Local and distant effects of isolated calf muscle lengthening in children with cerebral palsy and equinus gait

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Abstract

Purpose The purpose was to assess the local and distant effects of isolated calf muscle lengthening in ambulant children with cerebral palsy.

Methods The study included fifteen ambulant children with cerebral palsy (nine with diplegia and six with hemiplegia), average age 8.8 years, Gross Motor Function Classification System (GMFCS) level I and II. None of the children had previously undergone orthopaedic surgery, apart from one child who had tendo-achilles lengthening (TAL) nine years earlier. All the children underwent pre and post-operative clinical examination and three-dimensional gait analysis (gait analysis). Twenty calf muscle lengthenings were performed, ten TAL and ten gastrocnemius recessions (GR).

Results Post-operative ankle kinematics showed significant improvements in all parameters. Ankle power during push-off increased, but only significantly after TAL. Only one limb (5%) was over-corrected. Four limbs (20%) were under-corrected and one of these limbs remained in mild equinus position in stance. There was one recurrent equinus (5%) during the follow-up period of three years (range: 13–55 months). Distant effects on joints and segments were more marked in diplegia than in hemiplegia. Ten of 17 kinematic parameters distant from the ankle joint improved significant post-operatively when the

preoperative values were 1SD below or above the mean of the normal material. There was no significant deterioration in any of the measured parameters.

Conclusion The improvement in ankle kinematics and kinetics supported the experience of other studies. The distant effects, which have previously not been evaluated in three planes, showed improvement in several kinematic parameters indicating that additional surgery in selected patients could be abandoned or delayed.

Keywords Calf muscle lengthening · Cerebral palsy · Gait analysis

Introduction

Equinus deformity caused by contracture of the triceps surae is the commonest orthopaedic deformity in cerebral palsy [1] and adversely affects gait. In children with static contractures, lengthening of the calf muscle is required to allow for an appropriate range of motion and improved kinematics during functional activities such as gait. Two commonly performed operations for equinus deformity are tendo-achilles lengthening (TAL) and gastrocnemius recession (GR). Most studies comparing TAL and GR have reported improvements with each procedure [2, 3].

Calf muscle lengthening in combination with other orthopaedic surgical procedures are often undertaken to improve gait. In such multi-level surgery it is difficult to evaluate the contribution of the specific surgical procedures on the outcome. However, isolated calf muscle lengthening is sometimes performed in children with equinus gait and no other pronounced deformities. The aim of the current study was to evaluate this situation, asking the following questions:

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- 1 what are the local effects of isolated calf muscle lengthening;
- 2 what are the distant effects on other joints and segments than the ankle; and
- 3 is there any difference between hemiplegia and diplegia in postoperative results?

To our knowledge this is the first study where three-dimensional gait analysis (gait analysis) has been used to evaluate the entire limb in three planes including the pelvis after isolated calf muscle lengthening.

Patients and methods

This retrospective study included 15 ambulant children (seven females and eight males) with spastic cerebral palsy and isolated calf muscle lengthening. Six children had hemiplegia and nine children had diplegia. Only children with Gross Motor Function Classification System (GMFCS) [4] level I and II (walk independently without assistive devices) were included. Thirteen children were classified as level I and two as level II (spastic diplegia). Both children with hemiplegia and diplegia were classified according to their gait patterns [5, 6]. Four children with hemiplegia had true equinus (two type 2A and two type 2B) and two children had true equinus/jump knee (type 3). In the diplegic group five children had true equinus, three children had jump gait, and one child had an asymmetric gait. None of the children had previously undergone orthopaedic surgery on their lower extremities, apart from one child who had had TAL nine years earlier. None of the children had *Botulinum* toxin injections within 6 months prior to pre-operative gait analysis. The average age at the time of operation was 8.8 years (range 6–14 years). There was no significant age difference between children with hemiplegia and diplegia. The children were operated in the period March 2002–November 2005. Twelve of the 15 children were operated in our hospital by three different surgeons. The three other children were operated by co-operating surgeons using the same methods in three other hospitals.

All the children underwent pre and post-operative clinical examination and gait analysis including sagittal and coronal plane video recording, time and distance parameters registrations, and kinematic and kinetic data. The same multidisciplinary team (child neurologist, orthotist, physiotherapist, and orthopaedic surgeon) performed and assessed the pre and post-operative gait analyses during the whole study period. A 6-camera Vicon System (612) (Oxford Metrics, Oxford, UK) and two AMTI force plates (Advanced Mechanical Technology, Watertown, MA, USA) were used to collect motion analysis data. The

average time between preoperative gait analysis and surgery was five months (range 2–10 months) and the mean time between operation and post-operative gait analysis was 14 months (range 11–18 months).

To compare kinematic and kinetic data obtained by gait analysis, a representative trial from each subject was selected for analysis. If all trials showed similar patterns based on visual evaluation of the plots, the initial trial was selected. If two of three trials were similar, the first trial (of the two) was selected [7].

The gait data were used to determine whether or not lengthening of the calf muscle was necessary, but not to decide which type of surgical procedure. The degree of passive dorsiflexion was used to determine whether GR or TAL was indicated. Children who had dorsiflexion to at least 0° with the knee flexed usually underwent GR, while those whose ankles could not be dorsiflexed to the neutral position with the knee flexed usually had TAL.

A total of 20 calf muscle lengthening procedures (10 TAL and 10 GR) were performed. In the hemiplegic group there were four GR and two TAL, and in the diplegic group six GR and eight TAL. Five of the children with spastic diplegia had bilateral procedures.

Gastrocnemius recession was performed with the child in the supine position. A longitudinal posterior incision somewhat medial to the midline over the middle of the calf was used. An inverted V-shaped incision in the aponeurosis of the gastrocnemius muscle was made. Then, if passive dorsiflexion did not reach 10° with extended knee, the underlying soleus aponeurosis was also incised.

TAL was performed through a longitudinal incision along the medial border of the achilles tendon. Open Z-lengthening was done and the tendon was repaired using absorbable sutures. It was aimed at suturing the tendon with appropriate length so that the ankle could be preoperatively dorsiflexed to 10° with straight knee. After both GR and TAL a short leg cast with the ankle in 0°–5° of dorsiflexion was applied for five weeks; thereafter an ankle–foot orthosis (AFO) was used for at least six months.

As a help in defining the indications for calf muscle lengthening, gait data from normal material was provided (Table 1). This consisted of 24 healthy children (11 females, 13 males) with a mean age of 9.8 years (range 5–15 years), who were examined in our gait laboratory. The children were recruited from parents working at the hospital. The range of normal variation was defined as mean $\pm$ 2 SD (standard deviation).

The paired samples *t* test was used to compare the pre and post-operative data. Twenty-three clinical, kinematic, kinetic, time, and distance parameters were selected for evaluation (Table 2). The significance level was set at $P < 0.05$.

Table 1 Pre-and post-operative results of 20 calf muscle lengthening procedures in 15 children and in a control group of 24 healthy children; mean (SD)

Parameter	Pre-operative mean (SD)	Post-operative mean (SD)	Mean difference	P value	Normal material (SD)
<i>Clinical examination</i>					
Ankle passive dorsiflex in knee 0°	−7.7 (10.0)	10.6 (9.3)	18.3	<0.001	
<i>Ankle joint</i>					
Ankle angle at initial contact (°)	−21.9 (8.8)	−7.0 (6.7)	14.9	<0.001	−2.2 (3.1)
Max ankle dorsiflex in st (°)	−6.0 (12.3)	10.9 (6.0)	16.9	<0.001	13.2 (3.9)
Tim max ankle dorsiflex in st (% GC)	15.9 (9.5)	33.8 (14.2)	17.9	<0.001	41.2 (7.6)
Max ankle dorsiflex in swing (°)	−21.9 (9.1)	−2.6 (5.8)	19.3	<0.001	2.9 (3.1)
Ankle power during push-off (watts/kg)	1.3 (0.8)	2.0 (0.6)	0.7	0.001	3.0 (0.9)
Ankle power after TAL	0.9 (0.6)	2.0 (0.7)	1.1	<0.001	
Ankle power after GR	1.8 (0.8)	2.0 (0.5)	0.2	0.283	
<i>Knee joint</i>					
Knee flexion at initial contact (°)	23.9 (9.0)	17.5 (7.2)	6.6	0.009	4.9 (4.5)
Minimum knee flexion in stance (°)	1.3 (10.7)	4.4 (6.3)	3.1	0.143	1.6 (4.4)
Max knee flexion in swing (°)	56.2 (8.9)	57.5 (8.6)	1.3	0.616	59.7 (4.8)
Tim max knee flexion in swing (% GC)	76.7 (4.4)	75.2 (4.4)	1.5	0.166	71.6 (2.5)
Knee range of motion (°)	54.9 (9.6)	52.9 (11.1)	2.0	0.430	59.9 (6.8)
<i>Hip joint</i>					
Max hip extension in st (°) ^a	−3.1 (9.5)	−5.8 (7.3)	2.7	0.091	−11.7 (6.4)
Max hip flexion in swing (°)	50.2 (7.2)	42.9 (5.9)	7.3	<0.001	36.4 (5.9)
Hip range of motion (°)	54.0 (10.1)	48.9 (8.1)	5.1	0.040	49.4 (5.6)
<i>Pelvis</i>					
Anterior pelvic tilt (°)	19.3 (4.7)	15.4 (4.8)	3.9	<0.001	11.9 (3.9)
Pelvic range of motion (°)	9.6 (6.3)	5.6 (3.2)	4.0	<0.001	4.3 (1.9)
Pelvic obliquity (°)	−0.7 (4.6)	−1.0 (2.3)	0.3	0.817	0.0 (1.7)
<i>Transverse plane^b</i>					
Pelvic rotation (°)	−4.7 (7.7)	−2.7 (5.9)	2.0	0.179	−0.2 (3.8)
Femur rotation in st (°)	4.5 (8.7)	0.1 (7.8)	4.4	0.066	0.5 (7.3)
Tibial rotation midstance (°)	−3.0 (10.0)	−7.0 (8.0)	4.0	0.126	−11.9 (7.2)
Foot progression in st (°)	10.5 (10.7)	5.2 (11.0)	5.3	0.026	−4.5 (6.7)
<i>Time and distance</i>					
Cadence (strides/min)	142 (20)	138 (17)	4.0	0.741	132 (24)
Stride length (cm)	101 (18)	105 (14)	4.0	0.050	117 (15)
Velocity (cm/s)	115 (24)	116 (22)	1.0	0.793	124 (15)

SD, standard deviation; dorsiflex, dorsiflexion; Max, maximum; st, stance; Tim, timing; % GC, percentage gait cycle; TAL, tendo-achilles lengthening; GR, gastrocnemius recession

^a Extension (−), flexion (+)

^b External rotation (−), internal rotation (+)

Results

Local effects in the ankle

The results are summarised in Table 1. There were significant improvements in passive ankle dorsiflexion and in all ankle kinematic parameters. The child who underwent TAL 9 years earlier and who now was reoperated (TAL), had satisfactory results similar to the 14 previously unoperated children. The mean maximum ankle dorsiflexion in stance improved 17° (from −6° to 11°) and the timing of maximum ankle dorsiflexion was corrected into the normal

range. Preoperative maximum ankle dorsiflexion in stance was considerably lower in ankles with TAL than GR (−14° vs. 2°). Although the correction was greater after TAL than after GR (22° vs. 11°), the postoperative maximum dorsiflexion was still lower in the ankles that had undergone TAL (8° vs. 13°).

Adequate correction was defined as mean maximum ankle dorsiflexion in stance of the normal material ± 2 SD (13° $\pm$ 8°). Results outside this range (below 5° or above 21°) were called under- or over-correction. Only one limb (after GR) was over-corrected (21.5°) and in this limb ankle push-off power was reduced from 3.2 to 2.1 watts/kg

Table 2 Pre and post-operative kinematic and kinetic results of calf muscle lengthening according to type of cerebral palsy (spastic hemiplegia and spastic diplegia)

Kinematic and kinetic parameters	Hemiplegia			Diplegia		
	Pre Mean (SD)	Post Mean (SD)	<i>P</i> value	Pre Mean (SD)	Post Mean (SD)	<i>P</i> value
Ankle angle at initial contact (°)	−19.6 (8.7)	−9.2 (5.4)	0.019	−23.0 (8.9)	−6.1 (7.1)	<0.001
Max ankle dorsiflex in st (°)	0.0 (6.9)	10.8 (4.1)	0.010	−8.7 (13.3)	10.9 (6.8)	<0.001
Tim max ankle dorsiflex in st (% GC)	19.6 (10.6)	37.4 (10.6)	0.019	14.3 (9.0)	32.3 (15.6)	0.001
Max ankle dorsiflex in swing (°)	−18.2(8.2)	−1.9 (5.2)	0.013	−23.5 (9.3)	−2.9 (6.2)	<0.001
Ankle power during push-off (watts/kg)	1.4 (0.5)	1.7 (0.4)	0.092	1.3 (0.9)	2.1 (0.6)	0.003
Knee flexion at initial contact (°)	22.1 (12.9)	15.4 (7.4)	0.137	24.7 (7.3)	18.4 (7.2)	0.041
Minimum knee flexion in st (°)	2.4 (9.8)	5.1 (5.2)	0.332	1.1 (11.4)	3.8 (6.8)	0.346
Max knee flexion in swing (°)	58.4 (3.8)	52.9 (12.6)	0.354	55.3 (10.3)	59.4 (5.9)	0.107
Tim max knee flexion in swing (% GC)	73.6 (3.9)	73.2 (2.9)	0.849	78.0 (4.1)	76.1 (4.7)	0.144
Knee range of motion (°)	56.7 (11.8)	46.9 (13.7)	0.163	54.1 (8.9)	55.4 (9.2)	0.552
Max hip extension in st (°) ^a	−1.2 (6.3)	−2.5 (9.0)	0.600	−3.9 (10.7)	−7.2 (6.3)	0.115
Max hip flexion in swing (°)	52.5 (3.4)	41.9 (5.8)	0.001	49.3 (2.2)	43.3 (6.1)	0.001
Hip range of motion (°)	55.0 (7.0)	47.4 (11.3)	0.095	53.6 (11.4)	49.5 (6.7)	0.192
Anterior pelvic tilt (°)	20.6 (4.9)	17.4 (6.5)	0.177	18.7 (4.7)	14.5 (3.8)	<0.001
Pelvic range of motion (°)	8.7 (3.3)	5.6 (6.9)	0.053	10.0 (7.3)	5.6 (3.7)	0.002
Pelvic obliquity (°)	−0.6 (1.1)	−2.0 (1.3)	0.152	−1.3 (5.0)	−0.5 (2.6)	0.538
Pelvic rotation (°) ^b	−8.4 (5.6)	−5.9 (4.2)	0.475	−3.1 (8.1)	−1.4 (6.2)	0.281
Femur rotation in st (°)	5.6 (6.2)	−0.6 (11.5)	0.104	4.0 (9.7)	0.4 (6.1)	0.247
Tibial rotation midstance (°)	−6.0 (3.2)	−6.8 (3.1)	0.870	−1.7 (2.9)	−7.0 (2.3)	0.106
Foot progression in st (°)	1.7 (11.7)	−0.56 (14.4)	0.496	14.3 (8.0)	7.6 (8.7)	0.037

Pre, preoperative; Post, postoperative; SD, standard deviation; Max, maximum; dorsiflex, dorsiflexion; st, stance; Tim, timing; % GC, percentage gait cycle

^a Extension (−), flexion (+)

^b External rotation (−), internal rotation (+)

at the postoperative gait analysis, but the power was still within the normal range. Four limbs were under-corrected (range -2° to 4.5°) after TAL whereas no under-correction occurred after GR. Despite under-correction ankle push-off power increased in all these four limbs.

The mean ankle angle at initial contact and maximum ankle dorsiflexion in swing improved 15° and 19° , respectively, but remained postoperatively >1 SD below the mean of the normal material. Ankle power during push-off improved after both TAL and GR, but only statistically significantly after TAL.

Comparison between diplegia and hemiplegia regarding the kinematic and kinetic results is presented in Table 2. Ankle kinematics showed good correction of the equinus in both groups. The mean ankle power during push-off increased in both groups but the increase was only statistically significant among children with diplegia. This group had an over-representation of TAL (eight TAL and six GR).

Distant effects

There were significant improvements in the sagittal plane kinematics in knee, hip, and pelvis (Table 1). Knee flexion at initial contact, maximum hip flexion in swing, hip range of motion, anterior pelvic tilt, and pelvic range of motion were reduced and thus improved postoperatively. Foot progression also improved significantly. Stride length increased ($P = 0.05$), but there was no difference in walking velocity and cadence. There was no significant deterioration in any of the measured parameters.

In both children with diplegia and hemiplegia there was significantly reduced maximum hip flexion in swing (Table 2). No other distant effects (other joints and segments than the ankle) were found in children with hemiplegia. The distant effects were more marked in children with diplegia who had significant improvements in several parameters: knee flexion at initial contact, anterior pelvic tilt, pelvic range of motion, and foot progression.

Table 3 Knee, hip, pelvis, and foot kinematics before and after calf muscle lengthening when the preoperative parameters were outside mean value $\pm$ 1SD of the normal material given in Table 1

Kinematic parameters	Number of limbs		Pre	Post	<i>P</i> value
	Hemiplegia	Diplegia	Mean (SD)	Mean (SD)	
Knee flexion at initial contact (°)	5	19	25.0 (7.7)	18.0 (7.0)	0.005
Minimum knee flexion in st (°) > +1SD	2	7	11.7 (4.7)	8.0 (6.6)	0.176
Minimum knee flexion in st (°) < −1SD	2	6	−9.7 (3.2)	0.31 (3.9)	0.031
Max knee flexion in sw (°) < −1SD	1	6	46.3 (5.9)	56.2 (5.4)	0.012
Tim max knee flexion sw (% GC) > +1SD	2	12	78.9 (3.2)	76.3 (4.6)	0.067
Knee range of motion (°) < −1SD	2	6	45.4 (4.2)	50.1 (9.6)	0.093
Max hip extension in st (°) > +1SD ^a	4	7	3.0 (8.3)	−1.5 (6.7)	0.089
Max hip flexion in swing (°) > +1SD	6	11	51.9 (6.1)	43.6 (5.9)	<0.001
Hip range of motion (°) > +1SD	3	5	64.2 (7.3)	52.0 (8.2)	0.005
Anterior pelvic tilt (°) > +1SD	5	0	21.8 (4.4)	18.4 (6.8)	0.238
Pelvic range of motion (°) > +1SD	5	0	9.7 (2.6)	5.5 (2.3)	0.025
Pelvic obliquity (°) < −1SD	1	5	−5.2 (5.3)	−2.2 (1.4)	0.248
Pelvic obliquity (°) > +1SD	1	2	5.8 (2.2)	1.3 (3.1)	0.245
Pelvic rotation (°) < −1SD ^b	4	5	−10.9 (6.5)	−5.0 (5.0)	0.021
Femur rotation in st (°) > +1SD	1	3	18.7 (3.6)	3.2 (8.1)	0.035
Tibial rotation midstance (°) > +1SD	2	8	5.2 (7.2)	−5.9 (8.1)	0.002
Foot progression in st (°) > +1SD	2	13	15.4 (7.0)	8.6 (9.4)	0.026

SD, standard deviation; Pre, pre-operative; Post, post-operative; St, stance; Max, Maximum; sw, swing; % GC, percentage gait cycle; Tim, timing

^a Extension (−), flexion (+)

^b External rotation (−), internal rotation (+)

To see whether the effects in other joints than the ankle will depended on the degree of pre-operative abnormality, limbs with pre-operative kinematic parameters >1SD above or below the mean value of the normal material were evaluated separately (Table 3). There was no differentiation between hemiplegia and diplegia due the low number in certain parameters. The results showed that the mean value of all the 17 kinematic variables tended to improve and the change was statistically significant in ten of these parameters. The improvement was most pronounced in femur rotation (15° less internal) and tibial rotation (11° less internal). When maximum hip flexion in swing was large preoperatively, it decreased 8° post-operatively. When maximum knee flexion in swing was low pre-operatively, it increased 10° after the operation post-operatively. When knee flexion at initial contact was increased it decreased 7° after operation.

The average follow-up period from the time of operation to the closing of this study was three years (range 13–55 months). There was one recurrent equinus. This child with diplegia had undergone unilateral GR 52 months previously and the postoperative result was satisfactory with maximum ankle dorsiflexion in stance of 15°. Another gait analysis 37 months later showed maximum ankle dorsiflexion of −12° in the operated ankle. She then

underwent multi-level surgery bilaterally consisting of calf muscle lengthenings, hamstrings and psoas lengthenings, and rectus femoris transfers. None of the other children have undergone additional orthopaedic surgery on their lower extremities during the follow-up period.

Discussion

Local effects in the ankle

Post-operative ankle kinematics confirmed the experience of previous studies of a good correction of the ankle [2, 3, 8]. The mean maximum ankle dorsiflexion in stance increased to 11°, which is close to the normal mean (13°). Over-correction may lead to calcaneal gait that predisposes to crouch gait, which is a major concern. Over-correction has been reported in 0–36% of children following calf muscle lengthening [9]. There are however, different definitions of over-correction. In our study it was defined according to Borton et al. [2] as maximum ankle dorsiflexion in stance >2 SD above the mean value of the normal material (21°). In the studies by Yngve and Chambers [3] and Segal et al. [8] more than 1SD was chosen and, not unexpectedly, over-correction in no less

than 30% of the children was reported with this strict upper limit [8]. In another publication over-correction was defined as 5° [9] above the mean value of the normal material, resulting in over-correction of 36% after TAL and 22% after GR. By our definition one limb (5%) was over-corrected, but push off power was still in the normal range and no crouch gait developed.

Four limbs (20%) were under-corrected. The four under-corrected limbs had undergone TAL. In the TAL group the preoperative maximum ankle dorsiflexion in stance was -14° compared to $+2^\circ$ in the GR group. We believe that this marked preoperative equinus gait in the TAL group contributed to the under-correction. This is in accordance with other studies [3, 9]. The frequency of under-correction varies from 5 to 23% [9], but the definition varies. Borton et al. [2] defined under-correction in accordance with our definition, while Yngve and Chambers [3] defined it as maximum dorsiflexion 1SD below the normal mean in stance and Kay et al. [9] as persistent equinus gait (maximum ankle dorsiflexion in stance below 0°). When applying the latter definition only one limb in our study was under-corrected.

Although the mean value of both ankle angle at initial contact and maximum ankle dorsiflexion in swing corrected into the normal range (mean $\pm$ 2 SD), six limbs remained below 2 SD at initial contact and ten limbs remained below 2 SD in swing phase. This may be caused by tibialis anterior dysfunction or premature gastrosoleus contractions when the knee is extending in terminal swing before initial contact. Orendurff et al. [10] reported post-operative mean values of maximum ankle dorsiflexion in swing phase in plantarflexion, while Baddar et al. [11] had mean post-operative values in dorsiflexion. Comparing these two studies with ours indicates that a marked equinus in stance pre-operatively has a negative influence on the postoperative outcome in the swing phase. All the children walked barefoot during the gait analysis. A well adjusted AFO will stop the tendency to dynamic swing phase equinus, and many children were recommended an AFO after the postoperative gait analysis.

Pre-operative ankle power was lower in the TAL group than in the GR group (0.9 vs. 1.8 watts/kg). This may be explained by the more pronounced equinus in the TAL group. Post-operatively, the power was equal in the two groups. The increase in power was statistically significant after TAL only, which probably was caused by the considerably lower pre-operative power in this group. This experience is in accordance with the study by Yngve and Chambers [3], who also had a more marked equinus and greater post-operative correction of ankle dorsiflexion in the TAL group than in the GR group.

The equinus recurrence rate was 5% (one limb) compared to other studies with 22–35% recurrence rate [2, 9,

12], but the post-operative follow-up period (three years) was relatively short and further follow-up is needed to confirm the outcome. Other authors think that the cause of equinus recurrence is multifactorial, including AFO use, physical therapy, and hamstring contracture [9, 12]. Our low recurrence rate indicates adequate postoperative rehabilitation and that hamstring spasticity in the pre-operative decision making was not overlooked.

Distant effects

Following isolated calf muscle lengthening there were significant improvements in six of the 15 kinematic parameters measuring distant effects (Table 1). This means that correction of equinus gait by TAL or GR and no additional surgery had a marked effect on the whole limb including pelvis. Only one previous study [11] has evaluated distant effects (sagittal plane only) and found improvement in knee flexion at initial contact and no change in minimum knee flexion in stance. Baddar et al. [11] examined hip and pelvic motion, but observed, in contrast to our study, no significant changes postoperatively. Their study consisted of 11 children with spastic diplegia who underwent isolated gastrocnemius–soleus recession bilaterally. The children in our study had preoperatively a more marked equinus gait (maximum ankle dorsiflexion in stance -6° vs. $+7^\circ$) and the magnitude of change was larger, 19° vs. 8° . This could possibly explain the kinematic differences in hip and pelvis between the two studies.

Reduced ankle dorsiflexion in swing phase causes foot clearance problems. This was compensated by increased hip flexion and not, as might be expected, increased knee flexion. After calf muscle lengthening and improved dorsiflexion in swing the compensation was reversed and hip flexion was significantly reduced into normal range. To our knowledge this compensation has not been previously reported.

The distant effects were less profound in hemiplegia, where only maximum hip flexion in swing was significantly changed, than in diplegia where several parameters in all levels were improved (knee flexion at initial contact, maximum hip flexion in swing, anterior pelvic tilt, pelvic range of motion, and foot progression in stance). Pre-operative equinus gait was more marked in children with diplegia than in children with hemiplegia. This might partly explain the differences in distant effects. However, the small number of children with hemiplegia makes this comparison somewhat uncertain.

In both hemiplegia and diplegia there were pre-operatively three different gait patterns. These gait patterns have in common the equinus position of the ankle in stance, but other joints and segments may be in normal position or have different degrees of abnormalities. The distant

kinematic parameters were pre-operatively defined as slightly abnormal when the parameters were $>1SD$ above or below the mean value of the normal material. Using this definition the mean values of all the distant parameters improved postoperatively and in ten of 17 parameters the improvement was statistically significant (Table 3). This means that the distant effects are more pronounced when the kinematic parameters tend to be abnormal preoperatively than when these parameters are normal. The correction was most pronounced in internal femoral rotation (15°) and internal tibial rotation (11°). These effects on rotation have not been examined in previous studies.

Calf muscle lengthening is most often combined with other surgical procedures, and this makes it difficult to evaluate separately the effect of the procedure on the whole limb including the pelvis. The current evaluation showed that moderate dynamic abnormalities in distant joints and segments improved after isolated calf muscle lengthening and that there was no deterioration. Despite a good overall result we cannot exclude that some of the children would have benefited from additional surgery, but the study showed that additional surgery in many cases could be abandoned or delayed. Thus, we do not agree with Borton et al. [2] who maintained that isolated calf muscle lengthening had few if any indications in the growing child.

Time and distance factors showed a trend towards significant improvement in stride length. Velocity remained unchanged, which means that walking speed did not influence on kinematic parameters. Only one [11] of the previous three studies [2, 10, 11] of isolated calf muscle lengthening evaluated these parameters and reported the same results as in our study. The major benefit for the child is a better gait control through the achieved ability of walking on the whole foot.

Conclusion

The improvement in ankle kinematics and kinetics supported the experience of other studies. The distant effects,

which have previously not been evaluated in three planes, showed improvement in several kinematic parameters indicating that additional surgery in selected patients could be abandoned or delayed.

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