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The Impact of Operative Correction of Equinus in Cerebral Palsy on Gait Patterns

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Abstract

Background: This study aimed to evaluate gait outcomes and strength following the surgical correction of equinus in cerebral palsy (CP) based on different surgical procedures. We included the Baumann and Strayer procedures, as well as the Achilles tendon lengthening (ATL).

Methods: A retrospective analysis was performed in patients with infantile, bilateral CP who received instrumental 3D gait analysis before and after surgical correction (18.66 months postoperatively). Patients were divided into 3 groups: Strayer surgery, Baumann surgery, and ATL. Gait performance and muscle strengths were compared between studied surgeries.

Results: A total population of 204 patients (15.43 years) with 341 operated lower limbs (LLs) was analyzed. Dorsiflexion in swing and stance phases significantly improved in all groups postoperatively. The Strayer and the ATL group showed higher postoperative dorsiflexion than the Baumann group. However, no loss of strength was observed with the Baumann method. Maximum power improved in this group postoperatively. An 8.2% loss in calf muscle strength was recorded in the Strayer group.

Conclusion: Operative pes equinus treatment successfully improved the gait of children and adults with CP postoperatively. There were differences in postoperative results between studied operative techniques regarding range of motion and power.

Level of Evidence: Level III, retrospective cohort study.

Keywords: equinus, surgery, gait analysis, Strayer, Achilles tendon lengthening, Baumann

Introduction

Equinus deformity is a very common pathology affecting the gait of individuals with cerebral palsy (CP), with the spastic type being the most predominant subtype. Among these individuals, the prevalence rate of equinus is 83%[19] to 93%.[20] Because of a spastic increase in muscle tone, individuals show a spastic dynamic contracture triceps surae muscle resulting in a restricted range of motion (ROM) of the ankle.[4] Also, spasticity can be the result of the loss in the corticospinal tract innervation, which can subsequently result in smaller muscle size, reduced strength, and an increase in connective tissue.[40]

Dynamic pes equinus is usually treated successfully using conservative therapy.[23] Treatment options include physiotherapy, casting, orthoses, and botulinum injections, all of which are efficient in reducing spasticity.[1,2,6,7,9,10,13,17] If there is a high level of spasticity in the muscle or the conservative treatment is not sufficient, a fixed deformity can develop.[19,39] Such spasticity that impedes proper musculoskeletal development can, subsequently, cause contractures, subluxation at joint sites, loss of coordination/dexterity, and fatigue.

This "fixed" equinus may then require surgical care. The degree of spasticity can be objectively measured using the modified Ashworth Scale.[18] There are different surgical procedures usually held during a single operative session/setting, namely, Single Event Multilevel Surgery (SEMLS).[38] Regarding the ankle, the main goal is to achieve

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a neutral plantarflexion/dorsiflexion. Depending on both the pathology and preoperative patients' characteristics, operative procedures are carried out in different areas of the triceps surae muscle. The Zonal Classification is the most commonly used measure in this regard.[8]

This study addresses the operative techniques according to Achilles tendon lengthening (ATL), Baumann, and Strayer procedures. It is generally agreed that operative correction of equinus is an effective and safe way to treat children and adults with CP.[15,16,22,24,30] However, the question, which surgical method should be preferred is still a topic of debate. The option to do lengthening on different levels of the triceps surae muscle results in different postoperative outcomes[12] and several studies have focused particularly on ATL and the possibility of provoking overcorrection.[14,37] Meanwhile, the Strayer procedure, which involves gastrocnemius recession, has previously been described as the basic procedure of choice in managing pes equinus spasticus.[35] The benefit of both the Strayer and Baumann procedures is their ability to lengthen the affected muscle by variable amounts.

In 2021, a review by Ma et al[25] summarized the current data regarding gastrocsoleus lengthening, revealing a high degree of variability given the poor quality of included studies. It is recommended that further studies should consider the type of cerebral palsy, the active function of dorsiflexion, the surgical method, and the type of equinus deformity.[25] For these reasons, we conducted a chart review analysis to evaluate the comparative efficacy of ATL, Baumann method, and the Strayer procedure in changing gait outcomes and strength among CP individuals with equinus deformity.

Materials and Methods

Patients and Eligibility Criteria

Data from December 2002 to January 2021 were retrospectively reviewed. All individuals were diagnosed with infantile CP and underwent operative treatment of pes equinus as part of multilevel surgery. Only individuals with bilateral involvement and data from a 3D gait analysis and a clinical examination pre- and postoperation were included. During this examination, all individuals were classified based on the Gross Motor Function Classification System (GMFCS).[28,32] Because a higher GMFCS score is associated with a higher number of deformities, only individuals with a GMFCS score of I to III were included to avoid bias.[26,28] All individuals with missing data, study dropouts, unilateral CP, GMFCS IV, and Botox injections within 6 months preoperatively were excluded (Figure 1).

Surgical Techniques

Procedures that are applied to the Achilles tendon differ from those that address the muscle itself. The decision to perform each of the examined surgeries was done based on the degree of equinus during the operation. For instance, lengthening of the proximal third of the gastrocnemius was initiated, if passive dorsiflexion in knee extension was $\leq 20°$; however, it was correctable to neutral position in knee flexion. Combined gastrocnemius and soleus lengthening at the proximal third was done in the case of passive dorsiflexion $\leq 20°$ in knee extension and flexion. However, when fixed equinus of $>20°$ was sustained only in knee extension, the Strayer procedure would be attempted. Otherwise, ATL was done if the patient had passive dorsiflexion $<20°$ in both knee extension and flexion.

The Baumann and Strayer operations are intramuscular methods. The Baumann procedure is performed more proximally than the Strayer operation (Supplemental Figure 1). The Strayer[36] and Baumann and Koch[5] procedures were performed as highlighted in the literature. In the Strayer procedure, the gastrocnemius tendon is incised distally near the attachment point to the Achilles tendon. Meanwhile, in the Baumann procedure, the plane between gastrocnemius and soleus is then opened and the plantaris tendons are resected, and in a proximal manner, the aponeurosis is split through 2 parallel transverse incisions, with 1.5 cm between them. The septum in between is then divided, while the distal tendon sheet of the gastrocnemii that blends with Achilles tendon is contained. Eventually, the ankle is gradually dorsiflexed until a neutral position is reached with the knee being fully extended. At this point, the separation between both muscle (gastrocnemius and soleus) fasciae can be observed. As for ATL, patients lay in the prone position where an incision was made posteriorly, medial to the Achilles tendon while preserving the tendon's sheath. A longitudinal split was made down the tendon's center. A Z-lengthening was performed by cutting the top and bottom of the slit. Ankle dorsiflexion to neutral was maintained with the knee in extension, and the foot was put in a neutral position. Multiple horizontal mattress sutures were then applied to the tendon, after which the skin was sutured. The goal of ATL is to achieve 5 to 10 degrees of dorsiflexion in knee extension postoperatively.

During the postoperative period, lower limb casting was applied in a neutral position to all patients. The casting was maintained for 4-5 weeks in children and adolescents and for 6 weeks in adults. Then, imprints for orthotics were done while using plaster removables for physiotherapy until orthotics were ready for use. In patients who needed additional orthopaedic surgeries, no weightbearing with plaster was applied. Instead, a purely soft part-walking cast was used. The position of the foot was controlled radiologically in the plaster, with the plastering technique being the same in all cases.

Gait Analysis and Measurements

All individuals underwent a 3-dimensional gait analysis and a clinical examination before and after pes equinus

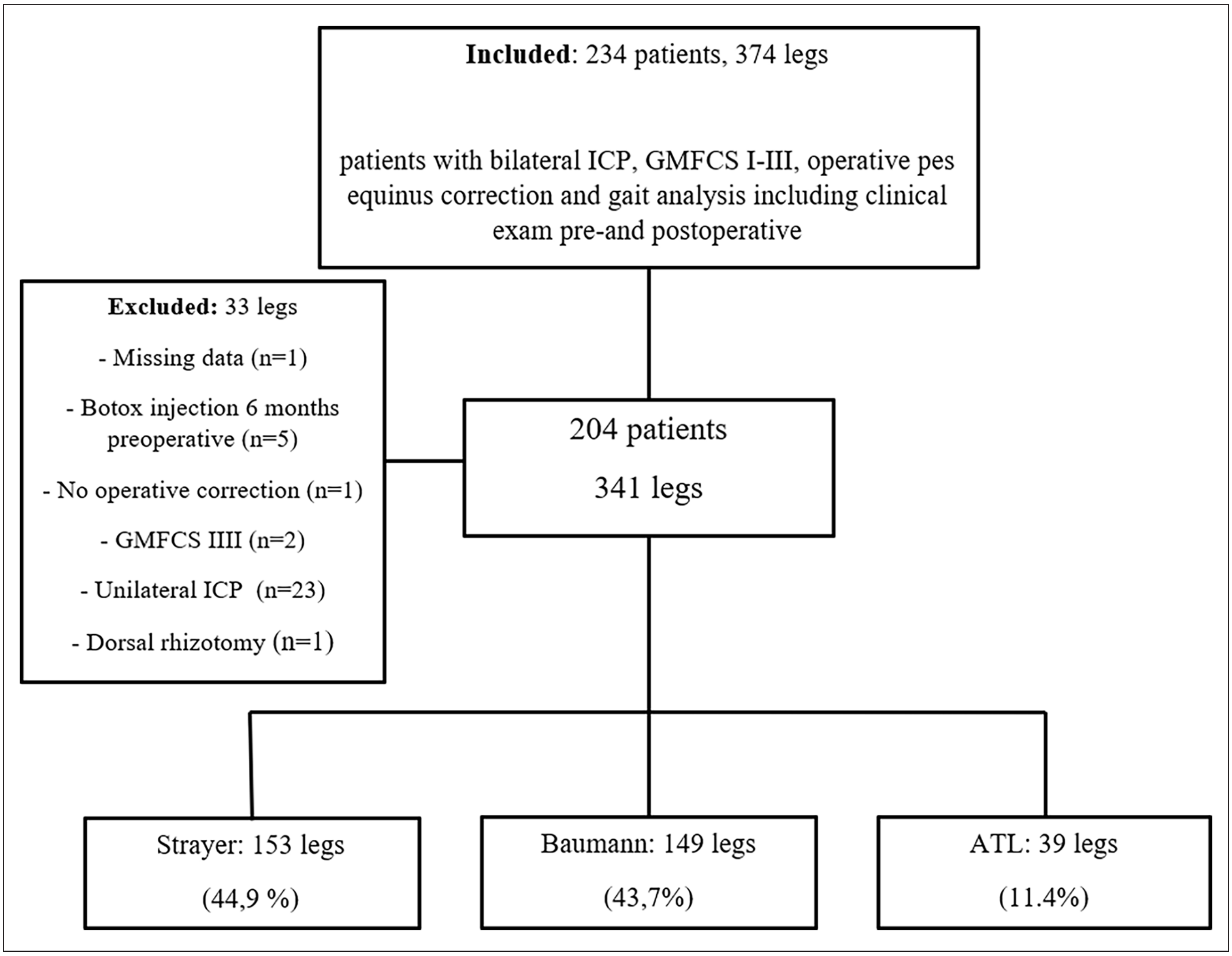

Figure 1. A flowchart showing the data retrieval process using our data set.

correction (Figure 2). The first gait analysis was performed 4.78 ± 6.5 months before the surgery, whereas the second gait analysis was performed 18.66 ± 15.47 postoperatively. In the clinical examination, ankle ROM was measured, and the Medical Research Council (MRC) Scale was used to measure muscle strength.[11,29] In addition, the modified Ashworth scale was used to assess the triceps surae.[18] Noteworthy, ROM was measured clinically with the use of a goniometer, the gold standard.

To analyze the movement of the lower body, 19 reflective markers are applied to landmarks on the skin according to the "Plug in Gait Model."[21,31] In that model, we used the "assume horizontal" option for static foot calculations. Among participants being able to maintain plantigrade foot during stance, we used the "assume horizontal" option before beginning the static trial. On the other hand, in participants who are not able to achieve plantigrade foot, the "assume horizontal" option was not used. Instead, the heel marker was placed at the same height above the plantar surface of the foot as the forefoot marker.

The ankle joint is measured with 3 markers. One marker is located on the lateral malleolus, another one on the calcaneus, and a third one is placed on the second metatarsal. Individuals' gait pattern was captured by 12 Vicon cameras (Oxford Metrics, Oxford, United Kingdom), and kinetic parameters were measured using 3 force plates (Kistler Instruments, Winterthur, Switzerland). This assessment was conducted barefoot and without the use of any assistive walking aids. Participants walked 7 m several times at their self-selected speed (Supplemental Table 1).

ROM and clinically measured calf strength were established as relevant outcome parameters in the clinical examination. The outcome parameters of gait analysis were gait profile score (GPS), Gillette gait index (GGI), ROM in the swing and stance phase, and maximal and mean power in the stance and preswing phase.

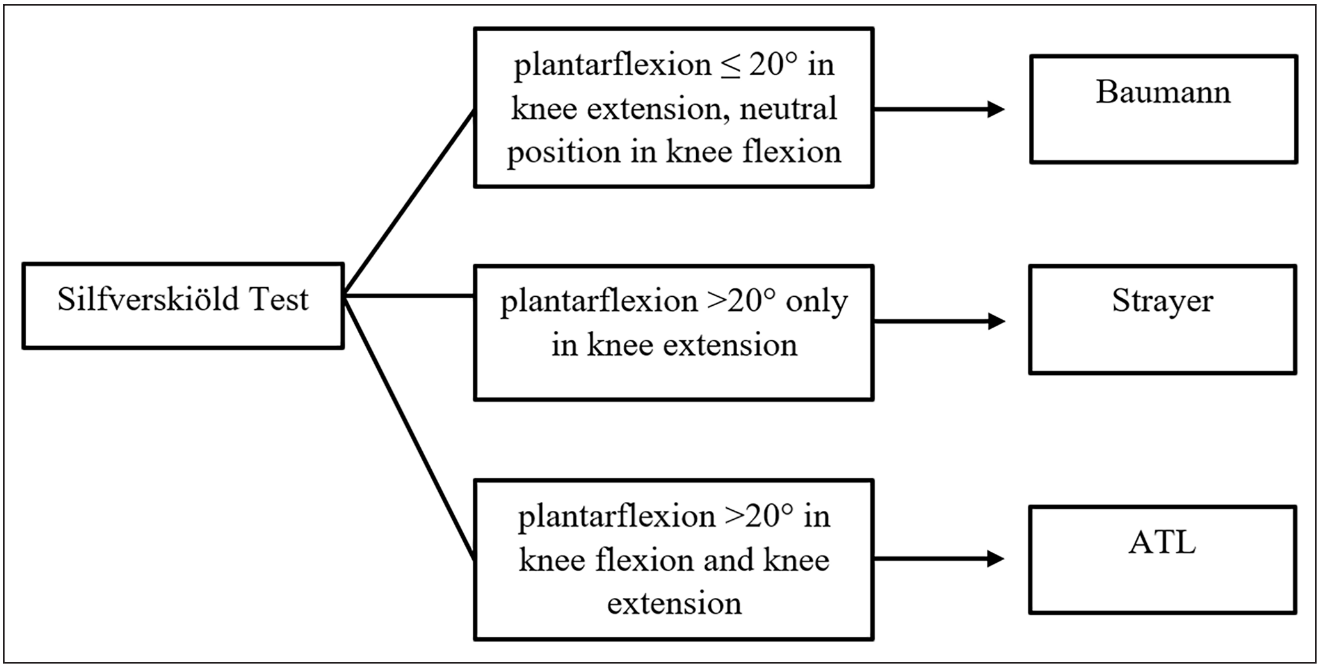

Figure 2. Illustration highlighting the details of the Silfverskiöld test.[30]

Statistical Analysis

MatlabR 2018 and HeiDataProViT, version 3.0.8, were used primarily for data collection. Statistical tests were performed using IBM SPSS Statistics, version 27. Participants' baseline characteristics are presented as numbers and percentages for categorical and dichotomous variables, as well as means and SDs for continuous variables. Importantly, depending on their age at the time of surgery, individuals were also divided into 3 age groups (Table 1). The choice of age groups was based on a prior observation that younger individuals have a higher risk of equinus recurrence following surgical correction.[34]

To compare the surgical interventions, an analysis of covariance was used with the surgical method as a fixed factor, the gait parameter as the dependent variable, and the base value of the parameter as a covariate. We ensured that the requirements needed to perform an analysis of covariance were met (ie, independence, homogeneity, linearity, and normality). For this purpose, a post hoc test with Bonferroni correction and Levene test was carried out. A paired *t* test was used to compare preoperative and postoperative values. The level of significance was set at $P < .05$ for all tests.

Results

Patients' Characteristics

We analyzed overall 204 individuals (341 limbs) (Figure 1), and most of them were male (58.9%) (Table 1). The mean age at the time of surgery was 15.43 ± 10.1 years.

Functional Outcomes of the Overall Population (Preoperative vs Postoperative)

ROM of the affected ankle joints significantly improved ($P < .001$). Clinical examinations showed that individuals could only achieve 6.14 degrees of dorsiflexion in knee flexion before surgery (± 7.1 degrees) and 12.0 degrees (± 7.9) postoperatively. Dorsiflexion in knee extension also improved ($P < .001$). In knee flexion and extension, clinically measured plantarflexion was reduced ($P < .001$). Postoperatively, the mean muscle strength during dorsiflexion significantly improved ($P < .001$), whereas that of plantarflexion was decreased. Spasticity was also lower in individuals postoperatively (mean difference = 0.602; 95% CI 0.51-0.70; $P < .001$).

Considering the kinematic data, all values changed statistically significantly after surgery ($P < .001$). In the stance phase, maximal dorsiflexion increased ($P < .001$). The mean ROM over the stance phase changed from 3.01 degrees plantarflexion to 7.45 degrees dorsiflexion ($P < .001$). These changes can also be observed in the swing phase (mean difference = 13.25; $P < .001$). Considering the values of the gait analysis, GPS[3,27] decreased by 4 points in children (<18 years old) and by 3 points in adults ($P < .001$). The GGI[27] decreased significantly referring to normal values in children and in adults ($P < .001$). Because a large value indicates a greater deviation from the normal values of a healthy individual, the values improved after surgery.[25,27]

Figure 3 shows the differences between the muscle strength of plantarflexion measured in physical examination and the power measured in gait analysis. Although in

Table 1. Baseline Characteristics of Included Bilateral Cerebral Palsy Patients Stratified by Procedure Type.

Variable/Category	Baumann (n = 149)	Strayer (n = 153)	ATL (n = 39)	*P* Value
Age during surgery, y, mean (SD) / range	12 (7.5) / 4-43	18 (11.4) / 6-57	16 (10) / 7-45	<.001
Children/adolescents (<18 y), n (%)	130 (87.3)	96 (62.7)	29 (74.4)	<.001
Adults (≥18 y) , n (%)	19 (12.7)	57 (37.3)	10 (25.6)	
Sex, n (%)				
Male	91 (61.1)	86 (56.2)	24 (61.5)	.65
Female	58 (38.9)	67 (43.8)	15 (38.0)	
Weight (kg), mean (SD) / range	35 (14) / 15-76	48 (24.6) / 14-170	43 (17) /17-87	<.001
Height (cm) , mean (SD) / range	138 (19.1) / 95-189	149 (21.6) / 109-191	148 (19.7) / 107-194	<.001
GMFCS level, n (%)				
I	32 (22.4)	33 (21.6)	15 (38.5)	<.001
II	80 (55.9)	61 (39.9)	22 (56.4)	
III	31 (21.7)	59 (38.5)	2 (5.1)	
IV[a]	0 (0)	0 (0)	0 (0)	
V[a]	0 (0)	0 (0)	0 (0)	

Abbreviations: ATL, Achilles tendon lengthening; GMFCS, Gross Motor Function Classification System.
[a]GMFCS levels IV-V were a part of the exclusion criteria.

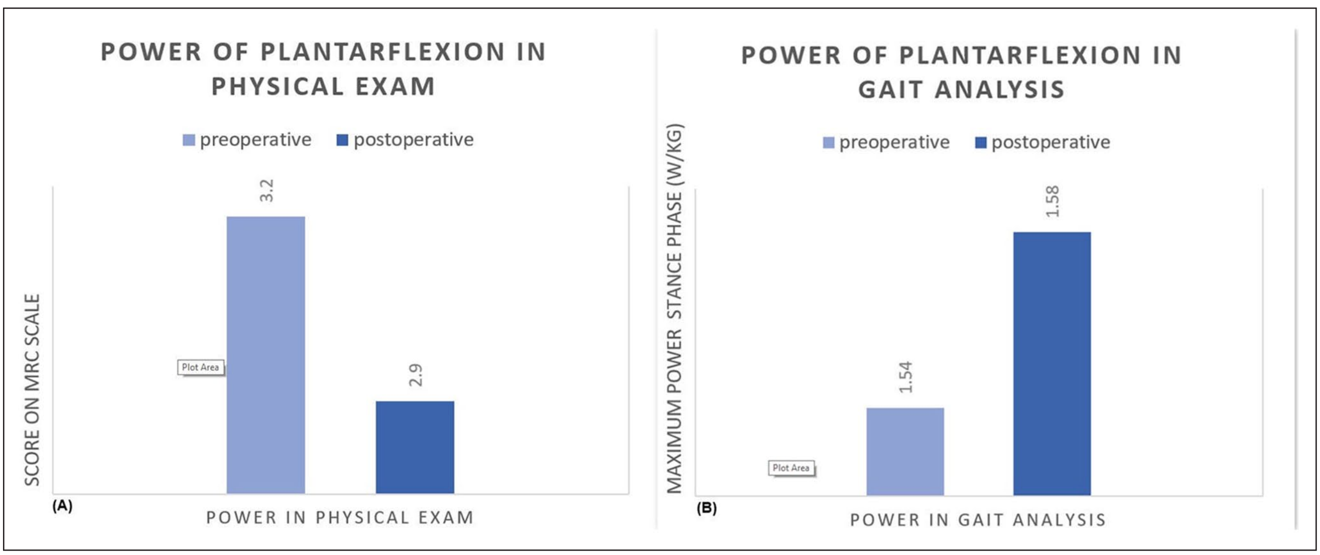

Figure 3. Change in (A) muscle strength and (B) power of plantarflexion postoperatively in the overall studied population.

the physical examination the MRC score, indicative of muscle strength, decreased from 3.2 (±0.8) to 2.9 (±0.8), the maximum power measured in gait analysis increased from 1.5 (±0.7) W/kg to 1.6 (±0.7) W/kg.

Comparison of Functional Outcomes Based on the Surgical Method

Ankle kinematic parameters (postoperative data). During the postoperative period, profile plots compare maximum dorsiflexion and plantarflexion, with significant differences being noted between studied groups regarding maximum dorsiflexion, both during the stance ($P < .001$) and swing ($P < .005$) phases (Table 2). In particular, the ATL group showed the highest degree of maximum dorsiflexion during the stance phase (Figure 4), whereas the Strayer group revealed the highest degree of dorsiflexion during the swing phase (Figure 5). Similarly, maximum plantarflexion was significantly different among studied procedures both during the stance ($P = .001$) and swing ($P = .004$) phases. The highest degree of maximum plantarflexion was noted in the Baumann group during the stance and swing phases.

Table 2. Ankle Kinematic Parameters of Bilateral Cerebral Palsy Patients Stratified by Surgery Type.[a]

Variable/Category	Baumann	Strayer	ATL	*P* Value
Range of motion				
Stance: preoperative	28.17 (12.6)	26.51 (10.5)	28.10 (11.5)	.43
Stance: postoperative	21.03 (7.2)	21.62 (6.1)	23.73 (7.5)	.08
Swing: preoperative	17.29 (9.8)	17.02 (9.2)	18.20 (11.3)	.79
Swing: postoperative	11.91 (5.9)	10.97 (5.1)	10.33 (4.9)	.16
Maximum dorsiflexion				
Stance phase	13.1 (5.8)	17.1 (6.4)	17.5 (8.0)	**<.001**[b]
Swing phase	4.3 (5.8)	6.5 (6.6)	4.2 (8.5)	**.009**[b]
Maximum plantarflexion				
Stance phase	7.9 (8.1)	4.5 (7.6)	6.2 (9.7)	**.014**[b]
Swing phase	7.6 (9.0)	4.5 (8.9)	6.13 (10.8)	**.001**[b]

Abbreviation: ATL, Achilles tendon lengthening.
[a]Data are presented as mean (standard deviation).
[b]Indicates statistically significant difference.

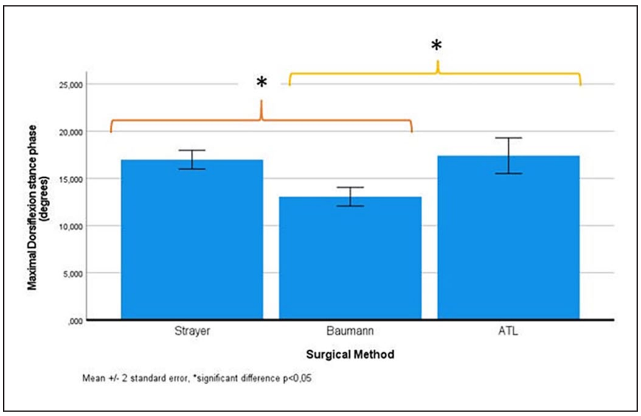

Figure 4. The difference in maximum dorsiflexion between studied procedures during the stance phase. Mean ±2 SE. *Significant difference, $P < .05$.

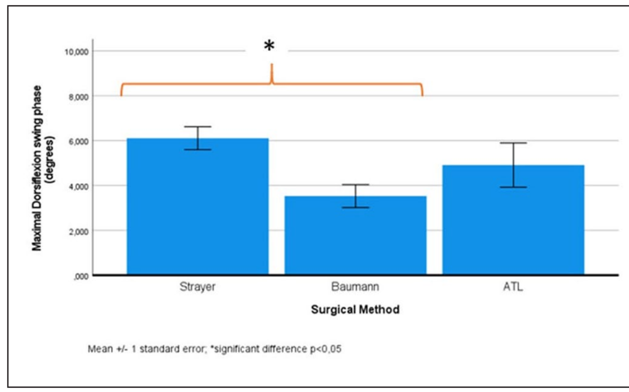

Figure 5. The difference in maximum dorsiflexion between studied procedures during the swing phase. Mean ±1 SE. *Significant difference, $P < .05$.

The difference in preoperative and postoperative ROM data between studied surgeries can be visualized in the kinematic curves provided in Supplemental Figure 2. Preoperatively, ROM values were below normal; however, after surgery, the initial contact was better in all groups, with ATL showing the highest maximum dorsiflexion during the stance phase and the Strayer group during the swing phase. That being said, no significant changes were observed in the ROM between all of the study's surgical procedures postoperatively, both during the stance (Baumann vs Strayer vs ATL = 21.03 vs 21.62 vs 23.73; $P = .08$) and swing (Baumann vs Strayer vs ATL = 11.91 vs 10.97 vs 10.33; $P = .16$) phases (Table 2). During the stance phase, postoperative ROM was highest in the ATL. However, during the swing phase, no significant differences in ROM were noted.

Ankle kinetic parameters (postoperative data). The difference in preoperative and postoperative power between studied surgeries can be visualized in the kinetic curves provided in Supplemental Figures 3 and 4. The preoperative curve shows the classic picture of equinus gait with the pathologic generation of force at 20%, which has improved significantly postoperatively. The absorption at the beginning of the gait cycle has also improved because of the improved foot placement in the initial contact. The maximum power has also improved in all 3 groups, with the Baumann group showing higher power followed by ATL and Strayer method, respectively. The loss of strength in the Strayer group after surgery, however, compared to preoperative values can be observed in Figure 7.

Kinetic results are shown in Figure 6. There are significant differences between the Strayer and Bauman groups. In the Baumann group, the maximum power is 1.7 W/Kg

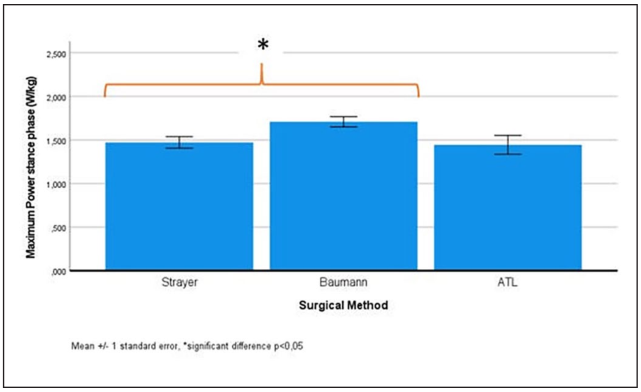

Figure 6. The difference in maximum power during the stance phase postoperatively between studied procedures. Mean ± 1 SE. *Significant difference, $P < .05$.

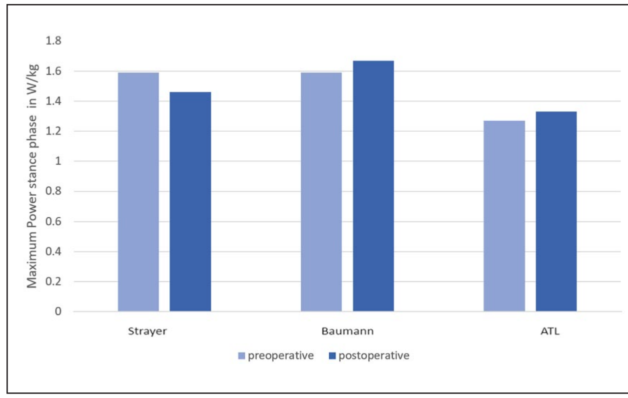

Figure 7. The difference between preoperative and postoperative maximum power in the stance phase among studied procedures.

(SE = 0.1). This value is significantly higher ($P = .04$) than in the Strayer group, showing a power of 1.5 W/kg (SE = 0.1). ATL individuals had a maximum power of 1.4 W/kg (SE = 0.1). However, no significant difference was found here in comparison to the other groups ($P = .220$). The difference between preoperative and postoperative maximum power in the stance phase for each surgical procedure is presented in Figure 7. Compared to preoperative data, the Strayer group showed 8.2% ($P = .043$) reduction in power, whereas both the Baumann procedure (5%, $P = .035$) and ATL (4.7%, $P = .336$) showed significant increase postoperatively. On comparing the percentage change in power between the Baumann procedure and the Strayer method, a significant difference was noted ($P = .044$); however, no significant differences were noted between the Baumann procedure and ATL ($P = .231$) or ATL and the Strayer method ($P = .071$).

Similarly, the mean power during the stance (Baumann vs Strayer vs ATL = 0.06 vs −0.03 vs −0.01; $P < .001$) and preswing (Baumann vs Strayer vs ATL = 0.87 vs 0.78 vs 0.67; $P = .024$) phases differed significantly between procedures. During the stance phase, the mean power was highest in the Baumann group. The mean power change in the Strayer group, in particular, means that more energy is absorbed than generated. The mean power during the preswing phase was the highest in the Baumann group followed by the Strayer and ATL procedures (Table 3).

Muscle strength, based on MRC measurements, was significantly different between all procedures, both during dorsiflexion ($P = .003$) and plantarflexion ($P = .002$). During dorsiflexion, muscle strength was the same for ATL and Baumann groups. Meanwhile, during plantarflexion, the Bauman procedure showed the greatest muscle strength (Table 3).

Dynamic clinical parameters (preoperative and postoperative data). The degree of spasticity differed significantly between procedures both preoperatively ($P = .009$) and postoperatively ($P < .001$) (Table 4). In all groups, spasticity was reduced postoperatively, with the extent of reduction being greatest in the Strayer group followed by ATL and Baumann procedures, respectively. In all of the studied groups, the degree of dorsiflexion, during knee flexion and knee extension, postoperatively, was improved ($P < .001$). Consistently, the degree of plantarflexion, postoperatively, both during knee flexion and extension was reduced as compared to preoperative values in each surgical procedure, individually (Table 4).

Gait analysis (postoperative data). The assessment of gait, postoperatively, revealed no significant change between all procedures, as measured by GPS ($P = .23$) (Supplemental Table 2). Stratification based on the age group revealed no significant change in gait score between all procedures both in children ($P = .083$) and in adults ($P = .20$). Importantly, a reduction in GPS reflects an improvement in gait. On the other hand, an increase in GPS score reflects a more abnormal gait pattern.

Discussion

Pes equinus correction helps individuals improve their walking ability.[15,16,22,24,30] However, there is still a debate about which procedure is preferable in which case. It is also an important question if there is a measurable loss of strength in the calf muscles and, therefore, if a surgical technique should be preferred. Our study indicates that all of the studied surgical techniques improved postoperative clinical outcomes to varying degrees, and although slight differences were found among them, we cannot conclude that a particular surgery is superior to others. These findings may be limited by our procedure selection criteria—as procedures were not randomized, but rather selected based on the degree of contracture.

Table 3. Ankle Kinetic Parameters of Bilateral Cerebral Palsy Patients Stratified by Surgery Type.[a]

Power	Baumann	Strayer	ATL	*P* Value
Dorsiflexion (MRC Scale)	3.6 (0.7)	3.3 (1.0)	3.6 (0.8)	**.003**[b]
Plantarflexion (MRC Scale)	3.0 (0.8)	2.8 (0.8)	2.6 (0.7)	**.002**[b]
Mean power (stance phase)	0.06 (0.1)	–0.03 (0.1)	– 0.01 (0.1)	<**.001**[b]
Mean power (preswing phase)	0.87 (0.4)	0.78 (0.4)	0.67 (0.4)	**.024**[b]

Abbreviations: ATL, Achilles tendon lengthening; MRC, Medical Research Council.
[a]Data are presented as mean (SD).
[b]Indicates statistically significant difference.

Table 4. Preoperative and Postoperative Dynamic Parameters of Bilateral Cerebral Palsy Patients Stratified by Surgery Type.[a]

Variable/Category	Baumann	Strayer	ATL	*P* Value
Dorsiflexion in knee flexion				
Preoperative	8.13 (7.3)	5.03 (6.8)	2.85 (4.9)	<.001[b]
Postoperative	13.65 (8.8)	11.03 (7.4)	9.38 (5.7)	.001[b]
Dorsiflexion in knee extension				
Preoperative	3.13 (4.8)	1.57 (4.8)	0.95 (2.5)	.003[b]
Postoperative	6.91 (6.5)	5.18 (5.5)	4.38 (4.1)	.01[b]
Plantarflexion in knee flexion				
Preoperative	42.22 (6.7)	41.05 (8.5)	46.27 (9.4)	.002[b]
Postoperative	35.83 (9.0)	33.32 (11.4)	31.51 (12.3)	.028[b]
Plantarflexion in knee extension				
Preoperative	41.93 (6.0)	40.98 (9.0)	46.54 (9.5)	.001[b]
Postoperative	35.17 (9.3)	32.83 (11.0)	31.38 (12.3)	.054
Spasticity (modified Ashworth scale)				
Preoperative	1.43 (0.7)	1.61 (0.8)	1.20 (0.8)	.009[b]
Postoperative	1.11 (0.6)	0.73 (0.7)	0.63 (0.6)	<.001[b]

Abbreviation: ATL, Achilles tendon lengthening.
[a]Data are presented as mean (SD).
[b]Statistically significant differences.

Individuals examined in this study showed an overall improvement in their gait pathology. The majority of kinematic and kinetic parameters significantly improved after surgical treatment. Also, the data of clinical examination, especially ROM of the ankle, improved after performing the operation. The gait pattern of the individuals moved closer to a physiological gait pattern because of the improvement of the maximum dorsiflexion in stance and in the swing phase. Even the initial contact with the forefoot was reduced. By comparing the clinical and gait analysis results, it can be concluded that calf muscle lengthening reduced its clinically measured strength. In gait analysis, however, an improvement in the maximum power during the stance phase was achieved through an almost plantigrade foot placement, leading to improved leverage. It should be noted that the maximal power of 1.6 W/kg is still below the data from normal values (normal values: 4.1 W/kg ± 1.0). This could potentially be related to superior walking speed (normal value = 1.2-1.4 m/s); however, the speed in our population was not high (preoperative = 0.85 [0.3], postoperative = 0.78 [0.3] m/s). Patients benefited significantly in terms of gait pattern in clinic results, as well as kinetics and kinematics. This is comparable to the findings from Putz et al[30] where these improvements also could be found but in adult individuals and a smaller group of individuals. It can be assumed that these results might be maintained over a prolonged period of time, although uncommon, as shown in different follow-up studies.[14,15,37]

Noteworthy, ankle strength decreased postoperatively and it was coupled with an increased plantarflexion power. This could be explained by the increase in the calf muscle length following surgery, which resulted in a reduction in the maximum power measured clinically. Meanwhile, during gait analysis, power is measured with force plates; thus, its biomechanical properties (ie, lever force) become better because of plantigrade foot placement. Subsequently, the overall power in the patient population would increase postoperatively.

The risk of muscle weakness in ATL described in the literature could not be measured in our work. In our data, there were no statistically significant differences between the postoperative results of the ATL group and the intramuscular techniques in terms of maximal power in the stance phase. However, comparing the intramuscular techniques, there's a difference regarding this parameter. The Baumann group showed a higher maximal power than the Strayer group. This was statistically relevant in the stance phase, but also in the preswing phase, which is important for push-off power from the ground. This can be explained by considering the surgical technique. The increased risk of weakening the muscle during operations according to Strayer,[39] as also mentioned in different studies, could be measured and confirmed by our data. Based only on our finding, a loss of power of 8.2% is to be expected after a Strayer procedure. Baumann and ATL groups, on the other hand, showed increased power of 5% and 4.7%, respectively. However, this difference reached statistical significance between the Baumann and Strayer methods alone using analysis of variance, whereas other comparisons were not significant. This is a surprising finding because ATL combines both gastrocnemius and soleus release as compared to the Strayer procedure, which includes only the gastrocnemius release. The greater increase in power in ATL could potentially be explained by the increase in ankle lever arm in addition to the improvement in ROM postoperatively.

The results of the kinematic data are in favor of the Baumann procedure. In the Strayer and in the ATL group, there was higher maximal dorsiflexion in the stance phase than in the Baumann group. This is also due to the more invasive technique used in this group, resulting in a greater gain in muscle length. These findings are comparable to the literature.[33,37] Researchers also found an improvement in ROM and the power of the ankle.[37]

This retrospective study has inherent limitations. The gait analyses are performed in our center in a standardized manner, and this enables the collection of comparable data even over a period of several years. The indication and evaluation of the gait analyses are also from a single center. However, this was performed by different medical professionals, which may lead to differences in the choice of the preferred surgical method. Also, clinical examinations always contain a subjective component, and thus, can lead to bias. Correct placement of markers on the skin can be complicated by deformities or a high BMI. Although a large sample was included of different age groups and clinical characteristics, 60.1% of patients were 7-18 years old. Additionally, the reported findings were based on the assessment of the foot as a whole and not the ankle joint in particular; therefore, some of our results might have been affected by midfoot break or other motion of the arch.

Conclusions

The Strayer procedure, although leading to an improvement in certain outcomes, resulted in a loss of strength of 8.2%. ATL is also associated with higher postoperative dorsiflexion. No significant difference in the strength of the plantar flexors was observed compared with other groups. If the Baumann method is chosen, the calf muscle can be lengthened to a lower extent and the postoperative dorsiflexion, therefore, has lower values. However, no loss of strength is to be expected with this surgical method. According to the available data, maximum power can even improve postoperatively. Because of the aforementioned differences, the choice of surgical method should be weighed among the factors mentioned in an interdisciplinary manner.

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Ethical Approval

The study protocol was approved by the institutional review board of Heidelberg University Hospital (S-576/2018) before the conduct of this research.

Declaration of Conflicting Interests

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