

Preoperative gait analysis has a substantial effect on orthopedic decision making in children with cerebral palsy

Comparison between clinical evaluation and gait analysis in 60 patients

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Background There is still some debate regarding the role of 3-dimensional gait analysis in routine preoperative evaluation of children with cerebral palsy. The aim of this prospective study was to evaluate to what extent introduction of 3-D gait analysis changes preoperative surgical planning.

Method Before gait analysis, 60 ambulatory children aged 10 (4–18) years with spastic cerebral palsy had a specific surgical plan outlined, based on clinical examination by orthopedic surgeons. After gait analysis, the proposed surgical procedures were reviewed to determine the frequency with which the treatment plans changed. A multidisciplinary team assessed the gait analysis.

Results Treatment plans for 42 of the 60 patients were altered after gait analysis. Surgical treatment was recommended for 49 patients whereas 11 were recommended non-surgical treatment. Of the 253 specific surgical procedures proposed, 97 procedures were not recommended after gait analysis and 65 additional procedures were recommended after the analysis. Thus, the number of procedures proposed was reduced by 13%. A total of 318 specific surgical procedures were proposed either clinically, by gait analysis, or both. There was overall agreement between the referring orthopedic surgeons and gait analysis in 156 of these 318 procedures (49%). Gait analysis proposed more surgery for psoas tenotomy and rectus femoris transfer, whereas less surgery was proposed for other soft tissue and bony procedures. There was good accordance between gait analysis recommendations and the surgery performed subsequently (92%).

Interpretation Gait analysis provided important additional information that modified preoperative surgical planning to a high degree. The high accordance between recommendations and surgery performed suggests that surgeons seriously consider the gait data and treatment recommendations.

Computerized gait analysis has become increasingly widespread in preoperative planning for children with cerebral palsy (CP). Gait analysis offers a more accurate and objective assessment of gait than is possible by conventional methods such as clinical examination and visual observation alone (Gage 1993). As a consequence of this development, there has been a change in treatment policy from staged surgical procedures to multilevel surgery (DeLuca 1991, Gage 1994). A prerequisite for multilevel surgery is an optimal preoperative evaluation.

There has been some debate regarding the role of gait analysis in routine preoperative evaluation of ambulatory children with cerebral palsy (Gage 1994, Watts 1994). A few previous studies have given valuable information suggesting that gait analysis can alter the surgical plans in more than half of the patients (De Luca et al. 1997, Kay et al. 2000, Cook et al. 2002). These studies had somewhat different designs, as the experience of the referring physicians varied and no differentiation between different types of CP was performed. Despite the objective nature of information from

gait analysis, there is some subjectivity involved in its interpretation (Skaggs et al. 2000). Thus, further studies in this field are necessary.

Our gait laboratory was established at the end of 2001. Before the study started, we had trained in other laboratories, gained information from clinical gait courses, and had supervision in our own laboratory from professionals with extensive experience in gait analysis. The aim of the study was to evaluate to what degree gait analysis in this setting changed our preoperative surgical proposals.

Patients and methods

The material consisted of 60 ambulant children (33 males) with spastic cerebral palsy who were referred to us consecutively (by experienced orthopedic surgeons) for preoperative gait analysis during the period January 2002 through October 2004. There were 46 patients with diplegia and 14 with hemiplegia. The referring surgeons were informed about this prospective study and all the patients had a specific surgical plan outlined, based on clinical examination and visual observation of gait. Patients without a specific surgical plan were excluded. Most of the children with cerebral palsy in Norway have their orthopedic operations performed at our hospital, and 49 of the 60 patients were referred by 3 orthopedic surgeons at our hospital. 39 of these 49 patients were referred by an orthopedic surgeon who is also a team member of the gait laboratory. The remaining 11 patients were referred from 3 orthopedic surgeons working at 3 other hospitals.

Average age at the time of gait analysis was 10 (4–18) years. There was no significant age difference between children with diplegia and those with hemiplegia. The average time between referral and gait analysis was 5 (0–11) months. 24 patients had undergone 70 previous surgical procedures (Table 1), whereas 19 patients had received botulinum toxin A injections in spastic muscles, and 1 patient had continuous intrathecal baclofen therapy. The average time between botulinum toxin A injections and gait analysis was 14 (4–36) months. With regard to gait function, the patients were classified according to the Gross Motor Function Classification System (GMFCS; Palisano et al. 1997). 25

Table 1. Previous surgery (24 patients)

Surgical procedure	Number of patients	Number of operations
Psoas	0	0
Adductors	7	13
Hamstrings	8	14
Rectus femoris	0	0
Gastrocnemius	20	28
Foot and ankle	5	10
Femoral osteotomy	4	4
Tibial osteotomy	1	1
Total		70

children were classified at level I, 24 at level II, and 11 at level III. The patients in the diplegic group had the following distribution: 13 level I, 22 level II, and 11 level III. In the patients with hemiplegia 12 were at level I, and 2 were at level II.

Gait analysis included physical examination (muscle strength and selective motor control, spasticity, passive and active joint range of motion, and rotational alignment of the lower extremities), coronal and sagittal plane video recording, and 3-dimensional kinematics and kinetics. We used a 6-camera Vicon System (612) (Oxford Metrics, Oxford, UK) and 2 AMTI force plates (Advanced Mechanical Technology Inc., Watertown, MA) to collect motion analysis data.

In this prospective study, we had the same team members (child neurologist, orthotist, physiotherapist, and orthopedic surgeon) in the assessment of the gait analysis. Agreement between the team members was obtained after careful discussion of each case. In cases of doubt about a decision, as a rule we did not recommend a surgical procedure. We also invited the referring surgeon to a meeting where the recommendations were presented. The recommendations—including the need for operative and nonoperative treatment and the level and type of operation that should be performed—were recorded for each patient.

To simplify the data, the specific procedures were divided into 8 categories: psoas tenotomy at the pelvic brim, adductor release, hamstring release, rectus femoris transfer to sartorius, gastrocnemius (or Achilles tendon lengthening), foot and ankle operations, femoral osteotomy, and tibial osteotomy. The soft tissue procedures were performed on muscles with the same function. We did

Table 2. Relationship between surgical procedures recommended before and after gait analysis (60 patients, 106 sides)

Surgical procedure	Number recommended		Total number proposed	Agreement		Disagreement	
	before gait analysis	after gait analysis		Number	Rate	Less surgery	More surgery
Psoas	25	39	45	19	0.4	6	20
Adductors	32	14	34	12	0.4	20	2
Hamstrings	46	38	53	31	0.6	15	7
Rectus femoris	36	53	64	25	0.4	11	28
Gastrocnemius	61	46	62	45	0.7	16	1
Foot and ankle	14	12	19	7	0.4	7	5
Femoral osteotomy	32	16	33	15	0.5	17	1
Tibial osteotomy	7	3	8	2	0.3	5	1
Total	253	221	318	156	0.5	97	65

not differentiate between gastrocnemius and Achilles tendon lengthening. In the category foot and ankle operations, we included plantar fasciotomy, tendon transfer (tibialis anterior or posterior), and subtalar arthrodesis. No recommendation was made as to the exact operation to be performed on any particular muscle; for example, no distinction was made between tenotomy, myotomy and fasciotomy. The charts of all the proposed surgical procedures before gait analysis were reviewed to determine the frequency with which the treatment plan changed after gait analysis.

In order to evaluate the degree to which the recommendations after gait analysis were implemented in clinical practice, we examined the surgical charts to see which specific procedures had actually been performed in the 49 children who were surgically treated.

We used the chi-square test for comparison of categorical variables. The significance level (*p*-value) was set at 0.05.

Results

All 60 of the children had been recommended surgical treatment after evaluation by the referring orthopedic surgeon. After gait analysis, 49 patients were recommended for a surgical procedure (33 multilevel) and 11 for nonoperative treatment (5 patients were recommended continued physiotherapy and 6 patients additional botulinum toxin A injections). 42 of the 60 patients had their treatment

plans altered after gait analysis. The total number of proposed surgical procedures was reduced by 13% from 253 before gait analysis to 221 after gait analysis (Table 2).

A total of 318 specific surgical procedures were proposed (253 after clinical evaluation and 65 more after gait analysis) (Table 2). There was overall agreement between the proposals of the referring orthopedic surgeons and gait analysis recommendations in 156 of these 318 surgical procedures (49%). Gait analysis proposed less surgery in 97 procedures and more surgery in 65 procedures (Table 2). The agreement was greatest for gastrocnemius lengthening and hamstrings tenotomy, and less for femoral osteotomy, psoas tenotomy, rectus femoris transfer, foot and ankle surgery, hip adductor tenotomy, and tibial osteotomy (Table 2). Gait analysis recommended more surgery for psoas tenotomy and rectus femoris transfer, whereas less surgery was recommended for the other soft tissue and bony procedures.

Of the 290 specific surgical procedures proposed in the group with diplegia, there was agreement between clinical evaluation and gait analysis in 138 procedures (48%). Of the 28 proposed procedures in the group with hemiplegia, there was agreement in 18. Thus, there was a trend toward greater agreement in patients with hemiplegia, but the difference was not statistically significant (*p* = 0.1). The most obvious disagreements in the group with hemiplegia were that gait analysis recommended more rectus femoris transfer (3 patients) and fewer foot and ankle operations (3 patients).

Table 3. Relationship between surgical procedures proposed before gait analysis and surgical procedures recommended after gait analysis, compared to procedures actually performed (60 patients, 106 sides)

Surgical procedure	Number proposed before gait analysis	Number recommended after gait analysis	Number performed	Disagreement between number proposed before gait analysis and number performed		Disagreement between number recommended after gait analysis and number performed	
				Less surgery	More surgery	Less surgery	More surgery
Psoas	25	39	39	6	20	0	0
Adductors	32	14	22	12	2	0	8
Hamstrings	46	38	37	16	7	1	0
Rectus femoris	36	53	50	11	25	3	0
Gastrocnemius	61	46	44	18	1	2	0
Foot and ankle	14	12	13	6	5	0	1
Femoral osteotomy	32	16	14	19	1	2	0
Tibial osteotomy	7	3	3	5	1	0	0
Total	253	221	222	93	62	8	9

In the 49 patients who were recommended surgical treatment after gait analysis—36 patients with diplegia and 13 with hemiplegia—operations were proposed in all 85 affected lower limbs. The 36 patients (72 limbs) with diplegia had 198 surgical procedures recommended after gait analysis, which means 5.5 procedures per patient and 2.8 procedures per limb. The group with hemiplegia had 23 operations recommended (1.8 procedures per limb). There was a trend towards more procedures per limb in the group with diplegia than in the group with hemiplegia ($p = 0.06$).

Table 3 shows the relationship between the recommendations after gait analysis and the surgical procedures actually performed. The orthopedic surgeons followed the gait analysis in 204 of the 221 specific surgical procedures recommended (92%). There was no significant difference in following the recommendations between the surgeon who was a member of the gait analysis team and the other surgeons. It is also obvious from Table 3 that there was a considerable discrepancy between the clinical proposals put forward before gait analysis and the procedures actually performed (48%).

Discussion

As a result of gait analysis, 11 patients were not recommended surgery and 42 patients (70%) had

their treatment plan changed. This is a higher proportion of changes than reported by DeLuca et al. (1997), who found that 52% of the patients had their treatment plan changed after gait analysis. However, Kay et al. (2000) found a considerably larger discrepancy (89% of patients).

The total number of surgical procedures was reduced by 13% after gait analysis, as 97 of the clinically proposed procedures were not recommended and 65 procedures that had not been proposed were recommended after gait analysis. The data support the experience of others (DeLuca et al. 1997, Kay et al. 2000, Cook et al. 2002) that gait analysis results in the detection of certain abnormalities that may benefit from intervention, and the avoidance of interventions that might otherwise have been done. There was disagreement between clinical evaluation and gait analysis in 51% of the proposed specific surgical procedures, which is in accordance with the 40% reported by Cook et al. (2002). This illustrates the limitations of using clinical examination and visual gait observation alone for surgical decision making. For example, evaluation of a child walking on the toes based on visual gait observation may mistakenly conclude that the equinus is real, when it is in fact apparent. Sagittal plane kinematics will show that the ankle has a normal range of dorsiflexion but the hip and knee are in excessive flexion throughout the stance phase of gait. In this case, lengthening of

Table 4. Comparison of results with those of previous articles

Surgical procedure	DeLuca et al. 1997	Kay et al. 2000	Cook et al. 2002	Present study
Psoas	Less ^a	More	More	More
Adductors	Less	Less	Less	Less
Hamstrings	Less	Less	Less	Less
Rectus femoris	More	Less	More	More
Gastrocnemius	More	More	Less	Less
Femoral osteotomy	Less	Less	Less	Less
Tibial osteotomy	Less	Less	Less	Less

^a "Less" means that less procedures were proposed after gait analysis than after clinical examination, and "More" means the opposite.

the Achilles tendon will provoke a crouch gait and result in impaired function. In our study, 6 patients with diplegia had apparent equinus and 3 of these patients were recommended Achilles lengthening before gait analysis.

Treatment of gait problems in cerebral palsy has gradually been changing over the past decade. Botulinum toxin A injections can delay and even reduce the need for surgery (Koman et al. 1999, Hägglund et al. 2005). In addition, methods of physiotherapy and orthotic intervention have undergone improvements (Gage and Quanbeck 2004). Botulinum toxin A treatment and previous orthopedic surgical history were not specified in previous publications (DeLuca et al. 1997, Kay et al. 2000, Cook et al. 2002). Important data such as classification of cerebral palsy and patient age have also been lacking in some reports, and the results have not been presented uniformly. Thus, it is difficult to directly compare our results with those of previous studies. Even so, a comparison between this study and previous studies is presented in Table 4. All the studies published so far have agreed that gait analysis suggests less lengthening procedures of the adductors and hamstrings and less femoral and tibial derotation osteotomies. In our study, less surgery was recommended for all the groups except psoas and rectus femoris muscles, which is in agreement with the experience of Cook et al. (2002). The 2 other studies (DeLuca et al. 1997, Kay et al. 2000) differed in that gastrocnemius lengthening procedures were recommended more often. This may reflect a change of surgical policy, since these studies were published some years earlier.

All the patients in the study of DeLuca et al. (1997) had diplegia, whereas the patients evaluated by Kay et al. (2000) had a mixture of neuromuscular diseases (mostly cerebral palsy classified as diplegia). No distinction between hemiplegia and diplegia was given by Cook et al. (2002). Our study seems to be the only one that has evaluated the need for preoperative gait analysis in patients with hemiplegia. The agreement between clinical judgement and gait analysis recommendations was somewhat better in patients with hemiplegia (64%) than in patients with diplegia (48%), but the difference was not statistically significant. There were only 14 patients with hemiplegia, which makes the results somewhat uncertain, and further studies will be necessary before final conclusions can be drawn. The number of proposed surgical procedures per affected limb was higher in the group with diplegia than in the group with hemiplegia, and the decision making process is probably more difficult with an increasing number of potential procedures. Thus, our experience indicates that gait analysis in preoperative decision making is more important for patients with diplegia than for patients with hemiplegia.

Only 2 previous studies have analyzed the discrepancy between gait laboratory recommendations and the specific surgical procedures that were actually performed. The results vary considerably, from an agreement rate of 51% (Kay et al. 2000) to one of 93% (Wren et al. 2005). One reason for the discrepancy could be that both of these studies included a mixture of neuromuscular diseases (mostly cerebral palsy). However, the main reason for the better agreement in the study of Wren et al.

(2005) was probably that most of the patients were operated on by the same orthopedic surgeon, who was a member of the team that drew conclusions and recommendations after the gait analysis. We had a similar arrangement in our study and a high agreement rate of 92% between recommendations and procedures performed, and there was no significant difference in agreement rate between the orthopedic surgeon on the gait analysis team and the other surgeons. The agreement rate between the clinical proposals of the referring surgeons and the procedures actually performed was only 52%. This means that surgeons, whether they are part of the gait analysis team or not, seriously consider the treatment recommendations from the gait analysis in surgical decision making. We usually discuss the recommendations of the gait analysis at a meeting with the surgeon who will perform the operation. In this way, our treatment plan is probably better understood by the surgeon than if delivered as an ordinary report, and it is more likely that the recommendations will be followed.

Electromyography (EMG) as part of the gait analysis was used by Kay et al. (2000). They used EMG together with kinematics in evaluation of rectus femoris. DeLuca et al. (1997) stated that EMG had a minimal role when they considered rectus femoris surgery, and that hamstring EMG did not affect their decision making. In a retrospective study on rectus femoris dysfunction in cerebral palsy (Marks et al. 2003), there was good correlation between abnormal EMG activity and kinematic pathology (reduced dynamic range of knee motion and delayed peak knee flexion in swing). With this background, it seems that EMG does not change the assessment substantially and may not be necessary in routine preoperative gait analysis.

We have not shown that the outcome after treatment will be improved by the recommendations of gait analysis, but we believe that the additional information and multidisciplinary approach has been of benefit in the preoperative planning for children with spastic CP, to ensure that they receive optimal treatment at the right time. We also consider that it would be ethically difficult to perform a study where one group was operated according to gait analysis recommendations and another group was operated according surgical proposals only, and

then to compare the results. 24 of our 60 patients had undergone previous orthopedic surgery before we introduced gait analysis as a preoperative routine (Table 1). 11 of the 24 patients had been operated twice and none of the patients had had psoas tenotomy or rectus femoris transfer. Preoperative gait analysis has changed treatment policy from staged surgical procedures to multilevel surgery (DeLuca 1991, Gage 1994), and surgical history indicates that some of these 24 patients would have benefited from multilevel surgery.

The experience of our gait analysis assessment team was somewhat limited. The members were experienced clinicians, however, and by using the same set of personnel and making team conclusions we had probably reached an adequate level of expertise before the start of this study. By doing so, we also reduced the chance of interobserver variation, which is clearly possible if several separate observers are involved, however experienced they may be (Skaggs et al. 2000).

Contributions of authors

BL: leader of the study and first author. TT: member of the multidisciplinary team, co-writer and supervisor of first author. IS, A-BH, RJ: all members of the multidisciplinary team, collected data and critically discussed the manuscript.

No competing interests declared.

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