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Single procedure tibialis anterior tendon shortening in combination with Achilles tendon lengthening in unilateral cerebral palsy improves swing phase dorsiflexion in gait

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Abstract

Purpose: Tibialis anterior tendon shortening combined with tendon Achilles lengthening showed satisfactory short- and long-term outcomes for pes equinus treatment. This retrospective study aimed to evaluate the effectiveness of a single tibialis anterior tendon shortening-tendon Achilles lengthening procedure for treating pes equinus, in a homogeneous unilateral cerebral palsy patient group.

Methods: Gait analysis was conducted on 22 unilateral cerebral palsy patients (mean age at surgery = 13.3 years, standard deviation = 3 years) before and within 2.5 years (standard deviation = 0.61 years) after the tibialis anterior tendon shortening-tendon Achilles lengthening procedure. Primary outcome measures included foot drop occurrence in swing, foot dorsiflexion and the first ankle rocker presence compared to healthy reference data. Movement analysis profile and gait profile score were also calculated for the entire gait cycle. The clinical exam and the A2 peak ankle power were analyzed. Statistical analysis used the paired Wilcoxon's sign rank test ($p < 0.05$).

Results: Post-operatively, significant improvements were observed in ankle dorsiflexion during swing ($p = 0.0006$) and reduced foot drop in swing ($p = 0.0107$). The occurrence of a first ankle rocker did not significantly change ($p = 0.1489$). Significant improvements in gait profile score and movement analysis profile for all joints and planes indicate overall gait quality improvement. The foot progression changed significantly ($p = 0.0285$), with a greater external orientation. Nineteen out of 22 patients were able to quit wearing their ankle foot orthoses.

Conclusion: Tibialis anterior tendon shortening and tendon Achilles lengthening combination yielded positive outcomes, showing increased foot dorsiflexion, first ankle rocker presence, and overall improved gait quality. These findings support the effectiveness of this surgical approach for treating pes equinus in children with unilateral spastic cerebral palsy.

Keywords: Pes equinus, cerebral palsy, surgical procedure, tendon Achilles lengthening, tibialis anterior tendon shortening

Introduction

Cerebral palsy (CP) is the most common cause of motor disability in childhood and the most common deformity in CP patients is pes equinus.[1]

The main pathomechanism of pes equinus is the persistence of primitive reflex patterns that result in hyperactive calf muscles, leading to an imbalance between muscle and bone growth.[1] Especially in patients with spastic hemiparesis, additional weakness or inefficiency of the ankle extensors also plays an important role.[1]

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With regard to pes equinus therapy, surgical and conservative treatments are available. Conservative therapy consists of physiotherapy, ankle foot orthoses, castings, and injections of botulinum toxin type A.[1]

The main concept of surgical therapy is in most cases to lengthen the gastrocnemius-soleus muscle-tendon complex.[2–5] Shore et al.[6] grouped by anatomic zones the outcomes of 10 different procedures in his systematic review. The goal of this systematic review was to assess surgical management of equinus foot in CP based on 35 articles. The study highlighted that age and the subtype of CP (hemiplegia or diplegia) were the two crucial factors influencing surgical outcomes in equinus foot cases.[6] However, the study also revealed limitations in the existing literature, that made the evidence insufficient to favor any specific surgical intervention.[6]

The first study published on the outcome of the combination of tibialis anterior tendon shortening (TATS) with tendon Achilles lengthening (TAL) was conducted by Rutz et al. in 2011. It showed that combining these two surgeries significantly reduced spasticity in the gastro-soleus muscle in spastic equinus. Hemiplegic patients also experienced reduction in spasticity in the tibialis anterior muscle. However, there were no immediate changes in muscle strength based on manual muscle tests. Post-operative gait analysis showed that 27 out of 29 patients had active ankle dorsiflexion, which was absent before surgery.[7] This was the first study to use the movement analysis profile (MAP) and gait profile score (GPS)[8] to assess surgical outcomes in treating equinus in CP children.

Based on the short-term study by Rutz, a long-term retrospective study (5.8 years) was conducted in 2017[9] to verify the efficacy of TATS in combination with TAL in patients with spastic equinus in CP, with Gross Motor Function Classification System (GMFCS) level I–II.[10] The study demonstrated highly satisfactory outcomes, with all patients able to walk without ankle foot orthoses (AFO) and achieve active dorsiflexion after surgery.[9] In 2016, Tsang et al.[11] found that combining anterior tibial tendon shortening (TATS) with calf muscle-tendon lengthening is beneficial for foot positioning during gait in spastic equinus.

A recent retrospective study by Dussa et al.[12] evaluated the efficacy of combining TATS and calf muscle lengthening procedure (CMLP) on ankle dorsiflexion in swing and foot position in the sagittal plane during gait compared to surgery with calf muscle lengthening alone. The Silfverskjöld test[13] in Dussa et al.[12] established the CMLP type that was done. According to the degree of fixed equinus contracture, patients with a negative test underwent a Strayer[4] or a Z-lengthening of the Achilles tendon.[12] Those with a positive test underwent aponeurotic lengthening of the gastrocnemius muscle. The study did not show a superior effect of the additional TATS compared to surgery with calf muscle lengthening alone.

Therefore, limited research has been conducted on the outcomes of combining TATS with TAL in children with CP and previous studies have shown limitations, such as heterogeneous patient groups[7,9,11,12] and the inclusion of multilevel surgery.[7,9,11] To gain a better understanding of the outcomes, it is important to examine more homogeneous patient samples who underwent TATS with TAL as an isolated procedure.

The aim of this study is to assess the follow-up results after TATS in combination with TAL as an isolated procedure in children with unilateral CP looking at parameters described to be clinically important for normal walking, such as dorsiflexion in swing for foot clearance and the presence of a first ankle rocker. In addition, this study aims to examine changes in the clinical exam, transverse plane gait parameters, the A2 peak ankle power, and to evaluate the MAP and GPS.

Methods

The study population included unilateral CP patients with equinus, 8–18 years old, who underwent a TATS in combination with a tendon Achilles lengthening (TAL) between August 2004 and July 2021. The targeted short-term mean follow-up duration was greater than 1 year. In addition, it was required to have a written informed consent, signed by a legally authorized representative.

The study was conducted in compliance with the protocol, the current version of the Declaration of Helsinki, the ICHGCP, the HRA, and was approved by the ethical committee. Patients who met the following criteria were excluded: a diagnosis other than CP, dystonic or mixed movement disorder, Botulinum toxin A injections within 6 months prior to the first pre-operative analysis, GMFCS level III or higher, TATS and TAL as part of a multilevel surgery, and not having complete pre- and post-operative gait analysis data available.

Indications

Surgical indication was contracture of the triceps in a unilateral CP patient. All patients underwent a pre-operative gait analysis including a clinical exam. The analysis explored equinus gait at initial contact and stance phase as well as the electromyography (EMG) profile, where the goal was to find activation of the tibialis anterior muscle during swing phase.

Surgical procedure

TAL was performed using an open Z-lengthening of the Achilles tendon to be able to control the amount of tendon lengthening. The tendon then was repaired under maximal tension using an absorbable suture (6 Vicryl, Ethicon Inc., Johnson and Johnson) with the foot in 10° of dorsiflexion in knee extension.[9]

TATS was performed distally with transosseous fixation to the medial cuneiform bone (suture with 6 Vicryl, Ethicon Inc., Johnson and Johnson until 2020, since 2020 use of 2.0 FiberWire, Arthrex Manufacturing Inc.) at the original insertion. The tendon was put under tension in a way that the foot maintained a neutral position at the ankle.

Post-operatively, a cast was applied in plantigrade position for 6 weeks, with weightbearing allowed after 4 weeks. Following cast removal, patients wore a rigid AFO for 6 weeks, transitioning to a hinged AFO at 3 months, and gradually reducing wear-time based on active ankle dorsiflexion during gait.

Clinical assessment and gait analysis

All patients had the standardized clinical assessment of the gait laboratory which includes the examination of the passive range of motion (ROM), spasticity according to the modified Ashworth/Bohannon scale[14] (scale: 0-4), and the manual muscle strength test[15] (scale: 0-5) of the dorsi- and plantar-flexors.

The pre- and post-operative instrumented gait analyses included kinematics and kinetics, using a state-of-the-art motion-capture system (VICON, Oxford Metrics Ltd, UK) and force plates (Kistler Instrumente AG, Winterthur, Switzerland). Patients walked barefoot at their self-selected speed. The Conventional Gait Model marker-set was used, and six complete gait cycles per leg were recorded. Anthropometric data were recorded for appropriate scaling.

From the three-dimensional (3D) gait data: temporal-spatial parameters, joint kinematics and kinetics were calculated using Vicon Nexus software (Oxford Metrics Ltd., UK). All data were expressed as a percentage of the gait cycle. Furthermore, the GPS and MAP[8] were calculated.

The primary outcome parameters were the presence of a first rocker and foot dorsiflexion/foot drop in terminal swing. The presence of a first rocker was a categorical variable and defined as a movement toward plantarflexion at initial contact (ankle dorsiflexion angle at $t=1$ less than the same angle at $t=0$). Foot dorsiflexion in terminal swing was reported as the mean ankle dorsiflexion angle between 80% and 100% of the gait cycle. In addition, a foot drop categorical variable was defined by comparing the mean foot dorsiflexion angle of the patients between 80% and 100% of the gait cycle with that of a reference data set of typically developing children. Foot drop was detected when the mean ankle dorsiflexion angle between 80% and 100% of the gait cycle was more plantarflexed than the mean in the reference data set minus two standard deviation in the reference data set.[16] The mean standard deviation of foot dorsiflexion in our normative data set was 6 degrees during 80%–100% of the gait cycle.

Secondary outcome measures included GPS, MAP,[8] and foot progression. The GPS gauges the quality of an individual's walking pattern by comparing it to an ideal model, while the MAP offers a detailed analysis, identifying deviations from the norm and tracking improvements over time. Integrating pre- and post-operative data comparisons becomes pivotal, providing an important evaluation of the effectiveness of the surgical intervention, as they allow for the assessment of the overall quality of the individual's gait.

Statistics

Paired *t*-test or Wilcoxon's mated-pairs signed rank test to asses paired data were used. Sequential data were assessed using repeated analysis of variance (ANOVA) with Bonferroni's post hoc analysis. For the statistic analysis SPSS® software (SSPS Inc., Headquaters, Chicago, USA; STATISTICA®, Statsoft Inc.) was used.

Study population

The study was performed in 22 subjects with unilateral CP pre- and post-TATS-TAL within 2.5 years (standard deviation (SD) = 0.61 years) of the time of surgery. Of these, 4 were girls and 18 were boys with an average age between 8 and 18 years; the average age at the time of the surgery was 13.3 years old (SD = 3 years).

In the pre-operative clinical examination, we found 18 patients with GMFCS level I and 4 patients with level II, 17 patients wore an orthosis (AFO) before surgery (Table 1).

Results

Primary outcome measures

Foot drop in swing. We found a positive change toward less occurrence of a foot drop in swing ($p=0.01073$). Foot drop being defined as less dorsiflexion than 2 times the SD (2 times 6 degrees) of the normal gait pattern.[16] According to our definition, pre-operatively 18 patients out of 22 had a drop foot. Looking at the data post-operatively, there was no foot drop anymore for 7 patients, 15 patients still had a foot drop greater than 12 degrees, but we found no onset of a new foot drop in any of our patients.

Foot dorsiflexion in terminal swing. Dorsiflexion in terminal swing improved (i.e. became less plantarflexed between 80% and 100% of the gait cycle) ($p=0.000593$). Although not quite back to normal (Figure 2: red dotted line) (Figure 2).

The presence of a first rocker. We found a first rocker in 3 patients post-operatively, which had no first rocker pre-operatively, the remaining patients still had no first rocker.

Table 1. Description of study population.

Patient characteristics	Number of patients (percentage or SD)	t-test (pre-/post-operative)
Sex		
Female	4 (18%)	
Male	18 (82%)	
Age at surgery	13.3 y (SD 3 y)	
Affected leg		
Left	7 (32%)	
Right	15 (68%)	
GMFCS		
PRE		
Level I	18 (82%)	
Level II	4 (18%)	
POST		
Level I	20 (91%)	
Level II	2 (9%)	
USE OF AFO		
PRE	17 (77%)	
POST	3 (14%)	
ROM affected leg		
PRE		
Plantarflexion	26.8 deg (SD 20.8 deg)	
Dorsiflexion Knee extended	-13.9 deg (SD 15.0 deg)	
Dorsiflexion Knee flexed	-6.1 deg (SD 12.6 deg)	
POST		
Plantarflexion	36.1 deg (SD 14.1 deg)	p = 0.067
Dorsiflexion Knee extended	-1.3 deg (SD 9.6 deg)	p = 0.002
Dorsiflexion Knee flexed	4.8 deg (SD 7.1 deg)	p = 0.001
Strength affected leg		
PRE		
Plantarflexion	3.3 (SD 1.3)	
Dorsiflexion	3.2 (SD 1.2)	
POST		
Plantarflexion	3.3 (SD 1.1)	p = 0.954
Dorsiflexion	3.5 (SD 1.3)	p = 0.154

However, there was no statistically significant improvement (p = 0.1489).

Secondary outcome measures

GPS. A statistically significant and clinically meaningful improvement in the gait pattern was observed (p = 0.000197). There was a positive change for 16 patients, a negative change in 1 patient, and no change in 5 patients (positive change meaning a decrease of GPS post vs pre more than 1.6, negative change meaning an increase more than 1.6, in between meaning no change).

Plotting the change in GPS and ankle gait variable score (GVS), there was a marked statistical improvement in ankle GVS and GPS (Figure 3).

In fact, when we plotted the MAP, improvements were visible in all joints and planes (Figure 4).

Foot progression. Foot progression changed significantly toward a more external feet position post- compared to pre-operatively (p = 0.0285) (Figure 5).

A2 peak ankle power. Kinetics data were available in 20 out of 22 subjects both pre- and post-operative. The change of A2 peak ankle power was not significant (p = 0.105) (Figure 6).

Pre-operatively, there was a mean equinus of −13.9 deg (SD = 15.0 deg) with an extended knee and −6.1 deg (SD = 12.6) of the affected leg in the clinical exam. We found a significant increase in ankle dorsiflexion (p = 0.002, respectively p = 0.001) post-operatively. No significant change in plantar- and dorsi-flexor strength was found from pre- to post-operatively.

50% of the patients with GMFCS level II pre-operatively achieved an improvement to level I post-operatively.

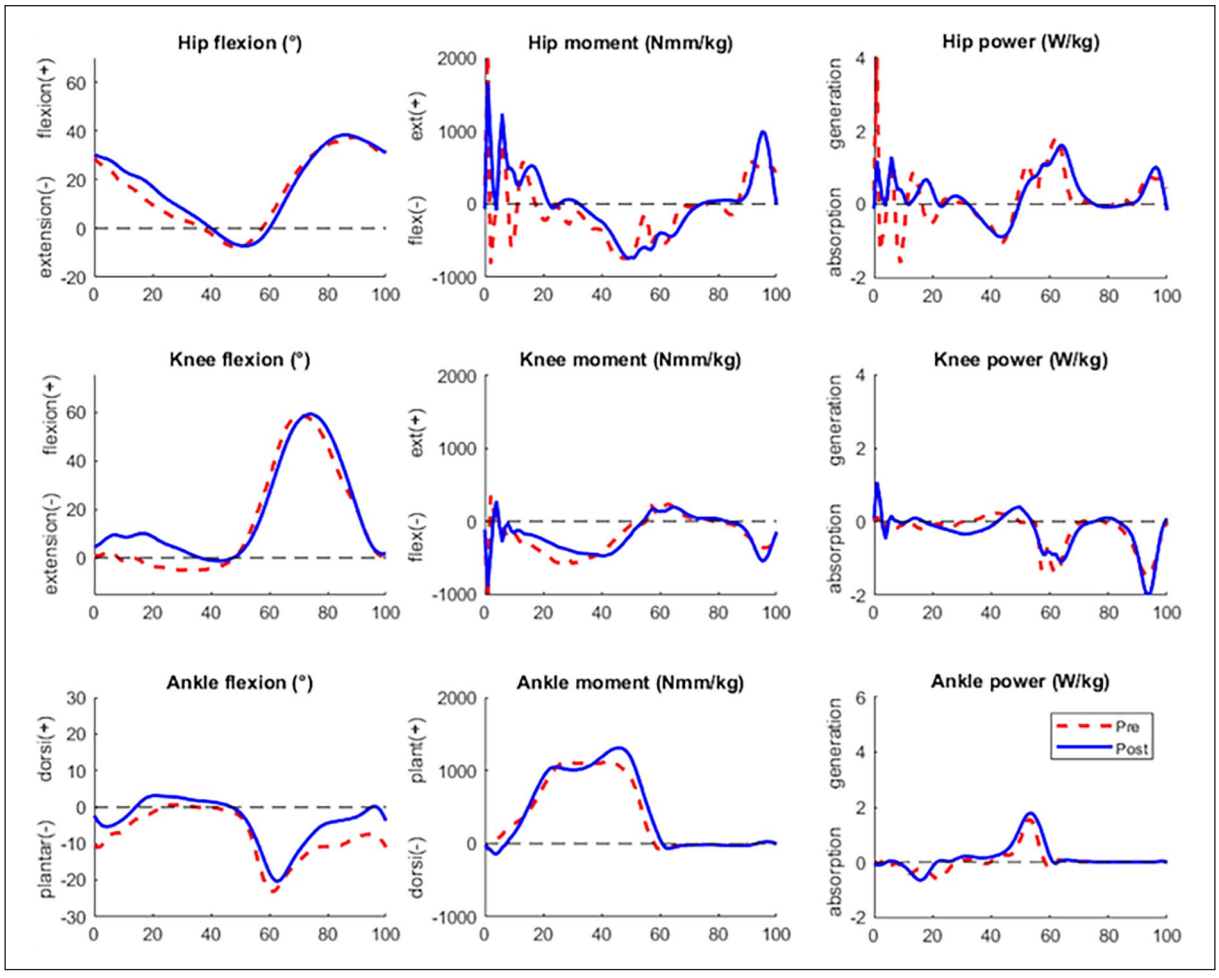

Figure 1. Representative sagittal kinematics and kinetics pre- (red) and post-operatively (blue) of one of the patients.

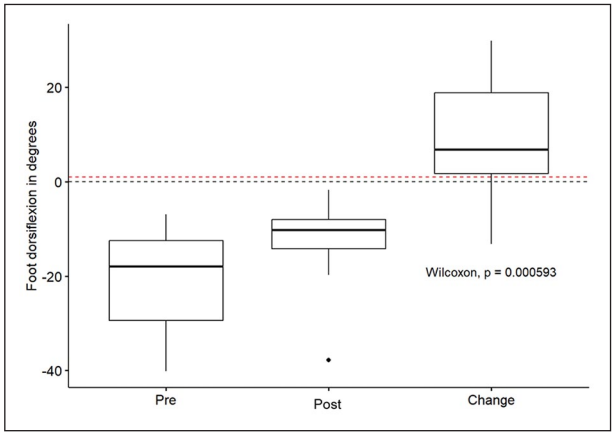

Figure 2. Foot dorsiflexion in terminal swing (between 80% and 100% of the gait cycle): shown is the comparison pre- and post-surgery and the change (in degrees) between pre- and post-operative foot dorsiflexion. The red dotted line showing the normal average of foot dorsiflexion in healthy individuals.

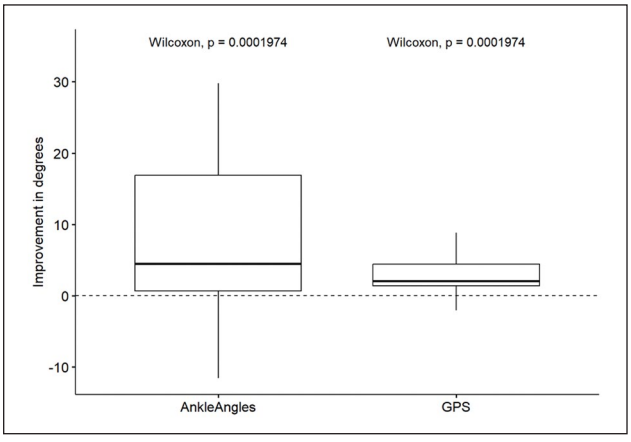

Figure 3. Change in GPS and ankle dorsiflexion (improvement in degrees).

100% of the patients with GMFCS level I pre-operatively reported no change after surgery. Pre-operatively 17 patients (77%) wore an AFO, whereas at time of the second gait analysis, only 3 patients (14%) were still wearing an AFO on a daily basis to improve their walking performance.

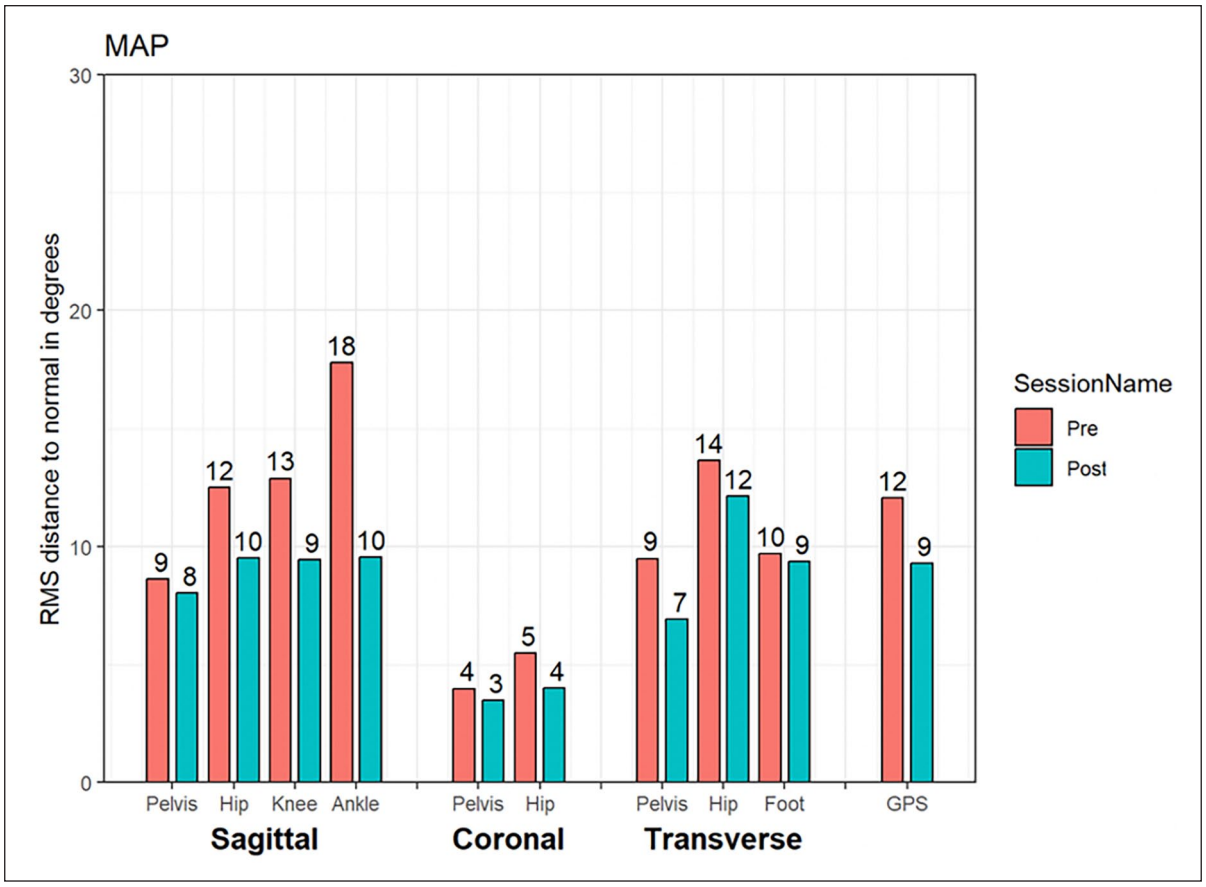

Figure 4. Pre- and post-MAP of all joints and planes.

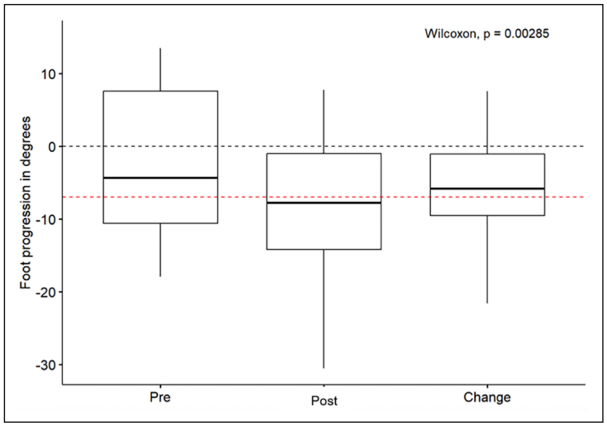

Figure 5. Overall foot progression: shown is the comparison pre- and post-surgery and the change (in degrees) between pre- and post-operative foot progression. The red dotted line showing the normal average of foot progression in healthy individuals.

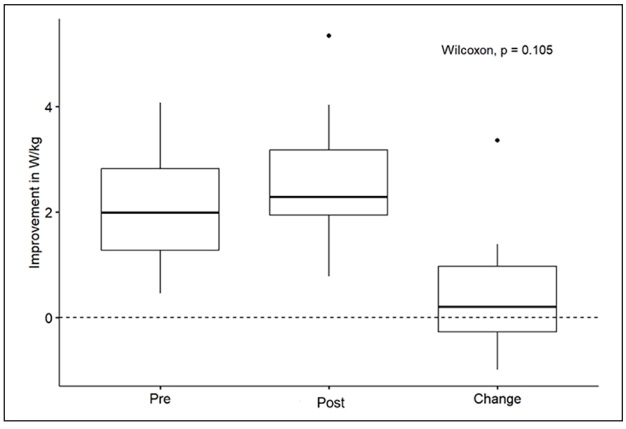

Figure 6. A2 peak ankle power: shown is the comparison pre- and post-operative.

Discussion

Our study shows that there has been an improvement of foot drop in swing as well as foot dorsiflexion during the swing's terminal phase (the final 20% of the gait cycle). A2 peak ankle power did not change significantly pre- and post-operatively.

We found statistically significant improvements in the GPS and in ankle GVS after 2.5 years from the time of surgery. Furthermore, plotting the MAP showed a

significant change in all joints and planes post-operatively. The change in foot progression was significant toward feet more external.

50% of the patients with GMFCS level II pre-operatively achieved an improvement to level I post-operatively. 100% of the patients with GMFCS level I kept their level. Without a decrease in function, only 3 patients out of 17 still need an AFO on a daily basis.

Looking at Gage et al.'s[17] prerequisites for normal gait, the combination of TATS and TAL improved foot clearance and prepositioning of the foot for initial contact. In three patients, we found a first rocker, which means an enhanced stability in stance for these patients. Furthermore, a decrease in GPS and ankle GVS indicated a progression toward a more efficient gait pattern, potentially leading to improved energy efficiency.

Considering the WHO ICF criteria,[18] this surgery can not only help to improve the components of body function and structure, but if orthotics are no longer required and gait becomes more efficient, it can also improve activity leading to improved self-care and mobility, which in return can impact overall participation. One of the limitations for this study is the absence of the inclusion of a standardized patient-reported outcome measures (PROMs) to provide a closer examination of the different components of the ICF.

In 2022, Scavlos et al.[19] published a review to summarize the literature on the function of the ankle dorsiflexor muscles after gastrocnemius-soleus lengthening (GSL) in ambulant children with CP. Their review included 33 studies, with 29 studies focusing on GSL (as either an isolated procedure or as part of multilevel surgery) and four studies examining the outcomes of TATS in combination with GSL. Most of the studies included both bilateral and unilateral CP patients, while only one study specifically focused on unilateral CP patients. Of total, 22 studies demonstrated a statistically significant improvement ($p < 0.05$) in ankle dorsiflexion ROM during the swing phase after GSL.[19] Only two studies reported a stratified outcome for children with unilateral spastic CP and bilateral spastic CP, suggesting a potentially greater improvement in maximum dorsiflexion in the swing phase in bilateral CP patients.[20,21] Lofterød et al.[21] reported a 47.5% frequency of persistent foot drop despite satisfactory correction during gait. However, the paper looking at unilateral CP only[22] did not report on foot drop during the swing phase.

The conclusion was that among children who underwent GSL for equinus, identifying suitable candidates for TATS is crucial to reduce persistent foot drop, to improve functional outcomes, and to minimize post-operative AFO use. GSL showed potential to improve ankle dorsiflexion during gait, but its correlation with reduced foot drop or long-term AFO use remains unclear. The review gave an indication that the function of ankle dorsiflexor muscles can improve after GSL, indicated by increased active ankle dorsiflexion ROM and manual muscle strength. PROMs were not reported and compared in this literature review.[19]

Compared to these findings, in our series, foot drop was fully corrected in 7 patients, while 15 patients still experienced persistence. However, foot dorsiflexion during the terminal swing improved significantly.

Notably, GPS and ankle GVS improved in 16 out of 22 patients, indicating a high success rate. We think MAP and GPS are especially relevant for an isolated procedure because it provides an idea of the broader impact of the procedure on the gait. Which leads to the discussion if a fully corrected drop foot is needed in daily life to avoid tripping and leads to compensation mechanisms or if a certain degree (in this case more 2 SD, i.e. 12 degrees, more plantarflexed than normal) of foot drop is acceptable for a good functional outcome.

Four studies have been published so far about TATS in combination with TAL.[7,9,11,12] Three of these were in favor of surgery,[7,9,11] while one study found no significant improvement compared to calf muscle lengthening alone.[12] All four studies had a limited number of patients and had heterogeneous patient groups, looking at unilateral and bilateral patients simultaneously. Three studies involved TATS-TAL as part of multilevel surgery,[7,9,11] and therefore, the effect of TATS-TAL as a single procedure has not been shown. Only the study by Dussa et al.[12] had a control group. Long-term follow-up was only described in one study,[9] which looked at uni- and bi-lateral patients, also including patients undergoing multilevel surgery.

Our study stands out by exclusively including unilateral CP patients and no further combined surgeries, resulting in a more homogeneous study population.

We also assessed results in the transversal plane, which has not been examined in previous TATS-TAL studies. This is particularly important to evaluate the result on overall walking quality, specifically, as there is a lack of information regarding the impact of correcting equinus on foot progression. While foot progression did not become normal after the procedure, there was a significant change toward more external foot progression. This addresses previous concerns about this surgery increasing the internal foot progression.

A2 peak ankle power did not change significantly pre- and post-operatively, which shows, that ankle push-off power was preserved, which indicates that strength was preserved, and TAL is a safe method in this patient population for Z-lengthening of the Achilles tendon. Also, in the clinical exam, we could not find a decrease of plantarflexor strength.

Our study stands out compared to studies looking at TATS in combination with TAL by looking at a more homogeneous patient sample (unilateral CP patients) without any other concurrent surgeries, but it also shows several limitations. The short follow-up time, no control

group except the normative data from typically developing children and its retrospective design. At our institution, most of our unilateral CP patients are operated with TATS in combination with TAL, and it was not possible to assemble a matched control group with TAL only. Further studies, if possible prospective, with a control group (possibly in a multicenter approach) and a long-term follow-up are necessary to further study the effect of TATS in combination with TAL.

Our surgical suture technique has changed now. We shifted to FiberWire sutures instead of the Vicryl sutures utilized in all patients of this study. Non-resorbable FiberWire enables to maintain the tension for a longer period, giving the tendon more time to heal in the shortened position.

We envisage comparing this study results (with Vicryl) with that we are currently collecting with FiberWire sutures in the future.

Conclusion

The aim of this article was to present the results of TATS in combination with TAL in a homogeneous unilateral CP patient group without multilevel surgery. Despite limitations, our study demonstrates the beneficial outcomes of TATS combined with TAL for equinus foot deformity in CP patients. The results indicate a positive change in reducing foot drop during swing and improving gait pattern significantly. A significant change toward external foot progression was observed, improving the functional gait pattern. As a perspective we may suggest that prospective studies, including evaluations of changes in general stability in walking and daily life functioning, with long-term follow-up and a control group, are needed to further investigate these findings.

Author contributions

M.W. is the first author, contributed to study conception and design, ethical approval, wrote the methods, analyzed the results, wrote discussion and conclusion. M.S. is the shared co-first author, looked for all the patient data in the computer system and paper archive, prepared the patient data and put them in a table, wrote the abstract and the introduction, analyzed study population data, and helped with the discussion. M.O. helped with data extraction, read and helped finalize manuscript. M.S. analyzed patient data in the gait laboratory and prepare the statistics, read and helped finalize manuscript. R.B. introduced surgical technique, read and helped finalize the manuscript. E.V. is the last author contributed to study conception and design, supervision, read and helped finalize the manuscript.

Declaration of conflicting interests

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Ethical approval

This study was approved by the ethical committee Nordwest- und Zentralschweiz (EKNZ) (Project-ID 2021-01855) on 26 October 2021.

Informed consent

All participants provided written informed consent prior to participating. Written informed consent was obtained from a legally authorized representative(s) for anonymized patient information to be published in this article.

Supplemental Material

Supplemental material for this article is available online.

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