Effect of a rigid ankle–foot orthosis on hamstring length in children with hemiplegia

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Eighteen children with hemiplegia, mean age 8 years 5 months, underwent gait analysis and musculoskeletal modelling using specially designed software. The maximum lengths of the hamstrings were determined for each child walking in and out of an ankle–foot orthosis (AFO). The muscles were deemed to be short if shorter than the normal average – 1SD. In bare feet 8 participants had short medial hamstrings with a higher proportion of these in the less involved individuals. All participants showed an increase in maximum hamstring length when wearing an AFO. In all but one child this was sufficient to restore hamstring length to within normal limits. These finding suggest that hamstring pathology in hemiplegic gait is usually secondary to more distal lower limb pathology.

Hemiplegia is one of the most common forms of cerebral palsy (CP) in Northern Ireland, constituting 38% of all those on the Northern Ireland Cerebral Palsy Register (Parkes et al. 1997). The typical findings during gait analysis include internal rotation of the lower limb and an equinus deformity of the ankle often in association with either hyperflexion or recurvatum at the knee (Hoffer 1976). Two different classification systems for hemiplegia have been proposed (Winters et al. 1987, Hullin et al. 1996). The gait classification system of Winters and colleagues (1987) has been more widely recognized and classifies the patterns of involvement into four different types on the basis of joint kinematics (Table I).

Most children with hemiplegia will benefit from the use of an orthosis but its role will differ depending on the type. Those with type I hemiplegia (the mildest form) require an orthosis primarily to assist the dorsiflexors in preventing foot drop during swing. However, those with type II hemiplegia require a device capable of controlling the equinus through stance and swing. Individuals with type IIIa require a device that will facilitate a heel contact and the development of an external knee extension moment. Those with type IIIb require a device that will resist the excessive external knee extension moment, which is pushing the knee into hyperextension. The proximal involvement in those with type IV hemiplegia may limit what can be achieved by orthoses. Individuals with type III and IV may often also have significant fixed contractures of the tendo Achilles, which cannot be controlled by an ankle–foot orthosis (AFO). The AFO also has the potential to support deformities of the foot. Despite the different requirements for the orthosis presented by the different types of hemiplegia it has been proposed that they can all be satisfied by the prescription of a rigid AFO cast in neutral or a mild degree of dorsiflexion (or the minimum plantarflexion that can be accommodated with regard to fixed contractures).

While the aims of the orthotic management of children with hemiplegia are clear, there is little evidence to prove the effectiveness of the treatment (Rowley 1998). Simon and coworkers (1978) showed that fixed AFOs may produce a long-lasting effect in correcting genu recurvatum in individuals with hemiplegia, possibly on the basis of motor learning. Rosenthal (1984) has shown that a stiff polypropylene AFO keeping the ankle in 5° of dorsiflexion may improve the gait of patients with CP who have genu recurvatum. Harrington and colleagues (1984) demonstrated that the use of a rigid AFO may produce a subjectively improved gait pattern in those with CP. Meadows (1984) demonstrated that the action of the ground reaction force at proximal joints can be modified by the use of an AFO and conjectured that this would influence the action of muscles about these joints. Recently, Buckon and colleagues (2001) compared the effects of the hinged ankle–foot orthosis (HAFO), posterior leaf spring (PLS), and solid ankle–foot orthosis (SAFO) in improving gait efficiency of children with spastic hemiplegia. They concluded that greater improvements were observed in functional mobility in the use of HAFO and PLS (Buckon et al. 2001).

In recent years computer models of the lower limb allowing the estimation of musculotendinous unit lengths (MUL) have been developed (Delp et al. 1990). Such models have been used to challenge a conventional understanding of muscle pathology in CP. For example, crouch gait patterns in diplegia have often been attributed to tightness in the hamstrings. Delp and coworkers (1996) showed that when the effect of hip as well as knee flexion is considered, most patients actually had longer hamstrings than a normally developing control group. It is often unclear whether abnormal patterns of movement in proximal muscles are a consequence of pathological function of these muscles or are a consequence of more distal pathology. If these patterns of movement become more normal as a result of AFO use then this is strong evidence that the pathology is indeed distal. The aim of this paper is to use muscle-length modelling as a tool for investigating whether proximal muscle function in hemiplegia is modified by AFO use.

Table I: Classification of hemiplegic gait according to Winters and colleagues (1987)

Type I	Ankle equinus in the swing phase of gait due to under-activity of the ankle dorsiflexors in relation to the plantarflexors.
Type II	Plantarflexion throughout stance and swing from either static or dynamic contracture of the triceps surae. Knee is often forced into slight hyperextension in middle or late stance.
Type III	Findings of type II with reduced range of knee flexion/extension. Reference is now common to sub-types IIIa: reduced knee extension during stance, and IIIb: hyperextension in stance and reduced flexion in swing.
Type IV	Findings of type III with involvement of the hip musculature. In the original paper, in which measurements were restricted to the sagittal plane, this was attributed to flexor and adductor involvement. A 3D analysis would almost certainly have included increased internal rotation.

Method

PARTICIPANTS

The study group consisted of 18 individuals with hemiplegia, comprising 8 females and 10 males, mean age 8 years 5 months (range 5 years 8 months to 11 years) all of whom usually walked wearing a rigid polypropylene AFO. Control groups comprised age-and sex-matched children for musculoskeletal modelling and adult kinematic control data was used because the SDs of non-disabled children were too great.

AFOs were custom made for each individual using 3 mm thick polypropylene which was vacuum moulded from a plaster cast of the lower leg. The trim lines extended to the mid point of the malleoli. A typical AFO worn by the patients in this study is shown in Figure 1.

All of the children had a diagnosis of CP and were community ambulators even without their AFOs. The AFOs that our

Figure 1: *A typical rigid ankle–foot orthosis.*

Figure 2: *Software for Interactive Musculoskeletal Modelling.*

patients used provided a small degree of medial–longitudinal support and held the ankle in a mild degree of dorsiflexion, using a three-point pressure system to control movement. Four patients had a history of tendo Achilles lengthening surgery, five had a history of previous foot surgery, and five had a history of previous botulinum toxin A (BTX-A) injection of their gastrocnemius or hamstrings (but none within 6 months of taking part in this study). The kinematic data resulting from gait analysis were used to categorize the children into the different types outlined in the introduction (see Table I). The data from 10 normally developing adults were used to provide comparative kinematic data.

GAIT ANALYSIS

Each child had gait analysis using a six camera Vicon 370 system (Oxford Metrics, Oxford, UK). Fifteen markers were placed on the child as required for the use of the Vicon Clinical Manager software (two of these are only placed for static tests). The system incorporates two AMTI strain gauged force platforms (Advanced Mechanical Technology Inc, Watertown, MA, USA).

Children were first assessed in bare feet. A static trial was captured with the heel markers in place. The heel markers were then removed and the child was asked to walk several times up and down the walkway. Three walks during which the child made clean contact with both force platforms were selected for further analysis. AFOs and shoes were then worn and the procedure repeated. Toe, ankle, heel, and tibial markers had to be replaced when the child was wearing an AFO. Particular care was taken, however, not to alter the positions of the other markers during the changeover.

All analysis was performed using the Vicon Clinical Manager Software, which has been based on the biomechanical model proposed by Kadaba and colleagues (1990) and Davis and coworkers (1991). The measurements from the two force platforms were only used to define initial contact and toe off. Temporal/spatial parameters of the child's gait pattern were taken as output variables and the joint angles calculated by the software used as the input for the muscle-length modelling. Pathological gait data were compared with the averaged data of 10 normally developing adults (Table II).

MUSCLE-LENGTH MODELLING

The kinematic data for each participant was then processed using Software for Interactive Musculoskeletal Modelling (SIMM, Musculographics, Evanston, IL, USA; Fig. 2). The computer model used in this study was developed by Delp (1990). Measurements of muscle length were based on the assumption that the length of the muscle could be estimated by finding the total length of a number of straight line segments between points fixed with reference to the moving axis systems of the bones. The coordinates defining these points have been taken from previous literature as outlined by Delp and his coworkers (1996) and were used in an unmodified form for this study. The hip has been modelled as a ball and socket joint. The model of the knee has been based on the work of Yamaguchi and Zajac (1989) and accounts for the translation of the tibiofemoral joint and movement of the instantaneous centre of rotation as a function of knee flexion. It is necessary to normalize muscle-length measurements in some way to the participant's height. Effectively a skeleton of adult proportions is moved to the position specified by the joint angles derived from the child's gait analysis data. Muscle lengths are then calculated as a percentage of muscle length in the anatomical position. This effectively normalizes the data for height and allows comparison between data

Table II: Mean (SD) for all those with hemiplegia grouped together and type I patients

Type	*Normally developing*	*All*			*Type I*		
		Barefoot	*AFO*	*Difference*	*Barefoot*	*AFO*	*Difference*
Cadence/min	N/A[d]	69 (6)	66 (6)	**–3[a]**	66 (6)	63 (4)	–3
Velocity, m/s	N/A[d]	2.2 (0.4)	2.4 (0.2)	**0.3[b]**	1.9 (0.4)	2.3 (0.2)	0.3
Mean anterior pelvic tilt, °	10 (4)	14 (4)	16 (5)	**1.6[a]**	12 (4)	13 (3)	**1.4[a]**
Max. anterior pelvic tilt, °	11 (4)	17 (5)	20 (4)	**2.5[a]**	14 (4)	16 (4)	**2.1[a]**
Affected limb							
Step length, mm	N/A[d]	453 (60)	538 (68)	**105[c]**	446 (84)	546 (78)	**100[b]**
Knee flexion at initial contact, °	12 (3)	20 (10)	16 (8)	**–3.9[a]**	16 (6)	12 (7)	**–4.0[a]**
Min. knee flexion in stance, °	6 (3)	7 (9)	4 (6)	**–3.5[a]**	6 (2)	2 (5)	**–4.1[a]**
Ankle range of motion, °	25 (6)	23 (6)	16 (5)	**–6.6[c]**	25 (6)	18 (4)	**–7.0[a]**
Ankle dorsiflexion at initial contact, °	3 (3)	–1 (10)	13 (11)	**14.0[c]**	2 (1)	12 (7)	**10.5[a]**
Max. ankle dorsiflexion in stance, °	12 (5)	15 (10)	24 (11)	**9.0[c]**	21 (4)	25 (8)	4.0
MUL (affected limb), %							
Semimembranosus	106.8	106.1 (2)	107.6 (2)	**1.5[c]**	105.4 (2)	107.1 (1)	**1.7[b]**
Semitendinosus	104.3	105.4 (2)	106.9 (2)	**1.5[c]**	104.8 (2)	106.5 (1)	**1.7[b]**
Biceps femoris – long head	104.5	107.2 (2)	108.5 (1)	**1.3[c]**	106.1 (1)	107.6 (1)	**1.5[b]**
Rectus femoris	105.4	107.7 (1)	108.5 (1)	**0.8[c]**	107.9 (1)	109.0 (1)	**1.1[a]**
Iliopsoas	106.8	100.7 (1)	100.7 (1)	0	101.5 (1)	101.6 (1)	0.1

Differences between barefoot and AFO conditions are displayed in adjacent column. Minor discrepancies between this value and apparent differences in the printed figures are due to rounding of figures for presentation. All differences were analyzed using Wilcoxon's test for matched pairs. If that difference is statistically significant then it is printed in bold. MUL, musculotendinous unit lengths.
[a]$p<0.001$; [b]$p<0.01$; [c]$p<0.05$; [d]These parameters are highly dependent on stature and normative values are thus not relevant.

from adults and children.

The maximum and minimum MULs from three walks were calculated for each individual. Mean and standard deviation of the maximum length of semimembranosus, semitendinosus, biceps femoris, rectus femoris, iliacus, and psoas were then calculated for the control group. Dividing the averaged maximum length of the muscle by its length in the anatomical position normalized this data (Table III). For the children with hemiplegia the approach of Delp and colleagues (1996) was adopted in which a muscle was deemed to be short if its maximum length was more than 1 SD below the mean value obtained from the control group of 10 normally developing, age-matched children.

Results

Table IV shows descriptive statistics of children allocated to different groups on the basis of type of hemiplegia. None of the children exhibited type IV hemiplegia. As in many such studies numbers are small, particularly in the type III groups. Tables II and V show selected temporal/spatial parameters, kinematic parameters, and MUL estimates for all the participants grouped together and the participants grouped by type of hemiplegia.

The main differences observed in the entire study group in the temporal/spatial parameters when the children walked in their AFOs were significant increases in cadence, step length, and walking velocity with significant improvements in knee kinematics. At the ankle the expected decrease in ankle motion and significantly improved ankle dorsiflexion at initial contact and stance were observed (see Table II). Figure 3 illustrates the effect on maximum knee flexion and extension during stance; wearing an AFO 'normalizes' knee kinematics during stance. Those participants who demonstrated knee recurvatum or knee hyperflexion in stance when walking in bare feet developed, respectively, improved knee flexion or extension when walking in their AFO. These findings were similar although less marked when considering children with type II and III hemiplegia on their own (see Table V).

Table VI indicates which muscle groups were assessed as being short for all participants together and each of the types separately. Because the modelling of semimembranosus and semitendinosus is virtually identical they are simply considered as medial hamstrings in this table. The model also assumes that the lumbar spine moves with the pelvis and thus iliacus and psoas are also modelled similarly and are considered here as the iliopsoas.

The main differences observed in the entire study group when the children were wearing an AFO in terms of maximum muscle length were significant increases in hamstring and rectus femoris maximum MUL (see Table II). In keeping with the temporal/spatial results these findings were similar although less marked when considering the children with type II and III hemiplegia on their own (see Table V).

Discussion

As in almost all similar clinical gait analysis studies, participant numbers were small. Statistically significant changes are observed for the group taken as a whole and for types I and II. No statistically significant changes were found in either of the type III groups. This pattern is commensurate with the statistical power of tests given the corresponding number of children in each group. The presence of statistical changes at all for types I and II, despite the small size of the groups, confirm the magnitude and clinical significance of those changes. But care is needed in generalizing any conclusions from such small groups to the wider population of children with hemiplegia. Care is also required when considering the results of multiple significance tests to avoid misinterpretation of both false positives and negatives. It can be seen from Tables II and V, however, that consistent patterns are present in the data giving confidence in the findings.

Table III: Normal values of maximum muscle length and excursion, derived from 10 non-disabled children

Muscle	*Maximum length (mm)*	*Excursion (mm)*	*Normalized maximum length*	*Normalized excursion*
Semimembranosus	433	53	1.043	0.127
Semitendinosus	488	59	1.043	0.127
Biceps femoris	460	51	1.045	0.115
Iliacus	456	58	1.109	0.141
Psoas	218	25	1.068	0.122
Rectus femoris	269	24	1.054	0.093

Table IV: Description of children allocated to different groups on the basis of gait kinematics

	All	*Type I*	*Type II*	*Type IIIa*	*Type IIIb*
n	18	7	5	3	3
Age, mean (y)	8.5	8.1	9.2	9.3	7.3
Age, range (y)	5.8–11.0	5.8–10.3	7.3–10.8	6.5–11	7.0–7.7
Tendo achilles surgery, *n*	5	0	3	1	1
Foot surgery, *n*	5	0	2	2	1
Botulinum toxin A, *n*	5	1	2	2	0

TYPE I HEMIPLEGIA

This was the largest single group in our study and the children generally displayed the characteristics identified by Winters and coworkers (1987). It is interesting, as this was the least involved group, that it exhibited the highest proportion of short hamstrings. This is because maximum hamstring length in non-disabled gait occurs at the end of swing when the hip is in maximum flexion and the knee in maximum extension. In those with type I hemiplegia the dorsiflexors can only function effectively if the mild tightness in the biarticular gastrocnemius is reduced by not fully extending the knee. This will reduce the distance between the origin and insertion of the hamstrings resulting in a 'short' muscle even though the hamstrings are not functioning pathologically. Wearing an AFO, which holds the ankle in a dorsiflexed position, allows the knee to fully extend and hence leads to longer hamstring muscle lengths. The shortness of the rectus femoris is probably a consequence of reduced knee flexion in swing although, again, it is not clear that this is indicative of primary pathology in the function of the rectus femoris. The iliopsoas was not short in any patient in this group reflecting only a mild increase in pelvic tilt.

TYPE II HEMIPLEGIA

This group did not show the characteristic pattern described by Winters and coworkers (1987). In particular they did not show the tendency to knee hyperextension. This is probably a consequence of the proportion of children who had undergone previous orthopaedic procedures. The group showed less extension at initial contact and during stance than in type I and marked plantarflexion at initial contact. Both are probably a consequence of increased tightness in the gastrocnemius. Despite this there was actually a smaller proportion of children showing short hamstrings in this group which may be a consequence of their increased pelvic tilt. Three out of five participants thus showed short iliopsoas muscles. Use of the orthosis led to an improvement in knee and ankle kinematics but not in pelvic tilt, suggesting that the increased pelvic tilt is not a consequence of distal pathology. The net effect of changes at the hip and knee was to bring the hamstrings maximum muscle lengths within normal range.

Table V: Mean (SD) data for type II, IIIa, and IIIb patients

Category	*Type II*			*Type IIIa*			*Type IIIb*		
	Barefoot	*AFO*	*Difference*	*Barefoot*	*AFO*	*Difference*	*Barefoot*	*AFO*	*Difference*
Cadence/min	69 (3)	68 (5)	–1	77 (2)	69 (1)	–9	72 (8)	70 (12)	2
Velocity, m/s	2.2 (0.3)	2.4 (0.2)	0.3	2.4 (0.2)	2.7 (0.1)	0.2	2.2 (0.3)	2.4 (0.4)	0.2
Mean anterior pelvic tilt, °	16 (6)	17 (5)	1.9	15 (2)	18 (4)	2.7	18 (4)	18 (4)	0.5
Max. anterior pelvic tilt, °	19 (6)	21 (6)	1.7	18 (3)	21 (4)	3.2	21 (3)	22 (3)	1.0
Affected limb									
Step length, mm	439 (44)	510 (43)	**71[a]**	479 (61)	581 (62)	102	470 (122)	524(95)	54
Knee flexion at initial contact, °	25 (13)	19 (8)	–5.9	28 (2)	15 (4)	–12.8	11 (4)	20 (10)	8.2
Min. knee flexion in stance, °	16 (10)	12 (12)	**–3.5[b]**	18 (1)	10 (3)	–7.6	–4 (2)	3 (4)	6.7
Ankle range of motion, °	20 (6)	15 (3)	**–5.0[a]**	22 (4)	18 (7)	–4.4	23 (10)	11 (4)	–12.0
Ankle dorsiflexion at initial contact, °	–6.9 (3)	10 (6)	**16.8[a]**	–4 (11)	24 (20)	28.0	–14 (3)	7 (9)	21.0
Max. ankle dorsiflexion in stance, °	5 (5)	21 (8)	**15.6[a]**	25 (9)	34 (16)	9.0	5 (7)	15 (9)	9.7
MUL (affected limb), %									
Semimembranosus	106.0 (2)	107.7 (2)	**1.7[a]**	105.6 (1)	108.0 (1)	2.4	107.8 (1)	108.0 (2)	0.2
Semitendinosus	105.5 (2)	107.0 (2)	**1.5[a]**	104.9 (1)	107.6 (2)	2.7	107.0 (1)	107.2 (3)	0.2
Biceps femoris – long head	107.4 (2)	109.0 (2)	**1.6[a]**	106.9 (1)	109.2 (1)	2.3	108.0 (1)	108.5 (2)	0.5
Rectus femoris	107.0 (2)	108.0 (1)	**1.0[a]**	108.5 (1)	108.1 (2)	–0.4	107.0 (1)	108.4 (1)	1.4
Iliopsoas	101.0 (1)	101.0 (2)	0.2	100.0 (2)	100.0 (2)	0.0	101.6 (1)	103.0 (1)	1.4

Differences between barefoot and AFO conditions are displayed in adjacent column. Minor discrepancies between this value and apparent differences in printed figures are due to rounding of figures for presentation. All differences were analyzed using Wilcoxon's test for matched pairs. If that difference is statistically significant then it is printed in bold. MUL, musculotendinous unit lengths.
[a]$p<0.001$; [b]$p<0.01$.

Table VI: 'Short muscles': muscle groups with a maximum MUL more than 1SD below mean MUL for normally developing individuals

Muscle group	*All (n=18)*		*Type I (n=7)*		*Type II (n=5)*		*Type IIIa (n=3)*		*Type IIIb (n=3)*	
	Bare foot	*AFO*	*Bare foot*	*AFO*	*Bare foot*	*AFO*	*Bare foot*	*AFO*	*Bare foot*	*AFO*
Medial hamstrings	8	1	5	0	2	0	1	1	0	0
Lateral hamstrings	7	2	3	0	1	0	1	1	1	1
Rectus	9	2	3	0	3	0	0	0	3	2
Iliopsoas	5	4	0	0	3	2	2	2	0	0

TYPE III HEMIPLEGIA

As with type II, the children in the type III group did not show exactly the patterns described by Winters and colleagues (1987) and this is, again, probably attributable to the effects of previous surgery. Analysis of both group IIIa and IIIb showed just one of three children to have short hamstrings on the basis of the criteria specified. In both groups anterior pelvic tilt is pronounced. Delp and colleagues (1996) observed that children with diplegia do not exhibit short hamstring despite pronounced knee flexion because this is accompanied by increase pelvic tilt and hip flexion. These data suggest the same may be true for children with type III hemiplegia. There is no significant difference in hamstring length between the two types despite markedly different knee kinematics. This again reinforces the importance of hip joint position in determining hamstring length. The combination of extended knees and an anteriorly tilted pelvis led to short rectus femoris in all of the three children with type IIIb.

The effect of the AFO on the two types is different. In type IIIa the effect of the AFO is to increase knee extension at initial contact leading to increases in hamstring length. Excessive dorsiflexion is observed during stance suggesting either AFOs cast incorrectly or, more likely, that the AFO is buckling. In these individuals the AFO is resisting a considerable dorsiflexion moment during stance (it is functioning similarly to a anterior ground reaction orthosis), and particular care is required to ensure that the device is stiff enough. In type IIIb gait there is a tendency to hyperextend and the orthosis, which is acting to resist this, leads to increased flexion and hence has a greater effect on increasing the length of the muscles of the anterior thigh. Despite this, however, two children still had short rectus femoris with AFOs. It is clear that while the AFO helps these children it does not result in a normal gait pattern.

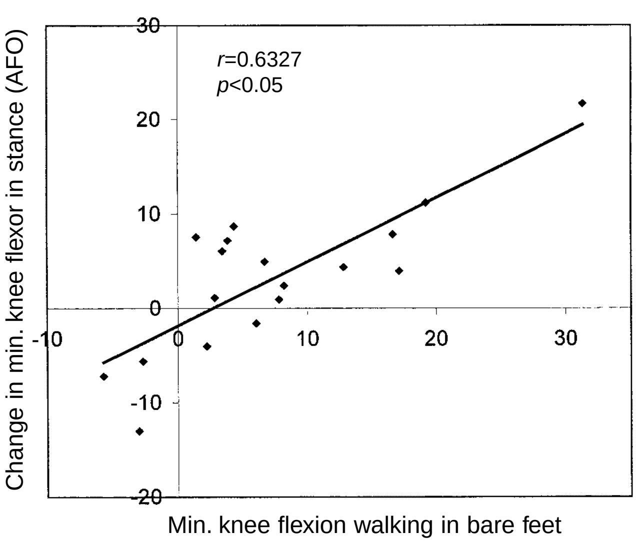

Figure 3: *Change in minimum knee flexion during stance (AFO) compared with minimum knee flexion in stance when walking in bare feet.*

ALL PARTICIPANTS

It is clear from Table III that AFO use does lead to differences in gait pattern which are both statistically and clinically significant. Figure 3 shows a strong correlation between the amount of knee flexion in barefoot walking and the change in knee flexion brought about by the use of an AFO. Use of the AFO tends to reduce excessive knee flexion and, in the three children exhibiting recurvatum, limits excessive hyperextension.

Hamstrings were found to be short in only eight out of 18 participants and the majority of these were of the milder types I and II. Some caution is needed in making clinical inferences from muscle length data. Just because a muscle is short does not mean it is tight (much less that it is spastic) and just because it is of adequate length does not mean it is functioning normally. Use of an AFO led to increased muscle length of the hamstrings, however, and this is strong evidence that the hamstrings are short during gait as a consequence of distal pathology, which is directly affected by the device, and not because of any intrinsic pathology of the muscle.

LIMITATIONS

The approach developed for this study has a number of limitations. The system used to classify patients with hemiplegia into five different types is based on patterns observed in persons with hemiplegia with no previous surgical intervention (Winters et al. 1987). Nearly a third of children in this cohort had a history of previous calf surgery and a similar number of foot surgeries. Although it was possible to assign all participants one of the types, some did not exhibit all the features of the gait patterns as described. Children with type II gait did not show the same tendency to knee hyperextension and type IIIa patients showed quite marked ankle dorsiflexion in stance. Both of these findings might be expected given the previous surgical history of these individuals. Care is thus needed in using this classification in those who have had previous orthopaedic surgery.

Muscle-length modelling has all been carried out using a standard skeleton and does thus not account for any musculoskeletal abnormalities in these individuals. Care was taken not to displace markers on the pelvis, thigh, or knee while wearing orthoses and shoes. Inevitably tibia and ankle markers needed to be replaced during this process but small changes in the placement of these markers would not be expected to have a large effect on the calculation of the thigh muscle length. Markers on the barefoot and those on the shoe were not considered equivalent and it is for this reason that no modelling of gastrocnemius or soleus length was attempted.

The use of comparative data from adults is not ideal. However, Sutherland in a recent review (1997) has confirmed the findings of the earlier work of his own group (Sutherland et al. 1988), that mean joint kinematics for children over the age of 4 years are not significantly different from those of adults. There are no explicit data on muscle-length estimates but as these are mathematical functions of joint kinematics it does not seem unreasonable to assume the same independence of age.

Perhaps the biggest limitation of the methodology is the comparison of barefoot walking without orthoses to walking in shoes with orthoses. There has been little previous work on the effect of shoes on the gait patterns of children with CP.

The shoe is integral to the function of the orthosis and thus a more valid comparison for future work might be to compare walking in shoes with and without orthoses. Both shoe and orthosis could affect balance in both standing and walking which may explain some of the changes noted above.

Conclusion

This study has demonstrated that pathological gait patterns in CP are reflected in measurements of maximum muscle length during the gait cycle. Due to the increased pelvic tilt in more severely involved children the hamstrings were more likely to be short in the less involved individuals. It has also established that where shortness is observed it is markedly reduced by use of an AFO. Overall, the findings suggest that hamstrings tightness may be less of a factor in pathological gait in hemiplegia than has often been assumed. As Delp and coworkers (1996) and Thompson and colleagues (1998) found for those with diplegia who have crouch gait, the hamstrings are rarely short in more severely involved persons with hemiplegia. Where it is encountered, in less involved individuals, it is largely corrected by use of an AFO. It is thus probably a consequence of poor distal control and not, primarily, of pathology of the muscle itself.

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