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Split Anterior Tibialis Tendon Transfer (Splatt) and Achilles Tendon Lengthening for The Correction of The Varus Foot after Stroke a Prospective Longitudinal Study

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Abstract

Background: The imbalance between tibialis anterior and peroneus activation in the swing phase of gait after stroke is responsible for an ankle varus leading to foot instability and poor quality of gait. In such case, a split anterior tibialis tendon transfer (SPLATT) procedure is indicated to correct imbalance. The aim of the study was to prospectively evaluate the effect of the SPLATT procedure in varus foot after stroke.

Methods: We prospectively evaluated 26 consecutive hemiplegic patients (mean age 48.3 ± 10.2 years) with a varus foot operated for a SPLATT and an Achilles tendon lengthening procedure with a 6 months follow-up. Before and 6 months after surgery, the spasticity (Ashworth scale), muscle strength (MRC scale), active and passive ankle range of motion, gait parameters (10 meter walking test), gait kinematics (video) and need for assistive device were assessed.

Results: A decrease in triceps spasticity and an increase in ankle dorsiflexion were observed. The varus in swing and stance phase of gait was improved. After surgery, 90% of the patients didn't fit their ankle foot orthosis in comparison with 30% before. In contrast, gait speed, proximal spasticity, hip and ankle gait kinematics and need for crutches remained unchanged.

Conclusion: This study is the first prospective study using objective validated scales confirming that the SPLATT procedure in combination with Achilles tendon lengthening is able to correct the varus and to reduce the need for orthosis in stroke patients with varus foot.

Level of Evidence: Level IV / Prospective longitudinal case series study

Keywords: Stroke; Tibialis anterior transfer; Varus

Introduction

Stroke is one of the main causes of avoidable mortality and a major cause of handicap worldwide [1]. Spastic equinovarus foot (SEF) is a common deformity among stroke patients, with an incidence estimated at 18% [2]. The deformity is mainly caused by spasticity of the triceps surae (soleus and gastrocnemius muscles) and tibialis posterior muscles, sometimes associated with Achilles tendon shortening and tibialis anterior weakness. An imbalance between the tibialis anterior and peroneus muscles activation may also be responsible for a varus in swing phase leading to a poor positioning of the foot at the beginning of the stance phase and to foot instability. Such imbalance can be the only cause of SEF and can be also worsened by triceps muscle spasticity and/or contracture. When such imbalance is responsible for the equinovarus deformity, an ankle foot orthosis, a tibialis posterior transfer or a split anterior tibial tendon transfer (SPLATT) procedure is proposed. The SPLATT procedure is a well-known technique recommended to correct imbalance and varus in the swing phase of gait. Several publications have studied the ability of the SPLATT procedure to correct the varus foot after stroke [3-13]. However, only two studies were prospective and none of them have studied spasticity, range of motion, gait speed or gait kinematics.

The aim of this study was to prospectively evaluate the effects of SPLATT procedure in association with Achilles tendon lengthening on gait in hemiplegics patients suffering from varus foot in swing phase by means of objective and validated assessment scales. Our research hypothesis was that the SPLATT procedure would improve the varus and decrease the need for AFO devices.

Methods

Study design

A prospective intervention (before-after trial) study with a follow-up period of 6 months was conducted with 26 consecutive hemiplegic patients with a SEF operated for a SPLATT procedure. Assessment was performed before surgery and 6 months after STN. Our institutional review board approved the study and informed consent was obtained from all the patients.

Patients

The patients were recruited and treated by an interdisciplinary spasticity group in a referral center of a university hospital. Inclusion criteria were a stroke history of more than 1 year, the presence of a disabling ankle varus related to imbalance between tibialis anterior and peroneus activation, the absence of disabling spasticity at the level of the soleus and tibialis posterior muscles and an ability to walk without shoes. Exclusion criteria were a previous history of surgery at the level of the foot tendon.

Based on the inclusion and exclusion criteria, 26 patients were prospectively selected for SPLATT surgery. Out of the 26 patients, 19 had previously benefited from a selective tibial nerve neurotomy to permanently treat soleus and tibialis posterior disabling spasticity.

Table 1 describes patient characteristics.

Characteristics		Values
Age Mean ± SD (years)		48,3 ± 10,2
Time post stroke ± SD (months)		40,3 ± 46,7
Affected side	Right	11
	Left	15
Etiology	Ischemic	18
	Hemorrhagic	8
Treatment	SPLATT	7
	SPLATT + Achille's tendon lenghtening	19

Table 1: Patient characteristics (N=26).

Surgical treatment

The split anterior tibial tendon transfer (SPLATT) procedure was performed under general anesthesia. The distal tibialis anterior tendon was dissected in 2 parts over 10 cm and the external part was sutured on the short peroneus tendon. When the passive ankle dorsal flexion with extended knee doesn't exceed the neutral angle an Achilles tendon lengthening associated to a flexor hallucis and digitorum longus tenotomy was performed by posterior approach in order to be able to put the ankle in a 10° of dorsal flexion position. A cast was placed for 6 weeks and the patients were authorized to walk. After removing the cast, the patients were invited to avoid passive and active plantar flexion and varus position in order to protect the tendon transfer. A daily rehabilitation program identical to the pre-operative program including gait rehabilitation was conducted. The use of oral antispastic medications was not monitored.

Test protocol

Before and 6 months after surgery, the degree of spasticity, muscle strength, passive range of ankle motion, gait parameters, gait kinematics and the need for assistive device were assessed by the same therapist. The degree of spasticity was measured at the triceps surae (with the knee in extended position), tibialis posterior, quadriceps and hamstring muscles by using the Ashworth scale [14]. The muscle strength was measured at the quadriceps, hamstring, tibialis anterior, peroneus and triceps muscles by using the MRC (Medical Research Council graded 0-5) scale. The passive range of ankle motion (ROM in degrees) was measured with a goniometer with the knee in the flexed (soleus) and extended (soleus and gastrocnemius) position. The active range of ankle motion (ROM in degrees) was measured with a goniometer in sited position with the knee in flexed position asking for an analytic (isolated ankle dorsiflexion) and syncinetic (global lower limb flexion) activation. Gait parameters (gait speed, step cadence and step length) were obtained during a 10 meter walking test with shoes and orthosis. Gait kinematics (equinus, varus and knee flexion both in swing and stance phase) was measured using video analysis and expressed in degrees; the video was made with a digital camera recorder and analyzed on a 20 inches screen. The use of light (plastic or leather) or heavy (metallic) ankle foot orthosis (AFO) as well as the need for crutch in daily activity were noticed. Adverse effects of surgery were monitored and recorded.

Statistical analysis

Numerical parameters are expressed as means ± standard deviations and as medians into brackets and as means ± standard deviations for some selected parameters. Differences between values before and after treatment were compared by Wilcoxon signed rank tests. All tests were two-tailed and were performed by the SPSS 15.0 statistical software (SPSS Inc, Chicago, USA). As correction for multiple tests, a p value less than 0.01 was considered as statistically significant.

Results

From the 26 patients, all benefited from a SPLATT procedure and 19 benefited from an additional Achilles tendon and flexor hallucis and digitorum longus lengthening at the same time.

Table 2 shows the spasticity, muscle strength, passive and active ankle range of motion, gait parameters and kinematic parameters before and after surgery. There was a statistically significant decrease in triceps spasticity and an increase in passive ankle dorsiflexion with extended knee and in active analytic ankle dorsiflexion. These improvements are associated to a decrease in varus position observed both in swing phase, at foot switch and in stance phase of gait while equinus remains unchanged. In contrast, there were no changes in quadriceps and hamstrings spasticity, in muscle strength, in hip, knee and ankle flexion during gait and in gait speed.

	Before	6 Months	p-value
Spasticity (Ashworth)			
Triceps surae	1,1 ± 1,1 [1]	0,5 ± 0,8 [0]	p = 0,008*
Tibialis posterior	0,4 ± 0,8 [0]	0,4 ± 0,8 [0]	p = 0,564
Quadriceps	1,7 ± 1,0 [0]	1,8 ± 0,9 [0]	p = 0,157
Hamstrings	1,0 ± 0,9 [1]	1,2 ± 0,9 [2]	p = 0,206
Muscle strength (MRC)			
Triceps surae	1,6 ± 1,2 [2]	1,2 ± 1,2 [1]	p = 0,031

Tibialis anterior	3,6 ± 1,0 [4]	3,2 ± 1,2 [4]	p = 0,021
Quadriceps	4,0 ± 0,4 [4]	4,0 ± 0,4 [4]	p = 0,157
Hamstrings	2,2 ± 1,0 [2]	2,2 ± 1,0 [2]	p = 1,000
Passive ankle dorsiflexion (°)			
Extended knee	-2,0 ± 10,1 [0]	11,3 ± 6,1 [10]	p < 0,001*
Flexed knee	9,3 ± 8,3 [10]	15,0 ± 5,6 [15]	p = 0,026
Active ankle dorsiflexion (°)			
Flexed knee (analytic)	-18,4 ± 18,6 [-20]	-4,0 ± 15,6 [0]	p = 0,004*
Flexed knee (syncinetic)	-2,9 ± 13,7 [0]	1,3 ± 15,6 [5]	p = 0,093
Gait kinematics (vidéo) (°)			
Hip flexion (SwP)	29,5 ± 7,3 [30]	28,2 ± 9,6 [25]	p = 0,536
Hip extension (StP)	-17,4 ± 8,9 [-20]	-16,0 ± 9,5 [-15]	p = 0,498
Knee flexion (SwP)	22,2 ± 14,8 [20]	22,6 ± 17,8 [20]	p = 0,826
Knee flexion (FS)	12,1 ± 8,1 [10]	10,4 ± 8,6 [10]	p = 0,340
Knee flexion (StP)	9,6 ± 12,9 [10]	10,9 ± 10,9 [15]	p = 0,606
Varus (SwP)	20,6 ± 10,4 [20]	5,0 ± 5,6 [5]	p < 0,001*
Varus (FS)	22,0 ± 11,8 [20]	3,9 ± 7,2 [0]	p < 0,001*
Varus (StP)	8,5 ± 12,8 [5]	0,9 ± 4,9 [0]	p = 0,003*
Equinus (SwP)	15,4 ± 10,3 [15]	11,3 ± 12,1 [10]	p = 0,044
Equinus (FS)	15,4 ± 11,6 [15]	12,0 ± 10,9 [10]	p = 0,086
Equinus (StP)	4,8 ± 11,4 [0]	- 0,2 ± 7,1 [0]	p = 0,033
Gait parameters (10-m walking test)			
Gait speed (Km/h)	1,1 ± 0,6 [0,8]	1,2 ± 1,1 [0,9]	p = 0,959
Step length (m)	0,6 ± 0,2 [0,4]	0,6 ± 0,3 [0,6]	p = 0,653
Step cadence (step/min)	32.5 ± 12.6 [30]	30,1 ± 10.9 [25]	p = 0,354

Table 2: Spasticity (Ashworth Scale), Muscle strength (Medical research Council Scale), Passive and Active Range of Motion (Median), Kinematic Parameters (Video Analysis) in the Swing and Stance Phases (Median) and Gait parameters (10-Meter Walking Test) (Means ± SD) before and 6 months after SPLATT surgery.

Abbreviations: SwP, swing phase of gait; FS, foot switch of gait, StP, stance phase of gait

* Significant difference versus pretreatment values

*Significant difference between before and after surgery

Table 3 shows the need for AFO and crutch before and after surgery. After surgery, 89% of the patients didn't fit AFO in comparison to 30% before while the crutch was still used by 68% of the patients after surgery in comparison to 74% before.

	AFO None	AFO Light	AFO Heavy	Crutch	
				Yes	No
Before	30%	35%	35%	74%	26%
6 Months	89%	5%	5%	68%	32%

Table 3: Use of "light' (plastic) and "heavy" (metal, carbon) Ankle Foot Orthosis (AFO) and crutch (in %) before and 6 months after SPLATT surgery.

One patient presented a local infection complicated by a rupture of the tendon transfer confirmed by ultrasonographic examination. No neurologic or general complications were observed.

Discussion

The reasons leading to the spastic equinovarus foot (SEF) deformity after stroke were shown to be varied and complex, due to a variety of deforming forces explaining why a single procedure does not exist to correct all deformities [15]. Furthermore, the SEF is frequently associated to other abnormalities such as knee recurvatum, stiff knee gait and toe claw making thinks still more complex. The SEF is mainly caused by the calf muscles spasticity, the triceps surae – Achilles tendon complex shortening and the weakness and/or imbalance of the tibialis anterior and peroneus muscles. Therefore, the treatment(s) vary and are combined accordingly [16,17]. The calf spasticity can be treated by physical therapy, oral medications, chemo-denervation with phenol, alcohol and botulinum toxin (BTXa) injections and selective tibial neurotomy. The triceps surae–Achilles tendon complex shortening can benefit from orthosis, BTX injections associated with cast and surgical gastrocnemius aponevrotomy or Achilles tendon lengthening. The tibialis anterior weakness is compensated by AFO or functional electrical stimulation. Finally, the imbalance between tibialis anterior and peroneus activation leading to a varus position in the swing phase of gait will be corrected by an ankle foot orthosis or a tendon transfer such as the SPLATT procedure. Indeed, Perry showed that the tibialis anterior activation is the main cause of the varus in the swing phase of gait [3]. However, such varus related to imbalance between tibialis anterior and peroneus activation is frequently worsened by the triceps muscle spasticity and/or shortening and is not only present in the swing phase of gait but also at the foot switch and stance phase of gait leading to ankle instability, inability to walk barefoot and finally falls with potentially disastrous consequences. When the AFO are ineffective and/or poorly tolerated or simply when the patient wants to be able to walk barefoot, a surgical correction is indicated.

Table 4 shows previous studies evaluating the efficacy of the tibialis anterior transfer in case of adult spastic equinovarus foot. Several surgical techniques have been described: the SPLATT [4-9,12,13], the transfer of the entire tibialis anterior tendon [10,11] and the peroneus transfer to tibialis anterior [6]. Furthermore, the transfer was frequently associated to other surgical procedures such as Achilles tendon lengthening [4-7,10,11,13], toe flexors lengthening [5-7,13], talonavicular arthrodesis and tibial neurotomy [4]. These studies have demonstrated an improvement in ambulatory status [4,5,8-10,13], a reduction in walking aids (orthotics shoes and AFO) requirement (4-9,13) and, in contrast with our results, an improvement in gait speed [5,10]. However, all these studies except 2 were retrospective with different neurological etiologies and used subjective and/or not validated scales while statistical methods and results were poorly described.

Authors	Study Design	Treatment	Patients Number & Follow-Up	Assessment Tool	Side Effects	Results
Asencio, et al. (1993) [4]	Retrospective	SPLATT Tibial neurotomy AT lengthening Talonavicular arthrodesis	20 1-7 years	Ambulatory aids requirement	3 Tendon rupture, CRPS 8	Reduced aids requirement Subjective imrprovement
Carda, et al. (2009) [5]	Retrospective	SPLATT AT lenghtening Toe flexors lengthening FHL-FDL transfer	177 1 year	Walking handicap score (WHS) Gait analysis Aids/ orthosis requirement	thrombosis, wound infection, muscle hematoma	WHS 3.78 → 5.13 Gait speed 0.32 → 0.4 m/sec Improved kinematic and kinetic data AFO discontinuation (22 patients)
Curvale, et al. (1999) [6]	Retrospective	Peroneus transfer to tibialis anterior AT lengthening Toe flexors lengthening	41 1–9 years	Patients satisfactionAFO requirement	2 wound delayed	80% satisfied AFO discontinuation (not precised)
Edwards, et al. (1993) [7]	Prospective	SPLATT AT lengthening Toe flexors lengthening	42 12-79 months	Subjective	NR	35% AFO discontinuation
Hosalkar, et al. (2008) [8]	Retrospective	SPLATT dorsoplantar vs lateromedial routing	47 24-84 months	Functional ambulation scale Ambulatory aids requirement	3 Screw pullout	Reduced aids requirement Improved ambulation scale
Keenan, et al. (19990 [9]	Prospective	SPLATT vs FHL-FDL transfer	55 11-80 months	Level of ambulation	NR	Improved ambulatory status Reduced AFO requirement
Morita, et al. (1998) [10]	UN	TA-FHL-FDL transfer TA lengthening	125 >2 years	Walking ability scale Gait speed Ground reaction force (25 patients)	Varus recurrence (15%)	Ability to walk outdoor 38 → 58% Gait speed 23,6 → 29,5 m/min Improved body weight support
Pinzur, et al. (1996) [11]	UN	TA transfer AT lenghtening	54 2-5 years	Electrogoniometer AFO requirement	2 wound infection	Stance and double-support phase of gait improved
Vlachou, et al. (2010) [12]	Retrospective	SPLATT vs SPOTT	48 >4 years	Hoffer and Kling & Kaufer scale	NR	Not precised
Vogt (1998) [13]	Retrospective	SPLATT AT lengthening Toe flexors lenghtening	69 1-14 years	Orthotics shoes & orthosis requirement Functional status	12 rupture, wound, CRPS	Orthotics shoes & orthosis requirement reduced Functional status improved

Table 4: Assessment of tibialis anterior transfer efficacy in different selected articles. UN: Unknown; NR: Not Recorded; SPLATT: Split Anterior Tibialis Transfer; TA: Tibialis Anterior; AT: Achilles Tendon; FHL: Flexor Hallucis Longus; FDL: Flexor Digitorum Longus; AFO: Ankle Foot Orthosis; CRPS: Complex Regional Pain Syndrome

In a prospective controlled study comparing SPLATT procedure isolated (control group) or in association with flexor hallucis and digitorum longus tendons transfer to the os calcis (study group), Keenan et al found an improved calf strength, a greater increase in function and less reliance on orthosis when the flexors tendon is transferred in addition to the SPLATT [9]. In a prospective study on 42 patients, Edwards observed that 35% of the patients were able to discontinue their orthosis [7]. In a retrospective study of 177 patients operated from tendon surgery (including 32 SPLATT) using gait analysis, Carda &, al found an improvement in the walking handicap score, in temporo-spatial parameters of gait and in ankle kinematic [5]. The surgical complications are rare including wound infection, tendon rupture, screw pullout and CRPS type 1.

In contrast with Morita which described a decrease in the tibialis anterior muscle strength necessitating AFO use in 5 of 15 patients, we didn't observe such decrease in muscle strength which is coherent with the absence of modification of the equinus after surgery. However, it's well known that a tibialis anterior muscle activation in the swing phase of gait is a prerequisite before a SPLATT procedure can be proposed.

Only one surgical complication (infection complicated by transfer rupture) was observed.

Our study is the first one to prospectively assess the efficacy of the SPLATT procedure and Achilles' tendon lengthening on spasticity, tendon length, muscle strength, gait speed, gait kinematics and need for walking aids by means of validated scale. This prospective longitudinal study with a 6 months follow-up demonstrates that SPLATT procedure in association with Achilles' tendon and long toe flexors tendons lengthening reduces triceps spasticity, increases passive and active ankle dorsiflexion, decreases varus position in the different phases of gait and reduces the AFO requirement. In contrast, proximal spasticity, tibialis anterior and triceps muscle strength, hip, knee and ankle flexion kinematics, gait speed and need for crutch stay unchanged. Our results confirm the ability of the SPLATT procedure to correct the varus deformity in the different phases of gait allowing a better foot stability and AFO withdrawal.

This study has several limitations. First, the number of subjects is small. Secondly, the patient and the investigator were not blinded. Thirdly, we used video as a gait kinematics analysis tool, but the reliability of this procedure in stroke patients has never been published. Finally, our study mainly focused on the body function and structure level (spasticity, strength, gait kinematics) of the International Classification of Functioning (ICF) and did not investigate activity and participation domains [18].

Disclosures

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