

# Gait improvement surgery in ambulatory children with diplegic cerebral palsy

## A 5-year follow-up study of 34 children

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**Background and purpose** — Instrumented 3-D gait analyses (GA) in children with cerebral palsy (CP) have shown improved gait function 1 year postoperatively. Using GA, we assessed the outcome after 5 years and evaluated parental satisfaction with the surgery and the need for additional surgery.

**Patients and methods** — 34 ambulatory children with spastic diplegia had preoperative GA. Based on this GA, the children underwent 195 orthopedic procedures on their lower limbs at a mean age of 11.6 (6–19) years. On average, 5.7 (1–11) procedures per child were performed. Outcome measures were evaluation of gait quality using the gait profile score (GPS) and selected kinematic parameters, functional level using the functional mobility scale (FMS), and the degree of parental satisfaction.

**Results** — The mean GPS improved from 20.7° (95% CI: 19–23) preoperatively to 15.4° (95% CI: 14–17) 5 years postoperatively. There was no significant change in GPS between 1 and 5 years. The individual kinematic parameters at the ankle, knee, and hip improved statistically significantly, as did gait function (FMS). The mean parental satisfaction, on a scale from 0 to 10, was 7.7 (2–10) points. There was a need for additional surgical procedures in 14 children; this was more frequent in those who had the index operation at an early age.

**Interpretation** — The main finding was that orthopedic surgery based on preoperative GA gave marked improvements in gait function and quality, which were stable over a 5-year period. Nevertheless, additional orthopedic procedures were necessary in almost half of the children and further follow-up with GA for more than 1 year postoperatively is recommended in children with risk factors for such surgery.

During the last 2 decades, instrumented 3-D gait analysis (GA) has been recommended for preoperative evaluation of children with cerebral palsy (CP). Previous studies have shown that it makes a substantial impact on orthopedic decision making (DeLuca et al. 1997, Lofterød et al. 2007). With the introduction of instrumented GA, the organization of surgery has changed. Previously, single-level surgery was common. This has been replaced by multi-level surgery in order to correct as many deformities as needed during 1 operative session. The advantage is that the patients need only one hospital admission and one period of rehabilitation. Favorable short-term outcome of multi-level surgery has been reported (Saraph et al. 2002, Yngve et al. 2002, Lofterød and Terjesen 2008). When the present study was planned, only a few studies had followed the children more than 1 year postoperatively (Saraph et al. 2005, Rodda et al. 2006). Thus, the long-term development of gait function had not been clarified.

Relevant outcome measures after gait improvement surgery are changes in selected kinematic parameters (assessed by GA), functional changes (assessed by the need for assistive devices during gait), and the degree of parental satisfaction with the surgery. Previous studies have usually used only 1 of these methods. Since these outcome measures reflect important, but different, aspects of the effects of surgical treatment, we included all 3 of them.

Spastic muscles fail to grow in proportion to the bone, and present as dynamic tightness. Over time, muscle weakness, contractures, and bony deformities may develop. It is therefore not surprising that gait function in unoperated children with cerebral palsy decreases somewhat with age (Bell et al. 2002). In spite of multi-level surgery aimed at improving

gait function, there is sometimes a need for further surgery because of relapse or worsening of deformities during follow-up (Kay et al. 2000).

The aims of this study were to answer the following questions: (1) Are the improvements in gait parameters and gait function seen 1 year after surgery still present at longer follow-up? (2) To what degree are the parents satisfied with the outcome of the surgery? (3) What is the need for additional orthopedic surgery during follow-up after multi-level surgery?

## Patients and methods

This prospective study involved 34 ambulant children and adolescents (19 of them boys) with bilateral cerebral palsy, classified as spastic diplegia, who were successively recruited for orthopedic surgery on their lower extremities during the period 2002–2005 to improve their gait function. The children were part of a previous study in which 1-year results were reported (Lofterød and Terjesen 2008).

Before the index surgery, 17 children had undergone orthopedic surgery on their lower limbs. The mean age at previous surgery was 5.6 (3–9) years, and 6 of these 17 children had been operated a second time at a mean age of 9.2 (6–13) years. They had undergone 60 procedures, of which the most common were calf muscle lengthening and hamstring tenotomies (Table 1). A relapse occurred in 12 sagittal deformities, which necessitated reoperation of 6 calf muscle lengthenings and 6 hamstring tenotomies. 7 of these procedures were performed at the index surgery and 5 were performed during later follow-up.

According to the gross motor function classification system (GMFCS) (Palisano et al. 1997), 2 children were at level I, 23 were at level II, and 9 were at level III preoperatively. Gait function was evaluated with the functional mobility scale (FMS), rating walking ability at 3 specific distances: 5, 50, and 500 m (Graham et al. 2004). A rating of 6 means that the child walks independently on all surfaces, and 5 means walking without support on level surfaces. Children using a wheelchair are rated as 1, those using a walker or frame for support are rated as 2, those needing crutches are rated as 3, and children using sticks are rated as 4.

### Gait analysis and decision making

Preoperatively, 1 year postoperatively, and 5 years postoperatively, the children were evaluated with conventional physical examination and instrumented 3-D GA. Mean age at preoperative GA was 11 (6–18) years. A 6-camera Vicon System (612; Oxford Metrics, Oxford, UK) and 2 AMTI force plates (Advanced Mechanical Technology, Watertown, MA) were used to measure time and distance parameters, kinematic data, and kinetic data. The children walked barefoot at a self-selected speed along a 10-m walkway and a minimum of 3 trials were captured. The mean of 3 representative trials was

**Table 1. Previous and present orthopedic surgery of the lower limbs (number of procedures) in 34 children with spastic diplegia**

Surgical procedures	Previous surgery (17 children)	Index surgery (34 children)
Adductor tenotomy	7	22
Psoas tenotomy	0	38
Hamstrings tenotomies	12	35
Rectus femoris transfer	0	44
Triceps surae lengthening	27	30
Femoral derotation osteotomy	2	14
Subtalar arthrodesis	10	0
Other procedures <sup>a</sup>	2	12
Total no. of procedures	60	195

<sup>a</sup> Other procedures in “previous surgery” include bilateral proximal tibial hemiepiphyodesis, and in “index surgery” they include the following procedures: 2 pelvic osteotomies, 3 tibial osteotomies, 2 triple arthrodesis, 2 plantar fasciomyotomy, 2 operation for hallux valgus, and 1 operation for hammer toe.

used for analysis. The GA data were evaluated by a multidisciplinary team, resulting in recommendations for surgical and nonoperative treatment. The same multidisciplinary team (child neurologist, orthotist, physiotherapist, and orthopedic surgeon) performed and assessed the pre- and postoperative GA during the whole study period.

In addition to an analysis of the individual kinematic parameters, a summary statistic of the gait was calculated using the gait profile score (GPS; Baker et al. 2009). The GPS provides a single index of the overall gait quality and is based on 9 relevant kinematic variables (pelvis and hip in 3 planes, knee and ankle in the sagittal plane, and foot progression). GPS was calculated as the mean root square difference between the patient data and a reference score derived from our laboratory database of typically developing children. The mean GPS of this group was 5.3°. Improved gait function results in a reduction in GPS value. Since Baker et al. (2012) found the minimal clinically important difference for GPS to be 1.6°, we used 2° as the limit for improvement when comparing preoperative and postoperative GPS results.

As a help in defining the indications for surgery and when calculating GPS, gait data from a material of typically developing children were used. This consisted of 24 children (13 boys) with a mean age of 9.8 (5–15) years, recruited from parents who were working at the hospital. Normal ranges of the gait parameters were defined as mean  $\pm$  2 SD of this material. Preoperative kinematic parameters outside this range were used as indications for surgery. However, other factors were also of importance when deciding the surgical treatment: age of the child, physical findings such as range of motion and muscle contractures, and the child’s estimated motivation and ability to cope with the postoperative regime.

### Index surgery

The mean time between preoperative GA and index opera-

tion was 7.1 (1–22) months. 195 surgical procedures were performed at a mean patient age of 11.6 (6–19) years (Table 1). About 90% of the procedures were in accordance with the GA recommendations (Lofterød and Terjesen 2008). Multi-level surgery, defined according to previous studies (Rutz et al. 2013, Thomason et al. 2013) as at least 1 surgical procedure performed on 2 different anatomic levels bilaterally, was performed in 24 children at a mean age of 12.6 years. The mean number of surgical procedures in multi-level surgery was 7.2 (4–11) per child. In the 10 children with less extensive surgery, the mean age was 9.3 years, which was significantly lower than that in those with multi-level surgery ( $p = 0.01$ ).

The surgical procedures followed common surgical techniques. In rectus femoris transfer, the tendon was cut 2–3 cm proximal to the patella and released as far proximally as necessary to avoid a kink when the tendon was transferred medially to the sartorius muscle. Hamstring tenotomies were done by elongating the medial hamstrings, by distal tenotomies of the gracilis and semitendinosus and recession of the distal semimembranosus muscle. Calf muscle lengthening was done by either open Z-plasty of the Achilles tendon or gastrocnemius recession. The latter was done with an inverted V-shaped incision in the aponeurosis of the gastrocnemius muscle. Then, if passive dorsiflexion did not reach  $10^\circ$  with extended knee, the underlying soleus aponeurosis was also incised. Psoas was lengthened by tenotomy at the level of the pelvic brim, and adductor tenotomy included tenotomy of the adductor longus, proximal myotomy of gracilis, and, if necessary, partial myotomy of the proximal part of adductor brevis.

Most of the patients had epidural anesthesia the first postoperative days and physiotherapy was started on the first day. The children who had undergone calf muscle lengthening had a plaster cast for 5 weeks, and afterwards ankle-foot orthosis until the GA 1 year postoperatively. Children operated for crouch gait used a ground reaction ankle-foot orthosis for a minimum of 6 months to keep the knee extended. Children who had multi-level surgery had a 4-week training period with intensive physiotherapy in a rehabilitation center, starting 3–6 weeks postoperatively. Children with less extensive surgery had a less comprehensive postoperative physiotherapy regime.

### 5-year and later follow-up

All the children had GA 1 year after the operation. The intention was that all should have another GA 5 years postoperatively. This was, however, not accomplished in 5 children, 1 of whom died from congenital heart failure 3.5 years after the operation. 2 children did not attend the 5-year GA, and 2 children were not called in. 1 of the latter children had such good function that it was considered unnecessary to have further GA, and the other was not called in because of a lapse in our follow-up routines. Thus, 5-year follow-up with GA was available in 29 children. The average time between operation and GA was 5.6 (3.4–7.6) years. Follow-up was earlier than planned in 2 patients, 1 of whom had relapse of equinus and

had GA 3.4 years postoperatively; the other had GA at 3.8 years because of increasing crouch gait. The mean age of the children at the last GA was 16.8 (11–26) years. At the 5-year follow-up, proposals were made for additional surgery based on clinical evaluation and GA.

The degree of parental satisfaction with the surgery, and additional information about the children's gait function when such information was lacking in the case reports, were provided by telephone interviews performed by TT in 2014 (8–12 years postoperatively). With regard to satisfaction, we followed the procedure of Lee et al. (2009), using a 10-point visual analog scale (VAS) where 0 means total dissatisfaction and 10 means complete satisfaction with the overall outcome of the index operation. The parents were informed about the purpose of the study and were told that "satisfaction" should refer only to the index surgery and that they should not be influenced by possible changes caused by later surgery. They were also instructed to answer honestly and not to give overly positive answers just to please the surgeon. We obtained answers from the parents of all except 1 of the 33 children who were alive.

### Statistics

Distribution of data was tested with the Kolmogorov-Smirnov test for normality. Variables that were normally distributed were analyzed with t-test. Variables that were not normally distributed were analyzed with non-parametric tests (Mann-Whitney test and Wilcoxon signed rank test). The results for the worst limb preoperatively were used in the preoperative and postoperative analyses of the development of the individual kinematic variables. Chi-square test was used for comparison of categorical variables. All tests were 2-sided. Differences were considered significant when the p-value was  $< 0.05$ . The statistical analyses were performed using SPSS software version 21.

### Ethics

The study was approved by the Data Protection Officer, according to the Health Personnel Act paragraph 26.

### Results

Gait function, evaluated by FMS, improved from the preoperative score to 1 year postoperatively for the 5-m and 50-m distances ( $p = 0.04$  and  $0.01$ ), but the difference at 500 m was not statistically significant ( $p = 0.07$ ). FMS at 5 years postoperatively had improved from the preoperative score for all 3 distances. 7 children had an improved score by at least 1 category when walking 5 m, 9 improved at 50 m, and 16 children improved when walking 500 m. The pattern of change differed according to functional level preoperatively (Table 2; see Supplementary data). Children with GMFCS level II walked without assistive devices at household distances and therefore had

**Table 3.** Gait profile score (GPS) in degrees, expressed as mean (SD). All 34 children were included in the comparison between preoperative and 1-year postoperative GPS, whereas 5-year GPS was available in 29 patients

Leg/n	Preop.	p-value <sup>a</sup>	1 year	p-value <sup>b</sup>	5 years	p-value <sup>c</sup>
Both legs						
n = 34	20.4 (5.0)	< 0.001	15.6 (4.4)			
n = 29			15.8 (4.1)	0.5	15.4 (4.0)	
n = 29	20.7 (5.0)				15.4 (4.0)	< 0.001
Right leg						
n = 34	19.4 (5.2)	< 0.001	14.3 (4.2)			
n = 29			14.5 (4.1)	0.9	14.4 (3.8)	
n = 29	19.7 (5.0)				14.4 (3.8)	< 0.001
Left leg						
n = 34	18.7 (5.0)	< 0.001	15.1 (4.4)			
n = 29			15.4 (4.1)	0.4	14.9 (4.3)	
n = 29	19.0 (5.0)				14.9 (4.3)	< 0.001

SD: standard deviation; n: number of children.  
<sup>a</sup> Compares preoperatively and 1 year postoperatively.  
<sup>b</sup> Compares 1 year and 5 years postoperatively.  
<sup>c</sup> Compares preoperatively and 5 years postoperatively.

unchanged FMS level at a distance of 5 m, whereas gait function improved statistically significantly at greater distances. The improvement was most pronounced (1.6 levels) when moving 500 m. Children at GMFCS level III had improvements at all 3 distances, and the greatest change was at 5 m, where 4 of 7 children who used a walker preoperatively could walk without support and 2 children used sticks at 5 years.

The mean preoperative GPS (combined for both legs) was 20° (95% CI: 19–22) (Table 3). There was a higher preoperative GPS in children with GMFCS level III (mean 23°, CI: 20–27) than in those at level II (mean 20°, CI: 18–22). The mean improvement in GPS from before surgery to the 5-year follow-up was 5.3° (CI: 3.4–7.1), and there was no significant change between the 1-year and 5-year follow-ups. Improvement in GPS, defined as 2° of reduction from before surgery to

5 years postoperatively, was seen in 19 of 29 children whereas 10 were unchanged (difference of < 2°). Children with improvement in GPS had a larger preoperative GPS than those with no improvement (23° vs. 17°;  $p = 0.003$ ). No association was found between improved GPS and the following parameters: age at index surgery, sex, GMFCS level II vs. III, whether or not operations had been performed before index surgery, whether or not multi-level surgery had been performed, and whether or not additional operations were necessary. For the 5 children with no 5-year GA, the mean improvement in GPS from before surgery to 1 year postoperatively was 4.7°. 4 of these children had improved function with a reduction in GPS of 1.9–13°, and 1 had deteriorated with an increase of 4.2°.

In the 17 children who had undergone calf muscle lengthening as part of index surgery, there was a marked improvement in maximum ankle dorsiflexion in stance 1 year postoperatively (21°) (Table 4; see Supplementary data). Although dorsiflexion decreased by an average of 4° during further follow-up, it was statistically significantly larger at 5 years than preoperatively. Similar changes occurred in maximum ankle dorsiflexion in swing. Maximum ankle dorsiflexion in children who had not undergone calf muscle lengthening decreased by 3–5° during the study period.

Minimum knee flexion in stance in the 16 children who had undergone medial hamstring tenotomies and rectus femoris transfer improved from 37° preoperatively to 15° at 1 year, and there was no deterioration between 1 and 5 years (Table 5). Maximum knee flexion in swing decreased both from preoperatively to 1 year postoperatively and from 1 year to 5 years. Knee range of motion increased statistically significantly after surgery. In the children who had not had hamstrings and rectus femoris surgery, knee kinematics from the preoperative GA values were similar to those 5 years postoperatively.

In the 20 children who had undergone psoas tenotomies, minimum hip flexion in stance improved from 15° to 9° during the first postoperative year ( $p = 0.002$ ). From 1 to 5 years, no

**Table 5.** Pre- and postoperative kinematic results for the knee according to operations at this level, expressed as mean (SD) in degrees

Operation Parameter	Preop.	p-value <sup>a</sup>	1 year	p-value <sup>b</sup>	5 years	p-value <sup>c</sup>	Normal material
Hamstrings lengthening and rectus femoris transfer (n = 16)							
Min. knee flexion stance phase	37 (19)	0.001	15 (14)	0.8	14 (12)	< 0.001	2 (4)
Max. knee flexion swing phase	63 (13)	0.03	54 (7.6)	0.049	50 (7.3)	0.003	60 (5)
Knee ROM <sup>d</sup>	27 (12)	0.001	39 (12)	0.07	35 (11)	0.002	60 (7)
Timing of max. knee flexion <sup>e</sup>	82 (5.5)	0.04	79 (3.6)	0.9	79 (4.5)	0.04	72 (3)
No knee operation (n = 18)							
Min. knee flexion stance phase	12 (15)	0.6	14 (13)	0.7	15 (12)	0.9	
Max. knee flexion swing phase	51 (14)	0.1	56 (8.2)	0.008	51 (8.0)	0.1	
Knee ROM <sup>d</sup>	39 (20)	0.4	42 (14)	0.001	36 (14)	0.2	
Timing of max. knee flexion <sup>e</sup>	79 (5.7)	0.04	77 (5.5)	0.4	77 (5.6)	0.1	

<sup>a-c</sup> For abbreviations, see Table 3.

<sup>d</sup> ROM: range of motion;

<sup>e</sup> Timing of maximum knee flexion in swing (% of gait cycle).

statistically significant change occurred. Mean anterior pelvic tilt was 23° preoperatively and 19° at 5 years ( $p = 0.1$ ). During the study period, hip and pelvic sagittal kinematics were similar in children who had not undergone psoas tenotomies.

Mean gait velocity was 0.89 m/s preoperatively, 0.89 at 1 year, and 0.91 m/s 5 years postoperatively ( $p = 0.3$ ). Stride increased from 0.83 m to 0.95 m ( $p = 0.001$ ) and cadence decreased from 127 to 113 steps per min ( $p = 0.001$ ). The mean height of the patients increased from 135 cm to 158 cm, and their mean weight increased from 34 kg to 52 kg.

The mean score for parent satisfaction with the outcome of index surgery (on a VAS scale from 0 to 10) was 7.7 (2–10) points. 14 parents were very satisfied with scores 9–10, 14 were satisfied with scores 6–8, and 4 parents were less satisfied or dissatisfied with scores 2–5. The mean improvements in GPS during the study period in these 3 groups were 6.7°, 4.2°, and 3.7°, respectively. Thus, there was a greater GPS improvement in the group with the highest degree of satisfaction, but the differences were not statistically significant. Parents of boys were significantly more satisfied than parents of girls ( $p = 0.02$ ), whereas there were no statistically significant associations between degree of satisfaction and the following parameters: age at index operation, preoperative GMFCS level, previous operations, multi-level surgery vs. less extensive surgery, and whether or not additional procedures had to be performed.

### **Additional surgical procedures**

14 of the 29 children with 5-year follow-up were recommended additional orthopedic surgery (Table 6; see Supplementary data). 51 procedures were proposed, with a mean of 3.6 (1–10) procedures per child. Children who were recommended surgery were significantly younger at the time of the index operation than those with no further surgery (9.6 years as opposed to 13.0 years;  $p = 0.003$ ). The girl with the most additional surgery (10 procedures) was only 7 years old at the index operation. In spite of abnormal kinematics at the knee and hip levels, unilateral gastrocnemius recession was only done at index operation, because of her young age and supposed difficulties in following the extensive postoperative rehabilitation.

There were no statistically significant associations between the need for additional surgery and the following parameters: sex, preoperative GMFCS level, previous operations (before index operation), preoperative GPS score, and multi-level surgery versus less extensive surgery. None of the 5 children who had no 5-year GA have had additional surgery.

Indications for surgical correction of abnormalities in the sagittal and transverse planes were based on deteriorations in the GA parameters. Deviations in the sagittal plane were the most common (25 procedures). No index operations had been performed for 21 of the sagittal deviations whereas 4 limbs had undergone calf muscle lengthening at the index operation with a satisfactory short-term result, but relapse of equinus

occurred during longer follow-up. Clinical assessment was used for diagnosis of contractures in the frontal plane at the hip. Adductor tenotomies were performed in 8 limbs because of decreased hip abduction; 2 of these had undergone adductor tenotomies at the index operation and had relapse. The indications for the 12 foot operations were based on conventional clinical examination. The proposed operations have been performed in 12 children, at a mean age of 14 (11–19) years. 10 of these children were operated after the 5-year GA, whereas 2 were operated before GA (1.5 years and 3.8 years postoperatively) because of complaints and clinical deterioration. 2 children have so far chosen not to undergo further surgery.

### **Discussion**

Our main findings were that orthopedic surgery based on preoperative GA gave a marked improvement in gait function, documented by kinematic analyses, functional measures, and parental satisfaction. The improvement was stable over a 5-year period. Nevertheless, there was a need for additional surgical procedures in nearly half of the children.

Before a more detailed evaluation of the outcome of surgery, it should be recognized that the natural history of gait deviations in bilateral spastic CP shows a trend of deterioration with age (Johnson et al. 1997, Bell et al. 2002, Gough and Shortland 2008). Thus, even an unchanged outcome after surgery could represent an improvement compared with the natural history. Gough and Shortland (2008) followed 45 children with bilateral spastic CP and found that GA could distinguish between children who would benefit from surgery and children who would not need surgery because of a better natural history.

Our study had certain limitations. The number of children was small, and there was considerable variation in age at operation and in the functional levels of the patients. The types of gait deviations, the type and number of previous operations, and combinations of index surgical procedures made it difficult to evaluate the effects of a specific procedure. Because we had no control group without surgery, changes in gait function cannot be caused by surgery alone. The strength of the study was that the same multidisciplinary team assessed almost all of the patients over the whole study period, using the same GA laboratory and the same gait parameters. Another strength was that the children were evaluated with 3 different outcome measures. We have not found any previous studies with such broad outcome evaluation.

We used GPS because summary statistics of gait function has been recommended in recent years as a primary outcome measure after multi-level surgery (McGinley et al. 2012, Cimolin and Galli 2014). Such statistics include a combination of gait parameters and will allow for the fact that certain gait parameters may improve and others may deteriorate postoperatively. The higher the GPS preoperatively, the more abnormal is the gait. We found a mean preoperative GPS for

both legs combined of 20°, the same as reported by Rutz et al. (2013), whereas Thomason et al. (2013) had children with better gait function, since their preoperative GPS was 15°. The mean improvement in GPS over the 5-year period was 5° in the present study and in the study of Thomason et al. (2013), whereas Rutz et al. (2013) reported a slightly better improvement. We found similar GPS results for 1-year and 5-year follow-up, in line with recent studies (Rutz et al. 2013, Thomason et al. 2013). In these studies, additional surgery was performed before the last GA and may have contributed to better results at the 5-year GA than in our study, where most of the additional procedures were performed after the 5-year GA.

Because the most common gait problems in children with diplegia are in the sagittal plane and include crouch, stiff knee, and equinus (Wren et al. 2005), we consider it important to address these individual deformities. The effects of surgery at the knee and ankle were considerably greater when surgery involved specific procedures on muscles that crossed these joints. Maximum ankle dorsiflexion in stance increased by a mean of 21° during the first postoperative year in children with calf muscle lengthening. Other studies have found an improvement of 15–23° after similar procedures (Yngve and Chambers 1996, Svehlik et al. 2012). With longer follow-up, our results showed a reduction of 4°. Svehlik et al. (2012) reported that maximum dorsiflexion in stance increased by a mean of 4.4° between 1 and 5 years of follow-up and then decreased by 3.7° between 5 and 10 years. Our somewhat earlier reduction in dorsiflexion might explain why we had some recurrences of equinus.

Inability to extend the knee in the stance phase represents a severe problem in many children with diplegia. A marked improvement in minimum knee flexion of 22° occurred during the first year after hamstring lengthening and rectus femoris transfer. Rodda et al. (2006) reported a 31° reduction after similar surgery in patients with severe crouch gait, whereas others found 10–12° reduction after multi-level surgery (Saraph et al. 2005, Rutz et al. 2013). At follow-up 5 years postoperatively, no change in minimum knee extension in stance occurred in our patients, whereas moderate deteriorations of 4–7° were reported by others (Saraph et al. 2005, Rodda et al. 2006) and an improvement of 4° was found by Rutz et al. (2013).

An important goal in gait improvement surgery is to reduce the assistive devices (sticks, crutches, or rollator) that are needed during gait. FMS is an appropriate measure of functional effects because it distinguishes between different gait distances. Thomason et al. (2013) found that almost half of their children at 5 years postoperatively had improved functional mobility at 50 m and 500 m, which has been confirmed by our results. In agreement with the results of Yu et al. (2014), we found that the pattern of improvement was related to preoperative functional level. In children who needed assistive devices (GMFCS level III), the most pronounced improvement occurred in household ambulation (5 m). In children at GMFCS level II, the greatest improvement occurred at the

longest distance (500 m)—where several children who had needed a wheelchair preoperatively were able to walk without any assistive devices at the 5-year follow-up. These functional improvements have made daily activities for the patients and their families easier.

The degree of satisfaction with the result of surgery is an interesting and important consideration that has seldom been addressed. Lee et al. (2009) appear to be the only group who have focused on parental satisfaction after gait improvement surgery. They used 3 questions on satisfaction, asking about functional outcome, cosmetic outcome, and overall outcome. We used only the question about overall outcome, as we thought this would reflect the most reliable and clinically relevant aspect of satisfaction. Moreover, when interacting with the parents, it was obvious that change in gait function was the most important single factor that determined their answer to the question about satisfaction. Using a VAS of 0–10, a mean overall satisfaction score of 7.9 was reported by Lee et al. (2009). We found a similar mean score of 7.7. Almost half of the parents were extremely pleased with the outcome of surgery and some thought that their child would soon have lost gait function if they had not been not operated. Whereas Lee et al. (2009) reported a higher degree of satisfaction in children at GMFCS level I, in children of younger age at surgery, and in children with a shorter duration of follow-up, we found that the only predictor of satisfaction was male sex.

Even if single-event multi-level surgery is aimed at correcting all existing deviations in gait, additional surgery is sometimes necessary. Kay et al. (2000) found a need for such surgery already at the 1-year follow-up. Wren et al. (2009) reported that the amount of additional surgery increased with length of follow-up, and when the surgeons did not follow the GA recommendations during the index surgery. Additional procedures were indicated in half of our children, which is somewhat less than the rate in previous studies (Rutz et al. 2013, Thomason et al. 2013). One reason for the discrepancy might be differences in how closely the surgeons followed the GA recommendations (about 90% of the proposed procedures in this study).

Rutz et al. (2013) reported that 9 of 14 children needed additional surgical procedures—5 because of new problems and 4 because of relapse of deviations that had been corrected at index surgery. Thomason et al. (2013) pointed out that the need for additional surgery could undermine the concept of single-event multi-level surgery (SEMLS). However, even though additional procedures may be necessary later, most of the index surgery will have a lasting effect. Patients and parents should be informed along these lines, so that they can gain a realistic understanding of the prognosis after SEMLS.

Most of the additional procedures were caused by deviations in the sagittal plane. GA is important for detection of such deviations, whereas conventional physical examination is sufficient to detect other deviations, especially foot deformities. Svehlik et al. (2011) studied children with flexed knee

gait and they found no association between age at index surgery and the number of additional procedures, which differs from our experience of more additional surgery in younger children.

During the current study period, GA 5 years postoperatively was our routine practice for children with bilateral spastic CP. However, GA is a resource-demanding procedure and we have experienced that 5-year GA is not necessary in all children. Factors indicating that longer follow-up is necessary were young age at the time of operation and borderline kinematics ( $> 1$  SD) at the 1-year GA. Patients with such risk factors should be followed further with GA 3 years postoperatively—or earlier if needed—because of clinical deterioration. We have now changed our routines along these lines.

### Supplementary data

Tables 2, 4, and 6 are available at Acta's website ([www.acta-orthop.org](http://www.acta-orthop.org)), identification number 8082.

TT and BL initiated and planned the study, examined and treated the patients, analyzed the data, and wrote the manuscript. IS examined and treated the patients, did part of the statistical analysis, and contributed to revision of the manuscript.

No competing interests declared.

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