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ORIGINAL PAPER

The split anterior tibialis tendon transfer procedure for spastic equinovarus foot in children with cerebral palsy: results and factors associated with a failed outcome

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Abstract
Purpose The aims of the study were to evaluate the outcomes and predictive factors of the split anterior tibialis tendon transfer (SPLATT) procedure for the treatment of the spastic equinovarus deformity in children with cerebral palsy (CCP).
Methods Forty-five ambulatory CCP with 68 equinovarus feet, positive for the flexor withdrawal reflex test, aged 8.1± 2.5 (range four to15) years were enrolled. All feet underwent a soft tissue release procedure combined with the SPLATT procedure and were followed for at least 12 months after surgery. The functional outcome was rated using the criteria of Kling and co-workers. Pre-treatment gross motor functional classification system (GMFCS) levels were compared to the patients' latest evaluations. Factors associated with outcomes and success rate were assessed.
Results At an average follow-up of 5.5±3.3 (range 1.1–16) years, feet were rated as excellent in 48 cases (70 %), good in ten (15 %) and poor in ten (15 %), respectively. Thirty-four CCP showed an improvement for the GMFCS level, $P<0.001$. The factor that could predict a poor outcome was the pre-treatment GMFCS levels 3–4 with an odds ratio (95 % CI) of 4.92 (0.96–25.2), $P=0.03$. The ten years success rate of the SPLATT procedure between CCP with GMFCS levels 1–2 and levels 3–4 were not different with a mean±SD (95 % CI) of 0.85±0.1 (0.5–0.96) versus 0.6±0.1 (0.3–0.8), $P=0.08$, respectively.
Conclusions The SPLATT procedure provides a balanced function of the foot, thus improving the ambulatory ability in CCP and should be integrated into the surgical plan. Pre-treatment GMFCS levels 3–4 predicted unfavourable outcomes and should be addressed during pre-operative parental counselling.

Keywords Spastic equinovarus foot · Cerebral palsy · Surgery · Split anterior tibialis tendon transfer · Outcome · Predictive factors

Introduction

An equinovarus deformity renders the foot and ankle in an unsuitable posture for gaiting, wearing shoes and bracing, as well as resulting in formations of callosities [1]. This deformity is attributed to the imbalance of the ankle invertor, including the anterior tibialis (AT), posterior tibialis (PT) and evertor muscles [2, 3]. A combination of a split AT (SPLATT) or PT transfer of the tendon and lengthening of the ankle plantar flexor muscles have been proposed to position the plantigrade foot [1, 4–8]. Biomechanically, SPLATT is an appealing procedure [7]. The function of the AT is to maintain the neutral position when the hindfoot is corrected and therefore many authors prefer the SPLATT procedure [1, 4].

The objectives of this study are to review the results of the SPLATT procedure for treating equinovarus deformity in children with cerebral palsy (CCP) and assess the factors associated with a failed outcome at our centre.

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Methods

Medical records of ambulatory CCP who had the SPLATT procedure and were followed for more than 12 months post-SPLATT were retrospectively reviewed. The ambulatory level of the children was based on the Gross Motor Function Classification System (GMFCS). Children with at least a GMFCS level 4 were enrolled [6, 9]. The indications for the SPLATT procedure were identified by an equinovarus deformity of the foot with a prominent AT tendon when gaiting and a positive flexor withdrawal reflex test (confusion test) for AT overactivity [1], and the deformity could not be controlled by conservative measures. Physical examinations at pre-operative and follow-up period were assessed by the senior author (P.P.). Laboratory gait analysis was not available during the study time. The procedure was performed as a part of a multilevel soft-tissue surgery of the lower limb (MLSL) [10].

The SPLATT procedure was performed based on the technique previously described with some modifications [4]. The tendo achilles (TA) and ankle plantar flexor muscles such as the PT, flexor digitorum longus (FDL) and flexor hallucis longus (FHL) were lengthened to correct the equinus deformity [1, 11]. The subtalar fusion was performed if needed. TA tenodesis was employed if excessive ankle dorsiflexion was noted during the surgery by dividing the middle third of the TA tendon from the musculatendinous junction and placing it through a drill hole on the tibia. For the SPLATT procedure, a longitudinal midline incision was centred over the dorsum of the foot (Fig. 1a). The lateral half of the AT tendon was sharply disjoined from the base of the first metatarsal and its ends were sutured with Krackow stitches. A distally-based periosteum flap was raised and a hole was drilled in a dorsoplantar direction over the cuboid in the same line with the longitudinal axis of the fourth metatarsal (Fig. 1b). The prepared AT tendon was rerouted through the drilled hole to the plantar skin of the foot by a Keith needle (Fig. 1c). The two ends of the suture were tied over a gauze pad while the foot was held in the desired position. The two halves of the AT tendon were adjusted to balance the tension [7]. A short leg cast was applied and maintained for 12 weeks [12]. If the children also had a concomitant soft tissue surgery around the knee, a ground reaction ankle-foot orthosis was prescribed.

The outcomes of the SPLATT procedure for the position of the foot and gait were assessed according to the criteria described by Kling et al. [6]. For the most recent data, the results of the SPLATT were rated as excellent, good or poor [1, 6]. Kling et al.'s poor result was designated as a failed outcome. The logistic regression analysis was used to assess the factors associated with a failed outcome. The Wilcoxon sign rank test was used to assess the changes of the GMFCS levels before the treatment and at the most recent follow-up visit. A survival analysis was used to calculate the success of treatment. Statistical analysis was performed using a STATA 12.0 (StataCorp, College Station, TX, USA). *P* values of <0.05 were considered statistically significant. The study was approved by the Institutional Review Board Committee of the Faculty of Medicine, Chulalongkorn University, Thailand (COA 599/2010) and has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

Results

Between the years 2000 and 2011, 45 CCP met the inclusion criteria. Their demographic data are shown in Table 1. The SPLATT procedure was performed on 68 feet. The average age of the patients was 8.1±2.5 (range four to 15) years. The reflex circuitry from the flexor withdrawal reflex test before (Fig. 2a) and after (Fig. 2b) SPLATT were compared to each other. All feet also had a concomitant surgery to correct for an equinovarus posture by intramural lengthening of the TA, PT,

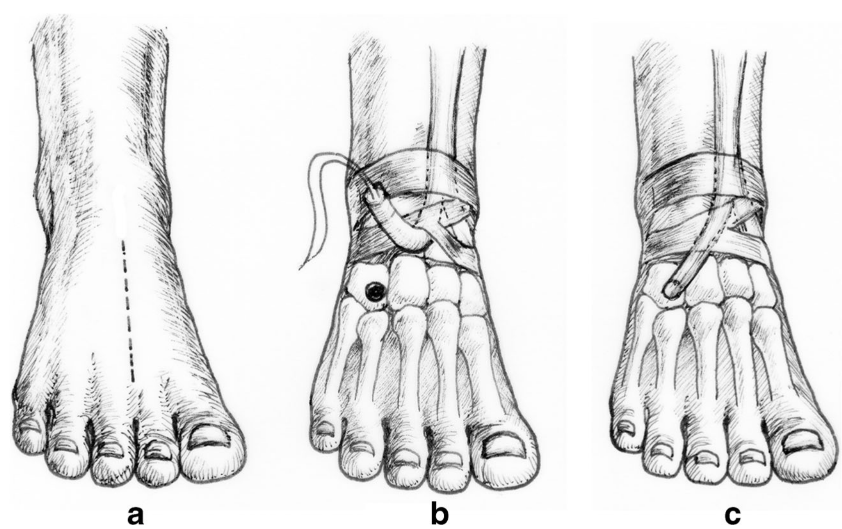

Fig. 1 Illustrations depicting the split anterior tibialis tendon transfer procedure. An incision was made longitudinally along the *dotted line* over dorsum of the foot (**a**). The lateral half of the anterior tibialis tendon was mobilised and tagged (**b**), then it was transferred to the cuboid through a drilled hole (**c**)

Table 1 Demographic data of children with cerebral palsy underwent the SPLATT procedure

Demographics		Number	Percent
Gender	male	30	67
	female	15	33
Type of cerebral palsy	hemiplegia	6	13
	diplegia	39	87
Laterality of foot involvement	unilateral	20	44
	bilateral	25	56

SPLATT split anterior tibialis tendon transfer

FDL, FHL (feet, n=52) combined with subtalar fusion (feet, n=10) or TA tenodesis (feet, n=6). Twenty-two children underwent operations to correct the deformity of the knees and/or hips. This was done by lengthening the hamstring tendon in combination with the transfer of the rectus femoris tendon to the sartorius and release of the adductor longus tendon as indicated.

The average age of the patient at the most recent follow-up visit was 13.5±3.3 (range 7.7–22) years. The average duration of the follow-up was 5.5±3.3 (range one to 16) years. Based on the Kling et al.'s criteria [6], 48 feet (70 %) and 10 feet (15 %) were rated as excellent and good respectively post-surgery. Ten feet (15 %) were rated as poor because three feet were overcorrected and seven feet had recurrent equinovarus deformity. All failed cases needed additional surgery. During the study period, there were no other complications, such as the rupture of the transferred tendon or infections of the wound. The GMFCS level was improved by two levels for three patients (7 %) and one level for 31 patients (68 %). Nine patients (21 %) did not experience any changes in the GMFCS level. Two patients (4 %) had a deterioration of the GMFCS level during the follow-up period. Figure 3 shows that there were significant differences of the GMFCS level before and after the procedure among the CCP (P<0.001) over the mean follow-up of 5.5 years.

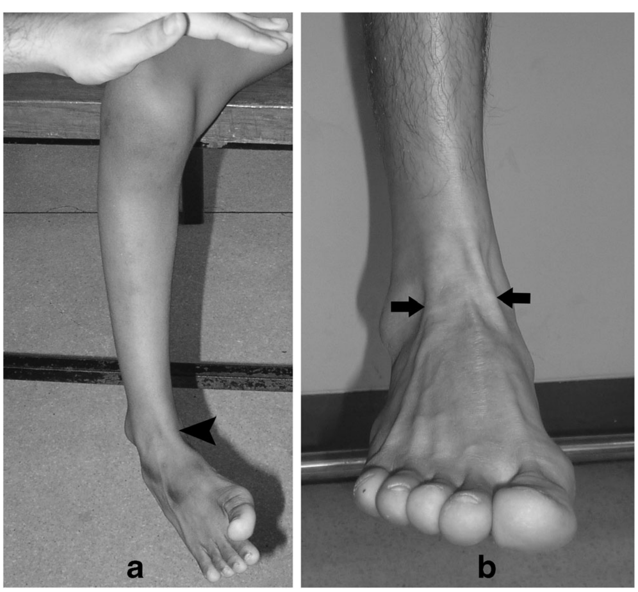

Fig. 2 The flexor withdrawal reflex test before (**a**) and after (**b**) the split anterior tibialis tendon transfer procedures were demonstrated. An *arrowhead* showed an overactive anterior tibialis tendon by the flexor withdrawal reflex. *Arrows* showed the two halves of the anterior tibialis tendon with a balanced position of the foot after the procedure

Table 2 demonstrated details of cases differentiated by the outcomes. A univariate logistic regression analysis was used to identify an association between the pre-treatment GMFCS level and a failed outcome. Children with GMFCS levels 3 and 4 had a higher chance of having an unfavourable outcome compared to the children with GMFCS levels 1 and 2 with an odds ratio (95 % CI) of 4.92 (0.96–25.2), P=0.03. Other variables were not associated with the failure of treatment: age at the procedure (P=0.93), duration of follow-up (P=0.33), laterality involvement of the foot (P=0.51) and the level of surgery performed (P=0.52). From the Kaplan-Meier analysis, in Fig. 4, the 10 years success rate for all children regardless of the GMFCS levels were comparable (P=0.08).

Discussion

The functional status of the CCP has a tendency to deteriorate over the observational period [13, 14]. A surgical treatment is advised when the deformity cannot be controlled by conservative means [4, 8, 13]. In this report, the SPLATT procedure combined with tendon and bone operations at the posterior aspect of the ankle was performed as a part of the MLSL surgery to correct the equinovarus foot deformity and improve foot posture suitable for gaiting [1, 10, 11, 15, 16]. The majority of the children maintained their GMFCS levels and balanced-plantigrade foot position in the operated foot at their latest visit. The spastic equinovarus foot deformity was once considered to be caused by an overactivity of the PT tendon, but several subsequent reports found that both AT and PT tendons were responsible for the deformity [2, 3], therefore the advantage of using the AT tendon as the transferred motor is recommended. The split transfer of the AT functioned as the mechanical servo-mechanism works as a foot evertor, which is the most desired function to balance the equinovarus deformity [7]. A previous biomechanics study confirmed that functions of the SPLATT were less altered by subtalar joint motions compared to those of the split PT transfer [7].

It should be noted that the evaluations used before the surgery are variable but must indicate that the AT muscle is clinically overactive, otherwise performing the SPLATT procedure would not be suitable [1, 4]. A pre-operative dynamic electromyography (EMG) helps in differentiating between an overactive AT and PT muscles and has been shown to result in a successful correction of the equinovarus deformity [3, 4]. On

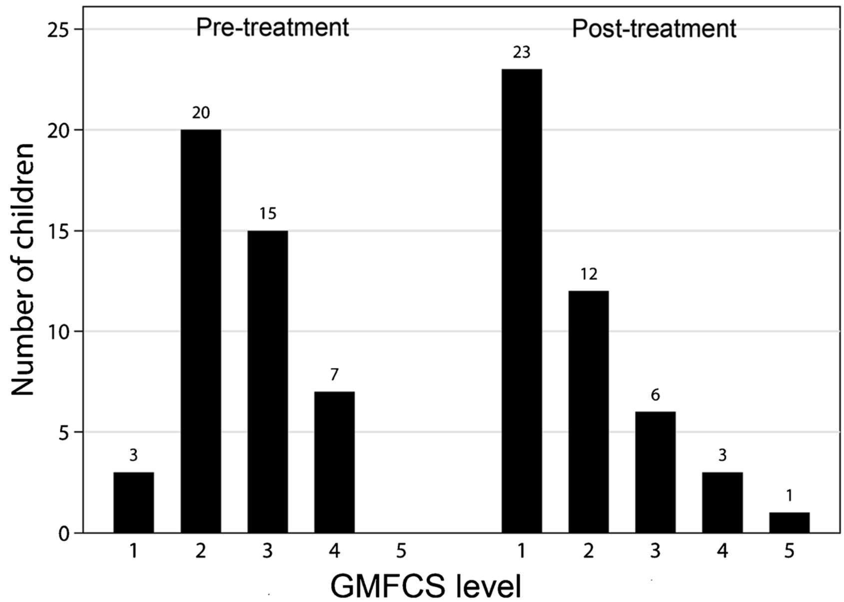

Fig. 3 The number of children with cerebral palsy and their GMFCS levels before (*left panel*) and after (*right panel*) the procedures were presented. *GMFCS* Gross Motor Function Classification System

the other hand, others have reported that the EMG data did not correlate well with the clinical findings and warned of the use of needle EMG while children walk [2, 9]. In this study, the decision to perform the SPLATT procedure was based on the observational pre-operative gait analysis and the positive reflex withdrawal test [1, 11]; however, the observers agreed that the deviations of the gait were rated fair to moderate [17], which could affect the surgical planning [9, 11, 18]. Furthermore, AT tendon overactivity could be a contributing factor of a failed outcome if a split PT transfer was employed [9]. Hence the authors recommend the use of dynamic EMG, but if it is not available, then the physician, preferably an experienced surgeon, must do the pre-operative physical assessments diligently [18].

When it comes to performing the SPLATT procedure, the procedure used was a single anterior incision over the dorsum of the foot, thus maintaining the proximal part of the AT tendon under the extensor rectinaculum at the ankle joint level [1] instead of using the three-incision technique previously described, which redirected the lateral half of the AT tendon to

Table 2 Data of children with cerebral palsy differentiated by the outcomes

		Outcomes	
		Success	Failed
Side of foot underwent the procedure	right	30	5
	left	28	5
Gender	male	27	3
	female	12	3
Type of cerebral palsy	hemiplegic	6	0
	diplegic	33	6
Laterality of foot involvement	unilateral	18	2
	bilateral	21	4
Age at the surgery (years)		8.2±2.7 (7.3–9.0)	8.0±1.6 (6.8–9.3)
Duration of the follow-up (years)		5.5±3.3 (4.4–6.6)	4.9±2.0 (3.2–6.6)
Pre-treatment GMFCS level	1	3	0
	2	19	1
	3	12	3
	4	5	2
Level of surgery performed	ankle and foot	21	2
	combined with knee/hip	18	4

The data were presented in number or mean±standard deviation (95 % confident interval) when appropriate
GMFCS Gross Motor Function Classification System

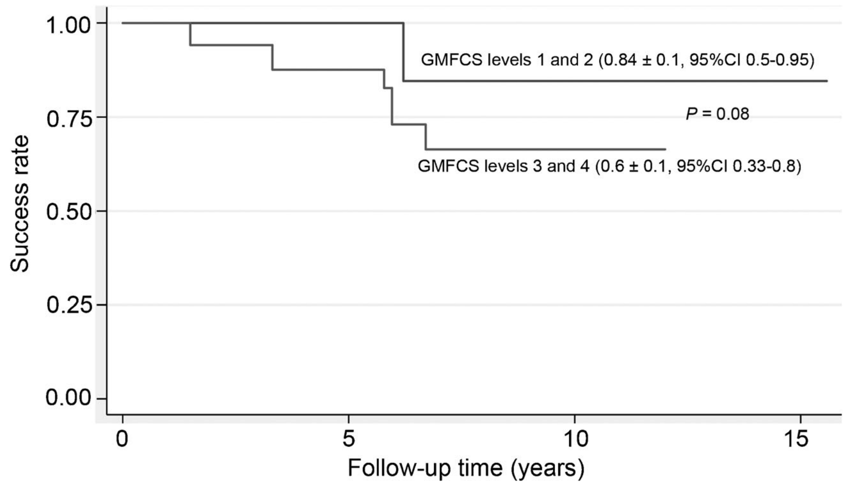

Fig. 4 The Kaplan-Meier analysis of the 10 years success rate of children with cerebral palsy with GMFCS levels 1–2 and 3–4 were compared. *GMFCS* Gross Motor Function Classification System

the subcutaneous tissue above the extensor retinaculum of the ankle [4]. This technique maintained the AT tendon moment arm and helped to conserve the AT muscle architecture, thus preserving a near normal subtalar joint torque [15, 19]. The preference of this technique is supported by a previous animal model, which showed that when the AT tendon pulley was released, this reduced the cross-sectional area and the force produced by the AT muscle [19]. Re-routing the AT tendon under the rectinaculum prevented an unsightly bowstringing [1] and might create fewer soft scar tissues around the transferred route [20]. It has been shown that re-routing the lateral half of the AT tendon onto the long axis of the fourth metatarsal was the most effective way [5, 21] of correcting the deformity and is confirmed by the authors' clinical experiences. However, others have reported successful results by anchoring the AT tendon to the lateral cuneiform to coincide with the third metatarsal [22, 23]. In addition, a single dorsoplantar direction tunnel with tie-over sutures was also found to be clinically effective. Post-operative immobilisations ranging from six weeks [1, 4] to 12 weeks [12] were previously recommended. After 12 weeks of immobilisation, the transferred tendon incorporated into the bone tunnel and the periosteum flap by forming a new collagen fibre, resulting in the formation of a new tendon at the appropriate site enough to acquire sufficient strength to resist the pulling out force [24, 25]. Accordingly, the authors recommend that the transferred site needs to be protected during this interval. The tendon pull-through technique used in this report did not have any risk of developing a tunnel roof fracture [26], even though a lateral-medial tunnel is recommended because of a lower pull-out rate [21].

The rate of failed outcome in our series is comparable to previous reports [1, 16]. Overcorrected outcomes in the study indicated an error in tensioning the transferred tendon. Proper tension of the re-routed tendon should be determined carefully during the procedure [5, 7]. The recurrence of deformity could be contributed to by improper patient selection, inadequate correction of the deformity and the lack of an appropriate rehabilitation program. The only factor associated with the failure of the treatment in this study was the status of the child's ambulatory level before the surgery, which contradicted the findings from a previous report conducted in an adult patient with a sustained cerebrovascular disease or head trauma [16]. This difference may be due to the fact that children with GMFCS level 3 or more has a poorer ambulatory capacity to begin with so any visual assessment of their gait is variable [17] and will increase the chance of having an unpleasant outcome. Results of children with GMFCS levels 3 and 4 and levels 1 and 2 were similar; this would imply that the CCP did not have a sufficient follow-up time [11, 16], thus the number of children may be too small to detect the difference between the groups. Concomitant knee and hip surgery and type of cerebral palsy can increase the deterioration of the gait during the follow-up period but the authors did not detect any significant association between these factors and a failed outcome [14]. Tendon necrosis, tendon pull-out or wound complications [8, 16] have been reported to be one of the few complications that are directly related to the SPLATT procedure. In this study, the authors did not observe any of these complications in their patients.

One of the limitations of the study was the availability of the laboratory gait data which could have significantly impacted the indication for surgery [17]. Other factors such as the level of cognitive involvement, the degree of the muscle spasticity and family compliance may also influence the decision for the operation [11]. These factors could affect the ambulatory status of CCP in the long term. Another limitation of the study is its follow-up period. Because the recurrent rate of the deformity may increase over time [10, 14], thus it is recommended to have a longer follow-up period. Other confounding factors should be taken into consideration in determining the results of CCP surgery. Additional evaluations of the CCP with GMFCS levels 3 and 4 are warranted before having a lower extremity surgery.

In conclusion, the SPLATT procedure is effective in balancing and maintaining the foot for gaiting. The procedure yields an acceptable complication rate. Therefore the authors recommend incorporating the SPLATT procedure into the surgical planning for the CCP with the presentation of an equinovarus deformity with an overactive AT evidenced by a positive flexor withdrawal reflex.

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Institutional review board This research is approved by the Institutional Review Board of Faculty of Medicine, Chulalongkorn University, Bangkok Thailand. COA No.599/2010.

Conflict of interest The authors declare that they have no conflict of interest. No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

Ethical approval All procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

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