidity is less common and includes resistance throughout the available range of motion and is not velocity dependent. Tremor usually accompanies other types of CP and occurs most often with clients with traumatic brain injury (TBI). Dyskinesias are the result of basal ganglia damage (Guyton & Hall, 1996).

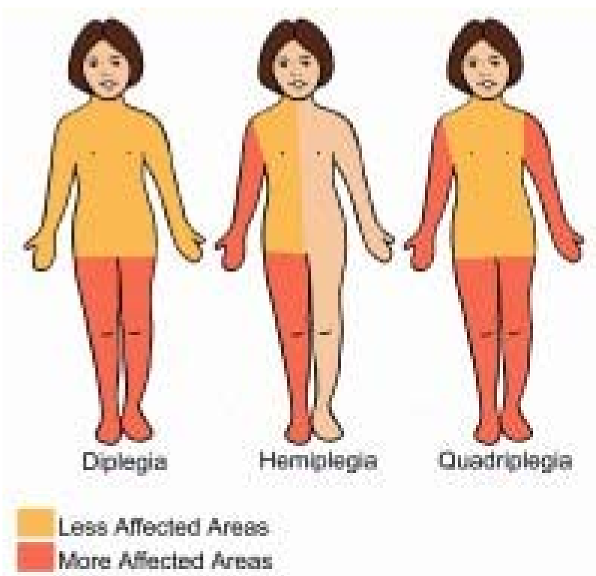
Ataxia is primarily a disorder of balance and control in the timing of movements. The result of cerebellar damage, this type represents fewer than 10% of the cases of CP (Esscher et al., 1996). These children exhibit intention tremors that interfere with fine motor function and typically walk with a wide based gait (Olney & Wright, 2006).

Hypotonia is usually a transient condition. Actually, there is controversy as to whether it should be considered a type of CP, but is currently characterized as CP (Olney & Wright, 2006). The main feature of hypotonia is diminished resting muscle tension. This lack of tension makes the initiation of movement very difficult (Miller, 2005). There has not been a particular neurological lesion associated with hypotonia (Howle, 1999).

Classifying by Topography

In addition to the motor impairment, CP is also described by the body parts affected. The three primary categories are: diplegia, involving the lower body more than upper body; hemiplegia, involving primarily the upper extremity and lower extremity of the same side of the body; and quadriplegia, involving the entire body. Figure 1 shows the topographic distribution of CP.

Figure 1. Topographic distribution of CP.



Classification by Motor Abilities

There is also a classification system based on functional abilities, referred to as the Gross Motor Function Classification System (GMFCS), which is often used for children with CP (Palisano et al., 1997). The GMFCS helps clinicians describe and predict the severity of gross motor impairments of children with CP (Bower et al., 2001) and correlates this with restrictions in social integration. The focus of the GMFCS is on self-initiated movements with emphasis on sitting and walking. The system uses a five-level ordinal grading system, with the distinction between the levels of motor function based on functional limitations and the need for assistive technology, including mobility devices and wheeled mobility. The grading of the items takes into consideration the child's usual performance at home, school, and community (Palisano et al., 1997). The GMFCS is a classification system and has been found to be stable over time and is not typically used as an outcome measure (Wood & Rosenbaum, 2000).

Diagnosis

There is no definitive laboratory test for CP, making the diagnosis a clinical one based on observation of motor functioning and physical examination. Magnetic Resonance Imaging (MRI) and Computed Topography (CT) scans may be of use in diagnosis to rule out other treatable conditions such as brain tumors or hydrocephalus. Many children with CP have normal brain imaging and the studies are of little use in making a definitive diagnosis or predicting functional outcomes (Miller, 2005). Typically, the diagnosis is not usually made before the child is 2 years old, due to the phenomenon of transient dystonia, unless of course there is severe involvement or neuroimaging to back up the diagnosis (Miller, 2005). At this point in time there is no cure for CP, thus once a person has been diagnosed as having CP, that label continues throughout their lifespan. The term cerebral palsy should not be used as an etiologic diagnosis, but as a clinical descriptive term (Bax et al., 2005).

The majority of children who are diagnosed with CP have had the condition since birth. Approximately 10% of children have acquired the brain damage after birth in the first few months of life up to age 2 (Miller, 2005; Olney & Wright, 2006). Regardless of whether the injury took place prior to, during, or after birth, the diagnosis of cerebral palsy will still be considered, which is why CP is considered an "umbrella term". UCP of

America (2001) estimates around 764,000 children and adults in the United States currently live with the diagnosis of cerebral palsy.

2.5 Spasticity Issues and Function

The primary impairment involved with CP is spasticity. This damage in the central nervous system and is referred to as an upper motor neuron lesion. Spasticity in turn can interfere greatly with purposeful movement of body parts and can be responsible for secondary impairments of muscle shortening, leading to contractures and changing the biomechanics, timing, and synergies of typical movement. Therapists sometimes prefer to use the term hypertonicity, since it not only includes the resistance to passive movement, but also refers to the altered mechanical properties of the muscles and connective tissue. The term spastic hypertonia is sometimes used in the literature to refer to the neural components of spasticity, as well as the histological changes in the muscle.

The definition and classification of spasticity is controversial. The most common definition of spasticity comes from Lance, who defined spasticity as a component of an upper motor neuron disorder characterized by velocity dependent increases in tonic stretch reflexes with exaggerated tendon jerks and clonus resulting from hyperexciteability of the stretch reflex (Lance, 1980). Spasticity has been described as an imbalance between excitatory and inhibitory impulses to the alpha motor neuron; in other words, a lack of descending inhibitory input to the alpha motor neuron, as well as a lack of inhibition to the Golgi tendon organ which increases the excitation of the stretch reflex (Mayer, 1997). Another description of spasticity has been documented as an increase in muscle activity from the agonist that is not balanced by the antagonist, resulting in persistent abnormal joint position leading to contracture. The Support Programme for Assembly of Database for Spasticity Measurement (SPASM) group defines spasticity as “disordered sensori-motor control, resulting from an upper motor neuron lesion, presenting as intermittent or sustained involuntary activation of muscles” (Pandyan et al., 2005). Sanger et al. (2003) defines spasticity as a hypertonia in which one or both of the following signs are present: Increases in resistance to externally imposed movement with increasing speed of stretch that varies with the direction of joint movement, or resistance to externally imposed movement that rises rapidly above a threshold speed or joint angle. The constellation of positive clinical findings is increased tone, hyperactive reflexes, extensor plantar responses, and clonus (Mayer, 1997).

Spastic hypertonia can interfere with mobility and activities of daily living (adl’s). It may cause pain and sleep disturbances and can make care more difficult. Spastic hypertonia may actually have some positive benefits in that it may help maintain muscle bulk, increase circulatory function, and may actually be used by some clients for postural control and to aid in transfers.

It is believed that children with CP are constrained in movement speed by spasticity. That is, if they move too fast, they will elicit the stretch response (Levin & Feldman, 1994). Consequently, most of the treatment of someone with CP is aimed at the reduction of the spastic hypertonia or the secondary issues arising from the spastic muscle. The premise is that if you can change the threshold of the spastic muscle you may be able to improve the child’s ROM and functional mobility, namely the ability to walk (Tuzson et al., 2003).

2.6 Disablement Process in Cerebral Palsy

The World Health Organization’s (WHO) International Classification of Functioning, Disability and Health (ICF) enabling-disabling model can be used in describing the disabling conditions of someone with CP. The three categories of impairment, functional ability and societal participation can be easily used with the person with CP, with the philosophy that disability is a function of the interaction between the person and the environment.

The Institute of Medicine (IOM) has recommended that research related to disability and the disablement process use the conceptual framework of the International Classification of Functioning, Disability and Health model (ICF) to unify rehabilitation research (Field, 2007). The model includes social and environmental concepts that can affect the progression or regression of disability. In October 2007 the ICF-CY was created to be used with children and youth. This model was developed on the ICF conceptual framework and provides a common language and terminology for recording problems involving body structure and functions, activity limitations, and participation restrictions manifested in infancy, childhood, and adolescence. It was designed specifically for children and youth to record characteristics of the developing child and the influence of the environments surrounding children (WHO, 2008). The interaction of the environment (physical and social) plays a significant role in the life of a child. The influence of environment on the overall development of all children has been well documented (Campbell, 2006).

When dealing with children with disabilities, pediatric physical therapists focus on the functional consequences of the health condition of the child. For the child with spastic cerebral palsy, the ICF model fits nicely due to the importance placed on the components of health and the role of environmental and personal factors involved in the disablement process.

For the child with spastic cerebral palsy, body functions/ structure impairments may include tightness of the hamstring muscles and weakness of the lower extremity muscles due to impairment in the neuromuscular system. This impairment may then lead to an activity limitation in the ability to stand and walk in the community, finally leading to a restriction in the child's ability to play with peers at the neighborhood park or go on evening walks with the family. Contextual factors in the environmental domain may include the attitudes of the parents regarding the importance of encouraging the child to walk or even the time constraints of a busy family. The accessibility of the playground and neighborhood in which the child lives may impact the ability to practice walking. Finally, the personal factors of the child may play a mediating role in his development. Motivation, fear, and social abilities play a huge role in the overall development of children.

Typically, an intervention is performed to rectify the impairment such as a surgical correction to lengthen a tight muscle. It is questioned whether lengthening a tight muscle will increase a child's activity and participation. If the contextual factors of the environment and the intrinsic factors of the child are not considered in the overall assessment of a child's function, then a potentially successful surgery may not result in improved participation.

Participation

People with CP will have functional difficulties that affect their day-to-day life. The lack of ease of mobility can cause considerable stress and distress to the children, parents, caregivers, and siblings. The lack of mobility limits an infant's exploration of the environment. In developmental literature, there is a relationship between cognition and motor function. Burns, O'Callaghan, McDonell, and Rogers (2004) tested 198 children with birth weights of less than 1000 grams, and tested motor and cognition at 12 months and yearly until the children were 4 years old. The results of the study demonstrate that motor development was associated with all elements of cognitive functioning. Essentially, the study found a strong predictive relationship between motor development and cognition. A child with poor motor development often demonstrates low cognitive functioning (Burns et al., 2004). Exploring the environment allows a child to solve problems that arise while moving in and through space, manipulating objects, and communicating with others. Independent walking is one of the many ways a child is able to participate in society. Children with spastic cerebral palsy usually have difficulty with gait which causes them to have difficulty moving in their environment, affecting their ability to interact with others in society and increasing the risk for social isolation and rejection by peers.

2.7 GAIT

Functional mobility, especially the ability to walk, is a major concern for and children with CP and their parents. In order to understand the basics of gait and how children with spasticity perform gait, one must consider the terminology and prerequisites necessary for the most efficient gait pattern.

Normal human walking is a complex bipedal function made up of a cyclic pattern of body movement. A gait cycle is defined as the time from heel strike of one limb to the next heel strike of the same limb. The two phases of gait are described as stance and swing. The stance phase of gait makes up approximately 60% of the gait cycle and includes the entire time the limb is in contact with the ground. In contrast, the swing phase makes up approximately 40% of the gait cycle and is the time the foot is off of the ground (Perry, 1992; Perry, 2001). The overall gait cycle is further divided into eight phases; Table 1 lists and defines the phases. Basically, the gait cycle accomplishes three tasks, weight acceptance, single limb support, and limb advancement. There are certain ROM requirements for the joints of the lower extremity that are necessary for effective gait. The ankle must be able to move into at least 10° of dorsiflexion in terminal stance and 15° of plantarflexion in pre-swing. The knee appears to be at a neutral position at initial contact and midstance, but may really be in about 3°-5° of flexion. In order for proper swing to occur, the knee must be able to flex to about 60° at initial swing to help with foot clearance (Perry, 2001).

Table 1: Phases of Gait

Phase	**Definition**
Initial Contact	The moment the foot hits the ground
Loading response	The first period of double limb support, weight is transferred onto outstretched limb
Mid Stance	The body progresses over single stable limb
Terminal Stance	Progression of body over stance limb and weight transferred onto forefoot
Pre-Swing	A rapid unloading of the limb as weight is being transferred to the contralateral limb (second period of double limb support)
Initial swing	Thigh begins to advance as the foot comes off of the ground
Mid swing	The thigh continues to advance as the knee begins to extend; the foot clears the ground
Terminal swing	The knee extends; the limb prepares to contact the ground for initial contact

Walking or gait requires that many systems function together in a feed-forward and a feedback fashion. In addition, gait requires that an individual have abilities such as balance, adequate strength and muscle excursion, motor coordination and intact sensory system (Miller, 2005; Shumway-Cook & Wollacott, 2007).

Gait Analysis Techniques

Analyzing gait is an important part of physical therapist practice. Physical therapists utilize gait analysis whether it is simply observing a client walk or using more sophisticated gait analysis systems. Gait analysis is necessary to identify pathological gait from gait of typically developing individuals. Performing gait analysis before and after an intervention can provide important objective information regarding the effectiveness of that intervention. There are several methods available for analyzing gait, ranging from complex, three dimensional computerized systems, to simpler systems that are portable and can easily be utilized in the clinical setting (Kyriazis, 2001; Miller, 2005; Perry, 1992).

Depending on the information required, therapists and physicians have options when assessing gait, from visual observation, such as footfall count, electronic walkway systems and the gold standard, specialized 3dimensional (3D) motion analysis systems (Kyriazis, 2001; Narayanan, 2007; Perry 1992). Most studies have found 3D instrumented gait analysis to be reliable, but the systems usually are cost prohibitive for most physicians and therapy clinics. They also require a large space and are time consuming, taking 2-4 hours from set up to completion (Chang et al., 2006; Kyriazis, 2001; Narayanan, 2007).

Several studies have suggested variability in marker placement as a possible source of error affecting the reliability of gait analysis labs (Gorton et al., 2009; Noonan et al. 2003). Considering the large investment in expensive equipment and space, and the fact that variability in data has been documented, the motion analysis lab may not be the best the option for analyzing a child’s gait.

Visual observation performed in a systematic fashion is cost effective and fairly easy when compared to instrumented gait analysis. However, visual observation alone has not been found to be as reliable as needed, especially to assess the effects of an intervention (Chaleat-Valayer et al., 2006; Eastlack et al., 1991). Videoed observation paired with a relatively inexpensive computer program with slow motion and image freezing has been shown to improve intra and inter-rater reliability in patients with CP

(Brunnekreef et al., 2005; Chaleat-Valayer et al., 2006). When visual analysis of lower extremity ROM was compared to 3D gait analysis, fair to moderate agreement was found for the knee, but slight agreement was found with ankle ROM (Kawamura et al., 2005). Consequently, video observation with slow motion and a computer program to measure joint angles and gait speed may be a reasonable and cost effective option to assess gait when the gold standard 3D gait analysis is not available.

Gait in Children with Spastic CP

The gait limitations in children with CP include but are not limited to: reduced walking speed, decreased step and stride length, decreased toe clearance, decreased knee extension in stance, and decreased knee flexion in swing due to muscle and joint restrictions (Graham et al., 2003; Ma et al., 2006; Saraph et al., 2005; Tang-Wai et al., 2006). Spastic muscle causes compensations that usually result in specific joint limitations (Miller, 2005; Perry, 1992; Sutherland & Davids, 1993).

The most common problem noted in children with spastic diplegia occurs in the sagittal plane and involves knee flexion contractures related to spasticity, causing increased knee flexion in the stance and terminal swing phase of gait as well as increased dorsiflexion throughout the gait cycle. This deformity is referred to as “crouch gait” (Miller, 2005; Rodda et al., 2006; Sutherland & Davids, 1993). Hamstring contractures are usually the main cause of this gait pathology. The treatment of crouch gait is usually aimed at lengthening the knee flexion contracture through a variety of methods (Graham & Selber, 2003; Miller, 2005).

Toe-walking gait is a common deformity found in about 75% of children with spastic hemiplegia and the young child with spastic diplegia (Miller, 2005; Graham & Selber, 2003). In children with hemiplegia, the toe walking is also observed on the less affected side as a compensation. Spasticity or contracture of the gastro-solues is the dominant component of this gait deviation (Rodda et al., 2004). Young children with spastic diplegia will initially walk on their toes with knees flexed or sometimes extended knees, but in adolesence due to rapid increases in their height and weight, the midfoot collapses, allowing the foot to be in contact with the floor, which in turn increases the knee flexion at midstance. Consequently, a crouch gait develops due to changes in center of mass as well as the stretch weakness of the quadriceps muscle (Miller, 2005; Sutherland & Davids, 1993). If these problems are not addressed the deformities will continue to get worse, ultimately interfering with a child's ability to walk independently in the home and community.

2.8 Treating Spasticity and Secondary Impairments

The main goal of managing spasticity and the secondary impairments in children with cerebral palsy should be to help the child and family fully participate in society. This may need to be done by helping families decide which medical management is going to be the most effective yet least restrictive option.

What is the most effective treatment for reducing spasticity or the secondary impairments from the spastic muscles? There are options that involve treating the spasticity pharmacologically or surgically. Likewise, there are techniques that address the secondary impairments that result from the spastic muscles, namely the muscle shortening or contractures through indirect and direct methods. The current medical procedures and techniques for spastic hypertonia management to provide for functional improvement in children with CP are serial casting, Botulinum Toxin Type A (Botox) injections, intrathecal baclofen pumps, tendon releases, tendon transfers, and a new minimally invasive myofascial release of the hamstring and gastrocnemius muscles. The majority of the procedures are used to improve range of motion and functional mobility, including gait. Improved gait abilities may facilitate the child's ability to participate with peers and family.

Casting as an Option

Casting is the least invasive and an indirect method for the treatment of the secondary impairments of spastic muscles, namely lengthening a tight or contracted muscle. It has been used since the 1960s in adults and children to stretch shortened muscles and improve range of motion. The rationale behind using casting is that prolonged stretch on the muscle will increase extensibility of the muscle and reduce reflex hyperexcitability (Lieber et al., 2004; Mortenson & Eng, 2003; Schmit et al., 2000). Classic animal studies by Tabary et al. (1976) showed that the sarcomeres actually increase in numbers when the muscle is casted in a lengthened position and decrease in numbers when held in a shortened position. If this is true in children with spastic muscles, the increase in the number of sarcomeres could eventually lead to the possibility of an increase in muscle strength.

The cast also may affect muscle tone by providing neutral warmth, which has been taught in most therapy programs as a mechanism to reduce spasticity. However, little evidence is available to support this theory. Also, the decrease in variable cutaneous sensory input to the extremity due to the cast covering the entire limb may actually be helpful in deterring the elicitation of the stretch reflex (Mortenson & Eng, 2003).

The negative effects of serial casting are the labor and time involved, not to mention the costs (both monetarily and in the families' time and disruption of their daily routines). Casting usually lasts four to six weeks, with the cast being changed weekly to every other week. The therapist must be very skilled at casting to prevent secondary issues, such as pressure sores, neurapraxia, and tibial subluxations (Westberry et al., 2006). Stretch weakness has also been reported as negative consequence of casting (Flett et al., 1999).

Autti-Ramo et al. (2006) reviewed articles on the effectiveness of upper and lower limb casting and orthosis in children with CP. He retrieved 40 articles, but only five were randomized controlled trials. The following evidence was found: 1) casting of lower limbs has a short-term effect on passive range of movement; 2) orthoses that restrict ankle plantar flexion have a favorable effect on an equinnus gait, but long-term significance is unclear; and 3) evidence on managing upper limb problems with casting in children with CP is inconclusive (Autti-Ramo, Suoranta, & Malmivaara, 2006). The study also identified the three outcomes that are to be met by serial casting: 1) improved passive range of motion (PROM); 2) decreased spasticity; and 3) improved function. Only the outcome of improved PROM has sufficient evidence to support the use of casting (Autti-Ramo et al., 2006). There was no consistency in functional outcome measures.

In 2006, Westberry et al. conducted a retrospective study of children with CP who had been treated for knee flexion contractures using serial casting alone, casting after tendon release surgery, and casting after Botulinum A toxin injection to the hamstring muscle. The children had been treated at Shriner's Hospital in South Carolina from 2001 to 2003. The measurements included pre-casting, completion of casting, and one-year post discharge of the casting. They found an overall success in treating the knee flexion deformities, but found it to be less successful in the teenage group and in subjects with more significant contractures. Similarly to the earlier review by Autti-Ramo et al., (2006) the only outcome identified in the study was increase in PROM; there were no measurements of spasticity/tone or functional skills (Westberry et al., 2006).

Serial casting and gait outcomes were examined in small sample of children with spastic CP with a mild fixed plantarflexion contracture (McNee et al., 2007). A randomized crossover design was used, with the casting period stopped when no further gain in range of motion (ROM) was achieved or when the target dorsiflexion range of 10° was reached. Outcome measures were goniometric passive range of motion (PROM) of ankle dorsiflexion, three dimensional gait analysis of child walking in bare feet, and the Gillette Functional Assessment Questionnaire. The only significant difference at the 12 week measurement time was a small change in PROM of the dorsiflexion of the ankle with knee flexed. There were no changes in the functional mobility of the children as measured by the Gillette Functional Assessment Questionnaire (McNee et al., 2007).

Serial casting is more often being used as an adjunct after botulinum toxin injections or after tendon release surgery (Kay et al., 2004). A systematic review in 2007 concluded that there is little evidence to support that casting with or without Botulinum Toxin is effective in increasing ROM or decreasing spasticity. Although quality of the articles was limited by small sample sizes, short term follow up, and inconsistency in outcome measures (Blackmore et al., 2007). Complications of casting were related to skin irritation and breakdown, pain, weakness and difficulty bathing (Blackmore et al., 2007). It is hard to say that serial casting changes spasticity, but it does appear to affect the secondary impairment of muscle contractures due to the spasticity.

In summary, there is not overwhelming evidence for the long-term efficacy of serial casting; it can be concluded that there is some positive evidence for short-term benefits of lower limb casting on range of motion only (Autti-Ramo et al., 2006; Blackmore et al., 2007). The limited long term effects and lack of functional changes may not be sufficient to warrant the time intensity and possible negative consequences of casting.

Pharmacological Management

Oral medications may be useful in helping to control spasticity, but most parents of young children are reluctant to use them because of the side effects. The most common of the drugs are benzodiazapines, baclofen, and dantrolene (Verrotti, Greco, Spalice, Chiarelli, & Iannetti, 2006). Benzodiazapines and baclofen act at the spinal cord level, whereas dantrolene acts on the skeletal muscles by inhibiting the release of calcium necessary for muscle contractions. Most of these drugs have common side effects of sedation and dizziness, loss of appetite, and liver damage as well as overall weakness. They can also affect memory and attention and cause changes in behavior and hyperactivity (Krach, 2001; Nance & Young, 1999; Verotti et al., 2006). The drugs often have a side effect of constipation, which is already a major problem for these children. Some oral medications such as diazepam may be used at night to decrease nighttime spasms and aid with sleep.

Most of the oral medications also have the risk for overdosing and physical dependence (Krach, 2001; Nance & Young, 1999; Verrotti et al., 2006). Care must be taken to ensure the adequate dosage for the child is prescribed and administered. By the same token, the medications should not be stopped abruptly; withdrawal could include seizures and possible death (Nance & Young, 1999).

No one medication alone has been found to be effective in the management of spasticity. Coupled with the potential unpleasant side effects and serious risks, many parents choose to explore other options to reduce spasticity.

Therapeutic Use of Botulinum Toxin Type A (BtA)

Botulinum neurotoxin type A (BtA) is the most widely used injected preparation and has been used therapeutically since the late 1970s (Goldstein, 2005). Love et al. reported the first use of botulinum toxin in CP in 1988. It is mainly used for focal spasticity. A special preparation of Clostridium botulinum, which is the bacteria that causes botulism, is injected into the muscle. It works by inhibiting the release of acetylcholine at the neuromuscular junction (Koman et al., 1994; Seyler et al. 2008). The specific goal of injections is to weaken the overactive agonist muscle, which should facilitate improvement in range of motion and allow for the successive strengthening of the antagonist muscle. BtA has relatively no systemic effects but a few local adverse events, such as pain, bleeding, and infection at the injection site (Verrotti et al., 2006).

BtA has not been approved by the United States Food and Drug Administration for the treatment of spasticity in children or adults, but is currently used 'off -label'. In a retrospective study of 108 patients, improvements were made in lower extremity range of motion, muscle tone and gait parameters, using specific preparation of botulinum neurotoxin at a relatively high dose (Goldstein, 2006). Several other studies done in the late 1990s also showed short term benefits of decreasing spasticity, improved range of motion, improved gait patterns and improved mobility (Friedman et al., 2000; Komen et al., 2000).

A Cochrane systematic review by Ade-Hall and Moore found only three articles that met the methodological quality of random allocation to be considered in their review. One article examined BtA versus placebo and reported no significant differences in gait patterns (Komen et al., 1994). Two trials compared casting and BtA, with significant improvements noted in gait for both groups, but no difference between the groups (Corry et al., 1998; Flett et al., 1999). The final conclusion did not find any evidence to support the efficacy of BtA in improving function in children with lower extremity spasticity (Ade-Hall & Moore, 2000).

Several studies done in the late 1990s did show short term benefits (2-6 months) of decreased spasticity, improved range of motion, improved gait patterns and improved mobility. However, the post-injection management requires an increase in therapy visits involving aggressive stretching, positioning and strengthening programs (Friedman, 2000; Komen et al., 2000; Krach, 2001).

Since the early 2000s, the number of published reports on botulinum toxin injections in the treatment of CP has increased. In 2008, Seyler et al. performed a systematic review of the articles published from 2003 to 2007. Thirty-three studies met the stringent criteria, with twenty six of the studies addressing lower extremity treatments. Their final conclusions were as follows: 1) compared to placebo cohorts, children treated with BtA demonstrated improved clinical outcomes, 2) BtA with casting or therapy was more effective than BtA alone, and 3) relatively few adverse effect have been reported (Seyler et al., 2008). Unfortunately, the report did not discuss the length of time the positive outcomes lasted, nor did it report the clinical outcome measures.

As alluded to earlier, many children are now being treated with BtA and serial casting of the hamstring, gastrocnemius and biceps muscles. The thought is that combining the two treatments enhances the speed of resolution of a contracture due to spastic hypertonia, as well as delaying the recurrence of the contracture. In 2004, a randomized controlled trial was performed using 23 children ranging in age from 4 to 13 years with spastic CP exhibiting equinus deformities (Kay et al., 2004). The children were randomly assigned into two groups; one group received casting alone and the other group received BtA followed by casting. The children were followed at three, six, nine, and 12 months. Outcomes measures were range of motion, Ashworth Scale (AS), Gross Motor Function Measure (GMFM), and computerized gait analysis (VICON). The addition of BtA to casting did not decrease the duration of casting effect immediately after treatment. They found that the group treated with casting alone had a significant decrease in plantar flexor spasticity, using the AS and peak dorsiflexion during stance and swing improved in six, nine, and 12 months. The BtA plus casting group actually had greater spasticity at 6, 9, and 12 months (Kay et al., 2004). The results of the study were surprising to many people who were convinced by anecdotal reports that serial casting after BtA was superior to using the treatments alone.

Before using BtA as a treatment modality for children with CP, consideration needs to be given to the resultant lack of strength that will occur (Seyler et al., 2008). If the lack of strength will give the opportunity for better alignment then it is deemed worth the cost. BtA is expensive and temporary – lasting four to six months. The effects wear off due to axonal sprouting around the neuromuscular junction (Koman et al., 1994). Using BtA for spasticity management is expensive, costing approximately $2400 per treatment and usually involving a minimum of three treatment sessions. Not only is there a monetary cost, but also a huge time commitment for the families and children; after care requires the family to participate in aggressive stretching, positioning, and strengthening program in order for the functional gains to take place. The impact on the family must be considered before using this type of treatment.

Ethical issues are now arising since the medical community has embraced the use of BtA for the treatment of spasticity. It is more difficult to do randomized clinical trials, because the parents want their child to get treatment and not the placebo. There are now many studies comparing dosages for BtA injections, with the doses increasing. This brings up the issue of safe dosages. The U.S. Food and Drug Administration issued an early communication on February 8, 2008 regarding the safety of BtA. The report stated that "the safety, efficacy and dosage of botulinum toxins have not been established for the treatment of limb spasticity of cerebral palsy or for use in any condition in children less than 12 years of age." The report noted that cases of botulism had occurred in children less than 16 years of age with symptoms ranging from dysphagia to respiratory insufficiency with ventilator support and even death (FDA, 2008).

There are many issues to consider in the use and effectiveness of BtA injections such as: the optimal age for injection, severity of spasticity, timing of injection, dosage, therapies post injection, and consistency of outcome measure. The last, but possibly most important is the economic impact of its effectiveness compared with other interventions. Longer term studies with more than just a 3 month follow up are needed to determine whether positive outcomes are maintained. At this time, the studies do not indicate that BtA injections are effective in long term management of spasticity of the children with spastic cerebral palsy.

Intrathecal Baclofen

Intrathecal baclofen (ITB) has also been used to reduce spasticity. Baclofen is a GABA agonist – it binds to the GABA receptors in the spinal cord and causes a presynaptic inhibition, which in turn decreases muscle tone (Verrotti et al., 2006). The baclofen is infused directly into the subarachnoid space of the spinal cord. By using the infusion the side effects are minimized.

ITB is delivered via an implantable pump which is surgically placed in the abdominal area. A catheter is then inserted into the subarachnoid space of the spinal cord. Recommendations are for the catheter tip to be placed at T10-T12 for spastic diplegia and C5 to T2 for spastic quadriplegia (Albright et al., 2006). Its use has been recommended for intractable and generalized spasticity. It can be used in children with some precautions. The main consideration is the child's weight. Also, children with ventriculoperitoneal shunts require lower doses and have to be watched closely for the development of meningitis due to the possibility of infection at the pump. In a descriptive pilot study in 2003 regarding oral motor changes in children after ITB, Bjornson et al. reported improvements in speech, communication, and control of oral secretions after receiving ITB. Verrotti (2006) reported that other studies have shown improved range of motion via goniometric measurement, functional improvements and subjective reporting of decrease in painful muscle spasms.

Unfortunately, ITB is not without its complications. Problems with infection from the surgery, leakage of cerebrospinal fluid, and wounds on the abdomen from pressure on the pump or erosion through the skin have been reported. Because the pump uses a battery as its source of power, it must be replaced every 4-7 years. Due to the fact that these ITB's are being placed in children, the issue of growth may impact the catheter length and many times they need to be replaced. Lastly, the drug baclofen is being used and considerations must be given to issues including baclofen withdrawal, and possible over dosage (Albright et al., 2006).

Surgery as an Intervention

Surgical intervention is utilized in the form of orthopedic procedures of tendon and muscle lengthening, tendon transfer and selective dorsal rhizotomy in children with CP. Most of the time surgery is used when other interventions have not been successful. Orthopedic surgery does not change spasticity, but does affect the secondary impairments of contractures resulting from the hypertonicity. Selective dorsal rhizotomy is intended to treat spasticity especially in the lower extremity.

In selective dorsal rhizotomy (SDR), the specific afferent fibers or the rootlets from L2 to S2 that are contributing to the spasticity are found by direct electrical stimulation in the operating room (Steinbok & McLeod, 2002). The rootlets causing the largest spastic motor response are carefully cut. The reason for the electrical stimulation is to tease out the motor and sensory rootlets, with the goal being to cut the motor rootlets and leave the sensory rootlets preserving touch and position sense. The spasticity is reduced, but the client is left with varying degrees of muscle weakness. SDR is an irreversible intervention and requires one to two years of intensive therapy post surgery to increase strength and improve motor function (Steinbok & McLeod, 2002).

In a review of the published studies available in 2000, Steinbok reported very strong evidence that SDR decreases lower limb spasticity and increases range of motion using goniometric measurements and spasticity scales such as the Ashworth Scale (AS) and Modified Ashworth Scale (MAS). Strong evidence of functional improvements was found when using the GMFM. There is weak evidence that SDR may reduce the need for further orthopedic intervention.

Complications of SDR can be infection, leakage of cerebrospinal fluid, hypotonia, severe weakness, sensory changes, urinary incontinence, and spinal instability/deformity (Farmer & Sabbagh, 2007; Miller, 2005; Steinbok & Schrag, 1998). Aggressive and intensive physical therapy is recommended as part of the post operative management (Miller, 2005). Families must make the decision to pursue SDR based on their individual needs. Understanding the risk possible side effects and the economic and quality of life impact on the family needs to be considered.

Orthopedic surgical intervention does not necessarily have a direct effect on spasticity, but is used to help correct secondary impairments due to the hypertonia. The hypertonia includes the changes in muscle length causing contractures and the ultimate decrease in functional mobility. The surgical procedures of focus will be muscle lengthening and tendon transfer. Flexion deformities of the knee, as well as flexed knee posture during gait, are common in children with CP due to the involvement of the hamstring muscles (Ma et al., 2006). The main function of hamstring muscles is to flex the knee and a secondary function is extension of the hip. The release of the hamstring muscle is one of the most common procedures performed in children with spasticity. More recently, transfer of the rectus femoris muscle to a knee flexor has been performed to decrease the stiff knee gait or straight knee gait, which is sometimes a consequence of lengthening surgery (Yngve et al., 2002). In another surgical technique, the medial hamstring is lengthened and the semitendinosus tendon is transferred to the adductor tubercle (Ma et al., 2006). Both studies showed statistically significant improvements in changes in GMFCS level, gait analysis parameters, and range of motion changes.

In one study, children who had undergone orthopedic surgery were found to have improved gait status, energy efficiency, and improved function (Schwartz et al., 2004). The next question to ask is how long do the improvements last? Saraph et al., (2005) performed a long term follow up study on 32 children with spastic diplegia ranging in age from 8.7-13.5 years. The children met the criteria of having good vision, the ability to follow instructions, no history of previous orthopedic surgery on the lower limbs, and pre- and post-operative gait analysis. The children underwent a single-event multilevel surgery of the lower extremities, including muscle lengthening/transfer and correction of bony deformities, and then were followed over a three-year period. The subjects received daily physical therapy in their 4-6 week hospital stay. They also followed a rigorous standardized protocol while in the hospital, as well as after discharge which consisted of casting, ankle foot orthoses, standing activities, and gait training. Monitoring monthly by the orthopedic department was an additional requirement. Post-operative gait analysis was performed at years 1, 2, and 4 after surgery. The study found improvements in the movement of the hip and ankle joint were maintained and gradually improved over the three years. Gait function continued to change over the three years of follow-up with a general decrease in function between first and second post-op evaluation. They propose long-term follow-up of at least three years for surgeries to justify a positive outcome (Saraph et al., 2005).

Post-operative care after orthopedic surgeries requires aggressive pain management. If the pain is not adequately managed, it can exacerbate the spasticity, increasing muscle spasms and finally producing more pain (Karol, 2004). Children often are casted or have to use knee extension splinting (Karol, 2004; Miller, 2005; Saraph et al., 2005). Strengthening cannot begin until the tendons heal and the postoperative pain has resolved, usually 6 weeks after surgery (Miller, 2005). Complications of surgery include over-lengthening of gastrocnemius muscles, recurrent contracture, loss of knee flexion during swing, postoperative pain, and wound infections (Miller, 2005; Morrissey & Weinstein, 2006).

Surgery alters the musculotendinous unit in a way that decreases the tension in the muscle. Selecting the appropriate procedure is of the utmost importance. Surgery can permanently change the function of the muscle groups involved.

There is a trend toward performing selective dorsal rhizotomy (SDR) and orthopedic surgical techniques. The SDR is performed before surgical interventions. The belief is that the SDR improves dynamic knee flexibility reducing the need for tendon lengthening or transfer around the knee. It does not change bony problems or ankle problems (Schwartz et al., 2004). In a retrospective nonrandomized study, subjects that received orthopedic surgery including tendon release after rhizotomy showed improvement in gait, oxygen consumption, and overall functional mobility (Schwartz et al., 2004). This change does not appear unusual since having the two procedures target the main issues with CP – addressing spasticity with the SDR and the resultant muscle contractures with the soft tissue and bony surgeries.

Selective Percutaneous Myofascial Lengthening (SPML)

One of the newest techniques being purported for management of the secondary impairments of spastic hypertonia is Selective Percutaneous Myofascial Lengthening (SPML) was initially described by Roy Nuzzo, M.D. in the 1980's. He identified a technique that was first used in children with CP and severe cardiac conditions. The children were observed to turn blue when they walked due to the high energy demand of gait (Nuzzo, 2008). Their cardiac condition prevented them from being able to withstand long intervals of being under the effects of anesthesia, which was necessary for traditional tendon lengthening surgeries (Nuzzo, 2008).

A small scalpel is used to release the "tightness", creating small incisions of approximately 2-3 millimeters through the skin and into the area where the tendon begins to thin out and starts to blend into muscle, referred to as the myofascia. The lengthening involves only the palpable taut portions of the selected myofascia (commonly less than 1/10th of the width). When the myofascia is cut, the muscle can easily be stretched (Yngve, 2008). The SPML surgical procedure consists of four possible components, including lengthening the fascia of the hip adductor muscles, obturator nerve block with ethanol (ETOH), hamstring lengthening and lengthening of the gastrocnemius fascia. The examination of the patient and subsequent needs dictate which procedures are performed (D. Yngve, personal communication, September 18, 2009).

Obturator nerve blocks are necessary if the child is very reactive to adductor stretch. Electrical stimulation is used to locate the nerve and 3 milliliters of 50% ETOH are injected at the site. Adductor lengthening is performed a few centimeters from the groin crease with the adductor longus muscle being treated first and, if necessary, followed by release of the gracilis muscle. The hamstring muscles are then addressed with micro incisions a few centimeters proximal to the knee crease. Typically, the semitendinosus is the first muscle treated. Then as needed, the semimembranosus muscle and long head of the biceps femoris are lengthened. If necessary, lengthening of the gastrocnemius fascia is performed through several micro incisions at an area about midway between the calcaneus and the belly of the gastrocnemius muscle. The tightest areas of the muscle are lengthened first followed by testing of dorsiflexion range. The lengthening continues in a stepwise fashion until the correct amount of dorsiflexion, approximately 7 degrees, is achieved (D. Yngve, personal communication, September 18, 2009). There is no standard technique. Rather, the physician basically feels the muscle's palpable strands and decides where he/she will nick the fascia. Most children are placed in short leg casts especially after gastrocnemius lengthening, and walking is encouraged by putting a shoe directly over the cast. The use of knee immobilizers at night is recommended after hamstring lengthening. Typically, children can resume activity immediately and return to physical therapy 3-7 days following the procedure (D. Yngve, personal communication, September 18, 2009).

Advantages of SPML include: decreased time under anesthesia, can be performed in the supine position, smaller incisions, decrease in post-operative pain, and minimal scarring (Nuzzo, 2008; D. Yngve, personal communication, September 18, 2009). Both report a decrease in post-operative pain, increase in ROM, and quicker return to activity compared to other procedures (Nuzzo, 2008; D. Yngve, personal communication, September 18, 2009). However, there is no objective evidence on the effectiveness of this procedure.

There are many options to consider regarding interventions of a child who is having difficulty with activity due to the effects of spastic cerebral palsy. Many treatments are temporary while others are more permanent. It is a common assumption that improvements in ROM are theoretically expected to carry over to improvements in functional mobility, namely gait. This study focuses on the effectiveness of a minimally invasive surgical procedure for children with stiffness of the lower extremities, primarily the knee and ankle during a functional activity. It is the first to examine the outcomes from the SPML surgery examining the impairment and activity level using the of the ICF model.

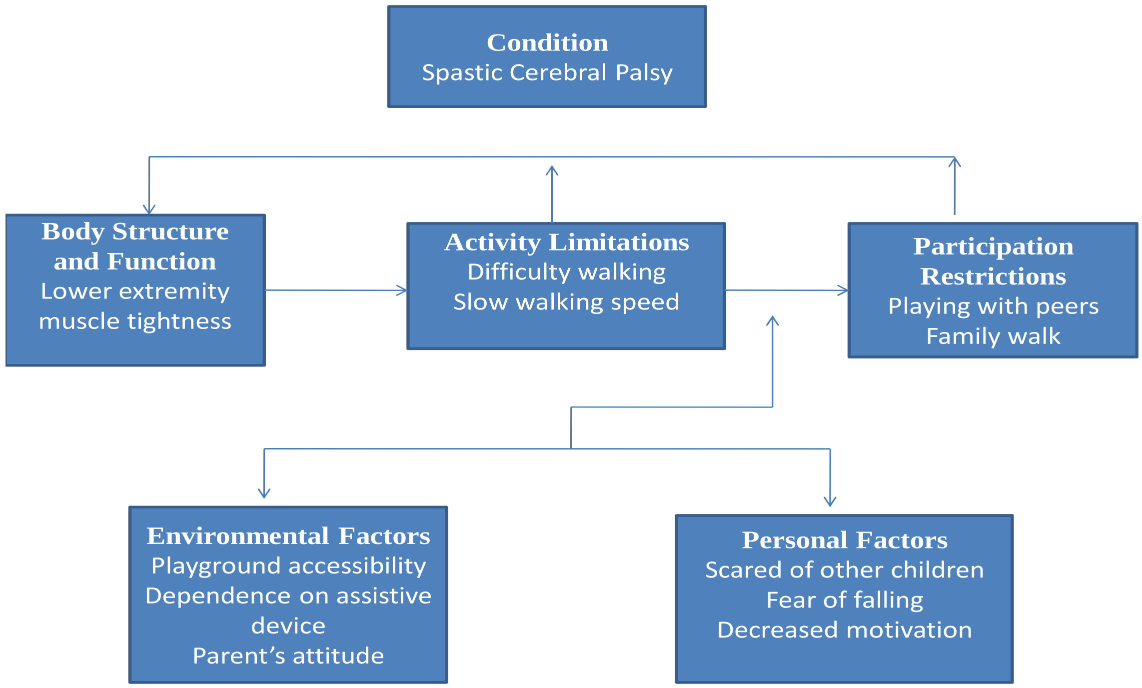
Chapter 3: Methods

This study was approved by the Institutional Review Board at the University of Texas Medical Branch IRB # 07-166, Cerebral Palsy Surgery. Parents gave permission for their children to be videotaped.

3.1 Conceptual Model

Figure 2 shows the conceptual model that drives this study. When dealing with children with disabilities, focus is on the functional consequences of the health condition of the child. For the child with spastic cerebral palsy, body functions and structure impairments may include tightness of the hamstring and gastrocnemius muscles of the lower extremity muscles due to impairment or condition of the neuromuscular system. This impairment may then lead to an activity limitation in the ability to stand and walk in the community, finally leading to a restriction in participation such as the ability to play with peers at the neighborhood park or go on evening walks with family. Contextual factors in the environmental domain may include the attitudes of the parents regarding the importance of encouraging the child to walk or even the time constraints of a busy family. The accessibility of the playground and neighborhood in which the child lives may impact the ability to practice walking. This study focused on the body structure and function by examining the efficacy of an intervention at the body structure and functional level which affects activity and ultimately impacts participation restrictions. This study did not focus on the environmental or personal factors that can influence the disabling process.

Figure 2. Conceptual Model illustrating disablement model for children with spastic cerebral palsy.



The primary goal of this study was to assess lower extremity ROM of the knee and ankle and functional mobility following SPML surgery in a group of children with lower extremity tightness. The hypothesis of this study was that Selective Percutaneous Myofascial Lengthening Surgery (SPML) of the lower extremities in children with Cerebral Palsy will change range of motion of the knee and ankle during specific phases of gait, change gait speed, and change functional mobility as measured by the Functional Mobility Scale (FMS). In this retrospective case series study, subjective and objective measures of functional mobility were analyzed using pre and post-operative gait videos.

3.2 Design

In this retrospective case series, data were analyzed from children who underwent SPML surgery from 2006-2008 and had pre-operative and post-operative gait videos.

Subjective and objective measures of functional mobility were analyzed using pre-operative and post-operative information from medical records and videotapes of the children walking. Using a computer program, range of motion of the knee and ankle were measured during specific stages of walking, as well as walking speed. The outcome measure of each child's functional mobility was assessed using the Functional Mobility Scale (FMS).

3.3 SAMPLE

This sample included 31 (62 extremities) children with a diagnosis of spastic cerebral palsy who had undergone SPML surgery at the University of Texas Medical Branch between 2006 and 2008, and had been videotaped pre-operatively and at least 4 months post-operatively.

Eligibility

Subjects under the age of 21, with the diagnosis of cerebral palsy who had received SPML surgery were included in this study. Only subjects that had before and after surgery videotapes were considered for this study. A total of 100 children met the criteria, of those, 47 had both pre-operative and post-operative videos. Seven were excluded due to poor quality of one of the videos which made analysis difficult, 9 were excluded due to lack of consistency with shoe or orthotic wear. A total of 31 subjects were included. Each subject had 2 (1 pre-operative and 1 post-operative) video tapes taken in the sagittal plane so that the knee and ankle joints could be observed. A Sony digital handicam DCR-TRV 130 NTSC 560x camera was positioned on a tripod 14 feet back from the carpeted walkway area. The child was asked to walk at a self selected speed along the 10 foot (305cm) carpeted hallway with only the middle 6 feet (210 cm) videotaped to eliminate an acceleration and deceleration effect. Figure 3 shows the equipment used for the video sessions. One view was taken with the child walking right to left and the second view was taken with the child walking left to right. This sequence was done to ensure that each individual lower extremity could be visualized and measured.

Figure 3. Equipment used for videotaping: video camera, tripod and laptop computer.

3.4 MEASUREMENTS

Demographic information regarding age, gender, ethnicity, diagnosis, payor source, and Gross Motor Function Classification System (GMFCS) level was obtained from medical records. Table 2 shows the measures, outcomes, data sources and definitions.

Table 2: Source of Information and Definition of Variables

Subject Characteristics	Data Source	Definition
Age	Epic Medical Record	Age at surgery in years
Gender	Epic Medical Record	Male/Female
Ethnicity	Epic Medical Record	Non-Hispanic white, non-Hispanic black, Hispanic
Diagnosis	Epic Medical Record	Cerebral Palsy
Payor source	Epic Medical Record	Private insurance/government sponsored
Gross Motor Function Classification Scale	Epic Medical Record/Video analysis	Rank order data: I-IV (none were V?)with I being the highest functioning
Objective Measures		
Knee angle at maximum Flexion in Swing	Video analysis	Continuous variable using computer program (Biogait) to measure joint angle
Knee angle at maximum Extension at Terminal Swing	Video analysis	Continuous variable using computer program (Biogait) to measure joint angle
Knee angle at maximum Extension in Stance	Video analysis	Continuous variable using computer program (Biogait) to measure joint angle
Ankle angle at maximum Plantarflexion at toe off (Pre-swing)	Video analysis	Continuous variable using computer program (Biogait) to measure joint angle
Ankle angle at maximum Dorsiflexion in Swing	Video analysis	Continuous variable using computer program (Biogait) to measure joint angle
Ankle angle at maximum Dorsiflexion in Stance	Video analysis	Continuous variable using computer program (Biogait) to measure joint angle
Gait Speed	Video analysis	Continuous variable using computer program to calculate speed to the nearest tenth of a second from video analysis
Outcomes		
Functional Mobility Scale	Epic and/or Video analysis	Rank order data: 1-6, with 6 being the highest functioning

The videos were loaded into a computer based software program, Biogait. The Biogait Biomechanics software (Seaside Software) is marketed as a trackside, sports science performance analysis program. It provides a suite of functions that permit detailed analysis and comparison of 2D digital video clips. The Biogait 2D motion system allows for the viewing and analysis of 60 frames per second. Of particular interest within the context of this study, is the ability to draw angles on specific joints, as well as the ability to calculate gait velocity. It permits for frame by frame analysis as well as freezing frames in order to ensure the measurements are taken at the appropriate time in the gait cycle. This software provides an attractive and cost effective clinical research tool, enabling the basics of 2D video analysis to quickly and easily be put into practice. To date, however there has been no published research conducted using this software (searches on Pub Med, CINAHL, and Google Scholar returned no relevant results).

Range of motion (ROM) measurement variables included: 1) Maximum knee flexion at swing, 2) Maximum knee extension at terminal swing, 3) Maximum knee extension in stance, 4) Maximum plantarflexion at toe off (pre-swing), 5) Maximum dorsiflexion in swing, 6) Maximum dorsiflexion in stance, and 7) Gait speed. Functional mobility was assessed using the Functional Mobility Scale (FMS).

Knee measurements' were defined using the terminology from Perry (2001). Maximum knee flexion in swing was defined as the point where the knee flexed maximally, clearing the foot from the ground. Maximum knee extension at terminal swing was defined as the final phase of swing; where the knee extends, reaching out to achieve step length, ending the moment before the foot strikes the floor. Maximum knee extension in stance was defined as the point where the opposite foot was lifting off of the floor and advancing, so that the body is progressing over the single limb in contact with the ground. Maximum dorsiflexion in swing was defined as point where the knee on the leg in swing phase begins to extend and the ankle must be position to maintain foot clearance. Dorsiflexion in stance is actually the position in terminal stance where the body is progressing past the forefoot and the ankle in typical gait is in approximately 10°of dorsiflexion. Plantarflexion was measured at the point of pre swing where the forefoot remains on the floor while the knee begins to flex in preparation for the advancement of the limb (Perry, 2001).

Gait speed was calculated by the formula of distance (cm)/time (sec). The distance of the videoed walk was 210 cm. Gait speed was calculated with the child walking from left to right and then repeated for a walk from right to left. The two scores were then averaged.

GMFCS

The GMFCS is a reliable and valid system (Morris et al., 2006; Palisano et al., 1997) for classifying children with CP based on functional abilities, e.g. how a child moves around in their environment (Palisano et al., 1997). It implements a level I through V scale. Level I includes the highest functioning children with minimal to no disability with walking and running in the community. Level V represents the child that has no means of independent mobility. The differences in the levels are based on functional limitations and the need for assistive devices (Palisano et al, 1997).

FMS

The FMS was developed as an evaluative measure of one aspect of activity limitation which is mobility (Graham et al., 2004). The FMS used to quantify mobility in children taking into account assistive devices and distances a child may walk. A child is assessed at three distances; 5, 50, and 500 meters. They are given a score ranging from 1-6, with 1 being wheelchair bound and 6 being independent without assistive devices or orthoses (Graham et al. 2004). It has been found to be a reliable and valid tool to demonstrate changes in functional mobility after orthopedic surgery (Graham et al. 2004; Harvey et al., 2007). Harvey et al. (2007) found it to be clinically useful especially when paired with video analysis. A rating of 1 to 6 for each of the FMS distances was assigned to each subject. Table 3 provides a summary and comparison of the GMFCS and FMS.

Table 3: Summary and comparison of the criteria for GMFCS and FMS

GMFCS	**FMS** (three scores; one each at 5, 50, and 500 m)
Level I-Walks without restriction; can run, but speed decreased	**6** –Independent on all surfaces; can run and climb stairs
Level II-Walks without restriction; uses assistive device or rails	**5**-No assistive device, needs help with stairs
Level III-Walks with assistive mobility devices and limited in walking outdoors and in community (uses wheelchair)	**4**- Uses canes (1 or 2); or uses walls for support or assistance
Level IV-Self mobility with limitations, can walk short distances with physical assistance	**3**-Uses 2 crutches
Level V-No self mobility	**2** -Uses walker without assistance
	1-Uses WC; may stand or walk with assistance

3.5 Reliability of the ROM Measurements

Analysis of intra-rater and inter-rater reliability for the computer based program was determined by calculating intraclass correlation coefficients (ICC's) using SAS 9.2 (SAS Institute Inc., SAS Campus Dr., Cary, NC 27513). Five pediatric physical therapists with 3-30 years of experience participated in the study. Each therapist was provided with an instruction sheet as well as 15 minutes of training on the use of the computer program to measure knee and ankle ROM from a video of gait. They were then allowed 10-15 minutes of practice using the program to measure the knee and ankle joint angles from a video of a child with CP walking across a room from left to right and right to left. They then analyzed the videos of 3 different children two times each. Measurement variables included: 1) Maximum knee flexion in swing, 2) Maximum knee extension in stance, 3) Maximum dorsiflexion in swing and, 4) Maximum dorsiflexion in stance. Figure 4 is an example of a knee measurement with the angle marked by a green line.

Intraclass correlation coefficients (ICCs) were computed for the 5 therapists examining 3 subjects for the above four variables. The ICC for the knee ROM ranged from 0.98 to 0.99 and ankle was 0.99. For each child, agreement of measurements within 5 degrees was observed at greater than 90% for each variable between raters (inter-rater) and greater than 80% for agreement within 2 degrees for each variable. In addition, intra-rater agreement between successive measurements was also more than 90% for each variable (Wild et al., 2009). In the SPML study, all of the dynamic measures from the video tapes were obtained by the same examiner.

Figure 4. Representative measurement of knee angle motion during swing

3.6 DATA ANALYSIS

All statistical procedures were performed with SAS 9.2 (SAS Institute Inc., SAS Campus Dr., Cary, NC 27513). Scatter plots were performed to explore the data followed by calculating simple linear correlations to estimate the relationships between ROM measurements and functional status. Means and standard deviations were determined for the three knee and three ankle pre-operative and post-operative ROM measures, as well as for the variables of age at time of SPML procedure and follow up time after procedure. To fully describe the study population, counts and frequencies were reported for demographic information of gender, ethnicity, payor source, GMFCS level, typography of CP, and type and number of procedures performed.

One of the main outcomes of interest was the change of pre and post-operative ROM measures of the knee and ankle. Since both the right and left lower extremity measurements were collected for each subject, mixed model for repeated measures was used to adjust for the clustering effect (or the correlation between the left and right measurements). In prior studies, paired t-tests on pre and post-operative measurements were used to analyze the stacked right and left lower extremity data (Gordon et al., 2008; Khot et al., 2008; Saraph et al., 2005; van der Linden et al., 2003). This traditional method ignores the clustering effect and may produce biased parameter estimates and inflated Type I error. The mixed model analysis has several advantages over the traditional method: (1) it produces correct parameter standard error estimates by adjusting for the clustering effect, (2) it can further adjust for other interested covariates such as age, gender, etc., and (3) it can accommodate missing data (Littell et al., 2000). In contrast, the traditional method will case-wisely delete a subject if there is any missing measurement on either side of lower extremities. A priori significant difference was defined as $p<0.05$ with confidence intervals also reported.

The FMS is considered data at the ordinal level. The Wilcoxin signed-rank (test) is the non parametric equivalent of the t-test. It is recommended for nonparametric data especially with paired comparisons (Riffenburgh, 2006). It was used to test the median FMS classification differences from pre-operative to post-operative. A priori significant difference was defined at $p<0.05$.

Paired t-tests were used to test difference in gait speed pre-operatively versus post-operatively with 95 per cent confidence intervals. The paired t-test assumes that the observations are normally distributed, but is robust for non normal data. In theory, using paired t-tests results in each subject becoming their own control (Riffenburgh, 2006).

To examine the relationship between post-operative ROM measurements and post-operative FMS scores, the Spearman rank correlation coefficient was used. The Spearman's rho is the non-parametric measure of correlation and is used with ordinal data (Portney & Watkins, 2000).

Chapter 4: Results

4.1 Subject Demographics

The descriptive characteristics of the subjects are shown in Table 4. Males were overrepresented in this sample, with 18 (58%) males and 13 (42%) females. The mean age of the sample at the time of surgery was of 8.5 years, ranging from 4-18 years with 64% of the subjects 7 years of age or older. The majority of subjects in this sample (64%) exhibited the topographical distribution of spastic diplegia. The remaining subjects were divided between hemiplegia (23%) and quadriplegia (13%). There were no differences in descriptive characteristics or GMFCS level between subjects included in the study and subjects excluded.

There were no children at GMFCS levels I or V. Over half of the children (16 52%), had a GMFCS level of II which indicated that they were ambulatory without restriction using an assistive device and/or rails for stairs. The rest of the subjects fell equally in level III (n=7) and IV (n=8) categories. Mean times for follow-up videos were 7.5 months (range 3-13) with 45% (n=14) having a follow up time of 8 months or greater.

Muscles that received SPML procedures included the hip adductors with ETOH injection, hamstring and gastrocnemius. Table 5 shows the muscles that received SPML procedures for each subject. Of the 31 subjects, 54 extremities received SPML and ETOH to adductor muscles, 56 extremities had the procedure performed to bilateral hamstring muscles. Only 2 subjects received unilateral procedures to the hamstring and gastrocnemius muscles. Twenty subjects (65%) received the procedure bilaterally to all three muscle groups for a total of 40 extremities.

Table 4. Subject Characteristics

Subject	**N**	**%**
Gender		
Male	18	58
Female	13	42
Ethnicity		
White	15	48
Black	5	16
Hispanic	9	29
Asian	2	7
Payor source		
Private	12	39
Government	19	61
GMFCS level		
II	16	52
III	7	23
IV	8	25

4.2 ROM

The pre-operative and post-operative means and standard deviations of the knee motion measurements during the swing an stance phases of gait were calculated for the 31 subjects (62 extremities). Figure 5 uses boxplots to compare pre-operative ROM measurements for knee flexion during the swing phase of gait. The mean pre-operative maximum knee flexion in swing phase of gait was 65.7° (range 41° to 89°). Post-operatively, knee flexion decreased with a mean of 57.6° (range 37° to 79°). Note the decrease in the median post-operatively and the equal distribution of the pre- and post-operative measurements by comparing the size of the boxes.

Similarly, Figure 6 illustrates the comparison of the pre-operative and post-operative knee extension (minimum flexion) at terminal swing. A decrease from a mean of 39.5° (range 15° to 75°) to 25.4° (3° to 44°) post-operatively is evident. The overall pre-operative dispersion of ROM measurements was greater due to the outlier; however the variability of the measurements decreased post-operatively.

Table 5. Muscles that Received SPML Procedures

Subject	Adductor*	Hamstring	Gastrocnemius
1	2	2	2
2	2	2	2
3	2	2	2
4	2	2	2
5	2	2	2
6	2	2	0
7	2	2	2
8	2	2	0
9	2	2	2
10	2	2	0
11	2	2	2
12	2	2	2
13	2	2	2
14	2	2	2
15	2	2	2
16	2	2	0
17	2	2	0
18	0	1	1
19	2	2	2
20	2	2	2
21	2	2	2
22	2	2	2
23	2	2	0
24	2	2	0
25	2	2	2
26	2	2	2
27	2	2	2
28	0	0	2
29	0	2	0
30	0	1	1
31	2	2	2

1=unilateral; 2=bilateral
*Adductor lengthening included ETOH injection

Knee extension (minimum flexion) in stance demonstrated the greatest change with a pre-operative mean of 23.2° (range 3° to 65°) compared to post-operative mean of 8.7° (range -15° to 31°), see Figure 7. The boxplots show the slight asymmetry in the pre-operative measurements and one outlier demonstrating severe knee flexion during stance.

Post-operatively the overall distribution of ROM measurements decreased and one subject exhibited extreme hyperextension during stance.

The ankle means and standard deviations were also calculated for the 31 subjects (62 extremities), the pre-operative mean for plantarflexion at toe off (pre-swing) of 26.8° (range -7° to 67°) and post-operative mean measure of 18.7° (range -10° to 75°) (see Figure 8). The overall range of ROM measurements pre-operatively was greater than the post-operative measurements. The data was distributed differently with a large dispersion pre-operatively. Post-operative ROM measurements for ankle plantarflexion appeared to decrease in variability except for the one outlier.

Figure 9 illustrates the large distribution of the pre-operative measurements for dorsiflexion (minimum plantarflexion) in swing with a mean of 10° (range -20° to 60°). Post-operative mean was 0.9° (range -18° to 24°) with a decrease in dispersion noted. Similarly, Figure 10 shows the means for dorsiflexion (minimum plantarflexion) in stance phase with pre-operative measures of 4.1° (range -26° to 45°) and post-operative mean of -4.3° (range -22° to 8.3°). The distribution of the measurement post-operatively is smaller when compared to the pre-operative measures.

Figure 5. Comparative boxplots for pre-operative and post-operative ROM of knee flexion in swing phase of gait, with means (in degrees) located in box.

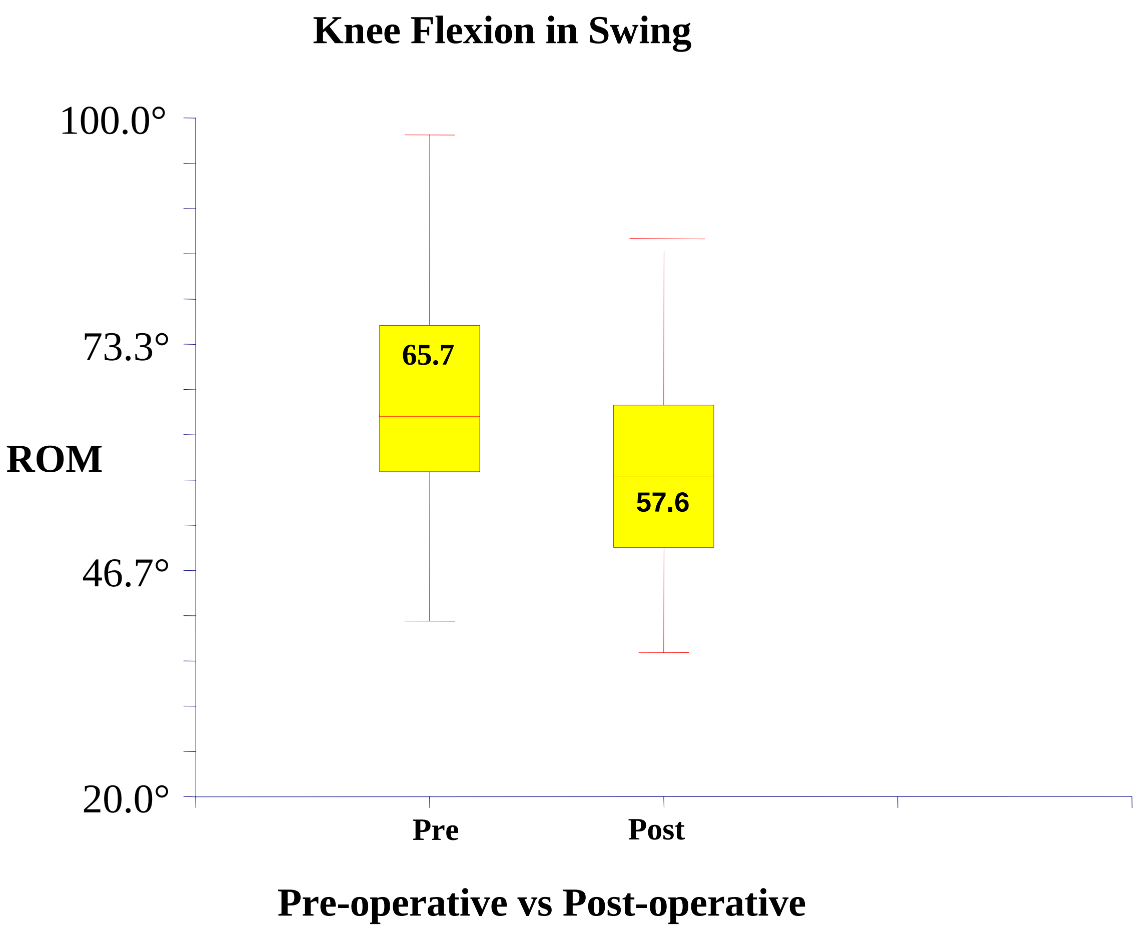


Figure 6. Comparative boxplots for pre-operative and post-operative ROM of knee extension in terminal swing phase of gait with means (in degrees) located in box.

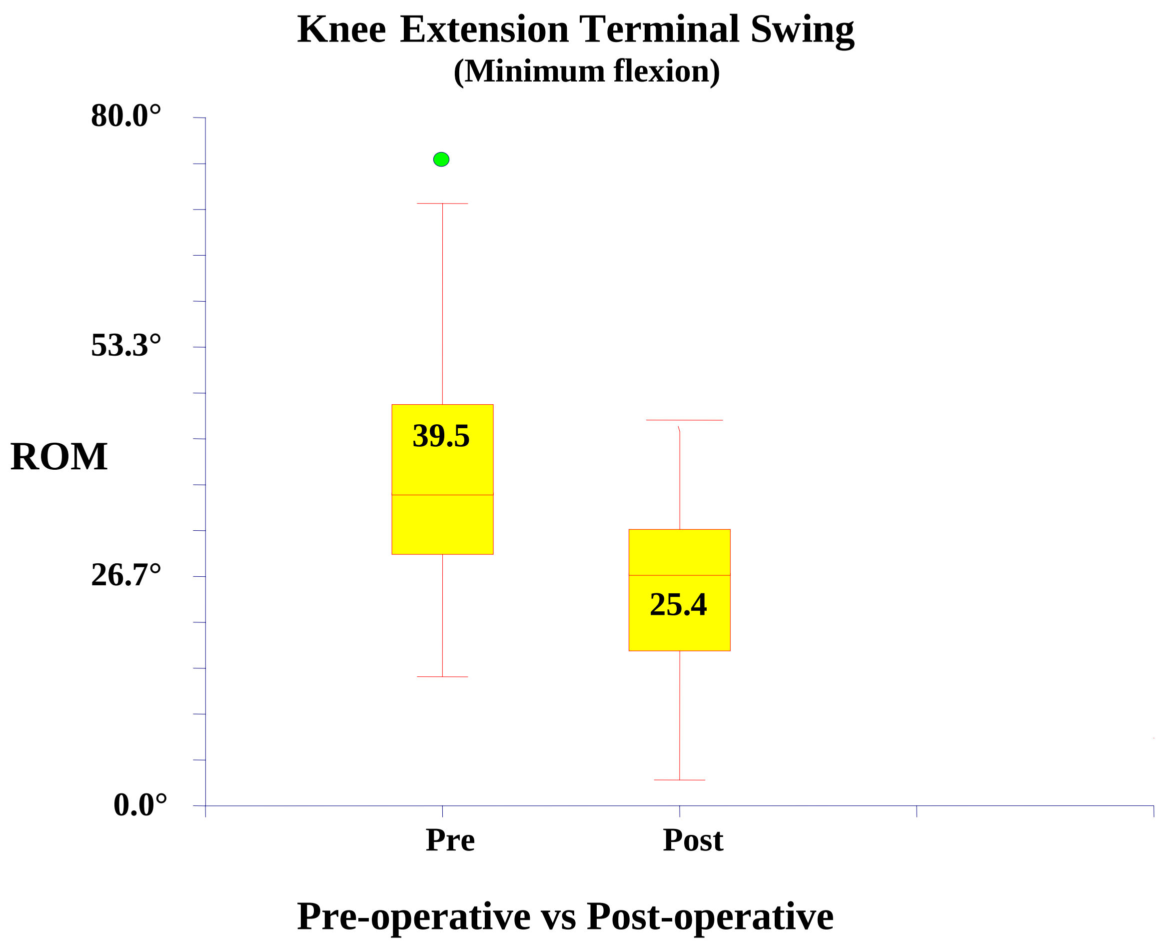


Figure 7. Comparative boxplots for pre-operative and post-operative ROM of knee extension in terminal stance with means (in degrees) located in box.

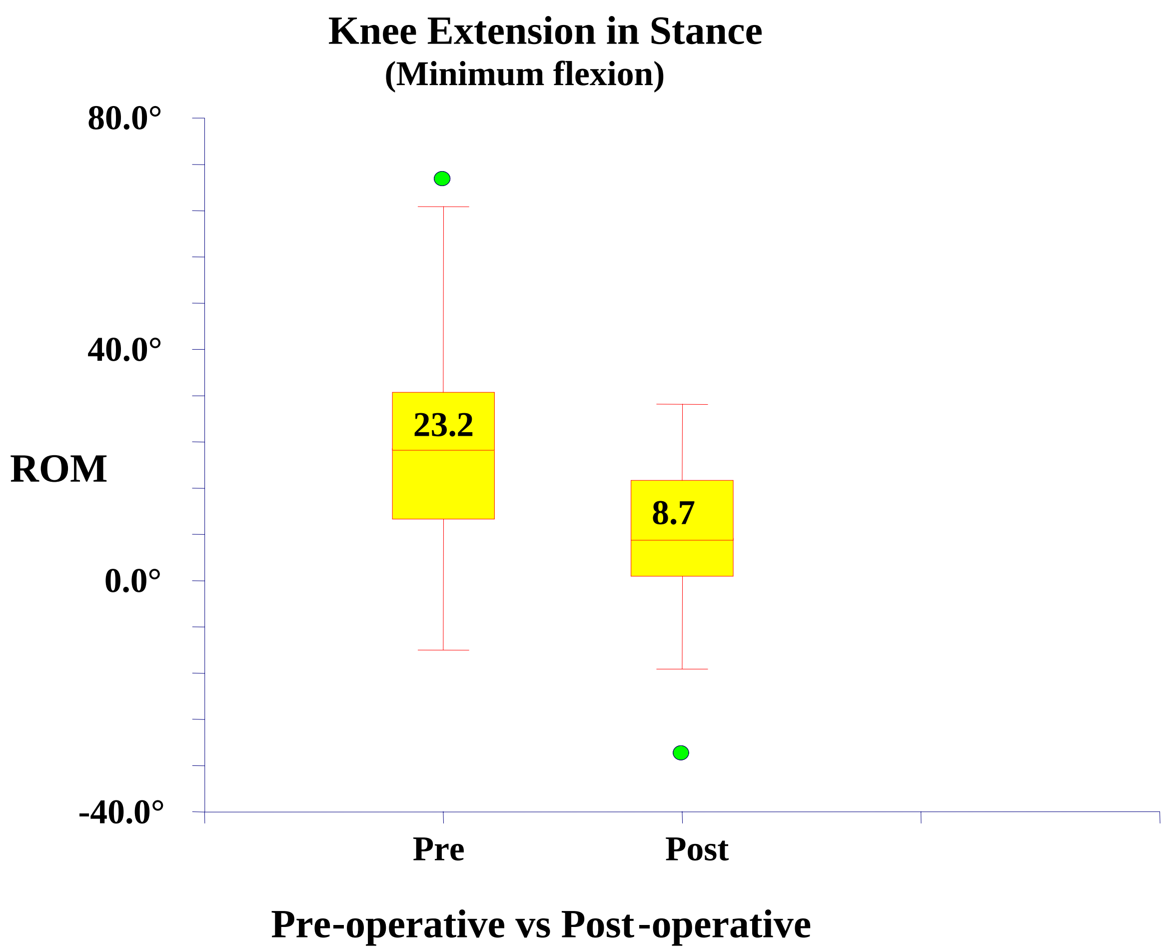


Figure 8. Comparative boxplots for pre-operative and post-operative of ankle plantarflexion at toe off with means (in degrees) located in box.

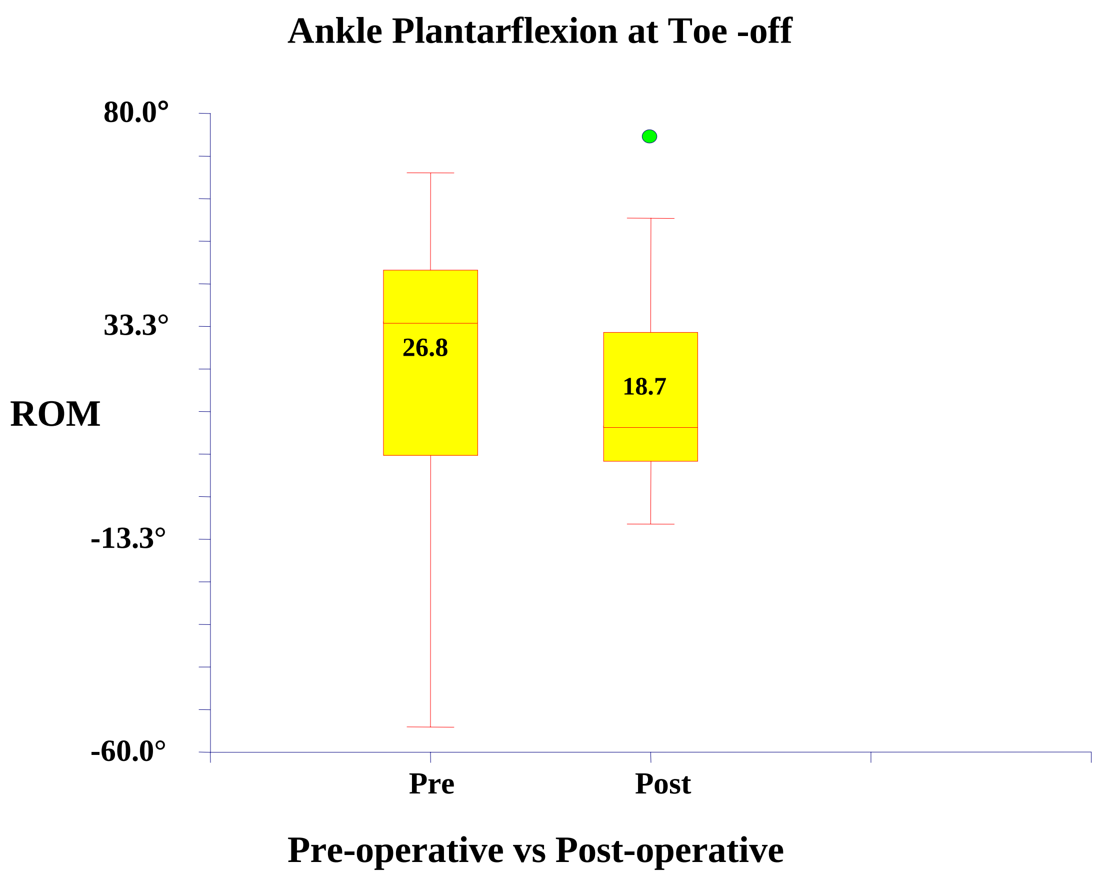


Figure 9. Comparative boxplots for pre-operative and post-operative of ankle dorsiflexion in swing with means (in degrees) located in box.

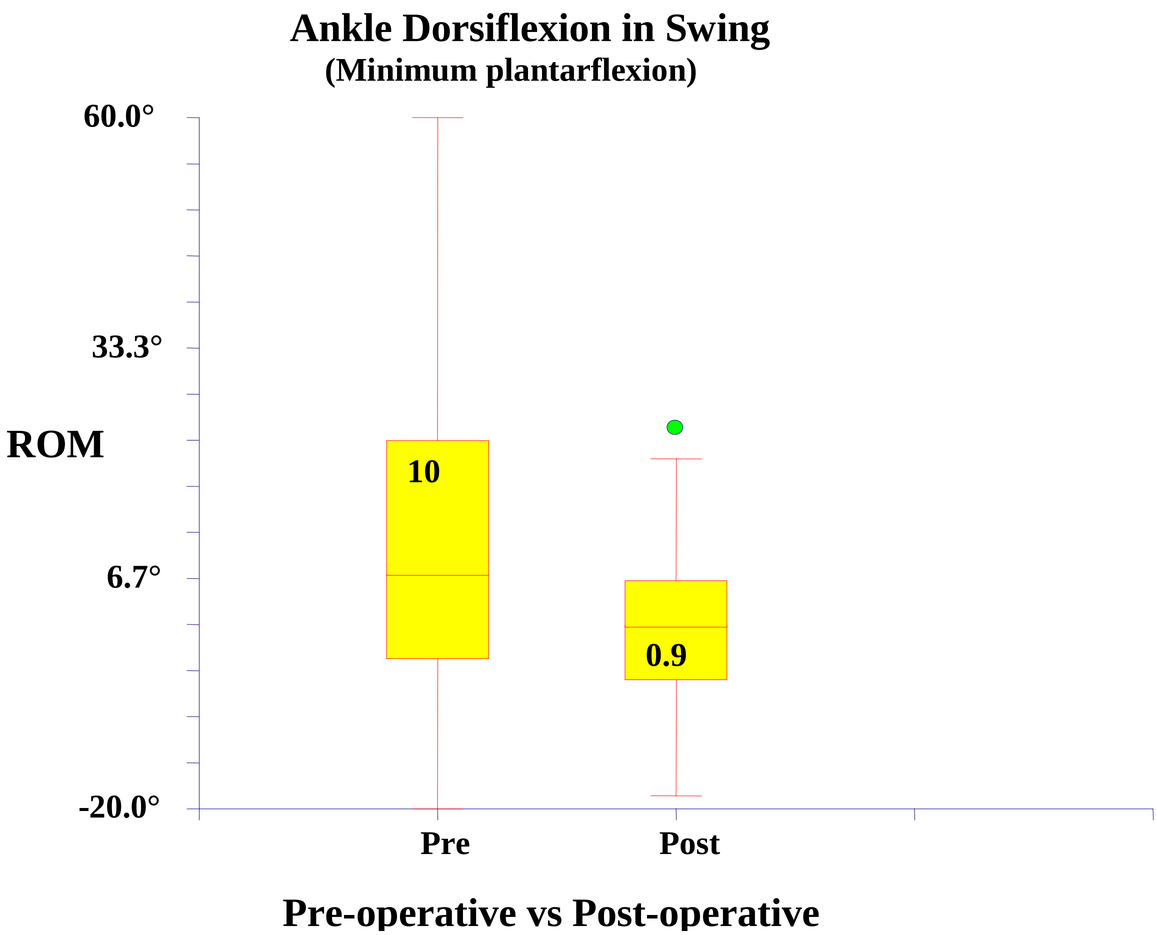
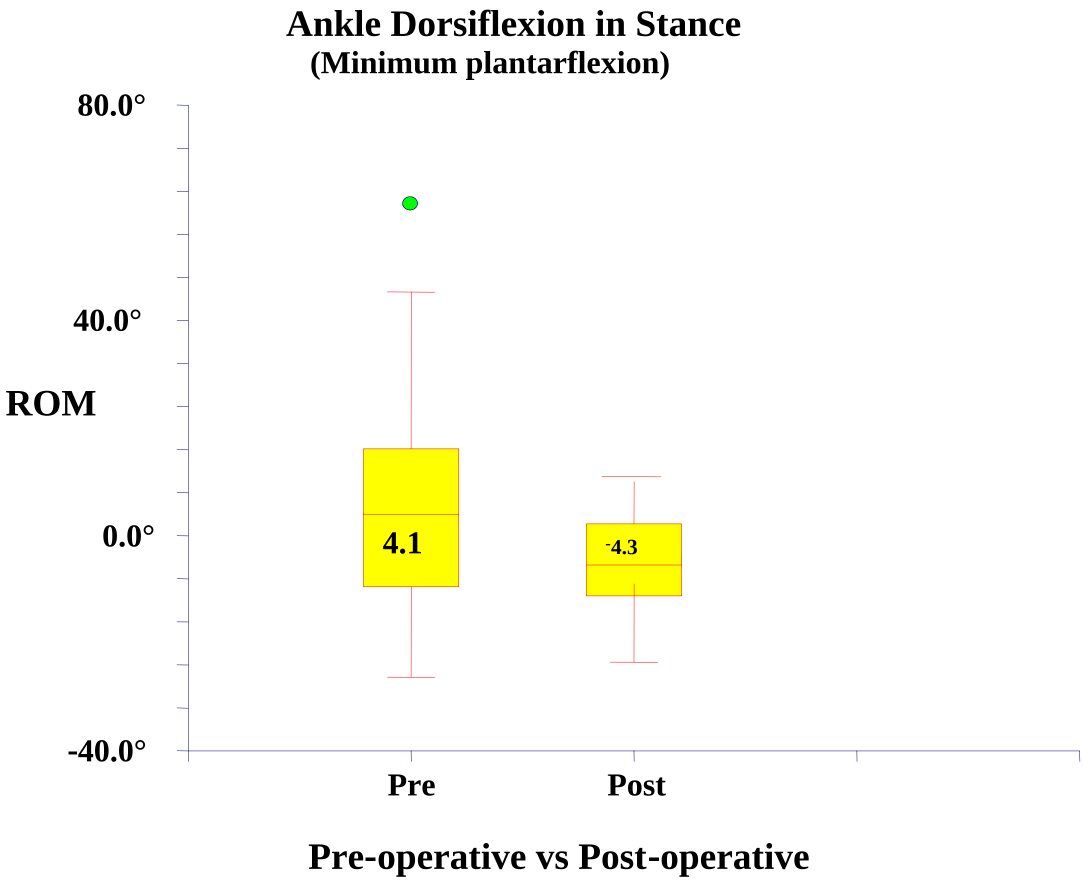


Figure 10. Comparative boxplots for pre-operative and post-operative of ankle dorsiflexion in stance with means (in degrees) located in box.



4.3 HYPOTHESIS 1

It was hypothesized there would be a significant change in knee flexion during the swing phase of gait. Table 6 shows the results of the mixed model for repeated measures. The estimated change in range of motion (ROM) of maximum knee flexion in the swing phase of the gait cycle confidence intervals illustrate the statistically significance (p=0.007). The change estimate according to the mixed model for repeated measures was a decrease in 7.1° of knee flexion in the swing phase of gait and Hypothesis 1 was confirmed.

Table 6. Changes in Knee and Ankle Joint Parameters (degrees)

	Estimate of difference	95% CI of difference	p-value
Knee flexion in SW	7.1	2.3, 11.9	0.007
Knee ex terminal SW	13.1	9.9, 17.9	< 0.001
Knee ex ST	13.0	8.1, 17.9	< 0.001
Ankle pf TO (pre-swing)	8.1	-0.3, 16.5	0.067
Ankle df SW	7.7	1.8, 13.6	0.016
Ankle df ST	9.0	3.0, 14.7	0.006

SW indicates swing; ST, stance; TO, toe off; ex, extension; pf, plantarflexion; df dorsiflexion; based on results of mixed model for repeated measures

4.4 Hypothesis 2

Hypothesis 2 proposed there would be a significant change in ROM of maximum knee extension in the terminal swing phase of the gait cycle. Mixed model for repeated measures estimated the change to be 13.1, there was a statistically significant difference (p=0.001, CI 9.9 to 17.9) in pre-operative versus post-operative measures (see table 6). Therefore the null hypothesis that there would be no difference in the ROM measures of knee extension at terminal swing was rejected and hypothesis 2 was accepted.

4.5 Hypothesis 3

It was hypothesized there would be a significant change in ROM of maximum knee extension at midstance in gait cycle. A statistically significant difference in ROM of maximum knee extension at midstance in the gait cycle was found with p=0.0001 (CI 8.1 to 17.9). The overall change in ROM from pre-operative to post-operative measures was a gain in knee extension of 13.0°(see table 6). Hypothesis 3 was also confirmed.

4.6 Hypothesis 4

Hypothesis 4 proposed there would be a change in ROM of ankle plantarflexion in toe off (pre-swing) after SPML surgery. Hypothesis 4 was not confirmed. The mixed model for repeated measures did not demonstrate a statistically significant difference in ROM of plantarflexion of the ankle at toe off (pre-swing) in the gait cycle, with p=0.07 (CI -0.3 to 16.5) (see Table 6). Total change was 8.1° was noted, but not statistically significant.

4.7 Hypothesis 5

Hypothesis 5 proposed there would be a significant change ROM of maximum ankle dorsiflexion in swing phase of the gait cycle. Mixed model for repeated measures showed a statistically significant change in range of motion, with p=0.02 (CI 1.8 to13.6). A total change of 7.7° was noted from pre-operative measures (see Table 6). Therefore, hypothesis 5 was confirmed.

4.8 Hypothesis 6

It was hypothesized there would be a change in ROM of maximum dorsiflexion in the midstance phase of gait. There was a statistically significant change in ROM of maximum dorsiflexion in the midstance phase of the gait cycle, with p=0.006 (CI 3.0 to 14.7). A total change in ROM measurements from the pre-operative measure was 9°. Hypothesis 6 was confirmed.

4.9 Hypothesis 7

Hypothesis 7 proposed that there would be a change in gait speed after the SPML surgery. There was no significant change in gait speed from pre-operative measures to post-operative measures. Pre-operative gait speed mean was 109.2 cm/sec (sd 51.0) with a range of 10-183 cm/sec. Post operative gait speed mean was 110.0 cm/sec (sd 49.8) with a range from 20-208 cm/sec. Paired t-test showed no significant change in gait speed after SPML surgery, p=0.91 (CI -15.7 to 32.3). However, the slowest speed pre-operatively was 10 cm/ sec and post-operatively increased to 20 cm/sec. In the same respect, there was a 25 cm/sec increase for the fastest speed noted.

4.10 Hypothesis 8

It was hypothesized there would be a change in FMS scores at the distances of 5 m, 50 m, and 500 m. The numbers of pre-operative subjects and post-operative subjects in each FMS category are described in Table 7. There were no pre-operative FMS scores of 6 at any distance; post-operatively 7 subjects scored a 6 at the 5 m distance, 4 subjects demonstrated a FMS score of 6 at the 50 m distance, and 3 subjects scored a 6 at the 500 m distance.

As demonstrated in Table 8, the median pre-operative scores for FMS were: 4 for the 5 m distance, 4 for the 50 m distance, and 2 for the 500 m distance. Post-operative medians were 5 for 5 m distance, 5 for 50 m distance, and 3 for 500 m distance, showing a change of 1 level in each distance category. Wilcoxin signed-rank (test) showed a statistically significant difference in pre-operative versus post-operative scores in the FMS at each distance of 5, 50, and 500 meters with $p<0.0001$ (see table 8) This supports the hypothesis that there was a change in FMS scores in children after the SPML procedure. At the 5 foot distance, one subject progressed from a FMS score of 1 to 5. There were no preoperative FMS scores of 6 at any distance; post-operatively there were 7 subjects that scored a 6 at the 5 m distance, 4 subjects demonstrated a FMS score of 6 at the 50 m distance and 3 subjects scored a 6 at the 500 m distance. The most striking finding was that of the 15 subjects that exhibited a FMS score of 1 at the 500 m distance pre-operatively, only 4 subjects scored a 1 at the post operative assessment.

Table 7. Frequency (percent) of FMS scores

FMS score	5m Pre	5m Post	50m Pre	50m Post	500m Pre	500m Post
1	6 (19)	---	7 (23)	---	15 (48)	4 (13)
2	7 (23)	8 (26)	8 (26)	11 (35)	3 (10)	10 (32)
3	1 (3)	---	1 (3)	---	1 (3)	2 (6.5)
4	5 (16)	4 (13)	4 (13)	4 (13)	6 (19)	2 (6.5)
5	12 (39)	12 (39)	11 (35)	12 (39)	6 (19)	10 (32)
6	---	7 (22)	---	4 (13)	---	3 (10)

Pre = pre-operative; Post = post-operative;--- indicates no subjects

Table 8. Median FMS scores before and after SPML surgery and results of Wilcoxin signed -rank test

FMS distance	Pre-operative	Post-operative	Change	P(CI)
5 Feet (meters)	4	5	1	0.0001
50 Feet (meters)	4	5	1	0.0001
500 Feet (meters)	2	3	1	0.0001

4.11 Hypothesis 9

It was hypothesized there would be a correlation between ROM measurements of the knee and ankle and changes in FMS score after the SPML surgical procedure. A significant but weak negative correlation was found between post-operative knee extension in terminal swing and post-operative FMS scores at 5 m (r= -0.33), 50 m (r= -0.33), and 500 m (r= -0.42). There was also a small but significant negative correlation between post-operative dorsiflexion in stance and FMS score at 50 m (r= -0.32). Hypothesis 9 was confirmed.

Table 9. Spearman correlation coefficients between post-operative knee and ankle parameters and each section of the FMS.

Knee and Ankle Parameters	FMS-5	FMS-50	FMS-500
Knee flexion in SW	-0.13	-0.09	-0.12
Knee ex terminal SW	-0.33*	-0.33*	-0.42*
Knee ex ST	0.11	0.11	0.16
Ankle pf TO	-0.15	-0.19	-0.17
Ankle df SW	-0.04	-0.03	0.03
Ankle df ST	-0.19	-0.31*	-0.22

* $p<0.05$ SW indicates swing; ST, stance; TO, toe off; ex, extension; pf, plantarflexion; df dorsiflexion

4.12 Surgical Complications

In this outpatient procedure, there were no surgical complications; including wound infections. Post operative pain was easily controlled with analgesics. A complication of stiff knee gait with hyperextension in stance was noted in one subject. However, this gait abnormality was controlled with the use of bilateral ankle foot orthosis (AFO).

4.13 Additional Findings

The results of the changes in ROM using the mixed models after SPML surgery did not change after adjusting for age at surgery, payor source, follow up time, ethnicity, or gender. This suggests that age, funding status, time of follow up, gender and ethnicity did not impact the surgical outcomes for the ROM measures on the knee and ankle in this sample.

4.14 Summary

The purpose of this study was to examine the outcomes of a minimally invasive surgical procedure, Selective Percutaneous Myofascial Lengthening (SPML) in 31 children with spastic CP ranging in age from 4-18 years. The specific focus was on the changes in dynamic range of motion of the knee and ankle joints during gait, gait speed, and the overall change in functional mobility. Statistical analysis revealed that the SPML surgical procedure resulted in statistically significant changes in ROM of the knee and ankle during swing and stance phase of gait, except for plantarflexion at toe off (pre-swing). Significant differences were also found in FMS scores at the distances of 5 m, 50 m, and 500 m., but gait speed did not change after the SPML procedure. There was a weak negative correlation between the post-operative ROM and post-operative FMS scores for knee extension in terminal swing at all three distances and ankle dorsiflexion in stance at 50 m.

Chapter 5: Discussion

There are many options available to manage the secondary impairments of lower extremity muscle tightness in children with spastic cerebral palsy. However, they are not without risks, time commitments, and limitations in long term effectiveness (Ade-Hall & Moore, 2000; Albright, 2006; Autti-Ramo, 2006; Friedman et al., 2000; Karol, 2004; Miller, 2005). Interventions for children with spastic cerebral palsy should be effective, safe, and minimally invasive.

SPML was specifically designed to be a minimally invasive procedure to lengthen tight muscles (Nuzzo, 2008). This study showed SPML was associated with improvement at the impairment level by changing ROM of knee flexion and extension and ankle dorsiflexion during gait during a relatively short follow up time period of 8 months (4-13 months). Activity level improvements included the changes in mobility as evidenced by changes in FMS scores at all distances (5, 50, and 500 meters). Without a true control group, (each child served as their own control) we cannot determine if the gains were the results of the intervention or due to natural history. However, it has been postulated that 90% of the gross motor function in children with CP is established by 5 years of age (Rosenbaum et al., 2002). The majority of the children (84%) in this study were over the age of 5, so it is probable that the changes seen following the SPML procedure were due to the intervention.

5.1 Discussion of Hypotheses

The hypotheses of this study focused on the changes in ROM measurements of the knee and ankle during gait, gait speed, and functional mobility. Hypothesis 1 examined the difference in pre-operative and post-operative knee flexion ROM measurements during the swing phase of gait. Hypothesis 1 was confirmed. The mean knee flexion in swing post-operatively was 57.6° which is approximating the normal value of 60° required for gait (Perry, 2001). These results are similar to other studies assessing knee kinematic changes after traditional hamstring tendon lengthening procedures (Carney et al., 2006; van der Linden et al., 2003). However, the results from those studies are based on 3 dimensional gait analyses and this study utilized 2 dimensional analysis.

A possible complication of traditional hamstring lengthening procedures is a loss of knee flexion in the swing phase of gait. Some authors report surgical lengthening of the hamstring muscles improves knee position in stance, but will result in less flexion in swing producing a stiff knee gait pattern (Adolfsen et al., 2007; Gage, 1990; Miller, 2005). In this study, a 7.1° loss of knee flexion in swing of was found, although this is not necessarily a negative finding. In crouch gait, more knee flexion is needed in swing to allow for sufficient foot clearance (Miller, 2005; Perry, 1992). It can be argued that the decrease in knee flexion in swing after the SPML surgery is due to the improvement in knee extension during the stance phase of gait. Consequently, there is no need for increased flexion during swing in order to adequately clear the foot.

Surgical overcorrection of the hamstring muscles (e.g. too much lengthening) may also result in a stiff knee gait (Gage, 1990; Miller, 2005). Some authors have reported an increase in knee extension during stance, but an overall decrease in knee ROM if a rectus femoris transfer is not also performed (Gage, 1990). The total dynamic ROM of the knee in this study increased significantly by 6.4°, from 42.5° (pre-operatively) to 48.9° (postoperatively). This increase is similar to other studies reporting surgical lengthening of the hamstrings with and without distal rectus femoris transfer (Carney et al., 2006; Gordon et al., 2008; Niiler et al., 2005; van der Linden et al., 2003). In contrast, other studies reviewing hamstring lengthening along with rectus femoris transfers found a greater total ROM for knee excursion of approximately 15° (Ma et al., 2006; Rethelefsen et al., 1999).

Niiler et al. (2007) evaluated 68 children who underwent rectus transfer alone or combined with additional procedures. They were grouped according to the concurrent surgeries that were performed: 1) rectus transfer only, 2) rectus transfer and hamstring lengthening, 3) rectus transfer and gastrocnemius lengthening, and 4) rectus transfer, hamstring and gastrocnemius lengthening. The overall change in knee ROM across all groups was 7.5° which is not clinically different than our finding of 6.4°, demonstrating that SPML was able to increase total dynamic ROM of the knee without a rectus femoris tendon transfer.

The second hypothesis was confirmed with a significant change (13.1°) in knee extension ROM at terminal swing. Knee extension of 0-5° (of flexion) is necessary in the terminal swing phase of gait in order for the knee to be fully prepared for the stance phase (Perry, 1992). The increase of knee extension at terminal swing of 13.1° is a significant finding. The post-operative mean for the knee flexion improved to 25.4° (±10), but this finding is still greater than the normal value of 0-5° necessary for the loading response (Perry, 1992; 2001). Several studies have demonstrated similar findings for knee extension at terminal swing (Adolfsen, 2007; Gordon et al., 2008; Chang et al., 2002). Gordon et al. (2008) looked at short term (<18 months) and long term (>18 months) outcomes of percutaneous tenotomies to the medial hamstring muscle. The short term follow-up group showed a post-operative mean for knee extension at terminal swing of 19.3° (of flexion) and a change in mean knee extension at terminal swing of 7.1°. The subjects in their study also had concomitant surgeries including open lengthening to other muscles, distal rectus femoris transfers, as well as osteotomies of the femur and tibia. A possible explanation for the difference is that the subjects in this study pre-operatively demonstrated less knee extension at terminal swing (see Figure 6).

Hypothesis 3 was confirmed with a significant change in knee extension in the stance phase of gait. According to Perry (1992) the knee should be in approximately 5° of flexion in the stance phase of gait. In the current study, knee extension in stance improved from 23.2° of flexion to 8.7° of flexion with an overall change score of 13.0°. This change implies improvement in stance stability by reducing knee flexion in stance and ultimately decreasing a crouch gait pattern. The findings of this study are comparable to previous studies (Carney et al., 2006; Niiler et al., 2007; van der Linden et al., 2003; Yngve et al., 2002). In a study of surgical lengthening of the hamstrings, Van der Linden et al. (2003) found a statistically significant improvement in maximum knee extension in stance but the final ROM measure of 20° of knee flexion during stance was much higher than this study's finding of 8.7° of knee flexion in stance. A combined hamstring lengthening and semitendinosus transfer resulted in a change of mean knee extension in stance of 18° of flexion and with a final mean of 16° of flexion in the stance phase of gait (Ma et al., 2006), which is more flexion of the knee at stance than what this study found. Gordon et al. (2008) also showed less of an increase in knee extension measures in stance of 6.2°. Final post operative means of 5.9° and 6.4°of flexion in the stance phase of gait were found for short term and long term follow-up groups respectively. However, the mean pre-operative measures for both the long term (12.1°) and short term follow-up (9.1°) groups were less than this study's pre-operative mean of knee extension in stance (23.2°). The findings from the present study indicate that the SPML surgical procedure was associated with improvement of knee extension in the stance phase of gait.

In examination of the ankle, there was considerable variability of ankle ROM of the 31 subjects included in this study. Some of the subjects walked with the ankle in an equinus position, while others exhibited an increase in dorsiflexion throughout the gait cycle. Consequently, calculations resulted in large standard deviations which are not unlike standard deviations found in other studies (Fabry et al., 1999; Lyon et al., 2005).

Hypothesis 4 was unconfirmed and proposed that there would be a change in ROM of ankle plantar flexion in toe off (pre-swing) after SPML surgery. The mean plantar flexion angle at toe off preoperatively was 26.8° and postoperatively 18.7°. These means are different than a previous study that reported a pre-operative mean for ankle plantar flexion of 14.0° and post-operative mean of 6.0° at toe off after recession of the aponeurosis (Granata et al., 2000). However, the post operative-mean of 18.7° in this study was near the normal measure required for gait of approximately 15° (Perry, 1992; 2001).

The finding of an increase in dorsiflexion ROM can have positive consequences for gait. Increase in dorsiflexion can allow for better foot clearance during swing (Perry, 1992). This study found a significant difference in ROM of maximum ankle dorsiflexion in swing phase of the gait cycle as proposed and confirmed by hypothesis 5. The finding of a mean post-operative dorsiflexion measure during swing of 0.9° (±8.6°) is similar to finding of other authors (Adolfsen et al., 2007; Saraph et al., 2005). In contrast, Lyon et al. (2005) reviewed 14 patients who underwent tendo achilles lengthening along with bony osteotomies, tendon lengthening and transfer which resulted in a post-operative mean of 15.8° (±10.7°) during swing. This study's finding of 0.9° of dorsiflexion during swing approximates the normal range of 0-5° required for adequate foot clearance in the swing phase of gait (Perry, 2001). The SPML surgical procedure allowed the ankle to assume a dorsiflexed posture in the swing phase, providing improved foot clearance.

Surgical overcorrection can be a concern for the ankle. A consequence of traditional heel cord lengthening procedures may result in a calcaneal gait pattern (Lyon et al., 2005; Segal et al., 1989). Calcaneal gait has been defined as a gait with more than 14° of dorsiflexion in stance (Segal et al., 1989). Lyon et al. (2005) also found in their study population that tendo achilles lengthening resulted in mild calcaneal pattern during midstance. Hypothesis 6 was confirmed and proposed that there would be a change in dorsiflexion ROM in the stance phase of gait after the SPML procedure. In this study, the means of dorsiflexion in stance after the SPML procedure was 4.3° (±7.6°). This finding is supported by other studies (Adolfsen et al., 2007; Fabry et al., 1999; Khot et al., 2008; Saraph et al., 2005). In contrast, Lyon et al. (2005) found a much higher value for the post-operative mean dorsiflexion in stance of 24.1° (±12.4) which resulted in a mild calcaneal gait. The post-operative mean of 4.3° of dorsiflexion found in this study approximated the normal range of 5° needed for gait (Perry, 2001).

The changes at the knee and ankle joints were positive. All post-operative mean ROM measures approximated normal values required for gait except for knee extension at terminal swing. The results of this study illustrate that the minimally invasive SPML procedure is effective in improving ROM of the knee and ankle during gait.

Hypothesis 7 was not confirmed, there was not a statistically significant difference in gait speed following the SPML procedure. The lack of change in gait speed in this study is supported by other research with most studies finding no change in gait speed after surgical lengthening of the hamstring and gastrocnemius muscles (Adolfsen et al., 2007; Lyon et al., 2005; Rethlefsen et al., 1999; van der Linden et al., 2003). In contrast, some authors have found short term and long term increases in gait speed after multilevel orthopedic procedures (Gannotti et al., 2007; Gordon et al., 2008; Saraph et al., 2005).

There are many factors that could explain the lack of change in gait speed. In the present study, gait speed was not standardized for body height. In addition, there was variability in the ages of the children ranging from 4 to 18 years of age. There were also large standard deviations in pre-operative and post-operative gait speed of 50.1 and 49.8 respectively. The subjects were asked to walk at self selected speed, some of the younger children running was the mode of choice. A few of the subjects actually stopped and looked at the camera during the walk, others refused partway through the walk then continued and still others refused requiring parents to intervene by assisting the child in completion of the walk. Methodologically, the distance that the children walked was 210 cm, many studies calculate gait speed during a distance of at least 10 meters (Rethlefsen et al., 1999;Rodda et al., 2006). Although, there was not a significant difference in pre-operative versus post-operative gait speed measures, the ranges of gait speed changed from 10-183 cm/sec to 20-208 cm/ sec.

Some have suggested that post-operative gait speed is related to pre-operative gait speed (Kay et al., 2001), meaning that if a child walks slowly at the pre-operative assessment, chances are they will also walk slower at the post-operative assessment. Clearly in this study population, there were subjects that demonstrated a slow pre-operative gait speed (10 cm/sec).

Hypothesis 8 focused on changes in functional mobility and a key finding in this study was the positive changes in FMS scores following the SPML procedure. There is a paucity of literature regarding orthopedic muscle/tendon lengthening surgeries that utilize an outcome measure related to functional mobility (Adolphsen et al., 2007; Fabry et al., 1999; Gorden et al., 2008; Saraph et al., 2005; van der Linden et al., 2003). Unlike the results of other studies, (Harvey et al., 2007; Ma et al., 2006) which used the FMS as an outcome measure, this study’s findings showed a significant increase in the median FMS scores at all distances of 5 m, 50 m, and 500 m. Harvey et al. (2007) described deterioration in FMS scores lasting up to 6 months after single event multilevel orthopedic surgeries at 5 m, 50 m, and 500 m. and the subjects in their study did not return to baseline levels or above until the 12 month follow up. Harvey et al., (2007) also reported improvements in FMS at the 2 year follow-up visit. It is important to note no subject in this study experienced deterioration in the FMS scores post-operatively. It is apparent that the minimally invasive surgical technique (SPML) for children with muscle tightness secondary to spastic CP allows for minimal loss of baseline functional mobility and in some cases improved functional mobility in a short time frame.

Hypothesis 9 investigated the correlation between the 6 post-operative ROM measurements of the knee and ankle and changes in the FMS scores at 5 m, 50 m, and 500 m after the SPML surgical procedure. Although significant correlations were detected for some ROM measures and FMS, the r-values were very low. A weak negative correlation was found between knee extension in the terminal swing phase of gait and the FMS scores at 5 m, 50 m, and 500 m. This negative correlation indicates that as knee flexion decreases and the knee approaches full extension (0°), the FMS score improves. There is a paucity of evidence correlating dynamic ROM measures with functional mobility scales. There is some evidence regarding the low correlation of static ROM measures and dynamic ROM measures (Desloovere et al., 2006; McMulkin et al., 2000) These studies compared multiple clinical measures including static ROM measures of the knee and ankle to dynamic measures from gait analysis. They found a low correlation between static ROM measures and dynamic ROM measures and gait speed from gait analysis, however, they did not use a functional gait measure.

The low correlations found in this study between dynamic ROM measures and a functional mobility measures suggest that multiple muscle groups contribute to functional mobility. Improving ROM of a single muscle contributing to knee and/or ankle motion is just one piece to the complex puzzle of dynamic mobility.

5.2 THERAPEUTIC IMPLICATIONS

This was the first study to examine the effectiveness of the SPML surgical procedure. The equipment used to gather the dynamic ROM information during gait is readily available, portable, and fairly inexpensive consisting of a video camera, tripod, computer and Biogait software. Videotaping subject's gait and analysis of ROM and gait speed was not burdensome.

Dynamic ROM measures were determined during a functional activity as opposed to a static position, which is how ROM is typically done in a clinical examination. Static ROM measures are not highly correlated with dynamic measures obtained from gait analysis (Desloovere, 2006; McMulkin et al., 2000).

This study utilized an outcome measure related to functional mobility. The literature is rich with studies that assess gait speed and change in ROM after orthopedic procedures (Adolfsen et al., 2007; Khot et al., 2008; Lyon et al., 2005; Rethlefsen et al., 1999; Saraph et al., 2005; van der Linden et al., 2003). Conversely, there is a paucity of literature addressing surgical intervention including a dependent variable such as functional mobility (Harvey et al., 2007). In the Harvey et al. (2007) study, the investigators that performed the reliability and validity studies for the FMS reported that it was clinically useful when used in conjunction with video assessment, especially when 3D analysis was not available (Harvey et al., 2007). The present study utilized the video component along with the FMS. This study will contribute to the body of literature utilizing outcome measures that focus on function.

This study utilized the ICF model by including outcome measures for body structure/function and activity. The use of the ICF model in research related to disability has been recommended by the Institute of Medicine and endorsed by the APTA (Bemis-Dougherty, 2009; WHO, 2008) The ICF provides for a universally applicable classification and framework for research ultimately allowing for comparisons of research results. Intervention studies that compare outcomes on similar populations will benefit from using the ICF model, by describing how the intervention affects the total person (WHO, 2009).

5.3 LIMITATIONS OF THE STUDY

There were several limitations of this study. When doing a retrospective study, the accuracy of the medical record regarding diagnosis and information regarding functional abilities is important. In this study, inaccurate or incomplete information regarding the true functional mobility of the children could have affected the results. Selection of cases based on complete data may have inadvertently resulted in selection bias in this study. There was no randomization in this study; therefore, the findings cannot be generalized to all children with spastic CP. Lack of a true control group in this study, precludes us from determining whether the changes seen in the subjects were due to the SPML surgery. On the other hand, each of the subjects served as their own control.

Due to clothing covering the skin, it was sometimes difficult on video to visualize the bony landmarks necessary to obtain the ROM measurements. The addition of external markers to help identify bony landmarks on the ankle, knee, hip and trunk as well as appropriate clothing, would improve the accuracy of measurements and allow for other joints, such as the hip to be examined.

Other studies regarding surgical interventions for children with CP, present one year or more years of follow-up data (Ma et al., 2006; Schwartz et al, 2004). In this study, we were limited to the video data that had been recorded as of September 2008 so there were only 9 (29%) subjects with 12 month follow-up data. Lastly, this case series was uncontrolled and therefore, information regarding other therapeutic interventions the child was receiving was not consistently available. Physical therapy or other related therapeutic interventions could have potentially affected the outcomes.

Despite these limitations, this study has provided important information regarding the efficacy of a minimally invasive muscle lengthening surgical procedure (SPML) in children who demonstrated muscle shortening that was limiting ROM of the knee and ankle and interfering with their functional mobility.

5.4 CONCLUSION

The purpose of this study was to examine the outcomes of a minimally invasive surgical procedure, Selective Percutaneous Myofascial Lengthening (SPML) surgery, designed to lengthen tight muscles of the lower extremity in children with spastic CP. The specific focus was on the changes in functional range of motion of the knee and ankle joints during gait, gait speed, and the overall change in functional mobility. The data demonstrated positive results from the SPML procedure. These changes included improved dynamic length of most muscles in the lower extremities as reflected by changes in the knee and ankle ROM during gait. In addition, a statistically and clinically significant increase in functional mobility at 5 m, 50 m, and 500 m distances of the FMS was noted. However, SPML did not result in an increase in gait speed. This study adds to the evidence regarding the treatment options available to children with cerebral palsy, focusing on dynamic ROM changes during gait and improvements in functional mobility.

5.5 FUTURES STUDIES

The information obtained from this preliminary case series study is the impetus for more rigorously designed prospective studies. Continuing to follow these children for several years will help to determine the long-term effectiveness of the SPML surgical technique. Future studies should examine the effectiveness of the SPML procedure in children who are described as toe walkers versus children that exhibit a crouch gait pattern. Other studies should examine how the combination of physical therapy and SPML affects a child's outcome compared to SPML alone. Future studies should determine the efficacy of SPML and physical therapy compared to other common interventions for children with CP including but not limited to casting, Botulinum Toxin injections, and tendon release/transfer surgeries. To fully embrace the ICF model, considerations for other contextual factors need to be addressed including parental stress, quality of life for child and family, and further assessment of participation.

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Vita

Dana Wild was born on December 10, 1962 in Texas City, Texas, to Eddie and Erin Sikes. She graduated from Texas City High School in 1981 and entered the University of Texas at Austin. She completed two years of prerequisite study and was accepted to the Physical Therapy program at the University of Texas Medical Branch. She graduated in 1986 with a Bachelor of Science in Physical Therapy. She began her career as a physical therapist working in the acute care setting at the University of Texas Medical Branch (UTMB). In 1987, she married her high school sweetheart, Stephen Wild. They had two precious daughters, Kendall and Lindsay. She continued to work as a physical therapist in many settings including home care, outpatient neurological rehabilitation, and pediatrics. In 2000, she was offered the opportunity to become an Assistant in Instruction in the Physical Therapy program at UTMB's School of Health Professions. She became a board certified Pediatric Clinical Specialist recognized by the American Physical Therapy Association in 2005 and certified in the NDT/Bobath technique for working with adults with hemiplegia and children with cerebral palsy. Dana enrolled in the Population Health Sciences/Rehabilitation Sciences curriculum graduate program at UTMB in 2006. She has concurrently held positions as Assistant in Instruction at UTMB, staff physical therapist at ECI Launch and physical therapist at Hallmark Rehabilitation. While at UTMB, Dana was awarded the Educational Excellence Award for the School of Health Professions, Jason E. Perlman Research Award, and a membership in Who's Who among American Universities and Colleges. She continues to teach, work in clinical practice, and participate in research pertaining to children with cerebral palsy.

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Publications

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Summary of Dissertation

Cerebral palsy (CP) is a neurodevelopmental condition defined as a disorder of posture and movement that is caused by a nonprogressive abnormality of an immature brain which can result in spasticity (Paneth, 2006; Pelligrino, 2002). Children with spastic CP usually present with muscle stiffness which eventually leads to decreased range of motion (ROM) in the knee and ankle joints interfering with gait and functional mobility (Graham, 2003). The purpose of this study was to assess changes in dynamic ROM of the knee and ankle and functional mobility

following Selective Percutaneous Myofascial Lengthening Surgery (SPML) in a group of children with spastic CP. SPML is a minimally invasive surgical procedure designed to lengthen tight muscles of the lower extremity. Subjective and objective measures were obtained from medical records and video tapes of gait. Pre-operative and follow–up videos of gait for 31

children with CP who underwent SPML surgery from 2006 to 2008 were evaluated retrospectively. The outcome measures considered for this study included sagittal plane kinematic parameters of the knee and ankle joint, gait speed, and functional mobility. Mixed model for repeated measures for the knee and ankle joint parameters were used to estimate the change in ROM. Statistically significant differences in ROM were found for most joint measurements at $p<0.05$ in pre and post-operative comparisons, except for plantarflexion at toe-off. There was no difference in gait speed. FMS ratings improved by 1 level at 5 m, 50 m, and 500 m distances. The results of this study indicate that the Percs surgery, can positively affect dynamic ROM of the knee and ankle during gait, as well as improve functional mobility at 5 m, 50 m, and 500 m. This study provides information regarding a minimally invasive surgical option for children with spastic CP.

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