UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

EFFECT OF A SUPINATION SPLINT ON UPPER LIMB FUNCTION OF CEREBRAL PALSY CHILDREN AFTER BOTULINUM TOXIN A

Madalene Delgado

A dissertation submitted to the Faculty of Health Sciences, University of Pretoria, in fulfillment of the requirements for the degree
of
Masters of Occupational Therapy

Pretoria, 2006

DECLARATION

I, Madalene Delgado declare that this dissertation is my own work. It is being submitted for the degree of Masters of Occupational Therapy in the University of Pretoria. It has not been submitted before for any degree or examination at this or any other University.

. . . . . .

. . . . . day of . . . . . , 20. . . . . .

For my family for their faith, support,
encouragement and
love during these
long months.

SYNOPSIS

The objective of this study was to investigate the effect a supination splint would have on the upper limb function of cerebral palsy children for six months after they were injected with botulinum toxin A.

Ten children aged 5.1 to 7.7 years who were attending weekly therapy were enrolled in this prospective quasi experimental design where each child acted as his own control. A pre-test was done before the children were injected with Botox®. This was followed by a post test and the experimental treatment which consisted of a soft supination splint and stretch massage. Follow-up assessments were done on a monthly basis over a six month period. These included the Modified Ashworth scores; goniometry measurements of the elbow, forearm, wrist and thumb; the Quality of Upper Extremity Skills Test (QUEST) and a subjective hand assessment that consisted of a series of preset tasks based on modified play activities. It required the subjects to perform specific upper limb movements and their performance was measured by an independent panel through videotaped records. A graded score of 0 – 5 was assigned to each preset task.

Eight subjects completed the study. These eight subjects wore the supination splint for an average of 10 hours a day.

The data was analysed and changes were observed. The reduction in spasticity was particularly evident in the forearm pronators, wrist flexors and the thumb adductors from pre-test to post-test in the sixth month. Improvements in the active range of movement in forearm supination and wrist extension, during the six month post-test assessment also differed significantly when compared to the pre-test. No significant change was noticed in the passive range of movement. The total score on the QUEST demonstrated a statistically significant improvement after the first month the children had been wearing their supination

splints. This significance was maintained for the remainder of the period that the children wore their supination splints. There was an improvement in the hand function assessment. A statistical significance was only seen from the second month onwards of the total scores of the hand assessment.

The findings support the premise that the supination splint is effective in improving upper limb function of children with cerebral palsy after they have received Botox® injections.

ACKNOWLEDGEMENTS

The researcher wishes to express her gratitude to the following people for their contributions to the completion of this dissertation:

- Margo Graham the head of the Occupational Therapy Department, University of Pretoria for her expert guidance and supervision.
- Kerry Hofmeyer and Genop Healthcare for donating the Botox®.
- Professor Lawrence Chait at Parklane Clinic for assessing and injecting the children.
- Megan Greig and Caroline Partridge at Parklane Clinic for organising and assisting with the injecting process.
- The children and their families who so willingly participated in this study.
- The occupational and physiotherapists at Forest Town School, Francis Vorweg School and Hope School for their invaluable assistance.
- Elaine Berner and Ilda Delgado for filming all the assessments.
- Wilma Smit, Nicola Selkon, Gillian Shead and Vanessa Rademeyer for performing the independent assessments of the videotapes.
- My colleagues in the occupational and physiotherapy departments at Forest Town School for their support and encouragement.
- Dr Piet Bekker from Medical Research Council of South Africa for his wealth of information and completing the statistical analysis for this study.
- Betsy Coville and Teresa Delgado for editing the dissertation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

DEFINITIONS OF KEY CONCEPTS

Spasticity

This is the persistent increase in the involuntary reflex activity of a muscle in response to stretch. Standardised scales have been developed[1].

Joint Range of Motion

This is a measurable definable entity of a joint as it moves in a certain direction. Motion is limited due to the joints structure and the integrity of surrounding tissues. Norms for joint motion have been recorded[2].

Hand Function

For the purpose of this study hand function refers to the ability of the arms and hands to effectively engage in an activity. It includes

- grasps - attainment of an object with the hand,
- in-hand manipulation - adjustment of an object within the hand after grasp and
- bilateral hand use - use of two hands together to accomplish an activity[3].

The child performs a series of activities, which are measured and rated according to a specific scale.

Upper Limb Function

For the purpose of this study upper limb function refers to the combinationof the above mentioned definitions, namely spasticity, joint range of movement, grasping an object, in-hand manipulation, bilateral hand use and the quality of upper limb movement.

Supination Splint

An appliance made of a soft, stretchable non-slip material. The splint is a long strap, which is secured around the thumb metacarpal joint, positioning it in abduction. It is then rolled around the forearm gently pulling the arm into supination. It is strapped proximal to the medial and lateral epicondyles of the humerus. The splint positions the forearm midway between neutral position and 90° supination. It is a dynamic splint as it assists the child to move the forearm into supination. It allows the child to move his forearm between 30° of pronation and 80° of supination,[4],[5].

Botulinum Toxin A

This refers to the protein toxin formed by the bacterium Clostridium Botulinum.

Botox®

Is the product manufactured by Allergan. It trades under this name.

He/His

Participants in this study were of both sexes but for easier readability, the masculine pronouns ”he” and “his” are used throughout this dissertation.

ABBREVIATIONS and ACRONYMS

CP	– Cerebral palsy
Botox®	- Botulinum Toxin A manufactured by Allergan
EMG	– Electromyography
SNAP 25	– Synaptosomal Associated Protein 25
U	– Units of Botox®
U/kg	– Units per kilogram
OT	– Occupational therapy
ROM	– Range of movement
PVC	– Poly Vinyl Chloride
MAS	– Modified Ashworth Scale
QUEST	– Quality of Upper Extremity Skills Test
LSEN	– Learners with special educational needs

CHAPTER 1 - INTRODUCTION

As an occupational therapist working with cerebral palsy children for several years, the researcher noticed that the children, even after various therapeutic interventions, continued to have difficulty using their upper limbs to perform some basic school activities. The researcher realised that the static splints the children used helped position their upper limbs but did not aid the children's ability to perform these activities. This motivated the researcher to look at a splint that allowed movement of the upper limb and to investigate the effect it had on upper limb function.

This chapter reveals the rationale and value of this study.

1.1 Rationale

Cerebral palsy is a clinical syndrome which is non-progressive. It occurs as a result of damage to the immature brain. This damage results in changes to the muscle tone, which in turn causes abnormal movement patterns[6,7,8].

A child with cerebral palsy has difficulty maintaining normal postures because of abnormal muscle tone. This lack of muscle co-activation brings about abnormal movement patterns in the child's day to day function e.g. a child who is unable to lift his* head will arch his back to be able to look up. These compensatory movement patterns occur in several muscle groups to maintain upright postures and to assist the child to move against gravity. However these compensatory movement patterns have an effect on the child's developing motor skills. A child who moves his arm in a flexor pattern will have difficulty reaching out to pick up a pen and manipulating it in his hand so that he can write his name[4,6].

* Participants in this study were of both sexes but for easier readability, the masculine pronouns are used throughout this dissertation.

When there is an increase in muscle tone, namely spasticity, there will be interference in the child's motor function, which will result in musculoskeletal complications[7]. These complications may be attributed to the decrease in the muscles' lengthening reaction time and the reciprocal inhibition of the antagonistic muscles. This leads to muscle imbalance which if left unattended will cause contractures and other complications. The impact of these contractures and other complications on the child's ability to perform daily activities is significant.

It is believed that these complications can be avoided if the child is diagnosed early on in life with cerebral palsy. Furthermore, if he receives early intervention, secondary disabilities will be prevented and the child's potential for development will be optimised[7].

For early intervention a child with cerebral palsy needs to be referred to occupational and physiotherapy. The therapist can help the child to adjust his movement patterns by facilitating the child to move in a more efficient method[9]. Law states that "Therapists use movement and handling techniques to alter tone and facilitate these normal movement patterns and postural reactions, while inhibiting abnormal tone and reflex activity."

Spasticity in the upper limb muscle groups affects the stability of parts of the arms and hands during activities and the types of movement possible. Spasticity can affect range of movement, decrease the speed of movement and reduce the stability of joints. To assist a child to obtain upper limb function, the therapist needs to facilitate the combined movements of the hand, wrist and forearm[10].

As the child's voluntary control increases, the therapist decreases the amount of handling while challenging the child to obtain more functional postures. Attempting to improve the performance of a neurologically impaired hand is a

challenging task. The hand uses complicated blends of movement in order to perform simple tasks.

These simple tasks are made possible by the hand, wrist and forearm's ability to work together in an organised manner. However in a child with CP, one of the common problems is an inability to perform specific movements. Instead, their movements are performed in a mass pattern, in which they use total patterns of flexion or extension throughout their upper limbs. They are unable, for example, to combine wrist extension with finger flexion or forearm supination with wrist extension.

Therapists attempt to facilitate these isolated movements, but often the child's tonal patterns are so strong that he resumes his patterns of total flexion or extension once the therapy session has ended. Thus therapists often need other modalities to maintain the correct patterns of movement to provide the child with the opportunity to function in his daily life and not only when he is attending therapy. Medication and splinting are two treatment modalities that are commonly used to assist the children.

In the past, medication has been used to help reduce spasticity. Antispasticity medication can improve motor patterns and range of movement. Muscle relaxants can reduce spasticity. These medications work on the neurotransmitter acetylcholine and are fast acting. However significant side effects often occur. These include drowsiness, excessive drooling, and physical dependency all of which tend to outweigh the potential benefit of the medication[11]. Neural Blocks have also been used to disrupt the reflex arc.

In recent years injectable botulinum toxin A has been used to block the nerve-muscle junction. Botulinum toxin A is injected intramuscularly; it binds to the presynaptic membranes at the neuromuscular junction. It then blocks the release of the neurotransmitter, acetylcholine, into the synaptic cleft, preventing neurotransmition. However axonal resprouting occurs and gradually

neurotransmission is re-established, so that muscle function is restored after about three months[12]. Blocking the neuromuscular junction helps the child to overcome his spasticity. This allows the child to use the hypertonic muscle with less interference from spasticity[7].

Splinting is a modality often used by therapists because it is effective in stretching muscles which may not be sufficiently stretched by therapy alone[13]. Therapists use splints extensively to help reduce tone, improve mobility and increase functional skills. When a splint is applied over a specific joint in a tone-inhibiting pattern, namely to position the thumb in abduction, wrist in extension and forearm in supination, and is worn for several hours a day, it allows the muscles to perform active movements and thus become stronger and more functional[6].

Therapists use either static or dynamic splints to achieve these aims of therapy. Dynamic splints allow movement and therefore assist the child with a specific wrist, finger or thumb movement. Static splints have no moving components and are used to keep the hand in a constant position or to 'rest' the specific joint. When the child's hand is kept in a constant position the spastic muscles are being stretched.

Various types of both static and dynamic splints can be used with cerebral palsied children. These include resting splints, volar and dorsal full hand and wrist splints, spasticity reduction splints and thumb positioning splints. However all of these splints involve only the finger, thumb and wrist joints. They do not involve the forearm movements[4,6,14].

Forearm movement into supination is essential in positioning the hand for function. Thus, it would be of huge benefit to develop a splint that incorporates forearm movement as well as wrist and thumb movement. The researcher felt

that if a splint was designed to encourage forearm movement, perhaps children with cerebral palsy would be able to participate more fully in their daily activities.

Since 1991 the centre where the researcher works has combined both medication and splinting as a treatment modality to treat children with cerebral palsy. Wall et al[15] conducted a study on five children at this centre. The five children in their study were injected with Botox® in their thumb adductor muscle. Static rigid splints were used to splint their thumbs in abduction. This static thumb splint was initially worn for twenty-four hours a day for the first 112 days and then for another 54 days it was only worn nocturnally. All the cases showed an improvement in function and appearance[15].

Since this study was carried out, there has been ongoing treatment using both of the above mentioned modalities. However the splinting now incorporates other joints. Several splints have been used, namely splints keeping the fingers abducted and extended, or fingers and wrist extended, or fingers extended, thumb abducted and wrist extended. However no splints have been used for forearm supination.

As previously mentioned the hand, wrist and forearm work together to allow for upper limb function. The combined movements of the forearm and wrist orientate the hand in space, placing it in the correct position to grasp an object. Together the forearm and wrist move the hand to a place where it can be useful and efficient[4]. Thus a simple but dynamic splint that would allow active movement was required to assist the child with cerebral palsy to position his hand correctly for efficient use. This splint would need to allow movement, be easy to apply and comfortable to use. The child would need to comply with the wearing regime so that an improvement could be seen in his hand function.

Since forearm supination is essential for upper limb function, the researcher decided to investigate the effects a supination splint might have on upper limb function of children with cerebral palsy after they had received Botox® injections.

1.2 Value of the Study

Researching the effectiveness of a supination splint after Botulinum toxin A injections, the results can help doctors and therapists in recommending the optimal therapy and treatment for cerebral palsy. This could have an impact on future treatment approaches and management of children with cerebral palsy.

If the supination splint is effective in improving upper limb function, it would seem that a treatment modality that is non-invasive, comfortable and easy to apply on the child has been found.

In order to investigate the effectiveness of the supination splint, it was necessary to first look at available literature on studies previously conducted on cerebral palsied children and the types of splints used by them.

CHAPTER 2 - LITERATURE REVIEW

A survey of literature was required for a thorough working knowledge of:

- the upper limb,
- the impact of cerebral palsy on upper limb function,
- supination splints and how they function,
- the action of botulinum toxin A on the neuromuscular junction

The obtained information, essential to conduct this study, is discussed below.

2.1 Upper Limb

The effective use of the upper limb to engage in functional activities depends on the complex interaction of hand skills, postural mechanisms, cognition and visual perception.

2.1.1 Upper Limb Development

Halverson in Case-Smith[16] stated that the major development in upper limb function occurs during the first year of a child's life, but continues to develop until the child is six years old. The baby should be able to achieve a tripod grip by the time he/she is 14 months,

An important sequence in the development of motor control is the use of frontal plane movement patterns before the emergence of controlled rotation patterns. Namely the infant first develops controlled stability and mobility in basic flexion and extension of the shoulder, elbow, and wrist. This is followed by control of internal and external rotation of the shoulder, and pronation and supination of the forearm[3].

In the same manner there is a proximal to distal progression in the development of prehension patterns, as holding with a mass grasp occurs before finger control of the object.
Initially the baby holds the object in the palm, then on finger surfaces, and finally at the finger pads with the tripod grip. This progression reflects the baby's increased ability to supinate the forearm. Mass or less differentiated movement patterns will precede discrete and highly specialised skills since basic and simple grasp and release patterns quickly develop into efficient and elaborate manipulative and bilateral skills[17,18].

Initially the baby uses his upper limbs in patterns that are not co-ordinated. Unilateral and bilateral skills develop sequentially rather than simultaneously. Unilateral skills precede bilateral skills as bilateral skills are more complex.
Gradually the baby develops the ability to move his two arms together in the same pattern. Since skilled use of symmetrical upper limb movement is refined, the "baby begins to use the two arms discriminatively for different parts of an activity". Thus the baby uses one hand to stabilise the object while his other hand is used to manipulate it[17].

Corbetta & Mounoud in Case-Smith divide the development of upper limb skills into three categories. In the first category the most important area of development is the gradual control of upper limb movement. This is based on the baby's ability to recognise where an object is in space. The baby will mainly use visual interaction with objects and his primitive hand reflexes will influence reach and grasp.

In the next category the baby learns to adjust the opening and shaping of his hand according to the particular characteristics of the object. During this time the baby uses various actions such as bringing the hands or objects to the mouth, banging objects together, bilateral reaching, pronation and supination to move the object in space.

In the last category the baby begins to discover how to relate objects to one another. The two hands learn to work independently of one another, but at the same time they need to work together in activities that need different hand movements; an example would be as one hand holds a container the other hand picks up the blocks and places them in the container. Eye-hand co-ordination begins to develop as hand orientation and placement during reach improves and the skills of voluntary release and tripod grip mature[16].

Normal development may be inhibited or altered by an injury that occurs before, during or after birth. Any change in the body systems can have a significant impact on the sequence of early development, causing a delay in developmental milestones[19].

2.1.2 Components of Upper Limb Movement

The hand is essential to most functional activities. It assists in a large number of daily tasks which involve reaching, grasping and releasing in the manipulation of objects such as a pencil. However it can't function on its own; the hand, wrist and forearm work together functionally for the upper limb to be able to weight bear, grasp and release objects. If the upper limb is unable to function adequately, these tasks are arduous or impossible to accomplish[20]. In order for a child to use his upper limb effectively he needs to be able to control and position the hands properly in space. The hand's functional role is to shape itself around objects, and to place itself on the top or bottom of surfaces. It accomplishes this through dynamic palmar arches and combined movement of the wrist and forearm[10,20]. It depends on connections through the trunk and the arm (shoulder, elbow, forearm, and wrist) to provide stability for its movement. Hand extrinsic and intrinsic muscular control is crucial in order for fine motor co-ordination to be achieved[21].

Hand movement may be described as:

- Prehensile – this incorporates grasping, manipulating or releasing an object
    - Precision grasps usually involve a combination of delicate movements in an attempt to accomplish an activity and are described by opposition of the thumb to finger tips with the intention of holding an object.
    - Power grasps require the whole hand and are used to oppose forces on the object being held. Depending on the control or power required, the thumb is held in either flexion or adduction to other fingers
- Non-prehensile – this entails pushing, pulling or lifting the object with the fingers or whole hand[17,19].

The grasp pattern the child will use is usually influenced by the specific activity and the characteristics of the object. Generally small objects are held in a precision grasp, mainly due to the large amount of sensory feedback that is produced through the fingertips, and large objects are held with a power grasp. If the child needs to pick up a bead he would most likely use a tripod pinch. This is when the thumb is opposed to the pads of the index and the middle fingers, thus providing increased stability of prehension. If the child were to pick up a tube he would probably use a cylindrical grasp. With this type of grasp the child has to flatten his transverse arch to allow his fingers to be held against the tube, his fingers are slightly abducted and the interphalangeal and metacarpal joint flexion is graded according to the diameter of the tube[17].

Exner describes the patterns of reaching, grasping and releasing as basic movements; the upper limb moves to make contact with the object, obtains it, and intentionally lets go of it. More complex skills include in-hand manipulation which require, adjustment of the object within the hand by either rotating or

translating the object, and bilateral hand use which entails working both hands together to accomplish an activity.

2.1.3 Proximal Control needed for Upper Limb Function

The upper limb is not an independent entity. For it to perform efficiently it depends on the proximal control and dynamic stability of the trunk and shoulder girdle. If the trunk and shoulder girdle are stabilised, the upper limb is able to participate in age-appropriate activities distally[21]. Proximal stability allows the arm and hand to move freely and accurately[22].

Refined movements of the upper limb are reliant on the child's ability to effectively combine patterns of stability and mobility. "The child must develop the ability to stabilise the trunk effectively and maintain it in an upright position without relying on frequent use of one or both arms to maintain his balance"[17]. The combined patterns of stability and mobility need to develop at the scapulo-humeral, elbow, forearm, wrist and finger joints for the child to be able to perform various activities.

The improvement in scapulo-humeral and trunk control is a prime focus of neurodevelopmental therapy. This approach is often used in the treatment of cerebral palsy children. By facilitating normal movement patterns, improved postural control will improve functional skills[21].

2.1.4 Positioning Upper Limb for Function

The optimum position from which the hand is able to function, is when the forearm is midway between pronation and supination, the wrist in extension, the thumb in abduction and the digits in moderate flexion. In order for the hand to assume or maintain this functional position there needs to be a balance between the extrinsic and intrinsic muscle groups of the forearm and hand, the wrist and digital joints[23].

Muscles are arranged about joints in pairs, so that each musculotendinous unit has at least one agonist and one antagonist muscle to balance the involved joint. The child needs to have a balance between his flexor and extensor muscles to have control of the movements in his upper limb. With control of balanced flexion and extension of the wrist, the child is able to hold his wrist in neutral alignment and work the digits from a proximal and dynamically stable position. Symmetrical wrist control is achieved by the long muscle groups that originate at the distal end of the humerus, cross over the elbow joint, wrist joint and insert into the carpal bones or the phalanges[10,23].

To a large degree the wrist is the crucial joint and has a strong influence on the long extrinsic muscle performance at the digital level. Maximal digital flexion strength is facilitated by wrist extension, which lessens the effective amplitude of the antagonistic extensor tendons, while maximising the contraction force of the digital flexors. Conversely, a posture of wrist flexion will markedly weaken grasping power[10,23].

However the wrist has larger structural stability when it is in flexion. The nature of the capsule and ligamentous structures allows for this greater structural stability. For effective hand function the child also needs control of the lateral movements at his wrist. He needs ulnar and radial deviation movement. There needs to be a balance between these muscles in order to obtain mid-range control of the wrist or the skill to bring the wrist back to the middle[10].

To be able to perform any functional activities, whether it requires a strong power grasp or a delicate precision pinch, the thumb must be able to rotate into an opposing position. The wide range of movement available at the carpometacarpal joint is exceptionally important to allow the thumb to be positioned accurately. Stability at this joint is crucial for most prehensile activities. This stability is made possible by a unique ligamentous arrangement, which allows mobility in the midposition and provides stability at the extremes[23].

Should the child need to use a power grip, the forearm must remain in the neutral position between pronation and supination, and the wrist in an extended position. With an extended wrist the extrinsic digital flexors allow the child to press the object firmly against his palm, while the thumb is in abduction closing firmly around the object. The thumb, ring and little finger's contribution in this strong grasp function is of vital importance since the value of the ulnar border digits cannot be minimised. In a power grip, not only are the extrinsic muscles of the hand involved, but so too are the interosseous muscles and the muscles of the thenar eminence[23].

To use a precision grasp, such as a tripod grip, the forearm needs to be maintained in the neutral position between pronation and supination, but the wrist position is not as important; although it still needs to be in neutral or extension. The thumb is opposed to the semi flexed fingers with the intrinsic tendons providing the majority of the finger movement. A compression force, to hold the object, is mainly provided by the extrinsic muscles and is assisted by the interossei, flexor pollicis brevis and adductor pollicis. Rotation of the first metacarpal is provided by the opponens pollicis muscle. In the movement of opposing the thumb to the fingers the flexor pollicis brevis is the least active of the thenar muscles, while the opponens pollicis is the most active[23].

In order to manipulate objects in the hand the child needs to be able to stabilise the thumb in opposition and abduction. He needs to be able to use isolated finger movements, be able to curve and adjust the distal transverse arch of the palm, and be able to grasp on the finger surfaces. To be able to do this effectively the wrist needs to be stable in a neutral or extended position, and the forearm needs to be able to supinate.

A study carried out by Timm et al[24] looked at supination strength when using different grasps to hold three different types of handles, namely a screwdriver, cylinder and a doorknob. The results showed that supination strength exceeded

pronation strength with all three types of grasps. It seems that the reason for the discrepancy between pronation-supination strength depends on wrist position and grip strength. Optimal grip strength is influenced by wrist position and the optimal wrist position is the combination of 35° extension and between neutral and 7°-10° of ulnar deviation.

2.1.5 Biomechanics of Supination

Forearm rotation is essential for various daily activities. Combined movements of the forearm and the wrist adjust the hand in space, placing it in the appropriate position to obtain an object or be placed on a weight bearing surface. The forearm and wrist move the hand to a position where it can be functional and efficient[10]. Average forearm rotation is approximately 0° to 80° or 90° for both movements of supination and pronation. A functional movement arc of forearm rotation is 100°. This 100° encompasses 50° of supination and another 50° pronation movement[25].

Forearm supination depends on the complex interplay between the distal radio-ulnar joint, interosseous membrane and the proximal radio-ulnar joint. Forearm movement occurs at the radio-ulnar joints. The proximal and distal radio-ulnar joints are mechanically linked. For forearm supination to occur there needs to be movement at both joints[26].

The proximal and distal radio-ulnar joints are formed by the articulation of the radius and the ulna. They form a pivot-type joint which brings about a stable rotatory movement of the forearm. The interosseous membrane connects the radius and the ulna at their interosseous borders[26]. The rotatory movement is caused by the radius rotating around the ulna. The longitudinal axis of the forearm is formed by a straight line passing through the capitellum, head of the radius, and fovea of the distal ulna. The forearm rotation axis passes through the attachment of the interosseous membrane at the ulna in the distal fourth of the forearm[27,28]. In supination the ulna and the radius lie parallel to one another. As

the forearm rotates the radius arcs over the ulna to move into the pronation position, thus in the pronation position the radius and ulna 'cross each other'. Boehme describes this as "the supinator muscle unwinds the forearm, and the biceps brachii pulls it into supination".

At the proximal radio-ulnar joint, the head of the radius has a concave surface which articulates with the convex capitellum. The radial articular dish has a radius of curvature that is larger than that of the capitellum. This difference in radius allows translation of the head during forearm rotation. The radius rotates on a vertical axis. With supination the radial head translates posteriorly and with pronation it translates anteriorly[10,26,27]. With the rotational movement at the proximal joint, the ulna head is displaced, but the mechanics are made possible by simultaneous external rotation of the humerus. Thus if a child's humerus is constrained by a strong pull into internal rotation, control of forearm movements is difficult if not impossible[10].

At the distal radio-ulnar joint, the head of the ulna articulates with the sigmoid notch of the distal radius. It does not articulate with the carpal bones, instead the triangular fibrocartilage complex (involving the triangular fibrocartilage articulate disc, dorsal and palmar radio-ulnar ligaments, meniscus homologue, and the sheath of the extensor carpi ulnaris) provides support and stabilises the ulna within the sigmoid notch during forearm rotation[10,26]. Since the ulna head is not in contact with the carpal bones of the wrist, displacement of the ulna is possible. If a child's wrist is forced into flexion and ulnar deviation, control of forearm movements will once again be restricted[10].

A rotational and sliding movement occurs at the distal radio-ulnar joint when supination and pronation are performed. The radius rotates longitudinally 150° around a moderately stable ulna. During this forearm rotation the ulna head is not immobile as it translates dorsally and palmarly within the sigmoid notch of the radius. When the forearm moves into supination, the ulna glides in a palmarly

direction. This will cause the dorsal radio-ulnar ligament to become taut, thus stabilising the forearm in supination[29].

The interosseous membrane is a fibrous structure in the interosseous space of the forearm. Its fiber bundles originate from the radius and are connected to the ulna in an oblique manner. The interosseous membrane becomes taut in the neutral position and more lax in both supination and pronation[26]. McGinley et al[30] found that there is a large quantity of collagen across the interosseous membrane. This large collagen content and the methodical arrangement of the fiber bundles provides the interosseous membrane with a large tensile strength that enables it to transfer large forces from the radius to the ulna. The extensive interosseous membrane can become restricted since spasticity limits the movement of the forearm. This restriction affects forearm as well as thumb movements since many important thumb extensor muscles originate on this membrane[10].

Any damage or interference to any of the muscles, joints or ligaments involved in forearm rotation, will bring about a decrease or loss of this movement. While shoulder abduction may compensate for the loss of pronation, no amount of shoulder or elbow compensatory movements can bring about supination of the forearm[25].

2.2 Cerebral Palsy

Cerebral palsy is a disorder of movement and posture that is caused by a non progressive brain lesion, occurring in the immature brain in utero, during or within the first few years after birth (usually before 4 years of age)[8,31]. It presents as irregular “impairments in the coordination of muscle action and sensation”[31].

The area in the brain where the lesion occurs will affect the development and characteristics of body movement patterns in the child. A lesion in the motor

cortex or pyramidal tracts will cause cerebral palsy with spasticity. Spastic cerebral palsy is one of the most common types of cerebral palsy. When the motor cortex has been damaged, the ability to regulate reflexes and postural reactions is impaired and thus the performance of automatic movements is difficult. Children with spastic cerebral palsy have difficulty controlling their movements. This is due to the tight muscle groups that are resistant to any movement. The irregularity and stiffness of the movement and the postural disorder may be classified according to which limbs have been affected, namely hemiplegia, diplegia, or quadriplegia[4,8,31,32].

Lance, in Katz et al[33] defines spasticity as "a motor disorder characterised by a velocity-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex, as one component of the upper motor neuron syndrome."

During normal movements, the child's' brain registers sensory feedback when he performs activities requiring weight bearing and weight shift. The child develops a stable base for performing cognitive and interactive tasks without having to consciously think about maintaining a particular position. When a child has cerebral palsy, this process is reversed. As a result of spasticity, a child with cerebral palsy usually has difficulty maintaining normal postures because of a lack of muscle co-activation. In an effort to try and obtain normal postures the cerebral palsied child starts to develop abnormal compensatory movements.

The sensory feedback from compensatory movements feeds into more compensations. These compensatory movement patterns develop in certain muscle groups over the course of time. Disruptions in the child's centre of gravity and other sensory stimuli, result in abnormal motor and postural responses. This is illustrated as a child attempts to pick up a pencil: he uses a poor tripod grip as a result of poor co-activation of his thumb and wrist flexors and extensor muscle

groups, which in turn will cause compensatory reactions in his forearm, elbow and shoulder as he attempts to hold onto the pencil[4,8,31].

Movement patterns are centrally programmed and are expressed through postural reactions. The expression of postural reactions is limited only by prevailing spasticity. If tonic spasticity is present, there is a "decrease in lengthening reaction of the muscle, with reciprocal inhibition of the antagonist, causing an imbalance in the muscles which eventually leads to the development of contractures"[8]. The muscles of the upper limb which are affected by spasticity will produce an imbalance between the agonists (flexors) and the antagonists (extensors) [4,20].

2.2.1 Spasticity

Spasticity was defined earlier as the result of exaggerated stretch reflexes. It is characterised by an increased resistance as one manipulates a subjects' joint through a range of movement (tonic stretch reflex), while the subject attempts to relax[33,34].

According to Chapman & Weisendander in Langolis, there are "three hypothesised mechanisms that explain the cause of spasticity: firstly the hyperactivity of gamma motoneurons, secondly the hyperactivity of alpha motoneurons and thirdly the lack of presynapitic inhibition." However, one of the most essential neural circuits that play a part in spastic hypertonia is the segmental reflex arc. This arc is made up of muscle receptors, their central connections with the neurons of the spinal cord, and the motorneuronal output to the muscle[33].

Within a muscle there are mechanisms which detect its length and velocity, namely muscle spindles. These spindles are normally maintained at zero point by impulses from the supraspinal control centers. This zero point refers to the precise match of the spindle length to the length of the muscle fibre it is

monitoring. When damage to the brain has occurred, this zeroing mechanism is disrupted. Hence, if too many supraspinal impulses are transmitted to the muscle spindle, it is stretched tight and it reacts excessively to slight stretches. Automatically movement is deficient because the muscle contracts reflexively and obstructs the opposite movement. This is evident as the 'catch' that can be felt when moving a child's limb through its range of movement at the point where the stretch reflex is triggered[35].

When spasticity is present the muscle spindle reacts in two modes: the static response is the muscle spindle's reaction to maintained extension; and the dynamic response is its reaction to the velocity and force of the stretched movement. The mechanisms for both these responses are found within each muscle spindle[35,36].

The "tension of a spastic muscle is dependent on the behaviour of the above mentioned stretch receptors; the level of motor neuron activity in the muscle; and the inherent visco-elastic, plastic and contractile properties of the muscle"[36]. The tension in the muscle will eventually alter the mechanical properties of the muscle and associated tissues, causing the muscle to shorten. But in turn, the shortened muscles may also assist in generating and maintaining the spasticity[21,37].

2.2.2 Impact Cerebral Palsy has on Child's Life

The lesion in the immature motor cortex can have a significant impact on the course of early development in the life of a child with cerebral palsy. A delay or absence of developmental milestones may occur. As the child is unable to move in the normal patterns he learns to use compensatory movements to overcome the abnormal development. But these compensatory movements might not always be appropriate and may impede further development. This will in turn result in limitations and deformities to the growing child's upper limb and will affect how he learns to function at home, at school and within his community[19].

The common limitations and impairments of the upper limb in cerebral palsy include weakness, sensory impairments, spasticity, reduced muscle length as a result of spasticity, or disuse. Numerous combinations of these impairments contribute to difficulties the child will have in reaching, pointing, grasping, releasing, and manipulating objects.

Posture can also influence the child's ability to perform upper limb tasks. This is due to a lack of a stable base of support from which the child would be able to perform functional activities such as writing, cutting, dressing or throwing[22, 38].

A child who is unable to stabilise his scapula during upper limb movement may exhibit:

- delays in reaching and grasping;
- fisted hands;
- an inability to open his hand unless his whole arm moves, or he/she flexes his wrist;
- muscle stiffening in anticipation of a movement;
- the inability to move in and out of different upper limb positions;
- difficulty in coordinating bilateral activities[3].

The movement pattern most commonly seen in the upper limbs of children with cerebral palsy involves adduction and internal rotation of the shoulder, elbow flexion, pronation of the forearm, wrist and finger flexion coupled with ulnar deviation and the thumb adducted and flexed into the palm of the hand[20].
Thus children have difficulty or are unable to supinate at the forearm. They often substitute supination with rotation of their humerus and at times chronic fixation of the shoulders in a retracted pattern. Therefore they are unable to move their upper limb freely which is a requirement for maximum function[39].
These movement patterns are completely opposite to the optimal functional position described earlier in this section of the forearm being midway between

pronation and supination, the wrist in extension, the thumb in abduction and the digits in moderate flexion. Instead the child maintains the arm in a pattern of forearm pronation, elbow and wrist flexion as a result of spasticity. If the spasticity is high, it begins to interfere with motor function, and may cause musculoskeletal complications[7].

2.2.3 Complications

The increase in spasticity in the upper limb muscles of a child with cerebral palsy causes an imbalance between the agonists (flexor) and the antagonists (extensor) muscles. This imbalance is most obvious at the forearm between the supinators and dominant pronators, and at the wrist between the extensors and dominant flexors. The dominant agonist muscles are usually tonically shortened and contracted and the antagonist muscles are generally lengthened and weakened. Spasticity affects these muscles so that the joints of the upper limb are inadequately positioned[20].

Spasticity causes the rate of the affected muscle growth to be reduced Gaebler states that “the effect of spasticity on growth is disproportionate in muscles versus long bone growth.” Consequently long bones grow at a faster rate than muscles as the muscle sarcomeres are not arranged in the same longitudinal manner as they are in the normally innervated muscles. Thus muscle shortening occurs as a result of the dynamic stretch reflex and reduced sarcomere formation[20,38].

As a result of spasticity and ongoing abnormal posturing, joints are unable to move through a full range of movement. Furthermore, if daily passive range of movement or posturing does not adequately maintain a full range of movement, the muscles begin to adapt to the shortened position resulting in contractures.
This adaptation is a combination of shortening of muscle fibres and remodelling of muscle connective tissue. This is accompanied by changes in the skin and

periarticular tissues[21,40,41]. These adaptations form a sequence of events which progress from inadequate muscle excursion, increased muscle stiffness and fixed musculotendinous contractures, to bony torsional abnormalities and joint instability over time[42, 43].

The time it takes for this progression to occur depends on the severity of the spasticity. However even in the same upper limb, different muscles appear to follow a different biological time before they form a fixed contracture. The muscle that usually develops a fixed contracture first is pronator teres; consequently, supination of the forearm will be restricted. A pronator teres contracture is usually followed by dynamic shortening of the long finger and wrist flexor muscles[13,38,43]. Contractures in the upper limb may become painful, limit appropriate personal hygiene, and change the child's position and stability[20]. Therefore to prevent the upper limb muscles from developing into fixed contractures, it is imperative that some form of intervention is started at a young age[43].

Spasticity is not the only cause of impaired voluntary movement. The antagonistic muscles remain in an elongated position beyond the neutral physiological rest position, but not beyond the normal range. As a result of remaining in this elongated position they begin to lengthen and weaken over time. This weakness also impairs voluntary movement[21].
Active range of movement may also be diminished due to a learned non-use of the affected hand[38,44].

2.2.4 Preventing Contractures

Management of spasticity, in order to prevent the development of contractures, involves one or a combination of procedures or interventions. These interventions include:

- therapeutic - stretching, positioning, splinting, strengthening, and teaching movement patterns;
- surgical - tendon muscle releases and transfers;

- pharmacological - baclofen, diazepam, botulinum toxin A[11,45].

2.2.4.1 Therapeutic Intervention

Therapy usually consists of movement and handling techniques to alter spasticity and facilitate the normal upper limb movement patterns and postural reactions, while inhibiting reflex activity[46]. It aims at improving function by increasing range of movement, strengthening, and improving motor planning and co-ordination of the upper limb[47].

Splinting is used extensively by occupational therapists to stretch tight soft tissues to reduce joint deformity and increase range of motion. This is discussed in more detail in section 2.3. Bobath in Casey and Kratz[48] mentions one way that therapy may reduce spasticity in the upper limb is by using "key points of control. This is done by positioning the child's thumb in abduction and the forearm in supination."

2.2.4.2 Surgical Intervention

Surgical treatment of spasticity occurs at four different levels: the brain, the spinal cord, peripheral nerves and the musculoskeletal. The most common of these is at the musculoskeletal level, namely at the muscles or tendons. Surgery is based on the theory of decreasing spasticity in the overactive muscles by performing release or lengthening procedures or by supplementing weak muscles with a tendon transfer. Muscle releases and tendon transfers can only be successful if the joints and ligaments allow passive movement[46,49,50].

Surgery to the upper limb of children with cerebral palsy may be done to correct shoulder, elbow, forearm, wrist and finger deformities. The pronator teres muscle in the forearm is usually the first muscle to develop a deformity[38]. There are several options for correcting a forearm pronation deformity. One of four releases could be done, namely pronator quadratus release, flexor aponeurotic release, flexor-pronator slide or a pronator teres tenotomy; or one of two transfers could be performed –flexor carpi ulnaris transferred to extensor carpi radialis brevis or

pronator teres rerouting[46,50,51]. However surgery for pronation deformity is seldom done in isolation; it is usually done in conjunction with correction of either elbow, wrist or finger deformity[50].

2.2.4.3 Pharmacological Intervention

Medication may be dispensed orally, through a feeding tube (enterally), directly to the cerebrospinal fluid (intrathecally) or by injection into the muscles.

The four most commonly used mainstream antispasticity drugs are baclofen, diazepam, dantrolene and tizanidine. These drugs are usually administered by a feeding tube or a catheter. Their mechanism of action varies but the overall aim is to either suppress muscle excitation or to enhance neural inhibition. All these drugs produce adverse systemic side effects related to central depression, including sedation, drowsiness and fatigue. Other side effects that need to be considered include deterioration of seizure control and liver toxicity[,,52]
Botulinum toxin A is injected intramuscularly into specific muscles. The use of this drug is discussed in section 2.4 in more detail.

2.3 Splinting

Splinting is a non-invasive and inexpensive procedure. Furthermore it focuses on the functional position of the hand, preventing deformities and substituting for loss of movement[34,53].

The aim of a splint is to maintain good alignment. This will facilitate the required muscle action which will ultimately lead to active control of alignment[54]. The challenge is to position the child's arm in a functional position, while allowing him/her to continue moving and experiencing the sensory feedback of correct movement[48]. In order to achieve this, one needs to understand the biomechanical and neurophysiological effects of splinting and how it affects the

upper limb; wearing schedules; different types of splints used in neurological conditions, and the materials out of which they are constructed.

2.3.1 Physiological Effects of Splinting

When there has been a lesion in the cerebrum, the muscle tissue remains histologically and electrically unaffected. There is however a reduction in the muscle size[55] . In studies carried out by Tardieu and Tabary, they found that if muscles are maintained in a shortened position for long periods of time, the muscle fibres are structurally shortened and the sacromere numbers drop considerably. In the upper limbs of children with cerebral palsy there is often an imbalance between the action of the flexor (agonist) and the extensor (antagonist) muscle groups. Eventually prolonged flexion causes shortening of the flexor muscles, since the muscles' physiological length adapts to their abnormal condition[56].

The muscle shortening, which is caused by spasticity, is best explained biomechanically. The main emphasis is on changing the muscle and joint position. This is done by stretching the muscle. If a safe force is applied to the shortened muscle, the muscle and surrounding tissues should be able to lengthen but this will depend on the viscoelastic properties of these tissues. This elastic response is associated with the unfolding of tissue and the temporary realignment of collagen fibres within the connective tissues. By applying a low-load prolonged stress to the shortened muscles at the end of their available range, they will ultimately be able to grow, because the crossbridges between the myosin and actin filaments in the sarcomeres will be disrupted and the periarticular connective tissue stiffness will be reduced[35,55,57].

When an adult muscle is chronically stretched, it responds by adding new sarcomeres. This makes them return to their optimum tension-generating length; and there is no change to the muscle tendon. However when a child's growing muscles are stretched this is not the case. Instead, sarcomeres only increase in

number for the first few days of stretch: after that they start decreasing and in so doing the muscle fibre length is also decreased. Thus the overall muscle length is maintained by lengthening of the tendon[21].

Therapeutic stretching should thus be very gradual because if it is done too fast or too forcefully, the muscle fibres could breakdown[21,55]. If the muscle is stretched gradually the additional sarcomeres will make the muscle less sensitive to stretch during movement[35]. Stretching should always be done within the child's sub maximal range of movement (i.e. 5 – 10 degrees less than maximal) to prevent elicitation of the stretch reflex[40]. To facilitate easier movements, prolonged manual stretch is often used to inhibit spastic muscles. This is done by holding the child's affected limb so that the muscle is kept at its greatest length for just over 20 seconds. This is repeated several times, until upon releasing the child's limb it is felt that the muscle has adjusted to the longer length[35].

A muscle can also be stretched by passive range of motion exercises. However, depending on exercise frequency, these can only provide intermittent muscle stretch and are unable to prevent progressive muscle shortening[21]. To prevent contractures, it is more effective to stretch spastic muscles continuously for several hours daily and the best way to apply low load prolonged stretch to contracted tissues is to use casting and splinting. Studies have shown that shortening of spastic muscles recurs if the stretch is not maintained[6,58].

In a study carried out by Brennan[59], subjects were exposed to continuous stretch of the appropriate joint by use of a splint. They were required to wear this splint for three months, only removing it twice a day for personal hygiene. They then wore the splints for diminishing periods for another two months. At the end of the five months, most of these subjects achieved and retained for long periods, a decrease in flexor spasticity and an increase in active extension, resulting in improved function. More recent studies by Tardieu[60]1989 and Glasgow[61] found

that long term stretch was most effective when it was applied continuously for time periods greater than six hours.

Mills[62] compared electromyographic (EMG) activity of spastic muscles before and during splint application. She found that there was no significant reduction in the integrated EMG activity when the two were compared, indicating good accommodation of the spastic muscle to the splinted position. Thus splinting can effectively control postural defects caused by spastic limb positioning without increasing muscle tone.

An increase in active and passive range of movement has also been reported after serial casting. Copley[40] describes an increase in passive and active range of movement after a series of 4-6 casts was applied, each cast being removed after one week. However a substantial increase in active movement was only seen in the subjects who could initiate some active movement prior to casting.

The effect of splinting and casting can either be explained biomechanically, as previously mentioned or neurophysiologically. The splint and cast may have an effect on the neurophysiological components of cerebral palsy by reducing the sensory input from cutaneous and muscle receptors. This is done by providing neutral warmth and constant cutaneous pressure to the skin area that is covered by the splint or cast. Since the excitability level of the alpha or gamma motoneurons is reduced, spasticity may be modified if the contact is circumferential[6,57,63].

A major limitation of current research is the lack of documentation regarding circumferential splints. However, several studies have been conducted using a series of circumferential casts worn for an extended time period[6,59,63,64], showing a decrease in spasticity. Yasukawa and Hill[65] used a cast to stabilise the wrist in the functional position of a nine year old with increased wrist flexor spasticity. This cast successfully reduced the spasticity in the wrist flexors. This enabled the

child to strengthen her wrist extensors in order to stabilise her wrist during grasp and release activities. Law et al also reported reduced spasticity and an improvement in hand function after casting was used.

2.3.2 Wearing Regime of Splints

Of the various studies done on splinting neurological conditions, there is a great deal of inconsistency regarding the wearing schedule of the prescribed splint. The wearing schedule variation is both in hours worn per day as well as in duration measured by weeks. Some studies advocate wearing the splint for two hours a day[66], others for twenty-four hours a day and others suggest an intermittent wearing schedule[67]. Flowers and LaStayo in Lee state that "the longer a splint is worn, the greater total end range time and the greater the return of passive range of movement." Thus wearing a splint for only two hours may be too short to be effective. While wearing a splint for twenty-two hours, may be uncomfortable and may result in the patient's poor or non-compliance. The latter was evident in the study done by Langlois et al[68] where subjects in one experimental group were expected to wear their splint for twenty-two hours.

Patient compliance can also depend on the comfort and ease of donning and doffing the splint. It has been suggested that the less functionally inhibiting a splint, the more often the patient will wear it[25].

2.3.3 Different Types of Splints

The literature available on splinting hand problems associated with spasticity is very limited. It usually records the theoretical rationale for the splint design and often provides a picture and descriptions of the splint, as well as recommendations regarding the patient population for whom the splint is considered most appropriate[48,69 ,70]. Existing literature of experimental research on the use of splints has been minimal, although some information is available[36,66,67]. Most of this literature is also on static rigid splints that are either worn on the dorsal or on the volar surface of the forearm. Rigid splints position

the hand statically and limit the sensory feedback that occurs during typical usage and movement[48]. These splints are usually poorly tolerated as they are uncomfortable to wear for long periods of time, and they often impede function as they prevent motion and limit sensation. This could also lead to further learned disuse of the affected arm[37,48, 71].

There is very little literature available on the use of circumferential splints. Johnstone[72] describes a circumferential splint that uses pressure to maintain the upper limb in reflex-inhibiting patterns in order to provide limb stability during rehabilitation sessions. Pressure splints increase sensory input to the upper limb as they are orally inflated so the warm air ensures a perfect fit, allowing the splint to be moulded to the childs' upper limb to provide constant pressure of not more than 40mmHg[73]. However pressure splints should not be worn for more than an hour at a time, because the pressure could cause hypoxia and if the pressure is continued it would lead to excessive spasticity[74].

The circumferential splint Bloch and Evans used on a head injury patient was an inflatable hand splint. This splint consisted of three pieces of canvas sewn together to form a 'glove'. As the 'glove' was inflated it extended both the metacarpal and proximal interphalangeal joints. After two weeks of application an increase in range of movement and a reduction in spasticity were noticed.

Semi-dynamic splints have no extrinsic moving parts, instead they position the thumb, hand and forearm in such a way that it can optimise its own movement[14]. But very limited literature is available on semi dynamic-splints. Casey and Kratz discuss the neoprene thumb abduction supination splint. This splint has a thumb abduction sleeve, which is used as a base to attach a neoprene strap that is wound around the forearm. This strap gently pulls the forearm into a position halfway between supination and pronation. Although the arm is gently pulled into this position it is still able to move within a prescribed range of both supination and pronation.

Lycra® splints produce a continuous low-level stretching force on the upper limb of patients with increased spasticity[71]. Studies done with these splints have shown an improvement in upper limb function and a reduction in involuntary movement. Blair conducted a study on thirty children with cerebral palsy. These children wore a Lycra® splint for an average of 6.5 hours a day for 53 days. After this the children had improved postural stability, dynamic upper limb function and patterns of movement associated with reduced spasticity[75]. The findings of this study were supported by Gracies[37] in their study of 16 hemiplegic patients. After wearing an upper limb Lycra® splint for three hours the subjects presented with reduced spasticity in their wrists and fingers, and improved passive range of movement. In this study the Lycra® splints were reported as being comfortable and were well tolerated during the three hours of wear.

2.3.4 Supination Splints

Supination splints assist with rotation of the forearm. This movement is necessary for functional use of the upper limb. Kapandji[76] observed that shoulder abduction and elbow flexion can compensate for the loss of pronation, but nothing can compensate for the loss of supination. Thus if supination range of movement is limited, all attempts should be made to improve it. There are very few supination splint designs available – Colello-Abraham[29,77] supination splint and the dynamic supination pronation kit from Rolyan Smith and Nephew[29, 78]. Both of these splints keep the elbow joint fixed at 90° flexion. Several studies have been done in which the researchers developed a supination splint, Shah et al[79], Murphy, Lee et al and Barr[80], but all of these have been for improving supination range of movement after fractures to the distal radius. These splints all looked bulky and had many parts and attachments, which might make them difficult to apply at home. Similarly it is easy to lose some of the many parts if insufficient care is taken. These supination splints often use a “corkscrew” design as they are wrapped around the forearm and secured above the elbow. This design allows for forearm rotation into supination, while the proximal attachment

allows the humerus to limit pronation of the forearm. The literature survey only found one supination splint being used with children with cerebral palsy: the neoprene thumb abduction supination splint[48] discussed in section 2.3.3. above.

2.3.5 Splinting Materials

Rigid splints position the hand statically. This static position may interfere with the performance of functional tasks[48]. Rigid splints are made from low-temperature thermoplastic materials. These materials may cause discomfort, pain and skin abrasions if the rigid splint design is unsuitable and poorly manufactured[14,59]. These could be some of the reasons for non-compliance with rigid splinting and the preference for softer splints such as neoprene and Lycra®[21]. These soft splints use a wraparound design with inserts to position the thumb and if reinforcement is needed, it is provided by splinting material or metal inserts[21].

Neoprene (also known as polychloroprene) was developed in 1931. It is a soft, stretchable, lightweight, durable rubberised foam. The rubber is latex-free and is either laminated on one or both sides by a variety of fabrics. The elasticity of the rubber is altered by the stretch characteristics of the laminated fabric. When stretched it returns to its original resting length, however with repeated stretching it loses about 10 – 15% of its elasticity. The neoprene is available in various thicknesses and colours. This thickness determines the amount of elasticity, thus thicker materials have a greater resistance to stretch and provide more support than the thinner materials[48,81].

Neoprene is composed of closed cells, so neither water nor air can pass through it and similarly neither perspiration nor moisture is absorbed. It may be necessary to dry the underlying skin periodically to prevent skin maceration[48,81]. Although rare, neoprene also poses some dermatological risks, namely allergic contact dermatitis and miliaria rubra (prickly heat). The symptoms of allergic contact dermatitis include itchiness, skin eruptions, swelling, and haemorrhaging into the

skin. Miliaria rubra produces small, red, elevated, inflammatory papules and a tingling, burning sensation[82]. These symptoms can be exacerbated if the neoprene has been inadequately washed and dried[81].

Lycra® was invented in 1959. It is a synthetic polyurethane-based elastane textile with elastic properties. It can be stretched repetitively and will still recover to its original length. It is stronger and more durable than rubber[83]. Like neoprene, Lycra® is flexible and allows movement, especially over bony structures as it is in close contact with the skin. As the Lycra® is soft and flexible, plastic boning is necessary if extra support is needed. The porosity of the material increases user comfort[75].

Lycra® splints move easily with the body's natural movements[84]. This was clearly evident in the study done by Gracies The position of the splint was altered with use of the arm, as the Lycra® would move against the arm's surface. They found that the forearm of healthy subjects was significantly rotated only when the Lycra® splint was fitted accurately. The amount of rotation also decreased progressively over the six hours the Lycra® splints were used. This was probably due to the Lycra® splint slipping or shifting as the subjects actively moved their upper limb. Thus these Lycra® splints were only effective if correctly applied and readjusted after a few hours of wear.

Although both neoprene and Lycra® are comfortable and have elastic properties, they are not always practical and ideal for making upper limb splints – they retain perspiration and slip easily on skin surfaces. A new splinting material was developed in 1990 – Fabrifoam ProWrap. Fabrifoam is a composite material. It combines open celled, elastomeric foam (polyether-polyurethane) with nylon/Lycra® fabrics. Fabrifoam is a breathable fabric as it wicks away perspiration, to keep the skin cool, dry and comfortable. The design of the elastomeric foam reduces slippage and bulkiness thereby resisting movement along the skin surface[85,86] (Figure 2.1).

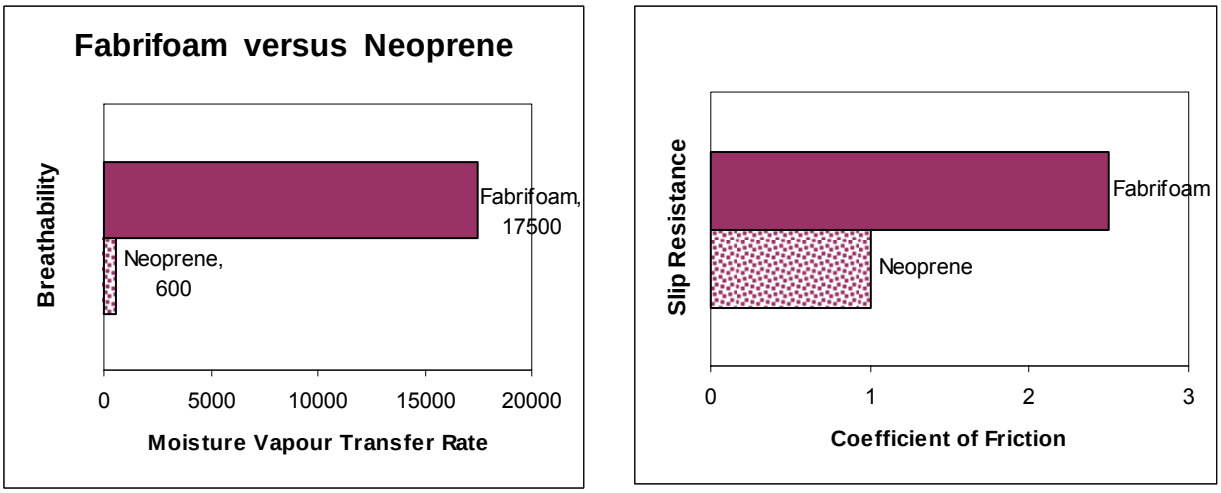


Figure 2.1 Comparison between Fabrifoam and Neoprene with regards to breathability and slip resistance[86]

The knitted blend of the nylon and Lycra® with the foam lining gives ProWrap a minimum to moderate degree of two directional stretch. This allows it to deliver the most strength with minimal elasticity. Fabrifoam is Latex free thus it does not cause any skin irritations[85,86].

2.4 Botulinum Toxin A

The clinical effects of botulinum toxin were first recognised at the end of the nineteenth century. It was only in 1949 that it was discovered as a toxin that could be developed for therapeutic use[42,87]. Botulinum toxin needed to be commercially purified for clinical use. Botulinum toxin A exists in two different biological formations. It is manufactured by Allergan under the trade name of Botox® and by Ipsen as Dysport® [88]. Its therapeutic manufacture has made it possible for it to be used to treat cerebral palsy. In the last 13 years that botulinum toxin A has been used in cerebral palsy to help reduce spasticity and improve function[7]. The early trials of Koman, Cosgrove and their respective

colleagues concluded that botulinum toxin A was a safe and successful treatment for spasticity in cerebral palsy[20].

2.4.1 Clinical Pharmacology

Botulinum Toxin A is one of several protein toxins formed by the bacterium Clostridium Botulinum. The different strains of this bacterium produce seven serologically distinct toxins of which Botulinum toxin A is the most potent. The active toxin molecules are synthesised as single-chain polypeptides with a molecular mass of approximately 150,000 Daltons, and then cleaved to form dichain molecules. This dichain molecule consists of a heavy chain that is linked by a disulphide bond to a light chain[7,42,88].

The botulinum toxins' primary functional effect is in the neuromuscular junction by 'chemodenervation' of the motor neuron from the associated muscle, causing relaxation of the muscle. The botulinum toxin works in three steps: binding, internalisation, and inhibition of neurotransmitter release[88].

Once the toxin has been injected into the muscle, its heavy chain rapidly and irreversibly binds to specific receptors on the cell surface of the presynaptic membranes of the cholinergic motor neurons at the neuromuscular junction[42, 89].

Internalisation of the toxin across the presynaptic membrane occurs via receptor-mediated endocytosis. Once the chains have internalised and are within a vesicle the light and heavy chains separate. The heavy chain forms a channel to allow the light chain to translocate across the vesicle's membrane, and to be released into the neuronal cytoplasm. The light chain cleaves one of the essential proteins which make up the vesicle docking complex hence impeding its function or formation. The light chain in botulinum toxin A cleaves the SNAP 25 (SyNaptosomal Associated Protein 25), a component of the neuroaxonal membrane essential for the exocytosis of acetylcholine[42, 88] (Figure2.2).

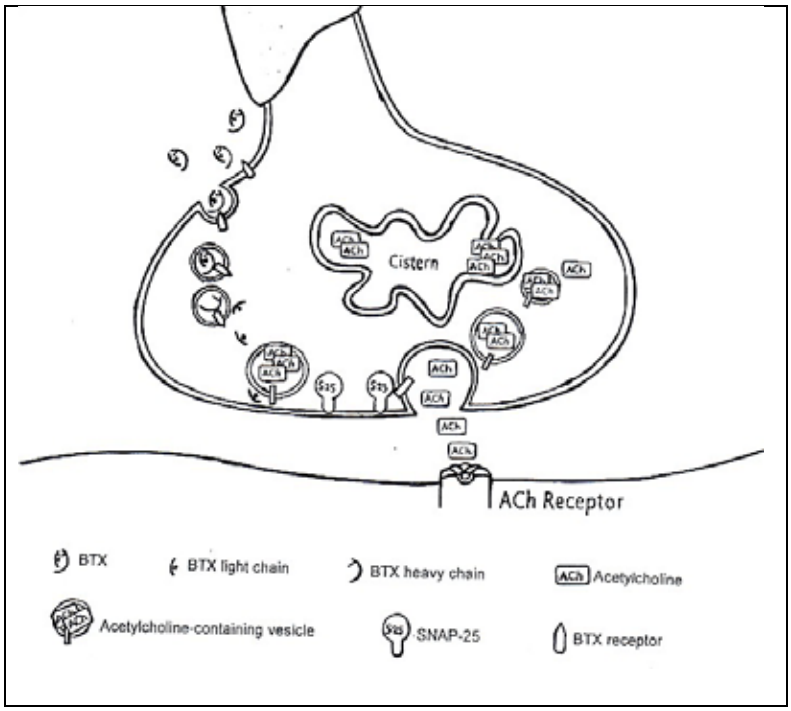


Figure 2.2 Endocytosis of Botulinum toxin A molecule, followed by cleavage and translocation of the light chain where it disrupts the normal binding of synaptosomal vesicles to the axon terminal membrane[88]

The acetylcholine-containing vesicle attaches itself to the vesicle docking complex so that the acetylcholine can be released into the synaptic cleft. But due to the actions of this light chain, the exocytosis of acetylcholine into the synaptic cleft is inhibited[42,88,90]. This blocks neurotransmission and prevents muscle contraction.

The effect of botulinum toxin is not immediate. The initial effect of this reduced muscle activity varies from 12 hours to 7 days, with peak effect at 4 to 8 weeks and usually lasts 12 to 16 weeks[8, 12, 42,44,].

The diminished muscle activity is dose dependent and is reversible. Thus recovery of the neuromuscular junction occurs by means of compensatory proximal axonal sprouting[8,89,91]. The re-innervation initially occurs through

noncollateral sprouting from the unmyelinated terminal axon immediately proximal to the end plate. As the function of the original nerve endplate is restored these new axonal sprouts eventually regress. The return of synaptic function to the original neuromuscular junction begins to occur later, as this regeneration of the membrane receptors is slow[42],[88],[92]. The full function of the muscle is only restored once contact with the myocyte is re-established and neurotransmission recommences[89].

2.4.2 Dosage

The potency of botulinum toxin A at the neuromuscular junction is dependent on the dosage injected into the muscle. Since a very low dosage won't have any effect and a very high dosage is dangerous, guidelines and consensus have been established regarding the recommended dosage of Botox® for children with cerebral palsy.

The dosage is described as Botox® units/kg body weight. The maximal dosage per visit should not exceed 12 U Botox®/kg, up to a maximum dose of 300 U. The dose has been determined by the size of the muscle to be injected, seeking to achieve a clinical response without excessive weakness or systemic side effects[42]. The maximum dose for a big muscle is 3-6 U/kg; for a small muscle, 1-2 U/kg and for the small muscles of the hand 0.5-1 U/kg (Table 2.1).

Table 2.1 Suggested Paediadtric Botox® Dosing[93]

Clinical Pattern	Potential Muscles Involved	Botox® Dose Units/kg	Number of Injection Sites
Flexed Elbow	Biceps	2	2 - 3
Pronated Forearm	pronator teres	1	1
Flexed Wrist	flexor carpi ulnaris flexor carpi radialis	1 - 2 1 - 2	1 1
Thumb-in-palm	adductor pollicis flexor pollicis brevis	0.5 - 1 0.5 - 1	1 1

The maximum dose per injection site is 50 U. A number of clinical situations may influence the recommended dosage, these are outlined in table2.2.[13,20,93]

Table2.2 Botox® Dose Modifiers[93]

CLINICAL SITUATION	DOSE PER MUSCLE	
	A decrease in dose may be indicated if:	**A increase in dose may be indicated if:**
Patient weight	Low	High
Muscle bulk	Very small	Very large
Number of muscles being injected simultaneously	Many	Few
Ashworth score	Low	Very high
Concern that treatment may result in excess weakness	High	Low

2.4.3 Side Effects and Resistance

As would be expected due to the nature of the toxin, questions have been raised on the safety of botulinum toxin A. Graham discusses a study done by Allergan, in which it was confirmed that the intact toxin remains at the injection site for at least 24 hours and the distribution to other tissues is of broken-down products and not the toxin itself. Thus there is no indication of the botulinum toxin A being conveyed from one neuron to the next.

With careful administration and the correct dosage, adverse side effects are uncommon and usually mild and transient. The occurrence of adverse side effects reported in several of studies that have been done is very low, and the effects are usually brief[42,92].

Local adverse effects of botulinum toxin A may include pain and swelling at the injection site. Dose dependant effects of excessive weakness in the injected muscle and unwanted weakness in the adjacent muscle may occur as a result of diffusion. Systemic effects are rare, but may include transient flu-like symptoms,

dry-mouth, blurred vision, or generalised mild weakness[13,42,44,92]. Brin & Aoki report that these systemic pharmacological effects are rare and permanent destruction of the tissues does not occur.
Careful injection technique and dose calculation minimises the risk of these side effects.

It has been reported that on subsequent administrations of botulinum toxin A, there has been no or reduced response to the toxin. This has been put down to the formation of neutralising antibodies against botulinum toxin A. Possibly improved purification of botulinum toxin A may reduce the antibody formation problem. Other theoretical reasons have been put forward, including change in muscle involvement over time, idealistic patient expectations and inappropriate dosage[13,42,44,88,89].

2.4.4 Injection Method

Botox® is supplied in 100 U vials in a vacuum dried state. It is diluted with 0.9% Sodium Chloride before it is injected into the designated upper limb muscle[94]. Direct injection via palpation of the muscle belly is often used with superficial muscles. The utilisation of electromyography (EMG) or electrical stimulation is generally used to identify deeper muscles, or the precise fascicles within the muscle[95]. Motor end plates usually lie in the centre of muscle fibers and are thus found within the main bulk of the muscle. Therefore the most effective injection method is to target the midpoint of the muscle fibres at the greatest muscle bulk[96]. The botulinum toxin A diffuses across muscle fascial barriers. Borodic et al in Boyd describe a “diffusion radius of 1.5 cm from a single injection, resulting in a circular denervation field, 3 cm in diameter.”

The muscles that are usually injected with botulinum toxin A are those that are most significantly affected by spasticity, or the ones that usually develop into contractures, and the muscles that limit function.

In the upper limb this incorporates the

- elbow - biceps brachii and brachialis;
- forearm - the pronator teres;
- wrist - flexor carpi radialis and flexor carpi ulnaris;
- hand - adductor policis and flexor policis brevis[43].

2.4.5 Patient Selection

The indication for the use of botulinum toxin A is the presence of spasticity in upper limb muscles. However, not all children with cerebral palsy may benefit from botulinum toxin A. Children who have fixed contractures, bony deformities, or unstable joints will not benefit from botulinum toxin A and another treatment intervention would be recommended[42].

Botulinum toxin A in the upper limb is most effective in children with dynamic muscle shortening and who have selective antagonistic muscle activity[13,42]. Research by Garcia Ruiz[97] and Boyd found that early intervention yields a better response, and children coming from a supportive home background, who complied with their therapy programme attained better results. Graham also emphasises that the earlier the botulinum toxin A is injected the greater the opportunity for a successful response and its prolonged effect is likely to assist in reducing contractures and delaying surgery. He suggests the most advantageous time for use of botulinum toxin A in children's upper limb is from 4 years of age onwards. Treatment during the active phase of motor development and growth has the advantage of possible permanent modifications to the tissues.

These recommendations were the outcome of some studies carried out on the upper limbs of children with cerebral palsy. The authors suggested that children who had a favourable functional response were those who were inclined to have:

- at least moderately high muscle spasticity[45,98],
- no fixed contractures[45],
- preserved grip strength[98],

- some distal voluntary control[98],
- younger age group[98],
- intact sensation[99],
- motivation to participate in post injection training[99].

2.4.6 Clinical Effects

As a result of the botulinum toxin's effective ability to partially denervate a muscle, the possibility of powerful muscle contraction is reduced. Since the strong spastic response is reduced, the muscle is able to function in its lengthened position[100].

Gaebler-Spira talks about the effect botulinum toxin A could have on muscle growth. Muscle shortening, as a result of spasticity, can be reduced and deformity is decreased by allowing the muscle to grow at the same rate as the bone. Thus the use of botulinum toxin A during the child's growing years could possibly change the length of their spastic muscles.

For these reasons, Botulinum toxin A provides a window of opportunity for several therapeutic interventions, to aid cerebral palsy children to learn motor skills and obtain selective motor control. Research has proposed that the decrease in the spastic muscles activity has the potential to:

- facilitate increased range of movement,
- strengthen the weak antagonistic muscles,
- improve motor control and
- optimise the learning of new movement patterns in order to improve functional abilities[44,101].

Pidcock states that 'therapeutic botulinum toxin A should be viewed as an adjunct to other therapies and not a replacement for them.' Thus a therapeutic programme of occupational and physiotherapy consisting of stretching, splinting and functional exercises should be used in conjunction with the botulinum toxin A

treatment[38,102]. Graham proposed that the "use of botulinum toxin A injections in the hemiplegic upper limb , combined with intelligent use of occupational therapy and splinting, should reduce deformity and improve function for many children."

Occupational and physiotherapy is aimed at facilitating active movement patterns through specific motor tasks, e.g. facilitation of elbow and wrist extension by reaching for an object. In using appropriate therapy techniques, a balance between the agonist and antagonist muscles may be achieved. This balance may assist with improved upper limb mobility, which may lead to further acceptance of tactile, proprioceptive and vestibular sensory input. This in turn facilitates the development of more complex neural patterns, improves motor response'.

The study carried out by Fehlings et al showed that cerebral palsy children who had received botulinum toxin A injections and received occupational therapy (OT) showed improved function compared to children who had only received OT. The OT consisted of "standard practice for therapy management of spastic hemiplegia and it incorporated activities for upper extremity strengthening and the development of skills for activities of daily living". However children in this study did not use any hand splints.

2.4.7 Previous Studies

Although much research has been done on the use of botulinum toxin A in the treatment of spasticity in the lower limbs, very little has been done on the treatment of upper limbs of children with cerebral palsy. A search of the literature found three randomised controlled trials[45,98,103], ten prospective single-group study design[7,12,15,89,91,99,101,104,105,106] and four case studies[107,108,109,110]. In most of these studies the authors found a decrease in spasticity and an increase in movement. However some of these findings were not statistically significant. The authors did not all assess functional changes in the children's upper limb. The type and amount of therapy the children received varied and in some studies the

children did not receive therapy. Splints were prescribed in only three of these studies.

In 1993, Wall et al. were the first to report on the use of botulinum toxin A in the upper limb of five cerebral palsy children. They injected the adductor pollicus muscle for thumb-in-palm deformities. A 24-hour wearing schedule of a rigid splint in the first web space was used for 112 days. This led to improvements in cosmetic appearance and hand function (key grip, precision pinch, palmer grip, bimanual dexterity). Both parents and teachers reported increased spontaneous use of the affected hand both at 'work' and at play.

Corry et al. performed a randomised, double-blind trial comparing the effects of botulinum toxin A with a saline placebo in children with cerebral palsy. The botulinum toxin A had an obvious clinical effect of reducing the spasticity in the injected upper limb muscles and increasing the range of movement, compared with the placebo group. Their study found a functional improvement in gross motor but not in fine motor function. This improvement was not initially evident at two weeks, but by twelve weeks it was detectable. In their study additional occupational or physiotherapy was not prescribed for either of the groups.

The single-blinded, randomised study carried out by Fehlings et al showed that cerebral palsy children who had received botulinum toxin A injections and received occupational therapy showed improved function as compared to children who had only received occupational therapy. In Fehlings et al's study, the occupational therapy consisted of standard practice for therapy management of spastic hemiplegia which incorporated activities for upper extremity strengthening and the development of skills for daily living activities. However the children in this study did not use any hand splints.

All the patients in the study carried out by Speth et al. were given a structured rehabilitation programme but only half received botulinum toxin A injections. The

control group did not receive placebo injections. The therapy programme included stretching, wearing splints, strength and co-ordination training and task specific training. It was tailored to the individual patient, depending on their hand function impairment (based on Zancolli[51] grade). The active range of movement was treated by stretch techniques and the passive range of movement by wearing splints. All the children wore a night splint with the elbow extended, the forearm in neutral position between pronation and supination, wrist in extension, the thumb in abduction and the fingers in opposition. Only the children who were graded Zancolli[51] IIB wore a wrist extension splint during the day. The children who had less impairment used a wrist extension or a thumb web-space spreader during certain activities. The children in the treatment group showed a clinically relevant increase in active wrist extension and reduced spasticity in the wrist. However no statistically significant difference was noted in the functional outcomes measured between the two groups. Their findings concluded that in spite of an intensive therapy programme there was reduced impairment, concerning spasticity and range of movement, but the effect of botulinum toxin A on activity level was still uncertain.

2.5 Summary

A reduction in the spasticity of a child with cerebral palsy may allow for more normal growth and lengthening of the affected muscles. If the range of movement could be improved, it would be possible to dynamically lengthen the muscle fibres. Since the addition of new sarcomeres would promote muscle growth. Having more muscle length, could increase mobility and function, and prevent the formation of contractures. Reduced spasticity could result in improved control of movement patterns and secondary strengthening of the antagonistic muscles

If a splint is worn over a specific joint for an extended period of time during the day, it may allow the muscles around this joint to strengthen and become more functional.

With this in mind, what would be the effects of botulinum toxin A, hand therapy, and splinting the first web space, wrist and forearm, have on the spasticity, range of movement and function of the upper limb of a child with cerebral palsy?

CHAPTER 3 - METHODOLOGY

This chapter establishes the aim and objectives of this study. It describes the design used in this research as well as the measurement instruments and methods used. The process of the pilot study that was done prior to the commencement of the study is described. The study sample, size, setting, selection of the study group and data collection are discussed. The intervention of the supination splint and home programme is explained. The various statistics used to analyse the raw data are mentioned.

3.1 Aim and Objectives of Study

The aim of this study was to investigate the effect of a soft supination splint on the upper limbs of children with cerebral palsy after they had received botulinum toxin A injections.

The objectives were to assess whether the following occurred:

- a decrease in spasticity;
- an increase in joint range of motion;
- an improvement in aspects of hand function: hand grasps, in-hand manipulation, bilateral hand use and the quality of movement.

3.2 Ethical Clearance and Sponsorship

In order to implement any research in the Department of Education, prior permission to conduct a study and ethical clearance had to be obtained from all stakeholders.

Prior permission to carry out a study in Schools for Learners with Special Educational Needs (LSEN) had to be obtained from the Gauteng Department of Education (Appendix A). Once this had been obtained, the protocol was submitted to the Ethical Committee of the University of Pretoria, as ethical clearance must be obtained before any study may commence. The ethical clearance number S182/2004 was allocated to this research (Appendix B).

The Botox® used in this study was donated by Genop Healthcare (PTY) LTD free of charge (Appendix C). The researcher was under no obligation to Genop Healthcare for their donation.

3.3 Research Design

A prospective quasi-experimental design was used in this study. This design was chosen as the researcher wanted to measure the response variables on the experimental unit over a six month period in the future. It was not possible to randomly assign the subjects into groups since the research took place at several schools where intact groups already existed[111, 112]. The wide variations of motor and sensory deficits in cerebral palsy, as discussed in section 2.2.2 of the previous chapter, as well as the differences in IQ's and socio-economical backgrounds made the selection of matched controls impossible.

As the researcher wanted to observe the effect the supination splint would have on the subjects' upper limb function over a specific time period, the time series design was used. By using the prospective time series design, the researcher was able to give each subject a pre-test followed by the experimental treatment (namely Botox® and supination splint) and a post-test. A period of time (a month) elapsed before another post-test was

performed. In total six post-tests were conducted with the same time period elapsing between each test[113]. The data collected when the intervention was in effect was compared with the data when the intervention was not in effect. In this manner each subject acted as his own control by comparing pre- and post-intervention states.

This design also allowed greater control over the quality of information that was collected. The dependent variables used in this study were spasticity, joint range of movement, quality of upper limb movement and various hand function activities. The independent variables used are Botox® and a supination splint.

The simultaneous interaction of the supination splint and the Botox® was analysed over time to see if there was any effect on the upper limb function of the subjects[114,115].

In this study, data was systematically collected, by assessing the subjects, prior to them being injected with Botox® and again before they were provided with the supination splint. By collecting this data the researcher was able to establish a pre-treatment rate of performance that was used as a basis for comparison after the treatments were introduced[116].

After the subjects received their intervention treatment, namely the Botox® injections and the supination splint, the researcher continued to collect data on a monthly basis by recording information on the subjects performance in the same method that was used prior to the treatment being introduced. This was done by repeatedly assessing the subject's upper limb function over a 6 month period. During the course of intervention treatment, the researcher kept an accurate system of measuring and recording upper limb function, so that the treatment effects could be analysed. Both subjective and objective assessments were used[117].

The data collected during the actual intervention phase of when the subjects wore their splints was compared with the data collected before the intervention was introduced. Any difference in the dependent variables between these sets of data is assumed to be caused by the independent variables. Since each subject to act as his own control, this allowed group conclusions to be drawn from the overall results[116,117].

A 'blinded independent' panel, made up of two physiotherapists and two occupational therapists, not involved in the trial and all having an interest or specific knowledge of cerebral palsy were invited to "score" the results. This required a subjective assessment. Their involvement negated any possible improvement which could arise from participant investigator bias. The role of this 'blinded independent' panel is discussed in section 3.4.3 of this chapter.

By using this prospective quasi-experimental research design method, the researcher was able to accomplish the following:

- Monitor the child's performance regarding spasticity, joint range of motion, hand grasps, in-hand manipulation, bilateral hand use and quality of upper limb movement.
- Determine whether the treatment was responsible for improved and maintained performance in upper limb function.

3.4 Measurement Instruments and Methods

The subjects were assessed on their spasticity, joint range of motion, hand function, and quality of movement. All the assessments were carried out by the researcher.

3.4.1 Spasticity

Spasticity was assessed by manually moving a limb through its full range of passive movement and then recording the movement according to the Modified Ashworth Scale (MAS). This scale was modified by Bohannon and Smith[118] in 1987, from the original scale Ashworth devised in 1964. It is a simple six point scale that enables the examiner to quantify the amount of muscle resistance felt while manually moving a limb through its full range of passive movement to stretch the specific muscle group[119,120]. The Modified Ashworth Scale described by Bohannon is illustrated in Table 3.1 below.

Table 3.1 Modified Ashworth Scale[118]

Grade	Description
0	No increase in muscle tone
1	Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of movement when the affected part is moved in flexion or extension
1+	Slight increase in muscle tone; manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the range of movement
2	More marked increase in muscle tone through most of the range of movement, but affected parts are easily moved.
3	Considerable increase in muscle tone; passive movement difficult
4	Affected parts rigid in flexion or extension

The scale has been used to assess spasticity in patients with various neurological disorders. These studies have found the Modified Ashworth Scale to have good inter and intrarater reliability in the muscle groups of the upper limb[118,119,120,121].

3.4.2 Joint Range of Movement

Norkin[122] describes “range of movement as the amount of motion that is available at a specific joint.” Joint range of motion was assessed using a goniometer. This was done by measuring the angle of the joints’ position and the total amount of movement available at that joint. The goniometer was

placed along the proximal and distal bones adjacent to the joint being measured.

The active and passive range of movement (ROM) was assessed. The active ROM can give an indication on the subjects' functional ability. It was assessed by allowing the subjects to voluntary move their upper limbs in the movements mentioned below. The passive ROM was assessed by the researcher applying an external force to the joint and moving it through its range of motion until a resistance for further movement was felt[2,122]. Brand[123] states that by using a spring one is able to objectively measure the passive ROM. As it is difficult to measure whether the force being applied is constant each time, the researcher used a calibrated spring scale to measure 1kg traction[123] to obtain the constant force[2] (Figure 3.1). The researcher attached a strap to the calibrated spring scale. This strap was then placed at 90° to the limb being moved and a force of 1 kg was exhorted.

Figure 3.1 Spring Scale and Strap used to measure Passive Range of Movement

The following movements were assessed:

- elbow flexion/extension

This was done by centering the goniometers' fulcrum over the lateral epicondyle of the humerus, the proximal arm of the goniometer was aligned with the lateral midline of the humerus, using the acromion process as a reference, and the distal arm was aligned with the lateral midline of the ulna, using the ulna head as a reference[122].

- forearm supination/pronation

The measurement of rotational movements of the forearm is difficult due to a lack of stable anatomical lever arms with which to align the goniometer[2,124]. Flowers adapted a conventional 6" 180° plastic goniometer by attaching a 1" PVC pipe to the rigid arms of the goniometer and a plumbline to the fulcrum of the goniometer (Figure 3.2). The PVC pipe was held by the subjects, it outlined the plane of the palm of the hand and the plumbline outlined the vertical plane by hanging against the face of the goniometers protractor.

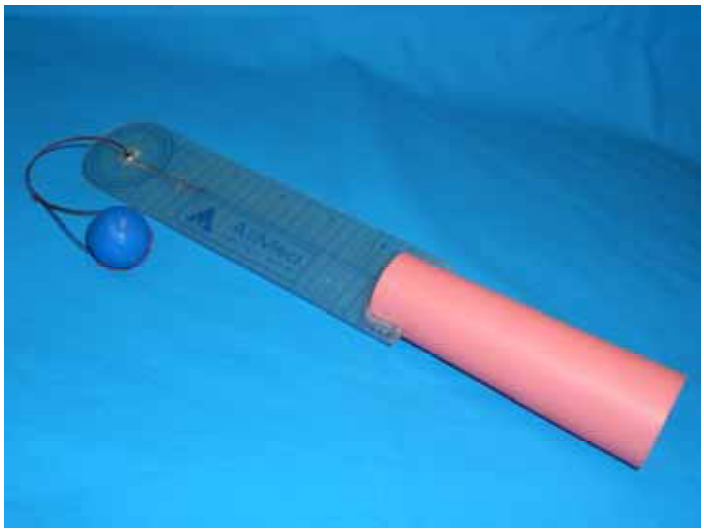


Figure 3.2 Adapted Goniometer

The subjects' humerus was stabilised with the elbow in 90° flexion to prevent internal and external rotation of the shoulder[122]. The subjects held the PVC pipe firmly with the wrist in neutral, if they struggled with this the researcher used her free hand to gently hold the subjects fingers around the handle and placed their wrist in the neutral position[124]. The study carried out by Flowers et al found that this new method of the adapted goniometer was reliable for measuring both supination and pronation. They also found that there was less error in measuring both these movements.

- wrist flexion/extension

For this assessment the researcher centered the fulcrum of the goniometer over the lateral aspect of the wrist close to the triquetrum. The proximal arm of the goniometer was aligned with the ulna and the distal arm along the 5th metacarpal[2,122].

- wrist ulnar/radial deviation

The fulcrum of the goniometer was placed over the middle of the dorsal aspect of the wrist near the capitate bone. The proximal arm was aligned with the dorsal midline of the forearm and the distal arm was aligned with the third metacarpal bone[2,122].

- thumb flexion/extension

The researcher centered the fulcrum of the goniometer over the palmer aspect of the first carpometacarpal joint. The proximal arm was aligned with the palmar midline of the radius and the distal arm with the palmar midline of the first metacarpal. The wrist was stabilised to prevent movement[2,122].

- thumb abduction/adduction

The researcher centered the fulcrum midway between the dorsal aspect of the first and second carpometacarpal joints, and the proximal arm was aligned with the lateral midline of the second metacarpal and the distal arm with the lateral midline of the 1st metacarpal[122].

3.4.3 Hand Function Preset Tasks

Several hand function assessments have been developed for use with children who have motor disabilities, but they have been standardised and validated on children without motor problems, (for example Peabody Developmental Scales[125] and the Miller Assessment for Prescholars[126]). Both these tests are used to differentiate between children who have or do not have a motor impediment. Since the subjects who took part in this study have already been identified as children with a motor impediment, using any of these standardised assessments would have been irrelevant.

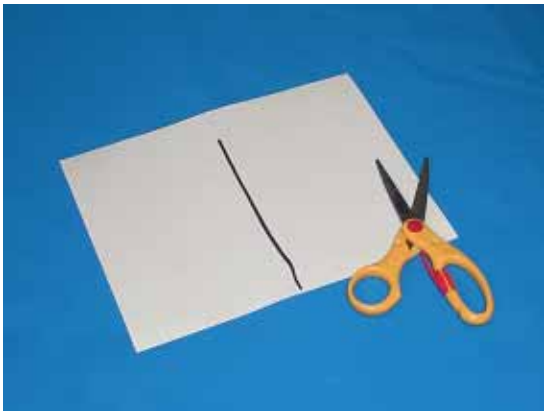
For this study the researcher needed to observe upper limb function from the aspect of the movement performed by the muscles which had been injected and splinted, namely supination, wrist extension and thumb abduction. The researcher decided to use a functional assessment that has previously been used in the studies conducted by Chait and Wall. This functional assessment is a series of preset tasks that are based on modified play activities. The subjects were required to perform specific upper limb movements and their function was measured through subjective clinical observations. A graded score of 0 – 5 was assigned to each preset task (Appendix D).

Once the researcher had demonstrated and used verbal instructions to illustrate what was required of the subjects, they were required to perform these preset tasks using the normal hand and the affected hand in a predetermined manner: proximal to distal, and development sequence of body position.

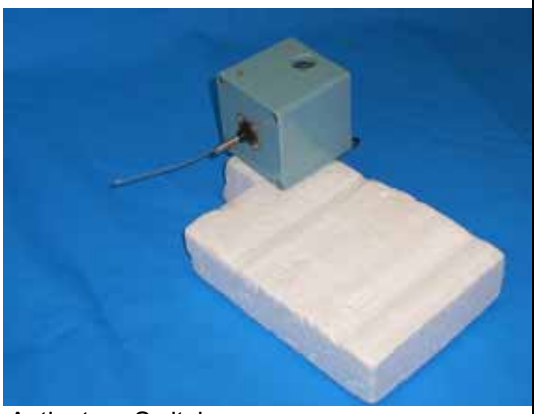
The preset tasks used to assess supination, involved the subject's ability to transfer tubes, turn barrels over and cut a piece of paper. Activation of a switch was used to assess wrist extension and threading beads and carrying a plate assessed the subjects' thumb abduction. These preset tasks allowed the researcher to assess hand grasps (transferring tubes and turning barrels), in-hand manipulation (threading beads) and bilateral hand use (cutting a piece of paper and carrying a plate) (Figure 3.3).

Transfer Tubes

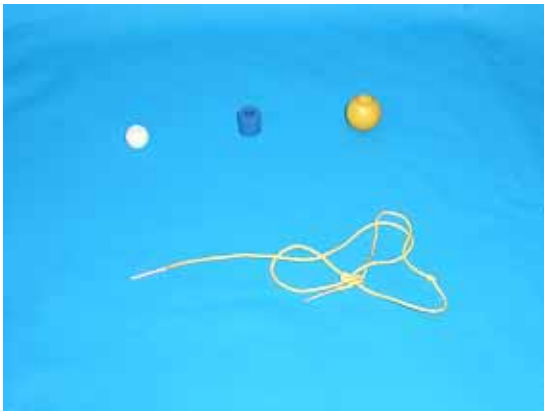
Turn Barrel Upside Down



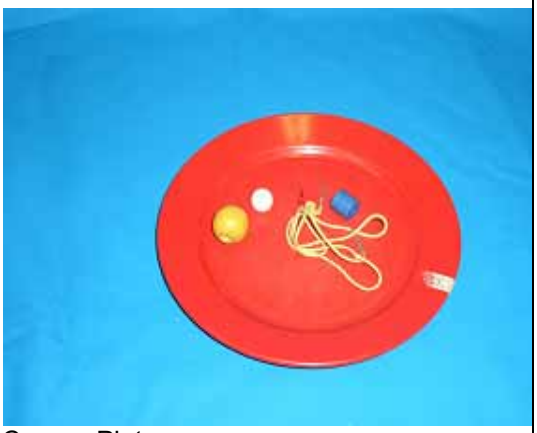
Cut Paper



Activate a Switch



Thread Beads



Carry a Plate

Figure 3.3 Hand Function Assessment – Preset Tasks

To prevent bias in this study the researcher did not score the subjects performance of these preset tasks; but videotaped them during task performance instead. A separate video tape was used for each subjects' performance of the preset tasks series. Each video tape contained all the assessments that is from the initial pre Botox® to the last sixth month follow up assessment. In order to score the subjects' performance of these tasks, the researcher put all the video recordings of the eight subjects hand function assessment sessions onto a set of tapes in random order. This set of tapes was randomised in respect of both trial subject and temporal sequence.

A 'blinded independent' panel consisting of two occupational and two physiotherapists not involved in the research and all having an interest or specific knowledge of cerebral palsy were invited to individually assess this randomised documentation. This panel had no information on how the assessments had been randomised. They also did not have any knowledge on the number of subjects involved in the study, any of the subjects' background information, what muscles had been injected and in what sequence the subjects appeared in the set of video tapes. Only the researcher had access to this information.

Each member of the 'blinded independent' panel received a set of video tapes with randomised assessments and information on how to score the visual data. Independently they rated these assessment sessions according to the rating scale on the scoring sheet (Appendix D).

3.4.4 Quality of Upper Extremity Skills Test[127]

In section 2.2 of the previous chapter, it was explained that children with cerebral palsy move in certain abnormal movement patterns. These patterns of movement often interfere with functional ability. The Quality of Upper Extremity Skills Test (QUEST) is a standardised test that was developed to

assess the qualitative components of movement in children who have a neuromotor dysfunction with spasticity. The QUEST has been validated with children between 18 months and 8 years of age. It evaluates quality of movement in four domains: dissociated movement, grasp, protective extension and weight bearing. These movements form part of normal development and are the foundation for upper limb function. It has good interrater reliability over time[127,128]. The researcher used the QUEST to assess the subjects' quality of movement. However, only three of the four domains, were assessed: dissociated movement, grasp and weight bearing. The protective extension domain was not assessed as it had not been considered in the pilot study (Appendix E).

The subjects' performances in the QUEST were facilitated by the researcher demonstrating the various positions or actions in the three domains and providing verbal encouragement. All the items in all the three domains were scored for both left and right upper limbs using a dichotomous (yes/no) scale. The researcher tallied the number of positive and negative responses to calculate the percentage scores.

The dissociated movement domain required the subjects to perform items in which they had to move out of the typical patterns of spastic synergies, e.g. shoulder flexion with the elbow and wrist in extension instead of the typical pattern of flexion at all the joints. The items in this domain represented each joint of the upper limb: shoulder, elbow, wrist, finger and thumb. The subjects were required to move their upper limbs into various positions; if they met the required criteria they would score positively.

The items in the grasps domain were arranged on a hierarchical and developmental basis. The subjects were required to grasp a 1" cube, grasp a 5mm peg and grasp a crayon; this was scored according to the specified

criteria. In this domain the researcher was required to evaluate the subjects' trunk and head posture while they performed these items.

In the weight bearing domain the items represented functional transitional movements that incorporated the upper limb, namely weight bearing in front, side and back; and with reach. The subjects performed these items in the four foot kneeling position. The researcher scored them hierarchically based on the degree of abnormality as represented by joint positions, namely weight bearing with elbow extended and the hand open scored the highest while weight bearing with the elbow flexed and hand fisted scored the lowest. The subjects scored zero if their thumb was tucked into the palm of their hand.

3.5 Pilot Study

A pilot study was performed in order to examine the validity of the various measurement instruments and the data record sheets, to ascertain the feasibility of the procedure and to determine if the data gathering method would be meaningful.

To allow the study to include as many subjects as possible, the subjects in the pilot study were between 7 – 8 years of age. The inclusion criteria that were incorporated in the research study were also used in the pilot study. Of all the children in this age group, only two were found that met these criteria as a result just two subjects were involved in the pilot study.

Implementation of the instrument used to measure spasticity (Modified Ashworth Scale) was simply to follow the rating scale the author had prescribed. No changes were necessary on the data collection documentation either, as it was very straight forward.

The researcher had difficulty assessing the supination and pronation range of movement of the subjects in the pilot study. This was due to the position of their hand as a result of increased spasticity, which made it very difficult for the researcher to determine if one arm of the goniometer was in the vertical plane as described by Norkin. Therefore the measurements the researcher obtained were not reliable due to the large discrepancy between all the goniometer readings. Other methods were tried in an attempt to obtain reliable readings. The method described by Flowers was eventually the one that produced reliable data. From this it was decided to use Flowers' adapted goniometer instead of Norkin's procedure to measure pronation and supination in the study.

The initial data collection form did not stipulate the various movements possible at the various joints. It thus became very unclear when filling out the form. This was especially true when recording data at the joints that could perform two movements. As a result it became necessary to include all the movements possible at the various joints in the joint range table on the data collection document, e.g. thumb flexion/extension and abduction/adduction.

The hand function preset tasks assessment was adapted slightly. The task that used the switch was changed. The switch that was initially used to assess wrist function was unable to measure wrist extension accurately. It did not allow for sufficient wrist extension – only 30°. Another problem was that the subjects used excessive elbow movement to activate the switch. Hence the decision to use the "cat whisker" switch. This switch was placed on a polystyrene arm board. The board allowed the subjects to move their wrists through a full range of movement of flexion to extension without interference. The polystyrene arm board had a strap to prevent the use of elbow flexion or extension when activating the switch.

Some of the wording in the hand function data collection form was changed so that the scoring criteria were clearer to the person scoring the subjects.

While performing the hand function preset tasks assessment, it was necessary to ensure the video camera was positioned so that the subjects' face would not be visible. The view had to be one where the subjects could not be identified. The camera was placed behind the subjects at 45° from their affected shoulder for all tasks except for the switch task. For this it was placed at 90° to their affected forearm.

The quality of upper extremities skills test assessment was straightforward; it has been standardised with specific criteria as to what constitutes a positive or negative response. Initially all four domains were used to assess the pilot study subjects: dissociated movement, grasp, protective extension and weight bearing. The items to assess the protective extension and the weight bearing are identical. Developmentally one needs to be able to have protective extension before one is able to weight bear. Thus to be able to weight bear one needs to have good protective extension. The subjects used in the pilot study were not severely disabled, (they had been diagnosed as cerebral palsy hemiplegia), and they had good protective extension reactions. It was therefore decided unnecessary to use the protective extension domain due to the redundancy.

The assessment forms for this test have also been standardised; they were not changed or adapted for this study (Appendix E).

3.6 Process and flow of study

3.6.1 Study Population

The study sample was selected from three Schools for Learners with Special Educational Needs (LSEN) in the Johannesburg area. Consent was

obtained from the Gauteng Department of Education and the principal of the school involved (Appendix A & F) for the study to be carried out at their school.

3.6.2 Study Sample

The subjects consisted of children from 3 – 7 years of age. They had all been diagnosed with cerebral palsy with increased muscle tone in one of their upper limbs. Due to the wide variations in the degree of deficit, as discussed in section 2.2, it was impossible to find large numbers of subjects with comparable motor difficulties. The research was carried out on 10 subjects.

The following criteria were used to determine whether to include or exclude the subjects in the study:

- Inclusion Criteria – Children who:
    - Were receiving regular therapy: occupational and/or physiotherapy at least once a week
    - Were recommended by the treating occupational or physiotherapist and plastic surgeon.
    - Had parents/caregivers who were reported as being compliant.
- Exclusion Criteria – Children who:
    - Had received previous Botox® in their upper limb.
    - Presented with fixed contractures

The sample was selected from the routine 'Botulinum Toxin Clinic' that is held at the LSEN school. At these 'Botulinum Toxin Clinics' the plastic surgeon, who has been involved with Botox® treatment for many years, visits the LSEN school regularly (3-4 times a year) to assess the children and if necessary to prescribe Botox® for their upper limbs. The subjects were selected from two of these regular clinic visits.

The plastic surgeon assessed the children and calculated the Botox® dosage according to the subjects' body weight and severity of spasticity (Appendix G). He calculated the dosage according to the dosage guidelines that have been recommended by Genop Pharmaceutical Company. These guidelines were discussed in section 2.4.2 and also in previous research.

Prior to the children attending the clinic, the parents/caregivers were given a consent form (Appendix H) requesting their permission for the child to participate in this study. It was made clear to the parents/caregivers that the child's care and therapy would not be compromised if they refused to sign the consent form. Consent was obtained from 10 parents/caregivers. Once the consent was obtained the child became a participant in the study.

3.6.3 Study Setting

The study was conducted in four places in Johannesburg. The Botox® injections were done at the plastic surgeons rooms at the Parklane Clinic. The assessment of the subjects was done at the various LSEN schools in which the children were enrolled.

3.6.4 Data Collection Procedure

Once consent had been obtained from the parents, the subjects were randomly allocated a number. This was done so that each subjects' identity would remain anonymous. The researcher allocated each subject a Data Entry file which contained an information form. This form included background information, type and degree of cerebral palsy as well as a full pre-intervention documentation on the hand status (Appendix I). This information was obtained by the researcher.

In the two weeks before the Botox® injections were administered the subjects' upper limbs were assessed. A red arm band was placed on the

affected arm whenever the assessments were being performed, to assist with easy identification of the affected arm. The upper limb was assessed from a functional point of view, with documentation of degree of spasticity, ranges of motion, quality of upper limb movement and the ability to perform preset tasks.

As discussed in section 2.2.2 of the previous chapter the degree of spasticity in children with cerebral palsy varies according to body and head positions (as a result of tonic reflexes) as well as with degree of effort required for the movements or fatigue induced. In order to minimize these induced variations, all the assessments were performed in a set sequence and in the same position. The subjects were seated at a table with their trunk well supported and their arms resting on the table. The subject's head was in the neutral position, looking forward.

The assessment format was the same throughout:

- Spasticity
- Joint range of motion
- Hand Function Preset Tasks
- Quality of movement

The findings of these assessments were recorded on data record forms.

Spasticity and joint range of motion were recorded in a table format on the same data form (Appendix J) and the quality of movement was recorded on the standardised assessment forms devised by the authors of the QUEST (Appendix E). As the Hand Function Preset Tasks Assessment is not standardised and scoring is very subjective, it was video taped on a separate tape for each subject for later scoring by an independent panel as explained in section 3.4.3.

For easier management and due to time constraints, the ten subjects were divided into two groups of five. The plastic surgeon had only one free afternoon a week in which to inject the children. Therefore the first group was injected one week and the second group was injected a week later.

The Botox® was injected into the subjects' upper limb muscles that showed evidence of increased spasticity, namely biceps, pronators, wrist flexors and thumb adductors. He injected the Botox® using fine needles and by palpation of the muscle belly.

The researcher met with the subjects' parents/caregivers the day the subject was being injected, to discuss the role they were to play at home. They were given a video and a written handout with information on the purpose of the home programme (Appendix K). Further detail on the home programme is provided in section 3.7.2. The parents/care givers were also issued with six time sheets on which they would monitor the wearing regime of the splint. On these time sheets they were required to indicate if the massage and passive stretch exercises were done and to record the time the splint was applied and removed. (Appendix L).

The researcher met with the therapists involved in the subjects' rehabilitation programme. They were issued with the same documentation and information that was given to the parents/caregivers because the therapists would need to remove the splint when the subjects attended their weekly therapy session and then reapply the supination splint once the therapy session was over.

A week after the subjects had received their Botox® injections they were reassessed, using the same assessment procedure that was used before they received their injections. They were then issued with a soft supination splint made out of Tensowrap® material. The splint's wearing regime

required daily usage from 8 – 10 hours a day. It was removed for therapy and when the subject went to sleep. Details on the construction of the supination splint are given in section 3.7.1.

After three months of wearing the supination splint all the subjects were issued with a new supination splint as the first one had become damaged with much wear and tear. At this time the researcher also contacted the parents/caregivers telephonically to ensure that they were not experiencing any problems or difficulties with the home programme and the splint wearing regime.

The subjects were reassessed a month after their Botox® injection and in the five subsequent months. In the fifth month the school vacation prevented assessment at the required time, the assessment therefore took place as soon as the subjects returned to school. All these reassessments followed the same format as the assessment that was done before the Botox® injections were administered. All the reassessments were administered by the researcher.

A six month period was used to assess the subjects as this period exceeds the 12 – 16 week period that the Botox® is in effect[8,12,42,44]. Thus subjects continued wearing the supination splint and being assessed after the Botox® effect had receded. This provided the researcher with the opportunity to assess the subjects' hand function when only the supination splint was being used.

During this six month period the subjects continued with the regular therapies that they had been receiving prior to being injected with Botox®. No additional therapy was prescribed.

3.7 Intervention

3.7.1 Supination Splint

The supination splint was made out of Tensowrap® Pro which is soft splinting material manufactured by Fabrifoam. It is supplied in rolls of various lengths and widths. The 5cm width roll was used for the construction of the supination splints used in this study. The pattern of the supination splint is illustrated in Figure 3.4

It is measured as follows:

- A-B is the circumference of the base of the proximal phalanx of the thumb, with an extra 1.5cm added for sewing
- C-D is measured by wrapping the material around the wrist, all the way up the forearm and around the distal end of the humerus just above the epicondyles. An extra 4cm is added for overlap of the Velcro strap.

The supination splint is constructed as follows:

- The Tensowrap® is cut according to the pattern, ensuring that the white rubberised surface will be against the child's skin, with part *e* being on the dorsum of the hand.
- Part *e* is sewn to part *f*
- A thin 4cm long strip of the rough Velcro® is sewn at *g*
- A 2.5cm width strap approximately 5cm in length of rough Velcro® is sewn at *h*

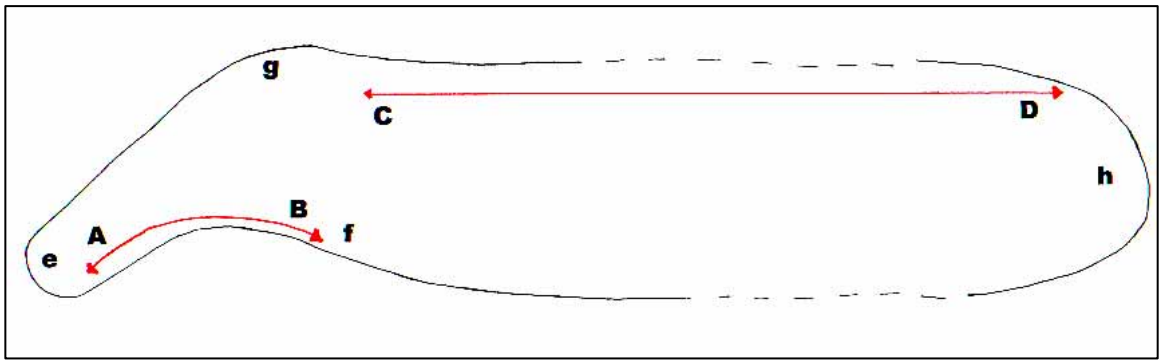


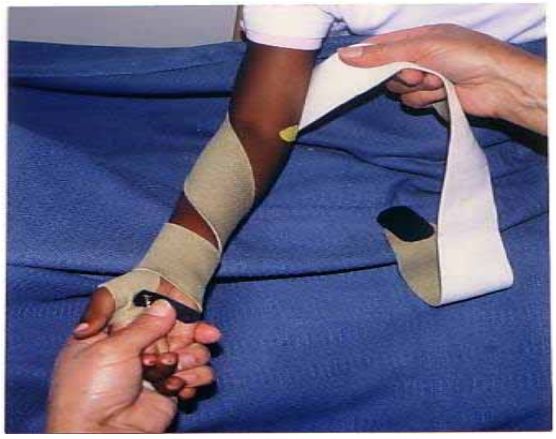
Figure 3.4 Supination Splint Design (adapted from Atronova)[129]

The supination splint is applied by placing the sewn loop of the splint through child's thumb; bringing it right down until the skin creases at the base of the thumb have been covered. The sewn parts must be on the dorsum of the hand. The splint should be taken around to the dorsum of the child's hand so that it comes out on the ulnar side. The splint is brought anteriorly onto the volar surface of the hand and covers the hypothenar muscles over the pisiform carpal bone. It is again taken posteriorly to the dorsal surface of the wrist. The splint should overlap the part around the thumb. The splint is brought anteriorly to the volar surface once again, just proximal to the wrist creases on the ulnar side. The splint should overlap the part around the wrist. It should be wrapped snuggly around the arm. The splint is continually wound up the forearm.

The Velcro® strap secures the splint around the elbow proximal to the epicondyles, ensuring that the medial epicondyle is not covered by the splint. The Velcro® strap at the thumb is pulled up in order to abduct the thumb. The Velcro® strap is secured on the part of the splint that covers the hypothenar muscles over the pisiform carpal bone. The application of the supination splint is illustrated in Figure 3.5

Step 1

Step 2



Step 3

Step 4

Step 5

Figure 3.5 Supination Splint Application

3.7.2 Home Programme

The home programme (Appendix K) was based on Roods' theory[130] on treating neuromuscular dysfunction. It incorporated the following:

- Stretch pressure is applied to superficial muscles to stimulate of the muscle spindles. This is done by placing the pads of the index fingers and thumbs on the skin surface. The underlying muscle fibres are stretched as a firm downward pressure is applied as the fingers and thumb move away from one another.
- Tendinous pressure is accomplished by applying manual pressure to the insertion of the muscle. This pressure assists in inhibiting the spasticity in the muscle.
- Maintained stretch assists with lengthening of the muscle spindle. This is achieved by placing a spastic limb in an elongated position; this position is maintained for several seconds.

These techniques were simplified for the use of the home programme. They were described as two sections, namely massage and stretch exercises. The home programme required the parents/caregivers to massage and passively stretch the child's upper limb muscles before they applied the splint. They were instructed to do these exercises for approximately 10 minutes each time. It was also necessary for the massages to be done once the splint was removed at night.

Using a mild cream the parents/caregivers needed to apply deep pressure to the upper limb when doing the massage and the passive stretch exercises. All the movements needed to be done slowly. Instruction were given on how to massage the various muscles that had been injected with Botox®; biceps, forearm muscles and the muscles on the volar aspect of the hand.

The stretch exercises consisted of passively stretching the involved joints namely elbow; proximal and distal radio ulnar; and thumb carpometacapal joints. The various stretches were held in the required position for several seconds then released slightly and then held again for several seconds. This was repeated 5 times.

The home programme was presented to the parents/caregivers in a video and a handout format. The video demonstrated the massage, stretch exercises and the splint application procedures. The handout contained written and pictorial information on the:

- massage,
- stretch exercises,
- splint application,
- splint wearing regime
- instructions for caring and washing the splint,
- precautions necessary when applying the splint.

3.8 Data Analysis

Descriptive and inferential statistics were used to analyse the data.
Pre intervention variables were compared with post intervention variables at one week, as well as at the end of each month for six months.

In order for the Modified Ashworth Scale to be analysed statistically, a numerical value of 1.5 was given to all the 1+ grades.

Due to the subjective assessment used to assess hand function, the four independent panelists' obtained diverse scores for some of the items in the various preset functional tasks. For the purpose of analysing the data statistically, all four panelists' scores were averaged, and this average score was the variable used to obtain a statistical reading.

All the statistical analyses were conducted using the Stata[131] Statistical software release 8, computer software programme. The following tests were used:

- A preliminary analysis included a thorough check of the data to review outliers and any missing data, a descriptive summary, and plots/outline of each variable.
- The mean and standard deviation was calculated for each group of data/variable.
- The Modified Ashworth Scale of spasticity is ordinal. Thus a nonparametric test (Wilcoxen's signed-rank test) was used as a conservative test for change between pre-test and post-tests. However, the assumption in nonparametric tests that a change of several steps is equal to a change of one step is not reasonable; therefore parametric statistics are also useful. Consequently, data was analysed using both parametric (Paired t-test) and non-parametric statistics.
- The variables used for the active and passive goniometry measurements, the QUEST scores and the hand function scores are all ordered in a logical sequence and are thus interval variables or data. Hence parametric (Paired t-test) statistics were used, but as the number of subjects used in the study was small non-parametric (Wilcoxen's signed-rank test) statistics were also used[113].

All analyses with differences with a p value of ≤0.05 were considered statistically significant.

In order to establish if the supination splint had any effect on the spasticity, range of movement and function of the upper limb of a child with cerebral palsy, the data was collected methodically for interpretation. Its analysis is discussed in the following chapter.

CHAPTER 4 - RESEARCH RESULTS

The data of the spasticity, joint range of movement, quality of movement and hand function was examined and the results of the study are depicted in this chapter. The descriptive and inferential statistics are presented. Graphs and tables are used to facilitate visualisation. Statistically significant and insignificant data is indicated where a p value of ≤0.05 was considered significant.

4.1 Descriptive Statistics

Consent was obtained from the parents/caregivers of ten children with cerebral palsy. The distribution of cerebral palsy among these ten children included three with diplegia, and seven with hemiplegia; and the distribution of sex included three females and seven males. See table 4.1

Table 4.1 Subject Information

Subject Number	Age	Sex	Diagnosis	Upper Limb Injected
1	5.1	M	R Hemiplegic	R
2	7.7	M	Diplegic	L
3	5.5	M	R Hemiplegic	R
4	5.1	F	R Hemiplegic	R
5	5.1	F	R Hemiplegic	R
6	7.2	M	Diplegic	R
7	7.2	M	R Hemiplegic	R
8	7	F	R Hemiplegic	R
9	6.1	M	Diplegic	L
10	7.3	M	R Hemiplegic	R

The ages of the children who took part in the study ranged from 5.1 to 7.7 years, with a mean age of 6.36 years.

One of the subjects left the school a week before the injections were administered, thus he was no longer able to participate in the study. The nine remaining subjects received Botox® and a week later were issued with a supination splint. The quantity of Botox® that was injected into each subjects upper limb is depicted in Table 4.2. It outlines the Botox® for each subject with respect to dosage and location.

Dosages varied from 0 to 50 units in the biceps, 20 to 50 units in the pronator, 10 to 40 units in flexor carpi ulnaris, 0 to 10 units in flexor carpi radialis and 0 to 20 units in the thumb adductors. The mean dosage was 27.2, 38.3, 25, 6.7 and 13.89 respectively. The dosage of Botox® that the children received in this study was substantially below the maximum dosage recommended per child of 300U and of the 12 Botox®U/kg[13,20]. In this study the Botox® dosage in units ranged from 80U to 160U, with the mean being 111.1U; and the quantity of Botox® /kg total body weight ranged from 4.35U/kg up to 8.48 U/kg, with the mean U/kg being 5.97.

Table 4.2 Botox® Dosage

Subject Number	Upper Limb Injected	Quantity of Botox® injected (U) per muscle					Body Weight (kg)	U/kg Body Weight
		Biceps	Pronator	FCU	FCR	Thumb Adductor		
1	R	30	40	20	10	15	17.4	6.61
2	L	50	50	40	0	20	29	5.52
3	R	50	50	40	0	20	28.2	5.67
4	R	0	35	20	10	15	18.4	4.35
5	R	0	40	30	0	15	19.2	4.43
6	R	30	20	20	10	0	12.7	6.30
7	R	30	35	20	10	15	16.1	6.83
8	R	30	35	25	10	15	20.8	5.53
9	L	25	40	10	10	10	11.2	8.48
10	R	Dropped out of study before injections were administered					21.1	

One of the subjects was reported as having a major protocol deviation (i.e. two months after the Botox® injections and the issue of the supination splint he stopped attending his weekly therapy sessions and refused to take part in the

assessment procedure that was used to collect data for the study). The limited data for this subject were not included in the analysis. Thus only eight children completed the study.

The parents/caregivers were required to record the time they put on the supination splint and the time they removed it. These times were analysed and the average number of hours during which the supination splint was worn per day was calculated. These are depicted in Table 4.3. The average time ranged from 8.39 to 11.93 with the mean time being 10.43 hours per day.

Table 4.3 Number of Hours Supination Splint was used

Subject Number	Upper Limb Injected	Average Time Splint Worn (hrs/p/day)
1	R	10.14
2	L	9.47
3	R	11.68
4	R	11.28
5	R	11.93
6	R	8.73
7	R	8.39
8	R	11.89

The average time for subject one was calculated from verbal information the researcher obtained from the mother because the time sheet was misplaced whilst the family was moving house as this coincided with the collection of the time sheets. The subject's mother gave the researcher an estimate of the average time when she would apply the supination splint and when she would remove it. The researcher considered excluding this subject but since the mother's recollection of how often the child wore the supination splint was virtually the same as the mean time of all the other subjects; it was decided to keep this subject in the study.

4.2 Spasticity

The Modified Ashworth Scale was used to obtain data on spasticity. In this scale the score of 1+ was converted to 1.5 in order to acquire a statistical numerical value.

Improved ratings in the Modified Ashworth Scale were generally found.
The mean change in spasticity of the forearm pronators, wrist flexors and the thumb adductors from pre-test to post-test in the sixth month is shown in graphs 4.1, 4.2 and 4.3 respectively. Spasticity decreased in the first four months and started increasing from the fourth month, however this didn't reach the level recorded at pre-test. The increase in spasticity was rapid in the fifth month and then very gradual in the sixth month.

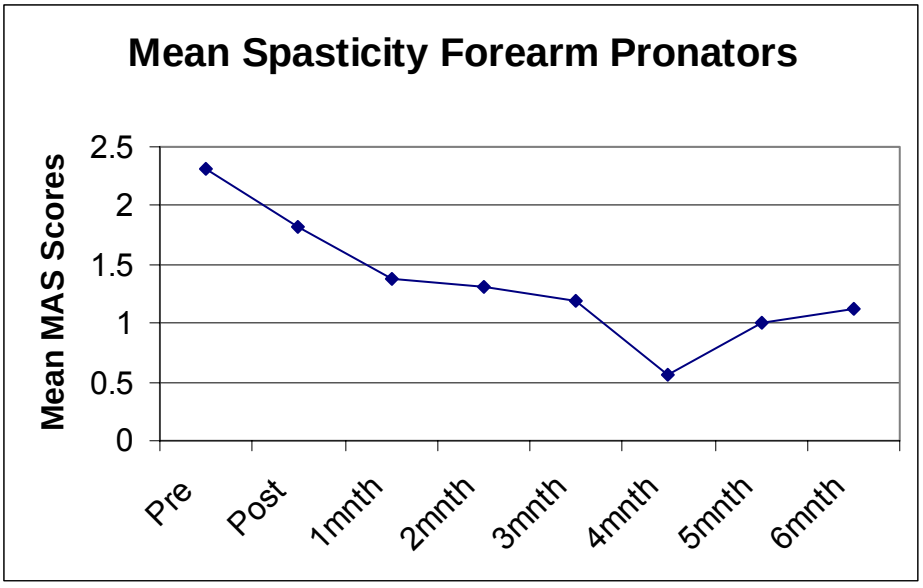


Figure 4.1 Mean Spasticity of Forearm Pronators

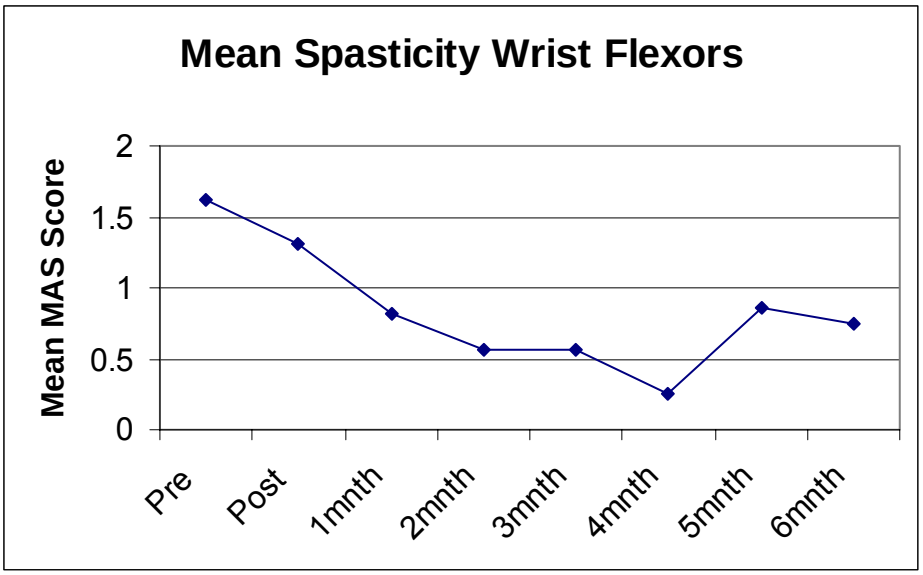


Figure 4.2 Mean Spasticity of Wrist Flexors

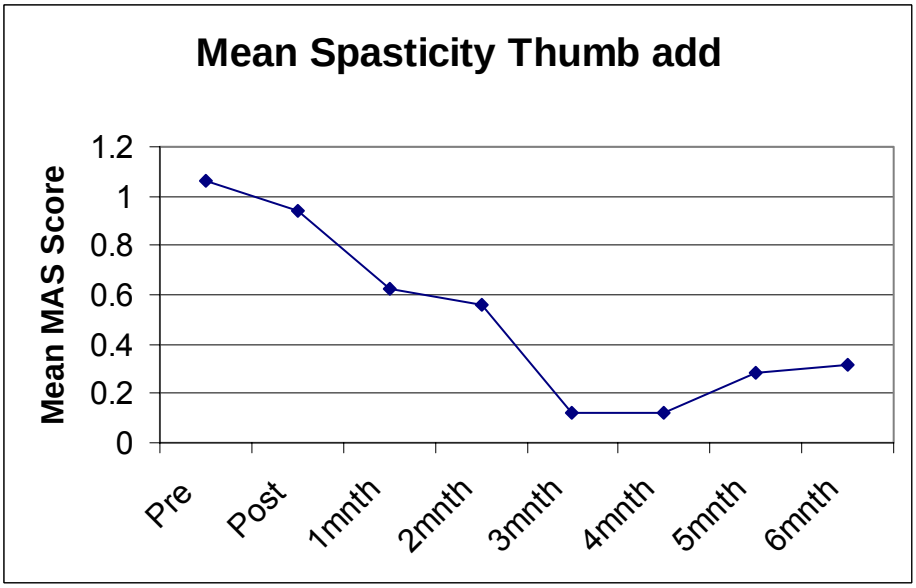


Figure 4.3 Mean Spasticity of Thumb Adductors

Although the change in spasticity caused the children's movements to be irregular, varying in magnitude, and not observed in some of the subjects' muscle groups, though on the whole the improvement in spasticity was statistically significant in a considerable number of the subjects' muscle groups.

The change between pre-test and post-test is seen in Table 4.4. It indicates the statistical findings using the paired t-test which were confirmed with the Wilcoxen signed-rank test.

Table 4.4 Spasticity -paired t-test data

	post	month 1	month 2	month 3	month 4	month 5	month 6
elbow flexors	0.08 ŧ	0.35 ŧ	0.03*	0.01 *	0.07 ŧ	0.16 ŧ	0.03 *
forearm pronators	0.05 *	0.0004 *	0.0005 *	0.0005 *	0.0003 *	0.0023 *	0.002 *
wrist flexors	0.05 *	0.01 *	0.0044 *	0.0019 *	0 *	0.05 *	0.0008 *
thumb adductors	0.17 ŧ	0.02 *	0.02 *	0.0011 *	0.0011 *	0.05 *	0.01 *
thumb flexors	0.03 *	0.20 ŧ	0.56 ŧ	0.01 *	0.02 *	0.14 ŧ	0.01 *

Key:	* statistically significant
	ŧ statistically insignificant

The changes in the spasticity of the forearm pronators and the wrist flexors from baseline to each re-assessment during the six months of the study were found to be statistically significant throughout. The elbow and thumb flexors and thumb adductors were statistically insignificant in the fifth month post intervention.

4.3 Joint Range of Movement

The goniometric readings obtained from the active and passive range of movement were analysed. The mean increase in active range of movement of forearm supination and wrist extension from baseline to post-test in the sixth month is seen in Figure 4.4 and 4.5. There was a mean increase from -3.13º to 46.86º (p=.0002) and -13.25º to 39.63º (p=.0046) respectively The active range

of movement increased rapidly in the first two to three months and thereafter this minimised or began to decrease slightly.

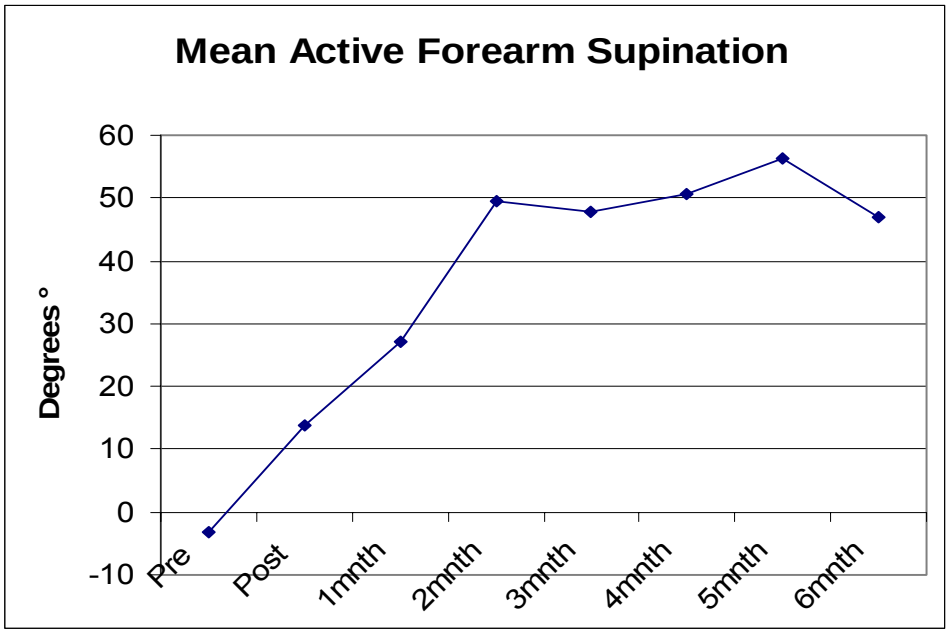


Figure 4.4 Mean Active Forearm Supination

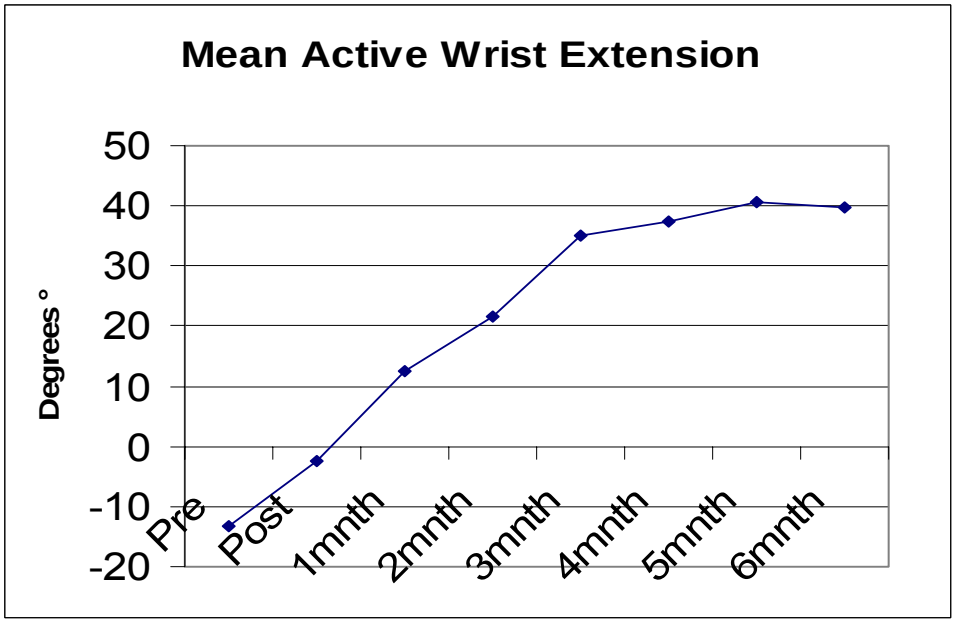
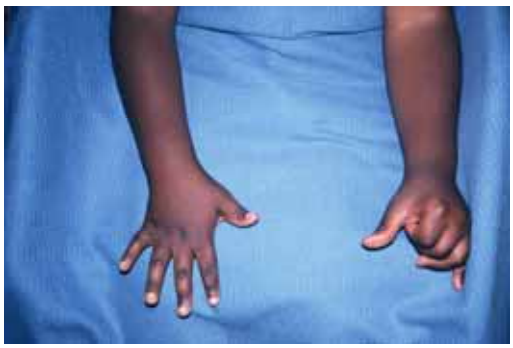


Figure 4.5 Mean Active Wrist Extension

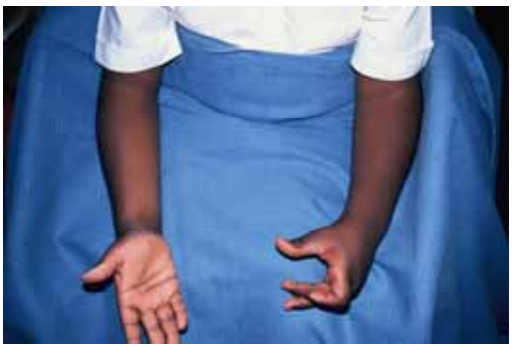
The mean change in active range of movement from pre intervention were significant at all follow up assessments and ranged from 17° - 60° supination and 11° - 54° wrist extension, with the biggest increase occurring in the 5th month for both supination and wrist extension.

Figure 4.6 and figure 4.7 illustrate how the forearm active range of movement changed over the six months of intervention for two of the eight subjects who took part in this study. Their range of pronation remained consistent throughout, but their supination at pre-intervention was very limited, however this had improved considerably by three and six months post intervention. The active range of movement between the third and sixth month is similar, but very different when compared to the range of movement at pre-intervention, indicating the large change in active range of movement during the first three months and a small if no change during the last three months of the study.

Pre Intervention



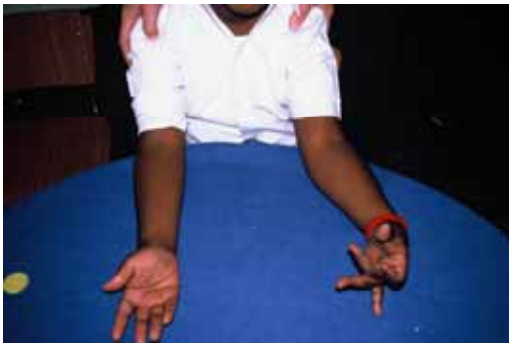
Pronation



Supination

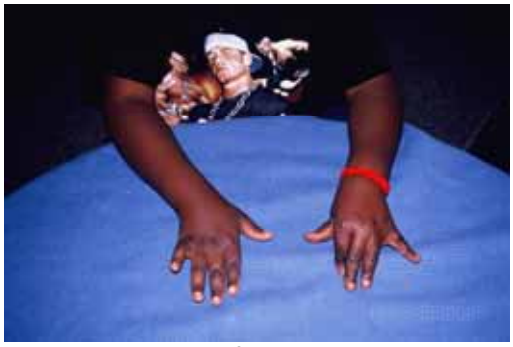
3 Months after intervention

Pronation

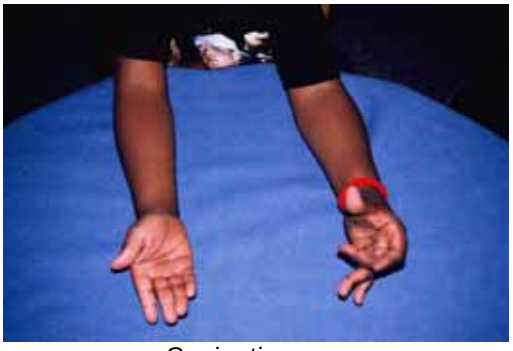


Supination

6 Months after intervention



Pronation

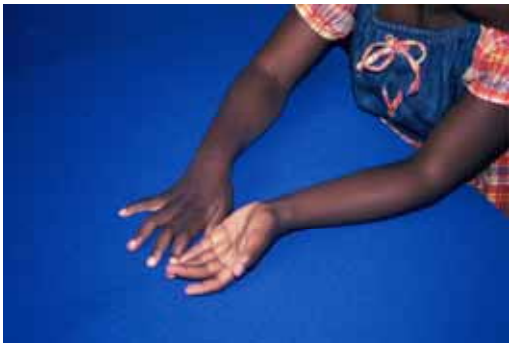


Supination

Figure 4.6 Active Supination Range of Movement – Subject Two

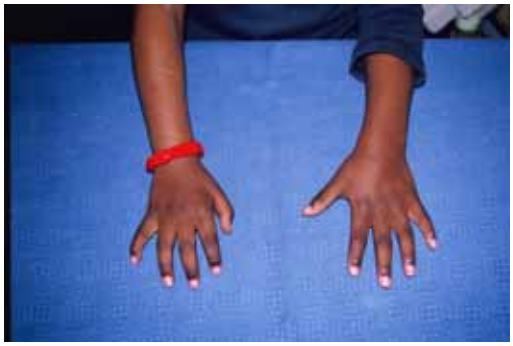
Pre Intervention

Pronation

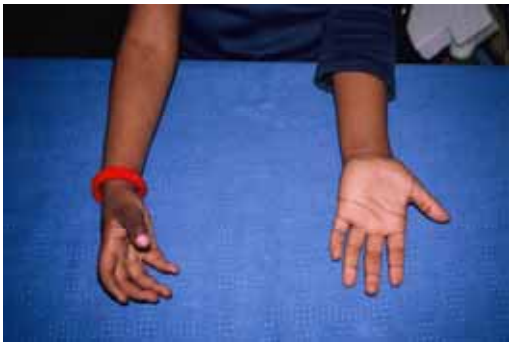


Supination

3 Months after intervention

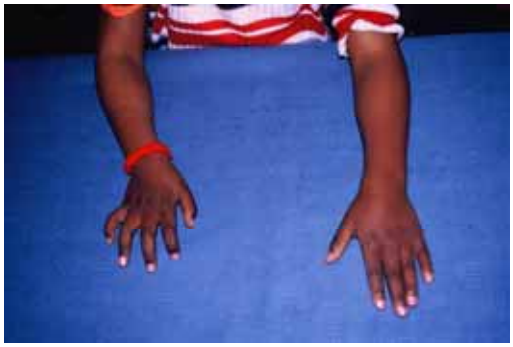


Pronation

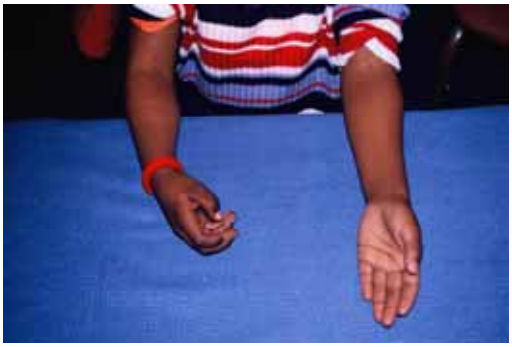


Supination

6 Months after intervention



Pronation



Supination

Figure 4.7 Active Supination Range of Movement – Subject Five

Table 4.5 portrays the statistical data obtained from the paired t-test for the active range of movement. The changes in the active range of movement in forearm supination and wrist extension from baseline to each month were found to be statistically significant after the first month after Botox® and wearing the supination splint ($p<0.05$).

No statistically significant change was observed on the thumb's range of movement.

Table 4.5 Active Range of Movement – paired t-test data

	post	month 1	month 2	month 3	month 4	month 5	month 6
act elbow ext	0.03 *	0.0481 *	0.0108 *	0.0067 *	0.0084 *	0.0248 *	0.0069 *
act elbow flex	0.3475 ŧ	0.4071 ŧ	0.7572 ŧ	0.2033 ŧ	0.0789 ŧ	0.2068 ŧ	0.2554 ŧ
act forearm pro	0.1165 ŧ	0.0476 *	0.0598 ŧ	0.0631 ŧ	0.0631 ŧ	0.0835 ŧ	0.0493 *
act forearm supi	0.0875 ŧ	0.0135 *	0.0002 *	0.0012 *	0.0002 *	0.0008 *	0.0002 *
act wrist ext	0.1499 ŧ	0.0131 *	0.0045 *	0.0038 *	0.0038 *	0.0096 *	0.0046 *
act wrist flex	0.0188 *	0.0492 *	0.095 *	0.0363 *	0.0383 *	0.1076 *	0.0581 ŧ
act wrist ulna deviation	0.1329 ŧ	0.1771 ŧ	0.1945 ŧ	0.6537 ŧ	0.479 ŧ	0.4421 ŧ	0.3415 ŧ
act wrist rad devi	0.9548 ŧ	0.9308 ŧ	0.1779 ŧ	0.0237 *	0.008 *	0.0359 *	0.0559 ŧ
act thumb ab	0.2515 ŧ	0.3625 ŧ	0.0917 ŧ	0.5556 ŧ	0.7411 ŧ	0.6585 ŧ	0.7239 ŧ
act thumb add	0.197 ŧ	.	.	0.3506 ŧ	0.3506 ŧ	.	0.3506 ŧ
act thumb ext	0.1079 ŧ	0.2587 ŧ	0.2222 ŧ	0.1368 ŧ	0.1886 ŧ	0.2348 ŧ	0.1502 ŧ
act thumb flex	.	.	.	.	.		.

Key:	* statistically significant
	ŧ statistically insignificant

The mean change in passive range of movement of forearm supination, wrist extension and radial deviation, thumb abduction and extension from pre-test to post-test in the sixth month are seen in Figure 4.8. Predictably the passive range of movement increased slightly in the first month and remained consistent thereafter, since most of the subjects had nearly full passive range of movement at the beginning of the study, thus leaving minimal room for any major change in the measurements.

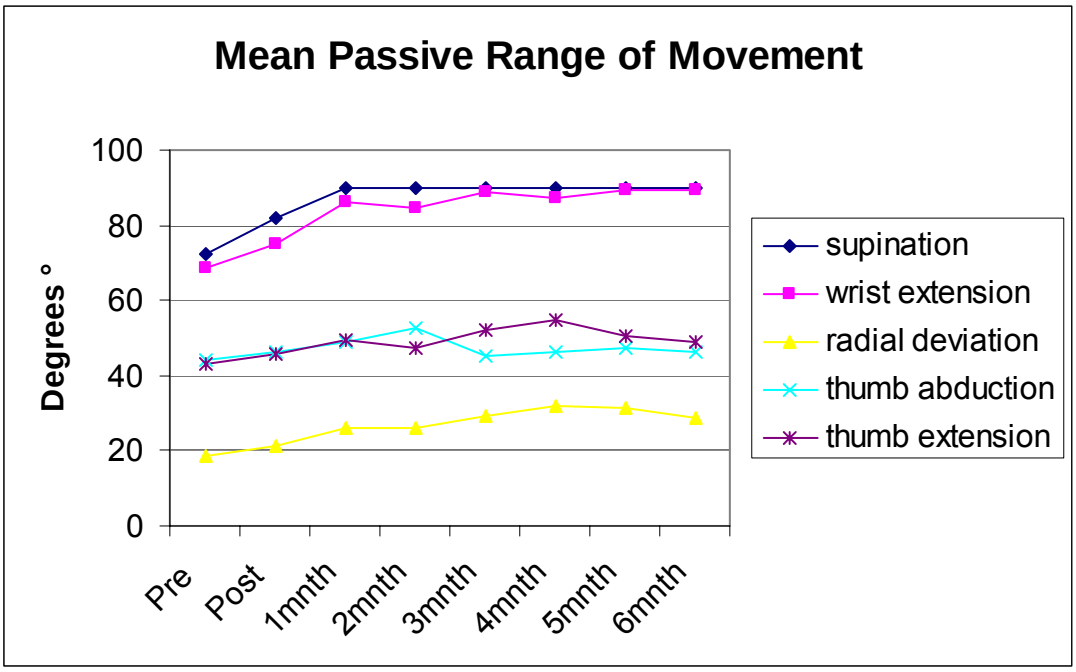


Figure 4.8 Mean Passive Range of Movement

As viewed in Table 4.6, the passive range of movement for wrist extension was statistically significant from the first month onwards ($p<0.05$). Passive elbow flexion showed a significant change at months 1, 3, 4 and 5. A significant change was noted in the passive radial deviation at month 4 and 5 when compared to the pre intervention assessment.

Table 4.6 Passive Range of Movement – paired t-test data

	post	month 1	month 2	month 3	month 4	month 5	month 6
pas elbow ext	.	.	.	.	.	.	.
pas elbow flex	0.7139 ŧ	0.0371 *	0.2318 ŧ	0.0372 *	0.0294 *	0.0447 *	0.0529 ŧ
pas forearm pro	.	.	.	.	.	.	.
pas forearm supi	0.2606 ŧ	0.1598 ŧ	0.1598 ŧ	0.1598 ŧ	0.1598 ŧ	0.2205 ŧ	0.1598 ŧ
pas wrist ext	0.0636 ŧ	0.0069 *	0.0024 *	0.0026 *	0.0025 *	0.0073 *	0.0035 *
pas wrist flex	.	0.3506 ŧ	0.3506 ŧ	0.3506 ŧ	0.3506 ŧ	0.3559 ŧ	0.3506 ŧ
pas wrist ulna deviation	0.1112 ŧ	0.0395 *	0.1439 ŧ	0.1991 ŧ	0.2515 ŧ	0.8646 ŧ	0.1991 ŧ
pas wrist rad deviation	0.5322 ŧ	0.1864 ŧ	0.2044 ŧ	0.0809 ŧ	0.0318 *	0.0077 *	0.0614 ŧ
pas thumb ab	0.4363 ŧ	0.4187 ŧ	0.0964 ŧ	0.866 ŧ	0.6448 ŧ	0.5976 ŧ	0.6625 ŧ
pas thumb add	.	.	.	.	.	.	.
pas thumb ext	0.2053 ŧ	0.1176 ŧ	0.3801 ŧ	0.0757 ŧ	0.0314 *	0.1291 ŧ	0.1079 ŧ
pas thumb flex	.	.	.	.	.	.	.

Key:	* statistically significant
	ŧ statistically insignificant

4.4 QUEST

The total score on the QUEST, demonstrated a statistically significant improvement after the subjects had worn the supination splints for the first month of intervention (P= 0.0093). This change was maintained for the remainder of the period that the children wore their supination splints. This is observed in Table 4.7 which indicates the statistical findings using the paired t-test. These findings were confirmed with the Wilcoxen signed-rank test.

Table 4.7 QUEST - paired t-test data

	post	month 1	month 2	month 3	month 4	month 5	month 6
Dissociated movements	0.0946 ŧ	0.0075 *	0.0018 *	0.0013 *	0.0013 *	0.0166 *	0.0004 *
Grasp	0.7395 ŧ	0.1572 ŧ	0.1016 ŧ	0.0054 *	0.0109 *	0.125 ŧ	0.001 *
Weight bearing	0.1329 ŧ	0.0123 *	0.0281 *	0.0077 *	0.0377 *	0.2857 ŧ	0.0263 *
Total	0.0607 ŧ	0.0093 *	0.0145 *	0.001 *	0.0024 *	0.0366 *	0.0012 *

Key:	* statistically significant
	ŧ statistically insignificant

On the 3 domains of the QUEST, the domain "dissociated movements" (p=0.0075) and "weight bearing" (p=0.0123) showed a significant improvement after the first month of the subjects wearing their supination splints. The statistically significant improvement in the "grasps" domain only became evident in the third month of splint usage (p=0.0054). A statistical significance was noted for the remainder of the time period that the subjects wore their supination splints, except that in the fifth month the "grasp" and "weight bearing" domains did not show a statistical significance. Figure 4.9 illustrates the mean percentage in these three domains.

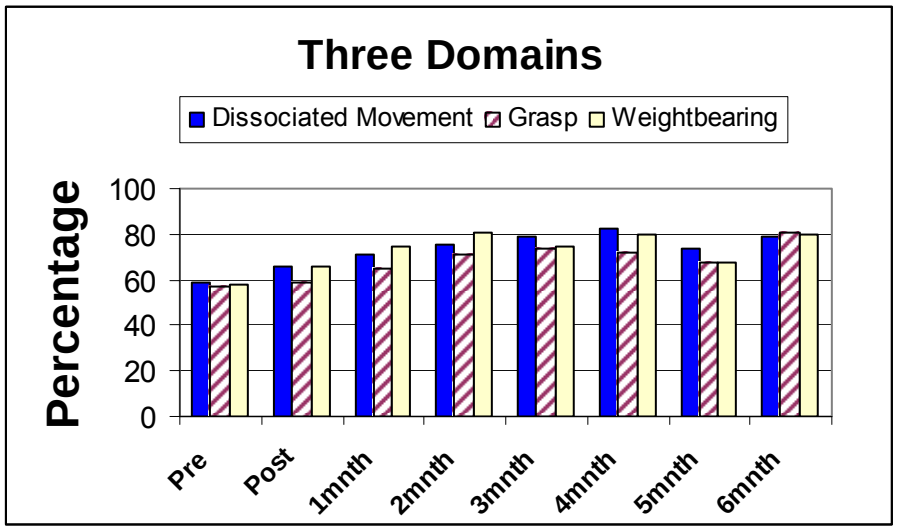


Figure 4.9 Mean Percentages of the Three Domains of the QUEST

The total scores the eight subjects obtained in the QUEST are demonstrated on Figure 4.10. These scores generally show an increase, which suggests an improvement; however all their scores decreased during the fifth month.

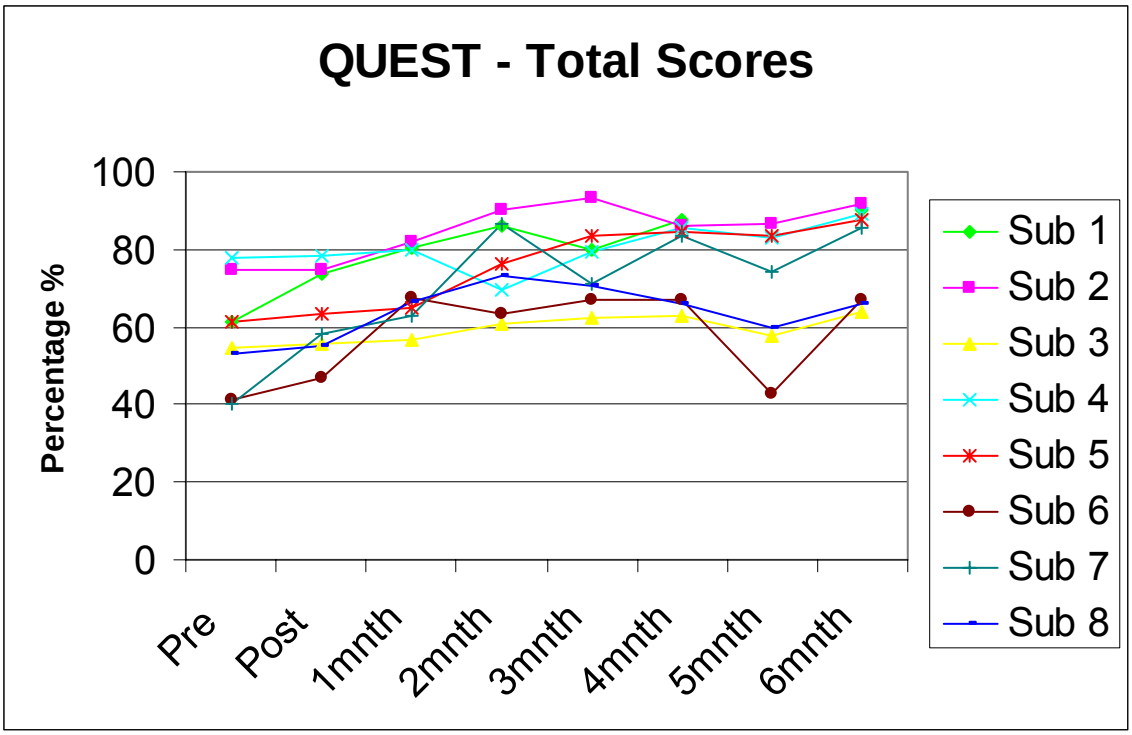


Figure 4.10 QUEST – Total Scores

The subjects in the study obtained a mean total score of 58.05% at baseline. One week after the subjects had had their Botox® injections, the mean total score on the QUEST was 63.27%. By the third month the mean total score was 75.92% and by the sixth month 80.12%. The mean change in the subject's overall quality of movements from pre-test to post-test in the sixth month was 22.07%. This is seen in Figure 4.11.

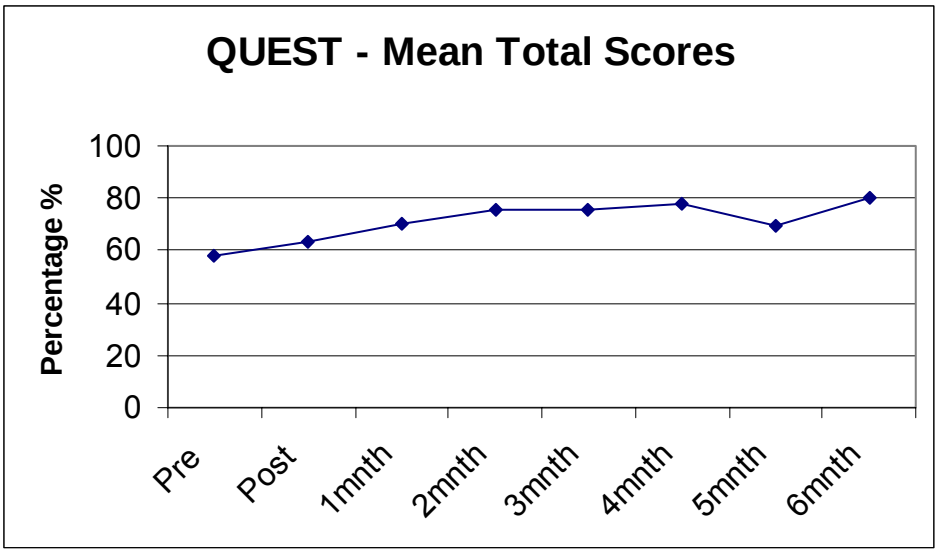


Figure 4.11 QUEST – Mean Total Scores

4.5 Hand Function

Figure 4.12 demonstrates the mean development in the total scores the eight subjects obtained in the hand function test. The average increase is gradual until the second month post Botox® and supination splint use, but this average increase becomes steeper between the second and the sixth month post intervention.

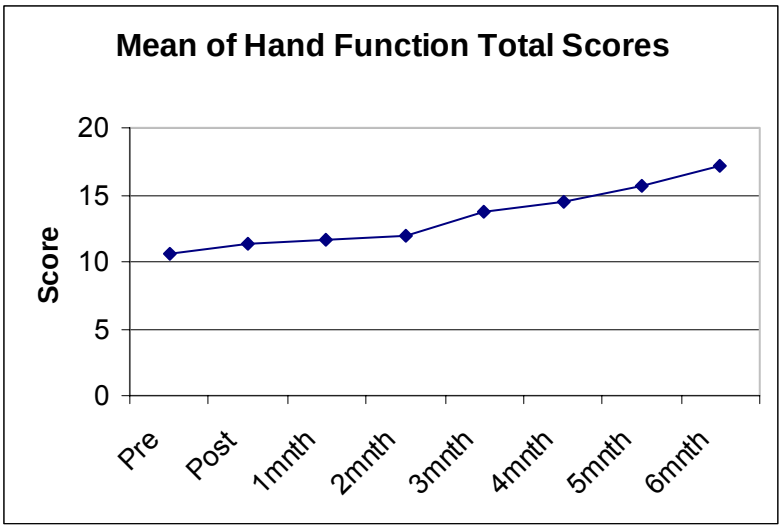


Figure 4.12 Mean of Hand Function – Total Scores

The mean scores for the preset tasks which involved hand grasps namely the transferring tubes and the turning a small barrel are depicted in Figure 4.13 and Figure 4.14. The preset task entailing in-hand manipulation is seen in Figure 4.15. The preset tasks which assessed bi-lateral hand utilisation, namely cutting paper and carrying a plate, are illustrated in Figure 4.16 and Figure 4.17 respectively. The mean scores for the switch activation preset task which evaluated wrist extension are shown in Figure 4.18.

A gradual average increase up until the second month, which then becomes steeper between the second and the sixth month post intervention is clearly indicated in Figure 4.15, 4.16 and 4.18.

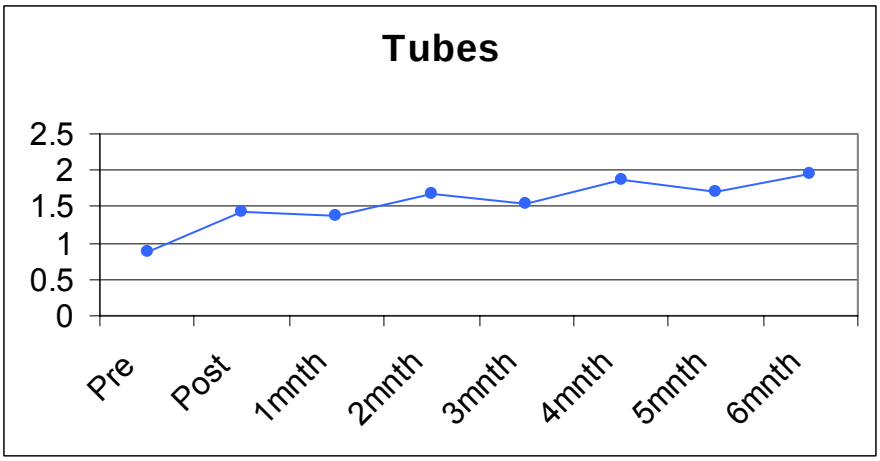


Figure 4.13 Mean Scores of Transferring Tubes Preset Task

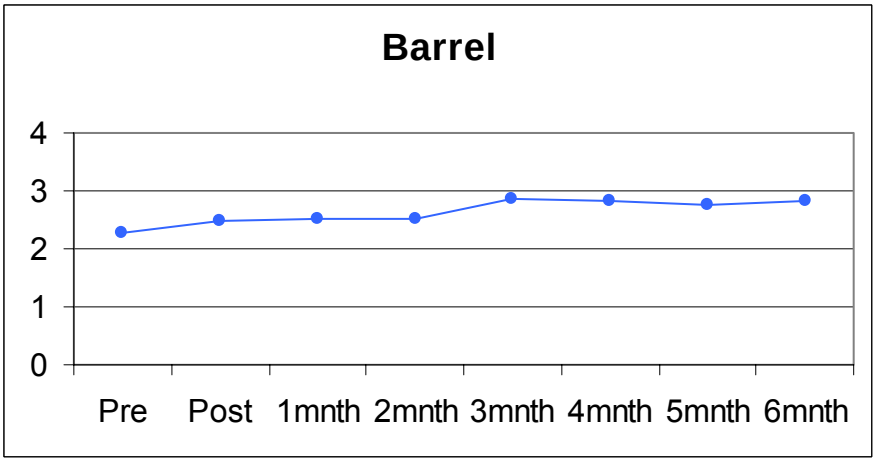


Figure 4.14 Mean Scores of Turning Barrel Preset Task

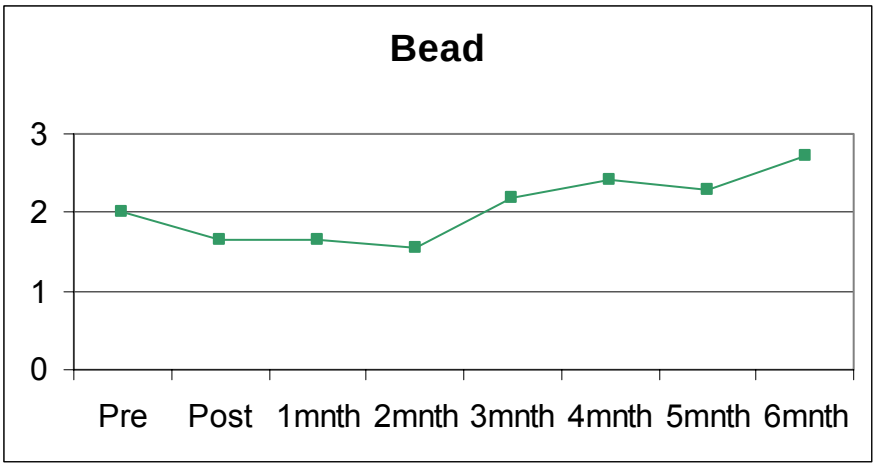


Figure 4.15 Mean Scores of Threading Bead Preset Task

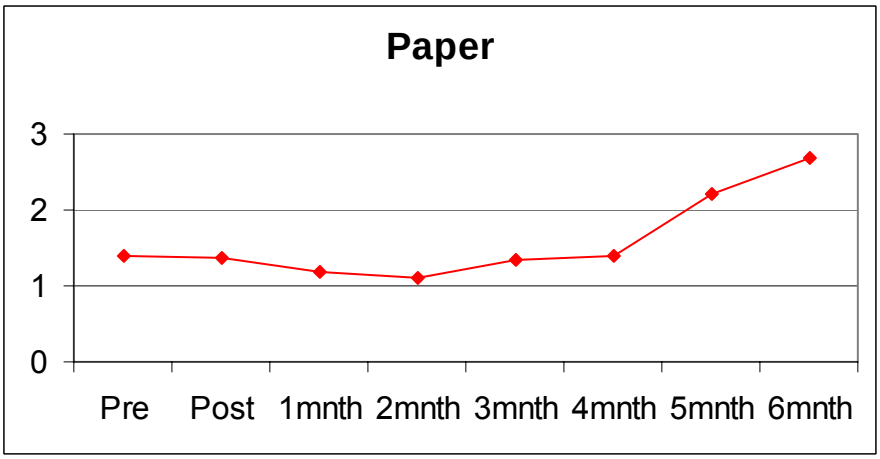


Figure 4.16 Mean Scores of Cutting Paper Preset Task

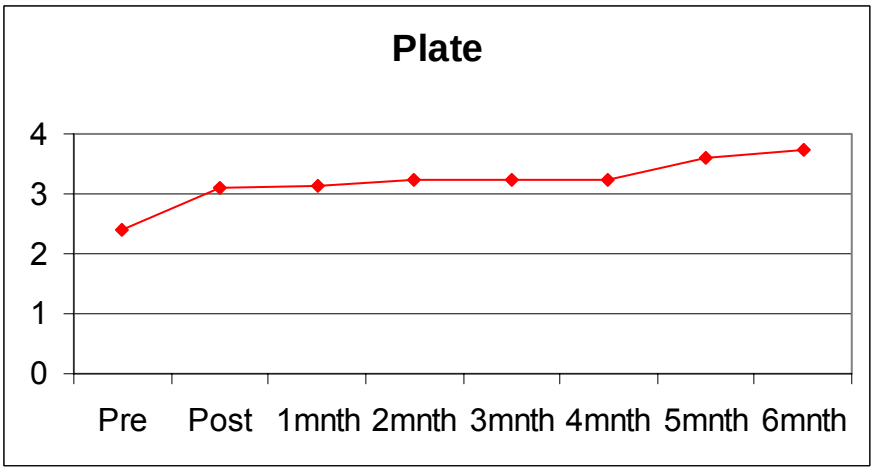


Figure 4.17 Mean Scores of Carrying a Plate Preset Task

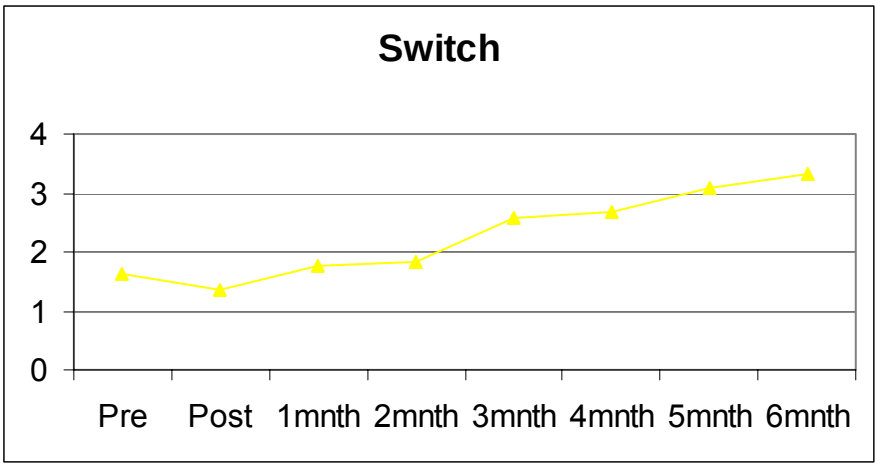


Figure 4.18 Mean Scores of Activating a Switch Preset Task

The statistical findings of the paired t-test for the hand function preset tasks are shown on Table 4.8. A statistical significance was only noted from the second month onwards of the total scores (p=0.0241 in the 2nd month, p=0.0051 in the 3rd month, p=0.0015 in the 4th month, p=0.0015 in the 5th month, and p=0 in the 6th month).

The preset task that required the subjects to turn over a small barrel did not show any significance between the pre-test and any of the post test assessments done during the six months. The other preset tasks only showed some statistical

significance in the later months – cutting a piece of paper at six months (p=0.0022), activating a switch at three months (p=0.036), picking up and threading a bead at six months (p=0.0195) picking up and carrying a plate at four months (p=0.0243). The transferring tubes preset task was erratic in its statistical significance and only became constant in the fourth month (p=0.0016).

Table 4.8 Hand Assessment Total Scores – paired t-test data

	post	month 1	month 2	month 3	month 4	month 5	month 6
Tubes	0.0316 *	0.0766 ŧ	0.0324 *	0.0875 ŧ	0.0016 *	0.0038 *	0.0044 *
Barrel	0.6115 ŧ	0.3506 ŧ	0.4358 ŧ	0.0743 ŧ	0.1286 ŧ	0.4067 ŧ	0.1747 ŧ
Paper	0.9453 ŧ	0.6642 ŧ	0.4908 ŧ	0.8835 ŧ	1 ŧ	0.2621 ŧ	0.0022 *
Switch	0.4463 ŧ	0.7746 ŧ	0.5429 ŧ	0.036 *	0.0292 *	0.0001 *	0.0016 *
Bead	0.2111 ŧ	0.2581 ŧ	0.0639 ŧ	0.5585 ŧ	0.109 ŧ	0.103 ŧ	0.0195 *
Plate	0.1181 ŧ	0.0608 ŧ	0.0544 ŧ	0.0836 ŧ	0.0243 *	0.0039 *	0.0003 *
Total	0.4598 ŧ	0.1335 ŧ	0.0241 *	0.0051 *	0.0015 *	0.0015 *	0 *

Key:	* statistically significant
	ŧ statistically insignificant

This data analysed in this chapter represents and illustrates the findings of this study. Will these results be able to establish whether the supination splint had any effect on the upper limb function of cerebral palsy children? An expanded discussion of how the results impacted on the objectives of this study follows in Chapter 5.

CHAPTER 5 - DISCUSSION

The objectives of this study were to investigate whether a supination splint, which is non-invasive and inexpensive, when used in conjunction with Botox® injections, would result in decreased spasticity, increased joint range of movement, and improved hand function of the child with cerebral palsy. The data presented in the previous chapter is discussed according to each of these objectives, to establish whether the subjects' upper limb function improved during the six month period that they wore their supination splint. The data was examined for statistically significant information and other trends. The limitations of this study were also reviewed.

As a result of the stringent selection criteria of candidates for this study, the number of subjects who were able to meet these criteria was small. However the data gained from the eight (out of the initial ten) subjects used in this study was sufficient for statistical analysis, and to yield statistically significant information.

5.1 Decrease in Spasticity

Spasticity decreased in the first three months. This finding was expected since Botox® blocks neurotransmission preventing muscle contraction. However the spasticity of the forearm pronators, the wrist flexors and the thumb adductors continued decreasing in the fourth month. Thereafter muscle contraction began increasing gradually, but did not reach the level recorded at pre-test. In the study carried out by Friedman et al, a decrease in spasticity was evident in the first three months and endured for four months. But as the effects of Botox® diminished, the spasticity returned to the level it had been prior to the administration of Botox®. In Friedman et al's study the subjects continued with their therapy programme, without alterations. Similarly, in this study no changes

were made to the subjects' therapy programmes, as they too continued with their regular therapies. But in addition to the Botox® subjects wore a circumferential supination splint. Furthermore as is evident in Figure 4.1, 4.2 and 4.3, spasticity levels were not as high by the sixth month as they were before the Botox® was administered. This was clearly evident in 63% of the subjects who participated in this study (Appendix M). This indicated that the circumferential supination splint assisted in maintaining the decreased levels of spasticity up until the sixth month.

The gradual increase in spasticity that started occurring in the fourth month, was initially quite sharp until the fifth month and became mild by the sixth month.
This sharp increase in spasticity coincided with the school holidays and the mild increase occurred while the children were back at school and into their usual routine. The assessment for the fifth month was done the day after the children returned to school and the assessment for the sixth month was done a month later. During the school holidays the children did not receive their regular weekly therapies and they wore their splints for a shorter time period during the day unlike their regular therapy attendance and longer splint usage during the school term. Thus the gradual increase in spasticity during the fourth month may have occurred as a result of insufficient weekly therapy and reduced splint usage, possibly indicating the crucial role weekly therapy and ten hour splint usage have on decreasing spasticity. This was particularly noticeable with subject 7 as his spasticity increased considerably during the school holidays and he only wore his supination splint for an average of eight and a half hours a day (Appendix N)

Law and Barnard found that circumferential splints provide neutral warmth and an even cutaneous pressure on the skin surface area that the splint covers. These reduce the cutaneous sensory input to the spinal cord thereby reducing the level of excitability of the gamma or alpha motor neurons in the muscles, The result would be to decrease the spasticity. Thus the circumferential supination splint used in this study may have helped maintain the reduced level of spasticity in the subjects' upper limbs by providing neutral warmth and even pressure.

Boyd 1997 states that older children with increased spasticity in their upper limbs have complex problems with regards to contractures and bony deformities while younger children may present with few contractures. These contractures develop as a result of the child's upper limb remaining or moving in a specific movement pattern over time. The young child has not usually established these specific movement patterns, whereas the older child more often than not has learnt to use these patterns. The eight subjects that completed this study aged from 5.1 to 7.7 years, with a mean age of 6.36 years. The selection of such young candidates for this study was to provide an intervention that prevented the formation of these severe contractures. Boyd 1997 also states that these contractures progress through a chain of events, the first of which is 'reduced muscle excursion'. In this study the spasticity was reduced and the joint range of movement increased thus augmenting the muscle excursion. It can therefore be assumed that the initial stage in the chain of events which Boyd[43] describes leads to the formation of contractures, has been eliminated.

The decrease in spasticity also provided the children with an opportunity to move with more ease, since they did not have to fight the severe spasticity in order to move their upper limbs. The antagonistic muscles were now able to move because they were no longer being pulled into the spastic pattern, namely elbow flexion, forearm pronation, wrist flexion and thumb adduction. Thus the balance between the agonist flexor and antagonist extensor muscles was improved, allowing a more neutral or supinated forearm, an extended wrist and thumb abduction when moving the upper limb to grasp an object. This position kept the agonist and antagonistic muscles at optimal length and resulted in more reliable and stable grasps.

5.2 Increase in Joint Range of Movement

The design and biomechanics of the supination splint allowed for a constant but gradual force to be applied to the supinator muscles in the forearm but also

maintained the agonists and antagonist forearm muscles in a balance between flexion and extension. According to Tardieu I and Wilton muscle fibres can be lengthened and sarcomere numbers can increase if muscles are gradually stretched and maintained in a balanced state. Figures 4.4 and 4.5 show that as the spasticity decreased the range of movement in the supinator muscles increased. As spasticity decreased the splint applied a gradual force to stretch the pronator and wrist flexor muscles and in so doing, allowed a slightly larger range of supination and wrist extension movement. Several of the subjects who participated in this study substantiate this since their active range of movement increased as their spasticity decreased (Appendix O). This gradual stretching of the muscles allowed for new sarcomeres to be added to the muscle. As a result, the muscle fibres were lengthened and growth of the forearm pronators and wrist flexor muscles was encouraged. Gaebler states that spasticity prevents bones growing at their 'normal' rate. She continues by pointing out that if the spasticity is reduced and that if these new sarcomeres are laid down in a longitudinal manner the muscles may be able to resume growing at the same rate as the long bones. Bone growth alters the number of sarcomeres in the muscles attached to it in order for the muscle to produce a stronger force.

Wilton states that muscle length adaptation due to the increase in number of sarcomeres and the lengthening of the shortened connective tissue elements in the muscle improves muscle 'strength'. She claims that the use of a splint that permits active movement provides weak muscles with the opportunity to move against gravity and to perform functional activities. The supination splint used in this study simultaneously stretched the forearm muscles and allowed active movement, thereby providing the muscles with the opportunity to lengthen and 'strengthen'.

As the antagonistic muscles were able to move with more ease, they were able to move the various joints through a larger range of movement. This is evident in the rapid increase in the active range of movement in the forearm supinators and

wrist extensors during the first two to three months post Botox® as seen in Figure 4.4, 4.5. and Appendix P. This increase occurred at the same time that the spasticity decreased and when the spasticity started increasing again the increase in the active range of movement slowed down. However the gradual increase in spasticity that occurred during the fourth month coincided with the biggest increase in active range of movement seen in the entire study (Figure 4.1, 4.2, 4.4 and 4.5). This may indicate that the children were able to continue moving their upper limbs despite the increase in spasticity as they had regained strength in the antagonistic muscles.

As the active range of movement increased so the children's ability to grasp objects improved. LaStayo and Chidgey[132] observed that when the wrist was slightly extended and forearm supinated there was an increase in grip strength compared to the lack of grip or weakness experienced when the wrist is flexed and the forearm pronated. The mean active range of movement, before the subjects involved in this study received their supination splints, was 3.1° pronation and 13.25° wrist flexion. After wearing their supination splints for three months, the subjects' mean active range of movement increased to 47.85° supination and 35° wrist extension and to 46.87° supination and 39.62° wrist extension by the sixth month. This increased active range of movement observed in Figures 4.4 and 4.5 while Figures 4.6 and 4.7 illustrates the increased active supination range of movement in two of the eight subjects who took part in this study (Appendix Q). Before wearing their supination splints their active supination was very limited or non existent but by the third month they were able to achieve active supination which was maintained until the sixth month. Consequently their grip strength improved as their active range of movement improved.

According to Wilton, a muscle lengthens and weakens if it remains in an elongated position beyond the neutral physiological rest position but not beyond the normal range of movement. When this study was initiated, the antagonistic muscles were held in an elongated position of elbow flexion, forearm pronation,

wrist flexion and thumb adduction, consequently they were lengthened and weakened. But as the subjects' active range of movement improved and the balance between the agonist and antagonistic muscles was restored, the antagonistic muscles returned to their neutral physiological position, thereby regaining their strength. The supination splint allowed for the return of the balance of the agonist and antagonistic muscles because it positioned the subjects' upper limb in the neutral physiological rest position, but it simultaneously allowed active movement into supination and pronation. This newly acquired active movement may have also provided the antagonistic muscles with the opportunity to regain their strength.

No significant improvements were observed as the children's upper limb joints were passively moved through a 1kg traction force (Figure 4.8). This is due to the fact that most of the subjects had nearly full passive range of movement at the beginning of the study, thus leaving minimal room for any major change in the measurements (Appendix R).

5.3 Improvement in Hand function

According to Brin it takes approximately 91 days for reinnervation to occur, in order for neurotransmission to recommence in the injected muscles. The children in this study wore their supination splints for an average of 10.44 hours a day during the 'window period' of no neurotransmission and a further 90 days after this period. Thereby extending the period of therapeutic intervention into these muscles. The supination splint allowed gradual stretching of the injected spastic muscles and at the same time allowed active movement of the antagonistic muscles. Significant improvements were maintained up to six months after the Botox® injections and wearing the supination splint. This is clinically important since the effect the supination splint had on function lasted longer than the Botox® neuromuscular block, which ceased at about three months[95].

Of particular interest was the rate at which the subjects hand function improved.

This was slower than that of spasticity and active range of movement. A very gradual improvement was noted in the subjects' mean hand function from one week post Botox® (mean total score of 11.34) until the second month of supination splint usage (mean total score of 11.96). Then from the second month of supination splint use, the subjects hand function improved steadily to reach a mean total score of 17.18 at six months. Appendix S further illustrates the improvement in hand function in a few of the subjects involved in the study. This indicates that neither the Botox® nor the supination splint had an immediate effect on the subjects hand function, despite the immediate reduction in spasticity and increase in active range of movement. The subjects seemingly needed a larger active range of movement and strengthening or time to practice the movements required for functional use of the upper limb. Therefore a combination of the various therapies was required before an improvement in upper limb function was noticed.

According to Graham, children with cerebral palsy have difficulty with immediate carry over of new functional skills, since motor learning needs to take place in order to benefit from the new biomechanical conditions of lengthened muscles, bigger ranges of movement and reduced spasticity. This was clearly evident in this study. Despite the subjects having decreased spasticity and slightly increased active range of movement by the second month of supination splint use, their hand function had not had any significant improvement. But as the children learnt to make use of their newly acquired active range of movement and lengthened muscles, their mean scores in the hand function assessment increased significantly.

The supination splint provided the subjects with the opportunity to actively move their upper limb, while it simultaneously stretched the muscles gradually and increased the range of movement, thereby facilitating participation in functional tasks. The six preset tasks of the hand function assessment only showed a statistical significance in the later months of the study. Although the preset task

that required the subjects to turn a small barrel had no statistical significance, many valuable functional gains were observed from the other preset tasks of the hand function assessment. Of particular interest was the significant improvement in bilateral hand use from the fourth month onwards (Figures 4.16 and 4.17). It may be assumed that the hand was able to improve to such an extent that it could assist the other hand in functional activities with much greater ease.

A clinically and statistically significant improvement in quality of hand function was seen at one month after the subjects had been wearing their supination splints. The subjects in the study obtained a mean total score of 58.05% before any intervention had been given (Figure 4.11). One week after the subjects had had their Botox® injections, the mean total score on the QUEST had improved to 63.27%. By the third month of donning the supination splint the mean total score had improved to 75.92% and by the sixth month to 80.12%. Thus the subject's overall quality of movements improved by 22.07% during the six months that they wore their supination splints. (Appendix T)

However during the fifth month of using their supination splints, the subject's mean total score decreased to 69.62% (Figure 4.11). This assessment was done the day after the subject's returned to school after a three week school holiday. During this time the subject's did not receive their regular weekly therapies and they wore their splints for a shorter time period during the day. It can therefore be deduced that in order to obtain optimal improvement in the quality of the subject's upper limb movements it is imperative that they receive regular therapy and wear the supination splint for an average of 10-11 hours a day.

Occupational and physiotherapy treatment protocols are directed at improving function in children with cerebral palsy. Splints augment therapy; thus, in order to improve function it is essential to have a combination of both therapy and splinting. The reduction in quality of movement during the school holidays

supports the need to combine both therapy and splinting to obtain functional improvements.

The supination splint positioned the subject's upper limb in a neutral position of forearm rotation. Since the biomechanics of the supination splint assisted with supination and the low force it created, it resisted pronation. The supination splint therefore allowed the subjects to actively extend the wrist without the forearm being pulled into pronation. Thus the subjects were able to perform dissociated movements with more ease. The dissociated movements subtest of the QUEST showed evidence of the most improvement (Figure 4.9). A significant improvement was noted after the first month of supination splint usage, which was consistent throughout the six months of intervention. Although the improvement decreased slightly in the fifth month it was still statistically significant.

The dosage of Botox® the subjects received in this study was smaller then the recommended dosage (12 Botox® U/kg). In spite of this the subjects were able to achieve a significant improvement in their upper limb function during the six months they were wearing their supination splints. This indicates that the supination splint had an effect on the upper limb function.

5.4 Limitations to the Study

The major shortcomings of this study were the small number of subjects and the lack of a control group, both of which could have some bearing on the overall outcome. The ideal method for determining how effective the supination splint is on the upper limb function would be to have two large groups of children with cerebral palsy. Both groups would be injected with Botox® but only one group would receive the supination splint. However the wide variations in the degree of deficit in upper limbs of children with cerebral palsy makes it very difficult to have

large numbers in a study as each subject is very different from the next. The availability of compliant subjects is also poor thus limiting the study to small numbers.

One of the inclusion criteria stipulated that only subjects whose parents were reported as being compliant could be used. This is a particularly difficult area to control.

The subjective hand assessment used in this study was not standardised, hence the different scores the four panelists gave each item. As a result the data obtained from these four panelists was averaged in order to obtain one score per item. Although this average score was still very relevant to the outcome of the subjects' performance over time, it was not as precise as it could have been had a standardised test been used.

CHAPTER 6 - CONCLUSION

The aim of this study was to investigate the effect of a soft supination splint on the upper limb function of children with cerebral palsy after they had received botulinum toxin A injections. This chapter summarises the conclusions reached for each of the objectives of this study, and the prospective value they have added to occupational and physiotherapy programmes. A proposed treatment plan for doctors and therapists working with cerebral palsy children is included. Suggestions are made for future research in this area.

6.1 Conclusions of Objectives

In this study the supination splint was worn for six months and according to Brin the effect of the botulinum toxin A lasts approximately 3 months. The spasticity in the forearm pronators, wrist flexors and thumb adductors decreased considerably in the first four months and started increasing in the fifth month. But by the sixth month the spasticity was still remarkably less than it had been at the beginning of the study. This indicated that the supination splint assisted in maintaining the decreased levels of spasticity even after the effects of the Botox® had worn off. The supination splint lengthened the 'window period' that the Botox® had created. Therefore it can be stated that the supination splint allowed for a longer period of rehabilitation intervention

The spasticity increased significantly during the school holidays when the subjects wore the supination splint for shorter time period during the day and they were no longer receiving their weekly therapy. This may signify the importance of wearing the supination splint for an average of ten hours a day and the vital role weekly therapy plays on decreasing spasticity. The effect of the supination splint on spasticity was maximised when the subjects wore their

splints for an average of at least ten hours, indicating that the longer a child wears a splint the more effective it will be.

This decrease in spasticity facilitated active movement, as the subjects no longer needed to struggle against severe spasticity to move their upper limbs. Thus as the spasticity was decreasing, so the active range of movement was increasing in the forearm supinator and wrist extensor muscles. The active range of movement continued to increase during the fourth month despite the gradual concurrent increase in spasticity. Since the supination splint was a dynamic splint allowing forearm movement between supination and pronation, it can be assumed that it encouraged active movement and thus brought about an increase in the active range of movement. This newly acquired active movement may have also provided the antagonistic muscles with the opportunity to regain their strength.

Neither the Botox® nor the supination splint had an immediate effect on hand function. A significant improvement in hand function was only evident from the second month to the sixth of the study. Improvement in hand function occurred during the month that the effect of the Botox® was practically wearing out. This indicates that a considerable amount of active movement and increase in upper limb muscle strength was necessary before the subjects were able to use their hands functionally. Therefore it can be assumed that upper limb function improved after the supination splint had gradually stretched the muscles and increased the range of movement, thus allowing the subjects to actively move their upper limb.

During the six months the subjects wore their supination splint, the quality of their upper limb movements improved by 22.07%. However during the subjects' school holidays when they were not receiving regular therapy, the quality of upper limb movement declined significantly. This indicates the vast impact that both occupational and physiotherapy have on the treatment of children with

cerebral palsy. Thus children with cerebral palsy who receive Botox® injection therapy in the affected upper limb, it is crucial to attend regular therapy in order to have the optimal benefit of the 'window period' the drug provides.

The supination splint applied a gradual force to the pronator and wrist flexor muscles. The stretching and lengthening of these muscles prevent them from shortening and developing into contractures. Thus the combination of Botox® and the supination splint will prevent the development of contractures in the pronator and wrist flexor muscles of young children with cerebral palsy.

From the above findings it may be concluded that the outcomes of this study support the premise that the supination splint was effective in reducing upper limb spasticity, increasing active range of movement, and improving hand function in children with cerebral palsy. It may be argued that the Botox® and the supination splint were effective in improving the upper limb function of the young children who participated in this study as they had not yet established fixed movement patterns. Whilst older children tend to move in habitual movement patterns, making it difficult for some form of intervention to have an impact on their upper limb function. The combination of Botox® and the supination splint should be used on children younger than seven years to ensure a better probability of achieving improved upper limb function.

6.2 Proposed Treatment Plan

This study supports Graham et al's proposal that the "use of botulinum toxin A injections in the hemiplegic upper limb, combined with intelligent use of occupational therapy and splinting, should reduce deformity and improve function for many children."

The combined use of the supination splint and the Botox® assisted in decreasing spasticity, increasing joint range of movement, and improving hand function in children with cerebral palsy. Thus the proposed treatment protocol for botulinum

toxin A injection therapy in the upper limb should ideally include splinting, occupational and physiotherapy.

A child with cerebral palsy should be supplied with a supination splint a week after being injected with botulinum toxin A. This splint should be worn for 9 – 11 hours during the day to facilitate forearm movement. Before the supination splint is applied the child's upper limb should be massaged and passively stretched. This should be repeated when the splint is removed at night. This massage and stretching should be done for approximately 20 minutes each time.

The massage consists of a deep pressure applied to the various muscles that have been injected with botulinum toxin A. The stretch exercises should entail the passive stretching of the involved joints. A mild cream should be used to apply deep pressure to the upper limb when doing the massage and the passive stretch exercises. All the movements should be done slowly.

For six months following the botulinum toxin A injections, the child should attend regular occupational and physiotherapy. Occupational and physiotherapy treatment protocols are aimed at improving function in children with cerebral palsy. Splints enhance therapy; thus, in order to improve function it is essential to have a combination of both therapy and splinting. It is proposed that the child attend one to two therapy sessions a week. It is suggested that these therapy sessions incorporate both neuro-developmental and biomechanical principles of treatment. These sessions should include weight bearing through the upper limb, joint compression and proprioceptive input, facilitation of elbow extension, forearm supination, wrist and thumb extension, and thumb abduction (Appendix U).

These therapy sessions are only a proposition. Further research needs to be conducted in order to clarify the amount and type of therapy programme needed to help children with cerebral palsy.

6.3 Suggestions for future research

The outcomes of this study are conclusive; however further investigations using a similar research design that includes a larger number of subjects and introduces a control group that does not receive the supination splint would confirm the results obtained in this study.

By broadening the study to the whole country, the problem of small number of subjects may be alleviated. The Botox® would have to be injected by different surgeons with differing levels of experience with this drug however this would necessitate the drafting of another research protocol.

It would be of value to observe upper limb function following use of the supination splint for a period longer than six months.

It would also be of significant value to investigate when the child with cerebral palsy would be able to discontinue use of the supination splint and still maintain adequate upper limb function. A study design could be used in which all the subjects receive the supination splint initially and after six months, half the study group discontinue its use and the other half continue wearing the splint.

Further investigations could be conducted to establish the optimal length of time the children could wear their supination splint daily. The children in this study wore their supination splint for an average of 10.43 hours a day. Even though there was an improvement in their upper limb function the time period they wore their supination splint could have been increased or decreased for perhaps even better function.

The regular occupational and physiotherapy that the children received in this study was not stipulated by the researcher. Thus it might be of value for therapists working with cerebral palsy children to have a prescribed therapy

programme incorporating neuro-developmental and biomechanical principles of treatment.

Given the difficulty in finding a suitably standardised test, there is a need to develop one that assesses hand function of children with disabilities. This assessment should ideally be standardised on children of all ages, namely from one to sixteen years. Such a standardised assessment would assist future investigations.

6.4 Summary

The aim of this study was achieved as it provided evidence that the supination splint had an effect on improving the upper limb function of children with cerebral palsy after they had received Botox® injections. Furthermore the supination splint could successfully be used with Botox® by children with cerebral palsy to decrease their spasticity, increase their active range of movement and improve their hand function.

ᔓᔓᔓᔓᔓᔓᔓᔓᔓᔓ

However it must be born in mind that no matter the type or quantity of intervention given to children with cerebral palsy, they will never be able to achieve normal upper limb function or movement. However if the intervention is able to enable the child to start using his upper limb in functional activities it may be described as a successful type of intervention. By providing a child with the opportunity to participate in functional activities, one is also enabling the child to contribute to the school environment where he/she can learn to be a functioning member of our society.

REFERENCES

[1] Glenn M, Whyte J. The Practical Management of Spasticity in Children and Adults. Philadelphia: Lea & Febiger; 1990.

[2] Cambridge-Keeling, C. Range of Motion Measurment of the Hand. In: Mackin EJ, Callahan AD, editors. Rehabilitation of the Hand and Upper Extremity. 5th ed. Missouri: Mosby; 2002. p. 169-182.

[3] Exner CE. Development of Hand Skills. In: Case-Smith J, editor. Occupational Therapy for Children. 4th ed. Missouri: Mosby; 2001. p. 289-328.

[4] Rogers S, Gordon CY, Schanzenbacher KE, Case-Smith J. Common Diagnosis in Paediatric Occupational Therapy Practice. In: Case-Smith J, editor. Occupational Therapy for Children. 4th ed. Missouri: Mosby; 2001. p. 136-190.

[5] Murphy MS. An adjustable Splint for Forearm Supination. Am J Occup Ther. 1990; 44:936-939.

[6] Law M, Cadman D, Rosenbaum P, Walter S, Russell D, DeMatteo C. Neurodevelopmental therapy and upper-extremity inhibitive casting for children with cerebral palsy. Dev Med Child Neurol. 1991; 33: 379-387.

[7] Yang Tf, Fu CP, Kao NT, Chan RC, Chen SJ. Effects of Botulinum Toxin Type A on Cerebral Palsy with Upper Limb Spasticity. Am J Phys Med Rehab. 2003; April: 284-289.

[8] Bell KR, Williams FW. Use of botulinum toxin type A and type B for spasticity in upper and lower limbs. Phys Med Rehab Clin N Am. 2003; 14: 821-835.

[9] Bly L, Whiteside A. Facilitation Techniques Based on NDT Principles. Texas: Therapy Skill Builders; 1997.

[10] Boehme R. Improving upper body control. An approach to assessment and treatment of tonal dysfunction. Arizona: Therapy Skill Builders; 1988.

[11] O'Flaherty S, Waugh MC. Pharmacologic management of the spastic and dystonic upper limb in children with cerebral palsy. Hand Clin. 2003; 19:585-589.

[12] Friedman A, Diamond M, Johnston MV, Daffner C. Effects of Botulinum Toxin A on upper limb spasticity in children with cerebral palsy. Am J Phys Med Rehab. 2000; 79: 53-59.

[13] Graham HK, Aoki KR, Autti-Ramo I, Boyd RN, Delgado MR, Gaebler-Spira DJ et al. Recommendations for the use of botulinum toxin type A in the management of cerebral palsy. Gait Posture. 2000; 11: 67-79.

[14] Hill SG. Current trends in upper extremity splinting. In: Boehme R. Imroving upper body control: an approach to assessment and treatment of tonal dysfunction. Arizona: Therapy Skill Builders; 1988. p.131-164.

[15] Wall S, Chait LA, Temlett JA, Perkins B, Hillen G, Becker P. Botulinum A chemodenervation: a new modality in Cerebral Palsied hands. Brit J Plast Sur. 1993; 46: 703-706.

[16] Case-Smith J, Pehoski C. editors. Development of hand skills in children. Rockville: American Occupational Therapy Association; 1992.

[17] Exner CE. Development of Hand functions. In: Pratt PN, Allen AS. Occupational Therapy for children. 2nd ed. Missouri: Mosby; 1989. p. 235-259.

[18] Case-Smith J. Grasp, release, and bimanual skills in the first two years og life. In: Henderson A, Pehoski C. Hand function in the child - Foundations for remediation. Missouri: Mosby; 1995. p. 113 -135.

[19] Erhardt RP, Lindley SG. Functional development of the hand. In: Gupta A, Kay SPJ, Scheker LR editors. The Growing Hand: Diagnosis and management of the upper extermity in children. London: Mosby; 2000. p. 71 - 82.

[20] Gaebler-Spira D, Revivo G. The use of Botulinum toxin in paediatric disorders. Phys Med Rehab Clin N Am. 2003; 14: 703-725.

[21] Wilton J. Casting,splinting, and physical and occupational therapy of hand deformity and dysfunction in cerebral palsy. Hand Clin. 2003; 19: 573-584.

[22] Nicholson JH, Morton RE, Attfield S,Rennie D. Assessment of upper limb function and movement in children with cerebral palsy wearing lycra garments. Dev Med Child Neurol. 2001; 43: 384-391.

[23] Strickland JW. Anatomy and kinesiology of the hand. In: Henderson A, Pehoski C. Hand function in the child - Foundations for remediation. Missouri: Mosby; 1995. p. 16 -39.

[24] Timm WN, O'Driscoll SW, Johnson ME, An KN. Functional comparison of pronation and supination strengths. J Hand Ther. 1993; July:190-193.

[25] Lee MJ, LaStayo PC, vonKersburg AE. A supination splint worn distal to the elbow: A radiographic, electromyographic, and retrospective report. J Hand Ther. 2003; July:190-198.

[26] Tang P, Failla JM, Contesti LA. The Radioulnar Joints and Forearm Axis: Surgeons' Perspective. J Hand Ther. 1999; April-June: 75 -84.

[27] Patterson SD. Anatomy and Kinesiology of the Elbow. In: Mackin EJ, Callahan AD, editors. Rehabilitation of the Hand and Upper Extremity. 5th ed. Missouri: Mosby; 2002. p. 88 – 97.

[28] Morrey BF. The Elbow and its Disorders. 2nd ed. Philadelphia: Saunders Company; 1993.

[29] Jaffe R, Chidgey LK, LaStayo PC. The Distal Radioulnar Joint: Anatomy and Management of Disorders. J Hand Ther. 1996; April-June: 129 – 138.

[30] McGinley JC, Heller JE, Fertala A, Gaughan JP, Kozin SH. Biochemical Composition and Histologic Structure of the Forearm Interosseous Membrane. J Hand Surg. 2003; May 28 (3): 503 -510.

[31] Carrasco RC, Powell N. Children wih cerebral palsy. In: Pratt PN Allen AS. Occupational Therapy for Children. 2nd ed. Missouri: Mosby; 1989. p. 396-421.

[32] Geralis E, editor. Children with cerebral palsy: A parents guide. Bethesda: Woodbine House; 1991.

[33] Katz RT, Rymer WZ. Spastic Hypertonia: Mechanisms and Measurement. Arch Phys Med Rehab. 1989;70: 144-155.

[34] Langolis S, MacKinnon JR, Pederson L. Hand Splints and Cerebral Spasticity: A review of the literature. Can J Occup Ther. 1989: 56; 113 - 119.

[35] Trombly CA. Managing deficit of first-level motor control capacities. In: Tombly CA, Radomski MV (ed). Occupational Therapy for Phsical Dysfunction. 5th ed. Pennsylvania: Williams & Wilkins; 2002. p. 571-584.

[36] McPherson J, Kreimer D, Aalderks M, Gallagher T. A comparison of dorsal and volar resting hand splints in the reduction of hypertonus. Am J Occup Ther. 1982; 36: 664-670.

[37] Gracies,JM, Marosszeky JE, Renton R, Sandanam J, Gandevia SC, Burke D. Short-term Effects of Dynamic Lycra Splints on Upper Limb in Hemiplegic Patients. Arch Phys Med Rehab. 2000; 81: 1547-1555.

[38] Boyd RN, Morris ME, Graham HK. Management of upper limb dysfunction in children with cerebral palsy: a systematic review. Eu J Neurol. 2001; 8 (suppl. 5): 150-166.

[39] Freeman JE. Treatment of hand dysfunction in the child with cerebral palsy. In: Henderson A, Pehoski C. Hand function in the child - Foundations for remediation. Missouri: Mosby; 1995. p. 282-298.

[40] Copley J, Watson-Will A, Dent K. Upper limb casting for clients with cerebral palsy: A clinical report. Aus J Occup Ther. 1996; 43: 39-50.

[41] Tabary JC, Tabary C, Tardieu C, Tardieu G, Goldspink G. Physiological and structural changes in the cats soleus muscle due to immobilisation at different lengths in plaster casts. J Physiol. 1972; 224: 231-244.

[42] Jefferson RJ. Botulinum toxin in the management of cerebral palsy. Dev Med Child Neurol. 2004; 46:491-499.

[43] Boyd R, Graham HK. Botulinum toxin A in the management of children with cerebral palsy: indication and outcome. Eu J Neurol. 1997; 4 (suppl. 2): S15-S22.

[44] Hoare BJ, Imms C. Upper limb injections of botulinum toxin A in children with cerebral palsy: A critical review of the literature and clinical implications for occupational therapists. Am J Occup Ther. 2004; 58; 4:389-397.

[45] Correy IS, Cosgrove AP, Walsh E, McClean D, Graham HK. Botulinum Toxin A in the hemiplegic upper limb: A double-blind trial. Dev Med Child Neurol. 1997; 39:185-93.

[46] Tonkin MA. The upper limb in cerebral palsy. In: Gupta A, Kay SPJ, Scheker LR editors. The Growing Hand: Diagnosis and management of the upper extermity in children. London: Mosby; 2000. p. 447 - 460.

[47] Leach J. Children undergoing treatment with botulinum toxin: The role of the physical therapist. Muscle Nerve. 1997; 6(Suppl):S194-S207.

[48] Casey CA, Kratz EJ. Soft Splinting with Neoprene: The Thumb Abduction Supinator Splint. Am J Occ Therapy. 1988; June: 395-398.

[49] Chambers HG. Surgical treatment for spasticity in cerebral palsy: Rhizotomy and orthopaedic procedures. Muscle Nerve. 1997; 6(Suppl):S121-S128.

[50] Gschwind CR. Surgical management of forearm pronation. Hand Clin. 2003; 19: 649-655.

[51] Zancolli EA, Zancolli ER. Surgical management of the hemiplegic spastic hand in cerebral palsy. Surg Clin N Am. 1981; 61: 395 -406.

[52] Gracies JM, Elovic E, McGuire JR, Nance P, Simpson DM. Traditional Pharmacologic Treatments for spasticity Part II: Systemic Treatments. Muscle Nerve. 1997; 6(Suppl):S92-S120.

[53] Reid DT. A survey of Canadian occupational therapists' use of hand splints for children with neuromuscular dysfunction. Can J Occup Ther. 1992; 59:16-27.

[54] Irwin-Carruthers SH. Splinting and spasticity. Physiotherapy. 1984; 40:29-37.

[55] Tardieu C, Heut de la Tour E, Bret MD, Tardieu G. Muscle Hypoextensibility in children with cerebral palsy:I.Clinical and experimental observations. Arch Phys Med Rehab. 1982; March: 97 -102.

[56] Tardieu G, Tardieu C, Colbeau-Justin P, Lespargot A. Muscle Hypoextensibility in children with cerebral palsy:II.Therapeutic implications. Arch Phys Med Rehab. 1982; March: 103-107.

[57] Wilton JC. Hand Splinting - Principles of design and fabrication. London: WB Saunders Company; 1997.

[58] O'Dwyer NJ, Neilson PD, Nash J. Reduction of spasticity in cerebral palsy using feedback of the tonic stretch reflex: a controlled study. Dev Med Child Neurol. 1994; 36: 770-786.

[59] Brennan JB. Response to stretch of hypertonic muscle groups in hemiplegia. Brit Med J. 1959; 13: 1504-1507.

[60] Tardieu C, Lespargot A, Tarbary C, Bret MD. For how long must the soleus muscle be stretched each day to prevent contracture? Dev Med Child Neurol. 1998; 9: 3-10.

[61] Glasgow C, Wilton J, Tooth I. Optimum daily TERT for contracture: Resolution in hand splinting. J Hand Ther. 2003 Sept 16; 3: 207-218.

[62] Mills VM. Electromyographic results of inhibitory splinting. Phys Ther. 1984; 64:190-193.

[63] Barnard P, Dill H, Eldredge P, Held JM, Judd DLM, Nalette E. Reduction of hypertonicity by early casting in a comatosed head-injury individual-A case report. Phys Ther. 1984; 10:1540-1542.

[64] Yasukawa A. Upper extremity casting: Adjunct treatment for a child with cerebral palsy hemiplegia. Am J Occup Ther. 1990; 9: 840-846.

[65] Yasukawa A, Hill J. Casting to improve upper extremity function. In: Boehme R. Imroving upper body control: an approach to assessment and treatment of tonal dysfunction. Arizona: Therapy Skill Builders; 1988. p. 165-188.

[66] McPherson JJ. Objective Evaluation of a Splint Designed to Reduce Hypertonicity. Am J Occup Ther. 1981; 35: 189-194.

[67] Snook JH. Spasticity Reduction Splint. Am J Occup Ther. 1979; 10:648-651.

[68] Langolis S, Pederson L, MacKinnon JR. The effects of splinting on the spastic hemiplegic hand: Report of a feasibility study. Can J Occup Ther. 1991; 58: 17 - 25.

[69] BlochR, Evans MG. An inflatable splint for the spastic hand. Arch Phys Med Rehab. 1977; 58: 179-180.

[70] Scherling E, Johnson H. A tone reducing wrist-hand orthosis. Am J Occup Ther. 1989; 9:609-611.

[71] Gracies,JM, Fitzpatrick R, Wilson L, Burke D, Gandevia SC. Lycra Garments Designed for Patients with Upper Limb Spasticity: Mechanical Effects in Normal Subjects. Arch Phys Med Rehab. 1997; 78: 1066-1071.

[72] Johnstone M. Current advances in the use of pressure splints in the management of adult hemiplegia. Physiotherapy. 1989; July:381-384.

[73] Johnstone M. The use of pressure splints. In: Johnstone M. Restoration of normal movement after stroke. New York: Churchill Livingstone; 1995. p. 49-74.

[74] Johnstone M. Sensory loss. In: Johnstone M. Restoration of motor function in the stroke patient:A physiotherapist's approach. New York: Churchill Livingstone; 1987. p. 49-71.

[75] Blair E, Ballantyne J, Horsman S, Chauvel P. A study of a dynamic proximal stability splint in the management of children with cerebral palsy. Dev Med Child Neurol. 1995; 37:544-554.

[76] Kapandji IA. The upper limb as logistical support for the hand. In: Tubiana R, editor. The hand vol 1. Philidelphia: Saunders; 1981. p. 94-106.

[77] Schultz-Johnson K. Splinting the wrist: Mobilisation protection. J Hand Therapy. 1996; 9: 165-177.

[78] Laseter GF, Carter Pr. Management of distal radius fractures. J Hand Therapy. 1996; 9: 114-128.

[79] Shah MA, Lopez JK, Escalante AS, Green DP. Dynamic splinting of forearm rotational contracture after distal radius fracture. J Hand Surg. 2002; 27A: 456-463.

[80] Barr K. The use of air bag splints to increase supination and pronation in the arm. Am J Occup Ther. 1994; 48: 746-749.

[81] Van Veldhoven G. Splinting with neoprene. Proceedings of the South African Society of Hand Therapists Conference on Splint Application for the Neurological Hand; 2003 Nov; Johannesburg, South Africa. p. 44-62.

[82] Stern EB, Callinan N, Hank M, Lewis EJ, Schousboe JT, Ytterberg SR. Neoprene Splinting: Dermatological Issues. Am J Occup Ther. 1998; 7: 573-578.

[83] Wikipedia [homepage on the Internet]. Spandex- fiber characteristics [updated August 2005; cited 2005 Sept 11]. Available from: http://en.wikipedia.org/wiki/Elastane#Spandex_fiber_characteristics

[84] Lycra [homepage on the Internet]. Lycra© Product Features: Lycra© Fiber [updated 2005; cited 2005 Sept 10]. Available from: http://www.lycra.com/prod/page_lycra.html

[85] Fabrifoam [homepage on the Internet]. ProWrap [cited 2005 Sept 21]. Available from: http://www.fabrifoam.com/p-prowrap.html

[86] Splinting materials - Fabrifoam. Homecraft AbilityOne 2005 Catalogue; p23.

[87] Jankovic J, Brin MF. Botulinum toxin: Historical Perspective and potential new indications. Muscle Nerve. 1997; 6(Suppl):S129-S145.

[88] Brin MF, Aoki KR. Botulinum Toxin Type A: Pharmacology. Muscle Nerve. 1997; 6(Suppl):S146-S168.

[89] Chait LA, de Aguiar G, Theron A, Bleloch S. The role of botulinum toxin in treating Cerebral Palsy hands. Hand and wrist. Curr Opin Ortho. 2002; 13: 251-255.

[90] Koman LA, Mooney KF, Smith BP, Goodman A, Mulvaney T. Management of spasticity in cerebral palsy with botulinum toxin A : Report of a preliminary, randomised, double-blinded trial. J Pediatr Orthoped. 1994; 14: 299-303.

[91] Denislic M, Meh D. Botuilnum Toxin in the Treatment of Cerebral Palsy. Neuropediatrics. 1995; 26: 249-252.

[92] Pidcock FS. The emerging role of therapeutic botulinum toxin in the treatment of cerebral palsy. J Pediatr. 2004; 145: s33-s35.

[93] Russman BS, Tilton AH, Gormley ME. Cerebral Palsy: A Rational Approach to the Treatment Protocol, and the Role of Botulinum Toxin in Treatment. Muscle Nerve. 1997; 6(Suppl):S181-S193.

[94] Issued by pharmaceutical company: Allergan; Propriety name - Botox. Registration number27/30.4/0164. Published 7 May 1999.

[95] Brin MF and Spasticity study group. Dosing, Administration, and a treatment algorithm for use of Botulinum Toxin Type A for adult-onset spasticity. Muscle Nerve. 1997; 6(Suppl):S208-S220.

[96] Childers MK. The importance of electromyographic guidance and electrical stimulation for injection of botulinum toxin. Phys Med Rehab Clin N Am. 2003; 14:781-792.

[97] Garcia Ruiz PJ, Pascual P, Bernardos VS. Progressive response to botulinum A toxin in cerebral palsy. Eu J Neurol. 2000; 7: 191-193.

[98] Fehlings D, Rang M, Glazier J, Steele C. An Evaluation of Botulinum-A Toxin injections to improve upper extremity function in children with hemiplegic cerebral palsy. J Pediatr. 2000;September: 331-337.

[99] Autti-Ramo I, Larsen A, Peltonen J, Taimo A, von Wendt L. Botulinum toxin injections as an adjunct when planning hand surgery in children with spastic hemiplegia. Neuropediatrics. 2000; 31: 4-8.

[100] Kay RM, Rethlefsen SA, Fern-Buneo A, Wren TAL, Skaggs DL. Botulinum toxin as an adjunct to serial casting treatment in children with cerebral palsy. J Bone Joint Surg. 2004; 86-A; 11: 2377-2384.

[101] Wallen MA, O'Flaherty SJ, Waugh MCA. Functional outcomes of intramuscular botulinum toxin type A in the upper limbs of children with cerebral palsy: A phase II trial. Arch Phys Med Rehab. 2004; Feb: 192-200.

[102] Goldstein M. The treatment of cerebral palsy: what we know, what we don't know. J Pediatr. 2004 ; 145(suppl): S42-S46.

[103] Speth LAWM, Leffers P, Janssen-Potten YJM, Vles JSH. Botulinum toxin A and upper limb functional skills in hemiparetic cerebral palsy: a randomised trial in children receiving intensive therapy. Dev Med Child Neurol. 2005; 47:468-473.

[104] Arens LJ, Goldschmidt RB, Leary PM. Experience with botulinum toxin in the treatment of cerebral palsy. S Afr Med J . 1997; 87: 1001-1003.

[105] Hurvitz EA, Conti GE, Brown SH. Changes in movement characteristics of the spastic upper extremity after botulinum toxin injections. Arch Phys Med Rehab. 2003;84: 444-454.

[106] Wong V, Ng A, Situation P. Open label study of botulinum toxin for upper limb spasticity in cerebral palsy. J Child Neurol. 2002; 17(2): 138-142.

[107] Autti-Ramo I, Larsen A, Taimo A, von Wendt L. Management of the upper limb with botulinum type A in children with spastic type cerebral palsy and acquired brain injury: Clinical implications. Eur J Neurol. 2001; 8(Suppl): 136-144.

[108] Hurvitz EA, Conti GE, Flansburg EJ, Brown SH. Motor control testing of upper limb function after botulinum toxin injection - A case study. Arch Phys Med Rehab. 2000; 81: 1408-1415.

[109] Gooch JL, Sandell TV. Botulinum toxin for spasticity and athetosis in children with cerebral palsy. Arch Phys Med Rehab. 1996; 77: 508-511.

[110] Mall V, Heinen F, Linder M, Philipsen A, Korinthenberg R. Treatment of cerebral palsy with botulinum toxin A: Functional benefit and reduction of disability. Three case reports. Pediatr Rehab. 1997; 4: 235-237.

[111] Neutens JJ, Rubinson L. Research Techniques for the health sciences. 3rd ed. San Francisco: Pearson Education; 2002.

[112] Marks RG. Designing a research project - The basics of biomedical research methodology. California: Wadsworth; 1982.

[113] Bailey DM. Research for the health professional - A practical guide. Philidelphia: F.A. Davis Company; 1991.

[114] Howie JG. Research in general practice. 2nd ed. London: Chapman & Hall; 1989.

[115] Hulley S, Cummings SR et al. Designing Clinical Researcg - An Epidemiological Approach. 2nd ed. Philidelphia: Lippincott Williams & Wilkins; 2001.

[116] Franklin RD, Allison DB, Gorman BS, editors. Design and Analysis of Single-case Research. New Jersey: Lawrence Erlbaum Associates; 1996.

[117] Ottenbacher KJ. Evaluating Clinical Change - Strategies for occupational and physical therapist. Baltimore: Williams & Wilkins; 1986.

[118] Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther. 1987; 67:206-7.

[119] Brashear A, Zafonte R, Corcoran M, Galvez-Jimenez N, Gracies JM, Gordon MF et al. Inter- and Intrarater Reliability of the Ashworth Scale and the Disability Assessmnet Scale in Patients with upper limb poststroke spasticity. Arch Phys Med Rehab. 2002; 83: 1349-1354.

[120] Haas BM, Bergstrom E, Jamous A, Bennie A. The inter rater reliability of the original and of the modified Ashworth Scale for the assessment of spasticity in patients with spinal cord injury. Spinal Cord. 1996; 34: 560-564.

[121] Gregson JM, Leathley M, Moore P, Sharma AK, Smith TL, Watkins CL. Reliability of the tone assessment scale and the modified ashworth scale as clinical tools for assessing poststroke spasticity. Arch Phys Med Rehab. 1999; 80: 1013-1016.

[122] Norkin C, White DJ. Measurement of Joint Motion: A guide to goniometry. Philadelphia: F.A. Davis Company; 1985.

[123] Brand P: Methods of clinical measurement in the hand. In: Brand PW, Hollister A, editors. Clinical Mechanics of the hand. 3rd ed. St Louis: Mosby; 1999. p. 322-354.

[124] Flowers KR, Stephens-Chisar J, LaStayo P, Galante BL. Intrarater reliability of a new method and instrumentation for measuring passive supination and pronation: A preliminary study. J Hand Ther. 2001; January: 30-35.

[125] Folio MR, Fewell RR. Peabody Developmental Motor Scales-second edition. Austin: Pro-ed; 2000.

[126] Miller LJ. Assessment for Prescholars. Englewood, CO: Foundation for Knowledge in Development; 1982.

[127] DeMatteo C, Law M, Russell D, Polock N, Rosenbaum P, Walter S. Quality of Upper Extremity Skills Test. Hamilton, Ontorio (Canada): Neurodevelopmental Clinical Research Unit; 1992.

[128] DeMatteo C, Law M, Russell D, Pollock N, Rosenbaum P, Walter S. The Reliability and Validity of the Quality of Upper Extremity Skills Test. Phys Occ Ther Ped. 1993; 13: 1-18.

[129] Artronova. Anatomy of the Hand. Proceedings of the Smith and Nephew workshop on Soft Splinting Techniques; 2002 April; Johannesburg, South Africa.

[130] McCormack GL. The Rood Approach to Treatment of Neuromuscular Dysfunction. In: Pedretti LW editor. Occupational therapy - Practice skills for Physical Dysfunction. 4th ed. Missouri: Mosby; 1996. p. 377-399.

[131] StataCorp. 2003.Stata Statistical Software: 8.0. Colege Station, TX: Stata Corporation.

[132] LaStayo P, Chidgey L. Quantification of the relationship between dynamic grip strength and forearm rotation: a preliminary study. Plast Reconstr Surg. 1995; 35:191-196.

APPENDICES

Appendix A – Gauteng Deptartment of Education Consent Form

UMnyango WezeMfundo
Department of Education

Lefapha la Thuto
Departement van Onderwys

Date:	18 October 2004
Name of Researcher:	Delgado Madalene
Address of Researcher:	110 Bishops Castle
	Home Road
	Malvern East
Telephone Number:	(011) 6460131
Fax Number:	(011) 6460134
Research Topic:	Effect of a Supination Splint on Upper Limb Function of Cerebral Pulsy Children after Botulinum Toxin A
Number and type of schools:	4 LSEN Schools
District/s/HO	Ekurhuleni East

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved to conduct the research. A separate copy of this letter must be presented to both the School (both Principal and SGB) and the District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted.

Permission has been granted to proceed with the above study subject to the conditions listed below being met, and may be withdrawn should any of these conditions be flouted:

1. ***The District/Head Office Senior Manager/s concerned must be presented with a copy of this letter that would indicate that the said researcher/s has/have been granted permission from the Gauteng Department of Education to conduct the research study.***
2. ***The District/Head Office Senior Manager/s must be approached separately, and in writing, for permission to involve District/Head Office Officials in the project.***
3. ***A copy of this letter must be forwarded to the school principal and the chairperson of the School Governing Body (SGB) that would indicate that the researcher/s have been granted permission from the Gauteng Department of Education to conduct the research study.***

Office of the Senior Manager – Strategic Policy Research & Development
Room 525, 111 Commissioner Street, Johannesburg, 2001 P.O.Box 7710, Johannesburg, 2000
Tel: (011) 355-0488 Fax: (011) 355-0286

4. ***A letter / document that outlines the purpose of the research and the anticipated outcomes of such research must be made available to the principals, SGBs and District/Head Office Senior Managers of the schools and districts/offices concerned, respectively.***
5. ***The Researcher will make every effort obtain the goodwill and co-operation of all the GDE officials, principals, chairpersons of the SGBs, teachers and learners involved. Persons who offer their co-operation will not receive additional remuneration from the Department while those that opt not to participate will not be penalised in any way.***
6. ***Research may only be conducted after school hours so that the normal school programme is not interrupted. The Principal (if at a school) and/or Senior Manager (if at a district/head office) must be consulted about an appropriate time when the researcher/s may carry out their research at the sites that they manage.***
7. ***Research may only commence from the second week of February and must be concluded before the beginning of the last quarter of the academic year.***
8. ***Items 6 and 7 will not apply to any research effort being undertaken on behalf of the GDE. Such research will have been commissioned and be paid for by the Gauteng Department of Education.***
9. ***It is the researcher's responsibility to obtain written parental consent of all learners that are expected to participate in the study.***
10. ***The researcher is responsible for supplying and utilising his/her own research resources, such as stationery, photocopies, transport, faxes and telephones and should not depend on the goodwill of the institutions and/or the offices visited for supplying such resources.***
11. ***The names of the GDE officials, schools, principals, parents, teachers and learners that participate in the study may not appear in the research report without the written consent of each of these individuals and/or organisations.***
12. ***On completion of the study the researcher must supply the Senior Manager: Strategic Policy Development, Management & Research Coordination with one Hard Cover bound and one Ring bound copy of the final, approved research report. The researcher would also provide the said manager with an electronic copy of the research abstract/summary and/or annotation.***
13. ***The researcher may be expected to provide short presentations on the purpose, findings and recommendations of his/her research to both GDE officials and the schools concerned.***
14. ***Should the researcher have been involved with research at a school and/or a district/head office level, the Senior Manager concerned must also be supplied with a brief summary of the purpose, findings and recommendations of the research study.***

The Gauteng Department of Education wishes you well in this important undertaking and looks forward to examining the findings of your research study.

Kind regards

ALBERT CHANEE
ACTING DIVISIONAL MANAGER: OFSTED

The contents of this letter has been read and understood by the researcher.	
Signature of Researcher:	
Date:	23/11/04

Appendix B – Ethical Clearance Certificate

University of Pretoria
Faculty of Health Sciences Research Ethics Committee
University of Pretoria
Tel (012) 339 8619 Fax (012) 339 8587
E Mail deepeka.behari@up.ac.za
Soutpansberg Road Private Bag x 385
MRC-Building Pretoria
Level 2, Room 20 0001
Date: 28/09/2004

Number : **S182/2004**

Title : Effect of a supination splint on upper limb function of Cerebral Palsy children after Botulinum Toxin A

Investigator : Madalene Delgado, Dept of Occupational Therapy, University of Pretoria
(SUPERVISOR: MARGOT GRAHAM)

Sponsor : **GENOP Healthcare (Pty) Ltd**

Study Degree : **Masters in Occupational Therapy**

This Student Protocol has been considered by the Faculty of Health Sciences Research Ethics Committee, University of Pretoria on 28/09/2004 and found to be acceptable.

Prof P Carstens	BLC LLB LLD (Pret) Faculty of Law
Prof S.V. Grey	(female) BSc (Hons); MSc; DSc: Deputy Dean
Prof V.O.L. Karusseit	MBChB; MFGP (SA); M.Med (Chir); FCS (SA): Surgeon
Dr M E Kenoshi	MB,CHB; DTM & H (Wits); C.E.O. of the Pretoria Academic Hospital
Prof M Kruger	(female) MB.ChB.(Pret); Mmed.Paed.(Pret); PhDd. (Leuven)
Dr N K Likibi	MB.BCh.; Med.Adviser (Gauteng Dept. of Health)
Dr F M Mulaudzi	(female) Department of Nursing
Miss B Mullins	(female) BscHons; Teachers Diploma
Snr Sr J. Phatoli	(female) BCur (Et.Al) Senior Nursing-Sister
Prof H.W. Pretorius	MBChB; M.Med (Psych) MD: Psychiatrist
Reverend PDG Richards	B.Th. (UNISA), M.Sc. (Applied Biology) (Knights), M.Sc (Med) (Wits), TechRMS, DipRMS
Dr L Schoeman	(female) Bpharm, BA Hons (Psy), PhD
Dr C F Slabber	BSc (Med) MB BCh, FCP (SA) Acting Head; Dept Medical Oncology
Prof J.R. Snyman	MBChB, M.Pharm.Med: MD: Pharmacologist
Dr R Sommers	(female) MBChB; M.Med (Int); MPhar.Med
Dr TJP Swart	BChD, MSc (Odont), MChD (Oral Path) Senior Specialist; Oral Pathology
Prof C W van Staden	MBChB; Mmed (Psych); MD; FTCL; UPLM; Dept of Psychiatry

Student Ethics Sub-Committee

Mrs E Ahrens	(female)B.Cur
Dr L Schoeman	(female) Bpharm, BA Hons (Psy), PhD
Dr R Sommers	SECRETARIAT (female) MBChB; M.Med (Int); MPharMed
Dr S.J.C. van der Walt	(female) B Art et Scien (PU for CHE),M Soc Sc (UFS), M Ed (UFS), D.Cur (RAU)
Mrs N Lizamore	(female) BSc(Stell), BSc (Hons) (Pret),MSc (Pret) DHETP (Pret)
Prof R S K Apatu	MBChB(Legon); PhD(Cambridge)
Advocate A G Nienaber	(female) BA(Hons) (Wits); LLB; LLM (UP); Dipl Datametrics (UNISA)
Dr S I Cronje	DD (UP) – Old Testament Theology
Dr M M Geyser	(female) BSc; MBChB; BSc HONS (Pharm); Dip PEC; MpraxMed

PROF J R SNYMAN
MBChB, M.Pharm.Med: MD: Pharmacologist
CHAIRPERSON of the Faculty of Health Sciences Research
Main Ethics Committee - University of Pretoria

DR L SCHOEMAN
Bpharm, BA Hons (Psy), PhD
CHAIRPERSON of the Faculty of Health Sciences Research
Students Ethics Committee – University of Pretoria

Appendix C – Pharmaceutical Company Approval of Funding Letter

GENOP HEALTHCARE

27 September 2004

To Whom It May Concern

This is to confirm that Genop Healthcare (Pty) Ltd will provide the required quantity of Botox® vials to Madalene Delgardo for her research project "Effect of Supination Splint on Upper Limb Function of Cerebral Palsy Children after Botulinum Toxin A".

Should you require further clarification, please contact Kerry Hofmeyr at 082 854 4488.

Trust you will find the above in order.

Yours faithfully

Michael Johnson
Botox® Business Unit Manager
083 448 1139

GENOP HEALTHCARE (PTY) LTD. Reg. No. 1984/11575/07
PO Box 3911 Halfway House 1685 South Africa. Telephone (27 11) 315-4260 Fax (27 11) 315-6008 Tollfree 0800 110876
Directors: Hon. A E Abrahamson (Chairman)* L P Abrahamson (Deputy Chairman)* G A Seftel (Managing) B E Shear F S Salomon (*Zimbabwe)
Exclusive distributors for

Appendix D – Hand Function Assessment Form

HAND FUNCTION ASSESSMENT FORM FOR THE BOTULINUM INJECTION

SUBJECT NUMBER: _____ DATE: _____

PRESET TASKS

SUPINATION	Score	
transfer tubes	**L**	**R**
0 Only able to transfer tubes in pronation		
1 Actively turns the affected hand slightly to +/- 45 degrees/midposition and transfers the tube		
2 Active supination into midposition and can take the tube off the rod		
3 Transfers tube with active supination into midposition		
4 Passively places the affected hand in supination and can take the tube off the rod		
5 Transfers the tube in supination with the affected hand		
turning barrel upside down	**L**	**R**
0 Unable to grasp barrel to move it		
1 Grasps barrel and lifts but hand stays in pronation		
2 Grasps barrel and attempts to supinate		
3 Grasps barrel and turns slightly to +/- 45 degrees movement		
4 Grasps barrel and turns to midposition		
5 Picks up barrel and turns over in hand into supination		
holding paper for cutting	**L**	**R**
0 Unable to hold paper		
1 Holds paper in prone; the normal hand places the paper in the affected hand		
2 Hand in prone between 90 - 45 degrees; the normal hand places the paper in the affected hand		
3 Thumb on top of paper with forearm in 45°/midposition supination		
4 Thumb on top of paper and forearm in midposition; paper must be horizontal		
5 Pick up paper with affected hand and hold correctly		

Comment: on grip and finger positioning

SUB-TOTAL

SCORE

WRIST EXTENSION	Score

switch	**L**	**R**
0 Unable to actively extend at the wrist at all		
1 Attempts to move in flexion to neutral position 0 degrees		
2 Attempts to move but no/minimal extension 0 - 25 degrees		
3 Wrist extends up to 45 degrees with associated reactions		
4 Wrist extends up to 45 degrees without associated reactions Able to activate the switch with effort		
5 Wrist extends up to the switch with ease and sustains for 3 seconds		

Comment: Finger position

THUMB MOVEMENT	**Score**	
threading beads (bead should be picked up with affected hand)	**L**	**R**
0 Unable to pick up bead		
1 Picks up bead in mass grasp; no manipulation		
2 Picks up bead in mass grasp; clumsy manipulation		
3 Picks up bead in tripod grip; no manipulation		
4 Picks up bead in tripod grip; slow manipulation		
5 Picks up bead and can manipulate bead and thread at normal speed		
carry a plate	**L**	**R**
0 Unable to hold plate in any way		
1 Holds plate with affected hand under plate		
2 Holds plate with fingers on top		
3 Correct placing of fingers but plate too heavy to hold for long		
4 Places plate in affected hand with thumb on top		
5 Pick up plate and carry it.		

Comment : Forearm Position

TOTAL SCORE

Appendix E – Quality of Upper Extremity Skills Test Record Form

QUEST©

Quality of Upper Extremity Skills Test

Carol DeMatteo, Mary Law, Dianne Russell, Nancy Pollock, Peter Rosenbaum, Stephen Walter

Child's Name: _____ Date: _____ (year/month/day) Time of Day: _____

Evaluator: _____ Age: _____ years _____ months

Testing Conditions:

Room _____

Seating (e.g., insert) _____

Table (e.g., cutout) _____

Orthotics (e.g., splints/AFOs) _____

Others Present (e.g., parent) _____

Score Key

✓ = Yes (able to complete item according to specification)

✗ = No (can not or will not complete item)

NT = Not Tested (not able to administer item)

*If a complete section is not tested, insert **NT** in summary score*

MAKE SURE THERE IS A SCORE ENTERED IN EVERY SCORING BOX

SUMMARY SCORE (transfer from QUEST Scoring Sheet)

A:	DISSOCIATED MOVEMENTS	
B:	GRASPS	
C:	WEIGHT BEARING	
D:	PROTECTIVE EXTENSION	

$$\text{TOTAL SCORE} = \frac{\text{SUM OF SCORES FOR EACH SECTION TESTED}}{\text{TOTAL \# OF SECTIONS TESTED}}$$

$$= \_\_\_\_\_$$

A. DISSOCIATED MOVEMENTS
Shoulder Items

Start Position: sitting in chair | no table | hands on lap

ITEM "SHOULDER"	SCORE L <90	SCORE L ≥90	SCORE R <90	SCORE R ≥90	CRITERIA
1. Flexion 	☐	☐	☐	☐	elbow: complete extension wrist: neutral to extension
2. Flexion with Fingers Extended 	☐	☐	☐	☐	elbow: complete extension wrist: neutral to extension
3. Abduction 	☐	☐	☐	☐	elbow: complete extension wrist: neutral to extension
4. Abduction with Fingers Extended 	☐	☐	☐	☐	elbow: complete extension wrist: neutral to extension

✔ ☐ ✘ ☐ NT ☐ 2.

A. DISSOCIATED MOVEMENTS continued
Elbow Items

Start Position: sitting in chair | no table | hands on lap

ITEM "ELBOW"	SCORE L half <range	SCORE L half ≥range	SCORE R half <range	SCORE R half ≥range	CRITERIA
1. Flexion	☐	☐	☐	☐	forearm: complete supination
2. Extension	☐	☐	☐	☐	forearm: complete supination
3. Flexion	☐	☐	☐	☐	forearm: complete pronation
4. Extension	☐	☐	☐	☐	forearm: complete pronation

✓ ☐ ✗ ☐ NT ☐ 3.

A. DISSOCIATED MOVEMENTS continued
Wrist Items

Start Position: sitting at table forearms may be on table

ITEM "WRIST"	SCORE L half <range	SCORE L half ≥range	SCORE R half <range	SCORE R half ≥range	CRITERIA
1. Extension	☐	☐	☐	☐	elbow: complete extension* *see manual for definition of complete extension
					
2. Extension	☐	☐	☐	☐	elbow: at least 10° flexion
					
3. Extension	☐	☐	☐	☐	forearm: complete pronation
					
4. Extension	☐	☐	☐	☐	forearm: complete supination
					
5. Flexion	☐	☐	☐	☐	forearm: complete supination
					

✔ ☐ X ☐ NT ☐ 4.

A. DISSOCIATED MOVEMENTS continued
Finger Items

Start Position: sitting at table forearms must rest on table

ITEM	SCORE L	SCORE R	CRITERIA
1. Independent Finger Wiggling 	☐	☐	dissociation of all fingers no associated reactions
2. Independent Thumb Movement 	☐	☐	no associated reactions

Grasp of 1" Cube

Start Position: sitting at table cube at distance requiring elbow extension

Note: If Item 1 is performed, then Item 2 should also be scored YES

ITEM	SCORE L	SCORE R	CRITERIA
1. Grasp Using Thumb 	☐	☐	shoulder: neutral elbow: extension wrist: neutral to extension
2. Grasp Using Palm 	☐	☐	shoulder: neutral elbow: extension wrist: neutral to extension

✔ ☐ ✘ ☐ NT ☐ 5.

A. DISSOCIATED MOVEMENTS continued
Release of 1" Cube

Start Position: sitting at table cube in child's hand *

* Allowable to put cube in child's hand if he/she can't actively grasp
Note: If Item 1 is performed, then Item 2 should also be scored YES

ITEM	SCORE L	SCORE R	CRITERIA
1. Release from Thumb and Fingers 	☐	☐	shoulder: neutral elbow: extension wrist: neutral to extension
2. Release from Palm 	☐	☐	shoulder: neutral elbow: extension wrist: neutral to extension

✔ ☐ ✘ ☐ NT ☐

Scoring for Part A: DISSOCIATED MOVEMENTS *(pages 2-6)*

Total ✔ : ☐ = a

Total ✘ : ☐ = b

Total NT : ☐ = c

TRANSFER TO QUEST SCORING SHEET ON PAGE i

6.

B. GRASPS
Sitting Posture *during grasps*

Note: **Observations for scoring this item should be made while administering the grasp items in the following section.**

ITEM	SCORE	
	NORMAL	ATYPICAL
Head	☐	☐ Left Right Flexion Extension *circle atypical posture*
Trunk	☐	☐ Forward ☐ Lateral *check off position*
Shoulders	☐	☐ Retracted ☐ Elevated *check off position*

Scoring for Part B1: GRASPS - Sitting Posture *(page 7 only)*

Total Normal (max. = 3) : ☐ = d

Total Atypical (max. = 5) : ☐ = e

TRANSFER TO QUEST SCORING SHEET ON PAGE ii

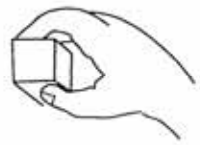
7.

B. GRASPS continued
Grasp of 1" Cube

Start Position: sitting at table cube on table within comfortable reach

Note: Once a grasp has been performed, give a YES score for all those below it. If grasp observed is not listed, then score NO in all boxes and describe it under "Other" below.

ITEM	SCORE L	SCORE R	CRITERIA
1. Radial Digital	☐	☐	wrist: neutral to extension
2. Radial Palmar	☐	☐	wrist: neutral to extension
3. Palmar	☐	☐	



Other:

✔ ☐ ✘ ☐ NT ☐ 8.

B. GRASPS continued
Grasp of Cereal

Start Position: sitting at table

Note: Once a grasp has been performed, give a YES score for all those below it.
If grasp observed is not listed, then score NO in all boxes and describe it under "Other" below.

ITEM	SCORE L	SCORE R	CRITERIA
1. Fine Pincer 	☐	☐	wrist: neutral to extension
2. Pincer 	☐	☐	wrist: neutral to extension
3. Inferior Pincer 	☐	☐	
4. Scissor 	☐	☐	
5. Inferior Scissor 	☐	☐	

Other:

_____

_____

✔ ☐ ✘ ☐ NT ☐ 9.

B. GRASPS continued
Grasp of Pencil or Crayon

Start Position: **sitting at table** **pencil placed midline vertical with point facing child**

Note: **Child must pick up pencil on his/her own.**
Once a grasp has been performed, give a YES score for all those below it.

Circle one of: **L** Dominance **R** Dominance **L** Preference **R** Preference

Circle one of: grasp of **Pencil** grasp of **Crayon**

ITEM	SCORE L	SCORE R	
1. Dynamic Tripod (pencil, grasped distally - precise opposition of thumb, index & middle finger)	☐	☐	
2. Static Tripod (pencil grasped proximally - crude approximation of thumb, index & middle finger)	☐	☐	
3. Digital Pronate	☐	☐	
4. Palmar Supinate	☐	☐	

Other: _____

✔ ☐ ✘ ☐ NT ☐

Scoring for Part B: GRASPS *(pages 8-10)*

Total ✔ : ☐ = f

Total ✘ : ☐ = g

Total NT : ☐ = h

TRANSFER TO QUEST SCORING SHEET ON PAGE ii

10.

C. WEIGHT BEARING

Start Position: **prone** *or* **4 point**

Note: **Once a position is scored, give a YES score for all those below it**

ITEM	SCORE L	SCORE R	CRITERIA
Circle test position: prone 4 point			
1. Weight Bearing			
a) elbow extended, hand open	☐	☐	Thumb must be out of palm for all weight bearing items or they are scored "NO".
b) elbow extended, fingers flexed	☐	☐	
c) elbow extended, hand fisted	☐	☐	
d) elbow flexed, hand open	☐	☐	
e) elbow flexed, fingers flexed	☐	☐	
f) elbow flexed, hand fisted	☐	☐	

ITEM	SCORE
2. Weight Bearing with Reach	
a) Bears weight on **LEFT** hand with **LEFT** elbow completely extended and reaches with other arm.	☐
b) Bears weight on **RIGHT** hand with **RIGHT** elbow completely extended and reaches with other arm.	☐

✔ ☐ ✘ ☐ NT ☐ 11.

C: WEIGHT BEARING continued
Sitting

Start position: sitting on floor preferably cross-legged

ITEM	SCORE L	SCORE R	CRITERIA
1. **Hands forward** - circle test position: cross-legged ring other _____			
a) elbow extended, hand open	☐	☐	Thumb must be out of palm for all items.
b) elbow extended, fingers flexed	☐	☐	
c) elbow extended, hand fisted	☐	☐	
d) elbow flexed, hand open	☐	☐	
e) elbow flexed, fingers flexed	☐	☐	
f) elbow flexed, hand fisted	☐	☐	
2. **Hands by side** - circle test position: cross-legged ring other _____			
a) elbow extended, hand open	☐	☐	Thumb must be out of palm for all items.
b) elbow extended, fingers flexed	☐	☐	
c) elbow extended, hand fisted	☐	☐	
d) elbow flexed, hand open	☐	☐	
e) elbow flexed, fingers flexed	☐	☐	
f) elbow flexed, hand fisted	☐	☐	
3. **Hands behind** - circle test position: cross-legged ring other _____			
a) elbow extended, hand open	☐	☐	Thumb must be out of palm for all items.
b) elbow extended, fingers flexed	☐	☐	
c) elbow extended, hand fisted	☐	☐	
d) elbow flexed, hand open	☐	☐	
e) elbow flexed, fingers flexed	☐	☐	
f) elbow flexed, hand fisted	☐	☐	

✓ ☐ ✗ ☐ NT ☐

Scoring for Part C: WEIGHT BEARING *(pages 11-12)*

Total ✓ : ☐ = i

Total ✗ : ☐ = j

Total NT : ☐ = k

TRANSFER TO QUEST SCORING SHEET ON PAGE iii

12.

QUEST *Scoring Sheet*

A. DISSOCIATED MOVEMENTS

1. Transfer score information from page 6 of QUEST.

Total ✔ = ☐ = a

Total ✘ = ☐ = b

Total NT = ☐ x 2 = c

2. Calculate unstandardized score.

$$\text{Score A} = \frac{2(a) + b}{128 - c} \times 100$$

c **a** is multiplied by 2 because each ✔ scores 2 points.

$$\text{Score A} = \frac{2(\quad) + (\quad)}{128 - (\quad)} \times 100$$

c The **128 - c** calculation adjusts the score for any items not tested.

Score A = ☐

c Round to two decimal points.

3. Obtain a standardized score ranging from zero to 100.

(Score A - 50) x 2 = (- 50) x 2 = ☐

This is the dissociated movements score and can be transferred to the front page of the QUEST.

i.

B. GRASP

1. Transfer score information on sitting posture from page 7.

Total Normal = ☐ x 2 = d

Total Atypical = ☐ x (-1) = e

Score B1 = d + e = ☐

2. Transfer score information on grasps from page 10.

Total ✔ = ☐ = f

Total ✘ = ☐ = g

Total NT = ☐ x 2 = h

3. Calculate unstandardized score.

$$\text{Score B} = \frac{\text{Score B1} + 2(f) + g}{54 - h} \times 100$$

c The **54 - h** calculation adjusts the score for any items not tested.

$$\text{Score B} = \frac{(\quad) + 2(\quad) + (\quad)}{54 - (\quad)} \times 100$$

Score B = ☐

c Round to two decimal points.

4. Obtain a standardized score ranging from below zero (if a child scores ✘ on all items and has atypical posture) to 100.

(Score B - 50) x 2 = (- 50) x 2 = ☐

This is the grasps score and can be transferred to the front page of the QUEST.

ii.

C. WEIGHT BEARING

1. Transfer score information from page 12 of QUEST.

Total ✔ = ☐ = i

Total ✘ = ☐ = j

Total NT = ☐ x 2 = k

2. Calculate unstandardized score.

$$\text{Score C} = \frac{2(i) + j}{100 - k} \times 100$$

c The **100 - k** calculation adjusts the score for any items not tested.

$$\text{Score C} = \frac{2(\quad) + (\quad)}{100 - (\quad)} \times 100$$

Score C = ☐

c Round to two decimal points.

3. Obtain a standardized score ranging from zero to 100.

(Score C - 50) x 2 = (- 50) x 2 = ☐

This is the weight bearing score and can be transferred to the front page of the QUEST.

Appendix F – School Principal's Consent Form

APPLICATION TO CONDUCT A RESEARCH PROJECT

TITLE OF STUDY:-
EFFECT OF A SUPINATION SPLINT ON UPPER LIMB FUNCTION OF CEREBRAL PALSY CHILDREN AFTER BOTULINUM TOXIN A

The Principal Date: _____

Request for a research project to be conducted at your school, amongst Cerebral Palsy children between the ages of 3 to 7 years.

1. THE NATURE AND PURPOSE OF THIS STUDY

The aim of the study is to observe the effect of a treatment modality that is highly likely to improve upper limb function allowing the children to participate in everyday activities. There are two components to this treatment, namely the Botulinum Toxin A which has been proven to work and the supination splint which we are hoping to prove will work. The latter treatment modality is non-evasive, comfortable and easy to apply.

2. EXPLANATION OF PROCEDURES TO BE FOLLOWED

The study involves children having their affected upper limb assessed for range of motion, tonicity, hand function and quality of movements. Prof Chait at the Parklane Clinic will be injecting Botulinum Toxin A into the specific muscles. This Botulinum Toxin A is a drug that will slightly paralyse the tight muscles of the children's upper limb. It takes approximately 7 days to achieve its maximum effect. At this stage the children will be supplied with a supination splint made out of a soft material. The children will need to wear this splint regularly, for approximately 8 hours a day. The children will be re-assessed at 1, 3 and 6 months after the injection date. The child's occupational therapist may need to assist with these assessments. The assessment should not take more than an hour on each child. During these 6 months the children will continue to receive the therapy they have been receiving.

3. POSSIBLE BENEFITS OF THIS STUDY

The results if any will help doctors and therapists in recommending the required therapy and treatment of cerebral palsy. This intervention may help children improve their ability to use their hands in everyday activities.

4. INFORMATION

For any questions regarding this study, please contact:
Madalene Delgado tel: 646-0134 or cell: 083-258-0577

5. CONFIDENTIALITY

All records obtained whilst the children are in this study, will be regarded as confidential. Results will be published or presented in such a fashion that participants remain unidentifiable.

6. CONSENT TO PARTICIPATE IN THIS STUDY

The permission of the Gauteng Department of Education and of the parents/caregivers of each of the children involved in the study will be secured before testing commences. All the relevant teachers will be informed and their support secured.
I hereby consent to a research project being conducted at my school.

I have received a signed copy of this informed consent agreement.

_____ _____
Principal signature Date

_____ _____
Person obtaining informed consent Date

_____ _____
Witness Date

Appendix G – Dosage Information

BOTULINUM TOXIN - DOSAGE SUMMARY

DATE of Injection:
TIME:
DR.: Dr. L. Chait

NAME	D.O.B	Subject Number	AGE	Side to be injected	DOSAGE					Date of 1st Assesment
					Biceps	Pronator	Wrist Flex - FCR	Wrist Flex- FCU	Thumb	

Appendix H – Parent/Caregiver Consent Form

AUTHORISATION TO PARTICIPATE IN A RESEARCH PROJECT

TITLE OF STUDY:-
EFFECT OF A SUPINATION SPLINT ON UPPER LIMB FUNCTION OF CEREBRAL PALSY CHILDREN AFTER BOTULINUM TOXIN A

Dear Parent/Caregiver Date: _____

Your child is being requested to participate in a research project which is a requirement for a Masters Degree in Occupational Therapy through the University of Pretoria.

1. **THE NATURE AND PURPOSE OF THIS STUDY**
   Your child _____ is being asked to take part in a research study. The aim of the study is to observe the effect that a certain treatment will have on the improvement of hand function, which will then allow the child to participate in everyday activities. There are two components to this treatment, namely the drug, Botulinum Toxin A which has been proven to work and the supination splint which we are hoping to prove will work. The splint is a soft, comfortable orthosis, which is easily applied to the child's arm enabling them to turn their wrist around.

2. **EXPLANATION OF PROCEDURES TO BE FOLLOWED**
   The study involves your child having their affected arm assessed for movement, stiffness, performance of specific hand tasks and quality of movements. Prof Chait at the Parklane Clinic will be injecting Botulinum Toxin A into the muscles your child uses to bend their elbow, lift and turn their wrist and open their thumb. This Botulinum Toxin A is a drug that will reduce the movement of the tight muscles of your child's upper limb. It takes approximately 7 days to achieve its maximum effect. With these muscles now being weaker we will then be able to strengthen the other muscles that your child has never had the ability to use. At this stage your child will be supplied with a supination splint made out of a soft material. Your child will need to wear this splint regularly, for approximately 8 hours a day. The splint needs to be used so that the tight muscles can be stretched to enable your child to have more movement in the affected joints. Your child will be re-assessed at 1, 3 and 6 months after the injection date. The assessment consists of measuring and videoing the various movements the child can perform with his arm. During these 6 months your child will continue to receive the therapy he has been receiving.

3. **RISK AND DISCOMFORT INVOLVED**
   The only risk and discomfort involved is the injecting of the Botulinum Toxin A and wearing the supination splint on a daily basis. Your child may experience some itchiness or pain at the injection site for a few hours after they have received the injection. Botulinum Toxin A is a poisonous drug, which if injected in very high dosages can be dangerous. However the pharmaceutical company has calculated safe dosages for the use of this drug. The Botulinum Toxin A your child will be receiving will be within these safe dosages, thus your child should not experience any unpleasant effects. No other risks have been found when Botulinum Toxin A is used.

4. **POSSIBLE BENEFITS OF THIS STUDY**
   The results if any will help doctors and therapists in recommending the required therapy and treatment of cerebral palsy. This intervention may help your child improve their ability to use their hands in everyday activities.

5. **I may at any time withdraw my child from this study**

6. **INFORMATION**
   If you have any questions regarding this study, you should contact:
   Madalene Delgado tel: 646-0134 or cell: 083-258-0577

7. **CONFIDENTIALITY**
   All records obtained whilst your child is in this study will be regarded as confidential. The filming of the video will only focus on the child's hand. Results will be published or presented in such a fashion that participants remain unidentifiable.

8. **CONSENT TO PARTICIPATE IN THIS STUDY**
   I have read or had read to me in a language that I understand the above information before signing this consent form. The content and meaning of this information have been explained to me. I have been given the opportunity to ask questions and am satisfied that they have been answered satisfactorily. I understand that if I do not allow my child to participate it will not alter their management in any way. I hereby consent for my child to participate in this study.

I have received a signed copy of this informed consent agreement.

_____	_____
Parent/Guardian signature	Date
_____	_____
Person obtaining informed consent	Date
_____	_____
Witness	Date

Appendix I – Background Information

Background Information

School Attending: _____

Child's name: _____

Date of Birth: _____ Age: _____

Sex: M F Weight: _____

Address: _____

_____

_____

Parents/Caregivers: _____

Contact Numbers: h _____ w _____ c _____

Home Language: _____

Diagnosis: _____

Hand Injected: R L

Subject Number: _____

Date of Injection: _____

Muscles injected:

	Muscles Injected	Dosage
Biceps		
Pronator Teres		
FCU		
FCR		
Thumb adductor		

Appendix J – Data Form

Botox and Supination Splint Data

Subject Number: _____ Date:_____

Tone

	Left	Right
Elbow Flexors		
Forearm Pronation		
Wrist Flexors		
Thumb Adductors		
Thumb Flexors		

Modified Ashworth Scale of Spasticity

0 = No increase in muscle tone
1 = Slight increased tone manifested by a catch and release of minimal resistance at end of ROM
1+ = Slight increased tone; a catch followed by minimal resistance through remainder of ROM (<½) ROM
2 = More marked increase in tone through most of range but affected parts are easily moved.
3 = Considerable increase in tone; passive movement difficult
4 = Affected parts rigid in flexion or extension

Range of Motion

	Left		Right	
	Passive	Active	Passive	Active
Elbow– ext/flex				
Forearm– pro/sup				
Wrist – ext/flex				
- ulna/rad dev				
Thumb – ab/ad				
– ext/flex				

Appendix K – Home Programme

Supination Splint

Compiled as part of Masters Degree in Occupational Therapy

Purpose

Children with cerebral palsy have very tight muscles. As they get older these muscles become shorter or don't grow as fast as other muscles. This makes it difficult for the children to use their hands.

The Botox injections helped to relax these very tight and stiff muscles, now making it easier to stretch them.

The only way to stretch these muscles so that they can 'grow' or become long again, is to stretch them for several hours at a time.

By wearing the supination splint for several hours a day, the child's muscles can be stretched.

Wearing Regime

The splint needs to worn during the day and removed when the child goes to sleep. It should be worn seven days a week for six months.

Before applying the splint, the arm should be massaged and stretched. This will make it easier to put on the splint.

The same massages should be done when the splint is removed at night, this will help relax the arm.

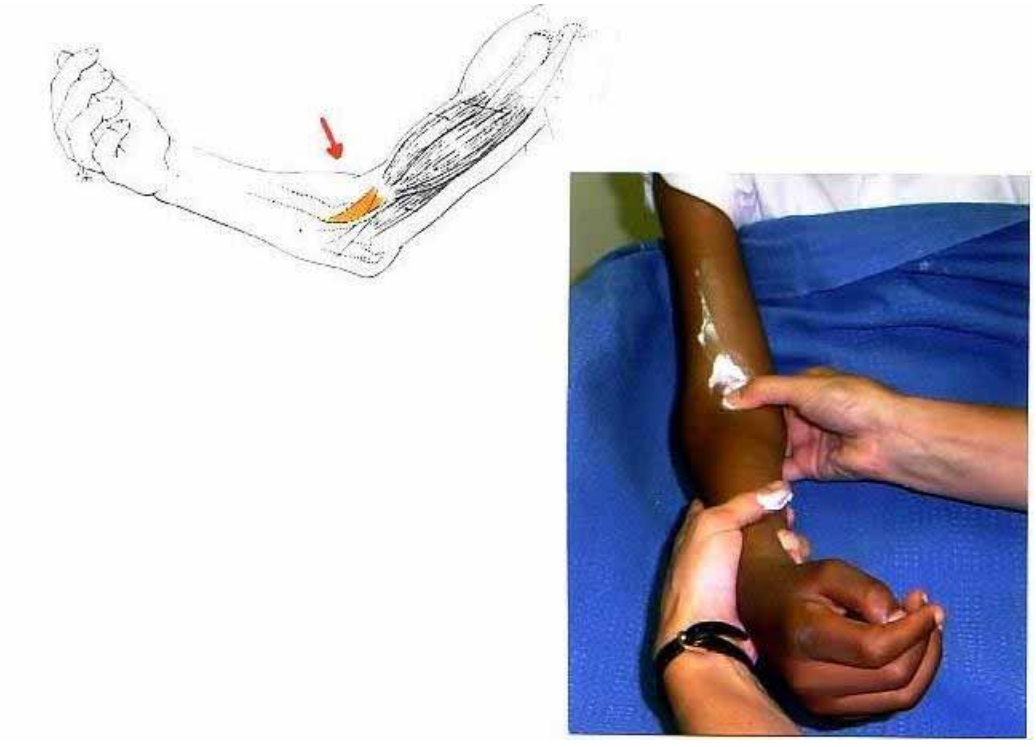
Washing Instructions

- ✓ The splint should be washed with a mild soap e.g. sunlight soap
- ✗ Strong washing powders should not be used.
- ✓ Wash gently.
- ✗ Do not rub or scrub roughly.
- ✓ Leave to dry on a flat surface in a shady place.
- ✓ It is best to allow to dry overnight.
- ✗ Do not place in direct heat.
- ✗ Do not iron.
- ✓ Store the splint rolled up.
- ✗ Do not fold the splint when storing it

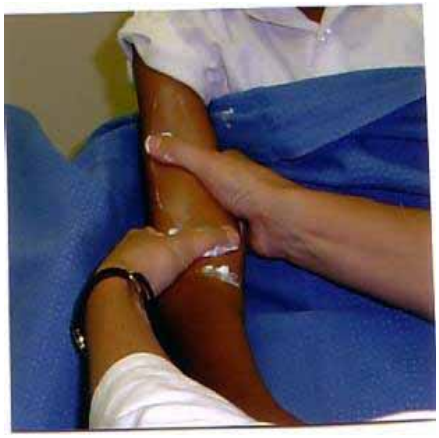
Massage and Stretch Exercises

The arm should be massaged and stretched before the splint is applied. This will make it easier to put on the splint. The same massages should also be done when the splint is removed at night, this will help relax the arm.
The massage and stretch exercises should be done for approximately 10 minutes each time.
These should be done before and after taking off the splint.
These exercises can be done with either you sitting behind or in front of the child, which ever is more comfortable for you and your child.
Use a mild cream e.g. Aqueous cream, and apply deep pressure to the arm when massaging. Movements should be done slowly.

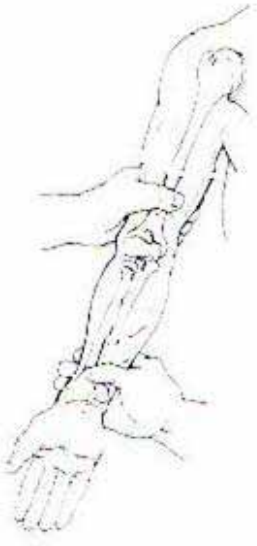
Turn the child's arm so that the palm is facing up. With the arm slightly bent, apply cream to the tendon (feels hard and thin) in the hollow of the elbow.
Rub by applying deep pressure to this area. Move your thumb in a circular motion.

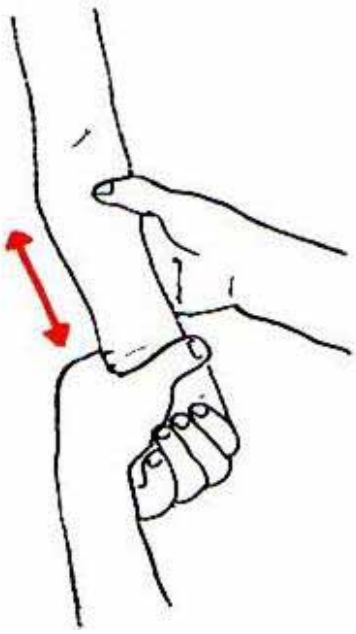


With the elbow still slightly bent, move hands above this hard tendon onto the soft muscle. Place thumbs one on top of the other. While applying deep pressure gently move the thumbs apart keeping them in contact with the skin, as one hand moves up towards the shoulder and the other moves down towards the elbow. Lift hands and keep repeating this process to slowly and gently stretch the muscle.

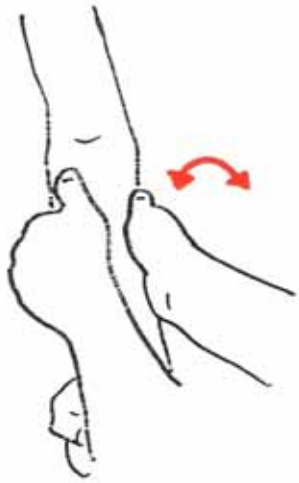


Keeping the elbow slightly bent, and the palm of the hand facing up. Place fingers underneath forearm and the thumb on top, between the two bones in the forearm. Firmly but slowly move the thumb down towards the wrist keeping it between these two bones. Still keeping the thumb between these two bones move it back up to the elbow. Repeat this several times.

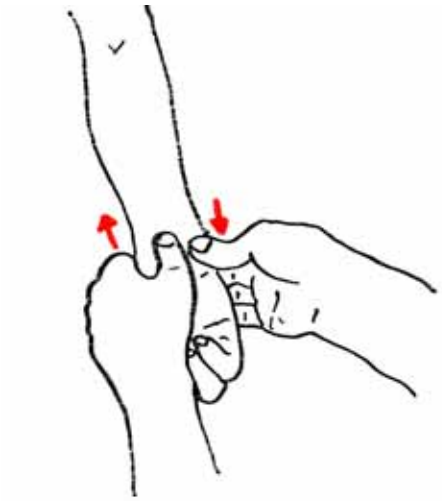


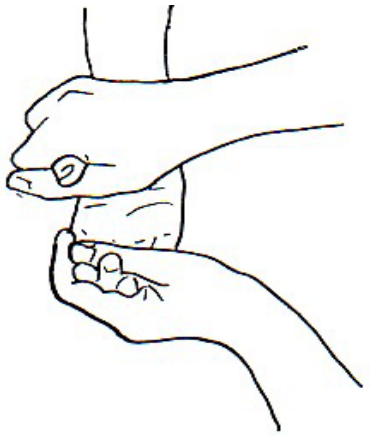


Move both hands to the muscle just below the elbow joint. Place fingers underneath the forearm and thumbs next to one another on top in the center of the forearm. Slowly move thumbs apart towards the side of the forearm. Repeat this all the way down the forearm, starting in the center and moving to the sides.



Still with the palm facing up, move both thumbs down to the wrist level, and keeping each thumb on each of the wrist bones. Keep index fingers underneath the bones, applying some force, slowly move one bone up and the other bone down.

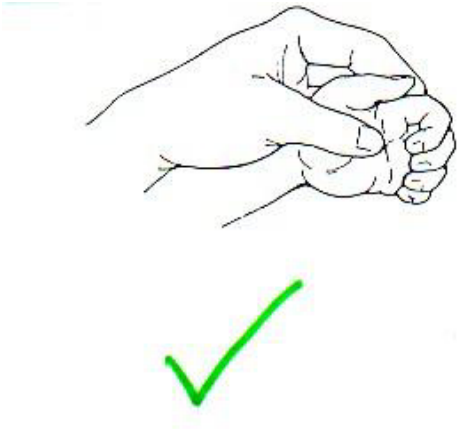


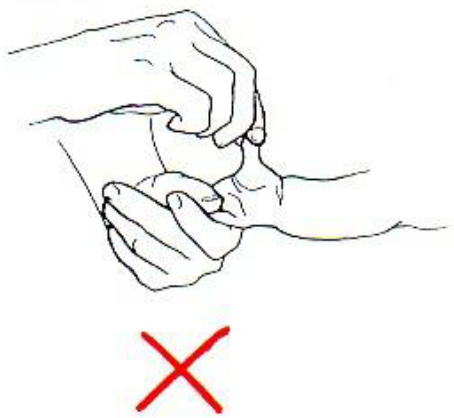


Move your hand to the palm of the child's hand. Using one hand grab the child's thumb at the base and slowly move to the tip of child's thumb (as if squeezing it out).
Repeat several times.

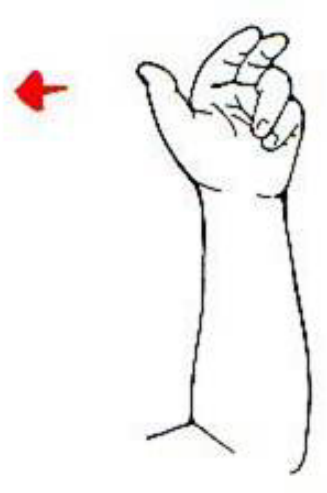
Move both your thumbs to the center of the child's palm. Keeping your fingers underneath the child's hand, move your thumbs apart. While doing so, move the child's hand bones as if forming a cup with the palm of his hand. Repeat several times.

Stretch thumb muscles by holding child's thumb over the muscle. Never hold child's thumb at the finger tip.

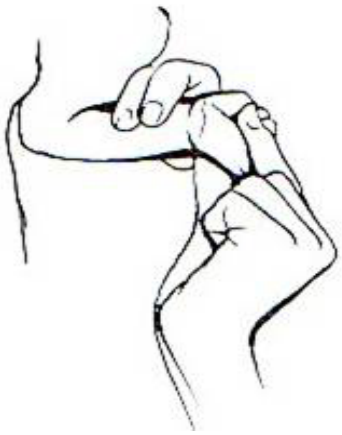




Slowly move child's thumb away from palm. Move in two directions – first move it to the side and then move it up.



Keep holding child's arm with the palm facing up.
Stretch wrist muscles by keeping the child's fingers and thumb straight.
Slowly move hand down.
Hold this position for several seconds. Release slightly and hold again for several seconds.
Repeat 5 times



With the elbow bent, stretch forearm muscles by keeping the wrist down and turning forearm out towards thumb. Hold this position for several seconds. Release slightly and hold again for several seconds.
Repeat 5 times

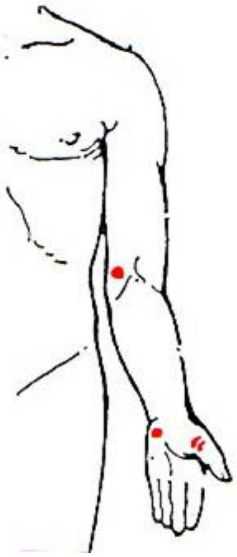
Stretch elbow muscles by straightening the elbow, turning palm up and holding wrist down. Hold this position for several seconds. Release slightly and hold again for several seconds. Repeat 5 times

Putting on the Splint

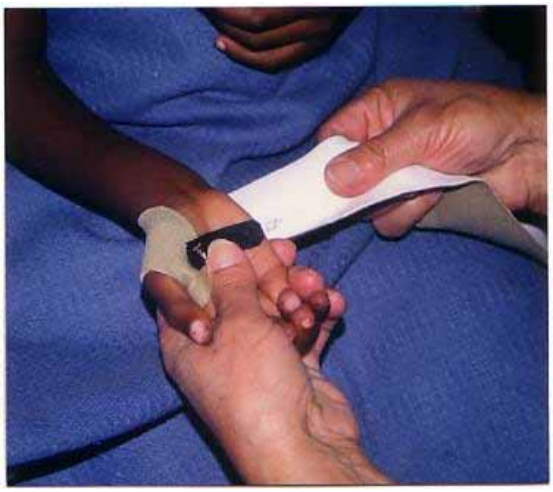
The splint should be applied after the massage and stretch exercises have been done. You should sit in front of the child when the splint is being applied. Splint should be applied quite tightly but not too tight so as to prevent blood flow. Hold the child's arm with the palm facing up.

Find the following skin features on the child's arm:

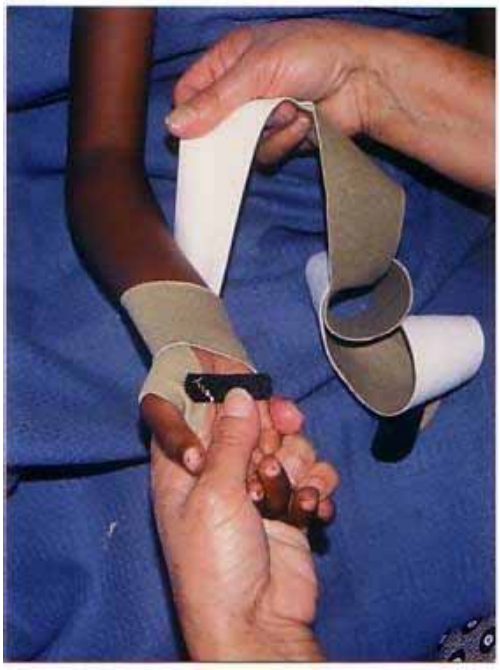
- Bony part at elbow on the side of the little finger (known as the funny bone)
- Muscle at wrist level on the side of the little finger
- Lines at the base of the thumb



Place splint through child's thumb; bring it right down until the lines at the base of the thumb have been covered.



Take splint round the back of the child's hand so that it comes out on the side of the little finger.



Bring splint round to the front and cover muscle at wrist level on the side of the little finger. Take splint round to other side of wrist. Splint should overlap part around the thumb.
Take splint round to the back again. Bring splint round to just above wrist level on the side of the little finger. Splint should overlap the part around the wrist. Wrap splint snuggly.

Keep winding splint up forearm. At elbow level just above the funny bone, bring the splint round from the back. Tie it around the elbow and secure with velcro strap. Make sure that **the funny bone is NOT covered** by the splint.

Lift the strap at the thumb and pull it so that it lifts the thumb. Place strap on the part of the splint that covers the muscle at wrist level on the side of the little finger. This strap allows the thumb to remain turned, so that the child is able to pick up objects.

The splint should position the child's arm with the palm facing slightly up and the thumb out of the palm of child's hand.

Precautions

Do not apply splint too tightly – could cause hand to swell

Watch out for swelling of the hand – remove splint and allow swelling to go down before reapplying splint.

Appendix L – Time Sheet

Supination Splint Time Sheet

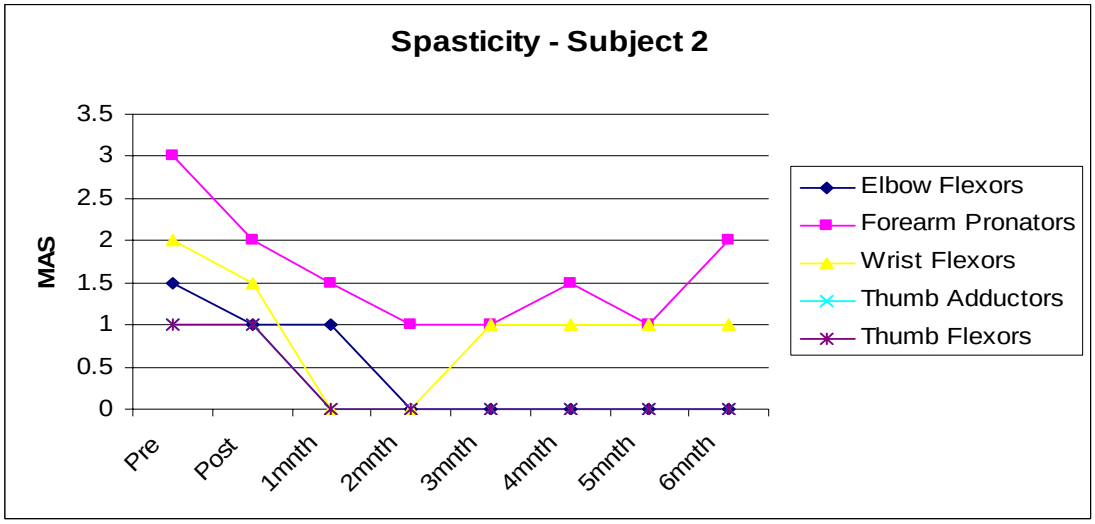
Child's Name: _____ Arm Affected: _____

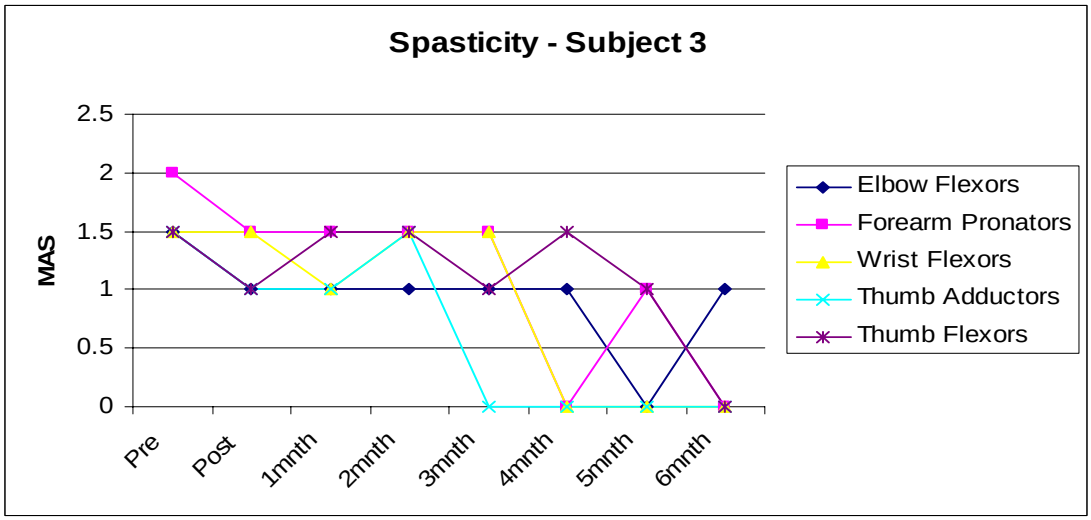
Date of Injection: _____ Date Splint Supplied: _____

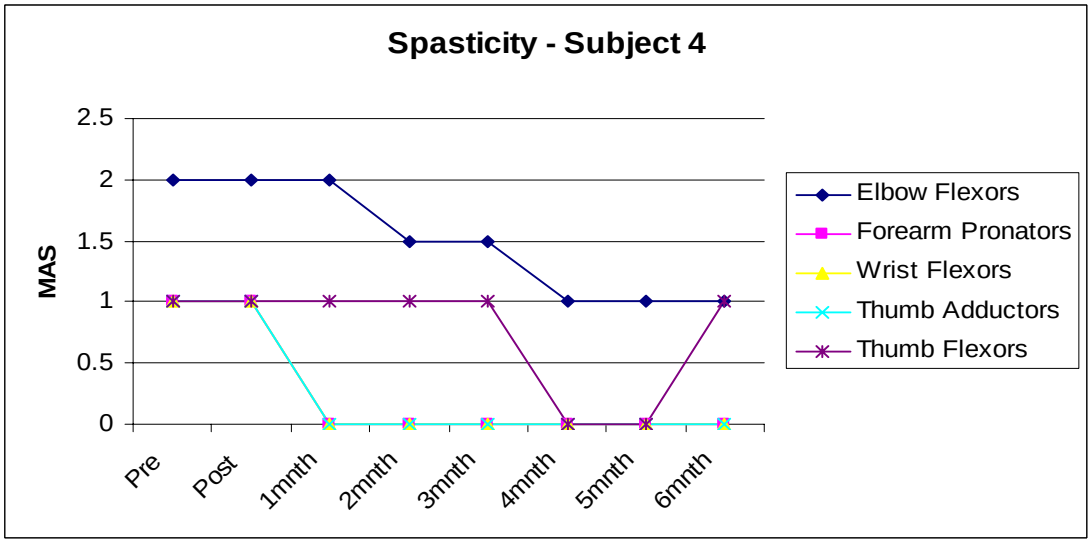
(Six tables as the one below were provided)

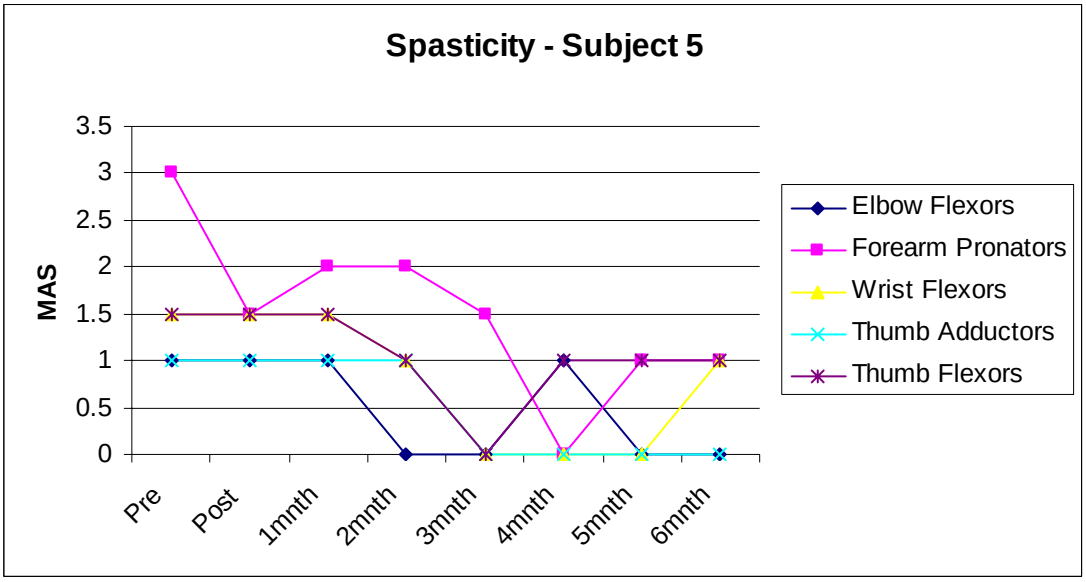
Date	Pasive Stretch Exercise Done		Time		Time		Total Time
	Yes	No	On	Off	On	Off	

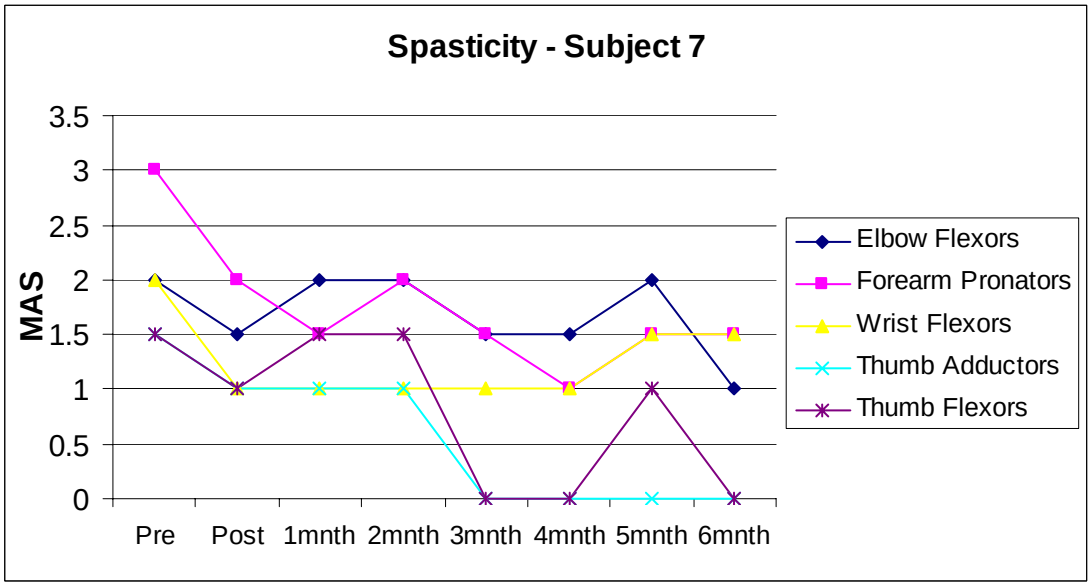
Appendix M – Spasticity Levels


Spasticity - Subject 2
MAS
3.5
3
2.5
2
1.5
1
0.5
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Elbow Flexors
Forearm Pronators
Wrist Flexors
Thumb Adductors
Thumb Flexors

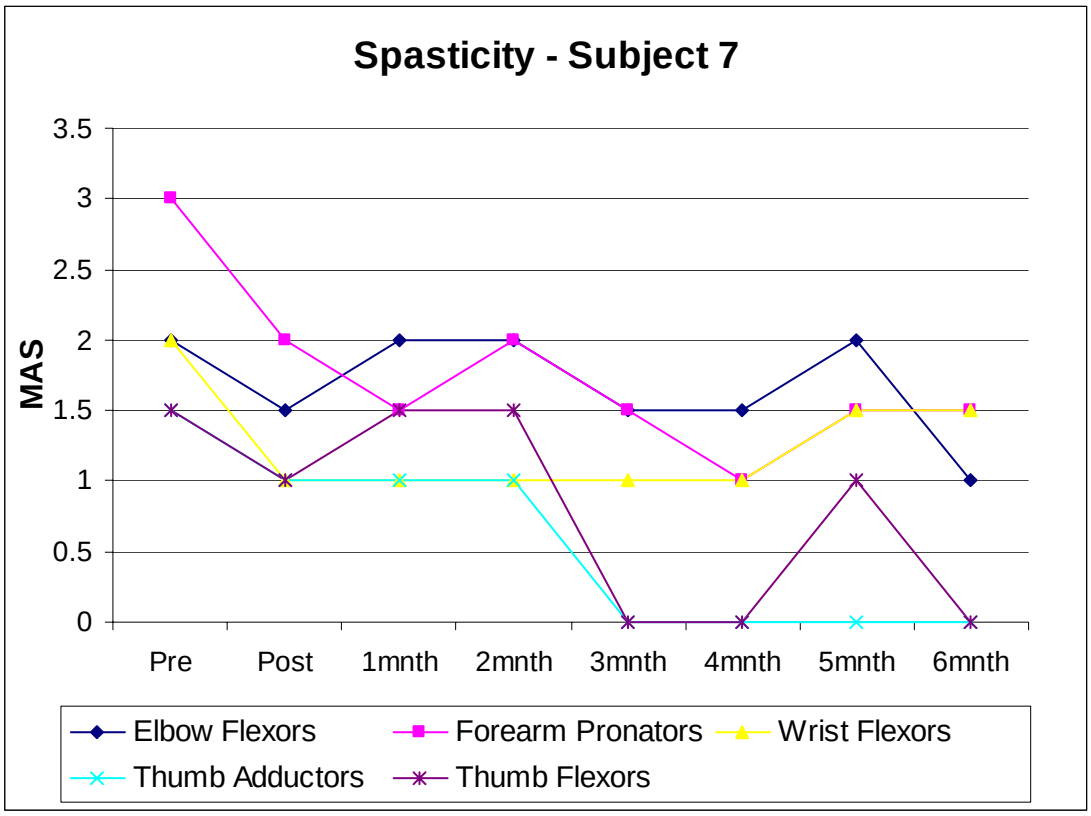

Spasticity - Subject 3
MAS
2.5
2
1.5
1
0.5
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Elbow Flexors
Forearm Pronators
Wrist Flexors
Thumb Adductors
Thumb Flexors


Spasticity - Subject 4
MAS
2.5
2
1.5
1
0.5
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Elbow Flexors
Forearm Pronators
Wrist Flexors
Thumb Adductors
Thumb Flexors

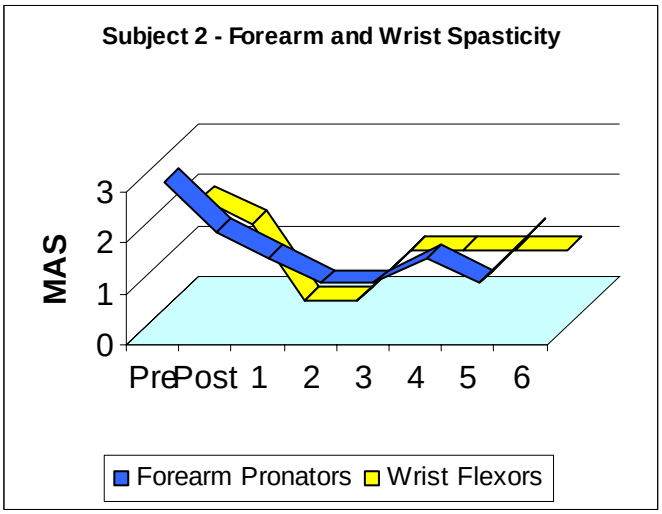

Spasticity - Subject 5
MAS
3.5
3
2.5
2
1.5
1
0.5
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Elbow Flexors
Forearm Pronators
Wrist Flexors
Thumb Adductors
Thumb Flexors

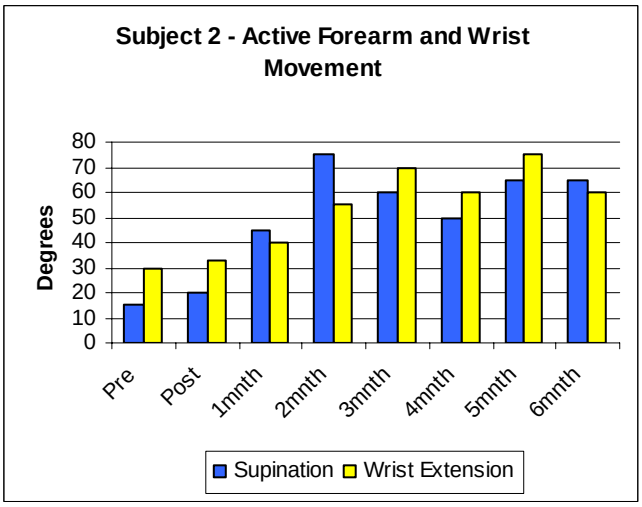

Spasticity - Subject 7
MAS
3.5
3
2.5
2
1.5
1
0.5
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Elbow Flexors
Forearm Pronators
Wrist Flexors
Thumb Adductors
Thumb Flexors

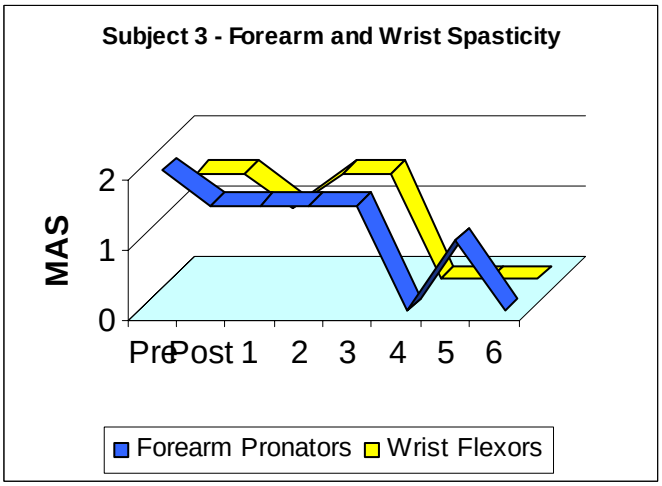
Appendix N – Spasticity – Subject 7

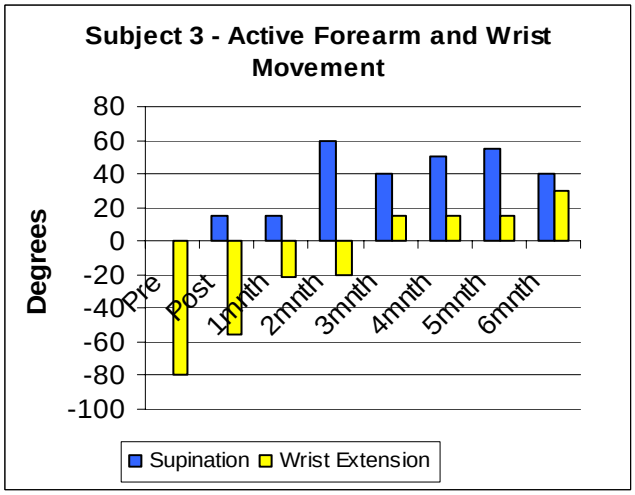

Spasticity - Subject 7
MAS
3.5
3
2.5
2
1.5
1
0.5
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Elbow Flexors
Forearm Pronators
Wrist Flexors
Thumb Adductors
Thumb Flexors

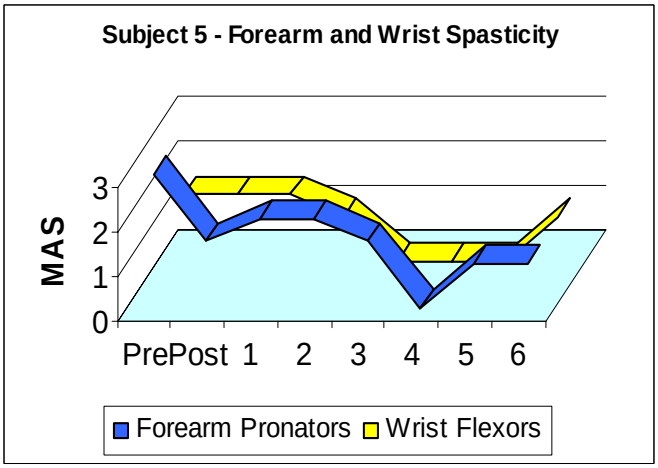
Appendix O – Spasticity Levels vs Range of Movement

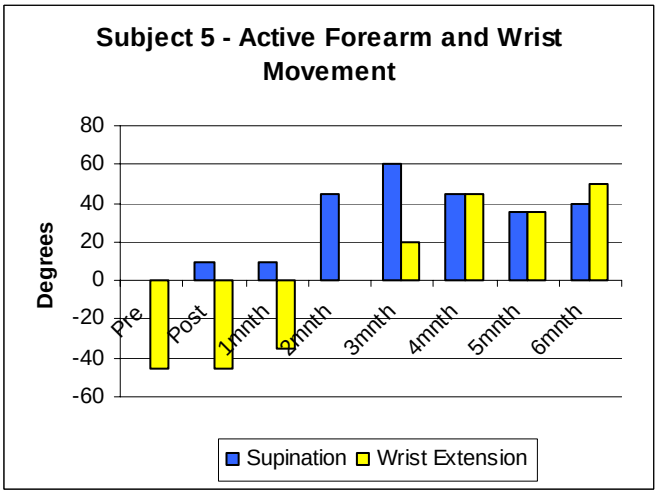

Subject 2 - Forearm and Wrist Spasticity
MAS
0
1
2
3
Pre
Post
1
2
3
4
5
6
Forearm Pronators
Wrist Flexors

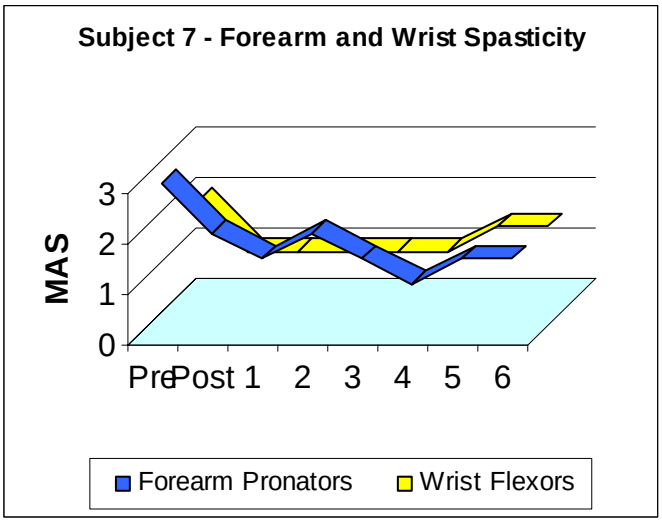

Subject 2 - Active Forearm and Wrist Movement
Degrees
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension

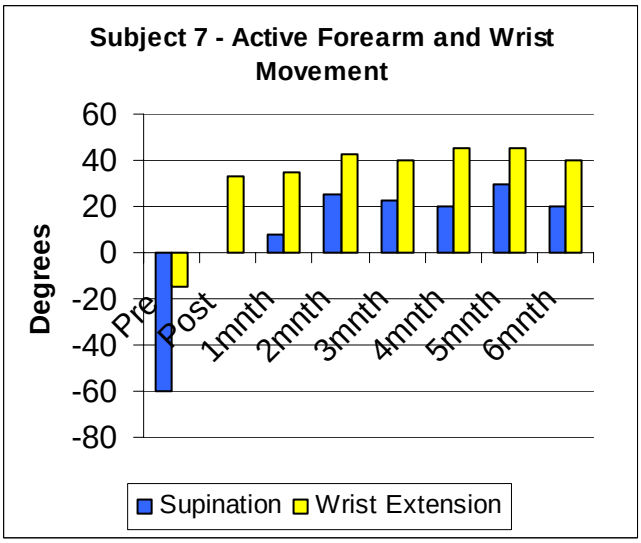

Subject 3 - Forearm and Wrist Spasticity
MAS
0
1
2
Pre
Post
1
2
3
4
5
6
Forearm Pronators
Wrist Flexors

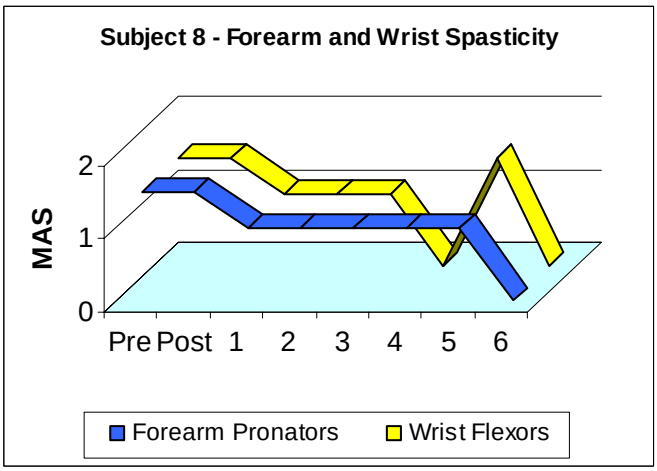

Subject 3 - Active Forearm and Wrist Movement
Degrees
80
60
40
20
0
-20
-40
-60
-80
-100
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension

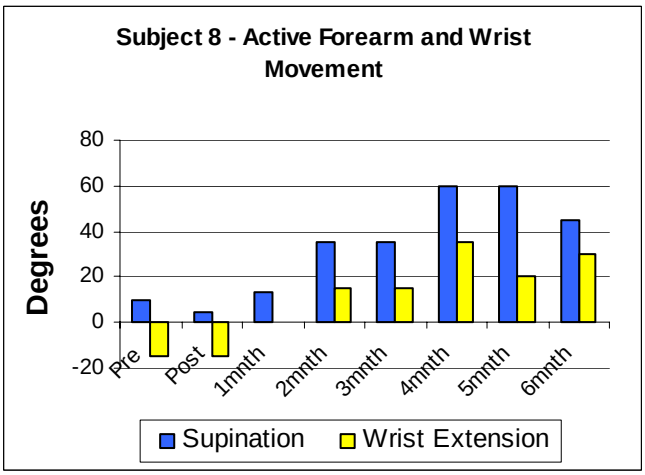

Subject 5 - Forearm and Wrist Spasticity
MAS
0
1
2
3
Pre
Post
1
2
3
4
5
6
Forearm Pronators
Wrist Flexors


Subject 5 - Active Forearm and Wrist Movement
Degrees
80
60
40
20
0
-20
-40
-60
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension

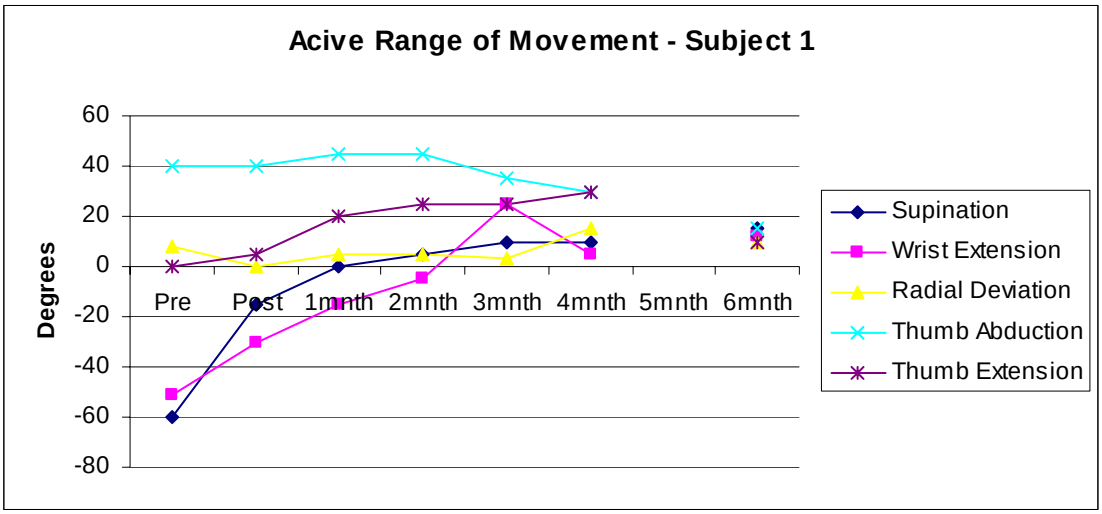

Subject 7 - Forearm and Wrist Spasticity
MAS
3
2
1
0
Pre
Post
1
2
3
4
5
6
Forearm Pronators
Wrist Flexors

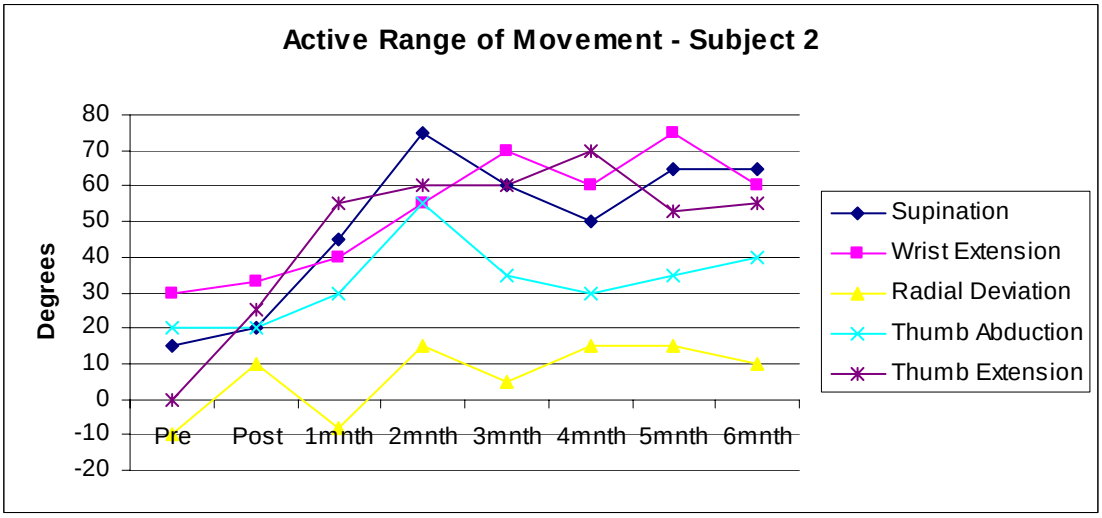

Subject 7 - Active Forearm and Wrist Movement
Degrees
60
40
20
0
-20
-40
-60
-80
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension

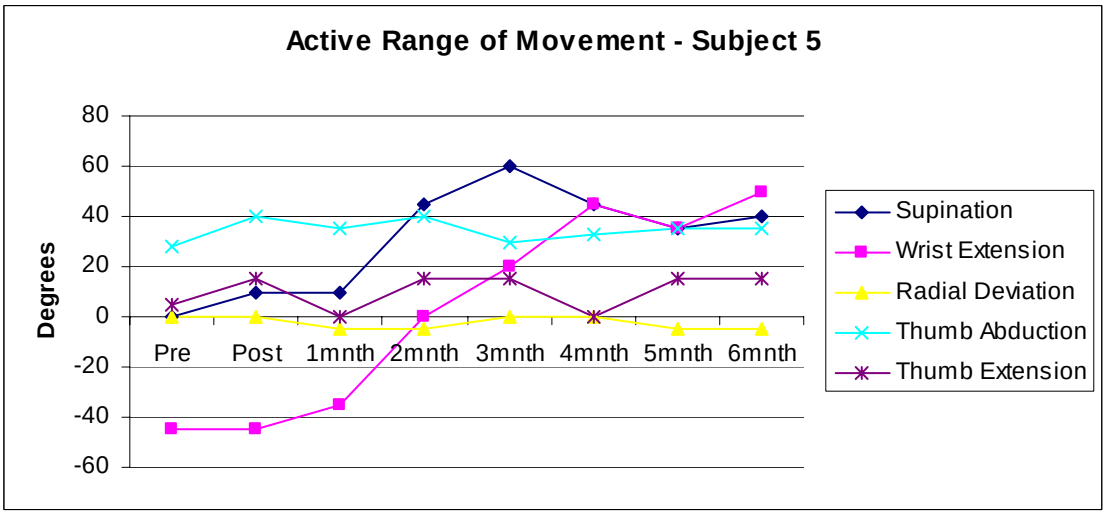

Subject 8 - Forearm and Wrist Spasticity
MAS
2
1
0
Pre
Post
1
2
3
4
5
6
Forearm Pronators
Wrist Flexors

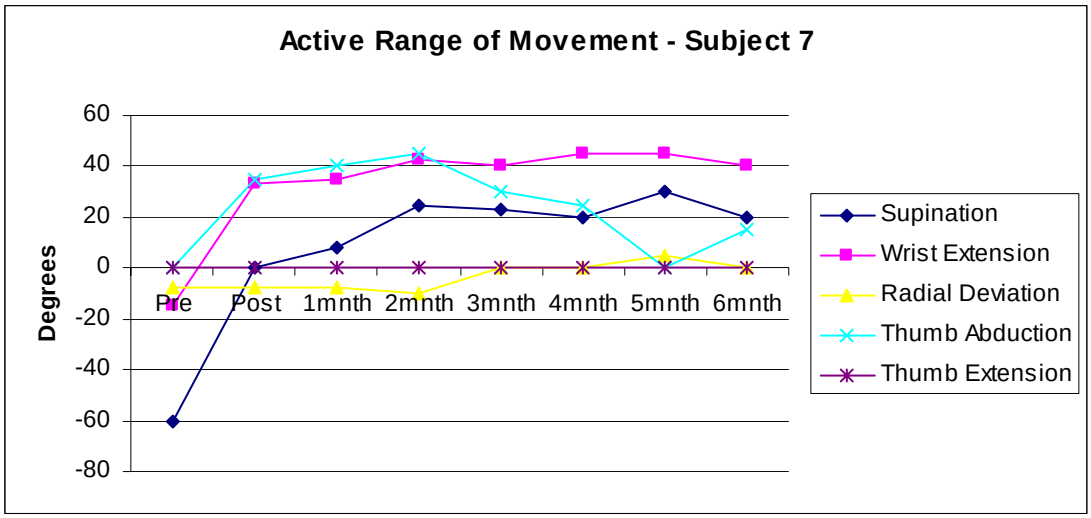

Subject 8 - Active Forearm and Wrist Movement
Degrees
80
60
40
20
0
-20
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension

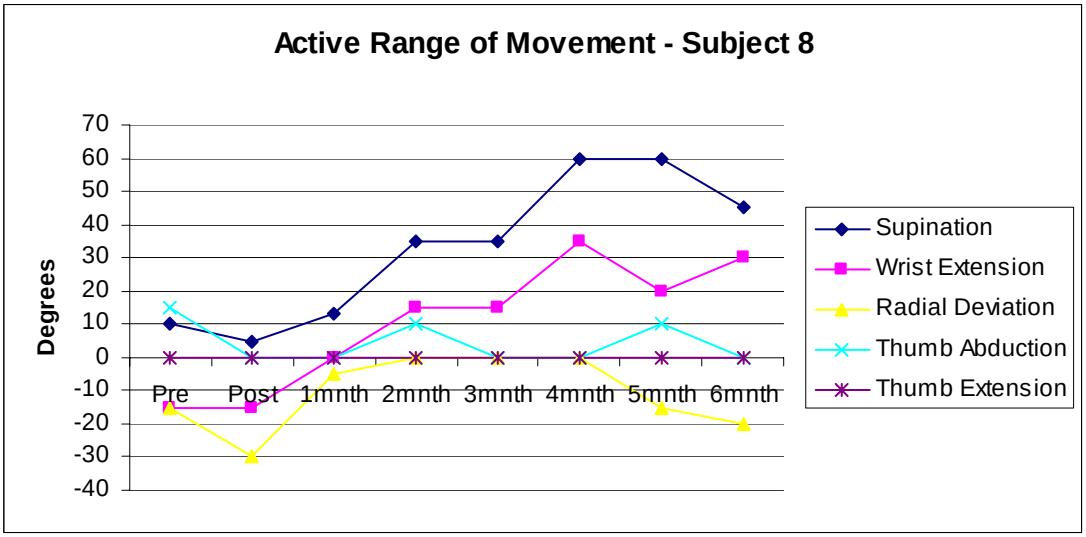
Appendix P – Active Range of Movement


Acive Range of Movement - Subject 1
Degrees
60
40
20
0
-20
-40
-60
-80
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension

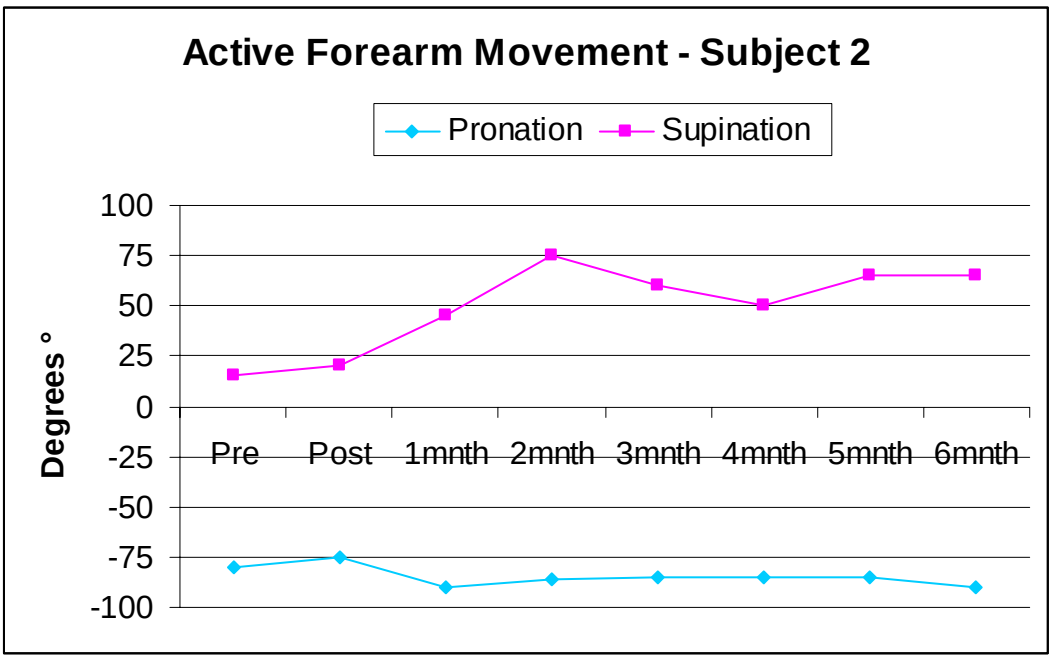

Active Range of Movement - Subject 2
Degrees
80
70
60
50
40
30
20
10
0
-10
-20
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension

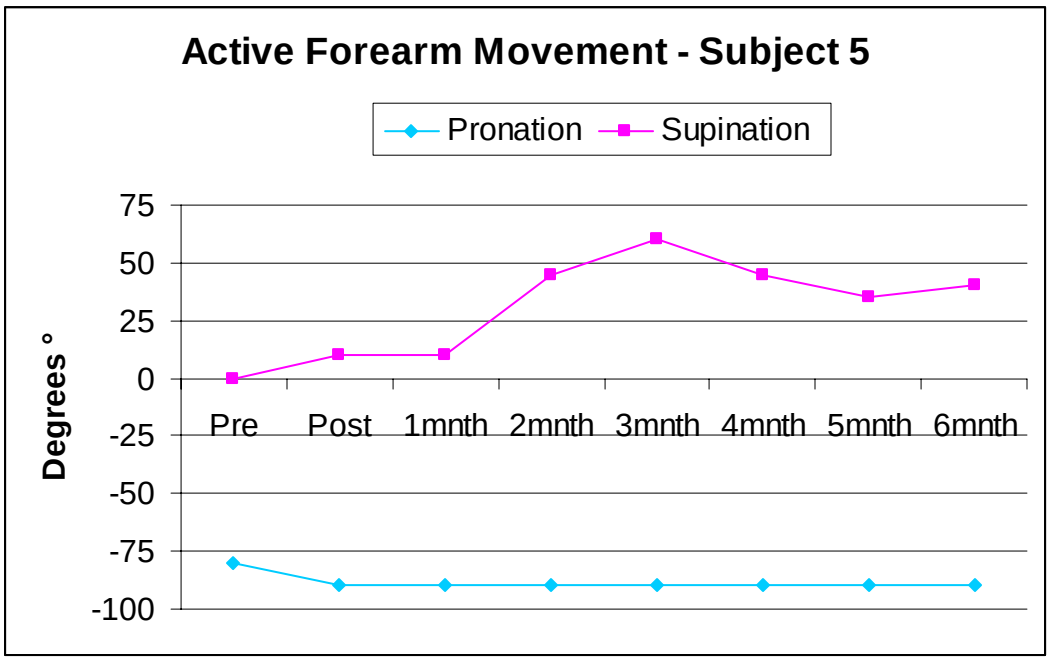

Active Range of Movement - Subject 5
Degrees
80
60
40
20
0
-20
-40
-60
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension


Active Range of Movement - Subject 7
Degrees
60
40
20
0
-20
-40
-60
-80
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension

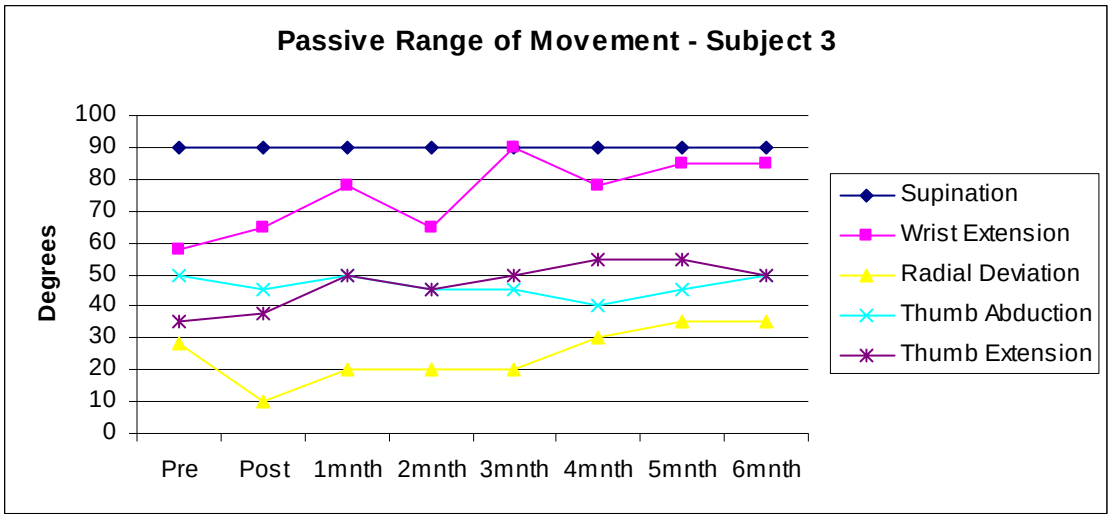

Active Range of Movement - Subject 8
Degrees
70
60
50
40
30
20
10
0
-10
-20
-30
-40
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension

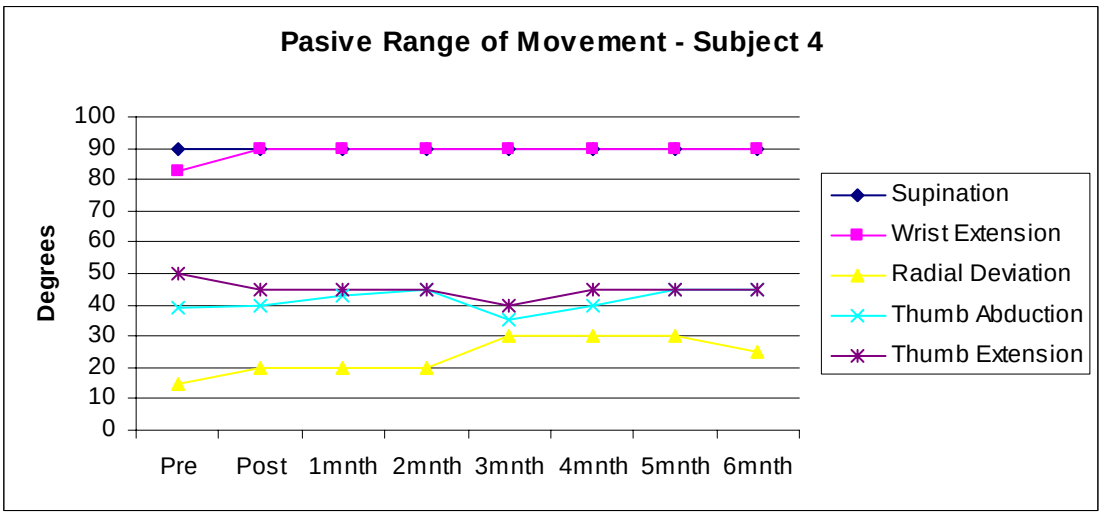
Appendix Q – Supination Range of Movement – Subject 2 & 5

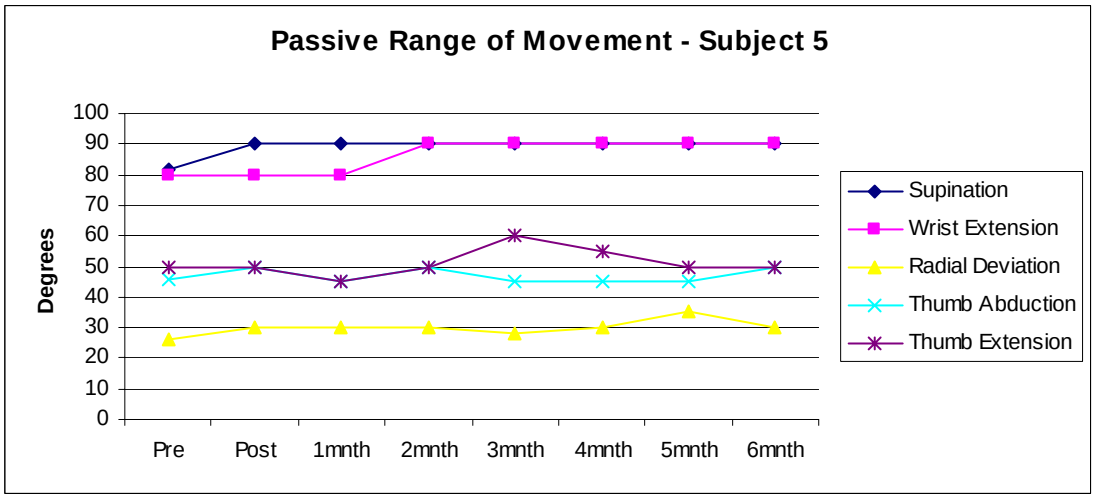

Active Forearm Movement - Subject 2
Pronation
Supination
Degrees °
100
75
50
25
0
-25
-50
-75
-100
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth

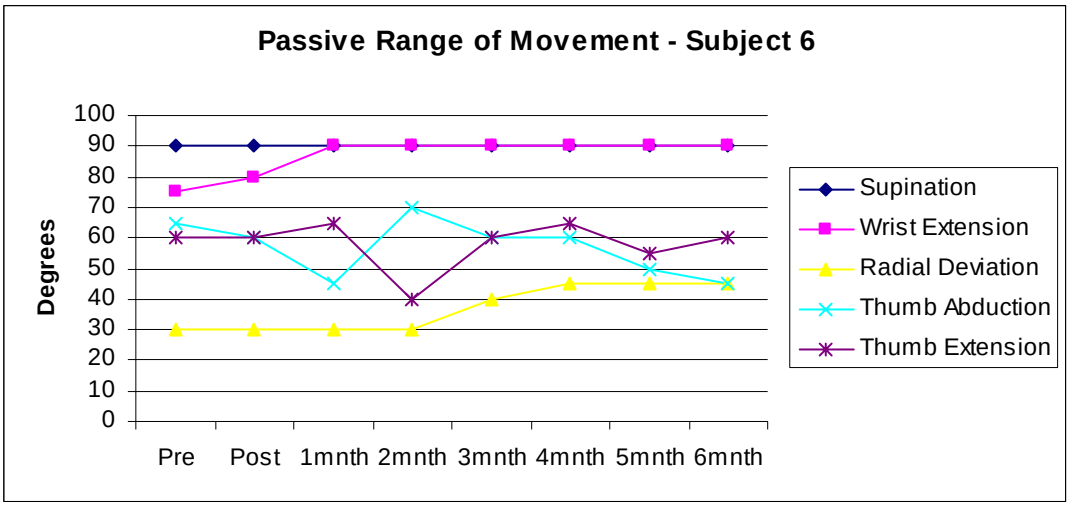

Active Forearm Movement - Subject 5
Pronation
Supination
Degrees °
75
50
25
0
-25
-50
-75
-100
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth

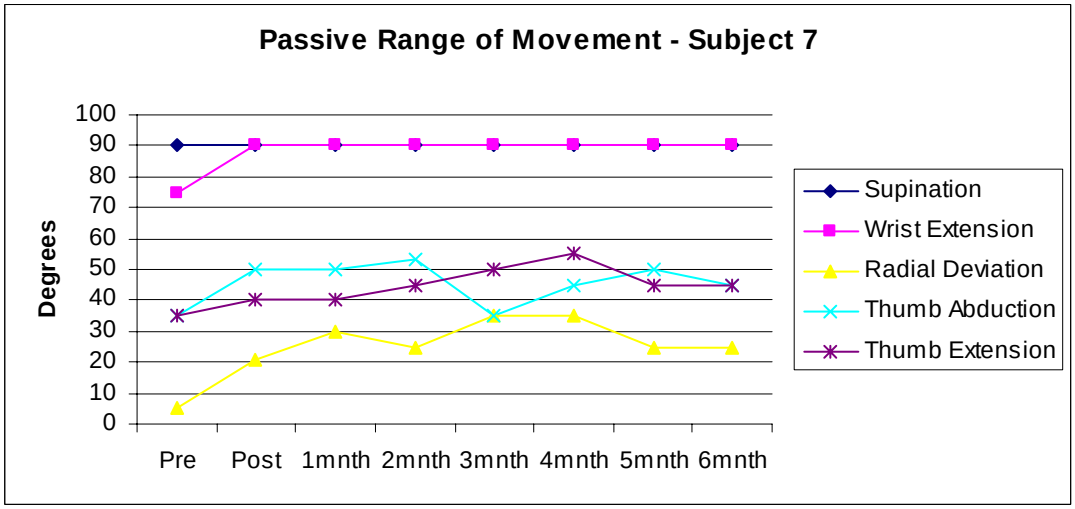
Appendix R – Passive Range of Movement

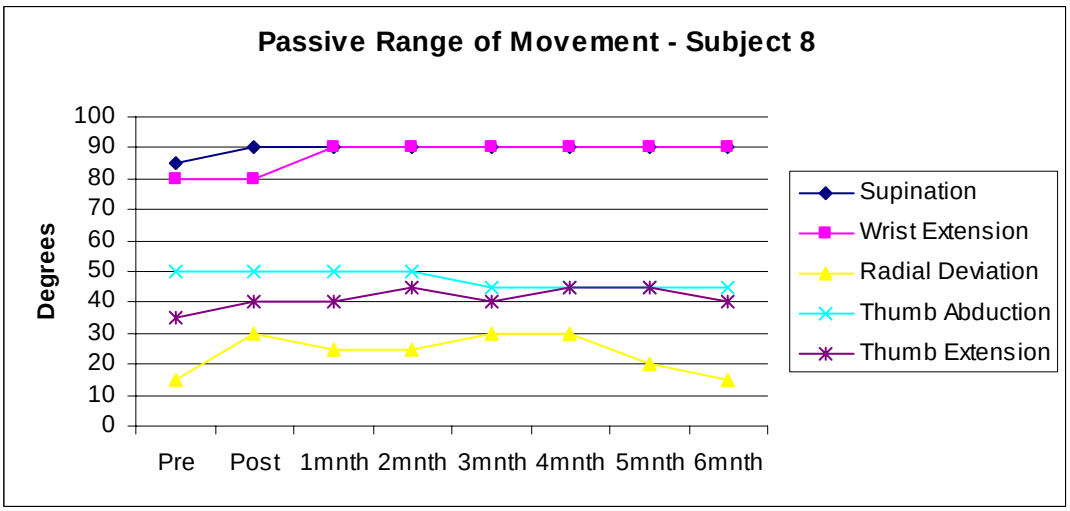

Passive Range of Movement - Subject 3
Degrees
100
90
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension


Pasive Range of Movement - Subject 4
Degrees
100
90
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension

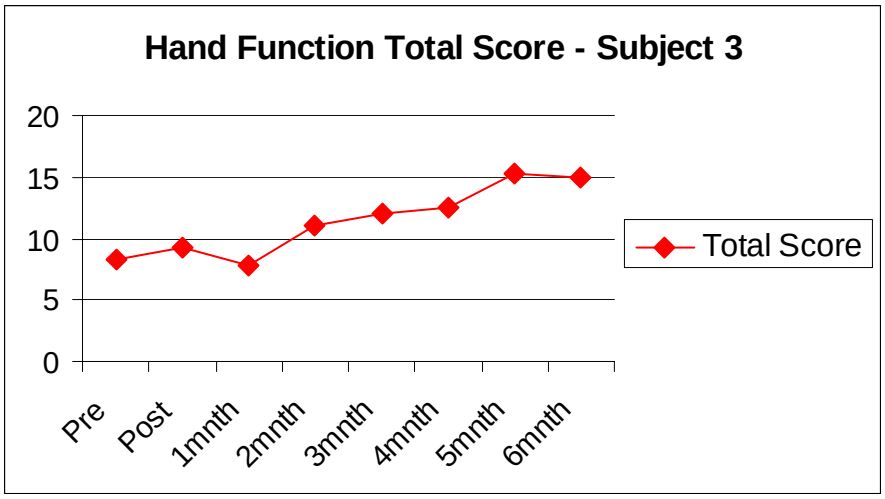

Passive Range of Movement - Subject 5
Degrees
100
90
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension

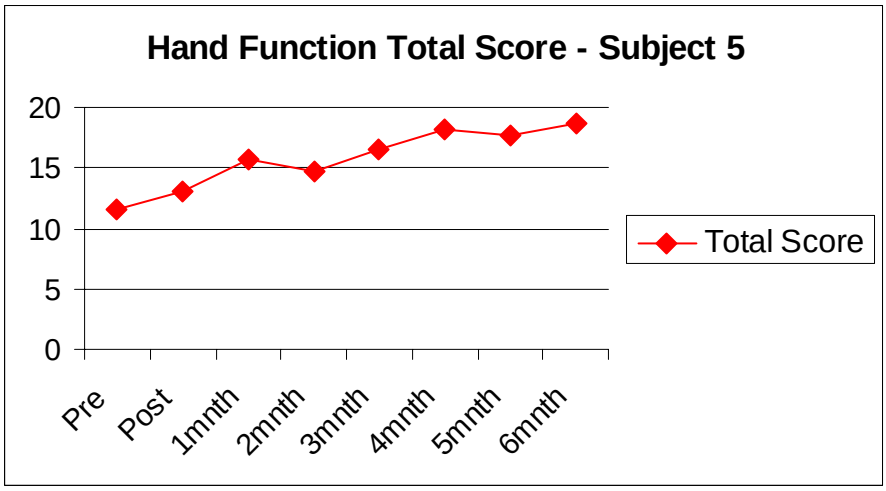

Passive Range of Movement - Subject 6
Degrees
100
90
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension

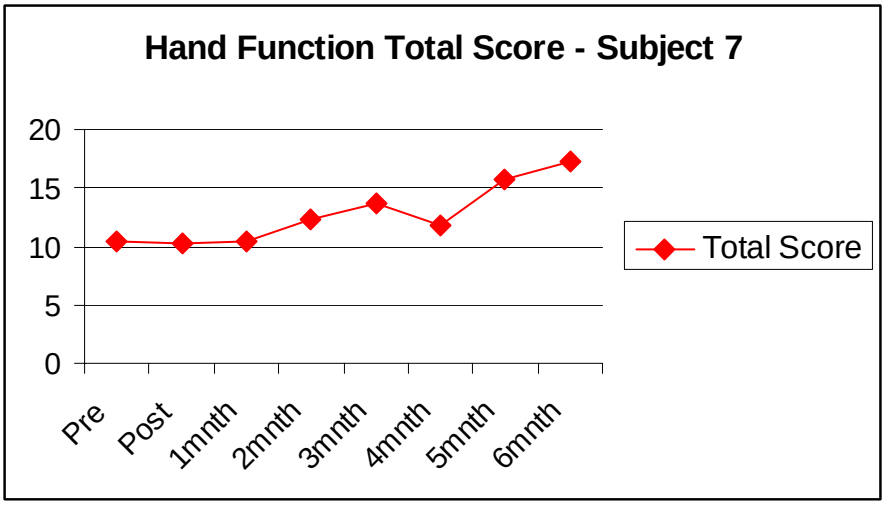

Passive Range of Movement - Subject 7
Degrees
100
90
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension


Passive Range of Movement - Subject 8
Degrees
100
90
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Supination
Wrist Extension
Radial Deviation
Thumb Abduction
Thumb Extension

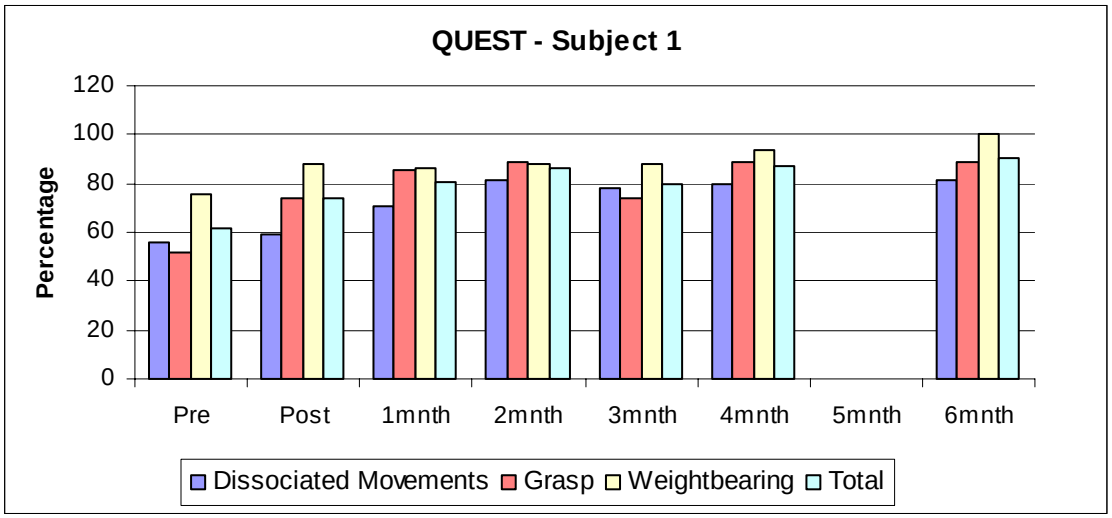
Appendix S – Hand Function Total Score

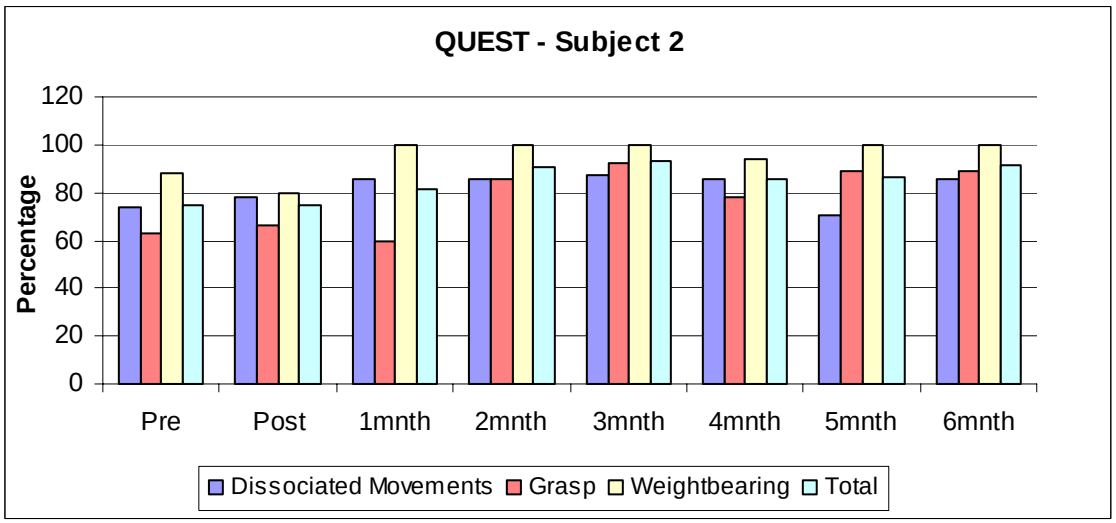

Hand Function Total Score - Subject 3
20
15
10
5
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Total Score

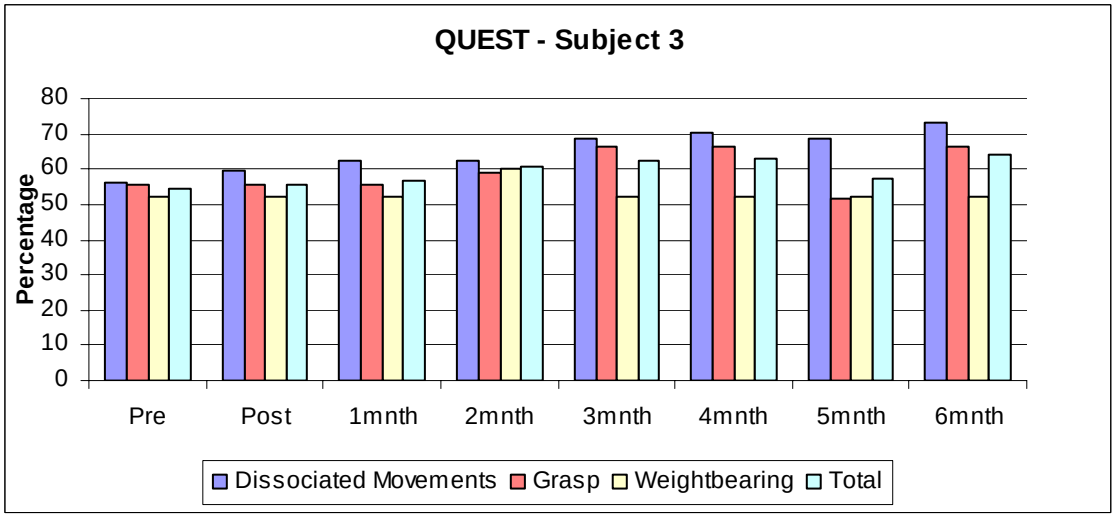

Hand Function Total Score - Subject 5
20
15
10
5
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Total Score

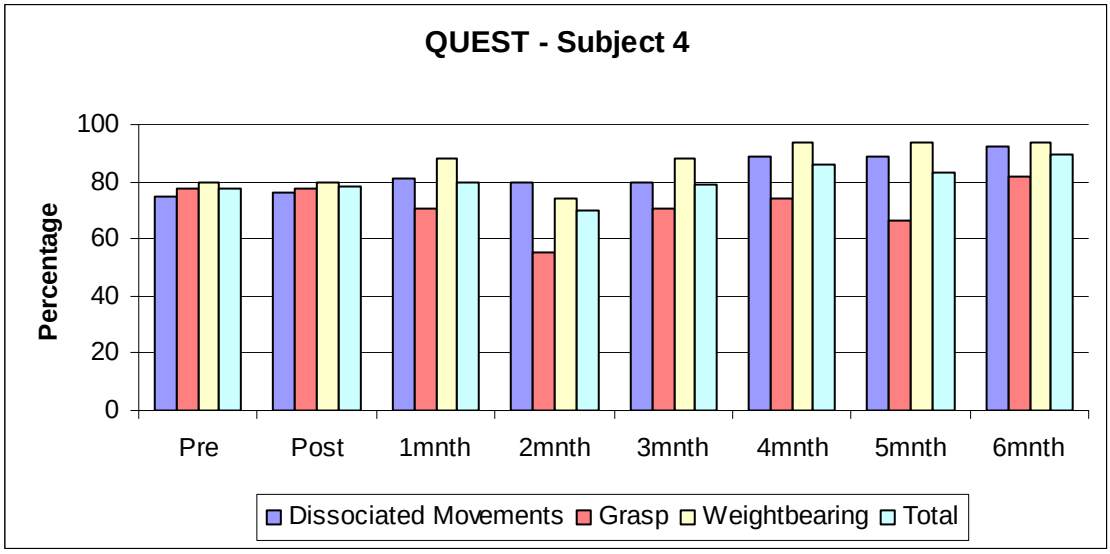

Hand Function Total Score - Subject 7
20
15
10
5
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Total Score

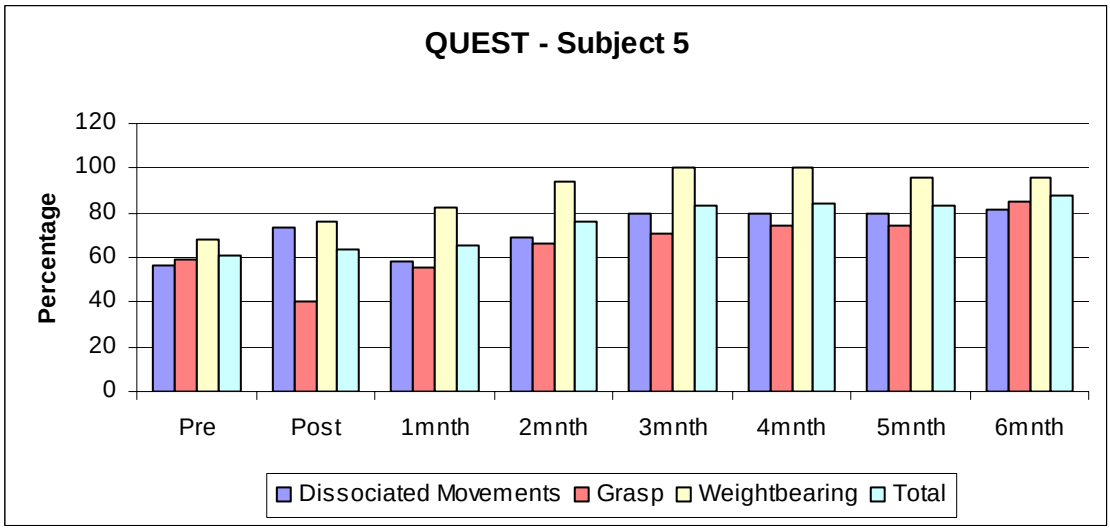
Appendix T – QUEST

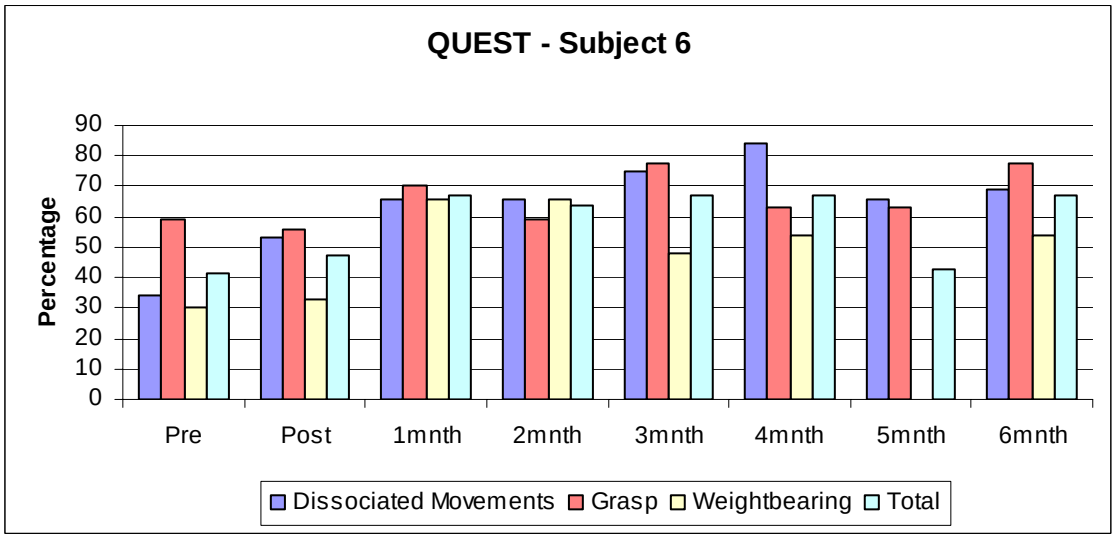

QUEST - Subject 1
Percentage
120
100
80
60
40
20
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Dissociated Movements
Grasp
Weightbearing
Total

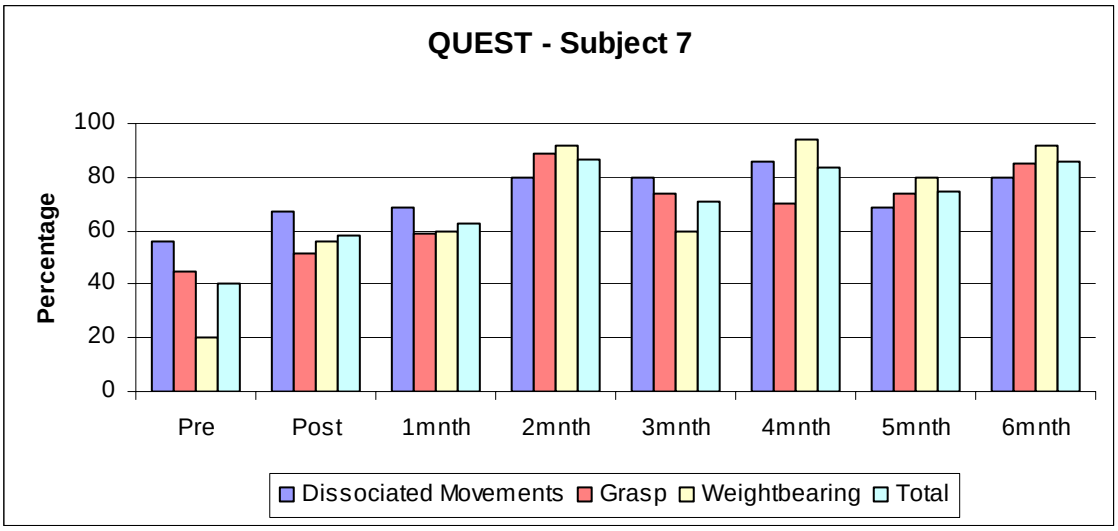

QUEST - Subject 2
Percentage
120
100
80
60
40
20
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Dissociated Movements
Grasp
Weightbearing
Total

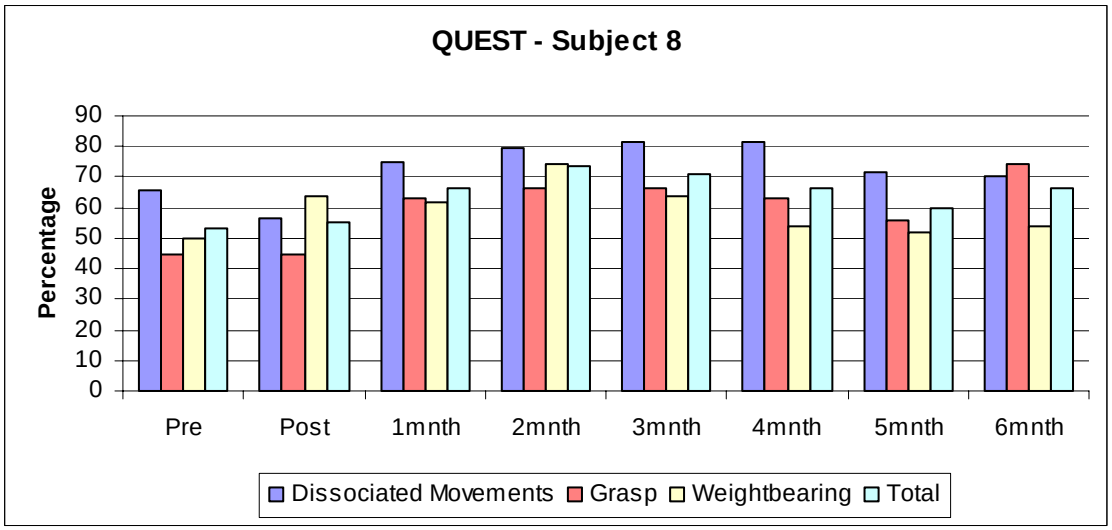

QUEST - Subject 3
Percentage
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Dissociated Movements
Grasp
Weightbearing
Total


QUEST - Subject 4
Percentage
100
80
60
40
20
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Dissociated Movements
Grasp
Weightbearing
Total

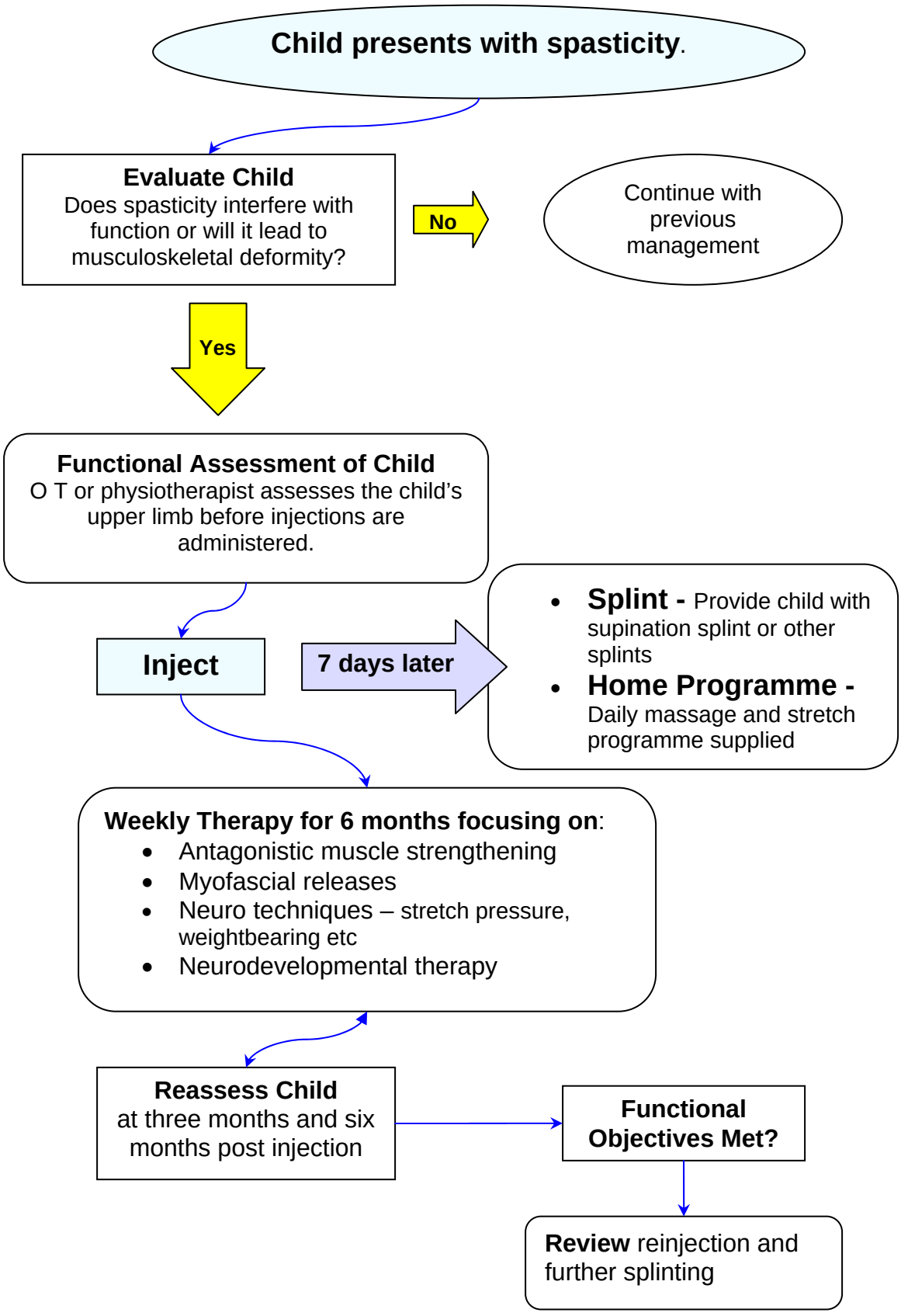

QUEST - Subject 5
Percentage
120
100
80
60
40
20
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Dissociated Movements
Grasp
Weightbearing
Total


QUEST - Subject 6
Percentage
90
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Dissociated Movements
Grasp
Weightbearing
Total


QUEST - Subject 7
Percentage
100
80
60
40
20
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Dissociated Movements
Grasp
Weightbearing
Total


QUEST - Subject 8
Percentage
90
80
70
60
50
40
30
20
10
0
Pre
Post
1mnth
2mnth
3mnth
4mnth
5mnth
6mnth
Dissociated Movements
Grasp
Weightbearing
Total

Appendix U – Proposed Treatment Plan


Child presents with spasticity.
Evaluate Child
Does spasticity interfere with function or will it lead to musculoskeletal deformity?
No
Continue with previous management
Yes
Functional Assessment of Child
O T or physiotherapist assesses the child's upper limb before injections are administered.
Inject
7 days later
Splint - Provide child with supination splint or other splints
Home Programme - Daily massage and stretch programme supplied
Weekly Therapy for 6 months focusing on:
Antagonistic muscle strengthening
Myofascial releases
Neuro techniques – stretch pressure, weightbearing etc
Neurodevelopmental therapy
Reassess Child
at three months and six months post injection
Functional Objectives Met?
Review reinjection and further splinting