Effects of Preoperative Gait Analysis on Costs and Amount of Surgery

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Background: The purpose of this study was to determine the effects of clinical gait analysis (GA) on the costs of care in ambulatory children with cerebral palsy (CP) and the amount of surgery these children undergo.

Methods: A retrospective review identified all ambulatory patients with CP who had undergone lower extremity orthopaedic surgery at our hospital from 1991 to 2005 with at least a 6-month follow-up. The patients were grouped into those who had undergone GA before their index surgery (GA group, N = 313) and those who had not (NGA group, N = 149). The groups were compared in terms of the number of procedures during index surgery and subsequent surgeries and the direct costs associated with these surgeries. Costs were calculated in US dollars by using a standardized protocol including fees for the surgeon, anesthesia, operating room, hospital stay, physical therapy, and GA.

Results: Patients in the GA group were significantly older and less functionally involved, had their first surgery in later years, and had a shorter follow-up than patients in the NGA group ($P < 0.001$). Adjusting for these differences, patients in the GA group had more procedures (GA: 5.8, NGA: 4.2; $P < 0.001$) and higher cost (GA: \$43,006, NGA: \$35,215; $P < 0.001$) during index surgery, but less subsequent surgery. A higher proportion of patients went on to additional surgery in the NGA group (NGA: 32%, GA: 11%; $P < 0.001$), with more additional surgeries per person-year (NGA: 0.3/person-year, GA: 0.1/person-year; $P < 0.001$) resulting in higher additional costs (NGA: \$3009/person-year, GA: \$916/person-year; $P < 0.001$). The total number of procedures (GA: 2.6/person-year, NGA: 2.3/person-year; $P = 0.22$) and cost (GA: \$20,448/person-year, NGA: \$19,535/person-year; $P = 0.58$) did not differ significantly between the 2 groups.

Conclusions: Clinical GA is associated with a lower incidence of additional surgery, resulting in lesser disruption to patients' lives. This finding has not been shown before and may assist patients, physicians, policy makers, and insurance companies in assessing the role of GA in the care of ambulatory children with CP.

Level of Evidence: Level III, retrospective comparative study.

Key Words: cerebral palsy, cost analysis, efficacy, gait analysis

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Orthopaedic surgical intervention to correct gait problems has traditionally been performed in a staged manner, addressing one deformity at a time.[1] For many patients, this has resulted in having surgery every few years, a practice commonly referred to as the "birthday syndrome."[1,2] Repeated surgical interventions and the associated rehabilitation can be very disruptive to patients and their families, interfering with participation in school, work, and social activities. These disruptions are compounded by the direct physical and psychologic burden of undergoing and having to recover from multiple surgeries over a period of years.

Computerized gait analysis (CGA) has made possible an alternative approach in which multiple deformities are addressed simultaneously.[3,4] By providing objective measurements of 3-dimensional kinematics and kinetics, and dynamic electromyography (EMG), CGA allows simultaneous assessment of multiple joints in multiple planes of motion. This has enabled orthopaedic surgeons to better identify the causes of gait problems and to intervene at multiple levels simultaneously (an approach called single event, multilevel surgery). The intent is to accurately identify a comprehensive surgical plan, to decrease the need for multiple, staged surgeries. CGA may also reduce the costs of care as commonly performed surgeries have much higher costs when performed in a staged manner compared with single event, multilevel surgery.[5]

It has been clearly documented that CGA alters surgical decision making and changes the treatment that patients receive.[6–10] However, the implications of these changes in terms of cost and the amount of surgery performed have not been documented. Therefore, the purpose of this large retrospective study was to determine the effects of CGA on the costs of care in ambulatory children with cerebral palsy (CP) and the amount of surgery that these children undergo.

TABLE 1. Comparison of Demographic and Clinical Characteristics Between GA and NGA Groups

Variable	Statistic	GA Group N = 313	NGA Group N = 149	P
Sex	Male	163 (52%)	91 (61%)	0.073
	Female	150 (48%)	58 (39%)	
Age (y)	Mean ± SD	9.9 ± 3.7	8.1 ± 4.0	< 0.001
Race	Asian	18 (6%)	8 (5%)	0.778
	Black	40 (13%)	22 (15%)	
	White	67 (21%)	33 (22%)	
	Hispanic	129 (41%)	53 (36%)	
	Other	59 (19%)	33 (22%)	
CP subtype	Hemiplegic	87 (28%)	33 (22%)	< 0.001
	Diplegic	171 (54%)	47 (32%)	
	Quadriplegic	52 (17%)	52 (35%)	
	Not specified	3 (1%)	17 (11%)	
Ambulatory state	Independent	185 (59%)	49 (33%)	< 0.001
	Assisted	128 (41%)	100 (67%)	
GMFCS	1	77 (25%)	18 (12%)	< 0.001
	2	154 (49%)	62 (42%)	
	3	74 (24%)	62 (42%)	
	4	8 (3%)	7 (5%)	
Date of first surgery	Median (range)	June 23, 2000 (September 23, 1991 to November 22, 2005)	February 6, 1998 (January 2, 1991 to December 6, 2005)	< 0.001
Duration of follow-up (y)	Median (range)	2.7 (0.5-12.6)	4.0 (0.6-15.8)	< 0.001

Means were compared by using the nonparametric Wilcoxon test. Medians were compared by using the nonparametric median test. Categorical variables were compared by using the Fisher exact test.

CP indicates cerebral palsy; GA, gait analysis; GMFCS, Gross Motor Function Classification System; NGA, no gait analysis.

METHODS

A retrospective review was conducted to identify all ambulatory patients with CP who had undergone lower extremity orthopaedic surgery at our hospital between 1991 and 2005 with at least a 6-month follow-up. Most of the surgeries were performed by 11 primary surgeons (surgeons coded as "other" operated on a total of 29 patients). Baseline demographic and clinical data were abstracted, along with whether the patient had undergone a clinical GA study, the number of procedures carried out during index surgery and subsequent surgeries, and the duration of follow-up.

The demographic and clinical characteristics examined included sex, age, race, CP subtype, ambulatory status, and Gross Motor Function Classification System (GMFCS) level. The primary outcomes examined included the number of procedures during index surgery, the number of additional procedures per person-year after index surgery, the total number of procedures per person-year, and the direct costs associated with these surgeries. Only lower extremity orthopaedic surgeries were included; upper extremity procedures or non-orthopaedic surgeries were not counted.

Costs were calculated in US dollars and were based on hospital charges. A standardized protocol was used as the actual charges for a surgery could vary due to changes in medical and billing practices over time. For example, in the past 15 years, there has been a trend toward shorter hospital stays and a change in how surgical charges are discounted. The direct costs in our study included the following: (1) surgeon's fees, (2) anesthesia fees, (3) operating room fees, (4) hospital stay fees, (5) physical therapy fees, and (6) GA fees. These costs were calculated by using our hospital's 2007 charge-master and standard billing practices. The surgeon's fees were based on the Resource-based Relative Value Scale values published by Medicare, with the standard 50% discount for all procedures after the first procedure. Anesthesia and operating room fees were based on an estimated usage time of surgery duration and an additional half an hour. The length of the hospital stay was standardized to 1 day for unilateral soft tissue, foot, or patella surgery, 3 days for varus derotation osteotomy of the femur with concomitant procedures, and 2 days for all other surgeries. Physical therapy was standardized to 33 visits (2 to 3 times per week for 3 mo) for soft tissue surgery and 65 visits (2 to 3 times per week for 6 mo) for surgery involving bone procedures. GA fees included charges for physical therapy evaluation, slow motion video analysis, instrumented GA, and dynamic EMG assuming that

TABLE 2. Comparison of the Amount of Surgery Between GA and NGA Groups

Amount of Surgery Indicator	Statistic	GA Group (N = 313)	NGA Group (N = 149)	P
No. procedures during first surgical session	Adjusted mean ± SEM median (range)	5.8 ± 0.2 5 (1-16)	4.2 ± 0.3 4 (1-14)	< 0.001
Additional surgery	% (#) No	89% (279)	68% (101)	< 0.001
	% (#) Yes	11% (34)	32% (48)	
No. Additional procedures per person-year	Adjusted mean ± SEM median (range)	0.1 ± 0.03 0.0 (0.0-2.6)	0.3 ± 0.04 0.0 (0.0-3.3)	< 0.001
Total no. procedures per person-year	Adjusted mean ± SEM median (range)	2.6 ± 0.1 1.9 (0.2-19.5)	2.3 ± 0.2 1.3 (0.1-10.2)	0.218

Means were adjusted for covariates by using parametric (raw data) GLM and compared between groups by using nonparametric (rank data) GLM. The covariates were age, GMFCS level, and year of first surgery. Categorical variables were compared by using the Fisher exact test (unadjusted).

GA indicates gait analysis; GLM, general linear model; GMFCS, Gross Motor Function Classification System; NGA, no gait analysis.

TABLE 3. Additional Surgical Procedures in GA and NGA Groups

Procedure	GA Group	NGA Group
Adductor lengthening	8	15
Psoas lengthening	3	7
Pelvic osteotomy	1	2
Varus derotation osteotomy	3	18
Distal femoral osteotomy	11	12
Hamstring lengthening (with or without capsulotomy)	21	32
Triceps surae lengthening	13	28
Other tendon lengthening (foot)	3	10
Tendon transfers (foot)	9	7
Distal tibial osteotomy	14	9
Foot osteotomy	26	15
Subtalar fusion	4	2
Hindfoot capsulotomy	3	8
Toe fusion	2	0
Plantar fasciotomy	1	2
Hardware removal	3	7
Total	125	174

GA indicates gait analysis; NGA, no gait analysis.

50% of patients had braces, 10% had force analysis, and 10% required fine-wire EMG.

Each demographic or baseline clinical characteristic was compared between patients who had undergone GA testing before index surgery (GA group) and patients who had surgery without GA testing (NGA group) by using univariate parametric or nonparametric tests as appropriate. The general linear model was used to derive adjusted means and standard errors (SEM) for the outcome measures, controlling for the variables identified by the univariate analysis as differing significantly between the GA and NGA groups (significant risk factors). As the data were not normally distributed, the nonparametric general linear model using rank data was used to determine the statistical significance of the adjusted difference of the outcome measures between the 2 groups.

The Cox proportional hazard model was also used to study the probability of remaining free from additional surgery, adjusting for the significant risk factors. Cox analysis was also performed for each GMFCS level in which GA (GA vs. NGA) was the primary independent factor.

RESULTS

The study cohort consisted of 462 ambulatory patients with CP; 313 had undergone GA testing before their index surgery (GA group), and 149 had surgery without GA (NGA group). The sample size for the cost analyses was 308 in the GA group and 132 in the NGA group (440 total). Costs could not be calculated for the remaining 22 patients due to missing information (primarily duration of surgery).

Patients in the GA group were significantly older at the first surgical session, were less functionally involved in terms of CP subtype, ambulatory status, and GMFCS level, had their first surgery in later years, and had shorter follow-up ($P < 0.001$) (Table 1). These factors were therefore adjusted for in the outcome assessments, using GMFCS level to account for severity of involvement.

Patients in the GA group had more procedures performed during index surgery (5.8 for GA vs. 4.2 for NGA, $P < 0.001$) (Table 2). However, a higher proportion of patients went on to additional surgery in the NGA group (32% for NGA vs. 11% for GA, $P < 0.001$) (Table 3). Patients in the NGA group had more surgeries per person-year after the index surgery, with an average of 0.3 (range: 0 to 3.3) additional procedures per person-year in the NGA group compared with 0.1 (range: 0 to 2.6) in the GA group ($P < 0.001$). The total number of procedures per person-year did not differ significantly between the 2 groups after adjusting for covariates ($P = 0.22$).

Costs for the initial surgery were higher in the GA group ($43,006 for GA vs. $35,215 for NGA, $P < 0.001$) (Table 4). However, the costs associated with subsequent surgeries were higher in the NGA group ($3009/person-year for NGA vs. $916/person-year for GA, $P < 0.001$). The breakdown of the additional costs was the same in both groups: 14% for the surgeon, 3% for anesthesia, 17% for the operating room, 29% for the hospital stay, and 37% for rehabilitation (physical therapy). There was no significant difference in the total cost per person-year

TABLE 4. Comparison of Costs Between GA and NGA Groups

Cost Indicator	Statistic	GA Group (N = 308)	NGA Group (N = 132)	P
Cost in first surgical session	Adjusted mean ± SEM	$43,006 ± 572	$35,215 ± 900	< 0.001
	Median	$41,906	$32,989	
	Range	($21,261-$69,628)	($18,097-$71,415)	
Additional cost per person-year	Adjusted mean ± SEM	$916 ± 286	$3009 ± 450	< 0.001
	Median	$0	$0	
	Range	($0-$26,800)	($0-$45,678)	
Total cost per person-year	Adjusted mean ± SEM	$20,448 ± 861	$19,535 ± 1355	0.581
	Median	$17,614	$11,216	
	Range	($2906-$95,229)	($1577-$94,638)	

Means were adjusted for covariates by using parametric (raw data) GLM and compared between groups by using nonparametric (rank data) GLM. The covariates were age, GMFCS level, and year of first surgery. Costs could not be calculated for 22 patients due to missing information.

GA indicates gait analysis; GLM, general linear model; GMFCS, Gross Motor Function Classification System; NGA, no gait analysis.

TABLE 5. Cox Proportional Hazard Model Results for Probability of Having Additional Surgery (N = 462)

Variable	Adjusted Hazard Ratio (95% Confidence Interval)	Adjusted *P*
Gait analysis (NGA group vs. GA group)	2.10 (1.32, 3.35)	0.002
GMFCS (per level increase)	1.37 (1.02, 1.84)	0.035
Age at first surgery (per year increase)	1.00 (0.94, 1.07)	0.975
Year of first surgery (per year increase)	0.99 (0.93, 1.06)	0.776

GA indicates gait analysis; GMFCS, Gross Motor Function Classification System; NGA, no gait analysis.

after adjusting for covariates ($20,448/person-year for GA vs. $19,535/person-year for NGA, $P = 0.58$).

The Cox analysis also indicated a greater likelihood of additional surgery in the NGA group (Table 5). Patients in the NGA group were twice as likely to have undergone additional surgery compared with patients in the GA group (adjusted hazard ratio = 2.1, $P = 0.002$) (Fig. 1A). The probability of undergoing additional surgery also increased with GMFCS level ($P = 0.035$) (Fig. 1B). Within each GMFCS level, similar results were observed with hazard ratios ranging from 1.6 to 3.9 (Fig. 2). Owing to reduced sample size, the stratified results were only statistically significant for GMFCS level 3 ($P = 0.008$).

DISCUSSION

This study indicates a benefit of clinical GA, namely, a reduction in the rate of subsequent surgery. Patients with CP who underwent preoperative GA had more procedures done during the initial surgery and therefore higher initial costs. However, annual costs after the initial surgery were reduced significantly due to a decrease in the rate of additional surgery. The overall result was no change in the total costs. On the basis of results of Ounpuu et al,[5] which showed much higher costs for common surgical combinations when performed in a staged manner compared with single event multilevel surgery, we expected patients with GA to have lower overall costs. Nevertheless, without increasing costs, there was a benefit of GA to the patients as the reduced rate of subsequent surgery means less disruption to the patients' lives. This information may be important in evaluating the role of clinical GA in a healthcare climate focused on evidence-based medicine and cost-benefit analysis.

The strengths of this study include the large clinical cohort and the length of follow-up (up to 15 y). Limitations are primarily related to the retrospective study design. Patients were not randomized to the 2 groups, and differences between the GA and NGA groups were adjusted statistically as they were not controlled by the prospective design. In addition, the study was performed at a single institution and may therefore be subject to institutional bias. Although costs were calculated by using the rates from a single hospital, these rates are based on a national standard (Resource-based Relative Value Scale). The costs essentially reflect the

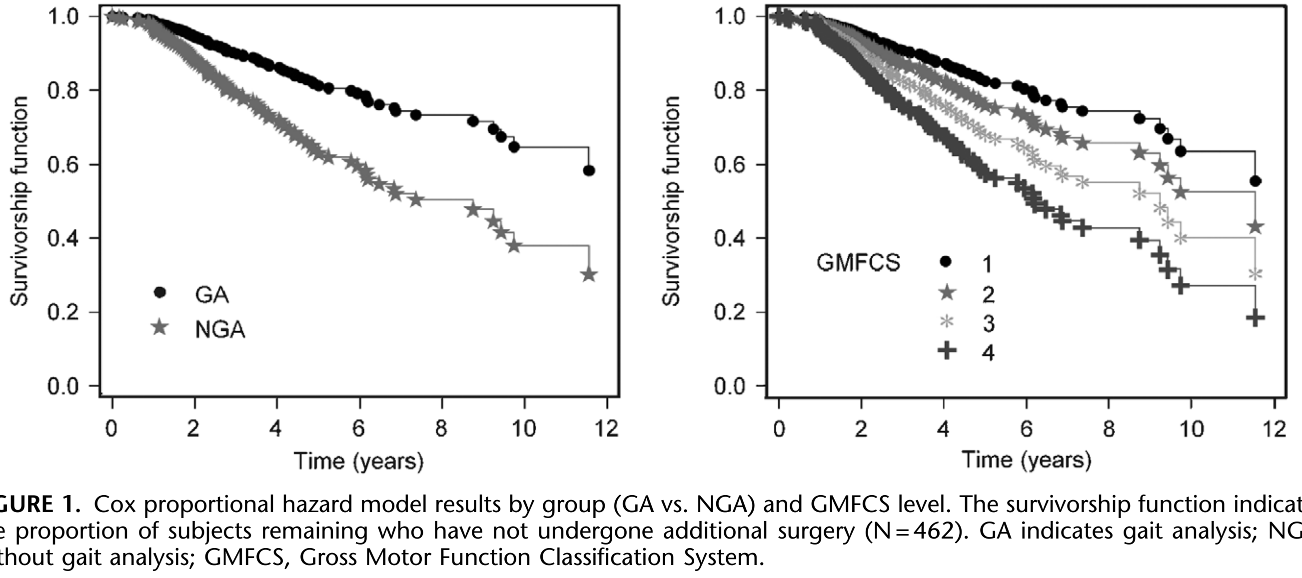

FIGURE 1. Cox proportional hazard model results by group (GA vs. NGA) and GMFCS level. The survivorship function indicates the proportion of subjects remaining who have not undergone additional surgery (N = 462). GA indicates gait analysis; NGA, without gait analysis; GMFCS, Gross Motor Function Classification System.

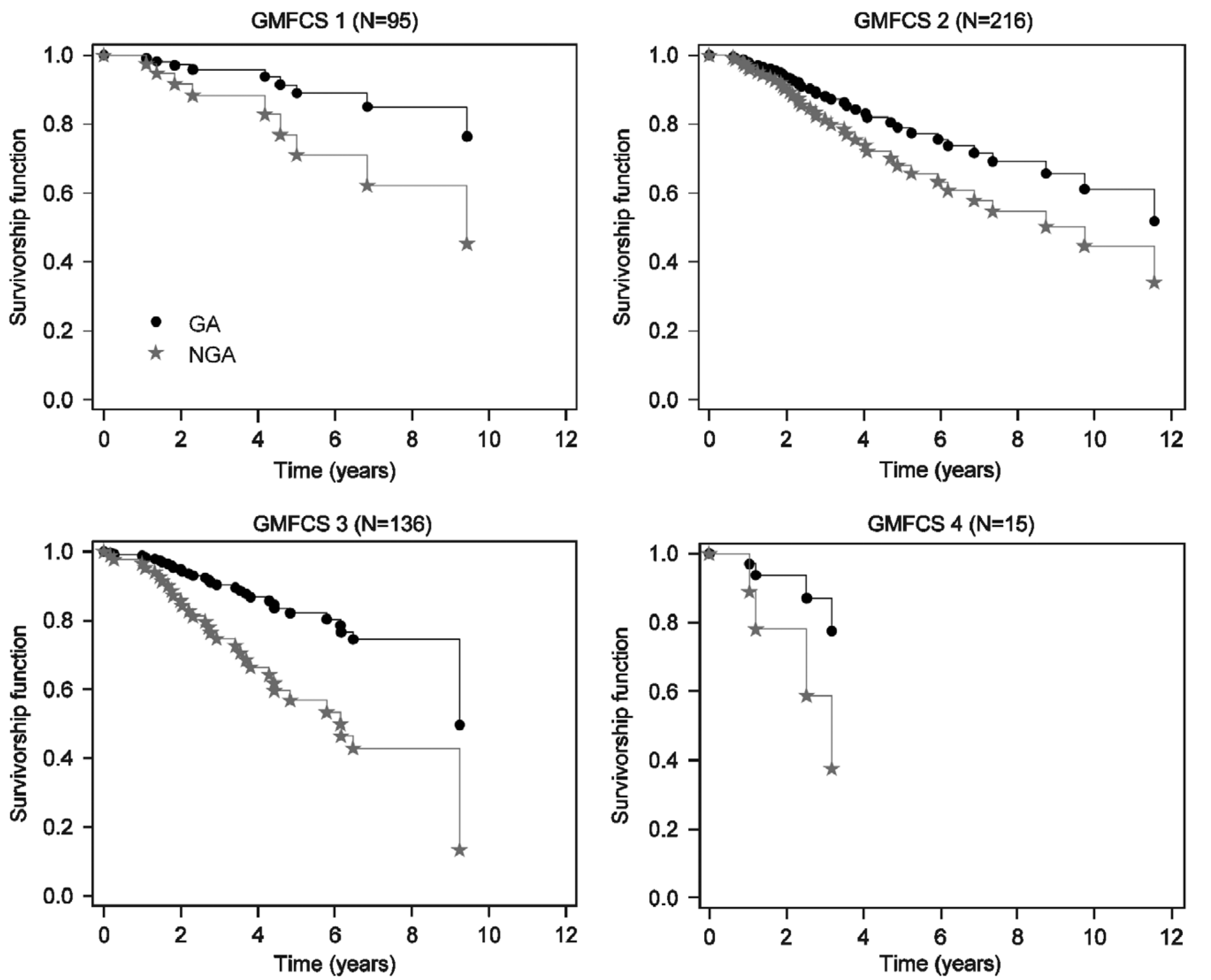

FIGURE 2. Cox proportional hazard model results for each GMFCS level. The survivorship function indicates the proportion of patients remaining who have not undergone additional surgery. GA indicates gait analysis; NGA, without gait analysis; GMFCS, Gross Motor Function Classification System.

amount of surgery performed and were not sensitive to details of cost calculations. Finally, the care patients received, including whether or not they had GA, was based on the clinical judgment of the patient's surgeon. There is no written protocol for surgical indications in children with CP at our institution. There is, however, a consensus with regard to the surgical indications for both soft tissue and osseous conditions. The general indications for soft tissue lengthenings are contractures which also interfere with gait. The indications for osseous surgery are significant deformity evident during static evaluation and during gait.

The only outcomes examined in this study were costs and the occurrence of additional surgery. As the study was retrospective, we were not able to evaluate other outcomes such as function, participation, and quality of life. These are important outcomes that need to be examined in future prospective studies.

In this study, costs were estimated by using billing charges because these are the only values that could be determined consistently for all of the cost components considered. As payers seldom pay the full charges, the actual direct financial costs to insurance companies, families, and government payers would likely be lower than the values cited. In contrast, indirect costs such as missing school and work, time and transportation to attend additional physical therapy sessions, use of facilities and healthcare resources, and psychologic effects of the additional surgery and rehabilitation were not included in this study. These indirect costs would be higher in the NGA group, increasing the total impact of the surgery on patients, families, and the healthcare system.

In summary, this study indicates that clinical GA results in a lower incidence of additional surgery, with less disruption to the lives of patients and their families. This finding has not been documented before and will assist patients, physicians, policy makers, and insurance companies in assessing the role of GA in the care of ambulatory children with CP.

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