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Original Research—CME

Comparative Effects of Multilevel Muscle Tendon Surgery, Osteotomies, and Dorsal Rhizotomy on Functional and Gait Outcome Measures for Children With Cerebral Palsy

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Abstract

Objective: To compare the impact of common surgical interventions (selective dorsal rhizotomy, muscle-tendon surgery, and osteotomies) for patients with cerebral palsy (CP) on Gross Motor Function Measure and temporal, kinematic, and kinetic gait variables as assessed via 3-dimensional motion analysis.
Design: Retrospective cohort study.
Setting: Motion analyses laboratory.
Participants: Ninety-four patients with CP, 56 of whom underwent surgery (37, muscle-tendon surgery; 11, osteotomy; and 8, selective dorsal rhizotomy) and 38 of whom did not have surgery; the patients were ages 4-18 years, with a Gross Motor Function Classification System classification of I, II, or III.
Interventions: Single-event, multilevel muscle tendon surgery, selective dorsal rhizotomy, and osteotomy.
Main Outcome Measures: Change scores (postintervention − preintervention) in Gross Motor Function Measure and temporal, kinematic, and kinetic gait variables.
Results: No statistically significant differences in change scores were found between groups in the Gross Motor Function Measure, velocity, or stride length measures after the observation period. The selective dorsal rhizotomy group had greater improvements in knee extension when compared with the nonsurgical group and greater hip and knee total range of motion during the gait cycle when compared with nonsurgical group and the muscle-tendon surgery and osteotomy cohorts. Lastly, the muscle-tendon surgery group had greater improvements in total knee range of motion compared with the nonsurgical group.
Conclusions: Patients who undergo selective dorsal rhizotomy and, to a lesser extent, muscle tendon procedures demonstrate greater improvements in kinematic gait variables compared with nonsurgical interventions in patients with spasticity resulting from CP.

Introduction

Cerebral palsy (CP) describes a group of permanent disorders that affect the development of movement and posture, causing activity limitations that are a result of a nonprogressive brain injury that occurs in utero, peripartum, or in the first year postpartum [1,2]. Clinical manifestations relate to the timing, location, and extent of the brain injury, and thus the phenotypic expressions of the injury include a wide range of patients with varying degrees of motor control deficits, sensory disorders, and muscle tone abnormalities [1]. Functional impairments ensue from these deficits, and surgical interventions can be used to address the bony and muscle tone abnormalities, as well as contracted muscle-tendon (MT) units [3,4].

Treatment approaches for impaired gait patterns in ambulatory children with CP have evolved during the past 70 years as a result of improved understanding of the pathophysiology of CP, the introduction of new treatments, and completion of larger scale clinical outcome studies that include instrumented measures of motion analyses. Impaired gait is often associated with lower extremity musculoskeletal abnormalities in ambulatory persons with CP. Osteotomies are often used to improve muscle moment arms due to bony abnormalities or to improve hip joint congruency, whereas MT surgeries and selective dorsal rhizotomies (SDRs) are used to address MT

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contractures and excessive muscle tone, respectively. A recent randomized controlled trial indicated that including a gait analysis in the treatment plan prior to performing an osteotomy can result in superior improvements in ambulation in children with CP when compared with osteotomy alone [5]. With regard to muscle-tendon lengthening procedures, it has been demonstrated that soft tissue surgery can improve abnormal gait patterns at joints distal and proximal to the MT being operated on [6]. A systematic review by Cans [7] suggests that SDR is an effective procedure to reduce spasticity and improve motor function. However, despite improved understanding of the neural mechanisms underlying the different patterns of abnormal ambulation in children with CP, clinical pathways are still not universally accepted. Furthermore, a comparison analyzing the relative effects of osteotomies, SDR, and MT surgery on gait parameters has not been performed up to this point.

The purpose of this analysis was to compare the outcome measures of a cohort of patients with CP who were undergoing SDR, MT surgery, or osteotomies with the outcome measures of a cohort that did not undergo surgical intervention. We analyzed the impact of these surgeries on the Gross Motor Function Measure (GMFM) and temporal, kinematic, and kinetic gait variables of the hip, knee, and ankle. Based on previous outcome reports, we expected to see small but appreciable improvements in GMFM scores and modest to large improvements in kinematic gait parameters for patients undergoing either SDR or MT surgery [4,8-10]. Further, we expected that MT surgery would increase stride length and knee motion [8-11] and that rhizotomy would increase sagittal motion of the hip and the knee [12]. Finally, we expected that osteotomies would improve the kinetics (moments and powers) of gait [13] by virtue of improving muscle moment arms.

Methods

Study Design

We performed a retrospective analysis of clinical cases of patients with CP who were followed up in one motion analysis laboratory between January 1993 and December 2008. A full body marker set (modified Helen Hayes) of 38 markers was attached to each subject. Subjects walked at a self-selected pace while 3-dimensional kinematic data were collected at 120 Hz using an 8-camera Vicon Motion Analysis System (Vicon, Denver, CO). Gait data analysis was performed with Vicon BodyBuilder software. All tests were performed in a motion analysis and motor performance laboratory.

The independent variable was "group" as indicated by surgical or nonsurgical interventions. The surgical groups included single-event, multilevel MT surgery or SDR. Also, osteotomies tended to follow MT surgery or be done concomitantly. However, patients who underwent an osteotomy regardless of other surgical interventions were allocated into the osteotomy cohort to determine if changing skeletal moment arms as theorized produced unique effects in this cohort.

The nonoperative cohort consisted of patients without any surgical intervention 1 year prior to and during the period of observation who were followed up over time. Of the 848 unique patients evaluated in the laboratory, 94 underwent multiple studies and were followed up and managed at our center; they constitute the cohort in this report. Inclusion criteria for this analysis were the following: a diagnosis of CP, age 4 to 18 years, Gross Motor Function Classification System (GMFCS) classification I, II, or III [14-16], and documented baseline and follow-up motion analysis in our clinical database with at least 12 months between assessments. Exclusion criteria included diagnosis other than CP, age outside of listed range, and GMFCS classification IV or V (ie, they were not able to ambulate well enough to capture motion data). In addition, patients were excluded if they had previous orthopedic surgery or rhizotomy or a history of a botulinum toxin injection within 1 year of the baseline assessment. Fourteen of 38 subjects in our nonoperative group had a history of previous surgery, with a mean time between the surgery and baseline motion capture of 5.2 years; only 3 of those subjects had surgery within 4 years of the baseline motion analysis. The Institutional Review Board for Health Sciences Research approved the analysis of this clinical database.

Surgical Indications

Patients who underwent an SDR presented with more generalized spasticity as reflected by increased tone during passive joint movements and very brisk deep tendon reflexes. MT surgery was indicated for patients with contracted MT units that restricted full knee extension and ankle dorsiflexion or prevented hip abduction past 30°. These passive restrictions in the MT group were further depicted by equinus, stance phase crouch, and scissoring gait patterns during clinical gait assessment. Osteotomies were performed to address abnormal transverse plane alignment due to excessive rotation in the foot, shank, or thigh. Some patients who underwent the derotational osteotomies may have had minimal MT contractures that were concomitantly lengthened. All subjects received postoperative physical therapy that included assisted joint motion and gait training 1-2 times per week for the first 8-12 weeks after surgery. None of the surgical patients included in this analysis sustained infections or required a return to surgery.

Subjects

Ninety-four patients (56 surgical and 38 nonsurgical) were followed up for a mean of 22.3 months (range,

12-37 months) between baseline and final evaluations. Descriptive characteristics of these patients are provided in Table 1. Of the 11 patients in the osteotomy group, 5 femoral, 2 tibial, and 3 foot osteotomies were performed for severe planovalgus deformities. One patient had concurrent femoral and tibial osteotomies. The number of MT procedures was determined by counting each procedure for a muscle in the single-event multilevel surgery. MT procedures most commonly involved the knee flexors (hamstrings), hip adductors, and ankle plantar flexors (gastrocnemius, soleus and Achilles tendon) as indicated in Table 1, but also included hip flexors, plantar fascia, and other intrinsic and extrinsic foot muscles. With regard to the nonsurgical cohort, either it was believed that they did not meet the surgical indications for SDR or MTS or they or their parents did not want to have a surgical intervention during the span of the study. No statistically significant differences were noted in patient demographics, including age, gender, height, or weight, between the surgical and nonsurgical cohorts.

Description of Outcome Measures

Outcome measures for this analysis included the GMFM and temporal, kinematic, and kinetic gait variables. Velocity and stride length were normalized to leg length for analysis, with leg length measured prior to each gait analysis by a physical therapist [8,12]. Kinematic variables included maximum and minimum sagittal hip, knee, and ankle position, as well as total excursion for the hip, knee, and ankle. Kinetic variables included moments of the knee and ankle and power of the hip, knee, and ankle.

All dependent variables were measured as change scores, where [post-test measurement]−[pretest measurement] = change score. For hemiplegic patients, the affected side was analyzed. For all other patients, the "weaker" or "more affected" side was used for analysis. The "weaker" or "more affected" side was documented by a physician or physical therapist in the clinical notes that were a part of the medical record for the patient. In cases in which one side was not "more affected," a coin toss determined the side used in the analysis.

Statistical Analysis

In the present study, SDR, MT surgery, osteotomy, and nonsurgical control groups serve as the independent variables. A one-way analysis of variance was performed to compare pre- to postintervention changes between groups for all outcome measures. Main outcome measures were GMFM and temporal, kinematic, and kinetic gait variables. Tukey post-hoc tests were performed to analyze any significant findings. The level of significance was set a priori at $P < .05$ for all analyses. In addition to

Table 1
Descriptive variables presented by group and mean (standard deviation) for continuous descriptive variables at the baseline assessment or based on day of surgery for the surgical group

	No Surgery, Control Subjects (n = 38)	Osteotomy With or Without Muscle-Tendon Procedure (n = 11)	Muscle-Tendon Procedure Only (n = 37)	Selective Dorsal Rhizotomy (n = 8)
Gender, males, females	22, 16	5, 6	22, 15	5, 3
Age, y* (SD)	8.4 (3.2)	9.9 (3.6)	9.0 (3.6)	7.8 (4.5)
Height, cm (SD)	123.7 (18.2)	127.9 (19.3)	124.8 (21.5)	117.7 (27.7)
Mass, kg (SD)	26.7 (11.1)	27.6 (14.3)	28.2 (14.1)	27.4 (15.4)
GMFCS				
I	16	3	11	0
II	13	5	12	4
III	9	3	14	4
Cerebral palsy subtype				
Diplegia	29	7	24	8
Hemiplegia	7	3	11	0
Other†	2	1	2	0
GMFM (SD)	88.3 (10.4)	84.2 (13.2)	85.0 (13.9)	70.5 (15.4)
Months between evaluations, mean (SD) [range]‡	22.4 (7.2) [12-37]	20.6 (7.2) [12-35]	23.1 (7.2) [12-36]	20.8 (5.5) [13-31]
Average number (SD) [range] of surgical procedures in the single-event, multilevel surgery‡	N/A	3.0 (1.5) [1-5]	2.2 (1.3) [1-4]	1 procedure for all
Muscle-tendon lengthening, recession, or release (common procedure frequency)				
Hamstrings	N/A	3	10	N/A
Hip adductors	N/A	3	10	N/A
Plantar flexors	N/A	6	24	N/A
Plantar fascia	N/A	2	3	N/A

SD = standard deviation; GMFCS = Gross Motor Function Classification System; GMFM = Gross Motor Function Measure; N/A = not applicable.
* Age was measured at baseline or at the preoperative motion analysis visit.
† A subtype where more than 2 limbs were affected (eg, triplegia or quadriplegia).
‡ Months between assessments (nonsurgical group) or between surgery and postoperative assessment (surgical group).

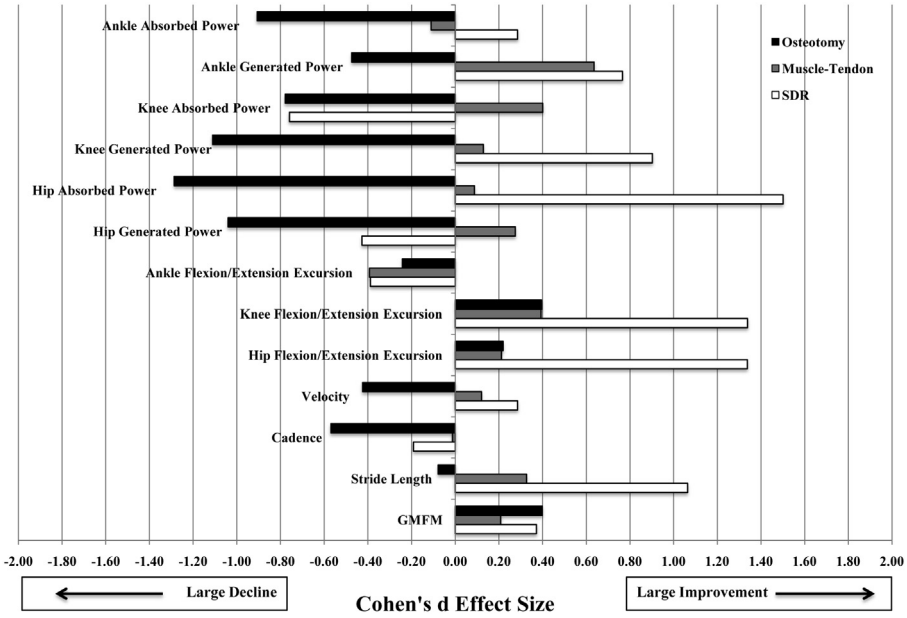

Figure 1. Cohen's d effect sizes as an estimate of magnitude of effect (preoperative to postoperative) for selective dorsal rhizotomy (SDR), muscle-tendon surgery, and osteotomy in ambulatory children with cerebral palsy. GMFM = Gross Motor Function Measure.

inferential statistical comparisons, Cohen's d effect sizes were calculated to estimate the magnitude of effect due to the surgical procedure (pre-effect to post-effect sizes; Figure 1). Effect sizes were interpreted as follows: $\geq$0.80 was large, 0.50-0.79 was moderate, 0.20-0.49 was small, and $<$0.20 was trivial [17]. Positive effect sizes represented improved function, whereas negative effect sizes represented diminished function after each respective procedure. Data were analyzed using Statistical Package for Social Sciences (SPSS) version 20.0 (SPSS, Inc, Chicago, IL).

Results

Gross Motor Function Measures and Temporal Gait Variables

No significant differences were noted between groups with regard to changes of the GMFM, cadence, velocity, or stride length measures (Table 2).

Kinematics

Results for all kinematics variables are listed in Table 3. Significant differences were identified for changes in maximum knee extension during mid stance, F (3,77) = 2.90, P = .040. Tukey post-hoc analyses indicated the SDR group (M = $-14.58^\circ \pm 14.45$) demonstrated a significantly greater increase in knee extension (improved knee extension) compared with the nonsurgical group (M = $-0.60^\circ \pm 9.75$, P = .045; Figure 2).

Additionally, significant differences were identified for the change in total hip and knee excursion, F (3,84) = 6.57, $P < .001$ and F (3,84) = 8.07, $P < .001$, respectively. For total hip excursion, post-hoc analyses indicated that the SDR group (M = $13.65^\circ \pm 12.22$) demonstrated significantly greater improvement in hip range of motion compared with the nonsurgical group (M = $-1.12^\circ \pm 5.41$, $P < .001$), osteotomy group (M = $1.44^\circ \pm 9.12$, P = .015), and MT surgery group (M = $2.14^\circ \pm 9.41$, P = .004;

Table 2
Changes in global measures of function and movement; specific means for each group and associated P values

	No Surgery, Control Subjects (n = 38)	Osteotomy With or Without Muscle-Tendon Procedure (n = 11)	Muscle-Tendon Procedure Only (n = 37)	Selective Dorsal Rhizotomy (n = 8)	Group Main Effect, P Value
GMFM, % (SD)	1.33 (3.03)	4.20 (10.29)	3.06 (5.41)	5.44 (4.99)	.199
Cadence, steps/minute (SD)	−6.43 (24.97)	−11.79 (18.04)	−0.40 (25.60)	−6.53 (23.36)	.515
Normalized velocity, [m/sec]/m (SD)	−0.03 (0.44)	−0.17 (0.42)	0.07 (0.38)	0.15 (0.35)	.264
Normalized stride length, % of leg length (SD)	3.51 (26.03)	−1.59 (21.96)	9.57 (19.16)	25.61 (25.99)	.051

(+) GMFM indicates improved function at post-test; (−) GMFM indicates diminished function at post-test.
(+) Cadence indicates less steps/minute at post-test; (−) cadence indicates more steps/minute at post-test.
(+) Velocity indicates faster velocity at post-test; (−) velocity indicates slower velocity at post-test.
(+) Stride length indicates greater stride length at post-test; (−) stride length indicates lesser stride length at post-test.
GMFM = Gross Motor Function Measure.

Table 3
Changes in sagittal plane kinematics; specific means for each group and associated *P* values

	No Surgery, Control Subjects (n = 38)	Osteotomy With or Without Muscle-Tendon Procedure (n = 11)	Muscle-Tendon Procedure Only (n = 37)	Selective Dorsal Rhizotomy (n = 8)	Group Main Effect, *P* Value
Hip flexion-extension excursion, degrees (SD)	−1.12 (5.41)	1.44 (9.12)	2.14 (9.41)	13.65 (12.22)	<.001
Knee flexion-extension excursion, degrees (SD)	−1.82 (7.31)	5.10 (15.17)	5.96 (12.28)	20.22 (17.66)	<.001
Ankle dorsi-plantar flexion excursion, degrees (SD)	−3.46 (9.88)	−1.65 (5.51)	−3.04 (8.32)	−4.28 (16.91)	.938
Maximum knee flexion, degrees (SD)	2.45 (13.35)	0.94 (9.21)	0.11 (13.80)	5.92 (11.25)	.682
Maximum knee extension, degrees (SD)	−0.60 (9.75)	−4.30 (14.85)	−7.00 (13.27)	−14.58 (14.45)	.040
Maximum ankle dorsiflexion, degrees (SD)	1.67 (8.54)	5.99 (15.11)	8.04 (20.94)	2.19 (10.30)	.456
Maximum ankle plantar −flexion, degrees (SD)	2.37 (17.99)	8.39 (15.75)	11.63 (23.14)	5.60 (24.75)	.393

(+) Hip or knee range indicates greater range at post-test; (−) indicates lesser range at post-test.
(+) Maximum knee flexion indicates more knee flexion at post-test; (−) indicates less knee flexion at post-test.
(+) Maximum knee extension indicates less knee extension at post-test; (−) indicates more knee extension at post-test.
(+) Ankle range indicates greater range at post-test; (−) indicates lesser range at post-test.

Figure 3). Similarly, for total knee excursion, the SDR group ($M = 20.22° \pm 17.66$) demonstrated significantly greater improvements in knee range of motion compared with the nonsurgical group ($M = -1.82° \pm 7.31$, $P < .001$), osteotomy group ($M = 5.10° \pm 15.17$, $P = .034$), and MT surgery group ($M = 5.96° \pm 12.28$, $P = .013$). Lastly, also for total knee excursion, the MT surgical group demonstrated significantly greater improvements in knee range of motion compared with the nonsurgical group ($P = .037$; Figure 4). No other significant kinematic differences were identified.

Kinetics

No significant differences were identified between groups for changes in knee or ankle moments or for changes in power at the hip, knee, or ankle (Table 4).

Discussion

Our purpose was to evaluate the impact of major surgical treatments (SDR, osteotomies, and MT surgery) on patients with CP using functional and gait outcomes measures and to compare the effects with a nonsurgical cohort. No statistically significant differences were found between groups on changes of the GMFM, velocity, or stride length measures. We identified differences in the magnitude of improvement for many kinematic variables between surgical and nonsurgical groups, yet no significant changes in kinetics were identified, disproving our hypothesis relating to the theoretic benefit of improving osseous lever arms with osteotomies.

We did not identify statistically significant changes in GMFM; however, all 3 surgical interventions resulted in small but meaningful improvements in GMFM when compared with the established minimally clinically important difference for a large effect size [18]. Therefore the lack of significance may be related to the small samples within each group and thus our lack of power to detect significant differences with this measure. Furthermore, other investigators have indicated

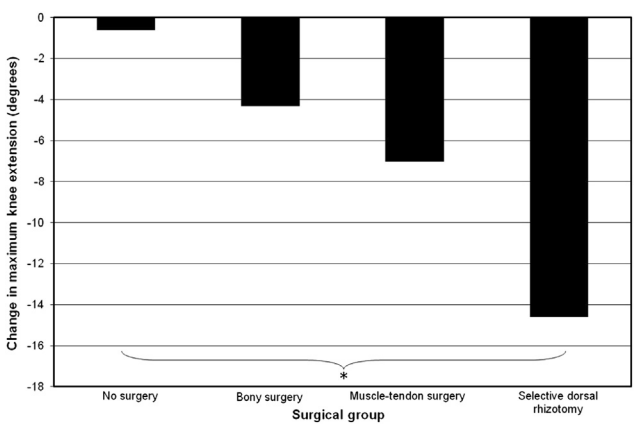

Figure 2. Change in maximum knee extension showed significant group differences. Post-hoc tests indicated that the selective dorsal rhizotomy surgical group demonstrated significantly more improved knee extension postoperatively compared with the nonsurgical group follow-up. *$P < .05$.

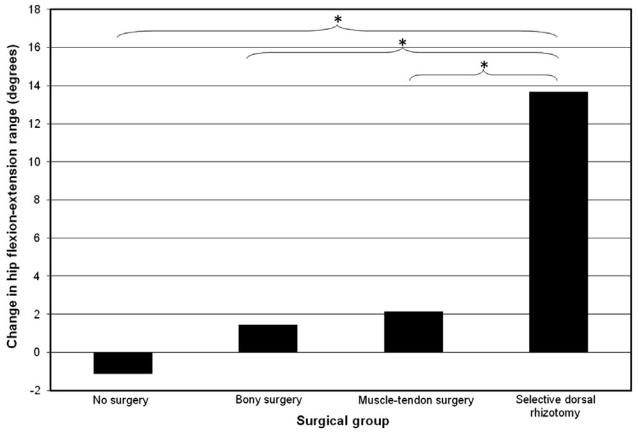

Figure 3. Change in total hip excursion showed significant group differences. Post-hoc tests indicated that the selective dorsal rhizotomy surgical group demonstrated significantly greater hip range postoperatively compared with the osteotomy group postoperatively, the MT surgery group postoperatively, and the nonsurgical group follow-up. *$P < .05$.

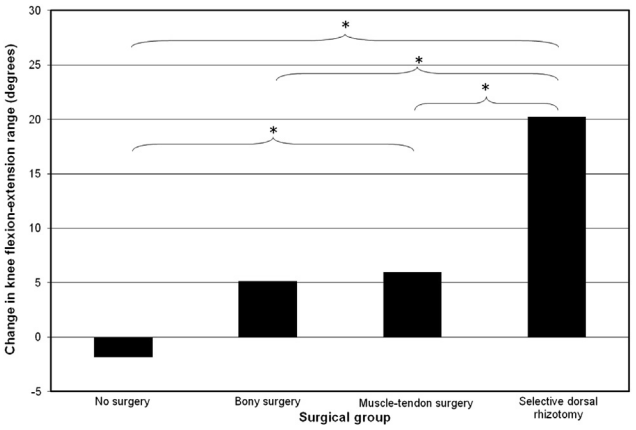

Figure 4. Change in total knee excursion showed significant group differences. Post-hoc tests indicated that the selective dorsal rhizotomy surgical group demonstrated significantly greater knee range postoperatively compared with the osteotomy group postoperatively, the MT surgery group postoperatively, and the nonsurgical group follow-up. Also, the MT surgery group demonstrated a significantly greater knee range postoperatively compared with the nonsurgical group follow-up. *$P < .05$.

that changes in GMFM may not be evident until long-term follow-up [10]. Interestingly, the SDR group had a larger proportion of patients in GMFCS classification II and III, as well as approximately 15% lower GMFM scores at baseline compared with the other surgical cohorts. However, there did not appear to be an interaction between baseline GMFM scores and the change due to surgical intervention on this measure, underscoring the importance of using multifaceted assessment tools in this patient population.

As hypothesized, patients who underwent SDR demonstrated greater improvements in joint motion during the gait cycle when compared with control subjects, the MT surgery group, and the osteotomy cohort. Although no significant differences were found in knee and hip total excursion between groups at baseline, we identified large improvements in these variables postoperatively in the SDR group, highlighting the benefit of SDR for joint motion during gait when performed on patients with clinical signs of diffuse spasticity. Furthermore, the increased hip and knee excursion in the SDR group manifested in large improvements in stride length. These patients also had moderate to large increases in ankle and knee power generation, as well as power absorption at the hip, suggesting a less equinus gait pattern. Our results are similar to those of Langerak et al [19], who demonstrated that not only do patients who undergo an SDR improve ankle and knee kinematics, but the improved functional capacity is maintained 15-20 years after the procedure. Collectively, these results suggest that the limited joint excursions seen in these patients with CP is due in part to spasticity and the overactivation of the monosynaptic reflexes that are mediated by the afferent input from the muscle spindle. Interestingly, a previous systematic review [20] suggests that SDR does have the ability to improve GMFM, which further indicates that our sample size was large enough to only detect changes in kinematic variables but not gross motor function, or perhaps that a 1- to 3-year follow-up was not long enough for improvements in gross motor function to manifest.

MT surgery is designed to alter joint position to allow a plantigrade foot, knee extension, and hip extension with reduced scissoring during gait. The typical targets are the iliopsoas, hamstrings, adductors, and gastrocsoleus complex. Thus we expected little change in excursion but rather a shift of the kinematic curves toward dorsiflexion in the ankle and toward hip and knee extension. Contrary to our expectations, the MT surgical group had significantly greater knee range compared with the nonsurgical group. It should be noted that the effect size for improvement in total knee range is small; however, the MT group concurrently

Table 4
Change in kinetics; specific means for each group and associated *P* values

	No Surgery, Control Subjects (n = 38)	Osteotomy With or Without Muscle-Tendon Procedure (n = 11)	Muscle-Tendon Procedure Only (n = 37)	Selective Dorsal Rhizotomy (n = 8)	Group Main Effect, *P* Value
Maximum knee extension moment, Newtonian meters (SD)	−0.03 (0.16)	−0.08 (0.26)	0.03 (0.26)	0.06 (0.09)	.445
Maximum ankle dorsiflexion moment, Newtonian meters (SD)	0.01 (0.03)	0.04 (0.06)	−0.01 (0.15)	−0.05 (0.10)	.522
Hip-generated power, watts (SD)	1.69 (0.78)	2.44 (1.65)	1.47 (0.60)	2.30 (1.96)	.086
Hip absorbed power, watts (SD)	−1.49 (1.39)	−1.68 (1.39)	−1.40 (1.17)	−1.25 (2.03)	.932
Knee generated power, watts (SD)	−0.01 (0.53)	−0.40 (0.56)	0.08 (0.46)	0.10 (0.23)	.082
Knee absorbed power, watts (SD)	−1.29 (0.64)	−1.78 (1.27)	−1.01 (0.68)	−2.17 (1.63)	.066
Ankle generated power, watts (SD)	0.09 (0.47)	−0.19 (0.41)	0.23 (0.67)	0.13 (0.21)	.253
Ankle absorbed power, watts (SD)	0.09 (0.68)	0.50 (0.87)	0.03 (0.89)	−0.03 (0.05)	.449

(+) Maximum knee and ankle moments indicate greater moments at post-test; (−) indicates lesser moments at post-test.
(+) Generated power indicates greater generated power at post-test; (−) indicates lesser generated power at post-test.
(+) Absorbed power indicates lesser absorbed power at post-test; (−) indicates greater absorbed power at post-test.

demonstrated small to moderate improvements in ankle-generated power, knee-absorbed power, and stride length. We posit that the improved ankle and knee position provided by MT surgery optimizes muscle fiber length and, similar to the findings of Adolfsen et al [6], these changes manifest into small improvements of ankle/knee/hip kinematics throughout gait.

Dreher and colleagues [21] noted that after MT surgery, muscle tone as measured by surface electromyography increased and subsequently gait kinematics slightly deteriorated in as little as 3 years after surgery. These results may highlight a key difference in SDR when compared with MT surgery, in that SDR procedures are eliminating a neurologic mechanism for increased muscle tone, and thus changes in gait may be expected to be maintained, whereas MT surgery does not eliminate neural mechanisms of spasticity, and thus a progressive deterioration in gait may be seen over time. With this in mind, our hypothesis that the nonsurgical group would have a decline in kinematic measures over the observation time was not confirmed; perhaps this outcome can be attributed to physical therapy and rehabilitation programs patients received between preobservation and postobservation measurements, which could not be captured or controlled for in the current study design. Accounting for the effects of rehabilitation should be a consideration for future research.

Finally, our hypothesis that the osteotomy group would demonstrate significant improvements in kinetic variables such as changes of knee or ankle moments, as well as power at the hip, knee, or ankle, was not confirmed by our inferential statistics. Furthermore, the small decreases in velocity and moderate decrease in cadence actually resulted in large reductions in power generation and absorption at the ankle, knee, and hip in the osteotomy cohort. However, the osteotomies did appear to have small but meaningful effects on GMFM, suggesting that the effects of derotational osteotomies are not depicted by the spatial, temporal, or sagittal plane kinematics or kinetics analyzed in our study. Although the concept of "lever arm dysfunction" as popularized by Gage [13] makes mechanical sense, changing levers with or without MT surgery had very little impact on our outcomes measures for this group. Our results differed from those of Schwartz et al [22], who noted that patients with hip anteversion and significant internal rotation demonstrate improved gait patterns after a femoral derotational osteotomy. On the other hand, their results were not as conclusive for patients with only mild internal hip rotation and anteversion, suggesting that the impact of bony surgery on gait parameters may be most advantageous in the presence of more severe structural deformity [22].

Measuring clinical improvement can be difficult in patients with CP. Several investigators [9,23] have reported on the most responsive instruments and what is considered a clinically meaningful change. In patients with CP, gait analysis is a frequently applied measuring tool to assess treatments aimed at improving gait. For example, the Gillette Gait Index [24], which is a measure of the gait deviation from normal seen in patients with CP, is particularly responsive to change. Our results confirm that changes in parameters of gait seem to be most responsive. However, the impact on gross motor function is small. Even in our previous studies [8,12], GMFM changes were in the range of 2-4 percentage points. Studies of SDR have shown GMFM changes to be in the range of 6 percentage points [20,25]. Furthermore, Palisano et al [26] suggested that patients with CP are more likely to have fluctuations in function *within* rather than *between* GMFCS levels and that functional change can be difficult to register on scales and indexes. Nevertheless, these improvements may be appreciated by the parent and patient in ways not measured with performance tools. Unfortunately, few Health-Related Quality of Life measures are validated, and none were employed in this cohort study [24,27]. Future studies may benefit from implementing multifaceted outcome tools that include not only gait-specific outcomes but also more generalized and comprehensive assessment tools such as the CP Quality of Life questionnaires or PedsQL questionnaires.

Limitations

Limitations of this study include the relatively low sample size that was utilized, which may have increased the potential risk of type II error where significant differences were not identified. Additionally, we acknowledge that the population with CP includes a wide spectrum and our ability to clearly define the characteristics of each treatment group is limited. The surgical indications are subjective, and patients offered and accepting surgery may not have obvious differences from nonsurgical subjects. The nature of a retrospective study is such that the timing of the visit and the wishes of the family may affect the treatment decisions. Lastly, we did not collect outcomes related to the child's quality of life and thus may have missed meaningful implications of orthopedic or neurosurgical interventions for these patients.

Conclusion

We have presented evidence that selective dorsal rhizotomy and, to a lesser extent, MT procedures offer improvements in kinematic variables compared with nonsurgical interventions in patients with spasticity related to CP. These results suggest SDR may be more beneficial at improving gait for ambulatory children with CP and might be worth considering prior to

reassessing for specific MT contractures and the need for lengthening in children with diffuse spasticity. Osteotomies do not have a major effect on sagittal plane kinematics, and because of the decreased velocity and cadence, power generation and absorption was also diminished postoperatively in this cohort. We believe the improvements in gait kinematics identified in our study may positively influence gross motor function but that this study may not have been powered to detect such changes. A large-scale, longitudinal multi-institutional study with well-defined treatment strategies may help determine if there are benefits that our data set is not powered to show and if the benefits from improved kinematics are short lived or muted over time by the natural deterioration of gait in persons with CP. Moreover, more evidence is needed to guide practitioners in managing medical resources for the CP population. Clear advances have been made in our understanding of CP and treatments have been adapted to this understanding, and although we often see profound functional benefits from these treatments in the course of daily practice, we have not yet produced the conclusive evidence needed to direct our decision making. For now, we echo the call for more research aimed at making these patients' lives better, both by improving our interventions and our knowledge of when to use them.

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Disclosure

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CME Question
In this study, which of the following resulted in greater improvements in joint motion during the gait cycle?

a. muscle tendon surgeries
b. osteotomies
c. selective dorsal rhizotomy
d. nonsurgical intervention

Answer online at me.aapmr.org