Full length article

Impact of gait analysis on pathology identification and surgical recommendations in children with spina bifida

Nicole M. Mueske[a,*], Sylvia Õunpuu[b], Deirdre D. Ryan[a], Bitte S. Healy[a], Jeffrey Thomson[b], Paul Choi[a], Tishya A.L. Wren[a]

[a] *Children's Hospital Los Angeles, Los Angeles, CA, USA*
[b] *Connecticut Children's Medical Center, Hartford, CT, USA*

A B S T R A C T

Background: Gait analysis provides quantitative data that can be used to supplement standard clinical evaluation in identifying and understanding gait problems. It has been established that gait analysis changes treatment decision making for children with cerebral palsy, but this has not yet been studied in other diagnoses such as spina bifida.

Research question: To determine the effects of gait analysis data on pathology identification and surgical recommendations in children with spina bifida.

Methods: Two pediatric orthopaedic surgeons and two therapists with > 10 years of experience in gait analysis reviewed clinical, video, and gait analysis data from 43 ambulatory children with spina bifida (25 male; mean age 11.7 years, SD 3.8; 25 sacral, 18 lumbar). Primary gait pathologies were identified by each assessor both before and after consideration of the gait analysis data. Surgical recommendations were also recorded by the surgeons before and after consideration of the gait analysis data. Frequencies of pathology and surgery identification with and without gait analysis were compared using Fisher's exact test, and percent change in pathology and surgery identification was calculated.

Results: Pathology identification often changed for common gait problems including crouch (28% of cases), tibial rotation (35%), pes valgus (18%), excessive hip flexion (70%), and abnormal femur rotation (75%). Recognition of excessive hip flexion and abnormal femur rotation increased significantly after consideration of gait analysis data (p < 0.05). Surgical recommendations also frequently changed for the most common surgeries including tibial derotation osteotomy (30%), antero-lateral release (22%), plantar fascia release (33%), knee capsulotomy (25%), 1st metatarsal osteotomy (60%), and femoral derotation osteotomy (89%). At the patient level, consideration of gait analysis data altered surgical recommendations for 44% of patients.

Significance: Since gait analysis data often changes pathology identification and surgical recommendations, treatment decision making may be improved by including gait analysis in the patient care process.

1. Introduction

Spina bifida is a congenital neural tube defect where the spinal column fails to form or close properly in utero, potentially damaging the spinal cord and meninges. Children with the most common and severe forms of spina bifida, myelomeningocele and lipomyelomeningocele, often exhibit complex gait abnormalities due to varying degrees of lower extremity weakness, paralysis, and torsional deformities [1,2]. Accurate identification of gait pathologies and their underlying causes is crucial to managing patients with spina bifida and maintaining their ambulatory and functional abilities [3]. Management often involves surgical intervention and may include three-dimensional (3D) gait analysis, which can provide important quantitative information about a patient's movement patterns.

Clinical gait analysis typically includes 3D kinematics, kinetics, and electromyography (EMG) along with comprehensive physical examination. Compared to observation and physical examination alone, gait analysis can help clinicians characterize a patient's function more objectively and completely. A primary advantage of 3D gait analysis is the ability to quantify joint and segment movement in all three planes throughout the gait cycle (stance and swing). This information can help clinicians to identify gait deviations that are difficult and, in many

Table 1
Pathology identification frequency by surgeons and therapists with and without gait analysis data.

	Surgeons		Therapists		p-value Surgeons vs. Therapists	
	Video	GA	Video	GA	Video	GA
Crouch	76 (44%)	90 (52%)	112 (65%)	100 (58%)	< 0.001	0.33
Recurvatum	2 (1%)	4 (2%)	2 (1%)	2 (1%)	1.00	0.69
Genu Valgum	13 (8%)	13 (8%)	62 (36%)	33 (19%)	< 0.001	0.002
Genu Varum	2 (1%)	5 (3%)	2 (1%)	2 (1%)	1.00	0.45
Stiff Knee	10 (6%)	14 (8%)	50 (30%)	51 (31%)	< 0.001	< 0.001
Hip Flexion	19 (11%)	78 (45%)	22 (13%)	37 (22%)	0.74	< 0.001
Hip Adduction	5 (3%)	6 (3%)	7 (4%)	7 (4%)	0.77	1.00
Hip Abduction	0 (0%)	11 (6%)	0 (0%)	0 (0%)	—	0.001
Tibial Rotation	72 (42%)	78 (45%)	78 (45%)	64 (37%)	0.59	0.15
Femur Rotation	11 (6%)	50 (29%)	29 (17%)	47 (27%)	0.004	0.81
Equinus	11 (6%)	15 (9%)	8 (5%)	11 (6%)	0.64	0.54
Calcaneus	15 (9%)	18 (10%)	34 (20%)	38 (22%)	0.005	0.005
Pes Varus	17 (10%)	16 (9%)	27 (16%)	27 (16%)	0.15	0.10
Pes Valgus	41 (24%)	42 (24%)	70 (41%)	65 (38%)	0.001	0.01
Cavus	11 (6%)	12 (7%)	36 (21%)	37 (22%)	< 0.001	< 0.001

Percentages are calculated based on 172 observations (86 sides × 2 assessors per group).

cases, impossible to appreciate through observation alone. For example, femoral and tibial torsion are common problems in children with spina bifida and contribute to abnormal rotational profiles during gait; however, rotational profiles are difficult to assess visually both during live observation and on 2D video. If rotational problems are not identified correctly, derotational osteotomies may be performed inappropriately or the rotational issue may be missed altogether resulting in the need for additional surgery at a later date. Additionally, gait pathologies are often multi-level, involving multiple joints and anatomic structures which are difficult to evaluate simultaneously. Finally, gait pathologies may be asymmetric adding to the complexity of understanding gait function. 3D gait analysis provides additional objective information that is not otherwise available [4,5] to assist clinicians in pathology identification and treatment decision making.

Multiple studies have demonstrated a large effect of gait analysis on treatment decision making in children with cerebral palsy. Surgical and non-surgical treatment plans change in 52–89% of patients after consideration of gait analysis data [6–10]. The changes affect 40–51% of surgical procedures, including both cancellation of planned procedures and addition of procedures that were not previously planned [7,10]. Gait analysis likely has a similar effect in other patient groups, but similar studies have not yet been conducted for other populations. The purpose of this study was to examine the effects of gait analysis on pathology identification and surgical treatment recommendations in children with spina bifida.

2. Methods

This study retrospectively reviewed data from a convenience sample of 43 ambulatory children with spina bifida (25 male, 18 female; mean age 11.7 years, SD 3.8, range 3.9 to 17.7; 39 myelomeningocele, 4 lipomyelomeningocele; 25 sacral, 18 lumbar) who were previously seen for clinical gait analysis at one of two pediatric hospitals between 2000–2010. As part of standard care, these children underwent a clinical gait analysis which included range of motion and strength testing, kinematics and kinetics during walking, and dynamic EMG. All data was accessed under a waiver of consent granted by each hospital's institutional review board (IRB). All study procedures were conducted in accordance with those approved by each hospital's respective IRB.

The available patient data were reviewed by one pediatric orthopaedic surgeon and one therapist (kinesiologist or physical therapist) from each of the two sites (4 assessors total). All of the assessors had at least 10 years of experience evaluating children with neuromuscular disorders including spina bifida in a clinical gait laboratory. Initially,

assessments were performed based on video and physical examination data only, without gait analysis data. The assessments were then repeated with the addition of gait analysis data which included kinematics, kinetics, surface EMG, and temporal spatial parameters; additionally pedobarograph was available for some patients. All assessors identified primary gait pathologies from a checklist (see Supplementary Material) both before and after review of the gait analysis data. The surgeons also identified surgical treatment recommendations before and after gait analysis. The overall recommendation of whether surgery was needed was done at the patient level, but individual pathologies and surgical procedures were specified separately for each limb.

The frequency with which surgeons and therapists identified each gait pathology or surgery was compared between the assessments with and without gait analysis using 2-sided Fisher's exact tests. Fisher's exact test was also used to compare pathology identification between surgeons and therapists. To evaluate changes in pathology identification and surgical recommendations within individual patients, percent change was calculated by dividing the number of cases in which the pathology identification or surgical recommendation changed (added or dropped) by the number of cases where the pathology or surgery was identified either before or after gait analysis (or both).

3. Results

3.1. Gait pathology identification

Surgeons and therapists identified similar gait pathologies. Prior to consideration of gait analysis data, both identified crouch (44% and 65%), tibial rotation (42% and 45%), and pes valgus (24% and 41%) as the most common pathologies (Table 1). Therapists identified pathologies more often than surgeons, with significant differences being observed for crouch, genu valgum, stiff knee, femur rotation, calcaneus, pes valgus, and cavus (p < 0.01). After consideration of the gait analysis data, both groups also identified abnormal hip flexion (45% and 22%) and femur rotation (29% and 27%) as common problems in addition to crouch, tibial rotation, and pes valgus. Therapists continued to identify pathologies more often for genu valgum, stiff knee, calcaneus, pes valgus, and cavus (p ≤ 0.01) although excessive hip flexion (45% vs. 22%, p < 0.001) and abduction (6% vs. 0%, p = 0.001) were identified more often by surgeons.

In terms of frequency of pathology identification, gait analysis increased the identification of excessive hip flexion and abnormal femur rotation for both surgeons and therapists (p < 0.05) (Table 2). Gait analysis also increased the identification of abnormal hip abduction

Table 2

Comparison of pathology identification change with and without gait analysis data.

	Video	GA	p-value	No Change	Change +	–	% Change
SURGEONS							
Crouch	76 (44%)	90 (52%)	0.16	68	22	8	31%
Recurvatum	2 (1%)	4 (2%)	0.69	2	2	0	50%
Genu Valgum	13 (8%)	13 (8%)	1.00	5	8	8	76%
Genu Varum	2 (1%)	5 (3%)	0.45	0	5	2	100%
Stiff Knee	10 (6%)	14 (8%)	0.53	5	9	5	74%
Hip Flexion	19 (11%)	78 (45%)	< **0.001**	17	61	2	79%
Hip Adduction	5 (3%)	6 (3%)	1.00	3	3	2	63%
Hip Abduction	0 (0%)	11 (6%)	**0.001**	0	11	0	100%
Tibial Rotation	72 (42%)	78 (45%)	0.59	62	16	10	30%
Femur Rotation	11 (6%)	50 (29%)	< **0.001**	6	44	5	89%
Equinus	11 (6%)	15 (9%)	0.54	10	5	1	38%
Calcaneus	15 (9%)	18 (10%)	0.72	12	6	3	43%
Pes Varus	17 (10%)	16 (9%)	1.00	13	3	4	35%
Pes Valgus	41 (24%)	42 (24%)	1.00	37	5	4	20%
Cavus	11 (6%)	12 (7%)	1.00	11	1	0	8%
THERAPISTS							
Crouch	112 (65%)	100 (58%)	0.22	90	10	22	26%
Recurvatum	2 (1%)	2 (1%)	1.00	1	1	1	67%
Genu Valgum	62 (36%)	33 (19%)	**0.001**	27	6	35	60%
Genu Varum	2 (1%)	2 (1%)	1.00	0	2	2	100%
Stiff Knee	50 (30%)	51 (31%)	1.00	31	20	19	100%
Hip Flexion	22 (13%)	37 (22%)	**0.045**	19	198	3	56%
Hip Adduction	7 (4%)	7 (4%)	1.00	3	4	4	53%
Hip Abduction	0 (0%)	0 (0%)	—	0	0	0	73%
Tibial Rotation	78 (45%)	64 (37%)	0.15	53	11	25	40%
Femur Rotation	29 (17%)	47 (27%)	**0.03**	21	26	8	62%
Equinus	8 (5%)	11 (6%)	0.64	7	4	1	42%
Calcaneus	34 (20%)	38 (22%)	0.69	31	7	3	24%
Pes Varus	27 (16%)	27 (16%)	1.00	26	1	1	7%
Pes Valgus	70 (41%)	65 (38%)	0.66	61	4	9	18%
Cavus	36 (21%)	37 (22%)	1.00	36	1	0	3%

Percentages are calculated based on 172 observations (86 sides × 2 assessors per group).

% Change was calculated by dividing the number of cases in which the pathology identification changed (added or dropped) by the number of cases where the pathology was identified either before or after gait analysis (or both). For example, for the first row Surgeons Crouch (22 added + 8 dropped) / (22 added + 8 dropped + 68 with problem identified and no change after GA) = 30 / 98 = 31%.

among surgeons (p = 0.03) and decreased the identification of genu valgum among therapists (p = 0.001). At the individual level, pathology identification changed after consideration of gait analysis data in a high percentage of cases for almost all pathologies among both surgeons and therapists. For the most common pathologies, pathology identification changed in at least 18% of cases for both surgeons and therapists (overall change 28% for crouch, 35% for tibial rotation, 19% for pes valgus, 70% for abnormal hip flexion, and 75% for femur rotation for surgeons and therapists combined).

3.2. Surgical recommendations

Based on video and clinical evaluation data alone, surgery on at least one limb was recommended in 57% (49/86) of cases, where each of the 43 patients was assessed by each of the two assessors (Table 3). Consideration of gait analysis data resulted in the recommendation for surgery being dropped in 3 cases and surgery being recommended in 7 additional cases. Thus, surgery was recommended before or after gait analysis in 56 cases, and the overall recommendation of whether surgery was needed changed in 18% (10/56) of these cases. There was at least one change in the surgical plan for 18/43 patients (42%) by Surgeon 1 and for 12/43 patients (28%) by Surgeon 2, with 19/43 (44%) of patients having a change in surgical plan by at least one surgeon.

The most commonly recommended surgeries both with and without gait analysis were tibial derotation osteotomy, midfoot osteotomy, antero-lateral release (tenotomy of the tibialis anterior tendon and extensor tendons at the level of the ankle), plantar fascia release, knee capsulotomy, 1st metatarsal osteotomy, and femoral derotation osteotomy (Table 3). For all of these procedures except midfoot osteotomy, the surgical recommendation was altered by consideration of gait analysis data more than 20% of the time. The most frequent changes by percentage involved femoral derotation osteotomy (89%), 1st metatarsal osteotomy (60%), plantarfascia release (33%), and tibial derotation osteotomy (30%). The most frequent changes by number were for tibial derotation osteotomy (17/57). Procedures were both added and dropped such that the overall frequency with which individual procedures were recommended was not altered by gait analysis.

4. Discussion

Children with spina bifida often have multiple gait abnormalities that are complex and interrelated, making it difficult to determine primary pathologies using visual assessments alone. For treatments to be prescribed appropriately, gait pathologies must be accurately identified. Gait analysis gives clinicians additional information to be able to more accurately and objectively determine primary pathologies based on quantitative data regarding function in terms of joint and segment kinematics and joint kinetics. Gait analysis has helped shift the orthopaedic management of pathologies from a radiographic perspective to a focus on function [11,12].

Past researchers have shown the utility of gait analysis in identification of differences in kinematic profiles in spina bifida [5,11,13]; however, to our knowledge, this study is the first to systematically assess the effect of gait analysis data on pathology identification and

Table 3
Comparison of surgical recommendations with and without gait analysis data.

	Video	Gait	P-value	No Change	Change +	Change –	% Change
Surgery recommended[a]	49 (57%)	53 (62%)	0.44	46	7	3	18%
Tibial derotation osteotomy	47 (27%)	50 (29%)	0.81	40	10	7	30%
Midfoot osteotomy	12 (7%)	12 (7%)	1.00	12	0	0	0%
Antero-lateral release	8 (5%)	8 (5%)	1.00	7	1	1	22%
Plantarfascia release	8 (5%)	7 (4%)	1.00	6	1	2	33%
Knee capsulotomy	6 (3%)	8 (5%)	0.79	6	2	0	25%
1st metatarsal osteotomy	6 (3%)	8 (5%)	0.79	4	4	2	60%
Femoral derotation osteotomy	2 (1%)	8 (5%)	0.10	1	7	1	89%

Results are shown for procedures recommended in at least 5% of cases before or after gait analysis.

% Change was calculated by dividing the number of cases in which the surgical recommendation changed (added or dropped) by the number of cases where the surgery was identified either before or after gait analysis (or both). For example, for Tibia Derotation Osteotomy (10 added + 7 dropped) / (10 added + 7 dropped + 40 with problem identified and no change after GA) = 17 /57 = 30%.

[a] Percentages are calculated based on 172 observations (86 sides × 2 assessors) except for the overall recommendation of surgery which was based on 86 observations (43 patients × 2 assessors).

treatment recommendations. In this study, we found that abnormal femoral rotation (internal or external hip rotation) and excessive hip flexion were often identified as primary gait pathologies only after the addition of gait analysis data. Even for experienced professionals with more than 10 years of experience evaluating children with neuromuscular disorders in a gait laboratory, determining femoral rotation from visual observation alone is difficult in these patients due to complex simultaneous rotational profiles during gait, which may include large transverse plane rotations of the pelvis in some patients [14]. Visual assessment of hip flexion is also challenging because of the difficulty appreciating pelvic sagittal plane motion (one component of the hip angle), which may be large and changing throughout the gait cycle in some patients [14].

Additionally, the observation of a visual valgus thrust, which can be comprised of abnormalities in all three planes (internal hip and pelvic rotation, knee flexion, and external foot progression), is difficult to discern and separate for treatment with visual assessment alone [15]; this is likely why the change in identification of genu valgum and hip abduction were observed. The coronal plane moment data provides definitive evidence of the presence of an actual knee valgus thrust and not the visual assessment from a frontal view video. The rapid internal pelvic and hip rotation provide a visual impression of hip adduction and knee valgus load, however, the simultaneous lateral trunk lean actually results in hip abduction. This explains the increase in hip abduction identification with the addition of motion analysis. The addition of the knee coronal plane moment also explains the large number of sides where the valgus thrust (genu valgum) was added or removed as an issue.

The other common pathologies such as crouch, tibial rotation and associated foot progression, and pes valgus could often be recognized based on physical examination and visual assessment and thus did not show as many changes as a result of the addition of gait analysis. However, less experienced practitioners may have more difficulty recognizing these pathologies than the highly specialized and experienced clinicians in this study. The foot/ankle model used in this study does not allow for detailed measurement of the foot except for foot progression, and so gait [6–8,10] analysis does not provide additional understanding of foot pathology which would require use of a more complex foot model such as a multi-segment foot [16–18]. However, the identification of these pathologies still changed frequently for individual patients (18–40% of the time). For the subset of patients with pedobarograph data, the change in recommendations for procedures at the foot may be a result of this data which highlights abnormalities in foot pressures and adductus deformity which may have been masked by proximal transverse plane deformity and abnormal movement.

The therapists in this study tended to identify more gait pathologies than the orthopaedic surgeons. This may be because the therapists identified all abnormalities they observed or those that may be treated with non-surgical modalities (strengthening, stretching, bracing, etc.), while the surgeons tended to focus on problems requiring surgical intervention. Regardless of the differences in frequency of pathology identification, surgeons and therapists found the same pathologies to be most common and had a similar response to the gait analysis data, increasing identification of excessive hip flexion and abnormal femoral rotation. These findings suggest a possible benefit of a multidisciplinary review of gait and clinical data for treatment decision-making.

In terms of treatment decision making, it is clear that gait analysis data frequently alters surgical recommendations. The decision of whether or not surgery was needed changed in 18% of cases, and at least one change was made to the specific surgical recommendations for 44% of patients. Recommendations for the most common individual surgical procedures changed 22–89% of the time. It is important to highlight that the gait analysis often not only added surgical recommendations, but also recommended dropping procedures. Not performing a necessary surgery at an optimal time point is not an ideal treatment; however, performance of unnecessary surgeries can be detrimental. The overall amount of surgery did not change with gait analysis, but the specific procedures recommended for individual patients often did change.

Strengths of this study include the involvement of both surgeons and therapists from two different centers and their high level of expertise interpreting gait analysis data for children with spina bifida and other neuromuscular disorders. Limitations include the retrospective convenience sample of patients and limited sample size. Also, patients of varying levels of lesion from sacral to lumbar were analyzed together. It is possible that those patients with a higher level of lesion who would have greater gait complexity would show even more changes in identification of gait pathology and surgical recommendations following review of the gait analysis data.

In conclusion, we found that surgical recommendations changed for 44% of patients and 22–89% of the time for the most common surgical procedures after consideration of gait analysis data. Gait analysis may be particularly helpful in identifying abnormal femoral rotation and excessive hip flexion.

Conflict of interest statement

Acknowledgements

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