

2

**Parameters related to the equinus ankle in ambulatory
children with cerebral palsy: an investigation of the
differences between children with the diplegic and
hemiplegic subtypes.**

By

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A thesis submitted in fulfilment of the requirements for the degree

Master of Science in Medicine in Anatomy

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July 2008

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Dedication

This thesis is dedicated to the late Prof Lawrence Francis Levy (1922-2007).

Prof L. F. Levy was the 'first neurosurgeon in Sub-Saharan Africa' (Wikipedia website, 2008). He was the consultant neurosurgeon for the Salisbury Group of Hospitals (Rhodesia) from the 1950s and his services extended as far as Congo, Tanzania and Mozambique. He was a Professor of Surgery and his hallmark contribution to surgery was the design of the Harare shunt to drain excess fluid from the brains of children with hydrocephalus. The Harare shunt used a normal \$US5 nasogastric tube and replaced the \$US230 Hakim-Codman tube (Bioline website, 2008). The nasogastric tube had a slit lower end and had 'no pump or antisiphon mechanism' and worked remarkably well (Bioline website, 2008). The Harare shunt has since been adopted in many countries in Africa and other developing countries, and has satisfactory long term effects.

Levy was also a Professor of Anatomy and was the Head of the Department of Anatomy at the University of Zimbabwe from the 1970s and until he retired in 2006. Prof Levy believed in me and it was during leadership at the Department of Anatomy that the department allowed me to be the first Zimbabwean from the Physiotherapy field to study the BSc (Intercalated) Honours in Human Anatomy degree in 2000. It was during the time that he was the Head of the Department of Anatomy, that I rose from being an applicant to the University of Zimbabwe for the BSc Physiotherapy degree programme to a student of Physiotherapy, a student of anatomy, an anatomy Demonstrator, a supervisor of a team of dissectors of anatomy specimens, an Anatomy Teaching Assistant, an Anatomy Junior Lecturer and finally a Course Convener for the Anatomy course studied by the Physiotherapy and Occupational Therapy undergraduate degree programmes. All this happened in a space of six years. I should note that during all the years that I was with him, I had never seen him wearing gloves in the dissecting laboratory, as he preferred using his bare hands. Prof Levy was my academic mentor and my research supervisor for the thesis entitled:

"The non-rarity of herniated discs in the indigenous population of Zimbabwe: A cadaveric and epidemiological study". BSc Hons Hum Anat Thesis, University of Zimbabwe. June 2001.

Lawrence was well respected by the staff and students in the department, the university fraternity and at the four referral hospitals. He used to bring a large consignment of mulberries

from his farm to refresh the staff at the department. He was a down to earth man and I will not forget that it was on my first ever trip to England, that he gave me a £20 note from his own pocket to use there.

‘Sekuru’ will be missed.

University of Cape Town

Declaration on plagiarism

I, Hope Gangata, hereby declare that this thesis is my own work and has not been submitted for a degree at any other university. All the resources that I have used or quoted are acknowledged by a complete list of reference.

Name Hope Gangata

Signed 28-08-2008
.....

Date

Signed by candidate

Abstract

Introduction: The equinus ankle is one of the most treated conditions of the ankle and foot. Previous studies have investigated the lower limbs in children with either the diplegic (D-Group) or hemiplegic subtypes (H-Group) of cerebral palsy (CP). Children presenting with diplegia have been reported to have crouched knees (knee in flexion deformity) and an equinovalgus, while children with hemiplegia tend to have genu recurvatum (over extended knees), ankle equinovarus and a shorter affected limb (AL) than the unaffected limb (UL). No study has specifically compared the impairments related to the equinus ankle between the subtypes of CP. In addition, treatment outcomes for the management of the equinus ankle have not been satisfactory documented and there may be crucial differences in the parameters related to the equinus ankle between the D-Group and the H-Group.

Aims of the study: The purpose of the study was to reveal how the parameters related to the equinus ankle might present in children with hemiplegic CP and in diplegic CP, and indicate to what extent the biomechanics of an equinus ankle are similar in the two groups. If differences were to be found, awareness of the differences and which of the parameters are most important to normal gait might assist in understanding the patho-physiology of the impairments seen in the two groups.

Methodology: The study utilised a cross-sectional, descriptive and analytical design. The demographic, anthropometric and medical profiles collected were the diagnosis of being diplegic CP or hemiplegic CP, height, weight, date of birth and the Gross Motor Function Classification Scale (GMFCS) of the child. The impairments and the activity limitations assessed included the passive R1 and R2 angles of the equinus ankle, the degree of equinovarus or equinovalgus, the length of the hamstrings, any differences between the lengths of the two limbs, the tautness of the tendon of the calcaneus (TOTC) and of the hamstring muscles, the level of spasticity of the triceps surae muscle and the muscle strength of the dorsiflexors, knee flexors and extensors muscle groups of the more affected limb (MAL) of the D-Group and the AL of the H-Group. Functional outcomes of cadence and the Physiological Cost Index (PCI, heart beats per minute) were measured.

Results: The demographic and anthropometric profiles of the D-Group (n = 17) and H-Group (n = 12) cerebral palsy were similar; in terms of the mean ages (10.3 ± 1.6 and 10.8 ± 1.7 years respectively), the sex distribution, the median scores of the Body Mass Index (BMI). An exception was that D-Group had undergone a greater number of surgical interventions and had greater difficulty in ambulation (had higher GMFCS levels) than the H-Group. Most impairment parameters of the MAL were similar in both groups; in terms of the R1 and R2 ankle dorsiflexion angles, ankle varus and valgus, the side tautness of the TOTC, the spasticity of the triceps surae, the strength of the knee flexors, ankle dorsiflexors and plantar flexors, and cadence. The tibiocalcaneal angle was found not to be a valid measure of ankle valgus and varus. The D-Group had weaker knee extensors and shorter hamstrings than the H-Group, and only the D-Group had crouch knees during the initial stance of gait. The children in the D-Group had shorter hamstring muscles than the H-Group despite having had 10 surgical interventions and the H-Group had none. Multiple regression analysis predicted a 0.22 hb/m reduction of PCI in the H-Group, and further 0.30 hb/m reduction, if a child was able to perform a single heel rise.

Discussion:

Children in the D-Group were more disadvantaged than those in the H-Group in having a triad of shorter hamstring muscles, crouched gait and weaker knee extensors, and also had both legs similarly affected and a higher PCI energy costs during gait. The D-Group might have experienced greater difficulty in achieving knee extension because of weak soleus muscles and gastrocnemius muscles that were not able to reduce co-contraction so as to allow extension of the knee and hamstring muscles that were not long enough to permit knee extension. The plantar flexors are normally used to store elastic energy during stance phase and release the energy in the pre-swing phase for forward body propulsion. The weakness of the plantar flexors impairs the recycling of the energy and makes the energy demands of walking greater and this could be the explanation for the increased energy expenditure in children who were unable to heel raise. The clinical goniometric measurement of the tibiocalcaneal angle in the coronal plane should not be used as a proxy of hindfoot inversion and eversion, because of the wide variability of the tibiotalar angle.

Conclusions: The parameters related to the equinus ankle are not homogenous between the D-Group and the H-Group. There is a clear need to resolve the crouch knees in the D-Group before knee contractures set in, otherwise the management of the equinus ankle ought to be altered to factor in the crouch knees. Secondly, preserving the strength of the plantar flexors is more important than increasing the length of the plantar flexors to make gait more efficient. Resolving the crouched knees, modifying the treatment of the equinus ankle to factor in the crouched knees and preserving the strength of the plantar flexors could improve the treatment outcomes of the equinus ankle in children with CP.

University of Cape Town

Acknowledgements

I thank God and Jesus Christ for the grace and providence that has made this major project possible.

I would like to express gratitude to the people that have made this research possible. The academia, staff at the schools, the children and their parents, persons who gave regulatory approval of the study, friends and acquaintances, and sponsors that have shaped and contributed to the study.

I would like to express my gratitude for the eminent support my two supervisors, Prof Graham Louw and Prof Jennifer Jelsma, gave me, which began while I was still in London and continued until the end of the research. I benefited a lot from their research experiences and contacts that they would refer me to for further assistance. Marianne Unger offered a lot of advice on the methodology of the research and at times transport to the schools. She lent us a hand-held dynamometer, the heart rate sensor and monitor. Many thanks to Nelleke, Kerith and Yumna for the time they gave to teach us how to use the Biodex and the gait analysis equipment, although the use of the Biodex and the gait analysis equipment in the study had to be abandoned after more than a year's effort. I also want to recognise the assistance that Joep Jansen and Hanneke Fischer from Holland gave.

The technical brilliance of Charles Harris was crystalised in the gadget that he made to load the ankle joint in the cranial direction, with the child lying in a supine position and is shown in Figure 11 on page 46. He made the gadget to such a high standard that it appeared to be a commercially manufactured product. He also assisted in the repairing and adjustment of other smaller devices used by the study, when they became faulty.

The children who participated in the study were all well behaved and were always cheerful. The children were from Eros School (Athlone), Vista Nova School (Rondebosch) and Agape School (Mitchels Plain). I always had a pleasant experience from the warm reception that I received from the staff at the three schools. The Head Physiotherapists (Heidi, Lousie and Rahema) from Eros, Vista Nova and Agape schools, respectively, and other therapists were more than helpful and often gave more insight to the condition of the child than what the medical notes would have given. Mention ought to be given to the Physiotherapy Assistants of

Eros and Vista Nova schools who would always collect the children on my behalf from the myriad of classes. The study would not have been possible without the parents and guardians giving written consent for their children to participate in the study.

I would like to thank the support that the Prof Marc Blockman and his team of the Ethics Committee of the Faculty of Health Sciences of the University of Cape Town, Dr RS Cornelissen of the Research Office in the Ministry of Education, Prof Vivienne Russel of the Postgraduate Research coordinator in the Department of Human Biology and the headmasters of the three schools who gave regulatory approval for the study.

I would like to extend my gratitude to the Head of the Department of Human Biology, Prof Sue Kidson, for providing a grant to help cover for the costs of the study and to the Postgraduate Funding Office of the University of Cape Town, for funding my tuition fees in one of the three years with a scholarship.

Many thanks to Marianne Unger, Rip DaSilva, Kundisai Dembetembe and Robert Ndou for proof reading my main document and to Tebogo Raphalane and Mikateko Mabaso for proof reading my references. The moral support and encouragement from family, relatives and my friends helped me gather steam at certain times of despair or when I was exhausted from a high work load.

I would also want to acknowledge the time in history in which this research was carried out. Decades after this research has been completed and after the currency has stabilised, the final cost of undertaking the Masters degree at the University of Cape Town in Zimbabwean dollars of \$2.3 pentillion will seem quite remarkable.

El Roi

Summary of Thesis

Introduction:

The equinus ankle is one of the most recognised and treated conditions of the lower extremity in children with cerebral palsy (CP). Children with the diplegic and hemiplegic subtypes of cerebral palsy may have differences in the parameters related to the equinus ankle. Children with diplegic CP (D-Group) have been reported to have crouched knees (knee in flexion deformity) in walking and an equinovalgus, while children with hemiplegic CP (H-Group) tend to have genu recurvatum (over extended knees) in walking, ankle equinovarus and a shorter affected limb (AL) than the unaffected limb (UL). The main aim of the study was to compare the parameters related to the equinus ankle between the more affected limb (MAL) of the children with diplegic CP and the AL of the children with hemiplegic CP, and to establish which parameters are responsible for higher energy demands during gait across the two groups.

After treatment, the long term prognosis of the equinus deformity or posture has not been satisfactory and has frequently resulted in relapses and over-corrections of the equinus deformity. It is hoped that by comparing the mechanisms of the deformity in the two groups of children, that a better understanding of the pathogenesis of the equinus deformity in each group may be attained. This, in turn, might hopefully contribute to the advancement of more appropriate strategies to manage the condition and may potentially boost the success rate of the treatments of the equinus ankle.

Specific Objectives:

The specific objectives of the study were in a group of ambulant children with diplegic and hemiplegic cerebral palsy:

- To determine if there was a significant difference between D-Group and H-Group of CP with regard to specific functional and medical parameters;
- To determine if there was a significant difference between the D-Group and H-Group with regard to specific impairment parameters related to tone, range of movement and muscle strength;
- To determine the basic biomechanical parameters which relate to underlying equinovarus and equinovalgus in the standing subjects;

- To establish which variables were predictive of the Physiological Cost Index (PCI) in heart beats per minute.

Methodology:

A prospective, cross-sectional and analytical descriptive study design was followed.

Sample

Children presenting with CP were selected for the study using the convenience sampling method. The CP group cluster was from three special schools and centres in Cape Town. After screening for inclusion and exclusion criteria and obtaining informed consent from the parents, 29 children (17 children in the D-Group and 12 children in the H-Group), were enrolled in the study. Permission to carry out this study was obtained from the Human Ethics Committee of the Faculty of Health Sciences of the University of Cape Town, the Department of Education under the Ministry of Education, and from the principals or medical superintendent of the schools or rehabilitation centres before the research began.

Procedure

The diagnosis, dates of birth and dates of assessment were noted from the medical records of the children. The height and weight of the children were measured with a vertical tape measure and a bathroom scale respectively and were used to calculate the Body Mass Index (BMI). The Gross Motor Function Classification Scale (GMFCS) level was determined by asking the child to walk a short distance of 10 metres. The evaluation for spasticity was made using the modified Ashworth Scale. An equinus ankle instrument was mounted onto the foot and created a force of 10N in the dorsiflexion direction along the transverse plane across the plantar surface of the first metatarso-phalangeal joint, to standardise the force applied. The R1 and R2 ankle angles in the sagittal plane were measured with a manual goniometer. The R1 angle was defined as the first catch of the ankle angle towards dorsiflexion that was allowed by the excursion the triceps surae muscle (composed of the gastrocnemius, plantaris and soleus muscles) and the R2 angle as the ankle angle at the end of the range of motion of dorsiflexion. The children in the D-Group and the H-Group were compared by measurement of: the relative lengths of the lower limbs, the length of the hamstring muscles (using the conventional popliteal test), the presence of crouch knees during the stance phase of gait, the degree of ankle varus and valgus, the strength of the ankle dorsiflexor, knee flexor and extensor muscle groups by using a hand-held dynamometer (HHD) and of the strength of the

ankle plantar flexors by using the one-leg heel-raise test. The strength was normalised by dividing the muscle strength by the body weight. The measurements needed to calculate the PCI were collected before and after a 100 metre walk along a concrete corridor.

Results:

The demographic, anthropometric and medical profiles

The following were the demographic, anthropometric and medical profiles of the children in the D-Group and the H-Group were: mean ages of 10.3 (± 1.6) and 10.8 (± 1.6) years; median scores for the BMI of 16.2 kg/m² (range 12.6 - 28.2 kg/m²) and 18.0 kg/m² (range 13.6 - 24.8 kg/m²); for the GMFCS levels, the D-Group ranged from Level I-III and the entire H-Group was at Level I; and surgical interventions with a median score of four (range 0-8) and a median score of one (range 0-4) respectively. Statistical differences were found in that the D-Group had undergone a greater number of surgical interventions than the H-Group, and that there were more children at Levels II and III of the GMFCS in the D-Group (association approached significance) than the H-Group.

The impairments and the activity limitations

The impairments and the activity limitations that were related to the equinus ankles were compared between the MAL of the D-Group and the AL of the H-Group: there was no difference between passive R1 and R2 dorsiflexion angles, between the spasticity of the triceps suare muscle, or in the strength of the knee flexors and ankle dorsiflexors and in the number of children who could heel raise. The two groups had similar levels of ankle varus and valgus, the side tautness of the tendon of the calcaneus (TOTC) and surface anatomical tibio calcaneal angles of the heel. Spasticity was correlated with R1 angle, but not with R2 angle. The children with diplegia had statistically significantly shorter hamstring muscles, and more demonstrated excessive flexion during initial stance, and weaker knee extensors (which approached significance) than in the H-Group.

The parameters related gait

The gait related parameters were examined. The D-Group had a less efficient gait pattern (as indicated by greater PCI values, which approached statistical significance) than children in the H-Group. There was no difference in the cadence between the two groups. Higher cadence was correlated with higher PCI results ($r = 0.57$) and was statistically significant. The PCI was higher among children with a higher GMFCS level. Forward stepwise multiple regression

analysis with PCI as the dependent variable, identified that H-Group membership was the only demographic and medical variable that was predictive and it reduced the PCI by 0.22 heart beats per minute hb/m. In terms of impairments, being able to perform a single heel rise was the only significant predictor of PCI and it decreased the PCI by 0.30 (hb/m). Children unable to perform a single heel rise had the highest PCIs and averaged 0.91 hb/m (normal persons have PCI values of 0.10 hb/m).

Discussion:

In general, both the D-Group and the H-Group in this study had milder ambulatory difficulty compared to the general population of children with diplegic or hemiplegic CP. The present study required that the subjects should be able to walk with or without a walking aid and this skewed the subjects obtained towards milder ambulatory difficulties. The BMI values and the obesity levels were similar to those of other studies involving children with CP.

The medical and demographic profiles between the children in the D-Group and the H-Group were statistically similar in terms of the mean ages, the distribution of sex and the means of the BMI. The D-Group had a greater number of past surgical interventions and also greater ambulatory difficulties than the H-Group, and it is not clear which one of these factors causes the other.

Knee extension requires the cooperation of four parameters: powerful quadriceps femoris and soleus muscles, gastrocnemius muscles that should be able to relax during the stance phase (co-contraction should be greatly reduced), and hamstring muscles that should be long enough to permit knee extension. The children with diplegia are faring poorly on the four parameters and therapy to reduce the use of crouch gait should address the four parameters. The gastrocnemius muscle ought to be more relaxed, to encourage knee extension during the stance phase, and the soleus and quadriceps femoris muscles strengthened among the children with diplegia to encourage knee extension. It is suggested that lengthening of the muscular portion of the hamstring muscles and not the tendinous portions, might preserve the elastic nature of the tendinous portions and the capability of the generating power by the muscle bellies. The additional length of the hamstring muscles that is created might promote more knee extension. It is interesting to note that the children in the H-Group did not have any past surgical interventions for the elongation of the hamstring muscles, while the children in the D-Group had a total of 10 surgical interventions, and yet the children in the D-Group still had

statistically significant shorter hamstring muscles than the children in the H-Group. This indicates a greater fundamental problem of shorter hamstrings in the D-Group than the goniometric measurements have shown in the present study, and may indicate that the surgical interventions are not effective in lengthening the hamstring muscles.

The clinical goniometric measurement of the tibiocalcaneal angle in the coronal plane should not be used as a proxy of hindfoot inversion and eversion because of the wide variability of the tibiotalar angle. The tautness of the sides of the TOTC did not follow the traditional theory, the soleus-gastrocnemius contribution or the ankle stabilising theory. The large number of surgical interventions to the TOTC could have interfered with the stabilising functions.

The recycling of energy helps in maintaining a low PCI during gait in a normal person. Walking in a crouch position is likely to be more costly than maintaining the stance phase in extension, as the force moments are increased when the knee flexes, although this did not emerge as a predictor of PCI. The co-contraction phenomenon may create a paradoxical situation where a muscle group works against an active antagonist and yet has a weaker recording on a HHD, when compared to the muscles of normal children. Larger strides could be recommended as a way to reduce the PCI and achieve a more efficient gait among children with cerebral palsy. However, shortened hamstrings and crouch knees may limit the stride length and in order to maintain an adequate gait speed, the cadence increases. In addition, the lack of the plantar flexors in feeding energy into the gait cycle at push-off is likely to result in abnormal muscle activity in the proximal hip muscles and a decrease in efficiency (see above, under functional implications of plantar flexor weakness). It was interesting that neither the excessive or limited range of motion of the plantar flexors (as a proxy of the length of the triceps surae muscle) were able to predict the PCI, but only the strength of the plantar flexors could.

Limitations:

A larger sample would have been preferable, but was not possible due to the reduced number of children with ambulatory CP presenting with an equinus ankle that were available for inclusion. This number was further decreased, after failure to secure parental consent of 15 children. An unavoidable change in the research protocol further reduced the numbers of children, whose data was included in the regression analysis. The findings of the study may be

limited and the results should be applied with caution only to children similar to the participants. The BMI of the children was assumed to be similar to the BMI of children living in the United States of America and the sex and age differentials of children could be different. A tape measure was not used to measure the lengths of the lower limbs of the children, because some children had flexion deformities of the knees and measuring the length of the lower limbs with a tape measure would have been inaccurate. The method that was used to compare the length of the lower limbs, involved comparing the levels of the patellae with the child in a supine position with flexed knees. The Ashworth scale may not be the most reliable instrument with which to measure spasticity and the use of iso-kinetic measurement might have been more objective, but costly to carry out.

- The tautness of the sides of the TOTC was graded by means palpation into three categories of very taut, mildly taut and slack and the proposed technique may unreliable. The measurement of the tibio-calcaneal angle as a measure of ankle varus and valgus using a goniometer proved to be an invalid indicator of movement at the subtalar joint. No equipment has been found to be reliable in the assessment of the strength of the plantar flexors and hence a manual method was used. EMG and gait analysis would have added value to the study.

Recommendations:

It is not always possible to establish a relationship between structure and function. It became clear in the present study that stronger plantar flexors play an essential role in decreasing the energy requirements during gait. The widespread practice of trading off muscle strength of the triceps surae for muscle length ought then to be reviewed, as it is making the ambulation of children with CP more difficult. The link between the ultrastructure and the strength of the triceps surae muscle should be sought. The analysis of the architecture of the triceps surae could focus on the ultrasonic layout of the fascicle length, fascicle angles, other length dimensions and should attempt to find a relationship between structure and the number of heel rises. It would be of interest to establish how the layout of the fascicle length and fascicle angles present in the two groups (with different knee positions). The children with diplegia would be expected to have shorter fascicle lengths and greater fascicle angles (which have less power generating capacity) after surgically lengthening the TOTC. These finding could have a profound influence on the future treatment protocols between children with diplegia and hemiplegia.

The considerable time therapists are spending on treating spasticity of the equinus ankle needs to be justified by demonstrating a functional link to spasticity. Follow up studies on the current one are recommended. There is a need to find the most accurate method of normalising strength between weight-normalised, height-normalised and BMI-normalised muscle strength methods. Further research work needs to be undertaken to determine how much the sides of the TOTC are influenced by the degree of ankle varus and valgus and by different postures of the body. The research on the tautness of the TOTC can be made more objective by measuring the thickness of each side of the TOTC and the fascicle architecture of the triceps surae with ultrasonography.

Conclusions:

The children with diplegia had shorter hamstring muscles (statistically significant), excessive knee flexion during the initial stance phase (statistically significant), and weaker knee extensors (which approached statistical significance) compared to the children with hemiplegia. The ankle impairments of the two groups appeared similar, while the knee impairments appeared different. Thus the management of the equinus ankle, which involves muscles that span the ankle and the knee joints, should factor in the difference at the knees. Therapists and clinicians should be prepared for a triad of shortened hamstrings, crouched knees and weakened knee extensors among the children with diplegia, which is unlikely in children with hemiplegia.

The two factors that predicted a rise in PCI were belonging to the D-Group, and very weak plantarflexors. Yet, the importance of the strength of the plantar flexors has been under-rated and commonly ignored when surgically managing the equinus ankle. The main deciding factor in the managing of the equinus ankle is the length of the triceps surae muscle and the current study found it not to be a predictor of PCI. The management of the equinus ankle ought to be reviewed and should take into account the strength of the plantarflexors.

Table of Contents

DEDICATION	II
DECLARATION ON PLAGIARISM	IV
ABSTRACT.....	V
ACKNOWLEDGEMENTS.....	VIII
SUMMARY OF THESIS	X
TABLE OF CONTENTS	XVII
LIST OF FIGURES	XX
LIST OF TABLES.....	XXI
LIST OF APPENDICES	XXII
GLOSSARY OF TERMS	XXIII
ABBREVIATION OF TERMS	XXV
1 INTRODUCTION	1
1.1 INTRODUCTION TO THE STUDY	1
1.2 OBJECTIVES OF THE STUDY	3
1.3 SIGNIFICANCE OF STUDY	5
2 LITERATURE REVIEW	6
2.1 INTRODUCTION	6
2.2 PREVALENCE OF CEREBRAL PALSY.....	6
2.3 THE GROSS MOTOR FUNCTION CLASSIFICATION SCALE.....	7
2.4 EQUINUS ANKLE DEFORMITY	8
2.5 OTHER DEFORMITIES OR STRUCTURAL CHANGES IN THE LOWER LIMBS	11
2.6 DIFFERENCES BETWEEN CHILDREN WITH CEREBRAL PALSY WITH HEMIPLEGIA AND DIPLEGIA.....	12
2.7 THE STRUCTURE AND BIOMECHANICS OF THE TENDON OF THE CALCANEUS.....	14
2.8 MUSCLE STRENGTH OF THE ANKLE AND KNEE MUSCLES	16
2.8.1 <i>The introduction of gait phases.....</i>	16
2.8.2 <i>The role of the plantar flexors during gait.....</i>	17
2.8.3 <i>The function of the knee extensors during gait.....</i>	18
2.8.4 <i>The effect of plantar flexors on knee extension in crouch gait.....</i>	18
2.8.5 <i>The use of a hand-held dynamometer to measure muscle strength.....</i>	19
2.8.6 <i>Normalising muscle strength.....</i>	19
2.8.7 <i>The use of manual methods to measure muscle strength.....</i>	20
2.9 THE ANKLE STABILISING ROLE OF THE TENDON OF THE CALCANEUS.....	20
2.10 SPASTICITY OF THE TRICEPS SURAE MUSCLE COMPLEX.....	22
2.11 THE INFLUENCE OF THE HAMSTRING MUSCLES.....	23
2.11.1 <i>The length of the hamstring muscles in crouch knees.....</i>	24
2.11.2 <i>Testing the length of the hamstring muscles.....</i>	25
2.11.3 <i>The tautness of the hamstrings muscle tendons.....</i>	26
2.12 CROUCH KNEE DEFORMITY	27
2.13 ASSOCIATION OF HIP, KNEE AND ANKLE CONTRACTURES.....	28
2.14 LOWER LIMB LENGTH DISCREPANCIES	29
2.15 CLINICAL MEASUREMENT OF HINDFOOT VARUS AND VALGUS.....	32
2.16 PHYSIOLOGICAL COST INDEX	34
2.17 CONCLUSIONS OF THE LITERATURE REVIEW.....	36
3 METHODOLOGY	37
3.1 RESEARCH DESIGN	37
3.2 ETHICAL CONSIDERATIONS	37
3.2.1 <i>Subjects.....</i>	38
3.2.2 <i>Instrumentation.....</i>	39
3.2.2.1 <i>The data collection sheet.....</i>	39
3.2.2.2 <i>Gross Motor Function Classification Scale (GMFCS).....</i>	40
3.2.2.3 <i>The Ashworth scale.....</i>	40
3.2.2.4 <i>The equinus ankle device.....</i>	41
3.2.2.5 <i>Heart rate monitor.....</i>	42
3.2.2.6 <i>The Lodox machine.....</i>	42
3.2.2.7 <i>Other instruments.....</i>	43

3.2.3	<i>Procedure</i>	43
3.2.3.1	Preparation	43
3.2.3.2	Confirmation of the inclusion and exclusion criteria.....	43
3.2.3.3	Collection of the demographic, anthropometric and medical data	44
3.2.3.4	Measurement of impairments and the activity limitations.....	44
3.2.3.4.1	Measurement of the R1 and R2 angles and increased tone	44
3.2.3.4.2	Measurement of the length of the hamstring muscles	45
3.2.3.4.3	Measurement of the relative lengths of the lower limbs	45
3.2.3.4.4	Measurement of the degree of ankle varus and valgus.....	46
3.2.3.4.5	Measurement of the radiological tibiocalcaneal angles.....	46
3.2.3.4.6	Measurement of the strength of the ankle and knee muscle groups	47
3.2.3.4.7	Measurement of the strength of the plantar flexors.....	47
3.2.3.5	Assessment of Crouch Gait.....	48
3.2.3.6	Measurement of data for the Physiological Cost Index	48
3.3	STATISTICAL ANALYSIS.....	49
4	RESULTS	51
4.1	INTRODUCTION	51
4.2	COMPARISON OF THE DEMOGRAPHIC, ANTHROPOMETRIC AND MEDICAL PROFILES	51
4.2.1	<i>Comparison of the age distribution between the two groups</i>	52
4.2.2	<i>Comparison of the distribution of sex between the two groups</i>	52
4.2.3	<i>Comparison of the use of walking aids between the two groups</i>	53
4.2.4	<i>Comparison of the level of difficulty of ambulation between the two groups</i>	53
4.2.5	<i>Comparison of the distribution of the Body Mass Index between the two groups</i>	54
4.2.6	<i>Comparison of the number of past surgical interventions between two groups</i>	56
4.2.7	<i>Summary of the comparisons of the demographic, anthropometric and medical profiles</i>	57
4.3	COMPARISON OF THE IMPAIRMENTS RELATED TO STRUCTURES AROUND THE ANKLE JOINT	58
4.3.1	<i>Comparison of the equinus angles of the two groups</i>	58
4.3.2	<i>The relationship of the R1 and R2 of the equinus angle to GMFCS level</i>	61
4.3.3	<i>Comparison of the spasticity of the triceps surae between the two groups</i>	61
4.3.4	<i>Comparison of the strength of the ankle dorsiflexors between the two groups</i>	62
4.3.5	<i>Comparison of the strength of the ankle plantar flexors between the two groups</i>	62
4.3.6	<i>Comparison of the ankle varus and valgus between the two groups</i>	63
4.3.7	<i>The radiological tibiotalar angles</i>	64
4.3.8	<i>Comparison of the tautness of the sides of the tendon of the calcaneus between the two groups</i>	65
4.3.9	<i>Summary of the comparisons of the impairments associated with the ankle region</i>	67
4.4	THE IMPAIRMENTS RELATED TO STRUCTURES AROUND THE KNEE JOINT.....	67
4.4.1	<i>Comparison of the length of the hamstring muscles between the two groups</i>	67
4.4.2	<i>Comparison of the strength of the knee flexors between the two groups</i>	69
4.4.3	<i>Comparison of the strength of the knee extensors between the two groups</i>	70
4.4.4	<i>Comparison of the presence crouch knees at initial stance between the two groups</i>	71
4.4.5	<i>Comparisons of the overall length of the right and left limbs of the two groups</i>	72
4.4.6	<i>Summary of impairments associated with the knee</i>	73
4.5	COMPARISON OF GAIT PARAMETERS BETWEEN THE TWO GROUPS	74
4.5.1	<i>Comparison of the cadence between the two groups</i>	74
4.5.2	<i>Comparison of the speed of walking between the two groups</i>	74
4.5.3	<i>The physiological energy efficiency of gait</i>	75
4.5.3.1	Comparison of the Physiological Cost Index between the two groups.....	75
4.5.3.2	Demographic predictors of the Physiological Cost Index	76
4.5.3.3	Impairment parameter predictors of the Physiological Cost Index.....	76
4.5.3.4	Effect of the strength of the plantar flexors on the PCI.....	78
4.5.3.5	Effect of the Ashworth level on the PCI.....	78
4.5.3.6	The summary of gait related parameters	79
4.6	SUMMARY OF THE RESULTS	79
5	DISCUSSION	81
5.1	INTRODUCTION	81
5.2	SAMPLE: DEMOGRAPHIC, ANTHROPOMETRIC AND MEDICAL PROFILES.....	81
5.2.1.1	Sample size	81
5.2.1.2	Comparability of the D-Group and the H-Group.....	82
5.2.1.3	The levels of ambulation of the two groups	83
5.2.1.4	The levels of obesity between the two groups.....	85
5.3	IMPAIRMENTS PARAMETERS RELATED TO THE EQUINUS ANKLE	87
5.3.1	<i>The strength of lower limb muscles</i>	87

5.3.1.1	Comparison between the two groups.....	87
5.3.1.2	Functional implications of muscle weakness	88
5.3.1.2.1	Length and strength trade-offs	88
5.3.2	<i>Hamstring length</i>	89
5.3.2.1	Comparison between groups	89
5.3.2.2	Functional Implications.....	90
5.3.2.2.1	Short hamstring muscles.....	90
5.3.2.2.2	The problem of crouched knees	90
5.3.3	<i>Spasticity of the triceps surae</i>	91
5.3.3.1	Comparison between groups	91
5.3.3.2	Functional implications	91
5.3.4	<i>Equinovarus and equinovalgus between the two groups</i>	93
5.3.5	<i>The reliability of the tibiocalcaneal angle</i>	94
5.3.6	<i>Tautness of the sides of the tendon of the calcaneus</i>	95
5.4	GAIT PARAMETERS.....	95
5.4.1	<i>Cadence</i>	95
5.4.2	<i>Physiological Cost Index</i>	96
5.4.3	<i>Factors relating to PCI</i>	96
5.5	LIMITATIONS.....	97
5.5.1	<i>External validity</i>	97
5.5.2	<i>Methodology</i>	98
5.5.3	<i>Lack of kinematic gait parameters</i>	100
6	CONCLUSIONS	101
6.1	INTRODUCTION	101
6.2	DISCUSSION CONCLUSIONS	101
6.2.1	<i>The demographic, anthropometric and medical parameters</i>	101
6.2.1.1	The sample	101
6.2.1.2	Differences between the two groups	101
6.2.2	<i>Parameters of impairment</i>	102
6.2.3	<i>The biomechanical principles underlying equinovarus and equinovalgus</i>	103
6.2.4	<i>Factors predictive of the Physiological Cost Index</i>	103
6.3	THERAPEUTIC IMPLICATIONS	104
6.4	RECOMMENDATIONS WITH REGARD TO FUTURE RESEARCH	105
6.4.1	<i>Shortness of the triceps surae and the hamstring muscles</i>	105
6.4.2	<i>Differential ultrastructure of the triceps surae between the two groups</i>	105
6.4.3	<i>Serial casting</i>	106
6.4.4	<i>The best way to normalise the measurement of muscle strength</i>	106
6.4.5	<i>Tautness of the sides of the tendon of the calcaneus</i>	106
6.5	SUMMARY OF THE CONCLUSIONS	107
7	REFERENCES.....	108
8	APPENDICES.....	120
9	REPORTS OF THE EXTERNAL EXAMINERS	135

List of Figures

FIGURE 1: A PICTURE SHOWING AN EQUINUS DEFORMITY	8
FIGURE 2: THE EXCURSION AND GEOMETRIC METHODS.	10
FIGURE 3: A DIAGRAM TO ILLUSTRATE THE PHASES OF GAIT.	17
FIGURE 4: ROLE OF TENDON OF THE CALCANEUS IN INVERSION AND EVERSION.....	21
FIGURE 5: THE CONVENTIONAL POPLITEAL ANGLE TEST ADAPTED FROM THOMPSON ET AL., 2001.	26
FIGURE 6: THE MEASUREMENT OF THE TIBIOCALCANEAL ANGLE, ADAPTED FROM STOCKLEY ET AL., 1990.....	32
FIGURE 7: THE TIBIOTALAR ANGLE.	34
FIGURE 8: A LATERAL VIEW OF THE SIMPLE EQUINUS ANKLE INSTRUMENT THAT EXERTED A 10N FORCE WHILE THE EQUINUS ANGLE WAS BEING MEASURED	41
FIGURE 9: A SUPERIOR VIEW OF THE SIMPLE EQUINUS ANKLE INSTRUMENT THAT WAS SUSPENDED BY A SHOE LACE TIED ALONG THE TRANSVERSE PLANE ACROSS THE METATARSO-PHALANGEAL JOINT	41
FIGURE 10: A POSTURE TO ILLUSTRATE THE METHOD USED TO ASSESS THE RELATIVE LENGTHS OF THE LOWER LIMBS.	45
FIGURE 11: DEVICE USED TO LOAD 5 KG WEIGHTS ON EACH ANKLE JOINT.	46
FIGURE 12: COMPARISON OF THE AGE DISTRIBUTION BETWEEN THE D-GROUP (N=17) AND H-GROUP (N=12).....	52
FIGURE 13: COMPARISON OF THE DISTRIBUTION OF THE BODY MASS INDEX BETWEEN THE D-GROUP (N=17) AND THE H-GROUP (N=12).....	54
FIGURE 14: THE BMI-FOR-AGE PERCENTILES ILLUSTRATING THE PERCENTAGE OF CHILDREN WITH OBESITY	55
FIGURE 15: THE PERCENTAGE OF CHILDREN WITH OBESITY ACCORDING TO THE GMFCS LEVELS.....	55
FIGURE 16: COMPARISON OF THE NUMBER OF PAST SURGICAL INTERVENTIONS BETWEEN THE D-GROUP (N= 17) AND THE H-GROUP (N= 12)	56
FIGURE 17: TYPES OF PAST SURGICAL INTERVENTION ADMINISTERED TO D-GROUP (N= 17) AND H-GROUP (N=12)	57
FIGURE 18: COMPARISON OF THE R1 ANGLE OF THE EQUINUS ANKLE BETWEEN THE MAL OF THE D-GROUP (N=17) AND THE AL OF THE H-GROUP (N=12)	59
FIGURE 19: COMPARISON OF THE R2 ANGLE OF THE EQUINUS ANKLE BETWEEN THE MAL THE D-GROUP (N=17) AND THE AL OF THE H-GROUP (N=12)	60
FIGURE 20: COMPARISON OF THE STRENGTH OF THE DORSIFLEXORS MUSCLE GROUP BETWEEN THE MAL OF THE D-GROUP (N=14) AND THE AL OF THE H-GROUP (N=9)	62
FIGURE 21: COMPARISON OF THE ANKLE VARUS AND VALGUS BETWEEN THE MAL OF THE D-GROUP (N=17) AND THE AL OF THE H-GROUP (N=12).....	64
FIGURE 22: THE RADIOLOGICAL TIBIOTALAR ANGLES OF THE 15 ANKLES OF CHILDREN WITH CP	65
FIGURE 23: A PHOTOGRAPH DEPICTION OF THE DIFFERENT LEVELS OF TAUTNESS OF THE TENDON OF THE CALCANEUS	66
FIGURE 24: COMPARISON OF THE TAUTNESS OF THE SIDES OF THE TENDON OF THE CALCANEUS BETWEEN THE MAL OF THE D-GROUP (N=17) AND THE AL OF THE H-GROUP (N=12).....	66
FIGURE 25: COMPARISON OF THE LENGTHS OF THE HAMSTRING MUSCLES BETWEEN THE MAL OF THE D-GROUP (N=17) AND THE AL OF THE H-GROUP (N=12).	68
FIGURE 26: COMPARISON OF THE TAUTNESS OF THE TENDONS OF THE HAMSTRING MUSCLES BETWEEN THE MAL OF THE D-GROUP (N=17) AND THE AL OF THE H-GROUP (N=12).	69
FIGURE 27: COMPARISON OF THE STRENGTH OF KNEE FLEXORS BETWEEN THE MAL OF THE D-GROUP (N=17) AND THE AL OF THE H-GROUP (N=12).....	70
FIGURE 28: COMPARISON OF THE STRENGTH OF KNEE EXTENSORS BETWEEN THE MAL OF THE D-GROUP (N=17) AND THE AL OF THE H-GROUP (N=12)	71
FIGURE 29: THE RELATIVE LENGTHS OF THE LOWER LIMBS OF THE D-GROUP (N=17)	72
FIGURE 30: THE RELATIVE LENGTHS OF THE LOWER LIMBS OF THE H-GROUP (N=12)	73
FIGURE 31: COMPARISON OF THE CADENCE BETWEEN THE D-GROUP (N=17) AND THE H-GROUP (N=12)	74
FIGURE 32: COMPARISON OF THE PHYSIOLOGICAL COST INDEX BETWEEN THE D-GROUP (N=16) AND THE H-GROUP (N=12)	75
FIGURE 33: SCATTERPLOT OF PREDICTED AND OBSERVED VALUES OF THE PCI (N=20)	77
FIGURE 34: COMPARISON OF THE GMFCS LEVELS OF THE CURRENT STUDY VS HURVITZ ET AL. (2007)	83
FIGURE 35: COMPARISON OF THE CURRENT STUDY AND PUBLISHED DATA USING THE GMFCS OF CHILDREN WITH HEMIPLEGIC CP	84
FIGURE 36: COMPARISON OF THE CURRENT STUDY AND PUBLISHED DATA USING THE GMFCS OF CHILDREN WITH DIPLEGIC CP	85
FIGURE 37: THE PERCENTAGE OF CHILDREN WITH CP HAVING OBESITY AMONG DIFFERENT STUDIES.....	86
FIGURE 38: THE PERCENTAGE OF CHILDREN WITH OBESITY IN FOUR DIFFERENT STUDIES OF CHILDREN WITH CP... ..	87
FIGURE 39: A PICTURE SHOWING AN EQUINUS DEFORMITY.	124

List of Tables

TABLE 1: PREVALENCE OF DEFORMITIES IN PATIENTS PRESENTING WITH CEREBRAL PALSY.....	11
TABLE 2: DIFFERENCES BETWEEN CHILDREN WITH THE HEMIPLEGIC AND DIPLEGIC TYPES OF CEREBRAL PALSY..	13
TABLE 3: LOWER LIMB LENGTH DISCREPANCIES TREATMENT (CHAPMAN AND MADISON, 1988).....	30
TABLE 4: MAXIMUM VOLUNTARY CONTRACTION TECHNIQUES USED.....	47
TABLE 5: THE AFFECTED/MORE AFFECTED LIMBS OF THE CHILDREN.....	51
TABLE 6: COMPARISON OF THE DISTRIBUTION OF SEX BETWEEN THE D-GROUP (N=17) AND THE H-GROUP (N=12)	53
TABLE 7: COMPARISON OF THE LEVEL OF DIFFICULTY OF AMBULATION BETWEEN THE D-GROUP (N=17) AND THE H-GROUP (N=12).....	53
TABLE 8: THE CATEGORISED R2 ANGLES OF THE ANKLE JOINT IN THE DORSIFLEXION DIRECTION	60
TABLE 9: COMPARISON OF SPASTICITY OF TRICEPS SURAE MUSCLE BETWEEN THE MAL OF D-GROUP (N=17) AND THE AL OF H-GROUP (N=12)	61
TABLE 10: COMPARISON OF THE STRENGTH OF THE PLANTAR FLEXOR MUSCLE GROUP BETWEEN THE MAL OF THE D-GROUP (N=14) AND THE AL OF THE H-GROUP (N=9)	63
TABLE 11: COMPARISON OF THE STRENGTH OF THE PLANTAR FLEXOR MUSCLE BETWEEN THE LAL OF THE D-GROUP (N=14) AND THE UL OF THE H-GROUP (N=9)	63
TABLE 12: COMPARISON OF THE KNEE POSITION DURING INITIAL STANCE PHASE BETWEEN THE TWO GROUPS.....	71
TABLE 13: THE PREDICTIVE VALUE OF THE DEMOGRAPHIC AND MEDICAL PROFILES TO THE PCI.....	76
TABLE 14: THE IMPAIRMENT PREDICTORS OF PCI USING A FORWARD STEPWISE ANALYSIS	77
TABLE 15: THE MEAN AND SD OF THE PHYSIOLOGICAL COST INDEX (N=23) FOR THE THREE HEEL RAISE CONDITIONS.....	78
TABLE 16: THE SCHEFFE POST HOC TEST ASSOCIATION OF THE ABILITY TO PERFORM HEEL RISE GROUPS (N=23) ..	78

List of Appendices

APPENDIX 1: TESTING FOR NORMALITY OF THE DATA USING THE SHAPIRO-WILK TEST AT 5% LEVEL OF SIGNIFICANCE	120
APPENDIX 2: THE LETTER OF APPROVAL FROM THE ETHICS COMMITTEE OF THE FACULTY OF HEALTH SCIENCE	122
APPENDIX 3: THE LETTER OF APPROVAL FROM THE MINISTRY OF EDUCATION	123
APPENDIX 4: INFORMATION SHEET FOR THE PARENTS OR GURDIANS	124
APPENDIX 5: INFORMED CONSENT SHEET	127
APPENDIX 6: ASSENT BY THE CHILD	128
APPENDIX 7: DATA COLLECTION SHEET	129
APPENDIX 8: THE MODIFIED ASHWORTH SCALE	131
APPENDIX 9: GROSS MOTOR FUNCTION CLASSIFICATION SYSTEM LEVELS FOR CHILDREN WITH CEREBRAL PALSY BETWEEN THE AGES OF 6 AND 12 YEARS.	132
APPENDIX 10: THE BODY MASS INDEX-FOR-AGE PERCENTILES FOR BOYS	133
APPENDIX 11: THE BODY MASS INDEX-FOR-AGE PERCENTILES FOR GIRLS	134
APPENDIX 12: THE REPORTS OF THE EXTERNAL EXAMINERS	135

Glossary of terms

Affected limb	- the operational definition was the lower limb with spasticity and muscle weakness, and was applied only to the children with the hemiplegic cerebral palsy
Crouch knees	- the presence of flexed knees during the stance phase of gait
Diplegia	- the diagnosis in children with cerebral palsy who are affected in both lower limbs, and the upper limbs are not involved
Quadriplegia	- the diagnosis in children with cerebral palsy who are affected in all the four limbs
Equinovalgus	- a combination of an equinus ankle and hindfoot valgus
Equinovarus	- a combination of an equinus ankle and hindfoot varus
Equinus ankle	- an ankle in a plantar flexed posture due to spasticity of the triceps surae muscle
Genu recurvatum	- the presence of hyperextended knees during the stance phase of gait
Gross Motor Function Classification Scale	- a scale used to grade the levels of difficulty in ambulation in children with cerebral palsy
Hemiplegia	- the diagnosis in children with cerebral palsy who are affected on one side only, namely the ipsilateral upper and lower limbs
Hindfoot valgus	- eversion of the calcaneum on the talus
Hindfoot varus	- inversion of the calcaneum on the talus
Less affected leg	- the operational definition was a stronger knee extension than the other limb, as measured by the hand-held dynamometer, and was applied only to the children with the diplegic cerebral palsy
Lordosis	- hyperextension of the lumbar vertebral column
Kyphosis	- exaggerated of the thoracic vertebral column
Modified Ashworth scale	- a scale used to manually determine the spasticity of muscle groups
More affected limb	the operational definition was a weaker knee extension than the other limb, as measured by the hand-held dynamometer, and was applied only to the children with the diplegic cerebral palsy

Patella alta	- a patella that is positioned more superiorly than normal and is common in patients with crouched knees
Physiological Cost Index	- is proxy of the amount of energy required to walk a specified distance and is the difference between the heart rate after walking and at rest divided by the speed of walkin
R1 ankle angle	- was the angle of the ankle at first catch when the triceps surae muscle complex was rapidly stretched in the dorsiflexion direction
R2 ankle angle	- was the angle at the end of the range of motion in the dorsiflexion direction
Scoliosis	- lateral curvature of the spine
Spondylolisthesis	- the movement of one vertebra laterally or posteriorly in relation to the vertebra below
Spondylolysis	- 'dissolution of a vertebra; a condition marked by platyspondylia, aplasia of the vertebral arch, and separation of the pars interarticularis' (Dorland's Dictionary, 2003)
Unaffected limb	- the operational definition was the normal limb, and was only applied to the children in the hemiplegic cerebral palsy

Abbreviation of terms

AL	- affected limb
BMI	- Body Mass Index
D-Group	- children with the diplegic form of cerebral palsy
FES	- Functional Electrical stimulation
GMFCS	- Gross Motor Function Classification Scale
H-Group	- children with the hemiplegic form of cerebral palsy
LAL	- less affected limb
MAL	- more affected limb
PCI	- Physiological Cost Index
TOTC	- tendon of the calcaneus
UCT	- University of Cape Town
UL	- unaffected limb

1 Introduction

1.1 Introduction to the study

Cerebral Palsy (CP) is a central nervous system condition, which invariably has a motor impairment component (Morrel et al., 2002). The worldwide average of the prevalence of CP is 2.0 per 1000 life births (Odding et al., 2006). The presence of motor impairments causes a number of musculoskeletal deformities of the lower limb. The equinus deformity or posture is one of these and is defined as the presence of the ankle in a plantar flexed position or presence of limitation to passive dorsiflexion beyond the neutral position (Graham and Fixsen, 1988; Cottalorda et al., 2000).

The equinus deformity and posture is the most common foot and ankle pathology (Bowers and Castro, 2007) and is very common in children with the spastic hemiplegia and diplegia variant of CP (Wren et al., 2005). Between 60% and 70% of patients with CP present with an equinus ankle, (Sussman and Aiona, 2004; Wren et al., 2005). The prevalence and standardised working definition of the equinus ankle has not been defined (Digiovanni et al., 2001). There have been a variety of definitions of the equinus ankle and these have made it difficult to compare clinical cases of the equinus ankle (Digiovanni et al., 2001). The misunderstandings have been caused by different definitions of the range of the ankle angle, the different positions of the knee and the inconsistent amounts of force being placed in the plantar flexion direction (Digiovanni et al., 2001).

Moreover, parameters related to the equinus ankle appear to be different in the groups of children with hemiplegia and diplegia. Children presenting with diplegia tend to have a crouched knee (knee in flexion deformity) and an equinovalgus while children with hemiplegia tend to have genu recurvatum (over extended knee) and equinovarus (Winters et al., 1987; Chapman and Madison, 1988; Aiona, 1996; Morrel et al., 2002; Sussman and Aiona, 2004). A child with hemiplegia tends to have a shorter AL than UL (Graham and Fixsen, 1988; Allen, 2000), while unequal lower limb length has not been documented in children with diplegia and is apparently rare. The children with hemiplegia may find the equinus ankle useful in order to lengthen the AL (Chapman and Madison, 1988; Song et al., 1997) and may be reluctant to change their position of the ankle, even after having had surgery to correct it. The equinus ankle may actually be an effective compensatory mechanism for patients with

- upper neurone injury and has been shown to require less ankle plantar flexor, ankle dorsiflexor and knee extensor muscle strength (Kerrigan et al., 2000).

These reasons might partially explain the recurrence of the equinus deformity or posture in children with hemiplegia. Equinus deformity or posture is often the target of intervention, i.e. therapeutic stretching, surgical lengthening or muscular partial paralysis with the botulinum toxin (Fulford, 1990; Aiona, 1996; Deluca, 1996; Abel et al., 1999). Differences in the parameters related to the equinus ankle in children with hemiplegia and with diplegia may imply that a different mechanism is at play in each group. By investigating factors related to equinus ankle between the two groups, it is hoped that a better understanding of how to best manage the equinus ankle deformity or posture may be gained.

In order to decide on the most suitable treatment for an equinus ankle, it is essential to know what is causing or triggering it. The pelvis, hip, knee and foot deformities are interrelated and muscle imbalances at the hip or ankle affect the knee (Canale, 1998). Among the deformities induced by CP are rapidly progressing scoliosis, increased kyphosis, lumbar lordosis, spondylolisthesis, spondylolysis, progressive hip flexion, and adduction of the hip joint, malformation of the femoral head, hip dislocation and a deformed acetabulum, patella alta and patella fragmentation (Morrel et al., 2002). The other deformities that may be seen are increasing equinovalgus and equinovarus of the foot and ankle, together with rocker-bottom deformity and loosening of the talonavicular joint (Morrel et al., 2002). The complexity of the multiple deformities in varying degrees makes the analysis of the cause of equinus foot difficult (Sussman and Aiona, 2004).

The study consisted of a comparison of the demographic and medical data, measurements to assess the impairments and the activity limitations, and the efficiency of gait using the Physiological Cost Index (PCI) between children presenting with hemiplegic CP and children presenting with diplegic CP.

1.2 Objectives of the study

The specific objectives of the study among the D-Group and H-Group cerebral palsy were:

1. To determine if there was a significant difference between D-Group and H-Group of CP in the following functional and medical parameters:
 - a. Use of a walking aid;
 - b. Level of ambulation difficulties using the Gross Motor Function Classification Scale (GMFCS);
 - c. Number of past surgical interventions;
 - d. Crouch gait or genu recurvatum.
2. To determine if there was a significant difference between the D-Group and H-Group in the following impairment parameters:
 - a. The angle of “catch” during a brisk passive movement (R1) and the end of range angle (R2) of passive ankle dorsiflexion;
 - b. Spasticity of the triceps surae muscle complex;
 - c. Strength of dorsiflexors, quadriceps and hamstring muscles;
 - d. Length of hamstrings (including differentiation between medial and lateral);
 - e. Tautness of the side of the TOTC ;
 - f. Relative length of legs.
3. To determine the basic biomechanical parameters which relate to the underlying equinovarus and equinovagis in the standing subjects:
 - a. By using a goniometer to determine the tibiocalcaneal angles in the coronal plane in children with CP;
 - b. By using radiographs to determine the tibiotalar angles in children with CP;
 - c. By assessing the validity of the tibiocalcaneal angle in the coronal plane as being indicative of the amount of ankle varus or valgus;
 - d. By quantifying the tautness of the medial and lateral sides of the TOTC between the D-Group and the H-Group;
 - e. By determining the association between the tautness of the medial and the lateral parts of the TOTC by palpation and the degree of ankle varus and valgus.

4. To establish which variables were predictive of the Physiological Cost Index (PCI):
 - a. By comparing the difference between the PCI of the D-Group and the H-Group;
 - b. To ascertain, if any, which of the following demographic, anthropometric and medical parameters were significantly predictive of the PCI:
 - i. Age;
 - ii. BMI;
 - iii. Diagnosis (as either having diplegic or hemiplegic CP);
 - iv. Sex.
5. To ascertain, if any, which of the following impairment parameters were significantly correlated to the PCI:
 - a. The values R2 of dorsiflexion (as limited dorsiflexion and as excessive dorsiflexion);
 - b. The strength of the four muscle groups (ankle dorsal and plantar flexors and knee flexors and extensors);
 - c. Spasticity of the triceps surae muscle;
 - d. Number of surgical interventions on the TOTC ;
 - e. The length of the hamstring muscles.

1.3 Significance of study

The purpose of this study was to reveal how the parameters related to the equinus ankle might present in children with hemiplegic CP and in diplegic CP, and indicate to what extent the biomechanics of an equinus ankle are similar in the two groups. The success rate of treatment of the equinus deformity or posture has not been satisfactory, especially in the long term. Under-correction and over-correction of the length of the TOTC and relapses of the equinus deformity or posture have been reported and can cause irreversible profound ankle weakness and a calcaneus gait (Sussman and Aiona, 2004). The equinus ankles of children with diplegia and hemiplegia have been treated as a homogenous group and treatment outcomes may improve when the differences between the two groups are taken into consideration. Moreover, the benefits of having one normal ankle among children with hemiplegia in terms of assisting bearing the body weight, decreasing the range of motion of the equinus ankles of the MAL in the dorsiflexion direction, prevention of crouched knees during gait and in increasing the overall gait efficiency need to be explored further.

Another purpose of the present study was to lay the framework for standardising of the working definition of the equinus ankle in children with CP. The current lack of a universally accepted classification of the equinus ankle in patients presenting with CP in the literature is hampering standardisation of equinus ankle assessments, treatments and research. Researchers and clinicians are currently uncertain as to whether or not they are describing the same feature or extent of the equinus ankle deformities.

2 Literature Review

2.1 Introduction

A literature review was undertaken by searching for electronic and hard copies of journal articles using search names. The search names included equinus ankle, triceps surae, Achilles tendon, cerebral palsy, spasticity, crouch, PCI and the hamstrings. Electronic articles were searched on the Pubmed website (Pubmed website, 2008) and the University of Cape Town (UCT) Faculty of Health Sciences library resource website (Library website, 2008). Relevant library textbooks and hard copies of journal subscribed by the UCT were also examined.

The literature review is presented under the following headings:

2.2 Prevalence of Cerebral Palsy

Cerebral Palsy (CP) is a nonprogressive disorder of motion and posture and is caused by brain insult or injury occurring during the early stages of brain development or within the first year (Allen et al., 2000; Canale, 1998). In a meta-study of CP literature of the last 40 years, Odding et al. (2006) found the prevalence of CP to be on average 2.0 per 1000 live births. The regional rates per 1000 are 1.5 to 2.5 in Western countries (Hensleigh et al., 1986; Deluca, 1996), 2.0 in USA (Canale, 1998), 2.2 in Northern Ireland (Dolk et al., 2006), 2 in Europe (Zwick et al., 2004) and 4.4 in Turkey (Serdaro et al., 2006). The incidence of CP in developing countries is much higher and has predominantly preventable causes (Aicardi, 1992). Couper (2002) found the prevalence of CP in Kwazulu-Natal in South Africa to be much higher than in other countries and was 10 per 1000.

Classification systems of CP are based on the pattern of extremity involvement and type of motor dysfunction (Aiona, 1996). The following subtypes of CP, in terms of the pattern of extremity involvement, are described: diplegic (affecting both lower limbs), hemiplegic (affecting the ipsilateral upper and lower limb), triplegic (affecting both the lower limbs and one upper limb) or quadriplegic (affecting all four limbs) (Aiona, 1996). The motor dysfunction can be described as spastic (having stiff joints due to high tone and weakness of the muscles), athetoid (involuntary movement) or ataxic (disturbed sense of balance) (Aiona,

1996). The most common type of CP is spastic diplegia, which primarily affects the lower limbs (Aiona, 1996). Children presenting with CP very frequently have muscle spasticity and contractures, and these, in turn, cause changes in the bones and joints (Morrel et al., 2002). The vertebral column and joints of the lower limb are most affected in CP (Morrel et al., 2002).

2.3 The Gross Motor Function Classification Scale

Children with CP have in the past been classified as 'mild, moderate, severe' or as 'household and community ambulatory' to allow for comparisons between children with CP. However, this has produced inconsistencies and has been very subjective. Palisano et al. (1997) introduced a five-level Gross Motor Function Classification Scale (GMFCS) to reduce the subjectivity of the descriptions of ambulation and their classification has been generally accepted internationally (Morris et al., 2004b). The GMFCS is shown in Appendix 9. The GMFCS is a standardised and validated system for describing and classifying the functional limitations and the use of mobility devices during ambulation among children with CP (Palisano et al., 1997; Morris et al., 2006). The GMFCS has been found to have good validity and reliability (Palisano et al., 1997; Wood and Rosenbaum, 2000). The GMFCS is simple enough that it can be used by families, who often have better knowledge of the child in different environments, to determine the reliability of the level of ambulation (Morris et al., 2004a; Morris et al., 2006). The GMFCS was used to compare the level of ambulation of the children with diplegia and the children with hemiplegia.

2.4 Equinus ankle deformity

The equinus deformity appears to be the most common musculoskeletal abnormality in CP patients (Graham and Fixsen, 1988; Chapman and Madison, 1988; Morrel et al., 2002) and is illustrated in Figure

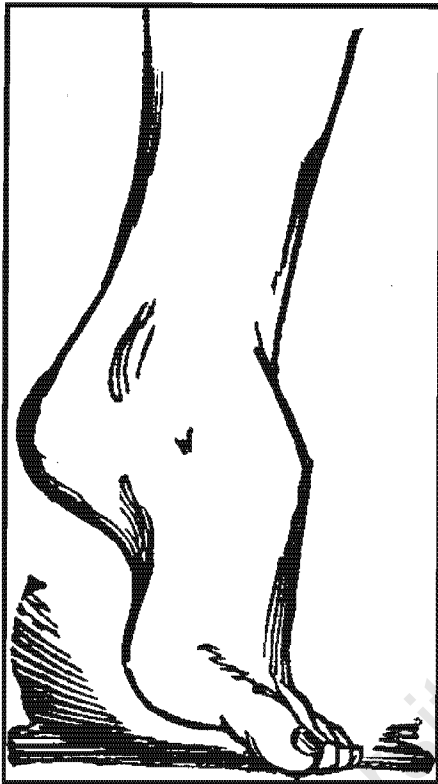


Figure 1: A picture showing an equinus deformity. Image from <http://www.gutenberg.org/files/18467/18467-h/images/advise692.png>

Rudimentary treatment approaches for the equinus ankle have been attempted since the days of Delpech (1823) around in the 19th century (Digiovanni et al., 2001). The equinus deformity is defined as the presence of the ankle in a plantar flexed position or presence of limitation to passive dorsiflexion beyond the neutral position (Graham and Fixsen, 1988; Cottalorda et al., 2000).

The prevalence and definition of the equinus ankle has been neglected (Digiovanni et al., 2001) and two articles on the reliability of diagnosis of the equinus ankle by Digiovanni et al. (2001) and Assal et al. (2003) were found. The equinus ankle can be defined as excessive tightness or spasticity of the triceps surae muscle that prevents full dorsiflexion (Digiovanni et al., 2001). In the literature, the equinus ankle has been measured as the end of range of motion

in the dorsiflexion direction or in the form of a categorical classification of absent, moderate and severe (Digiovanni et al., 2001; Buffenoir et al., 2004). These definitions are weak in that they are unable to detect the presence of a functional equinus ankle, which appears during walking and disappears at rest (Hillström et al., 1991).

A custom-designed ankle equinometer designed for persons with non-neurological foot disorders had satisfactory reliability ratings (Digiovanni et al., 2001; Assal et al., 2003). The equinometer had better control of the foot in the horizontal plane than previous manual methods and measured the ankle with the knee in extension. Knee extension position produces a better position for the measurement of the spasticity of the triceps surae, as the muscle is in a stretched position. However, knee flexion deformity is the most frequent knee abnormality in persons with spastic CP and presents in varying degrees (Chapman and Madison, 1988; Morrel et al., 2002; Arnold et al., 2006) and prevents full extension. During rapid passive movement, spastic muscles tend to demonstrate a first catch, and a second and final catch at the end of range of motion, and the two catches have been termed the R1 and R2 angles respectively [Tardieu et al. (1954) in Cooney et al., 2006]. There are six aspects that a clinically acceptable device to measure the equinus angle must address among children with CP. The device must be able to measure both the R1 and R2 angles of the equinus ankle, must be able to measure the triceps surae muscle in its most stretched position, must be able to stabilise the ankle in a standardised position at a local clinical level, should be able to load a constant force in the dorsiflexion direction among different patients (which includes the weight of the foot), should be cheap to construct (in order to be implementable in developing countries) and should limit hindfoot inversion and eversion.

Treatment of the equinus deformity primarily focuses on lengthening the TOTC and achieving the plantigrade position. Treatment is either surgical or non-surgical. Non-surgical treatments involve manual stretching, use of serial casting, use of intramuscular injections of botulinum toxin A or alcohol and ankle-foot orthosis (Fulford, 1990; Aiona, 1996; Deluca, 1996; Abel et al., 1999). Surgical treatment involves surgical lengthening of the triceps surae or cutting off or crushing the nerve supply to the triceps surae (Sutherland et al., 1999; Cottalorda et al., 2000). Manual stretching is insufficient in treating the equinus deformity. Serial casting applied for three or more weeks corrects the deformity, but as the main causative factor might be muscle group imbalance, the deformity tends to recur within a year (Fulford, 1990). There is currently no effective treatment for the causes of spastic equinus (Buffenoir et al., 2004). The most common foot surgery in children presenting with CP with fixed deformities is

lengthening of the TOTC and dynamic transfer of the medial head and tendon of gastrocnemius to the dorsum of the feet (Fulford, 1990). The two main methods that are used to determine how much TOTC release should be done, are the excursion and geometric methods (Chapman and Madison 1988) and are shown in Figure 2. In the excursion method, the amount of lengthening is one-half of the excursion taken by the TOTC when the foot moves from an equinus ankle to a neutral plantigrade position. In the geometric method, the amount of lengthening performed is one-half of the perpendicular distance that the first metatarsal protrudes inferiorly to the heel during maximum passive dorsiflexion.

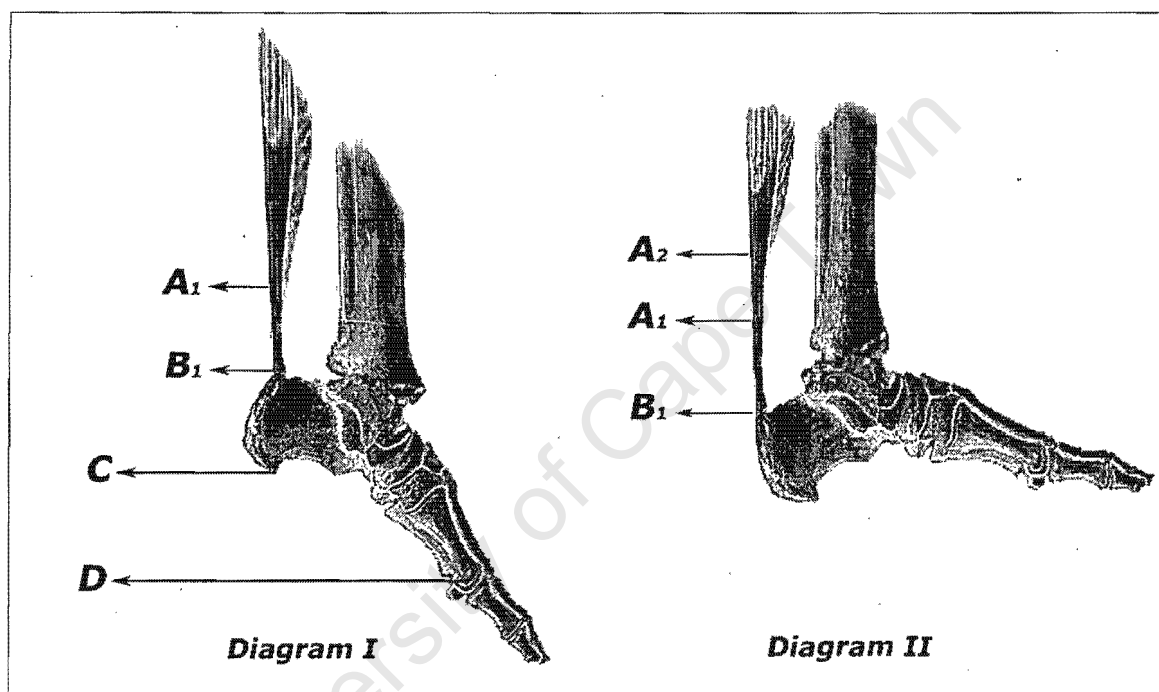


Figure 2: The excursion and geometric methods. The diagrams are modified from Orendurff et al. (2002).

In Diagram I: A₁ = the point where the two bellies of the gastrocnemius and soleus muscles become the TOTC;

B₁ = the insertion of the TOTC onto the calcaneus; C = level of the tuber calcanei; D = the level of the head of the 1st metatarsal.

In Diagram II: A₁ = the original point where the two bellies of the gastrocnemius and soleus muscles become

the TOTC; A₂ = the new point where the two bellies of the gastrocnemius and soleus muscles become the TOTC; B₁ = the insertion of the TOTC onto the calcaneus.

In the excursion method, the amount of surgical lengthening performed on the TOTC is half of the length of the excursion of the TOTC, when the ankle moves from an equinus ankle (Diagram I) to a plantigrade position (Diagram II). The length of the excursion of the TOTC is represented by the length between A₁ and A₂ in Diagram II.

In the geometric method, the amount of surgical lengthening performed on the TOTC is half of the vertical height between the head of the first metatarsal and the inferior border of the calcaneus bone, with the ankle in maximum passive dorsiflexion. The vertical height is represented by the distance between C and D in Diagram I.

2.5 Other deformities or structural changes in the lower limbs

The equinus ankle deformity or posture is by no means the only structural abnormality that children presenting with CP have. Other deformities are also common, some of which occur with a prevalence rate of greater than 60%. Table 1 below shows the prevalence of the deformities in children presenting with CP.

Table 1 Prevalence of deformities in patients presenting with Cerebral Palsy.

Condition and Prevalence	Reference
1. Equinus ankle	
70% of foot deformities in patients presenting with CP 61% of patients presenting with CP	Sussman and Aiona, 2004 Wren et al., 2005
2. Equinovalgus foot	
Most frequent foot deformity seen in spastic diplegia patients 92% of equinus deformities of children with diplegic CP 30% of patients presenting with CP	Aiona, 1996; Sussman and Aiona, 2004 Sussman and Aiona 2004 Wren et al., 2005
3. Equinovarus	
Less common than equinovalgus 8% of equinus deformities 15% of patients presenting with CP	Damron et al., 1994 Sussman and Aiona, 2004 Wren et al., 2005
4. Genu recurvatum	
50% of patients with spastic equinus 14% of patients presenting with CP	Buffenoir et al., 2004 Wren et al., 2005
5. Crouch knee (knee flexion deformity)	
Most common knee abnormality in children presenting with spastic CP 69% of patients presenting with CP	Arnold et al., 2006 Wren et al., 2005
6. Difference in foot size	
Virtually all children with hemiplegic CP have foot size differences	Renshaw (1996) in Morrissey and Weinstein, 2000
7. Lower limb length differences	
33% of CP hemiplegics had length difference of greater than 1.5cm Shortening of the spastic lower limb varied ranged from zero to 4 cm (mean 1.8 cm $\pm$ 0.9 cm SD) Leg length differences greater than 2cm were rare and isolated	Allen, 2000 Graham and Fixsen, 1988 Halliday et al., 1997

8. Excessive hip flexion	
65% of patients presenting with CP	Wren et al., 2005
9. Painful feet	
Not frequent in younger children presenting with CP, but in teenage years, the percentage of children with foot pain increases	Fulford, 1990

The scale of the musculoskeletal disorders is broad in patients with CP and is found at the ankle, knee and pelvis levels of the lower limbs.

Current treatment of the equinus ankle appears to be primarily aimed solely at lengthening the triceps surae muscle complex. Hardly any of the treatment approaches seem to take into account the role played by structures above and below this muscle. The role played by various parameters and deformities on the equinus ankle has not been evaluated in literature and are commonly ignored (Carpenter and Seitz, 1980; Graham and Fixsen, 1988; Hinderer et al., 1988; Fulford, 1990; Rattey et al., 1993; Rose et al., 1993; Deluca, 1996; Aiona, 1996; Cottalorda et al., 1997; Corry et al., 1998; Morrel et al., 2002; Orendurff, 2002). It may be that the other deformities are the underlying cause of the equinus and lead to the recurrence of the equinus after initial treatment in some patients. There is a need to analyse the association between the deformities to provide insight into the biomechanics of the equinus ankle in children presenting with CP.

2.6 Differences between children with Cerebral Palsy with hemiplegia and diplegia

Children with hemiplegic and diplegic CP have been seen as a homogenous group in relation to the equinus deformity or posture by numerous researchers (Fulford, 1990; Aiona, 1996; Deluca, 1996; Abel et al., 1999; Sutherland et al., 1999; Cottalorda et al., 2000). However, there are important differences between children with hemiplegic and diplegic types of CP and these are illustrated in Table 2 below.

Table 2: Differences between children with the hemiplegic and diplegic types of Cerebral Palsy

Condition and prevalence among the patients with Hemiplegic CP	Condition and prevalence among the patients with Diplegic CP	Reference
Equinus ankle – equally prevalent among both groups		
65% of children of consecutive CP patients undergoing computerised motion analysis had an equinus ankle	58% of children of consecutive CP patients undergoing computerised motion analysis had an equinus ankle	Wren et al., 2005
The most common deformity in children with spastic hemiplegia was an equinus ankle	<i>This group was not studied</i>	Graham and Fixsen, 1988
Equinovalgus – more prevalent among the diplegic CP		
<i>This group was not studied</i>	An equinovalgus is the most frequent foot deformity in children with spastic diplegia and an equinus ankle	Chapman and Madison, 1988; Aiona, 1996; Morrel et al., 2002
<i>This group was not studied</i>	92% having equinovalgus were children with diplegia and an equinus ankle	Sussman and Aiona, 2004
<i>This group was not studied</i>	20% of the patients with the diplegic and quadriplegic patterns CP had an equinovalgus	Bennet et al., 1982
15% of children of consecutive CP patients undergoing computerised motion analysis had an equinovalgus	30% children of consecutive CP patients undergoing computerised motion analysis had an equinovalgus	Wren, et al., 2005
Equinovarus – more prevalent among the hemiplegic CP		
The equinovarus appears most often in children with hemiplegia as compared to diplegia	<i>This group was not studied</i>	Chapman and Madison, 1988
The equinovarus deformity in 38% of patients with the hemiplegic pattern of CP	<i>This group was not studied</i>	Bennet et al., 1982
Ankle varus is usual in hemiplegic subjects	<i>This group was not studied</i>	Bleck, 1987
<i>This group was not studied</i>	8% having equinovarus were children with diplegia and an equinus ankle	Sussman and Aiona, 2004
Mentions ankle varus as common in adults with hemiplegia	No mention of ankle varus in patients with diplegia	McCoullough, 1978
31% of consecutive CP patients undergoing computerised motion analysis had an equinovalgus	15% children of consecutive CP patients undergoing computerised motion analysis had an equinovalgus	Wren et al., 2005

Crouch knees – more prevalent among the diplegic CP		
<i>This group was not studied</i>	Crouch gait is one of the commonest motion abnormalities among diplegic with cerebral palsy	Thompson et al., 2001
The different classifications of hemiplegic gait lacked the crouch knee type	<i>This group was not studied</i>	Winters et al., 1987
46% children of consecutive CP patients undergoing computerised motion analysis had crouch knees	73% children of consecutive CP patients undergoing computerised motion analysis had crouch knees	Wren et al., 2005
Genu recurvatum – more prevalent among the hemiplegic CP		
Equinus ankle deformity accompanied by knee hyperextension is a relatively common gait pattern in the adult hemiplegic	<i>This group was not studied</i>	McCoullough, 1978; Sussman and Aiona, 2004
Leg length differences – more prevalent among the hemiplegic CP		
33% of CP hemiplegics had lower limb length difference of greater than 1.5 cm Shortening of the spastic lower limb varied ranged from zero to 4 cm (mean 1.8 cm $\pm$ 0.9 cm SD)	<i>This group was not studied</i>	Allen, 2000. Graham and Fixsen, 1988
Calcaneum dorsiflexion in stance phase – more prevalent among the diplegic CP		
5% children of consecutive CP patients undergoing computerised motion analysis had calcaneum dorsiflexion	33% children of consecutive CP patients undergoing computerised motion analysis had calcaneum dorsiflexion	Wren et al., 2005

There has been very little research comparing between diplegic and hemiplegic subtypes of CP. The studies in Table 2 tend to give a description of either the diplegic or hemiplegic subtypes, and do not mention the other subtype.

2.7 The structure and biomechanics of the tendon of the calcaneus

The tendon of the calcaneus (TOTC) is the strongest tendon found in the body and extends for about 15 cm into the middle of the posterior part of the calcaneum (Romanes, 1981). It is the insertion of the gastrocnemius, plantaris and soleus muscle. The gastrocnemius (Standing et al., 2007; McGlamry et al., 1987) is the most superficial of the three muscles and it has a large medial and lateral head. The medial head arises from the posterior part of the medial femoral condyle and the lateral head from the lateral part of the lateral femoral condyle, and both

bellies insert into the TOTC. The two muscular volumes of the gastrocnemius remain separate until they attach onto a broad aponeurosis on the muscle's anterior surface. The aponeurosis gradually narrows and unites with a tendon from the soleus to form the TOTC or tendo calcaneus. The lateral head of the gastrocnemius muscle may be absent in some subjects (Standring et al., 2007).

The occasional absence of the lateral head combined with the fact that the lateral head is the smaller of the two heads (Standring et al., 2007; McGlamry et al., 1987), would imply that the medial head has a larger role to play than the lateral head. Most children (64%) presenting with CP are known to have internal rotation of the lower limb (Wren et al., 2005). The unequal belly size of the two heads of the gastrocnemius muscle probably contributes to the internal rotation of the lower limbs. If the foot is off the ground, contraction of the gastrocnemius alone would theoretically cause internal rotation of the leg due to the larger medial head. The medial hamstrings are larger than lateral hamstrings and have a tendency to be more strongly activated than the lateral hamstrings in persons with CP, causing internal rotation of the lower limbs (Sutherland et al., 1969; Chong et al., 1978).

Weishaupt et al., (2001) evaluated the appearance of injuries of the distal gastrocnemius. The distal gastrocnemius is the point at which the bellies of the medial and lateral muscles meet the aponeurosis, which then becomes the TOTC. Most of the injuries occurred when the knee was in extension and the ankle in dorsiflexion, as in stepping out of a bus or car (Weishaupt et al., 2001). They found that 82% of the tears occurred at the myotendinous junction of the medial gastrocnemius muscle and 4% at the myotendinous junction of the lateral gastrocnemius muscle. This seems to support the contention that the medial head of the gastrocnemius does most of the work eccentrically, when the triceps surae muscle (composed of the gastrocnemius, plantaris and soleus muscles) is stretched while it is contracting. This may be due to the fact that the medial head of the gastrocnemius arises more posteriorly on the femoral condyles and the lateral head more laterally on the femoral condyles. Children presenting with CP have shortened gastrocnemius muscles (Wren et al., 2004) and it might be that medial head of the gastrocnemius is more responsible for the knee contractures than the lateral head of the gastrocnemius. If so, treatment of knee contractures should focus more on lengthening the medial head than the lateral head of the gastrocnemius.

The soleus (Standring et al., 2007; McGlamry et al., 1987), is a broad muscle located anteriorly to the gastrocnemius that arises from the posterior aspect of the head and proximal

quarter of the shaft of the fibula, the middle third of the soleal line on the tibia and from a fibrous arch over the popliteal vessels and tibial nerve (Standring et al., 2007). The muscle fibres converge on an aponeurosis on its posterior surface, which then inserts onto the TOTC. The plantaris muscle is a small fusiform muscle and has a long tendon. It arises from the distal part of the lateral supracondylar line and inserts onto the calcaneum as the tendon of the calcaneus. Its contribution is negligible to the power generated and 'details are lacking' (Standring et al., 2007).

2.8 Muscle strength of the ankle and knee muscles

The strength of muscles around the ankle and knee joints plays a large role in enabling the normal functioning of the joints (O'Sullivan and Schmitz, 1994; Neptune et al., 2004). Understanding the functioning of the muscles in the context of the gait cycle is important.

2.8.1 The introduction of gait phases

This section gives a brief introduction to the gait phases that will help explain the functions of the muscles during the different phases of gait. Leland Stanford, the Governor of California, was the first researcher to record a gait analysis in 1872, when he asked photographer Eadweard Muybridge to take photographs of his horse running with all four feet in the air. Muybridge managed it by developing faster photographic emulsions and setting up a chain of cameras around the race course, triggered by wires as the horse passed by (Baker, 2007). These studies encouraged the crystallisation of gait terminology of stance and swing phases.

Gait analysis has now been incorporated into the pre-surgical assessment of children presenting with CP and is essential in defining abnormalities and the complex interactions that occur between the spastic muscles and the joints (McGlamry, 1987; Chapman and Madison, 1988; DeLuca, 1991; Gage, 1994; Deluca 1996). The diagram below (Figure 3) shows the main phases that are used to describe the gait cycle, which is characterised by a stance phase (with the leg on the ground) and a swing phase (with the leg in the air).

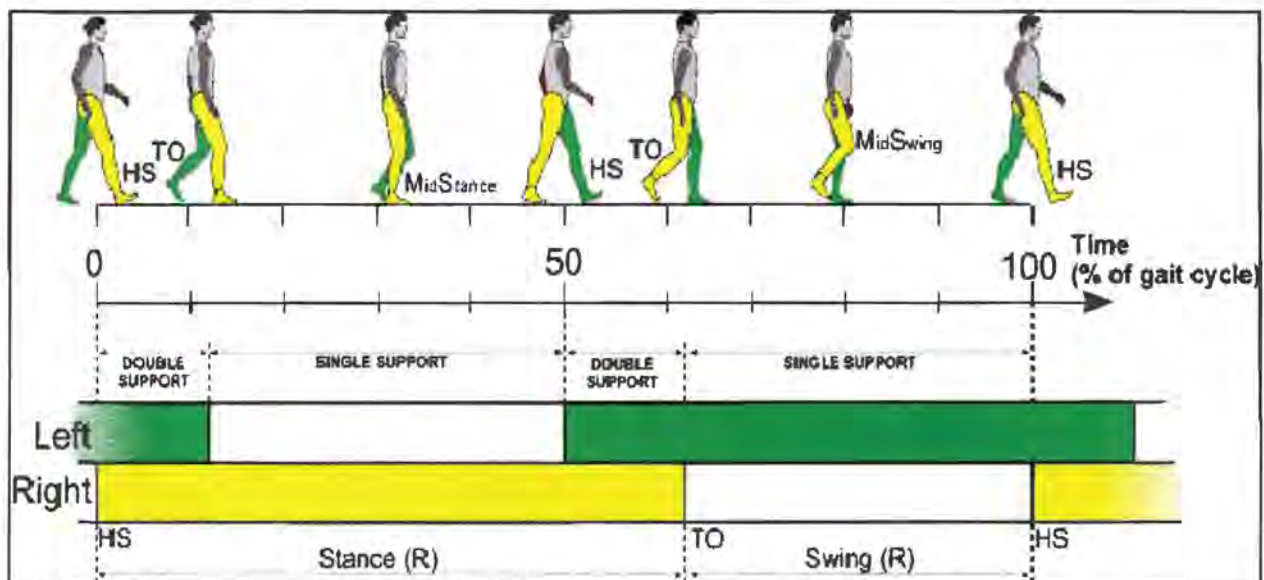


Figure 3: A diagram to illustrate the phases of gait. The diagram is adopted from the Sports Podiatry website (<http://www.sportspodiatry.co.uk/images/gaitcyc2.gif>).

Both the stance phase and the swing phases are each subdivided into early, mid and late phases. Double support occurs when both feet are on the ground and involve late stance of one leg and early swing on the other leg.

2.8.2 The role of the plantar flexors during gait

The plantar flexors play an important role during gait. Muscles absorb energy into elastic tissues in eccentric contraction and use the energy in concentric contraction (O'Sullivan and Schmitz, 1994). The storage of elastic energy and recoil of the plantar flexors are effective mechanisms to reduce a part of the positive muscle fibre work, which later provides body support and forward propulsion in late stance (Neptune et al., 2007). The utilisation of the principle of recycling energy helps in maintaining a low PCI during gait in a normal person. During the loading response in midstance, the gastrocnemius controls the dorsiflexion moment and the tibial advance (dorsiflexion with the foot on the ground moves the proximal end of the tibia anteriorly), (O'Sullivan and Schmitz., 1994). The gastrocnemius muscle is stretched and absorbs the energy to prepare for toe-off (O'Sullivan and Schmitz., 1994). The soleus muscle appears to store more elastic energy than the gastrocnemius muscle during the lengthening in single stance phase and recoils quickly during pre-swing (Ishikawa et al., 2005; Neptune et al., 2007). Although both the soleus and the gastrocnemius fascicles are lengthened during the early part of the stance phase, only the soleus keeps lengthening until the end of the single-

stance phase (Neptune et al., 2007). During pre-swing push off, the energy stored by the triceps surae and the other plantar flexors is then used to stabilise the foot as a propulsive lever and to accelerate the body forward by concentric contraction (O'Sullivan and Schmitz, 1994; Neptune et al., 2001; Hof et al., 2002; Neptune et al., 2004).

2.8.3 The function of the knee extensors during gait

The role of the natural knee extensor, the quadriceps femoris muscle, on leg and trunk acceleration is not easy to assess because this muscle acts as a flexor of the hip joint and an extensor of the knee joint (Neptune et al., 2004). The rectus femoris has a prominent burst at the beginning of stance and is believed to provide lower limb stability during the loading and to accelerate the leg into swing in late stance (Andersson et al., 1997; Annaswamy et al., 1999). The knee extensors help achieve full extension during heel strike by contracting eccentrically to absorb the body weight (Neptune et al., 2004; Neptune et al., 2007). The knee extensors also contract eccentrically to control the knee in 15° of knee flexion during mid-stance and cease contraction once the centre of gravity passes anteriorly to the hip and knee joints (Neptune et al., 2004; Neptune et al., 2007).

2.8.4 The effect of plantar flexors on knee extension in crouch gait

There has been strong evidence pointing to the soleus in producing extension of the knee. A Functional Electrical Stimulation (FES) study has established that electrical stimulation of the soleus muscle produces ankle plantar flexion and knee extension, whereas stimulation of the gastrocnemius produces ankle plantarflexion and knee flexion (Stewart et al., 2007). This implies that the soleus can accelerate the trunk forwards and the leg backwards, and gastrocnemius accelerates the trunk forwards and brings the leg anteriorly with flexion of the knee (Neptune et al. 2001). They therefore act as agonist and antagonist at the knee in mid-stance. A poorly functioning soleus muscle may result in an unopposed action of the gastrocnemius muscle and this will result in flexed knees, which may explain why crouched knees are common in children with diplegia.

The hip flexors are part of the significant compensatory mechanism for reduced plantar flexor power (Neptune et al., 2007). The hip flexors have also been shown to be indispensable in

restoring a normal gait in below-knee amputee gait pattern in the absence of the plantar flexors (Zmitrewicz et al., 2006). It is not surprising that children with CP have a high tendency towards having hip flexor contractures and in one study, 65% of patients presenting with CP had excessive hip flexion (Wren et al., 2005).

2.8.5 The use of a hand-held dynamometer to measure muscle strength

The maximum voluntary contractions (MVC) of the knee flexion, knee extension and ankle dorsiflexion muscle groups can be measured with a hand-held dynamometer (HHD). The MVCs of the three muscle groups using a HHD have been found to be a very reliable quantitative measure of muscle strength among children with CP (Berry et al., 2004; Crompton et al., 2007) (see Table 4 on page 47 in the Methodology Chapter).

2.8.6 Normalising muscle strength

Individual mean force values obtained by a HHD are generally normalised by body weight to allow comparisons between subjects (Damiano et al., 2001; Berry et al., 2004). Normalisation reduces the variability among the subjects so that the high correlations due to measurement variability, which are often reported in reliability studies are decreased (Kramer et al., 1994). The strength of muscle groups is generally normalised by dividing the strength value by body weight (Ayalon et al., 2000; Damiano et al., 2001; Hsu et al., 2002; Berry et al., 2004; Clark et al., 2006). Furthermore, force values are normalised by body weight because weight has been shown to be related to force in children with CP (Kramer et al., 1994). The problem with weight-normalised muscle strength is that it assumes that an over-weight child and an older child have the same strength. Total body height alone has also been used to normalise the data (Van den Berg-Emons et al., 1996).

Molnar et al. (1973, 1974) suggested that, particularly for measurements over time, both parameters related to growth should be used, i.e. body mass and body height and Buckon et al., 2002, implemented this approach. The rationale of Molnar et al. (1973, 1974) is that force multiplied by distance is equivalent to the quantity of torque measurements. As children grow older and taller, they tend to gain body weight. However, children with CP might have a tendency to obesity, due to restricted ambulation and movement. Therefore, dividing the

muscle strength by the BMI should be the best method to normalise muscle strength, in order to factor in the gain in body weight caused by the accumulation of adipose tissue.

2.8.7 The use of manual methods to measure muscle strength

Weak plantar flexors predispose people to a crouch gait during walking and handicap standing or the ability to perform activities involving the lower limbs (Sutherland et al., 1980; Horak et al., 1997; Gajdosik et al., 1999). Although objective measurement of the plantar flexors among persons with walking problems is advisable (Horak et al., 1997; Gajdosik et al., 1999), there is a consensus that the MVC of the ankle plantar flexors is very unreliable. The unreliability is caused by the short lever arm and enormous force produced by the plantar flexors that cannot be counteracted manually (Lunsford and Perry, 1995). The force produced by the plantar flexors is sufficient to propel the body into the air when jumping and is in the order of 2.7 times the body weight [Haxton (1944) in Lunsford and Perry, 1995]. As a result, the manual one-leg heel-raise test (OLHR) has gained credibility as an objective measure of the strength of ankle plantar flexors (Lunsford and Perry, 1995). In healthy adults, the normal number of OLHR before fatigue sets in is 20-25. It has been found that patients who are able to perform less than 10 OLHR, walk with excessive dorsal flexion at the ankle joints (Lunsford and Perry, 1995).

2.9 The ankle stabilising role of the tendon of the calcaneus

There are three major theories that attempt to predict the tautness of the medial and lateral sides of the TOTC during inversion and eversion, namely the traditional theory, the ankle stabilising theory or the soleus-gastrocnemius contribution theory.

In the traditional theory, the insertion of the TOTC is viewed as having a single point of insertion or has a cylindrical tendon on insertion (Brand et al., 1974; Pierrynowski 1995). The TOTC has traditionally been believed to play a role in both inversion and eversion and if the calcaneum inverts, the TOTC will encourage inversion, and the TOTC will encourage further eversion with eversion of the calcaneum (Brand et al., 1974; Pierrynowski 1995).

The ankle stabilising theory has been promoted by Zifchock et al. (2004) and Klein et al. (1996). To the contrary, as the TOTC inserts on the posterior-superior aspect of the calcaneum, it becomes flattened antero-posteriorly and is wide laterally (Standring et al., 2007; McGlamry et al., 1987). Recently, Kolodziej and his colleagues (Kolodziej et al., 1999), viewed the TOTC as flattened and noted that the width of the TOTC is approximately 30 mm. This is important because this view reveals a major role of the TOTC as an ankle invertor and evertor. The influence of the TOTC on inversion and eversion is easier to appreciate by observing the ankle from the posterior side, as shown in Figure 3. Zifchock et al. (2004) and Klein et al. (1996) have found that the TOTC will resist the action of everting or inverting the foot. In brief, the TOTC has a large stabilising effect on movements of the foot and that the tendon behaves as two separate tendons during inversion and eversion (Figure 4).

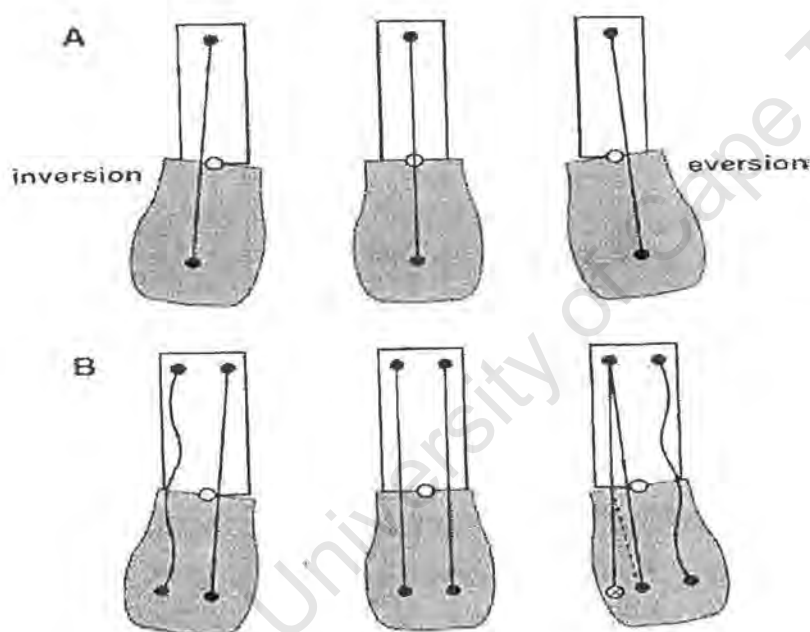


Figure 4: Role of tendon of the calcaneus in inversion and eversion. The diagram is adopted from Zifchock and Piazza 2004.

The top three diagrams, labelled **A**, reflect the traditional theory which assumes that the tendon of the calcaneus as a single line. The bottom three diagrams, labelled **B**, reflect the ankle stabilising theory and assume that the tendon of the calcaneus is flattened. The grey unit is the calcaneum and the lines represent the two sides of the TOTC. In B the two lines represent the medial and lateral parts of the TOTC.

The ankle stabilising theory or the soleus-gastrocnemius contribution theory has its origins in an anatomical perspective. The theory is that the tendon fibres of the lateral side of the TOTC are continuous with the muscle fascicles of the gastrocnemius muscle belly, and likewise the fibres of the medial side of the TOTC are continuous with those of the soleus muscle belly.

(Mozena and Pearson, 2004). The tauter side of the TOTC will be due to a greater tensile force being generated from the respective muscle belly.

The traditional surgical lengthening of the TOTC in patients presenting with CP might be removing this important stabilising effect on the ankle, leaving the patient more vulnerable to inversion and eversion sprains. On the other hand, the medial and lateral parts of the lower part of the TOTC may act as an 'inversion-eversion adjusting knob' to adjust the ankle joint into more inversion or eversion, by surgically releasing either the medial or lateral part of the lower part of the TOTC. Children with diplegic CP commonly have equinovalgus (Chapman and Madison, 1988; Aiona, 1996; Morrel et al., 2002; Sussman MD and Aiona, 2004), and children with hemiplegic CP commonly have equinovarus (McCoullough, 1978; Bleck, 1987; Chapman and Madison 1988).

Fortunately the tendon is very superficial, and as its medial and lateral margins towards its insertion can be palpated clinically, information could be gained to verify which theory is at play during inversion and eversion. The impact of the valgus or varus strain on the equinus ankle has not been explored in the literature and consecutively researchers frequently place an exclusion criterion on either valgus or varus strain at the ankles when reporting outcomes of the spastic equinus ankle treatment (Graham and Fixsen, 1988). The study seeks to establish which of the two theories can predict the tautness of the medial and lateral parts of the TOTC during inversion and eversion in the children with diplegia and hemiplegia. Relevant advice on the lengthening of one side of the TOTC may then be advocated for, to preserve the stabilising role of the TOTC on the ankle. Hindfoot valgus and hindfoot varus might benefit from this surgery.

2.10 Spasticity of the triceps surae muscle complex

The Ashworth scale and the Tardieu scale are manual methods that are used to measure the spasticity of muscles in patients. They both measure the amount of resistance a spastic muscle gives when stretched rapidly. The main differences lie in that the Ashworth scale uses one angular velocity and is easier to carryout, and the Tardieu scale, although believed to more accurately follow the definition of spasticity, uses three different velocities, is very time consuming to implement and lacks the standardisation of the three velocities (Haugh et al., 2006; Scholtes et al., 2006). The Ashworth scale and its variants are the most frequently used

clinical measures of spasticity in order to monitor the progress of a disease or results of an intervention in children with CP (Damiano, 2002). The Modified Ashworth scale was modified from the Ashworth scale by partitioning a category into two (Bohannon and Smith, 1987). The stretch responses recorded manually using the Ashworth scale compared well with the results obtained from using an isokinetic dynamometer, which quantified resistance to stretch (Damiano, 2002). The Modified Ashworth scale was used by the present study. Co-contraction is the simultaneous involuntary contraction of the antagonist muscles when there is voluntary contraction of the agonist muscles (Scholtes et al., 2006). The lower limb muscles of children with CP demonstrate a certain degree of co-contraction during gait (Wakeling et. al., 2007). The total cumulative intensity of the EMG recordings for the gastrocnemius muscle for the stance and swing phase for a given distance walked were greater in children with diplegia than in normal children, due to co-contraction (Wakeling et. al., 2007).

Although the modified Ashworth scale has been extensively used as a quantify of spasticity, the functional implications of the results of the scale remain unclear. The functional capabilities of children with CP tend to decrease as they get older and spasticity is thought to be the main factor, but without any supporting empirical research (Scholtes et al., 2006). Spasticity has been treated using stretching, botulinum injections and surgical procedures, and the time spent and financial burden need to be justified (Albright, 1996; Peacock et al., 1990; Meyer et. al., 2006; Pin et. al., 2006). There is a long standing controversy as to whether or not spasticity influences motor performance (Sahrmann and Norton, 1977). Surprisingly, studies have found a very weak relationship between spasticity and function (Damiano and Abel, 2000; Damiano, 2002). The present study will attempt to find the relationship between spasticity and PCI among children with diplegia and hemiplegia.

2.11 The influence of the hamstring muscles

The hamstring length is an important factor to be considered in studying the equinus deformities. Both the gastrocnemius and hamstring muscles cross the posterior aspect of the knee joint and the muscles may be responsible for the limited knee extension (Banks, 1980). One or both of the muscles may be responsible for crouch knees. The length of the hamstring muscles in crouched knees and how the length and the tautness of the hamstring muscles can be measured will be explored under the following headings.

2.11.1 The length of the hamstring muscles in crouch knees

Researchers are divided on whether the hamstrings are responsible for crouch knees or not. The members of the supportive camp (Drummond et al., 1974; Dhawlikar et al., 1992; Damron et al., 1994) believe that short hamstrings are the main cause of crouch knees. In turn, the crouch knees would, in the long run, encourage shortened hamstring muscles (Baumann et al., 1980; Sutherland and Davids, 1993).

The other camp has questioned the reported shortness of the hamstrings (Wren et al., 2004). In the 1990's, many researchers including Delp, using instrumented gait analysis and musculoskeletal modelling, concluded that, in virtually all cases, the hamstring muscles were of normal length in patients presenting with CP (Delp et al., 1990; Kadaba et al., 1990; Hoffinger et al., 1993). Many others are convinced that not all persons walking with crouch gait have shortened hamstrings, (Hoffinger et al., 1993; Schute et al., 1997; Cosgrove et al., 1997; Thompson et al., 1998; Thompson et al., 2002). A number of studies have indicated that only a minority have shortened hamstrings. Thompson et al. (2001) found that 10 out of 32 children presenting with CP had short medial hamstrings. Delp et al., (1996) found the same result, namely 10 out of 32 children presenting with CP had shortened hamstrings. Hoffinger et al., (1993) found that 4 out of 32 had short hamstrings.

Currently, surgeons tend to lengthen the hamstrings if the knee fails to reach the final 15° of full extension during the gait cycle (Chapman and Madison, 1988) and, in many treatment centres, the threshold is any conventional popliteal angle (see below) greater than 45°, and evidence of hamstring overactivity on electromyographic recordings (Rab, 1992). In many patients, knee extension during walking improves after surgery to the hamstrings (DeLuca et al., 1998; Abel et al., 1999). However, the cause of the excessive knee flexion and the biomechanics that may account for improvements of the patients postoperatively are poorly understood (Arnola et al., 2004).

It is still very difficult to predict which patients might benefit from hamstring lengthening (Arnold et al., 2006). The biomechanical effects of lengthening a muscle with normal length can be detrimental to the patient and very difficult to correct. Attempts at surgically restoring muscle strength after lengthening surgery have been unsuccessful (Sussman and Aiona, 2004).

From 6.25% to 40% of crouch knees undergoing hamstring surgery have developed genu recurvatum (Drummond et al., 1974; Bassett et al., 1976; Campos da Paz et al., 1984; Sharps et al., 1984) and this may lead to severe instability of the knee and may cause malformations of the tibial condyles as growth continues (Thompson et al., 2001). Genu recurvatum is full extension or hyperextension of the knee during stance phase of gait (Simon et al., 1978). About 16% of the patients who undergo hamstring release have an increase in anterior pelvic tilt and lumbar lordosis (Drummond et al., 1974), and this is perhaps an effort by the child to increase trunk stability. When the knee is flexed, the hamstrings are shortened, and flexing the hip joint lengthens the hamstring muscles, and the overall effect will be the original length of hamstrings (Delp et al., 1990; Kadaba et al., 1990; Hoffinger et al., 1993). When there is limited extension of the knee, some patients may demonstrate increased posterior tilting of the pelvis in an effort to increase stride length in walking (Banks, 1980). The short hamstring length may limit the stride length.

2.11.2 Testing the length of the hamstring muscles

The straight leg raise is normally used to assess the length of the hamstrings, but only if the knee can fully extend. Thus the straight leg raise cannot always be used in children presenting with CP, as they might have limiting flexion contractures (Drummond et al., 1974). The measurement of the popliteal angle has been the commonly accepted measure in assessing patients for hamstring length surgery and assessing post-surgery success (Thompson et al., 2001). The popliteal angle was invented by Bleck (1979). It is determined by measuring the angle that the tibia subtends with the extended line of the femur, when the ipsilateral hip is flexed to a right angle and the same knee is extended passively as much as possible (Thompson et al., 1998). The patient lying in a supine position with the contralateral limb lying extended on the table, as shown below in Figure 5:

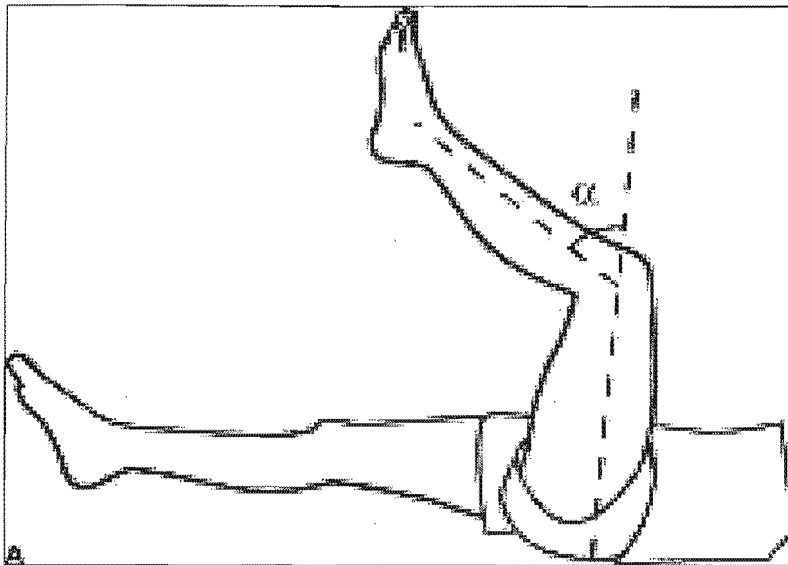


Figure 5: The conventional popliteal angle test adapted from Thompson et al., 2001.

Rab (1999), noted that, in many treatment centres, the threshold for surgery is any conventional popliteal angle greater than 45° , and evidence of hamstring over activity on electromyographic recordings. Delp et al., (1996) warned that the findings of one observer are not adequate to ensure the validity of the method without a repeatability study. However Thompson et al., 2001, have supported a validated experienced observer to use the modified popliteal angle as a useful indicator of short hamstrings. Values obtained by the conventional popliteal angle test were divided into R1 and R2 by Tardieu et al., (1954) (In Cooney et al., 2006). These authors described R1 as a point of resistance during a rapid stretch to a spastic muscle and R2 as the end of range motion during a slow velocity stretch. Cooney et al., (2006) compared the conventional popliteal angle test (as an indicator of hamstring length) with dynamic knee angles during terminal swing knee extension in children with CP and found a strong correlation of -0.73 between R1 values and terminal swing knee extension.

2.11.3 The tautness of the hamstrings muscle tendons

There have been studies indicating that short hamstrings are the main cause of crouch knees (Drummond et al., 1974; Dhawlikar et al., 1992; Damron et al., 1994). The shortness of the hamstring muscles may further be described as medial or lateral, depending on which hamstring muscles are under greater tension when the conventional popliteal test is performed. There are three hamstring muscles; the two medial muscles are the semitendinosus and semimembranosus muscles and the lateral muscle is the biceps femoris muscle. Shortened

medial hamstrings have been noted to cause internal rotation of the lower limbs in children presenting with CP (Sutherland et al., 1969; Chong et al., 1978; Wren et al., 2005) and may be attributed to the two medial hamstrings having a greater generated tension than the lateral hamstring. The internal rotation might have implications on whether an equinovalgus or equinovarus develops. The tautness of the hamstrings will be assessed in the current study in order to assess the implications on crouch knees and presence of equinovalgus or equinovarus.

2.12 Crouch knee deformity

The knee flexion deformity (crouch knee) is the 'most common knee abnormality among patients with spastic CP' (Chapman and Madison, 1988; Morrel et al., 2002; Arnold et al., 2006), especially among the children with diplegic and quadriplegic CP (Thompson et al., 2001). It is also the most troublesome movement abnormality among children with CP (Arnold et al., 2006). Over-lengthened or weak plantar flexors and hip contractures compound the crouch knee, and lengthening the TOTC worsens the crouched knee even in the absence of equinus ankle (Chapman and Madison, 1988). Crouch knee is uncommon among children with hemiplegic CP (Winters et al., 1987).

Individual joints among CP patients can not be evaluated in isolation (Chapman and Madison, 1988), because they affect each other. This is especially so with biarticulate muscles like gastrocnemius and hamstrings. The pelvis, hip, knee and foot deformities are interrelated and muscle imbalances around the hip or ankle joint affect the knee joint (Canale, 1998). Crouch knees are linked to hip and knee flexion contractures and spasticity of the hamstrings (Banks, 1980). Hoffinger et al., (1993) are of the impression that the crouch knees are secondary to a hip flexion deformity. This would make the treatment of crouch knees very difficult to approach, bearing in mind that the biomechanics of crouch knees is also poorly understood (Sutherland and Cooper, 1978). Some researchers are convinced that the weak plantar flexors are responsible for the crouch gait (Gage, 2004). Despite the disagreement, the general consensus in the surgical field is that the hamstring muscles are shortened in children with crouched gait (Drummond et al., 1974; Dhawlikar et al., 1992; Damron et al., 1994). Children with hemiplegia tend to have knee extension and children with diplegia tend to have flexed knees (McCoullough, 1978; Winters et al., 1987; Thompson et al., 2001; Sussman and Aiona, 2004).

With regard to identification of crouch gait, the visual observation of only the knees during the early stance phase (being described as excessive flexion, normal flexion and hyperextension) was reliably comparable to the three dimensional analysis kinematic data (Kawamura et al., 2007). Other visual observations of the knee, such as the position of the knees during terminal stance and at initial swing phase, were unreliable (Kawamura et al., 2007), and will not be assessed by the present study. There appears to be a link between the length of the hamstring muscles and the knee angle around the time of heel-strike. Cooney et al., (2006) managed to establish that during the conventional popliteal test, the angle at first resistance of the hamstring muscle when the knee is rapidly stretched is strongly correlated to terminal knee swing extension during gait. Evaluating the lengths of the hamstrings between the two groups with equinus ankles might help provide deeper understanding of crouch knees in children with CP among the medical fraternity.

2.13 Association of hip, knee and ankle contractures

Chii-Jeng et al., (2000) were among the first to note the linkage or set of the hip, knee and ankle contractures in crouched and recurvatum gait groups of children presenting with CP. They found that, throughout the gait cycle, crouched children with CP presented with the most hip flexion, the most knee flexion and the most ankle dorsiflexion than all the other groups. The recurvatum group presented with the most hip extension, the most knee extension and the most ankle plantarflexion than all the other groups of subtypes of children with CP. Baddar et al., (2002), reported that surgical treatment of equinus contracture with lengthening of the TOTC without simultaneous lengthening of the hamstring, will lead to increased flexion of the knee joint during the stance phase of the gait cycle. In this situation, treatment for the equinus deformity at the ankle resulted in decreased function of the knee joint.

Sussman and Aiona (2004) have observed that, with better descriptions of gait deviation in children presenting with CP through three dimensional gait analysis, the number of gastrocnemius-soleus lengthening procedures have been significantly reduced over the years. Children with crouched gait due to diplegia may have shortened iliopsoas muscles and hip flexion deformities (Sussman and Aiona, 2004). Release of the hamstrings to correct knee flexion contracture could make the hip flexion worse.

Care should be taken in defining an equinus deformity or posture. An observation of initial toe contact or lack of heel contact during stance is not enough, as knee flexion alone can also cause this foot pattern (Sussman and Aiona, 2004). This makes it imperative to assess the knee when considering the biomechanics of the ankle, and 3-dimensional gait analysis can provide this information. Little has been done to assess the angles of the hip and ankle joints during gait cycles after treatment of knee contracture or, alternatively, to assess knee and hip joints after lengthening of the TOTC for equinus ankle. Studies have focused only on the pre-surgical and post-surgical state of the joint being treated, and ignore the linkage of the ankle, knee and hip joints in crouched and recurvatum in children presenting with CP.

2.14 Lower limb length discrepancies

Children with hemiplegia are well known to have lower limb length discrepancy. 33% of CP hemiplegics have a lower limb length difference greater than 1.5 cm (Allen, 2000). The spastic lower limb is generally 0-4 cm (mean 1.8 cm $\pm$ 0.9 cm SD) shorter than the AL (Graham and Fixsen, 1988). Reports of a difference in lower limb lengths among children with diplegic CP have not been found in literature. Children with hemiplegia are known to have a shortened lower limb and among the reasons postulated for the limb shortness are: there is a slower physal (growth plate) growth, decreased blood flow, poor venous return, decreased neurogenic input to the physis and disuse atrophy (Chapman and Madison, 1988). Lower limb length discrepancy is challenging in children because they are still growing and one has to predict whether the discrepancy will become worse with time, stabilise or become less than the current discrepancy (Chapman and Madison, 1988).

Clinically, the degree of lower limb length discrepancy may be manifested by the use of toe-walking as a compensatory strategy (Song et al., 1997). The presence of an equinus ankle has the effect of lengthening the lower limb from the pelvis to the big toe. It could be that perhaps one of the lower limbs is shorter, and children presenting with CP use the equinus foot as a compensatory mechanism to lengthen the leg. Children find it easier than adults to compensate by walking on their toes on the short limb because they have greater joint flexibility and a favourably higher strength/weight ratio than of adults (Chapman and Madison, 1988). Surgical release of the TOTC could then have an unintended shortening effect on the AL, because the ankle is placed in a more dorsiflexion position, which reduces the vertical length of the leg. Different lower limb lengths have been found to be the main cause for recurrence of equinus

deformity after TOTC lengthening in CP patients (Banks, 1980). If sustained over a long time, contractures and joint changes may set in. When one walks on the toes to increase the length of the leg, the knees are used mainly in extension. It may be the reason why children with hemiplegic CP have a tendency towards knee the extension position (genu recurvatum).

Patients often circumduct the unaffected lower limb and tilt the affected side upwards to accommodate the UL. Compensatory lower limb length discrepancy and kinematic changes, such as excessive flexion at the hip, knee and ankle on the contralateral side, have been well documented [Feldkamp et al. (1985) in Saraph et al., 2006; Halliday et al., 1997; Allen et al., 2000]. As mentioned, virtually all children with hemiplegic CP have limb length inequality and differences in foot size [Renshaw et al. (1996) in Morrissy and Weinstein, 2000].

However, unequal lower limb lengths in diplegic patients should be far less common, as both the lower limbs are similarly affected. Some researchers found that large differences in length of the lower limbs (greater than 2cm) were rare and isolated in children presenting with CP (Halliday et al., 1997; Allen et al., 2000), and correction is seldom needed in children with hemiplegia, because the differences are small (Chapman and Madison, 1988). Graham and Fixsen (1988) found that the spastic lower limb was shorter by 0-4 cm on the AL (mean 1.8 cm $\pm$ 0.9 cm SD) in a group of 35 hemiplegic spastic patients. Three of the participants used a shoe raise and none had had a lower limb equalisation surgical procedure. It generally takes a difference of 3 cm to initiate compensatory strategies in walking (Halliday et al., 1997). Below is a table by Chapman and Madison (1988), showing the treatment normally given to lower limb length discrepancies;

Table 3: Lower limb length discrepancies treatment (Chapman and Madison, 1988).

Leg difference	Treatment
0 to 2 cm	No treatment
2 cm to 6 cm	Shoe lift, knee epiphysiodesis, femoral shortening
5 cm to 15 cm	Tibia or femur lengthening procedure
More than 15 cm	Amputation and simultaneous prosthetic fitting

It could be that there is initially an unequal lower limb length and the equinus ankle is a compensatory mechanism or there is an apparent lengthening of the leg after adopting the equinus ankle. In either case, there is a need to rule out the presence of unequal lower limb length in analysing the gait problems in the presence of the equinus ankle deformity. The length difference may be due to a longer lower (crus) or upper half (thigh) of the lower limb (demarcation mark being the knee) and the extent of each half can be evaluated by a method frequently used at the Harare Hospital Orthopaedic Ward*. The patient is made to lie on his or her back with the knees flexed and with feet both on the ground, as shown in Figure 10 page 45. It is important to ensure that the heels of both feet are at the same level and a ruler can be placed just posterior to the heels. If both patellae are at the same height, then both lower limbs are equal. If one patella is more caudal than the other, then that side has a shorter lower half than the other lower limb. If one patella is more cranial, then that side has a shorter upper half than the other lower limb. If the patella is at a lower height from the patient bed, being neither more caudal nor cranial than the other limb, then both halves of the lower limb are shorter. It should be noted that the lengths of the femur and tibia bones are not the only components that make up the total length of the leg. Hip abduction and adduction contractures, differences in foot height (Chapman and Madison, 1988) and abnormalities of the hip joint contribute to the length of a lower limb.

It will be of interest to determine the prevalence and the level at which any lower limb length discrepancy originates in individual cases, e.g. is it from flexion contractures, altered hip joint biomechanics, altered femoral neck angle, shortened femur, shortened tibia, and so forth. Feldkamp et al., (1985) (in Saraph et al., 2006) noted that there was virtually no dissimilarity in length of the two limbs in children with spastic hemiplegic CP.

The current study will have subjects who have diplegia and it is this group which generally has fewer problems of unequal lower limb lengths as compared to the hemiplegic group. It is important to rule out unequal lower limb length as a reason for the presence of the equinus foot in the subjects to be studied. Thus the current study will examine the level of the pelvis in the horizontal plane during the gait cycle and which half of the lower limbs is longer in children with hemiplegic and diplegic types of CP.

* No references to the method could be found in literature.

2.15 Clinical measurement of hindfoot varus and valgus

Equinus deformity is commonly seen together with knee flexion and varus or valgus deformities of the hind foot or fore feet (Morrel et al., 2002). When the equinus deformity is associated with hind foot or fore foot valgus, or hindfoot varus deformity, it is referred to as equinovalgus or equinovarus deformities respectively. Ankle inversion occurs with varus deformity and is a combination of rotation of the foot in the three anatomical planes, namely supination (frontal plane), adduction (transverse plane) and to a much lesser extent plantar flexion (sagittal plane). Ankle eversion is the opposite of ankle inversion and presents as pronation, abduction and dorsal flexion respectively and occurs with foot valgus. An equinovalgus foot is the most frequent foot deformity seen in the patient with spastic diplegia (Chapman and Madison, 1988; Aiona, 1996; Morrel et al., 2002) and quadriplegia (Chapman and Madison, 1988).

Stockley et al., (1990) devised a clinical method of grading ankle varus or valgus and used the coronal tibio calcaneal angle, as shown in Figure 6. The tibio calcaneal angle is measured with a patient in a standing position and the examiner measures the angle with a goniometer from behind the ankle. One arm is placed on the long axis of the tibia and the other arm is on the mid axis of the calcaneum and the centre of the goniometer at the talotibial junction. The centre of the goniometer should instead be at the talocalcaneal joint (subtalar joint), as most inversion and eversion occurs at the subtalar joint (Standring et al., 2007).

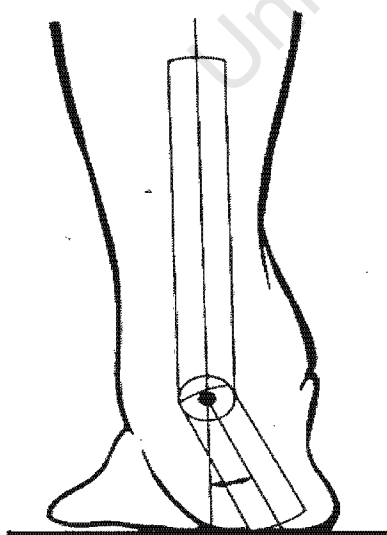


Figure 6: The measurement of the tibio calcaneal angle, adapted from Stockley et al., 1990.

The tibiocalcaneal angle was measured by placing one limb of the goniometer along the tibia and the other along the midline of the calcaneum (Stockley et al., 1990) and the centre of the axis through the subtalar joint.

The degree of ankle varus or valgus can be graded into 5 groups according to Stockley et al. (1990):

- Severe varus: the hindfoot (tibiocalcaneal angle) is in $>10^\circ$ varus;
- Varus: the hindfoot is in 5° to 10° varus;
- Neutral foot the hindfoot is neutral or in $<5^\circ$ varus or valgus;
- Valgus: the hindfoot is in 5° to 10° valgus;
- Severe valgus: the hindfoot is in $>10^\circ$ valgus .

Measurement of the coronal tibiocalcaneal angle involves a combination of the tibiotalar and subtalar joints. The tibiocalcaneal angle in adults was found to be $6.4^\circ \pm 1.9^\circ$ (Haight et al., 2005). About 40% of the patients are said to have tibiocalcaneal angles greater than 10° and 60% less than 10° (Stockley et al., 1990).

The radiological angle of the tibiotalar joint has been established in children and in adults and is illustrated in Figure 7. The tibiotalar angle is about 0° in a one year old and increases to 8° in a 12 year old, ranging from -6° to 14° (Beals and Skyhar 1984). In children of the 5 – 17 year age group, the tibiotalar angle was $1.1^\circ \pm 3.8^\circ$ and had a range of -9 to 12 (Davids et al., 2005). In adults, it was $2.4^\circ \pm 3.1^\circ$ (Knupp et al., 2005). The angle has not been established in CP children.



Figure 7: The tibiotalar angle. The radiograph was taken from the current study.

The angle indicated by the letter A is the junction of a line connecting the superior surface of the talus and the longitudinal bisector of the tibia bone. An angle of 90° is subtracted from the angle A to obtain the tibiotalar angle. Positive angles indicates an ankle valgus and negative values, an ankle varus.

However, most of the inversion and eversion occurs at the subtalar joint, rather than the ankle joint (Standring et al., 2007). This means that the tibiotalar joint needs to have a small range and variability for the tibiocalcaneal angle to reflect the subtalar joint. The tibiotalar angle was measured in the present study to establish its variability across subjects.

2.16 Physiological Cost Index

The involvement of the motor system in CP tends to create an abnormally high consumption of energy (Raja et al., 2007; Bowen et al., 1999). Children with CP use about 6 times more physiological energy than normal children in walking (Raja et al., 2007). Increased energy has been attributed to muscle spasticity, incoordination, loss of selective control, coactivation of antagonistic muscles, paresis, and involuntary movements and gait abnormalities (Bowen et al., 1999; Brunner, 2002; Maltais, 2005). As a result, children with CP tire more easily and

walk less (Bowen, 1999; Robb and Brunner, 2002; Maltais, 2005). Thus, kinematic and kinetic gait analyses and energy expenditure evaluations have been successfully used to monitor the gait progress of children with CP after treatment (Raja et al., 2007). Energy expenditure techniques can either measure the actual oxygen used for metabolism or use a proxy of the oxygen used, such as the heart rate (Raja et al., 2007).

The Physiological Cost Index (PCI) uses the heart rate as an indirect measure of energy consumption and has been confirmed as a reliable index of the efficiency of gait in children with CP (Raja et al., 2007). The PCI calculations are governed by the formula below:

$$\text{PCI (heart beats/meter)} = \frac{\text{Final Heart Rate} - \text{Resting Heart Rate}}{\text{Speed of walking}}$$

The PCI is a reliable indicator of how much oxygen has been used. The more efficient the walking is, the smaller is the PCI. The rationale is that if the body tissues require more oxygen, the heart rate will increase and there is a linear relationship between oxygen consumption and heart rate (Rose et al., 1985; Bartlett, 1989; Bar-On and Nene, 1990; Rose et al., 1991; Umnithan et al., 1991; Nene, 1993; Mossberg et al., 1990; Corry et al. 1996; Norman et al., 2004).

Furthermore, Raja et al. (2007) found that by feeling for the pulse after 50m, 100m and 150m walks enabled the reliable calculation of the PCI, and children with CP who have crouch gait tend to have the highest PCI values. There seems to be a clear association between Functional Mobility Scores (FMS) and PCI values (Raja et al., 2007). The FMS is a recent modification of the GMFCS and aggregates the mobility of a child across three different distances (Graham et al., 2004).

Orthotic ankle devices control or limit certain movements of the ankle, and have been used widely in children with cerebral palsy. Ankle orthotic devices have been found to reduce the energy expenditure (Mossberg et al., 1990). Bailey and Ratcliffe (2005) established that, by using the postexercise heart rate to calculate the PCI, they could produce reliable results similar to using the real time heart rate obtained during the walk. This enables the heart rate to be reliably and manually measured after the walk, rather than by using more complicated equipment (electrocardiography) during the walk (Raja et al., 2007).

2.17 Conclusions of the Literature Review

CP is a world wide condition that affects an average of 0.2% of life births (Odding et al., 2006), and the majority of children with CP have an equinus ankle (Wren et al., 2005). The factors that influence an equinus ankle are numerous and poorly understood. Differences in the parameters related to the equinus ankle between children with hemiplegia and children with diplegia may indicate that a different mechanism is at play in each group. The children with hemiplegia and diplegia have been treated as a homogenous group, and when differences between the two groups in the impairment parameters relating to the equinus ankle are taken into consideration, the relatively poor treatment outcomes may improve. The literature review led to a number of parameters related to the equinus ankle being identified and thus examined in the present study.

University of Cape Town

3 Methodology

3.1 Research design

The study used a prospective, cross-sectional, descriptive and analytical design (Currier, 1990). The study was descriptive in that no variables were manipulated, but analytical in that the relationships between certain demographic, medical, functional and impairment variables in children with hemiplegia and diplegia were investigated. It was prospective in that data were collected from the onset of the study and cross sectional as only one set of data were collected at one point in time from each child.

3.2 Ethical considerations

The study involved vulnerable subjects in the form of children with CP, and thus the researcher sought ethical approval from the local ethics committee and permission from persons entrusted with the care of the children, before the commencement of the study. Permission to carry out this study was obtained from the Human Ethics Committee of the Faculty of Health Sciences of the University of Cape Town (the letter is presented in Appendix 2), the Department of Education under the Ministry of Education (the letter is presented in Appendix 3), and from the principals or medical superintendent of the schools or rehabilitation centres before the research began. The study did not involve the patients undergoing invasive procedures. There was no foreseen risk to the patients who participated in the study. The parents and child were informed that they had a right to withdraw at anytime and that there was no payment, to or from them. The parents or guardian signed the consent forms on behalf of the children, after the participants agreed to participate. The children assented by signing their names on the research forms. Confidentiality and anonymity were protected and no names of the patients appeared on presentation of the findings. Photographs taken to illustrate certain deformities did not contain the faces of the subjects. Some of the parents or guardians understood Afrikaans better than English and thus some of the consent forms were translated into Afrikaans by a Physiotherapy lecturer.

Measurement of the PCI entailed strapping the monitor over the chest of the participants. As the researcher was male, the strap was put in place by female therapists for each female participant. If any child became agitated or distressed, testing was stopped until he or she felt comfortable.

3.2.1 Subjects

Convenience sampling was used to select suitable children with CP from three special schools (i.e. schools specifically for children with CP) in Cape Town. The children were identified as meeting the inclusion criteria by the treating therapists, and a physical examination was carried out by the author, to confirm that the children identified by the therapists did indeed meet the inclusion and exclusion criteria.

The parents of the children who met the following screening inclusion criteria were approached to participate in the study:

- A diagnosis of either spastic hemiplegic or spastic diplegic CP that was made by a medical practitioner or physiotherapist;
- Being aged between 8 and 14 years;
- Being able to ambulate independently or with mechanical aids;
- Having a classification of at least III on the Gross Motor Function Classification Scale (GMFCS) ;
- Being able to raise the forefoot while keeping the heel in contact with the floor during standing. For screening purposes, the equinus ankle was defined as the inability to dorsiflex the ankle beyond 5° with the knee in the maximum possible extension (Digiovanni et al., 2001).

Exclusion criteria included:

- Surgery on the lower limbs within the previous 12 months;
- Cognitively unable to understand the instructions and to co-operate with the testing procedures, as determined by the treating therapist.

A total of 45 children met the screening inclusion criterion and not meet the exclusion criteria. The parents of these children were given informed consent forms and 30 parents or guardians

returned satisfactorily completed forms. One child underwent surgery for lengthening of the TOTC and was excluded from the study. Of the 29 children who participated in the study, 17 children were in the D-Group and 12 children were in the H-Group.

The post-hoc analysis, utilising the results of the study, indicated that, if the difference in PCI between the two groups had been 0.25, 15 children would have been needed in each group to detect a difference at the significance level of $p = 0.05$, with a power of 80%. This was based on the finding that the standard deviation of the response variable was 0.27.

3.2.2 Instrumentation

3.2.2.1 *The data collection sheet*

A data collection sheet (Appendix 7), was developed and included demographic and medical characteristics, the impairments and the activity limitations and the Physiological Cost Index sections.

The 'demographic and medical profile' section was used to document:

- the name, diagnosis of diplegic CP or hemiplegic CP, height, date of birth, weight;
- the GMFCS of the child.

The 'measurements of impairments and the activity limitations' section documented:

- the R1 and R2 angles of the equinus ankle (degrees);
- the degree of equinovarus or equinovalgus (degrees);
- the length of the hamstrings (degrees);
- the relative lower limb length differences;
- the tautness of the TOTC and of the hamstring muscles (as taut, mild and slack);
- the level of spasticity of the triceps surae muscle (Grade 1-5);
- the muscle strength of the dorsiflexors, knee flexors and extensors muscle groups (kg force).

The 'Physiological Cost Index' section was used to document:

- the time taken to walk 100 metres (seconds);
- the cadences (number of steps walked per minute);

- the three readings of the resting heart rate (beats per minute);
- the three heart rate readings taken after the exercise (beats per minute).

3.2.2.2 Gross Motor Function Classification Scale (GMFCS)

The 5-level GMFCS (Appendix 9) was used to compare the level of ambulation between the D-Group and the H-Group. The children who can walk without any walking aids are at level I and children with severely limited self-mobility, even with the use of assistive gadgets, are at Level V (Rosenbaum et al., 2002). The GMFCS has been found to have good validity and reliability (Palisano et al., 1997; Wood and Rosenbaum, 2000).

3.2.2.3 The Ashworth scale

The Ashworth scale and its variants are the most frequently used clinical measures of spasticity to monitor progress of a disease or results of an intervention in children with CP (Damiano, 2002). The Ashworth scales have been used satisfactorily in the majority of all studies that had subjects who had CP and are used in the assessment of spasticity (Scholtes et al., 2006). The Ashworth scale has generally mild reliability ratings and it is advisable that it is used by single examiners only, and not by different examiners (Fosang et al., 2003). The modified Ashworth scale was used in the present study. The subject was assessed by positioning the child in a prone position, with the knees in a right angled position and the ankles in a plantigrade position. The forefoot was manually pressed in the dorsiflexion position during the test and recorded on the Data Collection Sheet (Appendix 7).

3.2.2.4 *The equinus ankle device*

A simple instrument was designed to standardise the force that was exerted on the plantar surface of the foot, as manual pressure varies from examiner to examiner. The instrument exerted a constant force of 10N acting vertically downwards from along the transverse plane across the plantar surface of the first metatarso-phalangeal joint. The instrument was made of two 0.5kg weights, which were suspended by a cord, and is shown in Figure 8 and 9.



Figure 8: A lateral view of the simple equinus ankle instrument that exerted a 10N force while the equinus angle was being measured



Figure 9: A superior view of the simple equinus ankle instrument that was suspended by a shoe lace tied along the transverse plane across the metatarso-phalangeal joint

3.2.2.5 Heart rate monitor

The heart rate was monitored by a heart rate sensor that was strapped onto the chest. The sensor sent the data wirelessly to a watch which was strapped onto the wrist of the child. The heart rate monitor was a Timex Ironman Triathlon® Bodylink Heart Rate Monitor system and Transmitter Series (M8xx/M5xx model, made by Timex, USA).

3.2.2.6 The Lodox machine

A low dose radiography machine, called a Lodox/Statscan® (made by Lodox Systems North America, LLC, USA), was available at the University of Cape Town and used for taking radiographs of the ankles of the children. It produced whole body radiographs using a very low dose of radiation, such that it can be used frequently without harm to the workers. The average radiation dose received by a group patients is 6% (ranged from 2% on radiographs of the pelvis to 72% on radiographs of the chest for individual patients) of the conventional radiography machine [Beningfield et al., 2003; Parry et al. (1999) in Boffard et al., 2006; Debtech division of De Beers (2002) in Boffard et al., 2006]. It produces normal “X-ray like” images which are available on a conventional computer, can be enlarged or printed out (Boffard et al., 2006). A study in South Africa (Boffard et al., 2006) recommended radiography using the Lodox equipment for paediatric assessment, due to the very low radiation dosage and the fact that the radiograph can be taken rapidly (13 seconds for the whole body).

In order to mimic weight-bearing, a device was made to create a 5 kg weight loading on each ankle joint with the patient lying in the supine position, as shown in Figure 11 on page 46. The board had wheels and moved independently to the stationary vertically placed weighing scale. A weight of 5 kg was mounted in such a way that it exerted traction of 5 kg on the board, and the force was transmitted through the foot of the child onto the weighing scale. The ankle joint was thus loaded with a weight that read 5 kg on the weighing scale. The radiograph was taken from vertically above through the glass area and radiographed the ankle joint in the anteroposterior direction.

3.2.2.7 *Other instruments*

The HHD used was a Myometer Transducer (model D11920 MK 1, made by Penny and Giles, Christchurch, England). The body weight was measured using a calibrated bathroom scale and the height of the child was measured with a tape measure mounted vertically on a wall. The photographs were taken with a 6 megapixel Concord digital camera (model type 6340z, made by Concord, UK). A simple goniometer, as shown in Figure 7 and 8, was used to measure joint angles.

3.2.3 *Procedure*

3.2.3.1 *Preparation*

The therapists of the school were approached and asked to list all the children under their care who satisfied the screening criteria for inclusion and exclusion. The parents of 45 children listed by the therapists were contacted by telephone. During the telephone call, the justification and design of the study, possible risks and benefits, and how much time the study would involve on their part was all explained to the child and parents. After the parent and child verbally agreed to participate, the letters of invitation (which contained information sheets, consent and assent forms and are presented in Appendix 4,5 and 6 respectively) were sent to the parents of the children by the therapists based at the school. A total of 30 parents returned the duly completed consent and assent forms and were recruited for the study.

3.2.3.2 *Confirmation of the inclusion and exclusion criteria*

The demographic information was collected and a physical examination was carried out by the researcher, to confirm the inclusion and exclusion criteria used by the therapist while making the list of suitable children. All of the 30 children listed by the school physiotherapists were found suitable for the study and were booked for the main research appointment at the school. If the study found anything that might require the attention of the clinicians or therapists during the data collection, the clinicians or the therapists at the school or hospital were to be notified.

3.2.3.3 Collection of the demographic, anthropometric and medical data

The collection of research data was performed at the school. The full name, diagnosis of having diplegic or hemiplegic CP and the date of birth were obtained from the medical records of the children, and the date of the assessment were recorded. The height and weight of the children were measured with a vertical tape measure and a bathroom scale respectively and the BMI was calculated. The GMFCS score was determined by asking the child to walk a short distance of 10 metres and classifying their walking according to the criteria, as presented in Appendix 9.

3.2.3.4 Measurement of impairments and the activity limitations

3.2.3.4.1 Measurement of the R1 and R2 angles and increased tone

The measurements of impairments and of the activity limitations were carried out in the physiotherapy treatment rooms of the schools. Each subject was made to lie in a prone position on a bed with the knee joint in 90° flexion and the ankle in a plantigrade position. The plantar flexor muscle group was manually and passively stretched maximally twice for 30 seconds in the dorsiflexion direction. This was followed by the evaluation for spasticity using the modified Ashworth Scale (Appendix 8). The equinus ankle instrument was then mounted onto the foot, and was used to create a force of 10N in the gravity dependent direction along the transverse plane across the plantar surface of the first metatarso-phalangeal joint. The ankle angle in the sagittal plane was measured with a goniometer. One arm of the goniometer was placed on the lateral side of the fifth metatarsal bone and the other arm was placed on the lateral side of the fibula (Meyer et. al., 2006).

With the child in the same position, the forefoot was held at maximum plantarflexion and allowed to drop passively, under the weight of the equinus instrument, to create a downward force of 10 N. The R1 angle was defined as the angle that the triceps surae muscle complex produced a first catch (a sudden cessation of the dorsiflexion movement) and the R2 angle as the angle at the end of the range of motion of dorsiflexion. The angle of the ankle in the sagittal plane was thus measured at two points, namely the R1 and R2 angles, after waiting for at least 10 seconds without a change in the ankle angle. If the number of seconds that allows the ankle joint to move from R1 to R2 angles is not standardised, the poor reliability of the readings can cause misinterpretations among researchers.

The anatomical plantigrade position was taken as the neutral position. Plantarflexion angles were allocated negative values and dorsiflexion angles positive values. The equinus ankle was defined as being unable to exceed 5° dorsiflexion (Digiovanni et al., 2001).

3.2.3.4.2 Measurement of the length of the hamstring muscles

The length of the hamstring muscles was measured with the subjects lying in a supine position. The lower limb to be tested was placed in 90° hip and knee flexion and the opposite lower limb was stabilised to prevent hip flexion. The lower limb to be tested was moved from 90° knee flexion towards maximum passive extension. The angle at which the knee joint could be maximally extended was the length of the hamstring muscle in degrees (Thompson et al., 1998).

3.2.3.4.3 Measurement of the relative lengths of the lower limbs

The relative lengths of the lower limbs was assessed by having a child lie in a supine position, with both hips at 45° of flexion, both knees at 90° of flexion and the plantar surface of the feet placed on the bed, as shown in Figure 10. If one of the knees was higher than the other knee, then that lower limb was longer. If one knee was more caudal than the other, then that lower limb had a relatively longer lower half, and if one knee was more cranial than the other, then that lower limb had relatively greater contribution by the upper half of the lower limb.



Figure 10: A posture to illustrate the method used to assess the relative lengths of the lower limbs. Adapted from www.dkimages.com/discover/previews/82343129.

3.2.3.4.4 Measurement of the degree of ankle varus and valgus

The degree of ankle varus and valgus was measured as the tibiocalcaneal angle in the coronal plane, with the subject standing upright. The tibiocalcaneal angle was measured by placing one arm of the goniometer along the length of the tibia and the other along the posterior midline of the calcaneum. The heel of the foot was at the edge of the bed, with the subject standing on the bed. The centre of the two goniometer arms was the talocalcaneal junction. While the subject was standing, the medial and lateral sides of the TOTC were also palpated to determine the tautness. One examiner performed all the measurements to improve reliability of the results. The tautness was graded as very taut, mildly taut and slack.

3.2.3.4.5 Measurement of the radiological tibiocalcaneal angles

The child was asked to lie in a supine position on the board shown on Figure 11. The child was strapped onto the board with Velcro straps at the shoulder, pelvis and knee levels. The board had wheels and moved independently of the stationary vertically placed weighing scale. A weight of 5 kg was mounted in such a way that it exerted traction of 5 kg on the board, and the force was transmitted through the foot of the child onto the weighing scale. A single ankle joint was thus loaded with a weight that read 5 kg on the weighing scale. The radiograph was taken from vertically above through the glass area, and imaged the ankle joint in the anteroposterior direction.

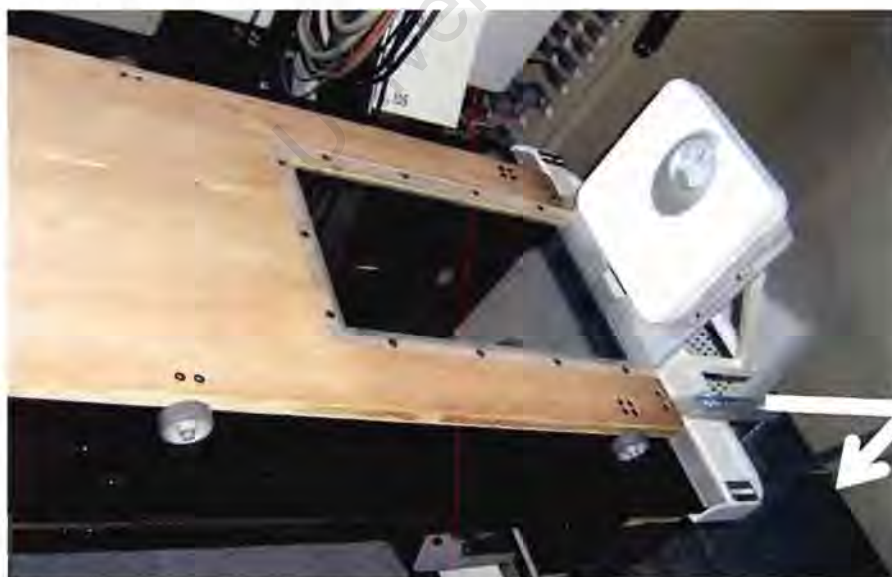


Figure 11: Device used to load 5 kg weights on each ankle joint.

The child lay in a supine position and had his or her feet resting on the white body scale. The white arrow indicates the right sided pull by the 5 kg force and the other left sided pull was on the left side of the weight scale.

3.2.3.4.6 Measurement of the strength of the ankle and knee muscle groups

The strength of each of the ankle dorsiflexor, knee flexor and extensor muscle groups was measured using a HHD in kg force. The techniques, postures of the subjects, methods of stabilisation and the positions that the HHD were placed for the ankle dorsiflexor, knee flexor and extensor muscle groups are indicated in Table 4. The children were motivated verbally to give their strongest possible push. The mean strength of the ankle dorsiflexor, knee flexor and extensor muscle groups was calculated from the average of three readings.

Table 4: Maximum Voluntary Contraction Techniques used

MVC Test	Posture	Stabilisations	Hand-held dynamometer placement	References
Knee flexion	Sitting with knees and hips at 90° and foot in plantigrade position	Thigh stabilised with a strap to prevent hip flexion	Anterior of calf, 2cm proximal to maleoli	Berry et al., 2004
Knee extension	Sitting with knees and hips at 90° and foot in plantigrade position	Pelvis stabilised to prevent hip extension	Posterior of calf, 4cm proximal to maleoli	Berry et al., 2004
Ankle dorsiflexion	Supine, knee extended, foot in plantigrade position	Thigh is stabilised (knee not allowed to flex) using a seat belt	Resistance to dorsal surface of metatarsal heads	Crompton et al., 2007

The strength of the ankle dorsiflexor, knee flexor and extensor muscle groups were normalised by dividing by the body weight.

3.2.3.4.7 Measurement of the strength of the plantar flexors

Initially, the investigator decided that there was no reliable method to determine the strength of the plantar flexors. However, it became apparent that it was essential to have such a measurement, even if only a proxy measure of the strength, and a further literature search revealed the one-leg heel-rise (OLHR) method, namely the technique described by Lunsford

and Perry (1995). Unfortunately, the OLHR method was undertaken four months after the original collection of the data. Two examiners were involved. One examiner observed when the 50% of the height was achieved and the other examiner held the one finger of each hand for balance support and the second examiner clapped every two minutes. The subject stood erect on one lower limb, and had to rise every two seconds onto the ball of their foot of the leg they were standing on and that coincided with manual clapping every two seconds, as measured with a wrist watch. The subject performed one maximum heel rise and the height of the heel was marked on a paper. The paper was placed on a wall, about 5cm lateral to the lateral side of the foot. The subject performed one single maximum heel raise and the height that the heel raised into the air was recorded on the paper placed on the wall. The subject had to achieve at least 50% of the maximum height on each heel rise, until the plantarflexors became fatigued and were unable to accomplish the required action. One examiner held one finger of the hand of each child for balance and monitored the prevention of knee extension. The other examiner ensured that each heel rise was at least 50% of the maximum heel rise and that each heel rise was done every two seconds. The test was stopped if the subject pushed too heavily with the hands, flexed the knees, was unable to reach 50% of the heel height or wished to stop due to fatigue.

3.2.3.5 *Assessment of Crouch Gait*

The three categories of the position of the knees during initial stance, namely excessively flexed, normal and excessively hyperextended knees. This was assessed visually by an examiner who observed from a perpendicular 5 metres away to the direction the subject was walking. The position of the knee was described as flexed, extended or hyperextended. The visual observation of the knees during early stance phase was reliably comparable to the three dimensional analysis kinematic data (Kawamura et al., 2007). Other visual observations of the knee such as the knees during terminal stance and the knees at initial swing phase, were unreliable (Kawamura et al., 2007) and were not assessed.

3.2.3.6 *Measurement of data for the Physiological Cost Index*

A functional parameter of gait in the form of the Physiological Cost Index (PCI) was calculated, and a relationship between the PCI and the equinus related parameters was sought.

The PCI is an indirect measure of energy consumption and is a reliable index of the efficiency of gait in children with CP (Raja et. al., 2007). The PCI calculations are governed by the formula:

$$\text{PCI (heart beats per meter)} = \frac{\text{Final Heart Rate} - \text{Resting Heart Rate}}{\text{Speed of walking}}$$

The measurements needed to calculate the PCI were collected before and after a 100 metre walk on a concrete corridor. Three resting heart rates spaced ten seconds apart, were collected after the child was rested and seated for 5 minutes. The mean resting heart rate was calculated as the average of the three readings, which were. The three readings had to be stable and if an unusually high reading was obtained, the collection of the three readings was restarted. The child was asked to walk 100 metres at a self selected speed. The cadence was counted and the walk was timed in seconds. When the child completed the walk, the heart rates at 0 seconds, 5 seconds and 10 seconds after the exercise, were measured while the child was standing.

3.3 Statistical analysis

Muscle strength was normalised by dividing the strength values by body weight. The sample data were first tested to determine whether or not the data were normally distributed by using the Shapiro-Wilk W Test, using a level of significance of 5%. If the variables were found to be normally distributed, parametric tests were utilised. The independent t-test was used to compare the mean values of the parameters between children with spastic diplegia and spastic hemiplegia. If the variables were found not to be normally distributed, the Mann-Whitney U test was used to compare the rank ordering of the variables between the two groups. Spearman Rank Order correlations were performed to determine the degree of correlation between the degree of equinus and the parameters. Exploratory Spearman Rank Order correlation was used to identify which factors are correlated to the Physiological Cost Index of walking. The level of significance for all the statistical tests was $p = 0.05$. STATISTICA software (2004) (data analysis software system, version 7) was used to conduct the statistical analysis.

Standard multiple regression analysis was performed in order to determine whether BMI, age, H or D-Group membership or sex were predictive of PCI. As there were so many relevant

impairments variables, a forward stepwise analysis regression was used to identify which impairments were predictive of PCI. The impairments included:

- The values R2 of dorsiflexion as two dummy variables of limited dorsiflexion and as excessive dorsiflexion. Limited dorsiflexion was defined as being unable to achieve less than 10° of plantar flexion and excessive dorsiflexion as beyond 10° of dorsiflexion;
- The strength of the three muscle groups (ankle dorsiflexors and knee flexors and extensors) normalised by body weight;
- The spasticity of the triceps surae muscle (dummy variable created with 0 = 1 to 2 on Modified Ashworth Scale and 1 = 3 to 4 on the Modified Ashworth Scale;
- The length of the hamstring muscles (in degrees);
- The ability to rise onto the toes (heel raise) as a measure of the strength of the plantar flexion entered as a dummy variable: 0 = no heel raises; 1 = > 1 heel raises.

As the normalised strength of the hamstrings and ability to heel raise were the only variables retained in the model, these were entered in the final model. Residual analysis was then performed.

4 Results

4.1 Introduction

The results commence with the description of the demographic, anthropometric and medical profiles of the children with the diplegic presentation of CP (D-Group) and the children with the hemiplegic presentation of CP (H-Group). The differences in the parameters relating to the equinus ankle, between the D-Group and the H-Group are explored next. Finally, demographic, anthropometric and medical profiles, and impairment parameters which could predict the Physiological Cost Index (PCI) of gait were sought. The data of the two groups were tested for normality using the Shapiro-Wilk test (Appendix 1) and data were found to be normally distributed, except when indicated.

4.2 Comparison of the demographic, anthropometric and medical profiles

There were 45 children at three schools who met the inclusion criteria. Of these, 30 children returned the signed informed consent forms and were included in the study. During the course of the study, one child underwent surgery to her TOTC and was excluded from the study, as data collection could not be completed. There were 17 children who constituted the D-Group and 12 who constituted the H-Group and both groups made up the present study.

The sides of the affected limb (AL) among the H-Group are shown in Table 5. There were twice (8 versus 4) as many children with a left AL than a right AL. For the D-Group, the operational definition of the more affected limb (MAL) was the lower limb with weaker knee extension than the other limb, as measured by the hand-held dynamometer (HHD), and the results are shown in Table 5. There were five times (15 versus 3) as many children with a left MAL than a right MAL.

Table 5: The affected/more affected limbs of the children.

	Right side	Left side	Total
H-Group (Affected limb)	4	8	12
D-Group (More affected limb)	3	15	17

4.2.1 Comparison of the age distribution between the two groups

The mean ages of the children in the D-Group and the H-Group were 10.3 ± 1.6 and 10.8 ± 1.7 years respectively. Although the H-Group had a slightly higher mean, the difference was not statistically significant ($t = 0.89$, $p = 0.38$). Figure 12 demonstrates the ages of the children of the two groups.

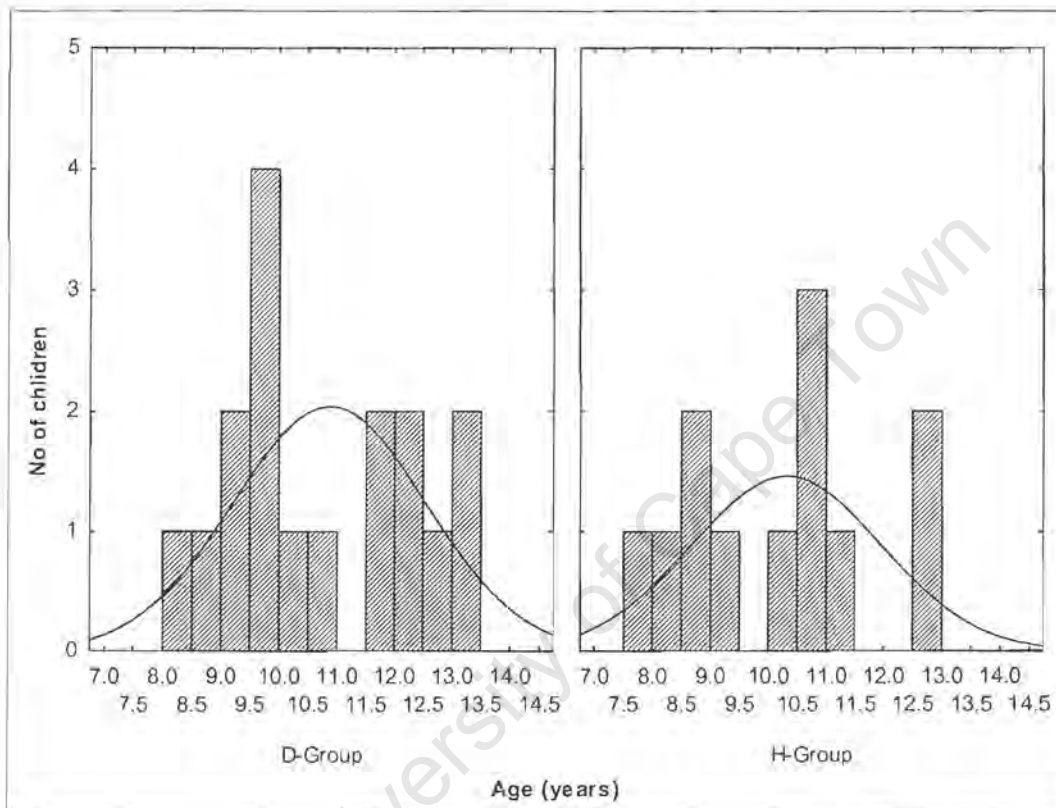


Figure 12: Comparison of the age distribution between the D-Group (n=17) and H-Group (n=12)

4.2.2 Comparison of the distribution of sex between the two groups

There were 13 males and 4 females in the D-Group. The sex distribution was equal in the H-Group (Table 6). The sex distribution was not associated with being in the D-Group or the H-Group ($p = 0.14$).

Table 6: Comparison of the distribution of sex between the D-Group (n=17) and the H-Group (n=12)

	Male	Female	Row Total
H-Group	6	6	12
D-Group	13	4	17
Totals	19	10	29

Chi Square = 2.18, p = 0.14

4.2.3 Comparison of the use of walking aids between the two groups

Walking aids were used by four children, all of whom were from the D-Group.

4.2.4 Comparison of the level of difficulty of ambulation between the two groups

The scoring system of the GMFCS has five levels (1-5), with the lower levels indicating that the subjects have no difficulty in ambulating. The children in the D-Group had higher GMFCS levels ranging from I-III and had a median score of one, while all the children in the H-Group were at Level I, as shown in Table 7. The association between group and levels approached significance (p = 0.07).

Table 7: Comparison of the level of difficulty of ambulation between the D-Group (n=17) and the H-Group (n=12)

	GMFCS Level of I	GMFCS Level of II	GMFCS Level of III	Row
D-Group	11	1	5	17
H-Group	12	0	0	12
Totals	23	1	5	29

Chi = 5.34, p = 0.07

4.2.5 *Comparison of the distribution of the Body Mass Index between the two groups*

The median values for the Body Mass Index (BMI) of the D-Group and the H-Group were 16.2 kg/m² (ranged from 12.6 - 28.2 kg/m²) and 18.0 kg/m² (ranged from 13.6 - 24.8 kg/m²) respectively, with the H-Group having a slightly higher mean, as shown in Figure 13. The differences between the rank sum ordering of the BMI values of the two groups were not statistically insignificant ($U = 71.00$, $p = 0.17$).

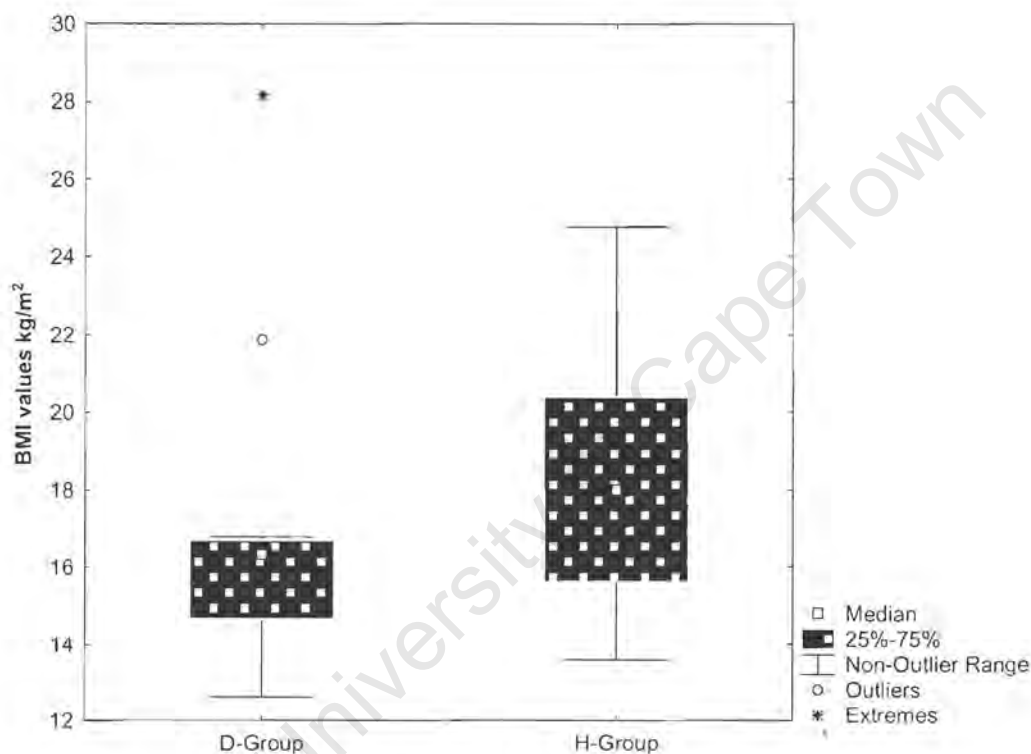


Figure 13: Comparison of the distribution of the Body Mass Index between the D-Group ($n=17$) and the H-Group ($n=12$)

The BMI values were then converted to sex-specific BMI-for-age percentiles by using the commonly used BMI growth charts developed by the National Center for Health Statistics in association with the National Center for Chronic Disease Prevention and Health Promotion (Growth Charts, 2000). The charts are separate for boys and girls, and are shown in Appendix 10 and 11. The charts allow for comparisons of obesity to be evaluated across studies. Obesity was defined as having a BMI greater than the 95th percentile on the charts (Hedley et al., 2004). The sex-specific BMI-for-age percentiles for two groups are shown in Figure 14.

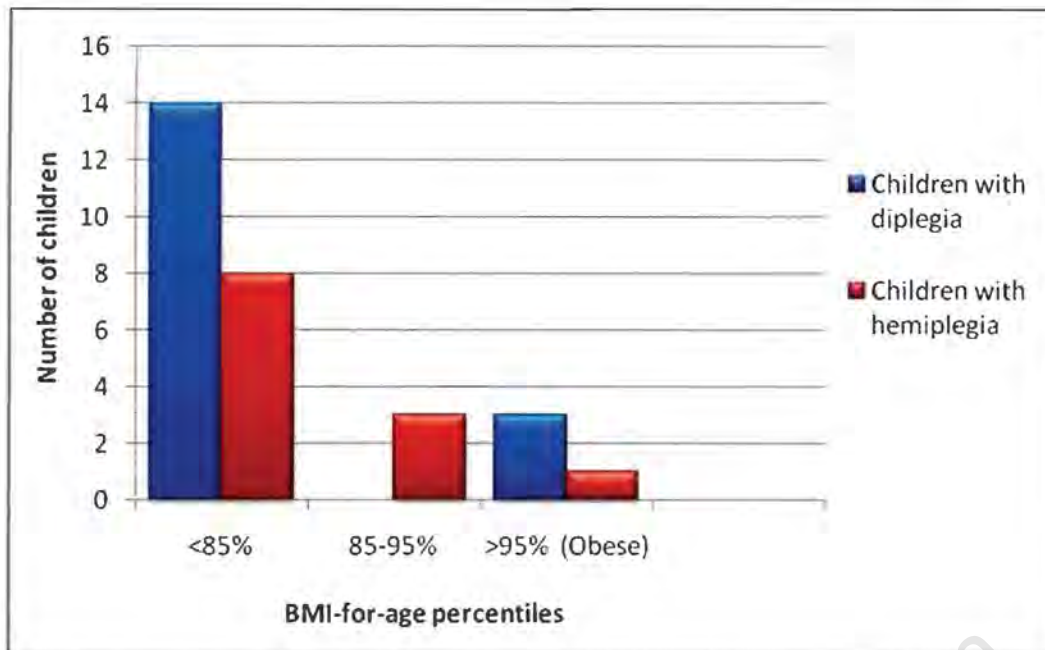


Figure 14: BMI-for-age percentiles illustrating the percentage of children with obesity

Out of the 29 children assessed, 22 children lay below the 85th percentile and 3 children lay above the 95th percentile (classified as obese).

The children with obesity were also analysed according to their GMFCS levels and are shown in Figure 15. Three children with obesity were at the Level I and one child with obesity was at Level III of the GMFCS.

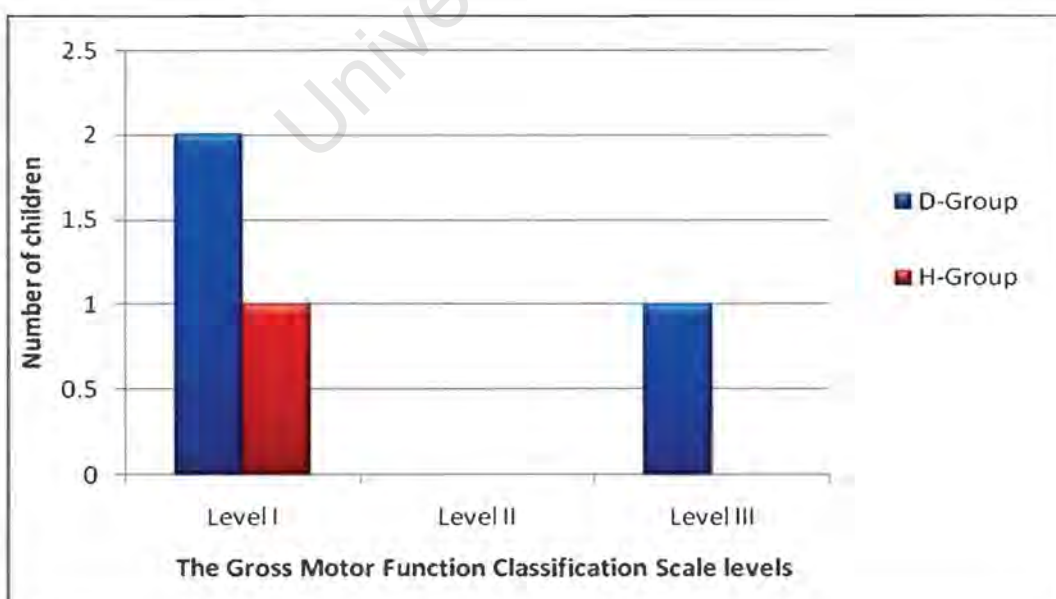


Figure 15: Percentage of children with obesity according to the GMFCS levels

4.2.6 Comparison of the number of past surgical interventions between two groups

Most children had had surgical intervention, with the children in the D-Group having undergone more interventions than children in the H-Group. The D-Group had a median number of surgical interventions of four (ranged from 0 - 8), while the H-Group had a median score of one (ranged from 0 - 4) surgical interventions, as shown in Figure 16. The differences were statistically significant ($U = 53.50$, $p = 0.03$).

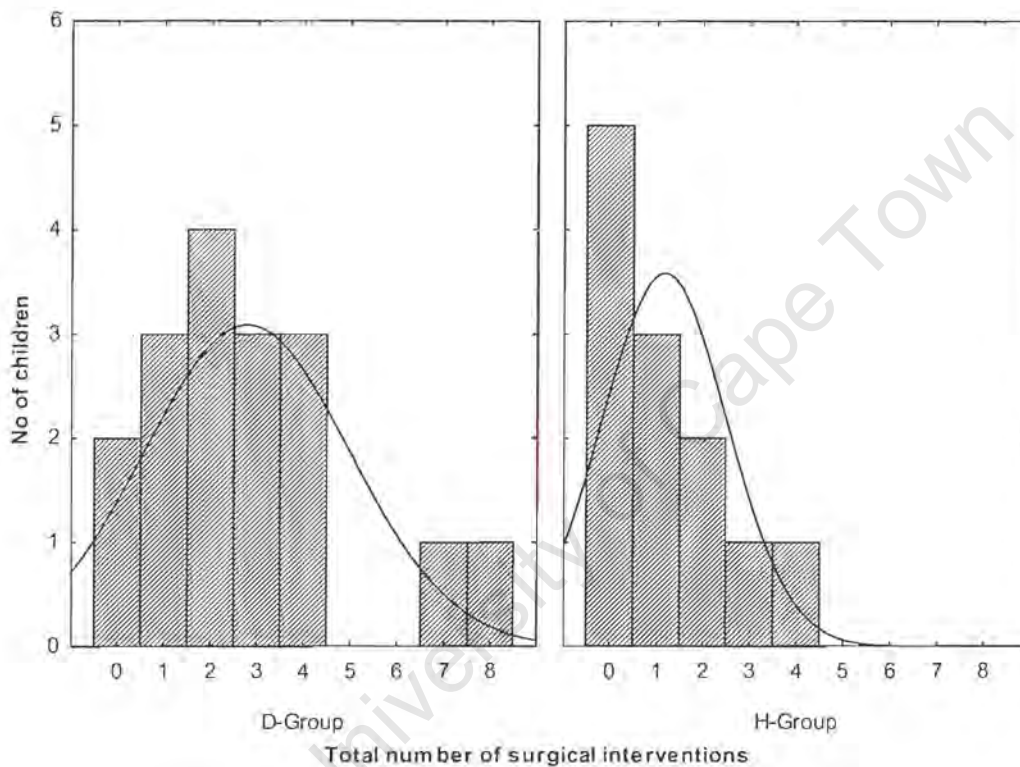


Figure 16: Comparison of the number of past surgical interventions between the D-Group ($n=17$) and the H-Group ($n=12$)

The types of past surgical interventions comprised of operations for the elongation of the TOTC, for the elongation of the adductor muscles of the hip, for the elongation of the hamstrings, as well as Botox injections and other surgical operations, as shown in Figure 17.

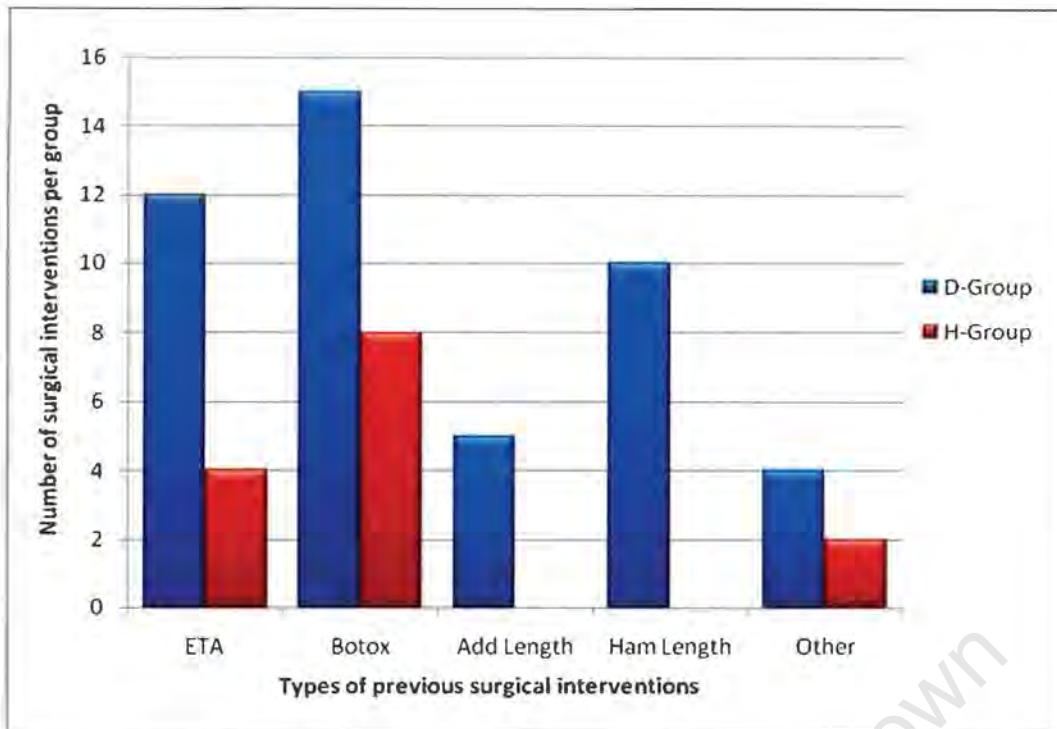


Figure 17: Types of past surgical intervention administered to D-Group (n= 17) and H-Group (n=12)

ETA = surgery for elongation of the tendon of the calcaneum, Botox = injections of Botox administered, Add length = surgery for the elongation of the adductor muscles of the hip and Ham Length = surgery for the elongation of the hamstring muscles.

The children in the D-Group had had more surgical operations for the elongation of the TOTC than had the children in the H-Group (12 versus 4). More children in the D-Group had had Botox injections (15 versus 8) and various types of surgery (4 versus 2) compared with the children in the H-Group. The children in the H-Group did not have any past surgical interventions for the elongation of the adductor muscles of the hip or of the hamstrings.

4.2.7 Summary of the comparisons of the demographic, anthropometric and medical profiles

In summary, the two groups appeared to be equivalent with regard to age, sex and BMI. However, the D-Group was more significantly involved in terms of: surgical intervention (association statistically significant) and ambulation classification (association which approached statistical significance), compared with the H-Group.

4.3 Comparison of the impairments related to structures around the ankle joint

The parameters around the ankle joint in terms of: the equinus angles, spasticity of the triceps surae muscle complex, the strength of the ankle plantar flexors and dorsiflexors, ankle varus and valgus, and the tautness of the medial and lateral sides of the TOTC, were compared between the D-Group and the H-Group. The radiological tibiotalar angles were analysed to examine the validity of the goniometric tibiocalcaneal angles.

4.3.1 Comparison of the equinus angles of the two groups

The means of the passive R1 angles, i.e. the angle of first catch of the LAL and the MAL in the D-Group were $-6.3^{\circ} \pm 9.1^{\circ}$ and $-6.1^{\circ} \pm 10.9^{\circ}$ respectively and were not statistically significantly different ($p = 0.90$). The means of the passive R1 angle of the AL and the UL in the H-Group were $-0.5^{\circ} \pm 9.1^{\circ}$ and $-10.8^{\circ} \pm 7.83^{\circ}$, respectively ($p = 0.001$). Although the catch was reached earlier in the H-Group, the differences between the means of the R1 angles on the MAL of the D-Group and the AL of the H-Group, were not significant statistically ($p = 0.22$) and are shown in Figure 18. The R1 and R2 values were highly correlated and statistically significant ($r = 0.71$, $p < 0.001$).

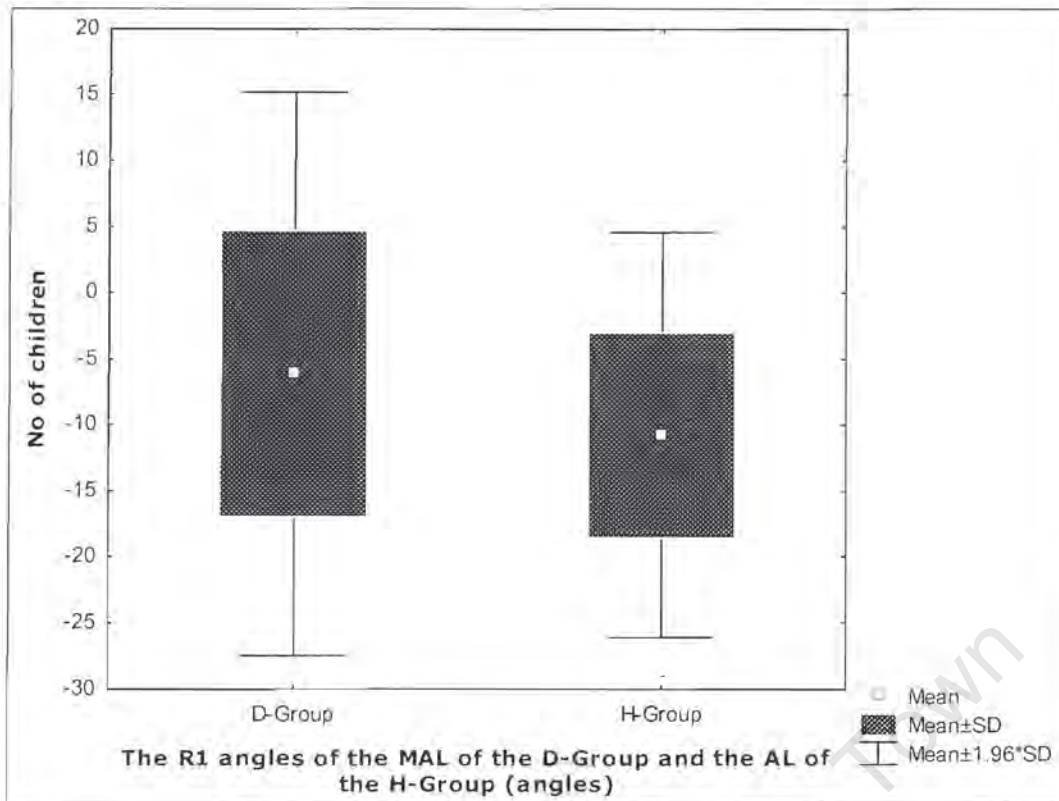


Figure 18: Comparison of the R1 angle of the equinus ankle between the MAL of the D-Group ($n=17$) and the AL of the H-Group ($n=12$)

The means of the passive R2 angles, i.e. the angle of the end of range of motion while maintained by a 10 N force, of the LAL and the MAL in the D-Group were $5.2^\circ \pm 11.0^\circ$ and $4.5^\circ \pm 11.8^\circ$ respectively ($p = 0.69$). The means of the R2 angle between the UL and the AL of the H-Group were $0.8^\circ \pm 11.4^\circ$ and $6.3^\circ \pm 5.8^\circ$ respectively ($p = 0.04$). As might be expected, there were significant differences between the AL and UL in the H-Group, but not between the MAL and LAL of the D-Group. A comparison of the R2 angles of the D-Group and the H-Group is shown in Figure 19.

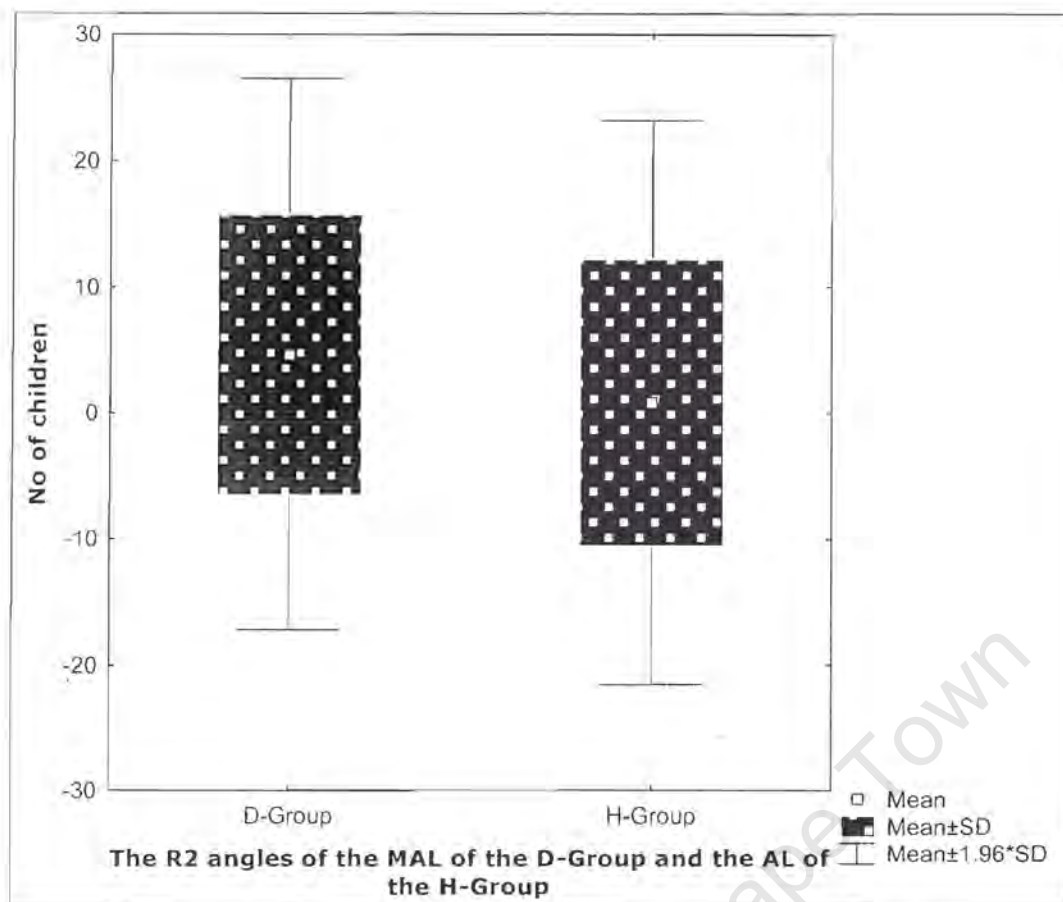


Figure 19: Comparison of the R2 angle of the equinus ankle between the MAL the D-Group (n=17) and the AL of the H-Group (n=12)

As excessive dorsiflexion (greater than 10°) and limited dorsiflexion (greater than 10° short of the anatomical position) are both functionally limiting, R2 was categorised into normal, excessive and limited, and a chi-square test indicated that there was no association between group and category ($p = 0.87$), as shown in Table 8.

Table 8: Categorised R2 angles of the ankle joint in the dorsiflexion direction

	Normal R2 angles	Limited R2 angles	Excessive R2 angles	Row totals
D-Group	11	2	4	17
H-Group	8	2	2	12
Totals	19	4	6	29

4.3.2 The relationship of the R1 and R2 of the equinus angle to GMFCS level

The ANOVA test revealed that there was a significant difference between the R1 values of children in the different GMFCS categories [$F(2, 24) = 5.78, p = 0.01$] and the use of the Scheffe post-hoc test indicated that this difference was between Level I (mean = -9.86 ± 1.74) and Level III (mean = 7.0 ± 4.81). The most affected children (at Level III of the GMFCS) therefore demonstrated a greater range of movement into dorsi-flexion and all of the children coincidentally had undergone lengthening of the TOTC and either hamstring or hip adductor releases. No such difference was detected between the groups for R2.

4.3.3 Comparison of the spasticity of the triceps surae between the two groups

The spasticity of the triceps surae was measured using the modified Ashworth scale and has possible scores of 1 to 5. The median spasticity scores of the triceps surae of the MAL of the D-Group and the AL of the H-Group were both 3 and are shown in Table 9. The spasticity scores were not associated with either the D-Group and H-Group (Chi-square = 1.67, $p = 0.64$).

Table 9: Comparison of spasticity of triceps surae muscle between between the MAL of D-Group (n=17) and the AL of H-Group (n=12)

	Grade 1	Grade 2	Grade 3	Grade 4	Row
D-Group	2	4	8	2	16
H-Group	2	3	7	0	12
Totals	4	7	15	2	28

Chi-square 1.67, $p = 0.64$

The Spearman's rank correlation between the modified Ashworth Scale and R1 angle was -0.46 ($p = 0.02$), but the correlation with R2 was not significant ($r = -0.29, p = 0.13$). This implies that, as the degree of range at which resistance was felt decreased towards the dorsiflexion direction, the subject scored higher on the Modified Ashworth Scale.

4.3.4 Comparison of the strength of the ankle dorsiflexors between the two groups

The strength of the ankle dorsiflexors was evaluated using a HHD. There was no difference in the strength of the ankle dorsiflexors between the MAL of the D-Group and the AL of the H-Group ($0.23 \pm 0.10 \text{ s}^2/\text{m}$ versus $0.19 \pm 0.08 \text{ s}^2/\text{m}$ respectively), as shown in Figure 20. The strength of the muscle group was normalised by dividing the actual strength measured in kg by weight ($\text{kg} \times 9.8 \text{ m/s}^2$) and resulted in units of s^2/m . The difference between the two groups was not statistically significant ($p = 0.35$).

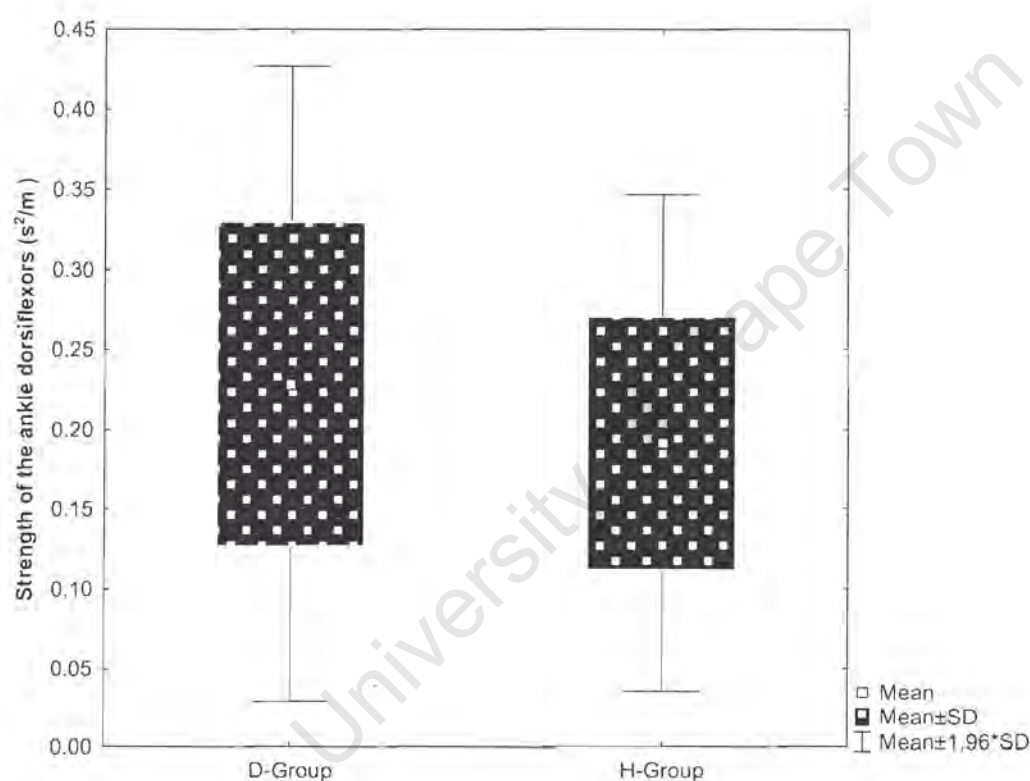


Figure 20: Comparison of the strength of the dorsiflexors muscle group between the MAL of the D-Group ($n=14$) and the AL of the H-Group ($n=9$)

4.3.5 Comparison of the strength of the ankle plantar flexors between the two groups

Initially it was decided by the investigator that the testing of the strength of the plantar flexors would be unreliable using a HHD. When it became apparent that this was a very important variable, a method was developed by the investigator based on the literature, which involved

counting the number of successful heel raises. Unfortunately, by the time this was implemented not all the children were available for testing and the data on six children were not collected. Despite excluding these six children from the analysis, the number of subjects was still sufficient for credibility. The strength of the plantar flexors between the MAL of the D-Group and AL of the H-Group were similar ($p = 0.22$), although half of the children in the D-Group could not achieve a single heel rise with the MAL, as shown in Table 10.

Table 10: Comparison of the strength of the plantar flexor muscle group between the MAL of the D-Group (n=14) and the AL of the H-Group (n=9)

	0 heel raises	1-14 heel raises	15 or more heel raises	Totals
D-Group	7	3	4	14
H-Group	2	5	2	9
Totals	9	8	6	23

Chi-square 2.99, $p = 0.22$

The strength of the plantar flexors of the LAL of the D-Group was statistically significantly weaker than UL of the H-Group ($p = 0.22$), as shown in Table 11.

Table 11: Comparison of the strength of the plantar flexor muscle between the LAL of the D-Group (n=14) and the UL of the H-Group (n=9)

Diagnosis	0 heel raises	1-14 heel raises	15 or more heel raises	Totals
D-Group	5	2	7	14
H-Group	0	0	9	9
Totals	5	2	16	23

Chi-square 6.46, $p = 0.04$

4.3.6 Comparison of the ankle varus and valgus between the two groups

The degree of ankle varus and valgus was measured with a goniometer as the tibioalcalneal angles. Positive values were allocated for ankle valgus and negative values for ankle varus. The MAL of the D-Group and the AL of the H-Group had the similar angles of ankle valgus, namely a mean of $5.1^{\circ} \pm 10.6$ and $5.1^{\circ} \pm 4.7$ respectively (Chi-square = 3.84, $p = 0.28$). The difference between the rank sum orderings of the MAL of the D-Group and the AL of the H-Group was not statistically significant ($U = 81.50$, $p = 0.36$). The results of the degree of ankle

varus or valgus were grouped according to the classification by Stokes (1990) and are presented in Figure 21.

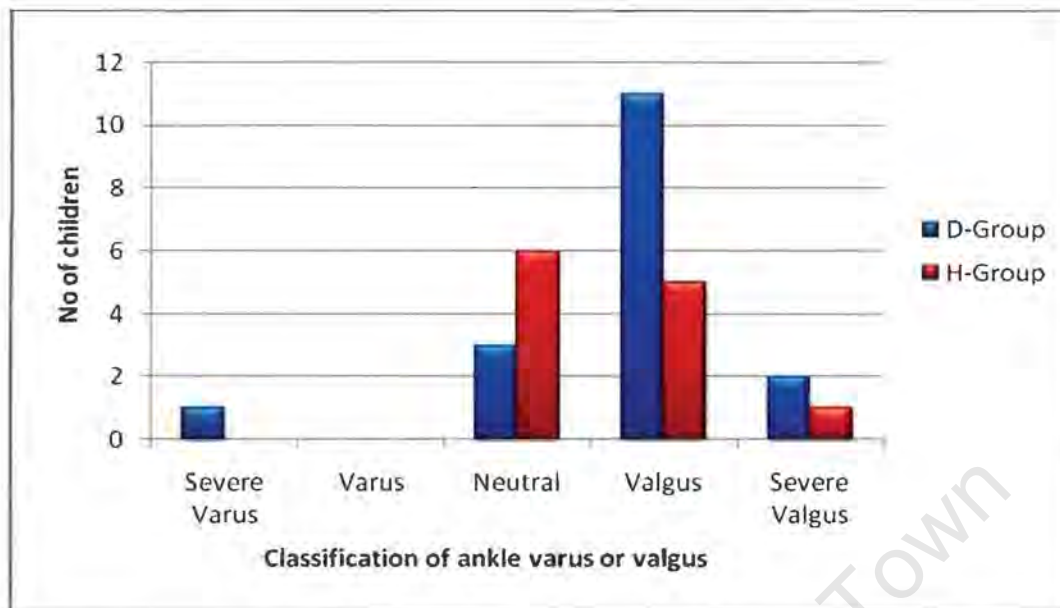


Figure 21: Comparison of the ankle varus and valgus between the MAL of the D-Group (n=17) and the AL of the H-Group (n=12)

4.3.7 The radiological tibiotalar angles

A total of 15 ankles were measured radiographically on both legs of the five children in the D-Group and the five AL of children in the H-Group as shown in Figure 22. The distribution was not normal (Shapiro-Wilk test: $W = 0.85$, $p = 0.02$).

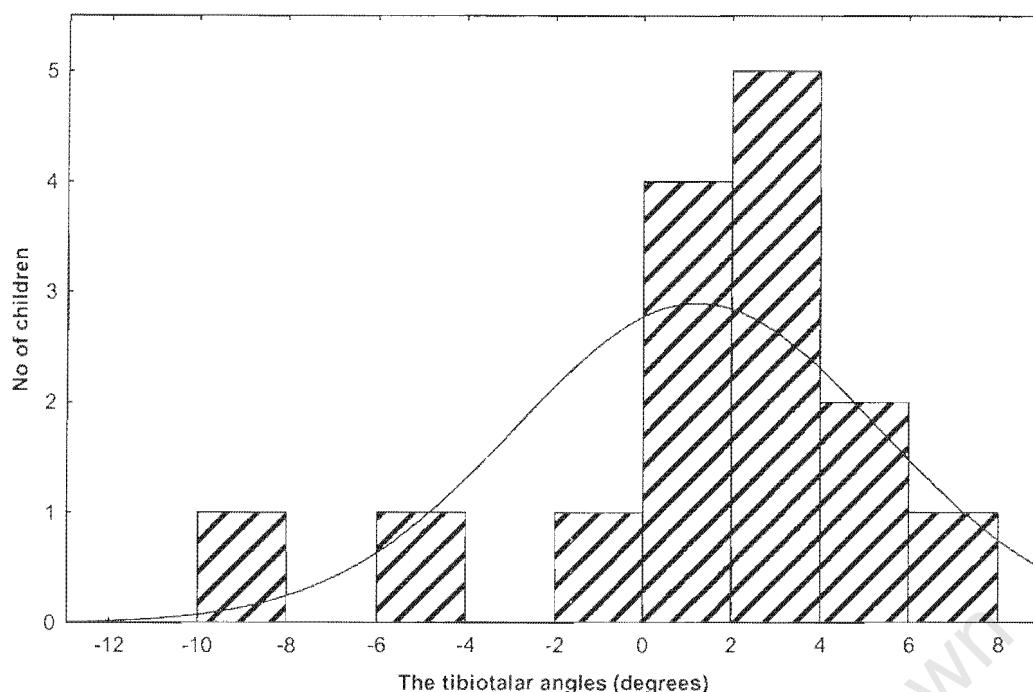


Figure 22: Radiological tibiotalar angles of the 15 ankles of children with CP

Positive values indicate ankle valgus and negative tibiotalar angles represent ankle varus.

In the present study, more presented children with ankle valgus than with ankle varus (12 versus 3), which is a usual finding (Stockley et. al., 1990; Haight et. al., 2005).

4.3.8 Comparison of the tautness of the sides of the tendon of the calcaneus between the two groups

The tautness of the sides of the TOTC may be influenced by the degree of ankle varus and valgus. The tautness of the medial and lateral sides of the TOTC of the two groups were graded as very taut, mildly taut and as slack and allocated scores of 3, 2 and 1 respectively. An illustration of the tautness of the sides of the TOTC is shown in Figure 22. The results of the tautness of the medial and lateral sides of the TOTC of the two groups are presented in Figure 23.



Figure 23: Photographic depiction of the differences in tautness between the lateral and medial sides of the tendon of the calcaneus.

The lateral side of the tendon (indicated by a yellow arrow) is tauter than the medial side of the tendon (indicated by a white arrow).

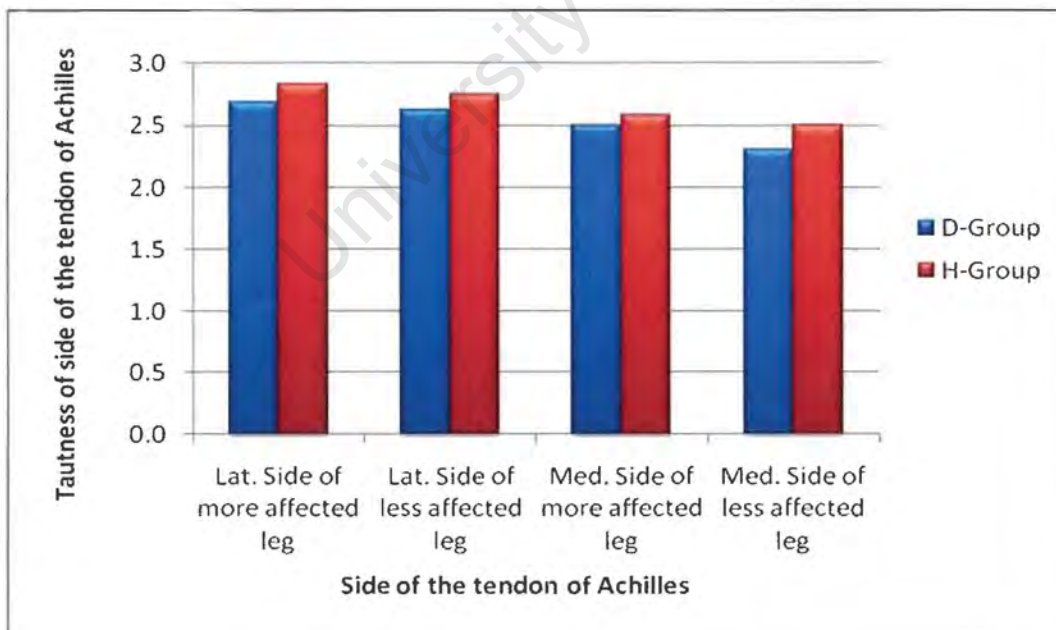


Figure 24: Comparison of the tautness of the sides of the tendon of the calcaneus between the MAL of the D-Group (n=17) and the AL of the H-Group (n=12)

The average tautness was greater on the lateral side than the medial side, on the MAL than the LAL for both the D-Group and on the AL than on the UL of the H-Group. The H-Group had higher tautness scores than the D-Group on both sides of the TOTC. All the categories with higher scores were not statistically significant.

4.3.9 Summary of the comparisons of the impairments associated with the ankle region

In general, both the D-Group and the H-Group had similar impairment parameters associated with the ankle region. There was no statistically significant difference in passive R1 and R2 dorsiflexion angles between the MAL of the D-Group and the AL of the H-Group. Spasticity was not associated with either of the D-Group or H-Group. Spasticity, as measured on the Ashworth Scale, was correlated with R1 but not with R2. Children at Level III of the GMFCS had an increased range at which the R1 angle was felt. The two groups had similar levels of ankle varus and valgus, the side tautness of the TOTC for both sides, and goniometric tibioalcanal angles of the heel.

4.4 The impairments related to structures around the knee joint

The parameters around the knee joint in terms of: the length of the hamstring muscles, the strength of the knee flexors and extensors, and the relative lengths of the two legs (using the level of the knee caps) were compared between the D-Group and the H-Group.

4.4.1 Comparison of the length of the hamstring muscles between the two groups

The length of the hamstring muscles was measured in degrees of flexion as the difference from full extension with the hip at 90° flexion, i.e. the greater the limitation, the greater the degree of flexion. The diagram on Figure 5 illustrates the position that was used for the measurement of the length of the hamstring muscles. The mean length of the hamstring muscles was $39^{\circ} \pm 11.9^{\circ}$ and $28^{\circ} \pm 13.6^{\circ}$ in the MAL of children of the D-Group and AL of the

H-Group respectively, as shown in Figure 25. The mean length of the hamstring muscles on the MALs was statistically significantly shorter in the D-Group when compared to the AL of the H-Group ($U = 47.50$, $p = 0.02$). There were seven children in the D-Group and one child in the H-Group who exceeded the clinical threshold of 45.

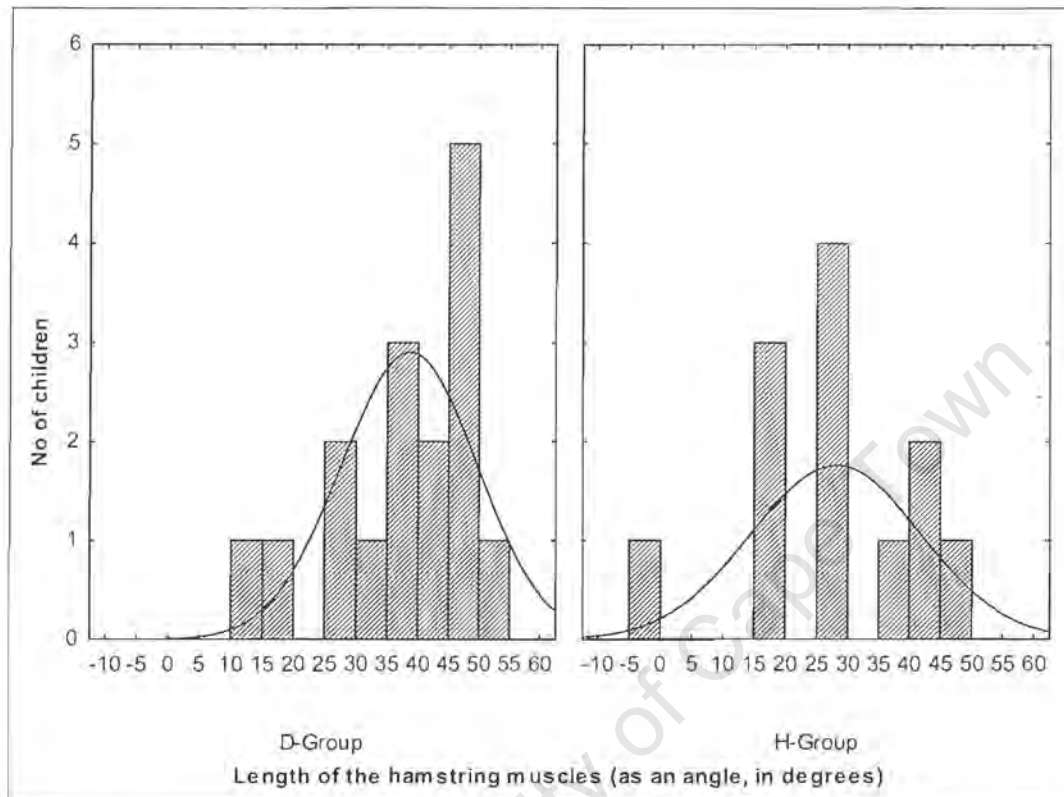


Figure 25: Comparison of the lengths of the hamstring muscles (as an angle, in degrees) between the MAL of the D-Group (n=17) and the AL of the H-Group (n=12). The angle recorded at the knee was the difference between a line along the crus and a line extending distally through the thigh (refer to Figure 5 on page 26). The length of the hamstring muscles was a reflection of the ability of the hamstring muscles to allow knee extension.

When the hamstring muscles were stretched to their maximum, the tendons of the biceps femoris muscles were less taut than the tendons of the semitendinosus and semimembranosus muscles in both the D-Group and the H-Group, as shown in Figure 26.

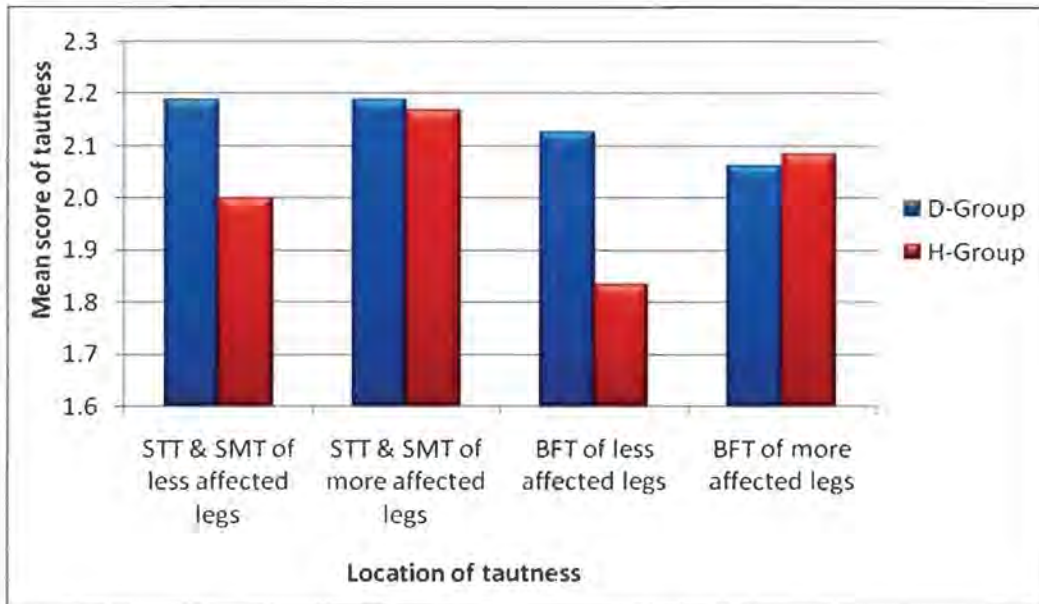


Figure 26: Comparison of the tautness of the tendons of the hamstring muscles between the MAL of the D-Group (n=17) and the AL of the H-Group (n=12). STT (semitendinosus tendon), SMT (semimembranosus tendon) and BFT (biceps femoris tendon).

4.4.2 Comparison of the strength of the knee flexors between the two groups

The strength of the knee flexors and extensors of the MAL was evaluated using a HHD. The mean strength of the knee flexors muscle group on the MAL was similar in the D-Group and in the AL of the H-Group ($0.21 \pm 0.08 \text{ s}^2/\text{m}$ versus $0.20 \pm 0.06 \text{ s}^2/\text{m}$ respectively), as shown in Figure 27. The strength of the muscle group was normalised by dividing the actual strength measured in kg by weight ($\text{kg} \times 9.8 \text{ m/s}^2$) and resulted in units of s^2/m . The difference between the two groups was not statistically significant ($p = 0.87$).

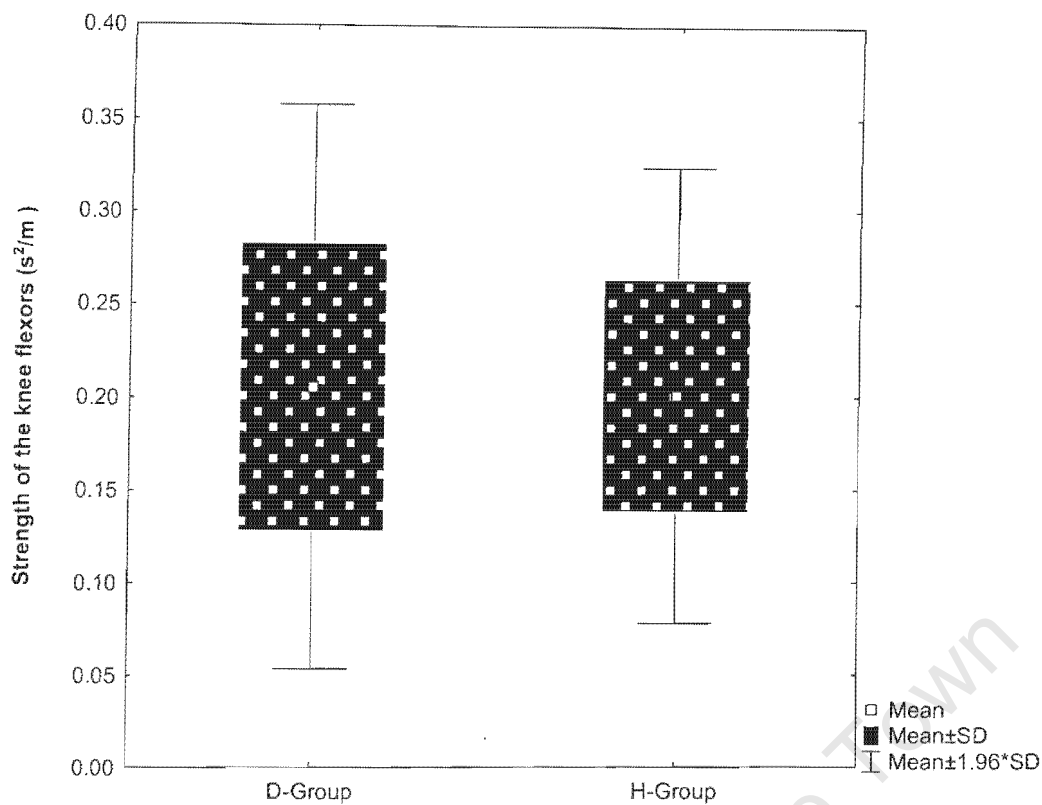


Figure 27: Comparison of the strength of knee flexors between the MAL of the D-Group (n=17) and the AL of the H-Group (n=12)

4.4.3 Comparison of the strength of the knee extensors between the two groups

The MAL of the children in the D-Group had a weaker mean strength of the knee extensor muscle group ($0.32 \pm 0.13 \text{ s}^2/\text{m}$) than the children in the H-Group ($0.41 \pm 0.09 \text{ s}^2/\text{m}$), as shown in Figure 28. The difference between the two groups approached significance ($p = 0.07$).

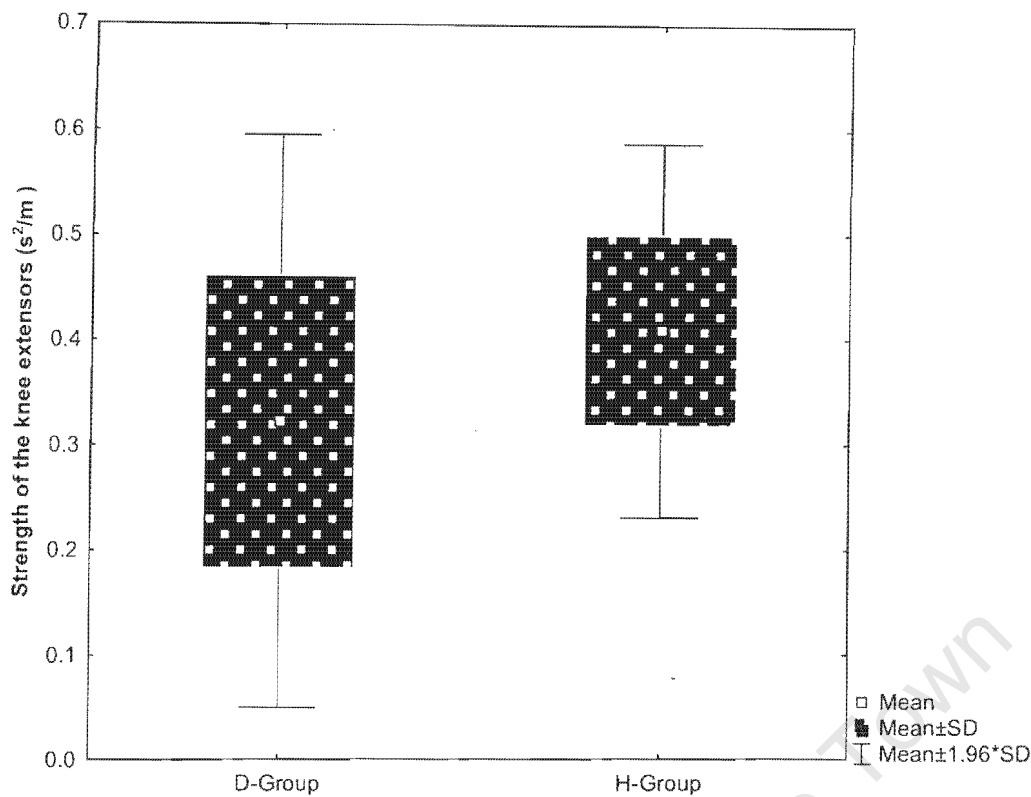


Figure 28: Comparison of the strength of knee extensors between the MAL of the D-Group (n=17) and the AL of the H-Group (n=12)

4.4.4 Comparison of the presence crouch knees at initial stance between the two groups

The knee angles of children in the D-Group and the H-Group were observed during the initial stance. The results are shown in Table 12.

Table 12: Comparison of the knee position during initial stance phase between the two groups

	Knees with extension	Knees with excessive flexion
D-Group (n=15)	2	13
H-Group (n=10)	7	3

Chi-square = 8.36, p = 0.003

The children in the D-Group had more flexed knee angles and the children in the H-Group had normal knee angles (were fully extended or had less than 5 degrees of flexion during initial stance) and the difference was statistically significant (p = 0.00). There was no difference in

the popliteal angle between those with excessive flexion and those without ($p = 0.78$). There were no observed cases of genu recurvatum during heel strike in either group.

4.4.5 Comparisons of the overall length of the right and left limbs of the two groups

The relative positions of the knee caps were used as a proxy of the relative length of the lower limbs. With the child in a supine position with the knee flexed, the more anterior knee cap belonged to the longer of the two lower limbs. Comparisons of the two limbs for the children in the D-Group and for the H-Group are presented in Figure 29 and 30 respectively.

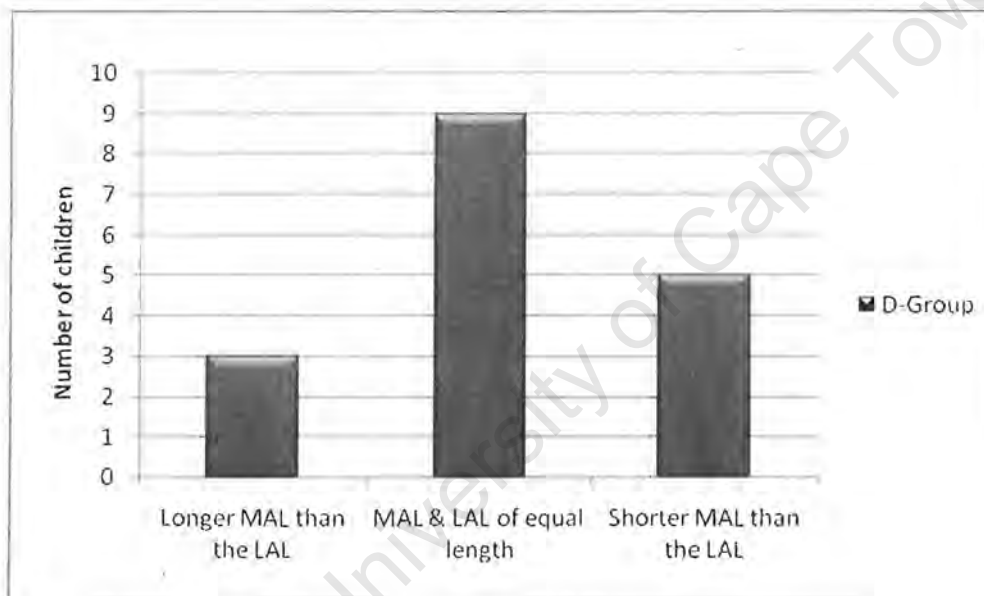


Figure 29: Relative lengths of the lower limbs of the D-Group (n=17)

The majority of the children in the D-Group had lower limbs which were of equal length.

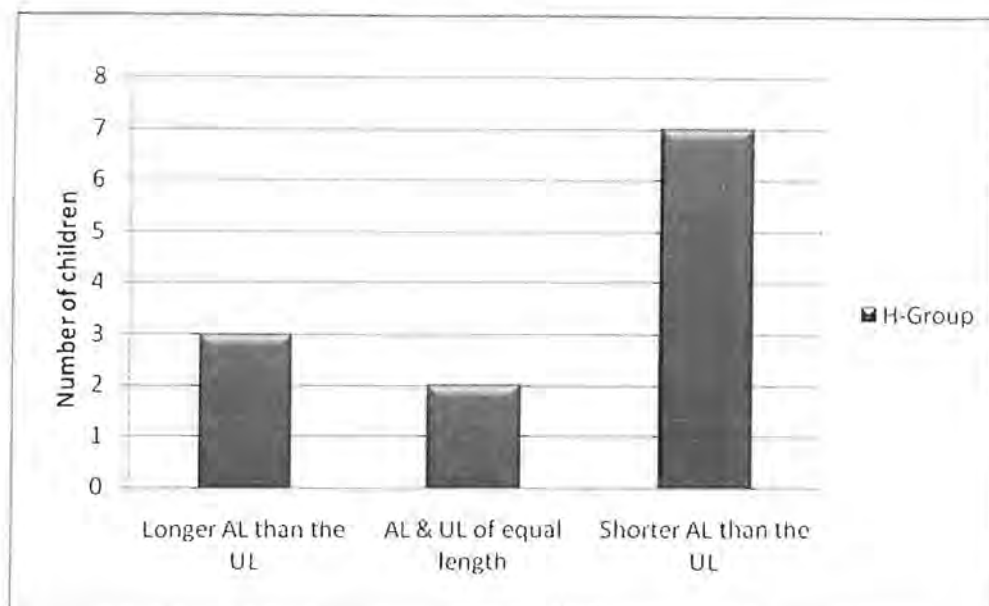


Figure 30: Relative lengths of the lower limbs of the H-Group (n=12)

The majority of the children in the H-Group had shorter AL than the UL. However, the comparison of the rank sum ordering between the D-Group and the H-Group was not statistically significant ($U = 83.00$, $p = 0.40$).

4.4.6 Summary of impairments associated with the knee

In summary, the hamstring muscles of the D-Group were shorter than in the H-Group. There was no difference in muscle strength between the two groups, except for the D-Group which had weaker knee extensors than the H-Group, (which approached statistical significance, $p = 0.07$). All other impairment parameters associated with the knees were similar between the two groups. The children in the D-Group had crouched knees and the children in the H-Group had normal knees during the initial stance phase of gait.

4.5 Comparison of gait parameters between the two groups

4.5.1 Comparison of the cadence between the two groups

Cadence is defined as the number of steps per minute. The children in the D-Group and the H-Group had cadences of 188 ± 24.8 and 175 ± 21.2 steps per minute, respectively, and are shown in Figure 31. The cadence difference was not statistically significant ($t = 1.48$, $p = 0.15$). However, the cadence was strongly correlated with the PCI ($r = 0.57$, $p < 0.05$).

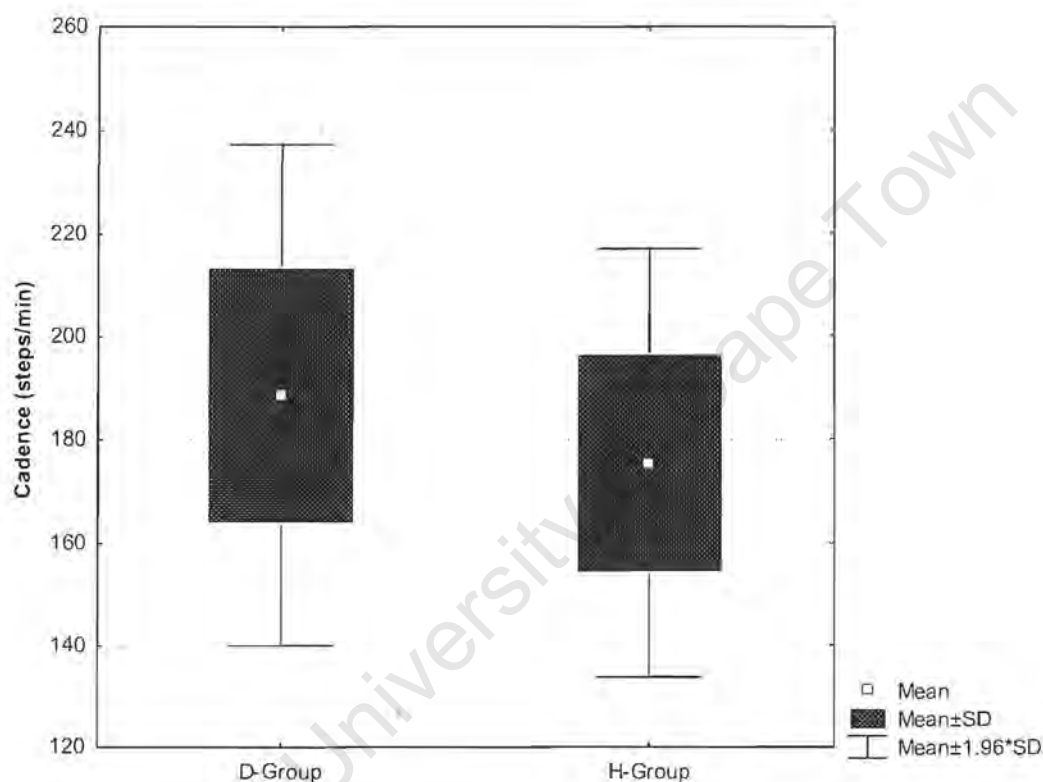


Figure 31: Comparison of the cadence between the D-Group ($n=17$) and the H-Group ($n=12$)

4.5.2 Comparison of the speed of walking between the two groups

The children of the D-Group covered 100 meters at a slower pace than children in the H-Group (66.5 m/min and 72.8 m/min respectively) and was not statistically significant ($t = -1.25$ and $p = 0.22$).

4.5.3 *The physiological energy efficiency of gait*

4.5.3.1 *Comparison of the Physiological Cost Index between the two groups*

The Physiological Cost Index (PCI) was calculated in beats per minute (hb/m). The PCI of typically developing children is 0.10 hb/m (Raja et al., 2007). The PCI could not be measured in one child due to poor cooperation. This reduced the number of PCI measurements to 28. The overall mean value for 28 children was 0.63 ± 0.27 hb/m. The mean PCI value for the D-Group (0.71 ± 0.32 hb/m) was higher than for the H-Group against (0.51 ± 0.15 hb/m) and approached statistical significance ($t = 1.97$, $p = 0.06$) as shown in Figure 31. As the data were incomplete for the heel raises, the data from only 19 participants was entered into the multiple regression analysis.

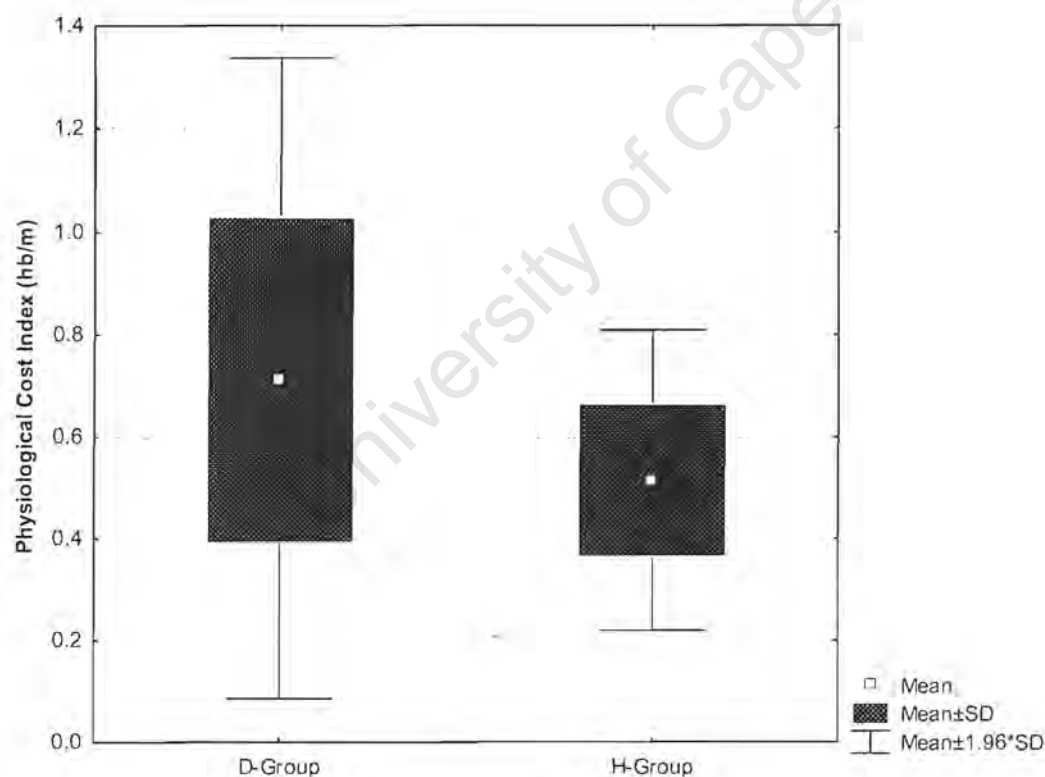


Figure 32: Comparison of the Physiological Cost Index between the D-Group ($n=16$) and the H-Group ($n=12$)

4.5.3.2 Demographic predictors of the Physiological Cost Index

Regression analysis, with all variables entered simultaneously, was used to determine which factors predicted PCI. The first model included age, BMI, sex and diagnosis of either diplegic or hemiplegic CP. This was a poor model in that it only explained 18% of the variance (adjusted $R^2 = 0.18$). The only parameter which contributed significantly to the PCI was the diagnosis, as shown in Table 13. A child belonging to the H-Group was predicted to have a PCI of 0.22 hb/m less than a child in the D-Group. Age, sex and BMI did not have any predictive value.

Table 13: The predictive value of the demographic and medical profiles to the PCI

	B	Std.Err.	t(23)	p-level
Intercept	-0.00	0.39	-0.01	0.99
Age	0.03	0.03	1.17	0.26
Hemiplegia	-0.22	0.10	-2.22	0.04
BMI	0.02	0.01	1.43	0.17
Sex	0.10	0.11	0.96	0.35

Adjusted $R^2 = 0.18$, $F(4,23) = 2.48$, $p = 0.06$

4.5.3.3 Impairment parameter predictors of the Physiological Cost Index

As described in the section on statistical analysis, eight variables were initially entered in the forward stepwise regression model. As the data were incomplete for the different variables, only 18 data sets were included in the forward step wise regression analysis. All values referred to the MAL of the D-Group and the AL of the H-Group.

The only variables to be retained were the ability to heel raise (statistically significant), and the normalised strength of the knee flexors (not statistically significant). Only these two variables were entered into the final model. Twenty one subjects had full data sets and were included in the analysis. Residual analysis identified patient 26 as having a residual value of more than two standard deviations and this was excluded from the final model (Chatterjee, 2006). This model resulted in a reasonable fit, accounting for 49% of the variance, as shown in Table 14. A child who was not able to heel raise was predicted to expend 0.30 hb/m more energy than a child that could rise on the toes.

Table 14: The impairment predictors of PCI using a forward stepwise analysis

	B	Std.Error of B	t (17)	p-level
Intercept	1.04	0.11	9.1	0.00
Ability to heel raise	-0.30	0.13	-2.4	0.03
Normalised Knee Flexion	-0.49	0.39	-1.2	0.23

Adjusted $R^2 = 0.49$, $F(2,17) = 9.98$, $p < 0.001$

The mean residual value (i.e. the mean difference between each predicted and observed value) was 0.00 with a range from -0.29 to 0.34, as shown in Figure 33.

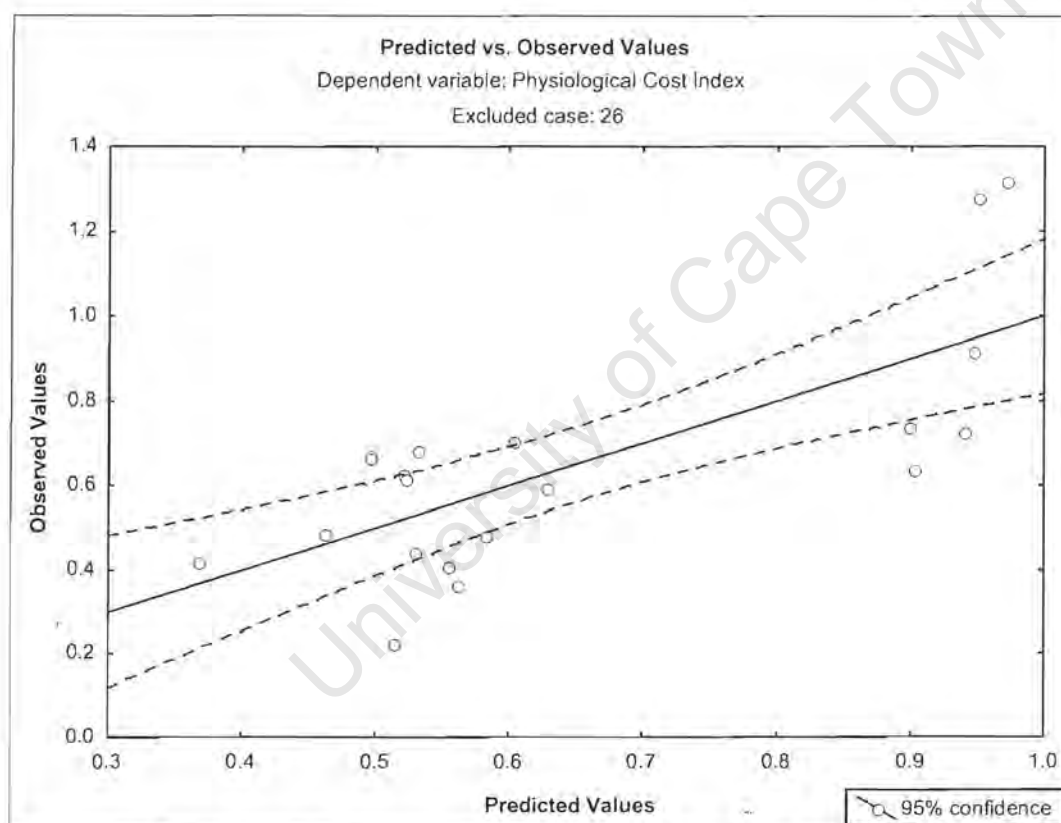


Figure 33: Scatterplot of predicted and observed values of the PCI (n=20)

The scatterplot above combined with the residual analysis and indicates that the model is a reasonable fit with a maximum residual value of 0.34.

As the role of the plantar flexors was obviously very important in determining the PCI, chi-squared tests were done to determine if there was any association between the ability to rise onto the toes and relevant variables. No association was found with diagnosis ($p = 0.18$), spasticity ($p = 0.92$), surgery to the TOTC ($p = 0.43$) or Botox injections ($p = 0.69$).

4.5.3.4 Effect of the strength of the plantar flexors on the PCI

The effect of the plantar flexors (as heel raises) was statistically investigated further. A one way ANOVA test indicated that there was a significant difference between the means of the different groups of heel raises: $F(2, 19) = 7.78, p = 0.00$. The group that was unable to perform a single heel raise had the highest PCI of 0.91 hb/m, as shown in Table 15.

Table 15: Mean and SD of the Physiological Cost Index ($n=23$) for the three heel raise conditions

	No of heel rises	Physiological Cost Index Mean	Standard error	N
1	0 heel raises	0.91	0.08	8.0
3	1-14 heel raises	0.58	0.08	8.0
2	15 and more heel raises	0.45	0.09	6.0

The Scheffe post-hoc test indicated that this difference was between the '0 heel raises' group, who were unable to do any heel raises, and the other two groups. There was no difference in PCI between those in the '1-14 heel raises' group and the '15 and more heel raises' group.

Table 16: The Scheffe Post Hoc test association of the ability to perform heel rise groups ($n=23$)

	No of heel rises	0 heel raises	1-14 heel raises	15 and more heel raises
1	0 heel raises		0.006	0.030
2	1-14 heel raises	0.006		0.603
3	15 and more heel raises	0.030	0.603	

Probabilities for Post Hoc Tests Error: Between MS = 0.05, $df = 19.00$

4.5.3.5 Effect of the Ashworth level on the PCI

An ANOVA test detected no difference in the PCI of children with different levels of Ashworth Scores ($p = 0.17$)

4.5.3.6 The summary of gait related parameters

The children in the D-Group had greater PCI values than the children in the H-Group which approached statistical significance. Higher PCI values were strongly correlated with a higher cadence. The PCI was higher in those with a higher GMFCS score. Multiple regression with PCI as the dependent variable identified that H-Group membership was the only demographic variable that was predictive and it reduced the PCI by 0.22 hb/m. In terms of impairments, being able to perform a single heel rise was a significant predictor of PCI and it decreased the PCI by 0.30 hb/m. Children unable to perform a single heel rise had the highest PCIs and averaged 0.91 hb/m. However an ANOVA test did not detect a significant difference between the levels.

4.6 Summary of the results

The demographic and anthropometric profiles of the groups of children with diplegic and hemiplegic subtypes of CP were similar in terms of: the mean ages, the distribution of sex, the mean BMI. An exception was that D-Group had undergone a greater number of surgical interventions (association statistically significant) and had more children at Level II and III of the GMFCS (association approached significance) than the H-Group.

Regarding the data for the impairments and the activity limitations that were related to the equinus ankles, there was no difference with R1 and R2 angles, the spasticity of the triceps surae muscle, as measured by the Modified Ashworth Scale, the strength of the knee flexors and ankle dorsiflexors and the number of children who could heel raise between the MAL of the D-Group and the AL of the H-Group. The MAL of the children in the D-Group had shorter hamstring muscles (statistically significant), crouched knees during the initial stance phase (statistically significant) and weaker knee extensors (which approached statistical significance) than the children in the H-Group. Spasticity of the triceps surae muscle was correlated with R1 angle, but not with R2 angle. Children at Level III of the GMFCS had an increased plantarflexion angle at which the R1 angle was felt. The two groups had similar levels of ankle varus and valgus, the side tautness of the TOTC and the goniometric tibioalcaneal angles of the heel.

The gait related parameters were examined. The D-Group had a more energy demanding gait pattern (as indicated by greater PCI values) than children in the H-Group, but this only approached statistical significance. There was no difference in cadence or speed between the two groups. Higher PCI values were strongly correlated with a higher cadence. The PCI was higher in the children with a higher GMFCS levels. Multiple regression with PCI as the dependent variable identified that H-Group membership was the only demographic parameter that was predictive and it reduced the PCI by 0.22 hb/m. In terms of impairments, being able to perform a single heel rise was a significant predictor of PCI and it decreased the PCI by 0.30 hb/m. Children unable to perform a single heel raise had the highest PCIs, which averaged 0.91 hb/m.

University of Cape Town

5 Discussion

5.1 Introduction

There were two noteworthy findings which emerged from this study. The first was that, although the impairment parameters around the ankle joint were similar between the MAL of the D-Group and the AL of the H-Group, the impairment parameters around the knee joint were strikingly different. The children in the D-Group had a triad of weak knee extensors, walking with crouch knees in the initial stance phase and had shorter hamstring muscles.

The second result of note was the preeminence of the role of the plantar flexors as a factor in predicting PCI. The ability to heel raise emerged as the major impairment that was predictive of PCI, but the range of movement of the ankle joint (the length of the triceps surae muscle complex) did not. As much as therapy and surgery are aimed at lengthening and stretching the TOTC, this finding might result in a reexamination of the aims of intervention of physiotherapy for the lower limb.

This chapter will start by discussing the equivalence of the two samples and the external validity of the results. The results related to impairments will be presented, starting with a comparison between the two groups, then highlighting the functional limitations of the impairment and the effect on PCI of the different impairments. Finally methodological concerns will be discussed.

5.2 Sample: Demographic, anthropometric and medical profiles

5.2.1.1 Sample size

It would have been preferable to have a larger sample, but there were limited numbers of children with CP, presenting with an ambulatory equinus ankle, that were eligible for inclusion. Unfortunately, the sample size was made even smaller than anticipated due to the lack of informed consent in 15 of the 45 eligible children. It was not possible for ethical reasons to determine if the children whose parents refused participation were different with

regards to the level of impairment. In intervention studies, the effect of informed parental consent might be an overestimation of the effect of the interventions because the subjects that are most likely not going to benefit from a study tend to refuse to participate (Mathews et al., 2005). In the current study, the lack of consent from some of the parents could be as a result of the fact that they were caring for children who were less affected with CP than the other children, and this might have introduced some bias.

In some cases, there were missing data due to various factors (surgery in one case, lack of cooperation and, in the case of the heel raise, a change in research protocol) and this further reduced the numbers available for regression analysis. Nevertheless, the number of subjects used was comparable to other studies (Maltias et al., 2005; Crompton et al., 2007; Ten Berge et al., 2007).

The smaller than anticipated sample size reduced the strength of the study. Post-hoc analysis, utilising the results of the study, indicated that if the difference in PCI between the two groups had been 0.25 instead of 0.2, 15 children would have been needed in each group to detect a difference at the significance level of $p = 0.05$, with a power of 80%. The sample size was inadequate to determine that a difference of 0.2 was statistically significant and 22 subjects would have been necessary for this difference to have been detected. This is based on the finding that the standard deviation of the response variable is 0.27. Because of the smaller sample size, results that approach significance, i.e. a $p < 0.1$, have been included in discussion.

5.2.1.2 Comparability of the D-Group and the H-Group

An attempt was made to ensure that the diplegic and the hemiplegic groups were comparable through the use of similar inclusion and exclusion criteria. When two groups have as many similar demographic and medical characteristics as possible, the comparisons of the impairments and the activity limitations of the two groups are more accurate.

The demographic profiles between the groups of children with diplegic and hemiplegic forms of CP were statistically equivalent in terms of the mean ages, the distribution of sex and the means of the body mass index. However, the children in the D-Group had a greater number of past surgical interventions, when compared to the children in the H-Group. It could be that more surgical interventions were required in children with greater ambulatory difficulty, as

compared to children with less ambulatory difficulty and the surgical interventions may have resulted in an improvement with regard to GMFCS level. On the other hand, the greater number of multiple surgical interventions could have made it more difficult for the children to ambulate. This issue cannot be addressed by this study.

5.2.1.3 The levels of ambulation of the two groups

The GMFCS was used to classify the ambulatory ability of the two groups. The GMFCS is a widely used, standardised and validated system for describing and classifying the functional limitations and the use of mobility devices during ambulation among children with CP (Palisano et al., 1997; Morris et al., 2006) and has a high reliability (Wood and Rosenbaum, 2000). The children in the D-Group had greater difficulty in ambulation (which approached statistical significance, $p = 0.07$). Most children with hemiplegia are self ambulatory, unlike children with the diplegic form of CP (Westbom et al., 2007).

A comparison of the levels of the GMFCS of the study to the general population of children with CP will help place the findings in the larger context. The subjects in this study had milder ambulatory difficulties, evident when the results were compared to an aggregated group of children with various types of CP, as the 137 children assessed by Hurvitz et al., (2007) (9.8 ± 4.7 years old) had more ambulation difficulty than the present study sample, as illustrated in Figure 34.

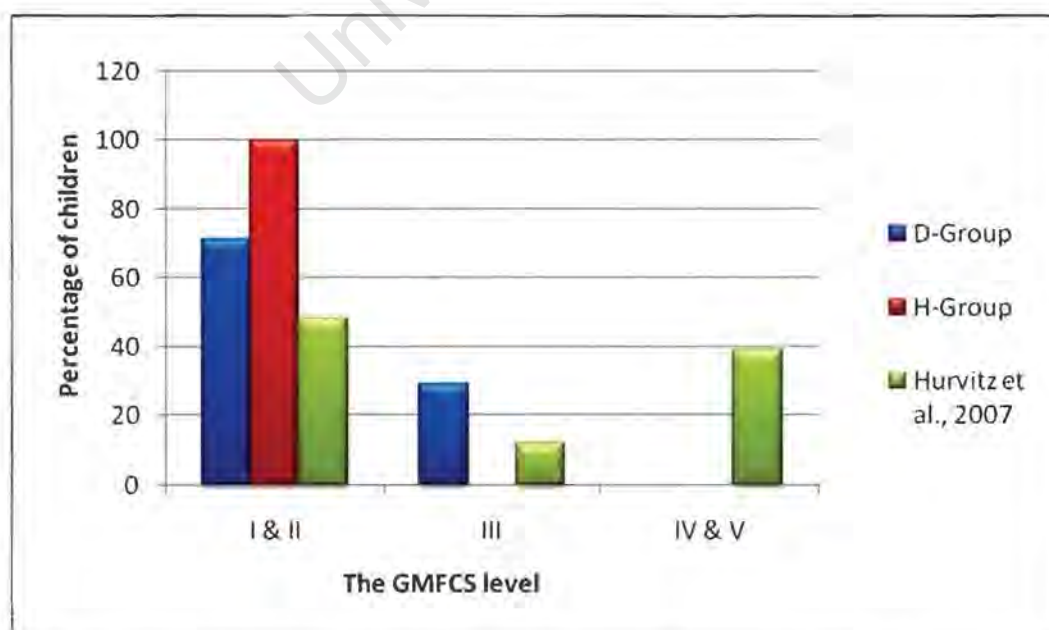


Figure 34: Comparison of the GMFCS levels of the current study vs Hurvitz et al. (2007)

Most of children in the current study were at Level I and II (i.e. could walk without assistive devices) and only children in the D-Group were at Level III of the GMFCS. The spread of children in the study by Hurvitz et al., 2007 had more children at Levels III, IV and V.

A closer look was taken to determine which of the children in the D-Group and the H-Group showed milder ambulatory difficulty in the study sample. Scandinavian countries seem to have comprehensive health systems which capture all children with CP into their medical systems. Two studies in Sweden and Norway examined the records of virtually all the children with CP in two counties and 20 counties respectively (Westbom et al., 2007; Andersen et al., 2008). Using this published data, the distribution of children in the current study was compared to these studies. The children have been tabulated according to their topography (hemiplegic and diplegic) and their GMFCS are indicated in Figure 35 and 36, respectively. The children with hemiplegia are represented by bar columns and the children with diplegia by lines.

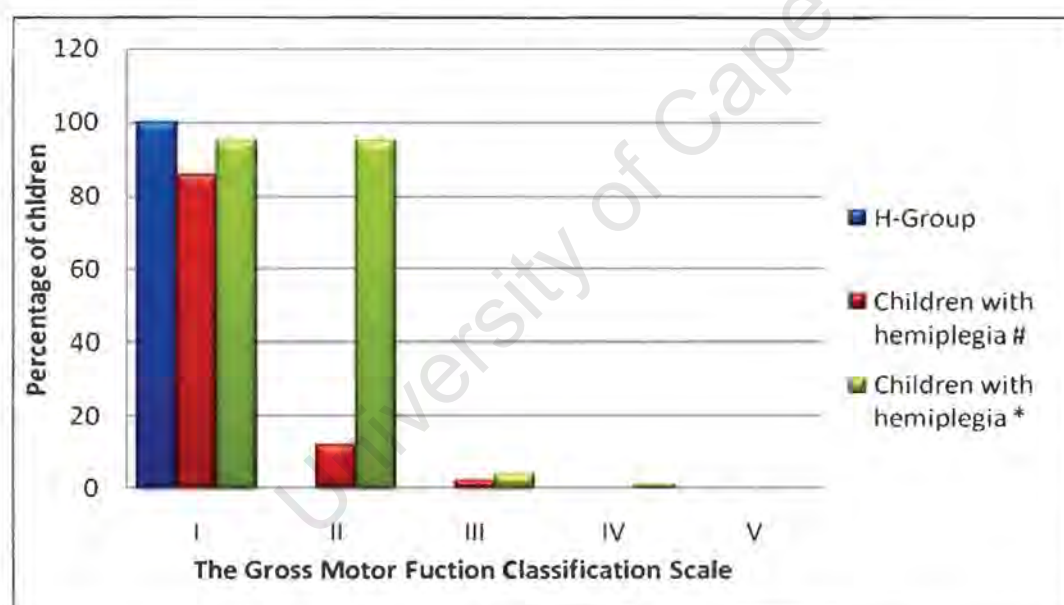


Figure 35: Comparison of the current study and published data using the GMFCS of children with hemiplegic CP

Present study, n = 29

= Signifies the results of the study by Westbom et al., 2007, n = 343

* = Signifies the results of the study by Andersen et al., 2008, n = 374

All children in the H-Group were at GMFCS Level I, whereas children with hemiplegia in both the other studies were at Level I and II. There were no children at Levels IV and V in any study.

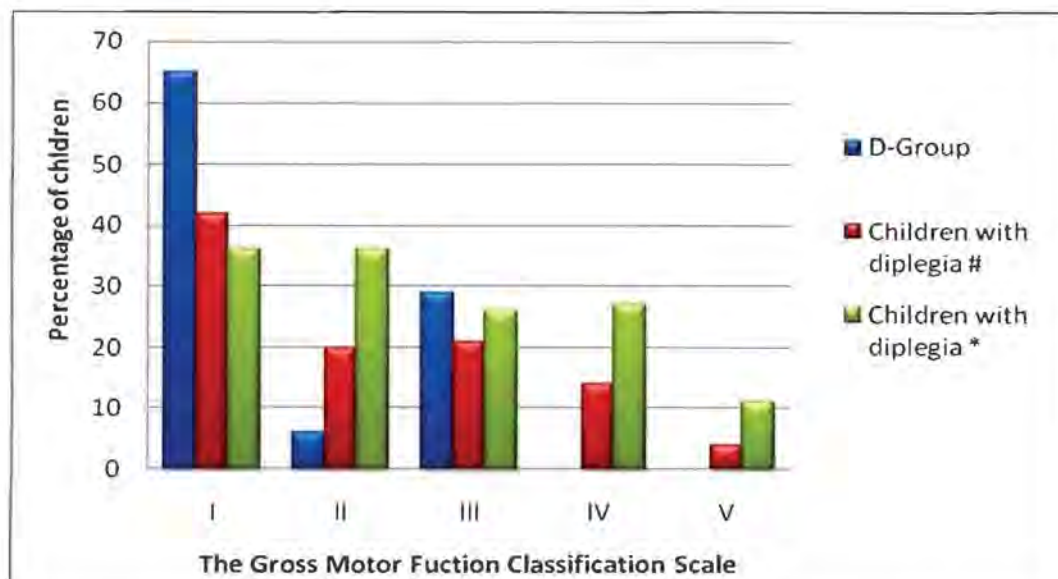


Figure 36: Comparison of the current study and published data using the GMFCS of children with diplegic CP

In the present study, n = 29.

= Signifies the results of the study by Westbom et al., 2007, n = 343

* = Signifies the results of the study by Andersen et al., 2008, n = 374

All children in the H-Group were at GMFCS Level I, whereas children with hemiplegia in both the other studies were at Level I and II. There were no children at Levels IV and V in any study. Similarly, the D-Group had less children in the higher levels compared than in the two other studies (Westbom et al., 2007; Andersen et al., 2008).

In general, both the H-Group and the D-Group had milder ambulatory difficulty than the children with diplegia or hemiplegia from the two other studies (Westbom et al., 2007; Andersen et al., 2008). The current study examined the parameters related to the equinus ankle during gait and placed an inclusion criterion on the subjects of being able to walk with or without a walking aid, which then skewed the subjects obtained towards milder ambulatory difficulties. The fact that the participants are not representative of the entire group of children with hemiplegia and diplegia limits the generalisability of the findings and the results may only be valid for less affected individuals of the population.

5.2.1.4 The levels of obesity between the two groups

The Body Mass Index (BMI) values obtained in the present study were compared to the BMI values of other studies. Feeley et al. (2007) obtained similar BMI values among children with CP to BMI values obtained by the present study. The study by Feeley et al. (2007) had BMI

values of $17.2 \pm 4.4 \text{ kg/m}^2$ in ambulatory children with diplegic CP and $16.8 \pm 2.8 \text{ kg/m}^2$ in children with hemiplegic CP ($p = 0.45$). The present study had median scores of the D-Group and the H-Group of 16.2 kg/m^2 (ranged from $12.6 - 28.2 \text{ kg/m}^2$) and 18.0 kg/m^2 (ranged from $13.6 - 24.8 \text{ kg/m}^2$) respectively.

The BMI values were then adjusted to sex-specific BMI-for-age percentiles by using the commonly used BMI growth charts developed by the National Center for Health Statistics in association with the National Center for Chronic Disease Prevention and Health Promotion (Growth Charts, 2000). The charts were separate for boys and girls and allow for obesity comparisons with other studies. Obesity was categorised as having a BMI greater than the 95 percentile of the charts (Hedley et al., 2004). The percentage of children with obesity in the present study was compared to other studies in Figure 37.

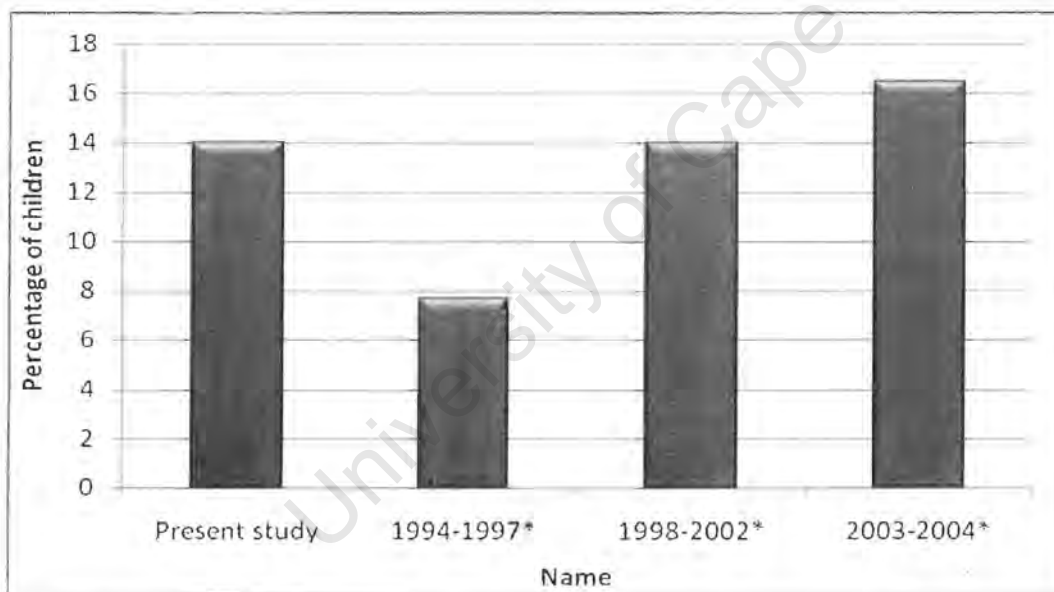


Figure 37: Percentage of children with CP having obesity among different studies

In the present study, $n = 29$.

* = the different periods that Rogozinski et al. (2007) assessed groups of children with CP; $n = 247$ for the 1994-1997 group, $n = 214$ for the 1998-2002 group and $n = 188$ for the 2003-2004 group.

The obesity levels in the present study was further broken down into children with the diplegia and hemiplegia subtypes and also compared to other studies, as shown in Figure 38.

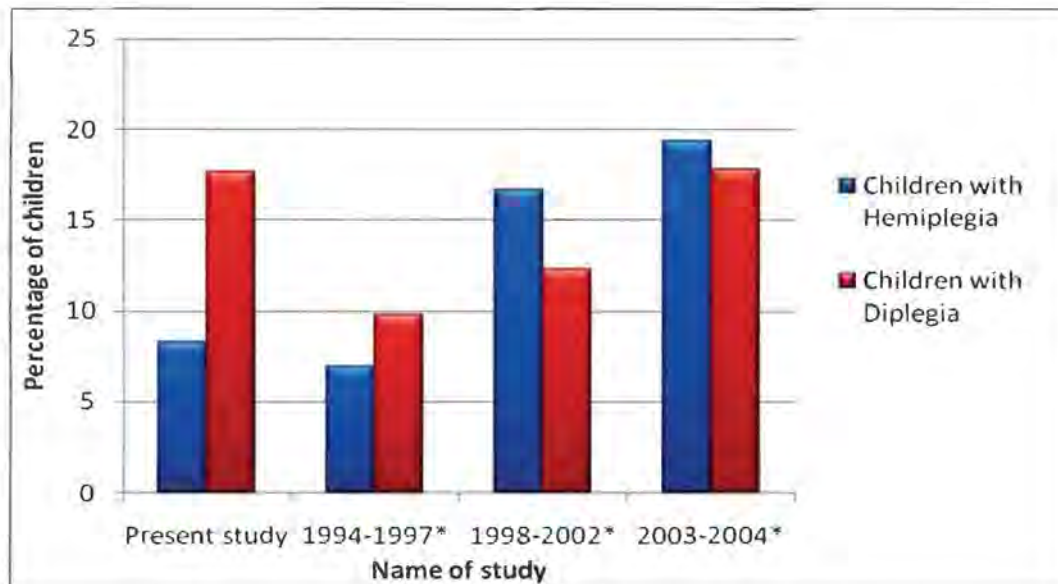


Figure 38: Percentage of children with obesity in four different studies of children with CP

* = the different periods that Rogozinski et al. (2007) assessed groups of children with CP.

In conclusion, the BMI values and the obesity levels were similar to those of other studies involving children with CP, although, in the current study, the children with diplegia showed a greater frequency of obesity. However, the mean BMI did not differ between the two groups.

5.3 Impairments parameters related to the equinus ankle

5.3.1 The strength of lower limb muscles

5.3.1.1 Comparison between the two groups

It was not anticipated that the children in the D-Group and the H-Group would have similar strength in most muscle groups (the plantar flexors, dorsiflexors, and knee flexors of the MAL of the D-Group and the AL of the H-Group. Only the difference in the strength of the knee extensors of the MAL were weaker in the D-Group than the AL of the H-Group H-Group and this only approached statistical significance ($p = 0.07$). Although the MAL of the D-Group and the AL of the H-Group were similarly affected, the H-Group has a normal lower limb to depend on, while the D-Group has another affected leg, which was in effect, similar to the MAL of the D-Group. It might be expected that, as the H-Group children were all ambulant and that the UL was much stronger than the LAL of the children with diplegia, that the children would utilise the MAL more and be more active. This was not the case and it might be that the H-Group children rely too heavily on the function of the LAL and consequently do

not utilise the MAL fully. This interpretation is lent support by the common finding that the MAL is shorter in children with hemiplegia, implying that it is used less often and consequently suffers from hypoplasia (Chapman and Madison, 1988).

5.3.1.2 Functional implications of muscle weakness

The most influential group among the four muscle groups studied was the plantar flexors, as this was the only statistically significant predictor of PCI. The ability to perform a single heel raise predicted a reduction of PCI by 0.30 hb/m [typical values for children are approximately 0.10 hb/m (Raja et. al., 2007)].

5.3.1.2.1 Length and strength trade-offs

Failure of the strength of the plantar flexors in children with CP might result in the need to recruit the hip and knee flexors to accelerate the lower limb from toe-off through the swing phase of gait to heel-strike. Surgical lengthening of the TOTC may account for the loss of strength of the plantar flexors. Lengthening of the TOTC by 1 cm and 2 cm has been shown to result in a loss of maximum isometric strength generated by the soleus of 30% and 85% respectively (Delp and Zajac, 1992). The recession technique of the gastrocnemius or soleus belly is thought to have fewer negative effects than tendon lengthening, as it detaches the respective muscle belly from the TOTC (Baddar et al., 2002). The loss of strength among children with CP would result in less energy being absorbed during the ankle dorsiflexion movement of the stance phase and less energy available for use when the plantar flexors are contracting in toe-off. However, it should be noted that surgical intervention was not found to be predictive of PCI in this study. This might be because many of the children who had surgery also were unable to do a heel raise, and there might have been an association between these two factors.

It has been reported that in the past, the strength of the individual muscles were seldom tested before surgical intervention of the individual muscles concerned (Crowninshield and Brand, 1981). It is hoped that this situation has improved in subsequent years and that the strength of the calf muscles is now routinely tested and taken into account when surgical intervention is planned.

The soleus muscle should assist in knee extension in mid-stance. In late stance, the influence of the soleus and the gastrocnemius muscle is greater than in midstance and contributes more to forward acceleration of the trunk (Neptune et al., 2004). The gastrocnemius muscle flexes the knees and its relaxation in pre-swing brings about acceleration of knee extension because of dynamic coupling and the unopposed soleus muscle (Neptune et al., 2004). This is an interesting point because children with CP having confirmed problems with co-contraction find it difficult to relax muscles during gait (Wakeling et. al., 2007). This is supported by the role that increased resistance to passive dorsiflexion plays in increasing the PCI that was found in this study.

5.3.2 Hamstring length

5.3.2.1 Comparison between groups

The conventional popliteal angle is a widely used measure for hamstring shortness in CP and normal patients (Ten Berge et al., 2007). The clinical threshold angle (an angle which when exceeded normally necessitates therapeutic or surgical intervention) is 45° (Rab, 1992) or 50° (Katz et al., 1992) and is a common outcome measure in clinical intervention studies in children with CP (Damron et al., 1991; Dhawlikar et al., 1992; Rab, 1992; Thompson et al., 2001). The mean angle for normal children aged between five and ten years is reported to be 26° and the range is 0 - 50° (Katz et al., 1992).

A comparison of the length of the hamstring muscles between children with the diplegic and hemiplegic forms of CP has been lacking in the literature. Children in the D-Group had a significantly reduced mean amount of knee extension (39°) compared to children in the H-Group but the mean did not reach the clinical threshold. The mean value of the H-Group (28°) fell within normal parameters. The reason that the participants appeared to have less limited hamstring length than expected may be that the sample represents the less affected section of the population. However, eight children in total had a limited range which fell above the clinical threshold.

It is interesting to note that the children in the H-Group did not have any past surgical interventions for the elongation of the hamstring muscles, while the children in the D-Group had a total of 10 surgical interventions between the children in the D-Group. Despite the

number of surgical interventions in the D-Group to elongate the hamstring muscles, the children in the D-Group still had statistically significant shorter hamstring muscles than the children in the H-Group. This indicates a greater problem of shorter hamstrings in the D-Group than the H-Group, than the goniometric measurements have shown in the present study.

5.3.2.2 Functional Implications

5.3.2.2.1 Short hamstring muscles

Hamstring shortness is well known to negatively affect gait (Hoffinger et al., 1993; Borton et al., 2001) in that the cycle of energy transfer from plantar flexors at toe-off to the trunk through the hamstrings at heel strike is impeded. In addition, the ability to bear weight on an almost fully extended knee in the stance phase is also affected. In late swing, the hamstrings decelerate the leg (the region between the ankle and the knee joints) while lengthening, and they accelerate the leg while shortening in the beginning of stance (Neptune et al., 2004). The reduced availability of the range of motion of the knee and hip joint in crouch gait increases energy consumption (Bleck, 1987; Gage, 1991), as the elastic tissue has a less opportunity to harvest energy. Maintaining the stance phase in a crouch position is likely to be more costly than maintaining the stance phase in extension, as the force moments are increased when the knee flexes. However, this was not found to be the case in this study as the limitation of range of knee motion was not predictive of PCI. Not all persons walking with crouch gait have shortened hamstrings (Hoffinger et al. 1993, Schute et al. 1997, Cosgrove et al. 1997, Thompson et al. 1998, Thompson et al. 2002). The effect of weak calf muscles can be a contributory factor (Gage, 2004). The lack of the predictive value of hamstring length could be due to the overriding influence of the weak plantar flexors in determining PCI. The shortness of the hamstrings in the children with CP is further compounded by the simultaneous shortness of the triceps-surae, which frequently leads to an equinus gait (Bladder et al., 2002). The roles of the muscles that act on two joints (such as the hamstrings) on leg and trunk acceleration are not easy to assess, because they act as a flexor at one joint and an extensor at the other joint (Neptune et al., 2004).

5.3.2.2.2 The problem of crouched knees

Knee extension requires the cooperation of some or every one of four parameters: contraction of the quadriceps femoris muscle, relaxation of the gastrocnemius muscle, contraction of the

soleus muscle and sufficiently long hamstring muscles. The children with diplegia in the present study had statistically significantly shorter hamstring and weaker quadriceps muscles (which approached statistical significance). The relaxation of the gastrocnemius muscle enables extension of the knee joint in the stance phase (Neptune et al. 2001; Stewart et al., 2007). Children with diplegia are known to have a significant amount of co-contraction (Wakeling et. al., 2007), which might prevent relaxation of the gastrocnemius to allow extension of the knee, and the resistance to passive dorsiflexion did increase the PCI in this study. The soleus muscle is the last option of the four possible knee extensors capable of providing knee extension (Neptune et al. 2001; Stewart et al., 2007). The plantar flexors of children with diplegia are well known to be weaker (Gage, 2004), and there is no reason to believe that the soleus muscle is not similarly weaker in children with diplegia, as compared to normal children. Lack of any of the four parameters that can create knee extension among children with diplegia will encourage crouched knees. The best chances of achieving knee extension among children with CP may lie with strengthening knee extension and using FES to activate the soleus muscle (Stewart et al., 2007).

5.3.3 Spasticity of the triceps surae

5.3.3.1 Comparison between groups

The MAL of children in the D-Group and the AL of the H-Group had similar spasticity scores of the triceps surae, using the modified Ashworth scale (Peacock version, Peacock and Staudt, 1991). The spasticity is one of the fundamental parameters that was closely related to the equinus ankle and this finding adds support to the notion that the nature of equinus ankle in the two groups is generally similar. The role of increased resistance to stretch of the plantar flexors emerged as a predictor of PCI, and there may be several reasons as to why that was the case.

5.3.3.2 Functional implications

Co-contraction is the simultaneous involuntary contraction of the antagonist muscles when there is voluntary contraction of the agonist muscles (Scholtes et al., 2006), and is common among children with CP during gait (Wakeling et. al., 2007). Co-contraction could have been masking the true amount of muscle power, which was measured by the HHD. For example,

when a flexor group is isometrically contracted, the antagonists tend also to contract to a lesser extent, and this reduces the net measurable muscle power generated by the flexors. Co-contraction would make one muscle group appear weaker as it has to labour against the antagonist. As a result, the total cumulative intensity of the EMG recordings for the stance and swing phases for a given distance walked for the tibialis anterior, gastrocnemius, quadriceps femoris and semimembranosus muscles were greater in children with diplegia than in normal children, due to co-contraction (Wakeling et. al., 2007). In contrast, the disability in gait experienced by the child with CP is not a result of a lack of viable muscle but rather inappropriate control of muscle contraction. The child with CP is able to absorb a large amount of oxygen to overcome his or her disability, but the additional energy produced is wasted in co-contractions and out-of-phase muscle activity. Thus, both groups of children have difficulty walking, yet children with CP absorb significantly more oxygen than do children with MD.

This may create a paradoxical situation where a muscle group works harder against its antagonist and yet has a weaker recording on a HHD when compared to the muscles of normal children. The paradoxical situation indicates a measure of inefficiency of the muscles in children with diplegia and the amount of co-contraction could be additively increasing the physiological cost of gait. The co-contraction causes an increased PCI (Bowen et al., 1999), and, in the current study, the presence of spasticity or hypertonia was found to have an influence on the PCI.

The co-contraction might result in an increased PCI, but, in the current study, the presence of spasticity or hypertonia was found to have no influence on the PCI. This might be due either to a lack of effect of spasticity on the PCI or the poor sensitivity of the Ashworth scale in detecting spasticity.

Although the modified Ashworth scale has been widely used as a measure of spasticity, the functional implications of the results of the scale remain unclear. The functional capabilities of children with CP tend to decrease as they get older and spasticity is thought to be the main factor involved, but without any supporting empirical research (Scholtes et al., 2006).

Spasticity has been treated using stretching, botulinum injections and surgical procedures, and the time spent and financial burden need to be justified, (Albright, 1996; Peacock et al., 1990; Meyer et. al., 2006; Pin et. al., 2006). There is a long standing controversy as to whether or not

spasticity influences motor performance (Sahrmann and Norton, 1977). Most studies have found no relationship, and a few studies have found a very weak relationship, between spasticity and function (Damiano and Abel 2000; Damiano, 2002). The current study also found that spasticity was not a predictor of the gait PCI. The lack of a relationship between the measured spasticity and a functionality could be attributed to the fact that spasticity is measured in a resting position and the functionality in an active position (Sahrmann and Norton, 1977; Thompson et al., 2001). The muscle tone at rest is known to change during active use of muscle (Sahrmann and Norton, 1977; Thompson et al., 2001).

Ways have been sought to reduce the co-contraction by the antagonist group of muscles, as a way to make gait more efficient. Buurke et. al. (2004) managed to reduce the effect of co-contraction by hamstring muscles on the knee extensors, by lengthening the hamstring tendons surgically. FES could be of assistance in teaching the children to relax muscle and produces a sound when there is unwanted muscle contraction during gait. It is also important to bear in mind that co-contraction is considered normal in all children who are less than six to eight years of age, and is a classical sign of gait immaturity (Berger et al., 1985; Shiavi et al., 1987; Granata et al., 2005). Gait immaturity is characterised by increased co-contraction of antagonistic and agonistic muscles during the stance phase and poor integration of descending and stretch reflexes (Granata et al., 2005). Children with CP tend to take longer to achieve gait maturity, usually in their early teenage years (Berger et al., 1985; Shiavi et al., 1987; Granata et al., 2005). Children with hemiplegia tend to have a more mature gait pattern in their unaffected lower limb and an immature gait on their affected lower limb. Children with hemiplegia tend to use, and depend on, their 'stronger lower limb' more, and this increases their overall efficiency of gait, and, consequently have lower PCI values than the children with the diplegic form (Raja et. al., 2007). Both legs of children with the diplegic form have the immature gait.

5.3.4 Equinovarus and equinovalgus between the two groups

The degree of ankle varus and valgus was measured with a goniometer as the tibiocalcaneal angle. The MAL of the D-Group and the AL of the H-Group had similar angles of ankle valgus with a mean of 5.1°. This differed from the findings in the literature. The literature indicates that equinovarus is more common in children with the hemiplegic form of CP (McCoullough, 1978; Bleck, 1987; Chapman and Madison, 1988; Harlaar et. al., 2000; Wren

TA et al. 2005) and equinovalgus is more common in the diplegic form (Chapman and Madison, 1988; Aiona, 1996; Morrel et. al., 2002; Sussman and Aiona, 2004). The similarity between the two groups in the current study could be attributed to the fact that the sample was made up of children with a milder version of CP.

5.3.5 The reliability of the tibiocalcaneal angle

By using a goniometric approach, the present study found the mean tibiocalcaneal angle of the legs of the children in the D-Group and the H-Group had ankle valgus angles of $4.8^{\circ} \pm 4.42^{\circ}$ and $8.1^{\circ} \pm 10.6^{\circ}$, respectively, and no statistically significant differences were found. This fell into the 5° to 10° hindfoot valgus classification by Stockley et al. (1990). It could be that the latter study excluded the more severe cases of children, which could have had more pronounced forms of equinovarus and equinovalgus. The tibiocalcaneal angles obtained by the present study were comparable to other goniometric studies that measured the tibiocalcaneal angle in adults of $6.40^{\circ} \pm 1.92^{\circ}$, (Haight et. al., 2005) and in patients with rheumatoid arthritis (40% had tibiocalcaneal angles greater than 10° and 60% had less than 10°) (Stockley et. al., 1990).

The tibiotalar angle of children with CP has not been reported previously. In the present study, the tibiotalar angle (with radiographs taken in an anteroposterior direction) had a mean of 1.2° ($\pm 4.1^{\circ}$ and range of -9.7° to 6.2°). This was reasonably comparable to the results of Beals and Skyhar (1984) who obtained a range of -6° to 14° in normal 8 to 12 year olds, and the values found by Davids et al. (2005) of 1.1° ($\pm 3.8^{\circ}$ and had a range of -9° to 12°) in normal 5 to 17 year olds.

The hindfoot valgus (tibiocalcaneal angle) is the arithmetic sum of the tibiotalar joint angle and the subtalar joint angle (Standring et al., 2007). More ankle inversion and eversion occurs at the subtalar joint than at the tibiotalar joint (Arndt et. al., 2004; Wong et. al., 2005).

However, the tibiotalar angles appear larger, more unstable and more variable (-9.7° to 14°) than the tibiocalcaneal angles (5° to 10°). The tibiotalar angle should have a smaller angular contribution to inversion and eversion than the subtalar joint (Arndt et. al., 2004; Wong et. al., 2005). The large variability of the tibiotalar angle makes the clinical goniometric measurement of the tibiocalcaneal angle in the coronal plane meaningless as a valid measure of hindfoot inversion and eversion.

5.3.6 Tautness of the sides of the tendon of the calcaneus

There were no differences found in the relative tautness of the medial and lateral sides of the TA between the two groups. There are two proposed explanations with regard to the tension of the medial and lateral sides of the TOTC in standing: the ankle stabilising theory (Klein et. al., 1996; Zifchock et. al., 2004) and the soleus-gastrocnemius contribution theory (Mozena and Pearson, 2004). The ankle stabilising theory states that the lateral side of the TOTC becomes tauter in order to resist the ankle varus strain and similarly a tauter medial side will resist ankle valgus strain (Klein et. al., 1996; Zifchock et. al., 2004). The soleus-gastrocnemius contribution theory proposes that the tendon fibres of the lateral side of the TOTC are continuous with the muscle fascicles of the gastrocnemius muscle belly, and, likewise, the fibres of the medial side of the TOTC are continuous with those of the soleus muscle belly (Mozena and Pearson, 2004). The tauter side of the TOTC will be due to having greater tensile forces being generated in the respective muscle belly. Neither the soleus-gastrocnemius contribution nor the ankle stabilising theory was supported by the present study. The large number of surgical interventions to the TA could also have interfered with the stabilising functions.

5.4 Gait parameters

5.4.1 Cadence

The cadence was similar between the two groups, which was surprising, as it was anticipated that the H-group would be the more efficient walkers of the two groups. The cadence across the combined group was strongly positively correlated with PCI values, with a higher cadence giving rise to a higher PCI value. Little literature was found exploring the relationship between cadence and PCI. Larger strides could be recommended as a way to reduce the PCI and achieve a more efficient gait among children with cerebral palsy. However, shortened hamstrings and crouch knees may limit the stride length and, in order to maintain an adequate gait speed, the cadence increases.

5.4.2 Physiological Cost Index

The children with diplegic form of CP had a higher PCI than in the children with the hemiplegic form (0.71 hb/m versus 0.51 hb/m) of CP and the difference which approached statistical significance ($p = 0.06$). Normal children tend to have PCI values of 0.10 hb/m (Raja et. al., 2007), and a PCI score of 0.70 hb/m in children with diplegia would indicate that children with diplegia are spending 7 times more energy than normal children in walking the same distance. The PCI values obtained were comparable to other studies. Raja et. al. (2007) noted that children with hemiplegia without an equinus ankle had a PCI of 0.29 hb/m, children with CP and an equinus ankle had a PCI of 0.69 hb/m, and children with diplegia with a crouch and an equinus ankle had a PCI of 0.79 hb/m.

Energy expenditure techniques can either measure the actual oxygen used for metabolism or use a proxy of the oxygen used such as the heart rate (Raja et al., 2007). The Physiological Cost Index (PCI) uses the heart rate as an indirect measure of energy consumption, and has been confirmed as a reliable index of the efficiency of gait in children with CP (Raja et al., 2007). It is also a convenient measure of energy consumption as it does not rely on sophisticated equipment.

5.4.3 Factors relating to PCI

One would have expected that factors such as the CP diagnosis, BMI, a history of relevant surgery and ambulation would predict the PCI. However, it was only diagnosis that was a predictor of the PCI. A child belonging to the H-Group was predicted to have a PCI of 0.22 hb/m less than a child in the D-Group. Children in the D-Group were at Level I, II and III, while all the children in the H-Group were at Level I. As the higher the GMFCS level a child was at, more energy was used (in the form of PCI) and this had an effect of raising the average PCI values of the D-Group.

The most influential impairment was the poor strength of the plantar flexors. As a result, the ability to perform a single heel raise was predicted to reduce the PCI by 0.30 hb/m with using muscle strength normalised by the body weight. It also interesting to note that the only two predictors of PCI retained in the forward stepwise regression analysis were muscle related parameters. There may be several reasons for this. The PCI is a function of how much energy

in the form of ATP is used and reflects that muscles are the main users of ATP during gait. In addition, the loss of the role of the plantar flexors in feeding energy into the gait cycle at push-off is likely to result in abnormal muscle activity in the proximal hip muscles and a decrease in efficiency (see above, under functional implications of plantar flexor weakness).

It was interesting that it was not the excessive or limited range of motion of the plantar flexors that predicted PCI, but the strength of the plantar flexors and the resistance to passive stretch. The common belief in the management of the equinus ankle for the last 200 years has been that the main problem is limited range of the triceps surae (Davis et al., 1999). The TOTC has been lengthened with the knowledge that muscle power is being sacrificed (Delp and Zajac, 1992).

The dual involvement of the plantar flexors and the knee flexors raises an interesting perspective. Both are on the posterior side of the lower limb and this aspect of the lower limb appears to have increased muscle tone compared to the muscles that lie anteriorly. Both triceps surae muscles and the hamstrings are frequently surgically lengthened at the tendinous part. However, when the tendinous portion of the muscles are lengthened, the contractile portions become shortened in the long term. In this case, lengthening of the tendinous portion could leave the muscle at a mechanical disadvantage with regard to generating muscular power. It was surprising that the number of past surgeries, the number of past Botox injections to the calf muscles and excessive or limited range of motion of the ankle did not predict PCI.

5.5 Limitations

5.5.1 External validity

The sample was smaller than expected and consequently the study lacked the ability to detect a difference between the two groups with regard to the PCI. As mentioned previously, a difference might have been detected if the sample had consisted of 22 children in each group instead of the 12 and 17 children that were recruited. The lack of parental consent resulted in the smaller sample and may also have resulted in a biased sample selection towards children whose parents were more involved in the school activities of their children than were other parents.

The two groups who participated in the study had milder ambulatory difficulty than the general population of children with CP because participants were required to be at GMFCS Levels III or lower to be eligible for inclusion in the study. Calculation of PCI is only possible if the children are at GMFCS Levels III or lower. This criterion then skewed the subjects towards milder ambulatory difficulties and therefore the results can only be applied to those children with mild disabilities.

The above factors limit the generalisability of the study and the results should be applied only to children with spasticity that is similar to the participants, albeit with caution.

5.5.2 *Methodology*

The BMI of the children was compared to the BMI of children living in the United States of America. The sex and age differentials of children may not be similar to those of children in South Africa.

The tape measure was not used to measure the lengths of the lower limbs of the children, but a method was used which had the children in a supine position with the knees flexed. Most children had flexion deformities of the knees and measuring the length of the lower limbs with a tape measure would not have been valid. To date, there has not been a study reported in the literature which measures the length of the lower limbs of children with diplegia, because of the knee flexion limitations. Similar difficulties were also encountered when the heights of children were being measured, in order to calculate the BMI. Some children had knee flexion limitations and could not fully extend the knees, and thus some children had shorter recorded heights than they actually are. As a result, the strength of the muscle groups was normalised using body weight rather than with the BMI.

As mentioned above, the Ashworth scale may not be the most reliable instrument with which to measure spasticity. It has been suggested that the use of an iso-kinetic measurement might be a more objective way of determining hypertonia and spasticity. Spasticity was measured in a resting position and the functional outcome in an active position, and this may have weakened the strength of the relationship of the levels of spasticity and the PCI of gait. The passive muscle tone changes during active use (Sahrmann and Norton, 1977; Thompson et al.,

2001). Unfortunately, the iso-kinetic equipment was not available for use in the present study. It is recommended that, in future studies, this should be used, if at all possible.

There was a statistically significant correlation between modified Ashworth Scale and the R1 angle and not the R2 angle. Evaluating the relationship between the R1 ankle angle at rest, the ankle angle during initial stance with computerised gait analysis and the modified Ashworth Scale may possibly lead to a functional link of spasticity, and may lead to the adopting of the R1 angles in patient assessments.

The reliability of the measurements of the length of the hamstring muscles could have been improved by blinding the goniometer (covering the scale on the goniometer while performing the measurement, and making the reading only afterwards) and creating an additional device to stabilise the pelvis and mechanically limit hip flexion to 90° (Gajdosik and Lusin, 1982; Rakos et al., 2001). However, the conventional popliteal test remains a good technique of measuring the length of the hamstring muscles (Gajdosik et al., 1993), and the measurement of the knee joint in the clinical setting is highly reliable (Rothstein et al., 1983).

The present study used palpation to determine the tautness of the sides of the TOTC in the three categories of very taut, mildly taut and slack. This newly proposed technique has not had any reliability or validity studies performed on it and might be a scientifically weak tool. The measurement of the tibiocalcaneal angle as a measure of ankle varus and valgus using a goniometer proved to be an invalid indicator of movement at the subtalar joint. The tibiocalcaneal angle is the arithmetic sum of the tibiotalar and the subtalar joints. The radiographs taken on 15 ankles of subjects of the study indicated a large variation at the tibiotalar joint, which resulted in the tibiocalcaneal angles not reflecting the subtalar angles. Although the radiological tibiocalcaneal angles were taken without a device to rigidly stabilise the ankle joint, the angles obtained were comparable with those of other studies.

The measurement of the strength of plantar flexion was delayed and was collected four months after the rest of the data. There have been no studies indicating the reliability of using a HHD or any equipment for the strength of the plantar flexors. It was later decided to use manual methods as a parameter of the strength of the plantar flexors. No child had undergone surgery or had increased the intensity of rehabilitation intervention in the interim, and it is unlikely that the ability to heel raise had altered during these four months. EMG and gait analysis would have added value to the study.

5.5.3 Lack of kinematic gait parameters

A major limitation of the study is that the impairment findings could not be linked to objective three dimensional gait analysis and electromyography. At the initiation of the study, it had been anticipated that a gait analysis laboratory with electromyography would be made available. Unfortunately this did not happen and no kinematic gait analysis data could be gathered or analysed. The influence of the measured impairments on parameters such as the degree of crouch gait in walking, the active range of movements of the ankle and knees, and the force exerted by the plantar flexors would all have been invaluable to the understanding of the difference between the two groups. The PCI was utilised as a measure of the overall efficiency of gait, but kinematic gait parameters would also have contributed to an understanding of the predictive factors. Electromyography would have elucidated the precise activations of the soleus and the gastrocnemius during the gait cycle and could have shed more light on the role of the two muscles during knee extension.

There has been a tendency for studies of the equinus ankle to focus specifically on outcome measures of parameters around the ankle joint and to ignore the implications on the knee and hip joints, the pelvis and the trunk muscles. The present study broadened the extent of the outcome measures and included the parameters around the knee joint. A further research protocol should be designed to compare parameters at more proximal joints and include parameters around the pelvis, such as horizontal pelvic tilting and rotation of the lower limbs during walking.

6 Conclusions

6.1 Introduction

The parameters related to the equinus ankle were compared between the MAL of the D-Group and the AL of the H-Group. The children in the D-Group were found to have limited knee extension and the strength of the plantar flexors played an important role in reducing the energy demands of walking. The discussion conclusion, therapeutic implications and recommendations are described in the following sections in the same order as the objectives.

6.2 Discussion conclusions

6.2.1 The demographic, anthropometric and medical parameters

6.2.1.1 The sample

Although the number of subjects used was small, it was comparable to other studies. However the meaning of the study was diminished and there may have been more differences than were detected between the D-Group and the H-Group. The two groups that participated in the study had milder ambulatory difficulty than the general population of children with CP because participants were required to be at GMFCS Levels III or lower to be eligible for inclusion in the study. This criterion then skewed the subjects towards milder ambulatory difficulties and therefore the results can only be applied to those children with milder disability.

6.2.1.2 Differences between the two groups

The children with diplegia had more previous surgical interventions and, predictably, had greater ambulatory difficulties than children with the hemiplegic form. As descriptive research cannot establish causality, it is impossible to know whether more surgical interventions were required in children with greater ambulatory difficulty or whether the greater number of multiple surgical interventions could have made it more difficult to ambulate. However, it

appeared that the children with diplegia were generally more affected and the surgical interventions were most probably applied to those who, prior to surgery, were more handicapped.

6.2.2 Parameters of impairment

Despite being more handicapped in terms of having higher GMFCS levels and greater number of surgical interventions, only three impairments among the children with diplegia differed from the children with hemiplegia. The children with diplegia had shorter hamstring muscles (statistically significant), crouched knees during the initial stance phase (statistically significant), and weaker knee extensors (which approached statistical significance) compared to the children with hemiplegia. The triad of knee problems was peculiar to the children with diplegia and signified a fundamental difference between the two groups. The ankles of the two groups appeared similar, while the knees appear different. Thus the management of the equinus ankle, which involves muscles that span the ankle and the knee joints, should be modified to factor in the difference at the knees. The gastrocnemius muscle ought to be eased or relaxed to encourage extension during the stance phase, and the soleus and quadriceps femoris muscles strengthened (with special exercises) among the children with diplegia. Emphasis ought to be placed on lengthening (surgically or otherwise) the muscular portion of the hamstring muscles more than the tendinous portion. The extra length of the hamstring muscles would allow more knee extension. This approach will preserve the elastic nature of the tendinous portions and the power generative capability of the muscle bellies.

The functional consequences of these three impairments around the knee joint may be profound and ought to be remedied. Knee extension requires the integration of four parameters: strong contraction of the quadriceps femoris muscle, relaxation of the gastrocnemius muscle (should not have co-contraction), strong contraction of the soleus muscle, and hamstring muscles that are long enough to allow knee extension. The children with diplegia are performing poorly in all these aspects and therapy should be aimed at improving their knee extension, to reduce the use of crouch gait. Hamstring shortness is known to negatively affect gait and encourages crouched knees among the children with diplegia. The children with diplegia had shortened hamstring muscles and are more likely to maintain a crouch position during stance phase. The movement in a crouch position is likely to be more costly to maintain and the D-Group did demonstrate a trend towards having a higher calculated PCI than the H-Group.

6.2.3 The biomechanical principles underlying equinovarus and equinovalgus

Equinovarus among children with the hemiplegic form of CP and equinovalgus among children with diplegic form was not confirmed, probably because the study sample comprised of children who were more mildly affected with CP. Neither the traditional theory, the soleus-gastrocnemius contribution theory nor the ankle stabilising theory was supported. The natural stabilising functions of the TOTC on the ankle could have been affected by the surgical interventions on the TOTC.

6.2.4 Factors predictive of the Physiological Cost Index

The most noteworthy finding was that excessive or limited range of motion of the plantar flexors did not predict PCI, but the strength of the plantar flexors as measured by the ability to rise on the toes was highly predictive. The storage of elastic energy and recoil of the plantar flexors is an effective mechanism to recycle energy and reduce the amount of energy input. An impaired triceps surae will poorly retain the recycled energy and will need more energy input. Failure of the strength of the plantar flexors in children with CP to enable push off might result in the need to recruit the hip and knee flexors to accelerate the lower limb from toe-off through the swing phase of gait to heel-strike. This phenomenon will over-work the hip and knee flexors, and contractures may eventually develop. Surgical lengthening of muscle by lengthening the tendon ought to be reviewed. Tendon lengthening might play a large role in the decreased strength of the plantar flexors and the use of techniques that lengthen the muscular, contractile section of the muscles, rather than the tendinous section, should be explored.

Attention ought to be paid to strengthening the plantar flexors as a way of increasing the efficiency of gait. Co-contraction of the antagonist muscles during walking might be contributing to the high PCI values among children with CP. There was a relationship between measured spasticity and a functional outcome, since greater spasticity levels of the triceps surae muscle predicted proportionally greater consumption of energy during walking. As cadence was found to be correlated with PCI, the aim of therapy should be to encourage longer strides. As shortened hamstrings and crouch knees may limit the stride length, stretching of hamstrings and strengthening of the knee extensors should be done in preparation for gait re-education.

6.3 Therapeutic implications

The findings of the current study have implications for the treatment of ambulant children with spastic diplegia and hemiplegia. The following recommendations need to be subjected to rigorous testing of their efficacy before they are implemented. However, the recommendations are based on the empirical findings of the study.

Therapists should approach the management of the equinus ankle in children with CP hemiplegia and diplegia differently at the knee level, even although the ankles are similar in presentation. The range of motion of hamstrings is decreased, and the weaker knee extensors among the diplegics encourage crouch knees. Therapists should be prepared for a triad of shortened hamstrings, crouched knees and weakened knee extensors among the children with diplegia, but not among children with hemiplegia. Children with hemiplegia do not seem to utilise the AL optimally and this should be discouraged.

Strengthening of the lower limb muscles, particularly the soleus and knee extensors, might play an important role in decreasing the PCI of walking, as only muscular strength related parameters (ankle plantar flexors) and none of the non muscular parameters were predictors of the PCI. Therapy involving FES and stimulating the soleus muscle during the stance phase, in combination with three dimensional gait analysis, may help encourage knee extension in children with diplegia.

A higher cadence across the combined group ($r = 0.57$) was strongly correlated with higher PCI values. Larger strides could be recommended as a way to reduce the PCI and achieve a more efficient gait among children with cerebral palsy. The current study found that spasticity was not a predictor of the gait PCI, and in the literature no link between spasticity and the functional outcome has been found. Clear functional benefits need to be justified to account for the significant time the therapists spent on treating spasticity of the equinus ankle for cosmetic reasons.

If it is deemed necessary to lengthen the triceps surae, it is suggested that the use of serial casting be considered. There is a theoretical agreement that immobilisation using casting will increase the number of sarcomeres and help resolve the equinus ankle (Gough, 2007). This approach might lengthen the muscular part and preserve the elasticity of the muscle tendon. On the other hand, Gough (2007) has expressed fears that casting might disrupt the elasticity

of the TOTC, and this will handicap the capability of the tendon to store and release elastic energy, and reduce the energy efficiency of walking. There have not been any proven functional benefits of casting and there has been little convincing evidence supporting casting as opposed to no casting, due to the contradictory nature of research findings and the preference of the articles to compare casting to the use of botulinum injection (Blackmore et al., 2007; Gough, 2007).

6.4 Recommendations with regard to future research

6.4.1 Shortness of the triceps surae and the hamstring muscles

It might be that both the hamstrings and the triceps surae are being lengthened at the tendinous part of the muscle. The muscles could have shortened contractile sections and any compensatory lengthening of the tendinous part could leave the muscle at a disadvantage with regard to generating muscular power. Further research is needed to describe the architecture of the hamstrings and triceps surae muscles and to establish what architectural features are associated with the ability to successfully heel raise among children with cerebral palsy. In effect it will seek to establish a link between structure and the strength. The analysis of the architecture could investigate the layout of the fascicle length, fascicle angles, and other length dimensions of the triceps surae muscle. Ultra-sound imaging might be a useful tool with which to examine the triceps surae, as it is non-invasive and can give real time images of muscle contractions.

6.4.2 Differential ultrastructure of the triceps surae between the two groups

The children with diplegia had knees in a flexed position, which was not found among the children with hemiplegia. This would imply that the triceps surae is shorter in children with diplegia than with hemiplegia. Given that lengthening the triceps surae by 1 cm and 2 cm would result in loss of muscle power by soleus of 30% and 85% respectively (Delp and Zajac, 1992), the effects of lengthening a muscle by 1 or 2cm would result in a more pronounced loss of muscle strength in persons with shorter muscles. It would also be of interest to investigate how the layout of the fascicle length and fascicle angles present in the two groups. Children with diplegia would be expected to have shorter fascicle lengths and greater fascicle angles

(which have less power generating capacity). These findings could have profound influence on the future treatment protocols between the two groups.

6.4.3 Serial casting

Future work to confirm the lengthening of the sarcomeres after casting and an improvement of the strength of the muscles are due, to provide possible options of lengthening the muscular part of muscles.

6.4.4 The best way to normalise the measurement of muscle strength

There is a general consensus that strength measurements ought to be normalised using weight (Ayalon et al., 2000; Damiano et al., 2001; Hsu et al., 2002; Berry et al., 2004; Clark et al., 2006), with the exception of a single study which advocated that strength be normalised using a product of weight and height (Van den Berg-Emons et al., 1996). Normalising with weight alone tends to treat a younger over-weight child on the same terms as an older heavier child, and is therefore misleading. Empirical studies to find the most accurate method of normalising strength by comparing weight-normalised, height-normalised and BMI-normalised muscle strength are warranted.

6.4.5 Tautness of the sides of the tendon of the calcaneus

Clinical palpation of the sides of the TOTC and understanding its involvement in ankle varus and valgus is a new research area and very little literature exists. Further research work is warranted especially to determine how much the sides of the TOTC are influenced by a certain degree of ankle varus and valgus, and by adopting different postures of the body. Research into the tautness of the TOTC can be made more objective and richer by measuring the thickness of each side of the TOTC and the fascicle architecture of the triceps surae with ultrasonography.

6.5 Summary of the conclusions

CP is a life-long condition and children affected deserve the most effective intervention. This intervention should not only be aimed at managing impairments, but the functional implications of the impairments need to be taken into account. It is the functional ability that ultimately determines how well the child will be integrated into society. For too long, intervention has been based on unproven theories and on the “clinical experience” of the therapists. It is hoped that this study will contribute to the growing body of empirical knowledge upon which evidence-based intervention can be developed.

The present study investigated how the impairment parameters related to the equinus ankle were linked to functional measures, such as PCI and cadence. The children with diplegia have impairments that are keeping the knees in a flexed posture, while the children with hemiplegia have normal knees. Medical management of the equinus ankle should be correspondingly altered among children with diplegia to reflect the condition of the knees. The strength of the plantar flexors was the most important determinant of the amount of energy used in ambulation, in contrast to the commonly belief that the length of the plantar flexors are the most important parameter. The practice of trading off the muscle strength for muscle length ought to be reviewed and the medical management of the equinus ankle ought to be linked to a functional measure.

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8 Appendices

Appendix 1: Testing for Normality of the data using the Shapiro-Wilk Test at 5% level of significance

The values highlighted in bold are variables that are not normally distributed.

Parameter	D-Group	H-Group	Decision on type of Variable
Age	$W = 0.91, p = 0.10$	$W = 0.96, p = 0.85$	Numerical "Normal"
Gross Motor Function Classification	$W = 0.63, p = 0.00$	N/A	Categorical data
Body Mass Index	$W = 0.72, p = 0.00$	$W = 0.97, p = 0.88$	Numerical "Non-Normal"
Sex	$W = 0.53, p = 0.00$	$W = 0.65, p = 0.00$	Categorical data
Use of Walking Aid	$W = 0.53, p = 0.00$	N/A	Categorical data
Total surgical Interventions	$W = 0.89, p = 0.05$	$W = 0.84, p = 0.03$	Numerical "Non-Normal"
R1 angle of Equinus angle of MAL of the D-Group and the AL of the H-Group	$W = 0.93, p = 0.24$	$W = 0.93, p = 0.40$	Numerical "Normal"
R2 angle of Equinus angle of MAL of the D-Group and the AL of the H-Group	$W = 0.96, p = 0.73$	$W = 0.90, p = 0.14$	Numerical "Normal"
R1 angle of Equinus angle of LAL of the D-Group and the UL of the H-Group	$W = 0.97, p = 0.91$	$W = 0.96, p = 0.71$	Numerical "Normal"
R2 angle of Equinus angle of LAL of the D-Group and the UL of the H-Group	$W = 0.91, p = 0.09$	$W = 0.98, p = 0.99$	Numerical "Normal"
Ankle Valgus angle of MAL of the D-Group and the AL of the H-Group	$W = 0.52, p = 0.00$	$W = 0.93, p = 0.41$	Numerical "Non-Normal"
Ankle Valgus angle of LAL of the D-Group and the UL of the H-Group	$W = 0.85, p = 0.01$	$W = 0.93, p = 0.41$	Numerical "Non-Normal"
Hamstrings muscle length of MAL of the D-Group and the AL of the H-Group	$W = 0.88, p = 0.05$	$W = 0.97, p = 0.94$	Numerical "Normal"
Hamstrings muscle length of LAL of the D-Group and the UL of the H-Group	$W = 0.90, p = 0.07$	$W = 0.95, p = 0.64$	Numerical "Normal"
Spasticity of the Triceps Suræ muscle of the MAL of the D-Group and the AL of the H-Group	$W = 0.87, p = 0.03$	$W = 0.73, p = 0.00$	Numerical "Non-Normal"

Spasticity of the Triceps Surae muscle of the LAL of the D-Group and the UL of the H-Group	W = 0.86, p = 0.02	W = 0.33, p = 0.00	Numerical "Non-Normal"
Strength of the ankle dorsiflexors of the MAL of the D-Group and the AL of the H-Group	W = 0.90, p = 0.09	W = 0.88, p = 0.14	Numerical "Normal"
Strength of the ankle dorsiflexors of the LAL of the D-Group and the UL of the H-Group	W = 0.94, p = 0.33	W = 0.98, p = 0.97	Numerical "Normal"
Strength of the knee flexors of the MAL of the D-Group and the AL of the H-Group	W = 0.94, p = 0.30	W = 0.90, p = 0.14	Numerical "Normal"
Strength of the knee flexors of the LAL of the D-Group and the UL of the H-Group	W = 0.96, p = 0.59	W = 0.93, p = 0.39	Numerical "Normal"
Strength of the knee extensors of the MAL of the D-Group and the AL of the H-Group	W = 0.93, p = 0.23	W = 0.94, p = 0.52	Numerical "Normal"
Strength of the knee extensors of the LAL of the D-Group and the UL of the H-Group	W = 0.97, p = 0.84	W = 0.92, p = 0.28	Numerical "Normal"
Cadence	W = 0.96, p = 0.58	W = 0.90, p = 0.16	Numerical "Normal"
The more anterior knee cap	W = 0.81, p = 0.00	W = 0.71, p = 0.00	Numerical "Non-Normal"
Physiological Cost Index	W = 0.89, p = 0.06	W = 0.97, p = 0.90	Numerical "Normal"



UNIVERSITY OF CAPE TOWN

Health Sciences Faculty
Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6338 • Facsimile [021] 406 6411
e-mail: preaward@curie.uct.ac.za

05 October 2006

REC REF: 311/2006

Mr H Gangata
Human Biology

Dear Mr Gangata

**PROJECT TITLE: AN INVESTIGATION INTO THE DIFFERENCES OF EQUINUS ANKLE
RELATED PARAMETERS BETWEEN CHILDREN WITH CEREBRAL PALSY WHO
PRESENT WITH SPASTIC DIPLEGIA AND SPASTIC HEMIPLEGIA**

Thank you for submitting your study to the Research Ethics Committee for review.

It is a pleasure to inform you that the Ethics Committee has **formally approved** the above-mentioned study.

However, your informed consent contains several typos which you should correct eg. pg 44 young child-your child And during walking they will be looking for (delete the).....will involving detecting how will the muscles in your child are being damaged.

Please could you add the following under contact information(p 46): A/Prof Marc Blockman Research Ethics Committee 406 6338.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please quote the REC. REF in all your correspondence.

Yours sincerely

A/PROF. M. BLOCKMAN
CHAIRPERSON, HSF HUMAN ETHICS

kmjedi

Appendix 3: The letter of approval from the Ministry of Education

Mr Hope Gangata
Department of Human Biology
Faculty of Health Sciences
University of Cape Town
OBSERVATORY
7325

Dear Mr H. Gangata

RESEARCH PROPOSAL: AN INVESTIGATION INTO THE DIFFERENCES OF EQUINUS ANKLE RELATED PARAMETERS BETWEEN CHILDREN WITH CEREBRAL PALSY WHO PRESENT WITH SPASTIC DIPLEGIA AND SPASTIC HEMIPLEGIA.

Your application to conduct the above-mentioned research in schools in the Western Cape has been approved subject to the following conditions:

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educators' programmes are not to be interrupted.
5. The Study is to be conducted from **22nd January 2007 to 31st September 2007.**
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December 2007).
7. Should you wish to extend the period of your survey, please contact Dr R. Cornelissen at the contact numbers above quoting the reference number.
8. A photocopy of this letter is submitted to the Principal where the intended research is to be conducted.
9. Your research will be limited to the following schools: **Eros, Vista Nova, Bel Porto, Paarl, Agape and Tembalethu.**
10. A brief summary of the content, findings and recommendations is provided to the Director: Education Research.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:

**The Director: Education Research
Western Cape Education Department
Private Bag X9114
CAPE TOWN
8000**

We wish you success in your research.

Kind regards.

Signed: Ronald S. Cornelissen
for: **HEAD: EDUCATION**
DATE: 10th August 2007

Appendix 4: Information sheet for the parents or gurdians

Hello

My name is Mr Hope Gangata. I am a graduate of an Honours Bachelors degree in Physiotherapy and I am currently undertaking this research as part fulfilment of my Masters degree at the Medical School of the University of Cape Town. I will be doing these tests together with Ms Marianne Unger who is a physiotherapist who is doing her PhD at the University of Cape Town.

The topic of my study is the stiff ankles that we often see in children with cerebral palsy. I am asking you and your child to take part in the study because your child has cerebral palsy and might develop a stiff ankle. You have been given this form by the physiotherapist who is treating your child. I will only be given this form and your child's name if you and he/she agree to take part in the study.

Reasons for undertaking the study

The study seeks to investigate the differences of the ankles and legs that children presenting with hemiplegia (children affected one side) have when compared to children presenting with diplegia (children affected on both legs and not the arms). The equinus deformity occurs when a child with cerebral palsy is unable to walk with the heel making contact with the floor. A photograph of the equinus deformity is shown below;



Figure 39: A picture showing an equinus deformity.

There have been indications that children affected on one side of the body have different equinus ankle symptoms to children affected both sides. These two groups have often had the same type of treatment and sometimes the treatment might not have been very successful. This study seeks to scientifically evaluate the differences and learn about the mechanisms that underlie the equinus ankle of the two groups.

What will your child be asked to do?

On agreeing for your child to participate in this study, I will arrange a suitable time with the physiotherapist who is treating your child. Your child will have his or her legs examined and will be asked to walk for 4 metres so that the heel contact can be observed. This will be done at the school. An appointment will be booked and he/she will then be taken to the Sports Science Institute in Newlands and will have a 3-dimensional computerised gait analysis performed. I will hire a private taxi to take your child plus two children at a time to the Sports Science Institute. The 3-dimensional computerised gait analysis will involve putting small wireless stickers on the legs and your child's walking pattern will be videoed on a computer monitor. In this way we will be able to accurately describe the movements of the ankle, knee and hip. The child will have an X-ray taken of the foot and ankle to enable measurement of the foot bones. When this information is combined, we hope that we will understand more about why equinus deformity develops and how it can be prevented and treated.

Payments

The researcher will pay for the transport to and from Sports Science Institute in Newlands for the data collection. No money will be given to the parents or children for being involved in the study and no financial contributions will be required from the parents of the participants.

Benefits/Risks in taking part

This research is intended to understand the mechanisms that underlie the equinus deformity in children presenting with cerebral palsy. In future the study may help in improving the treatment of the children presenting with cerebral palsy and having an equinus deformity. The 3-dimensional gait analysis and X-rays are the normal assessment tools used by medical staff in medical management of the legs of children with cerebral palsy. For your child's participation in this research, your child will have the opportunity of having a 3-dimensional gait analysis and X-rays performed at no cost to you. You will be given a copy of the X-ray and a report of the gait analysis to keep or to give to the physiotherapist or medical doctor who currently sees your child. There are no foreseen risks by being assessed by the 3-dimensional gait equipment. There is a small risk of any X-ray causing cancer. This study will use a machine which gives much less radiation (20 times less) than ordinary hospital X-rays so this risk should be very small.

The tests done at the school will take 30 minutes and the visit to the Sports Science Institute will take about two hours. The whole data collection will take place outside of ordinary class room hours.

I understand that I may refuse to allow my child to take part or withdraw my child at any time with no penalty to me or my child and this will not influence any further treatment that my child might need. I authorize Mr Hope Gangata to keep, use and dispose of the findings from this research with provision that my child's name will not appear. If any photographs which are taken, will illustrate a certain deformity of medical interest of the legs, the face will not be taken. I have been given the right to ask any questions and have been answered to my satisfaction. I have read and understood the contents of this form and have received a copy.

If you have any further enquiries or questions, please contact Mr Hope Gangata at the Human Biology Department at the University of Cape Town. The contact number is 0729541181 and email address is hopegata@yahoo.co.uk. This study has been approved by the Medical Research Ethics Committee of the University of Cape Town and if you are unhappy with anything related to the study you are welcome to contact the Chairperson of the Committee, Dr Marc Blockman at

Dr Marc Blockman
Faculty of Health Sciences
Research Ethics Committee
E52- 23 Old Main Building, Groote Schuur Hospital, Observatory ,7925
Tel: 27 21 4066492 Fax: 27 21 4066411

If you are happy to allow your child to take part in the study and if your child agrees to take part, please read and sign the attached consent form.

University of Cape Town

Appendix 5: Informed Consent Sheet.

Modified from the 'Sample consent form' in Currier (1990)

I understand the purpose of the study and what will be required of my child. I agree to let my child

Child's Name

take part in the research study. I understand that I have the right to withdraw my child from the study without giving reasons at any time.

Signed:

Child's Parent/Guardian's name

Signature

Date

Witness' name

Signature

Date

I have explained and described in detail the research procedure to which the subject and parent/guardian has consented to participate.

Researcher's name

Signature

Date

Appendix 6: Assent by the child

(For children over 8 years of age)

My name is Hope Gangata and I am studying at the University of Cape Town. I am trying to find out why children with problems with walking get stiff ankles.

I would like to test your muscles to see how strong your legs are and to measure your ankles and knees to see if they are able to move freely.

I would do some of these tests at your School and others at the Sports Science Institute in Newlands. I would take you and two of your class mates together. We will put wireless stickers on your legs and ask you to walk up and down while we take a video of your walking. Nothing will be painful but you will be asked to work hard so that we can measure your best work.

I will arrange a time with your physiotherapist to do these tests but it will not be during school time.

You do not have to take part in these tests if you do not want to. If you would like to, please make a mark below:

Child's name: _____

Child's mark. _____

Date _____

Appendix 7: Data collection sheet

1. Demographic Data

Name of Participant		Dates of Birth and of Assessment	
Diagnosis		Gross Motor Measure Classification score	
Height		Weight	

2. The measurements of impairments and the activity limitations

2.1 Equinus Ankle Angle

The patient will be lying in a prone position with the knee flexed to 90°. A weight of 1 kg will be strapped by tape across the foot sole at the level of the first metatarso-phalangeal joint to standardise the force applied across all subjects. One arm of the goniometre will be placed on the lateral side of the fifth metatarsal bone and the other arm on the lateral side of the fibula.

	30 sec stretch and 30 rest performed (Yes/No)	Weight strapped (Yes/No)	Equinus ankle angle
Right Ankle			
Left ankle			

2.2 Degree of Equinovalgus or Equinovarus (In standing)

	Right ankle	Left Ankle	
Tibiocalcaneal Angle value			

2.3 Hamstring length (In prone)

	Modified Popliteal R1 Angle	Modified Popliteal R2 Angle	
Right knee			
Left knee			

2.4 Lower limb lengths differences (Seated on carpet)

	Higher knee (R/L)	More anterior knee(R/L)	

2.5 Tautness of the tendon of the calcaneus (In standing)

Side of the tendon of the calcaneus	Very Taut	Mildly taut	Slack
R Medial Side			
R Lateral Side			
L Medial Side			
L Lateral Side			

2.6 Tautness of hamstrings (In prone lying)

Hamstring Side	Very Taut	Mildly taut	Slack
R Medial Side			
R Lateral Side			
L Medial Side			
L Lateral Side			

2.7 Level of Spasticity

R/L	Muscle under stretch	Modified Ashworth scale Score
R	Triceps surae	
L	Triceps surae	

2.8 Muscle Group strength

R/L	Muscle Group strength	Hand-held dynamometer Reading
R	Dorsiflexors	
L	Dorsiflexors	
R	Knee Flexors	
L	Knee Flexors	
R	Knee Extensors	
L	Knee Extensors	

3. Physiological Cost Index Data

Time taken to walk 100 metres	Total steps taken (for Cadence)	Rest Radial Pulse Heart rate (at 10 sec intervals)	Post-Exercise Radial Pulse Heart Rate (15 sec)
		Reading 1. Reading 2. Reading 3.	Reading at 0 sec. Reading at 5 sec. Reading at 10 sec.

Appendix 8: The Modified Ashworth scale

0. No increase in muscle tone
1. Slight increase in tone with a catch and release or minimal resistance at end of range
2. As 2 but with minimal resistance through range following catch
3. More marked increase tone through ROM
4. Considerable increase in tone, passive
5. Affected part rigid

University of Cape Town

Appendix 9: Gross Motor Function Classification System levels for Children with Cerebral palsy between the Ages of 6 and 12 years.

Adopted from Rosenbaum et. al., 2002.

Level I

Walks without restrictions; limitations in more advanced gross motor skills

Level II

Walks without assistive devices; limitations in walking outdoors and in the community

Level III

Walks with assistive mobility devices; limitations in walking outdoors and in the community

Level IV

Self-mobility with limitations; children are transported or use power mobility and in the community

Level V

Self-mobility is severely limited even with the use of assistive technology

2 to 20 years: Boys

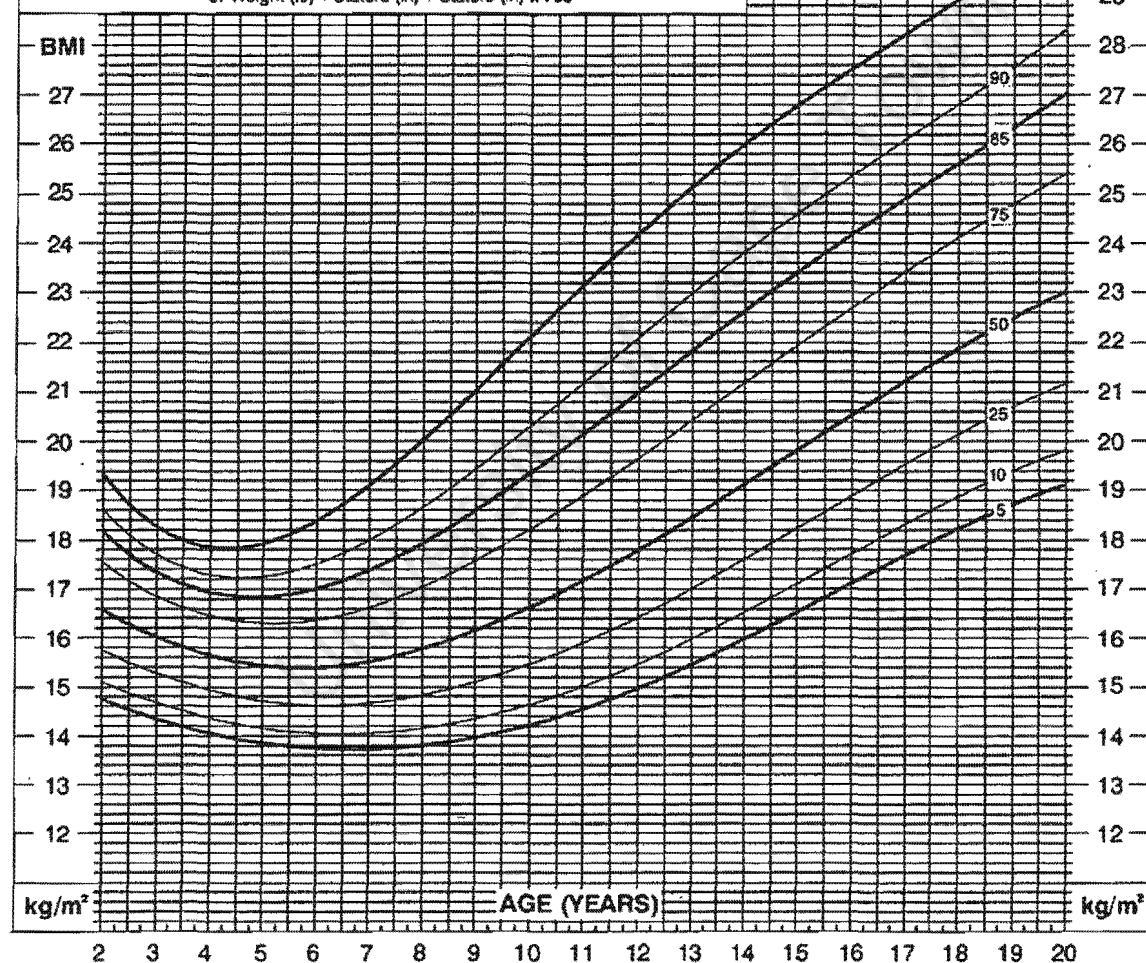
Body mass index-for-age percentiles

NAME _____

RECORD # _____

[illegible]

*To Calculate BMI: Weight (kg) ÷ Stature (cm) ÷ Stature (cm) x 10,000
or Weight (lb) ÷ Stature (in) ÷ Stature (in) x 703



Published May 30, 2000 (modified 10/16/00).

SOURCE: Developed by the National Center for Health Statistics in collaboration with the National Center for Chronic Disease Prevention and Health Promotion (2000). <http://www.cdc.gov/growthcharts>



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Appendix 11: The Body mass index-for-age percentiles for girls

2 to 20 years: Girls

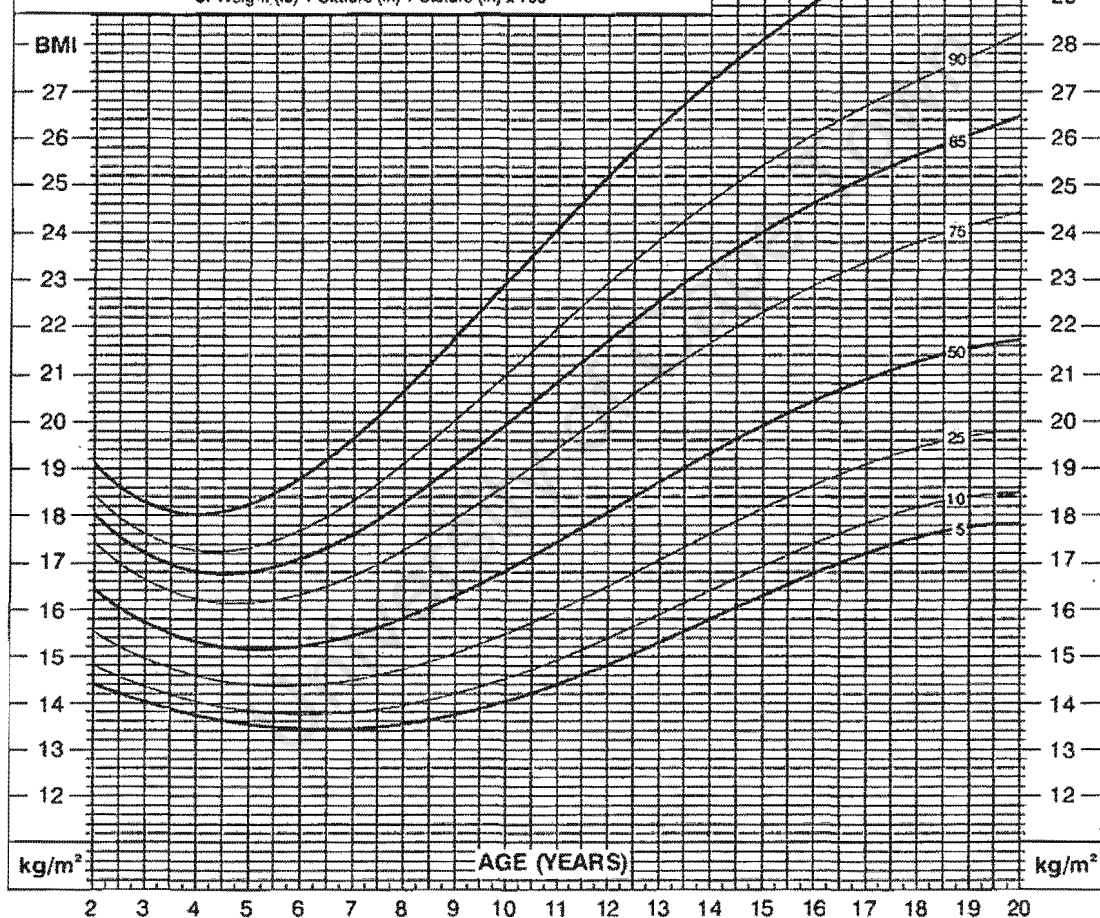
Body mass index-for-age percentiles

NAME _____

RECORD # _____

[illegible]

*To Calculate BMI: Weight (kg) ÷ Stature (cm) ÷ Stature (cm) x 10,000
or Weight (lb) ÷ Stature (in) ÷ Stature (in) x 703



Published May 30, 2000 (modified 10/16/03).

SOURCE: Developed by the National Center for Health Statistics in collaboration with the National Center for Chronic Disease Prevention and Health Promotion (2000). <http://www.cdc.gov/growthcharts>



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9 Reports of the External Examiners

First External Examiner

Professor Cristian Stefan
Associate Professor
Academy of Medical Education
Program Leader for the Neuroscience and Imaging in
Medical Education
United States of America

20-MAY-2008 09:22 FROM HSF Student Admin UCT

TO ADRI WINCKLER

P.05



May 12, 2008

Written Report Re:

Dissertation: An investigation into the parameters related to the equinus ankle in children with hemiplegic and diplegic forms of cerebral palsy
Mr. H. Gangata (GNGHOP001)

Supervisors: Associate Professor G. Louw and Associate Professor J. Jelsma
Department of Human Biology, Faculty of Health Sciences
University of Cape Town
South Africa

The subject of Mr. H. Gangata's dissertation is a significant one. Anyone who had the opportunity of examining or at least seeing children with cerebral palsy (CP) would endorse this statement without hesitation. Those who work with children affected by CP or have one child with CP in their family would appreciate even more the significance of any additional research in this field. As the candidate noted on page 5, "the success rate of treatment of the equinus deformity or posture has not been satisfactory, especially in the long term". Mr. Gangata correctly identifies some of the major problems that underlie this unsatisfactory outcome, which include: the lack of standardization of the equinus ankle assessment; treating patients with diplegia and hemiplegia as a homogenous group; and the occurrence of irreversible defects as a result of under-correction or over-correction interventions.

The dissertation is adequately structured and the chapters are balanced. The objectives of the study are well defined and usefully grouped in order to facilitate the collection of data and interpretation of results. Ethical issues related to human subjects research were taken into consideration and the proper procedures were observed.

C. Stefan, MD -- Report Re: Mr. H. Gangata's Dissertation (GNGHOP001)

Page 1

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One of the main strengths of the dissertation resides in the fact that the concepts, procedures and results are clearly presented, in a format that is easy to follow. At the same time, the subject is approached in a logical manner and follows the steps of proper clinical reasoning. Emphasis is placed on the practical relevance of the study, with direct implications regarding the short and long-term medical care of these children.

The literature review is comprehensive and generally up to date. The candidate demonstrates a solid understanding of the topic and the necessary knowledge and ability to collect, select, analyze and synthesize a large amount of information. Tables 1 (pp. 11-12) and 2 (pp. 13-14) are particularly useful as a concise presentation of key references. In addition, Table 2 provides evidence that, indeed, many previous publications in the field studied either patients with hemiplegic CP or diplegic CP, not both.

Mr. Gangata's presentation of regional normal anatomy and biomechanics is precise and didactic. He uses it as a starting point to progressively introduce and explain the abnormal features associated with equinus ankle and the clinical measurements used in these patients.

The candidate employs multiple methods to evaluate the biomechanical parameters and functional range of movement in the two groups of children. He has to be commended for paying a great deal of attention to each of these methods and recognizing their utility and significance. Another positive aspect is represented by the attention paid to the medical history and physical examination of the children (requiring good observational skills) in addition to the measurements per se.

It could be argued, as it often seems to be the case, that the number of children in each group could have been larger. This aspect is recognized by the candidate as well (pp. xiv, 37, and 101). Nevertheless, for the extent and purpose of this dissertation, the sample size appears adequate. In fact, it was comparable with other studies. Credit has to be given to the fact that appropriate and well defined screening inclusion/exclusion criteria were used. They resulted in the selection of a larger group of 45 children. However, only 30 parents or guardians complied in returning the completed informed consent forms.

The presentation of results greatly benefits from the clear tables and figures. A consistent graphic format adds to brevity and clarity. The statistical analysis of data is appropriate and the summary of results (pp. 81-82) is accurate.

The discussions indicate an objective, correct and at the same time cautious (when appropriate) interpretation of data. Mr. Gangata correlates well the theoretical concepts and data from the literature with his own findings and observations in a way that makes sense and opens the door to useful possible therapeutic implications. He highlights a number of significant differences between the two groups of children and discusses the relation between these features and the energy demands of walking.

C. Stefan, MD - Report Re: Mr. H. Gangata's Dissertation (GNGHOP001)

Page 2

One of the most important issues that emerges from the dissertation's discussions and conclusions is the need to accurately evaluate the disability before initiating a treatment plan. Moreover, the candidate emphasizes the need to prioritize the goals in managing children from the two groups, according to their particular problems. The recommendations made by Mr. Gangata in this respect are very practical and could have indeed a significant influence on the further treatment protocols specifically designed for children with diplegia and hemiplegia.

Consistent with the ethical approach he demonstrates in his work, the candidate cautions that the observations and conclusions deriving from his dissertation should be further tested and they should be applied only to children with spasticity that is similar to the children included in the study (as they presented with mild disabilities). This does not diminish the value of the study and its conclusions, especially in the view that children with mild disabilities would be even better candidates for improving their gait under an appropriate and timely instituted medical management.

Mr. Gangata's dissertation represents a step forward in the understanding of the equinus ankle associated with cerebral palsy. It advances the knowledge in this field and is based on original work in addition to a substantial literature review. It also has an educational value as it could help others (students, health care providers and to a certain extent family members) better understand this condition and provide better support and care to the children affected by it. Subsequently, it is recommended that this study should be adapted as an article and submitted for publication in a specialty journal in the fields of physical therapy, clinical anatomy or neurology.

Based on all of the above considerations, I highly recommend that the MSc (Med) in Anatomy degree be awarded with distinction to Mr. H. Gangata.

Report prepared and respectfully submitted by external examiner

Cristian Stefan, MD

~~Associate Professor, Academy of Medical Educators~~

~~Program Leader for Neuroscience and Imaging in Medical Education~~

C. Stefan, MD – Report Re: Mr. H. Gangata's Dissertation (GNGHOP001)

Page 3

Second External Examiner

Professor Narusha Lachman
Department of Anatomy
College of Medicine
Mayo Clinic
United States of America

20-MAY-2008 09:21 FROM HSF Student Admin UCT

TO ADRI WINCKLER

P.02

EXAMINER'S REPORT

Candidate: Mr H.Gangata (GNGHOP001)
Degree: MSc(Med) in Anatomy
Department: Human Biology
Title: An investigation into the parameters related to the equinus ankle in children with hemiplegic and diplegic forms of cerebral palsy

RELEVANT LITERATURE

The candidate has done a good review of the literature with an impressive list of referenced articles. The review appears to be up to date and covers a wide range of resources. The presentation of this chapter may be enhanced by the inclusion of more images to demonstrate the descriptions eg. (equinus ankle deformity)

RESEARCH METHODS

Research methods have been clearly demonstrated and appear to be scientifically sound. It is suggested that the section on "ethical considerations"(3.2) be moved to a point earlier in the chapter instead of appearing at the end (*since this was one of the first questions I asked after reading the introductory paragraph in chapter 3*).

The statistical tools have been correctly chosen and properly applied.

INTERPRETATION

The candidate has demonstrated a clear understanding of the topic at hand and correctly interpreted the data. Although with the excessive use of abbreviations, the dissertation was somewhat difficult to read, the candidate has managed to maintain a flow throughout the discussion that demonstrates the necessary research skills at a Master's level.

In spelling out the limitations of this study, the candidate has clarified some of the major questions that had come up during evaluation of this dissertation. It is indeed unfortunate that the sample size was restricted, but in any live subject study, and especially one of this nature, such limitations are to be expected. Indeed, the candidate has managed to verify the findings statistically, therefore supporting the scientific merit of this research. However, the relatively low sample size does make it an issue for solid recommendations and in view of this it would be integral to the progress of this area of research for this work to be on-going.

PRESENTATION

The dissertation is well presented and neatly set out. However, I have highlighted editorial errors and recommendations for implementation. I have marked these on the dissertation for easier access and integration (dissertation will be posted back to examination office)

ORIGINALITY OF WORK

Although other studies have been published in this area of research, the candidate has shown originality in his ideas and in the methodology employed.

RECOMMENDATION

I recommend that the candidate be awarded the Master of Science (Med) in Anatomy.

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