The split transfer of tibialis anterior tendon to peroneus tertius tendon for equinovarus foot in children with cerebral palsy

İlker Abdullah Sarıkaya1, Sema Ertan Birsel2, Ali Şeker3, Ozan Ali Erdal1, Barış Görgün1, Muharrem İnan1

1Department of Orthopaedics and Traumatology, Otoroplejia Academy of Pediatric Orthopaedics, Istanbul, Turkey
2Department of Orthopaedics and Traumatology, Istanbul Medicine Hospital, Istanbul, Turkey
3Department of Orthopaedics and Traumatology, Istanbul University Cerrahpaşa, Cerrahpaşa School of Medicine, Istanbul, Turkey

ABSTRACT

Objective: The aim of this study was to analyze the results of the split anterior tibialis tendon transfer (SPLATT) to peroneus tertius (PT) for equinovarus foot deformity in children with cerebral palsy (CP).

Methods: The medical records of 25 ambulatory CP patients (mean age: 8.7±3.2 years, range: 4-16 years) with equinovarus foot (33 feet), who underwent SPLATT to PT surgery between 2014 and 2016, were retrospectively reviewed. A senior surgeon performed all the surgical procedures. SPLATT was performed as part of a single-event multilevel surgery for the lower limb, and the concomitant procedures on the same extremity were recorded. The patients who required any additional foot or ankle surgery that could affect the clinical outcome (except heel cord lengthening) were excluded from the study. The Kling’s College Criteria were used to evaluate the procedural outcome of the foot position and gait, and the associated complications were recorded.

Results: The mean follow-up time was 28.8±5 months (range: 24-42 months). The postoperative Kling scores were excellent for 27 feet of the patients who had a plantigrade foot, without fixed or postural deformity, in a regular shoe, having no calluses; good for 5 cases for those who walked with less than 5° varus, valgus, or equinus posture of the hind foot, wearing regular shoes, having no callosities; and fair for 1 case for those who had recurrence of the deformity. There was only one wound detachment, which was treated with wound care and dressing. None of the patients had overcorrection, infection, or bone fracture.

Conclusion: The dynamic SPLATT to PT surgery for the management of the equinovarus foot deformities in the CP patients is a safe and less complicated surgical alternative with a good functional outcome. It is a safe and effective treatment method for the management of equinovarus foot deformities in CP.

Level of Evidence: Level IV, Therapeutic study

Equinovarus is a well-recognized foot and ankle deformity that leads to significant functional disability in cerebral palsy (CP) (1, 2). The equinovarus deformity may be secondary to spasticity and imbalance of gastrocnemius, soleus, anterior tibialis, posterior tibialis, flexor hallucis longus, or flexor digitorum overactivity (2-5). The mild equinovarus deformity can often be corrected by orthoses. However, the use of orthotics becomes difficult or impossible as the deformity progresses. The operative procedures to correct the deformity should then be considered. The split transfer and tenodesis of tibialis anterior tendon (TAT) to the dorsum of the foot has been used to correct the equinovarus deformity by many authors as a classical method (6-12). However, various complications and technical difficulties have been reported in the past, and there is no consensus regarding the best method (13, 14). Limpaphayom et al. reported a recurrence rate of 15% during a follow-up of 5 years in the CP patients who underwent split transfer and tenodesis of TAT to the cuboid bone; in their analysis, it was found that the tunnel roof fracture and skin-related problems were important complications (1). However, to reduce the recurrence and complication rates, the use of peroneus brevis tendon as a recipient site has been recommended by Kling who performed tibialis posterior tendon transfer for the treatment of equinovarus deformity of the foot in children with CP (9). Hoffer described the split anterior tibialis tendon transfer (SPLATT) to peroneus tertius (PT) for the treatment of recurrent clubfoot and claimed...
that the same transfers could also be performed during the treatment of other severe structural deformities, such as CP in which the dynamic supination or muscle imbalance is a contributing factor (15).

Considering these complications and recurrence ratios, we started performing the SPLATT to PT for equinovarus foot in children with CP. We hypothesized that the transfer of TAT to PT may improve the clinical results because of the lateral extension of the moment arm and because of the real tendon transfer instead of osseous tenodesis. This study aims to present the clinical results for the first 33 feet.

Materials and Methods

The institutional review board ethical approval was obtained from the Ethical Committee of Biruni University (2018-KAEK-43). The medical records of 25 ambulatory CP patients (33 feet) who underwent SPLATT to PT surgery for the equinovarus foot between 2014 and 2016 were retrospectively reviewed.

SPLATT was indicated for the patients with flexible equinovarus deformity, which was determined by a positive flexor withdrawal reflex test (confusion test) that pointed out the TAT overactivity for children older than 4 years (1). The patients who required any additional foot and ankle surgeries, which could affect the clinical outcome (except heel cord lengthening), were excluded from the study. Additional 2 patients (4 feet) with an absent PT were excluded, and SPLATT and tenodesis to the cuboid bone was performed for this patient group.

SPLATT was performed as part of a single-event multilevel surgery for the lower limb, and the concomitant procedures on the same extremity were recorded.

A senior surgeon performed all the surgical procedures under general anesthesia. The heel cord lengthening was performed to correct the equinus deformity, if necessary (11). A 1.5-cm dorsomedial incision was made over the medial cuneiform. Then, the tendon sheath was incised, and the fibular half of the TAT (F-TAT) was detached with a sharp dissection from the first metatarsal. Then, the Krackow stitches were sutured at its end to prepare the F-TAT for the transfer (Figure 1). A second incision was made at the anterior distal tibia, lateral to the tibial crest and directly over the TAT; the sheath of the tibialis anterior muscle was split longitudinally and the free end of the F-TAT was delivered into the second incision with the help of a hemostat or Ober tendon passer (making sure that it stays under the retinaculum and within the tendon sheath) (Figure 2). Following this, the PT tendon was approached through a third incision made on the subcutaneous border, just lateral to the lesser toe extensor tendons (Figure 3). Then, the sheath overlying the tendon was opened and a subcutaneous tunnel from the distal (third) incision to the second incision was created with the help of a large curved hemostat or dissecting scissors. Furthermore, the F-TAT was passed from the second incision area, and from the anterior of the tibia, it was re-routed into the third incision area through the subcutaneous tunnel. The F-TAT was transferred and sutured to augment the PT tendon while holding the ankle at 20° of dorsiflexion and 10° of eversion position (Figure 4).

A short leg cast was applied to the ankle in the neutral position and was maintained for 6 weeks. The intravenous patient-controlled analgesia (IV-PCA) was started immediately after the operation and maintained during the hospital stay (16-19).

HIGHLIGHTS
- The dynamic SPLATT to PT surgery for the management of the equinovarus foot deformities in the CP patients is a safe surgical alternative with a good functional outcome.
- This technique is a true tendon to tendon transfer, when compared to other osseous tenodesis techniques.
- Treatment of pes cavavars in cerebral pals.
The patient assessment was performed at week 6, 3 months, 6 months, and then yearly. The results were obtained from the last visit. The procedural outcome of the foot position and gait was evaluated according to the Kling’s criteria (Table 1, Figure 5, 6), and the associated complications were recorded (9).

Statistical analysis
The statistical analysis was performed using Statistical Package for the Social Sciences version 15 (SPSS Inc., Chicago, IL, USA). The data are provided as mean±standard deviation (minimum-maximum) for continuous variables and as frequency for categorical variables. The Wilcoxon rank test was used to compare the preoperative and postoperative Gross Motor Function Classification System (GMFCS) scores. The results were evaluated at a 95% confidence interval and an accepted significance level of p<0.05.

Results
Of 25 patients, 10 (40%) were males and 15 (60%) were females. The mean age was 8.7±3.2 years (range: 4-16 years), and the mean follow-up period was 28.8±5 months (range: 24-42 months). According to the topographic classification, 15 patients (60%) were diplegic and 10 patients (40%) were hemiplegic. The patients’ demographics, concomitant operations, and results are provided in Table 2.

According to the preoperative GMFCS scores, 14 patients (56%) were GMFCS level 2, 3 patients (12%) were GMFCS level 3, and 8 patients (32%) were GMFCS level 4. Postoperatively, 17 patients (68%) were GMFCS level 2, 7 patients (28%) were GMFCS level 3, and 1 patient (4%) was GMFCS level 4. All the patients who were GMFCS level 2 preoperatively remained as level 2 postoperatively; 1 of the GMFCS level 3 patients remained as level 3 but 2 of the GMFCS level 3 patients improved to level 2 postoperatively. Among the GMFCS level 4 patients, 1 improved to level 2; 6 improved to level 3, and 1 remained as level 4 (Table 2). The mean GMFCS score was 2.76±0.93 (median: 2) preoperatively and 2.36±0.57 (median: 2) postoperatively. There was a statistically significant improvement in the GMFCS scores postoperatively (p=0.004).

The postoperative Kling scores were determined as excellent for 27 feet (82%) of the patients who had a plantigrade foot, without fixed or postural deformity, in a regular shoe, having...
Table 1. Kling’s criteria

| Excellent | The child managed to walk with a plantigrade foot, without fixed or postural deformity, in a regular shoe, having no calluses. Patients and parents were pleased with the result, and no brace was required postoperatively. |
| Good | The child walked with less than 5° varus, valgus, or equinus posture of the hind foot, wearing regular shoes, having no calluses. Patients and parents were satisfied with the outcome. |
| Poor | The child had a recurrent equinovarus deformity or overcorrected into a valgus or calcaneovalgus deformity. |

Table 2. Results and concomitant surgery

| Foot | Side | Sex | Age (years) | Preop GMFCS | Postop GMFCS | Postop Kling score | Concomitant surgery | Complication |
|------|------|-----|------------|-------------|--------------|------------------|---------------------|--------------|
| 1    | R    | M   | 8          | 4           | 2            | Excellent        | Achilloplasty+plantar fasciotomy | s            |
| 2    | L    | M   | 8          | 4           | 2            | Excellent        | Achilloplasty+plantar fasciotomy | -            |
| 3    | R    | F   | 9          | 2           | 2            | Excellent        | Flexor carpi ulnaris tenotomy+pronator tenotomy | -            |
| 4    | L    | M   | 14         | 2           | 2            | Excellent        | Gastrocnemius tenotomy | -            |
| 5    | R    | M   | 12         | 2           | 2            | Good             | Gastrocnemius tenotomy+plantar fasciotomy | -            |
| 6    | L    | M   | 12         | 2           | 2            | Excellent        | Gastrocnemius tenotomy+plantar fasciotomy | -            |
| 7    | R    | M   | 9          | 2           | 2            | Excellent        | Gastrocnemius tenotomy+pronator tenotomy | -            |
| 8    | R    | F   | 5          | 4           | 3            | Excellent        | -                    | -            |
| 9    | L    | F   | 5          | 4           | 3            | Excellent        | -                    | -            |
| 10   | R    | F   | 6          | 2           | 2            | Good             | Gastrocnemius tenotomy | -            |
| 11   | L    | F   | 6          | 2           | 2            | Good             | Gastrocnemius tenotomy | -            |
| 12   | R    | M   | 6          | 2           | 2            | Excellent        | -                    | -            |
| 13   | R    | F   | 5          | 2           | 2            | Excellent        | -                    | -            |
| 14   | L    | F   | 5          | 2           | 2            | Excellent        | Gastrocnemius tenotomy | -            |
| 15   | R    | F   | 5          | 2           | 2            | Excellent        | Gastrocnemius tenotomy+pronator tenotomy | Wound detachment |
| 16   | R    | M   | 5          | 2           | 2            | Excellent        | -                    | -            |
| 17   | L    | M   | 5          | 2           | 2            | Excellent        | -                    | -            |
| 18   | L    | F   | 7          | 2           | 2            | Excellent        | Gastrocnemius tenotomy | -            |
| 19   | R    | F   | 16         | 4           | 3            | Excellent        | Supracondylar femoral extension osteotomy | -            |
| 20   | L    | F   | 16         | 4           | 3            | Poor             | Supracondylar femoral extension osteotomy | Recurrence |
| 21   | R    | F   | 9          | 2           | 2            | Excellent        | Plantar fasciotomy | -            |
| 22   | L    | M   | 13         | 4           | 3            | Excellent        | Supracondylar femoral extension osteotomy+tibial derotation osteotomy | -            |
| 23   | R    | M   | 8          | 4           | 3            | Excellent        | Achilloplasty | -            |
| 24   | R    | M   | 11         | 2           | 2            | Excellent        | -                    | -            |
| 25   | R    | F   | 8          | 4           | 3            | Excellent        | Supracondylar femoral extension osteotomy+achilloplasty | -            |
| 26   | L    | F   | 8          | 4           | 3            | Excellent        | Supracondylar femoral extension osteotomy+achilloplasty | -            |
| 27   | L    | M   | 13         | 3           | 2            | Excellent        | Plantar fasciotomy | -            |
| 28   | R    | M   | 6          | 4           | 3            | Excellent        | Supracondylar femoral extension osteotomy+achilloplasty | -            |
| 29   | L    | F   | 7          | 2           | 2            | Excellent        | Iliopsoas tenotomy+hamstring tenotomy | -            |
| 30   | L    | F   | 9          | 3           | 3            | Good             | Gastrocnemius tenotomy | -            |
| 31   | R    | F   | 9          | 2           | 2            | Excellent        | -                    | -            |
| 32   | L    | F   | 9          | 3           | 2            | Excellent        | -                    | -            |
| 33   | R    | F   | 10         | 4           | 4            | Good             | Achilloplasty | -            |

GMFCS: Gross Motor Function Classification System

Preop: preoperative; Postop: postoperative; R: right; L: left; F: female; M: male
no calluses; good for 5 feet (15%) for those who walked with less than 5° varus posture of the hind foot, wearing regular shoes, having no calluses; and fair for 1 foot (3%) for those who had the recurrence of deformity. The recurrent deformity was treated with the total transfer of the tendon and first metatarsal osteotomy at the first year of initial operation. There was only 1 (3%) wound detachment, which was treated with wound care and dressing. None of the patients had overcorrection, infection, depression of the first metatarsal, reflex sympathetic dystrophy, or bone fracture due to bone fixations.

Discussion

The overactive TAT is accepted as one of the factors responsible for the varus-inversion deformity of the ankle in the spastic CP (3, 4). Therefore, SPLATT and tenodesis to the cuboid bone are a widely preferred treatment method to reestablish the muscle balance in the varus-inversion deformity (20, 21). However, this method is related with fixation problems and significant discomfort due to wound breakage (13, 14, 22). To overcome these technical disadvantages, in this study, the SPLATT to PT was performed to correct the equinovarus foot in CP. At their last follow-up visit, 97% of the patients (postoperative Kling scores were excellent and good) achieved a stable plantigrade foot and had functional improvement.

The SPLATT technique performed through a pre-drilled bony tunnel and fastening to the dorsum of the foot with a button has been well described in the literature (6, 22-24). However, the major disadvantages of this technique are the development of ulcers in the underlying skin, wound infections related to skin ulcers, and early fixation failure (14). Moreover, the two-tunnel technique requires a larger incision, and there is a risk of getting a fracture between the two bony tunnels (14). Holsakar et al. evaluated the outcomes of SPLATT with screw fixation for the correction of spastic equinovarus in 47 patients with a mean follow-up of 51 months and reported that the implant breakage and pull-out are significant complications if the screw or screw-like implants are used (13). However, we observed that our modified technique of SPLATT to PT is easily applicable with low morbidity and without need for an additional procedure for implant removal. In addition, it is a tendon transfer instead of the previously described tenodesis techniques. Our results have also shown that the SPLATT to PT procedure is effective in balancing the foot and ankle.

As the PT muscle acts as dorsiflexor and evertor of the foot and ankle during the swing phase of the bipedal locomotion, we performed the SPLATT to PT procedure instead of tenodesis to the bone to achieve the dorsiflexion and eversion movement in the foot and ankle (25). We suggest that this technical modification provides dynamic dorsiflexion and eversion force instead of static tenodesis to the cuboid bone and results in good functional results with increased satisfaction.

Previously, few possible variations of the PT have been described. These variations are double tendon; an additional slip to the fourth metatarsal bone; a tendinous slip to the extensor digitorum longus tendon to the fifth toe; or in some patients, PT may even be absent (26). The PT absence rate was reported between 4% and 15% in the literature (25). In our study, we observed PT absence in 4 cases (10%), as concurrent with the literature, and these patients underwent SPLATT and tenodesis to the cuboid bone.

Previous reports on the split tendon transfers showed promising results, and our results support these previous findings (9, 11, 15, 22-24, 27-33). In his series with 11 SPLATT with a mean follow-up period of 7 years, Vlachou et al. reported that satisfying functional results were achieved in most cases (33). Similarly, we performed 33 SPLATT procedures in 25 patients and detected that the functional improvement and stable function of the foot can be achieved by SPLATT to PT.

Although the clinical results are favorable, the recurrence of the equinovarus deformity is still a significant problem (34). Moreover, Edwards claimed that the inadequate release of the deforming force and loss of fixation causing a failure to maintain the correction were also common (35). We also detected deformity recurrence in one patient who was much older (16 years old); her functional level was GMFCS level 4, and she had flexible but advanced equinovarus deformity when compared with other patients (mean age was 8 years, but the patient’s age was 16 years). In line with our results, Vlachou also reported that severe functional levels could affect the SPLATT results negatively (33). Her recurrence was treated with a complete transfer of the TAT and metatarsal osteotomy.

Limitations of our study were the short follow-up period and small sample size. To assess the long-term outcomes of this method, prospective studies with longer follow-up periods are required. Moreover, the preoperative and follow-up evaluation by gait analysis would significantly help to analyze the impact of the surgery on gait.

Our study was conducted in 33 feet of 25 CP patients who underwent dynamic SPLATT to PT surgery for the management of equinovarus foot deformities. Our results confirm that this is a safe and effective treatment method for the management of equinovarus foot deformities in CP. A total of 97% of the patients were able to walk pain-free and had a plantigrade foot without the need for an orthosis.

Ethics Committee Approval: Ethics committee approval was received for this study from the Ethics Committee of Biruni University (2018-KAEK-43).
Informed Consent: Written informed consent was obtained from the parents’ of the patients and the patient.

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