Extensor hallucis longus transfer as an alternative to split transfer of the tibialis anterior tendon to correct equinovarus foot in hemiplegic patients without overactivity of tibialis anterior

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This study assessed if transfer of the extensor hallucis longus is a valid alternative treatment to split transfer of the tibialis anterior tendon in adult hemiplegic patients without overactivity of the tibialis anterior.

One group of 15 patients had overactivity of tibialis anterior in the swing phase, and underwent the split transfer. A further group of 14 patients had no overactivity of tibialis anterior, and underwent transfer of extensor hallucis longus. All patients had lengthening of the tendo Achillis and tenotomies of the toe flexors. All were evaluated clinically and by three-dimensional gait analysis pre- and at one year after surgery. At this time both groups showed significant reduction of disability in walking. Gait speed, stride length and paretic propulsion had improved significantly in both groups. Dorsiflexion in the swing phase, the step length of the healthy limb and the step width improved in both groups, but only reached statistical significance in the patients with transfer of the extensor hallucis longus. There were no differences between the groups at one year after operation.

When combined with lengthening of the tendo Achillis, transfer of the extensor hallucis longus can be a valid alternative to split transfer of the tibialis anterior tendon to correct equinovarus foot deformity in patients without overactivity of tibialis anterior.

Following a stroke, the identification of patients with contracture-related deformities of the lower limb who could be helped by operative correction is seldom considered.^{1,2} The results have usually been assessed clinically by subjective evaluation and/or calculation of the number of patients who have discontinued their orthoses. Gait analysis is a reliable and repeatable means of evaluating patients following a stroke,³ and can be useful in the assessment of surgical outcome.

The most common deformity of the lower limb caused by contractures in spastic hemiplegia is an equinovarus foot,⁴ which can severely limit walking.⁵ Correction of equinus can be achieved by percutaneous lengthening of the tendo Achillis or procedures directed at the myotendinous junction^{6,7} but the correction of forefoot varus can be more challenging.

Split transfer of the tibialis anterior tendon (SPLATT) in the adult is intended to correct varus deformity of the foot and, in conjunction with lengthening of the plantar flexors, improve dorsiflexion during the swing phase.⁸ The indication for this procedure is forefoot varus with clinical or electromyographical

(EMG) evidence of overactivity of the tibialis anterior.⁸⁻¹⁰ In patients with an equinovarus foot, Pinzur et al¹¹ transferred tibialis anterior if the patient had a varus foot without evidence of overactivity of the tibialis posterior.

When overactivity of tibialis anterior and posterior was not present, some authors have successfully corrected equinovarus by performing an extensor hallucis longus (EHL) transfer to the third, fourth or fifth metatarsal, either in children¹² or adults.¹³

However, it is not clear if EHL transfer is a valid alternative to SPLATT in patients without evidence of tibialis anterior overactivity, since the outcomes of the two procedures have never been compared.

The aim of this study was to assess if EHL transfer could be a feasible and valid alternative treatment to SPLATT in patients with an equinovarus foot but without evidence of overactivity of tibialis anterior.

Patients and Methods

This retrospective, non-randomised study was approved by the Study Review Board of our institution. The patients were selected from

Table I. Patient characteristics

	Age (yrs)	Time from stroke (yrs)	Height (metres)	Weight (kg)
	Mean (range)	Mean (range)	Mean (range)	Mean (range)
EHLT* (n = 14)	51.2 (32.4 to 70.4)	6.8 (1.6 to 13.7)	1.62 (1.55 to 1.73)	66.6 (52 to 81)
SPLATT† (n = 15)	50.3 (20 to 67)	5.1 (1.2 to 10.3)	1.68 (1.57 to 1.80)	72.3 (57 to 98)

* EHLT, extensor hallucis longus transfer

† SPLATT, split transfer of the tibialis anterior tendon

those who had been evaluated at the Motion Analysis Laboratory of Physical and Rehabilitative Medicine Unit of Novara and the Villa Beretta Rehabilitation Center, between June 1999 and June 2008 and who underwent operative correction of equinovarus deformity of the foot.

The inclusion criteria were a left or right hemiplegia due to a confirmed ischaemic or haemorrhagic stroke, age of 18 years or above, at least one year since the stroke and a clinically relevant equinovarus foot, where passive dorsiflexion of the ankle was not possible above the neutral position with the knee in full extension. The deformity was considered to be a fixed contracture when plantar flexion of the ankle on weight-bearing was associated with a low-amplitude EMG of unchanging intensity.⁹ Patients with sustained clonic activity in the stance and/or swing phase, those with spastic dystonia and those requiring botulinum toxin/phenol block/selective neurotomy were excluded from the study. Patients treated previously with botulinum toxin were not excluded if the treatment had been performed at least nine months earlier. Patients had to be able to walk at least ten metres without shoes or orthoses, with or without assistance and aids.

The kinematic assessment was performed according to the SAFLo (servizio analisi funzionalita locomotoria) protocol.¹⁴ We used an ELITE 3D system (BTS SpA, Milan, Italy) with polyelectromyography and two piezoelectric force platforms (Kistler AG, Winterthur, Switzerland). All patients were assessed barefoot and the same engineers performed all gait analyses. Patients were asked to walk at their normal comfortable speed. No other instructions were given. At least five trials for each session were collected and the mean value was calculated. The operative plan was tailored to each patient according to clinical and instrumental data including the amount of contracture, the ability to recruit lower-limb muscles and the EMG pattern of the dorsiflexor and plantar flexor muscles. All the operations were performed by the same surgeon (PZ) and all patients gave informed written consent.

When forefoot varus was present in the swing and initial contact phases, the patient was considered eligible for tendon transfer. If dynamic EMG revealed overactivity of the tibialis anterior, contracture of the tibialis posterior and/or overactivity were assessed clinically and with fine-wire intramuscular EMG probes. If the tibialis posterior was not overactive and/or no evidence of contracture was present, the patient was referred for a SPLATT procedure.

When there was no overactivity of tibialis anterior activity of the EHL was assessed clinically and with surface EMG. If the EHL was overactive in the swing and stance phases, the patient was referred for its transfer.

The authors reviewed the gait analyses and EMG data separately and together with the patient. All the surgical programmes were decided by the surgeon in conjunction with a specialist in physical medicine and rehabilitation (SC, MB, FM, MI, CC). Of the 203 hemiplegic patients who underwent surgical correction of equinovarus deformity, 15 underwent lengthening of the tendo Achillis and tenotomy of flexor digitorum longus and brevis combined with SPLATT, and 14 had the same lengthening procedure and tenotomies combined with EHL transfer (Table I). The remaining patients underwent other operations such as myotendinous lengthening of the triceps surae, lengthening of tibialis posterior, transfer of the EHL to the third metatarsal and transfer of flexor digitorum longus to the os calcis, alone or in combination.

Surgical details

EHL transfer to IV metatarsal bone. The EHL tendon is divided distally; the distal part is sutured to the extensor hallucis brevis tendon, to provide support to the great toe. The proximal part of EHL is detached and passed subcutaneously around the base of the fourth metatarsal bone, forming a loop, which is fixed with suture of the tendon. This intervention is meant to correct varus foot by redirecting the pull of extensor hallucis longus tendon.

SPLATT. The anterior half of tibialis anterior tendon is detached from the first cuneiform bone and split. This part of the tendon is transferred through a tunnel created in the cuboid, and then fixed by an interference screw. This intervention is meant to correct varus foot by deviating part of the pull of tibialis anterior.

Immediately after surgery, the patients had rehabilitation sessions twice a day for four weeks which included passive mobilisation of the ankle and lower limb, therapeutic electrical stimulation of dorsiflexors, hip abductors and knee extensors, selective strengthening of hip abductors, extensors and flexors, and gait training. In order to protect the wounds, the foot was placed in a short-leg removable hinged cast with the pivot placed at malleolar level. An elastic rubber band was placed anteriorly, to provide continuous traction in dorsiflexion. The maximum dorsiflexion allowed was 10°, and the traction was maintained for three

Table II. Outcome measures

	Self-selected speed (m/s)	Maximum dorsiflexion during swing phase (°)	Cadence (steps/min)	Ant StL H* (m)
	Mean (range)	Mean (range)	Mean (range)	Mean (range)
Extensor hallucis longus transfer				
Before surgery	0.33 (0.19 to 0.75)	-16.7 (-20.2 to 5.1)	69.2 [‡] (39 to 118)	0.22 (0.04 to 0.34)
After surgery	0.43 [†] (0.12 to 0.94)	-9.73 [†] (-15.1 to 13.8)	73.4 (35 to 128)	0.31 [†] (0.9 to 0.41)
Split transfer of the tibialis anterior tendon				
Before surgery	0.29 (0.08 to 0.62)	-12.22 (-24.4 to -0.4)	63.5 (36 to 86)	0.26 (0.06 to 0.45)
After surgery	0.39 [‡] (0.14 to 0.67)	-8.43 (-22.5 to 8)	69.7 (47 to 85)	0.33 (0.2 to 0.46)
Reference range	1.06 to 1.47	-2 to 10	103 to 107	0.59 to 0.74

* Ant StL H, healthy limb step length

† p < 0.038 before – after surgery

‡ p < 0.038 between groups

Table III. Outcome measures

	Sw V* (m/s)	Step width (m)	Paretic propulsion	Walking handicap score
	Mean (range)	Mean (range)	Mean (range)	Mean (range)
Extensor hallucis longus transfer				
Before surgery	0.86 (0.41 to 1.49)	0.24 (0.2 to 0.31)	0.18 (0 to 0.99)	3.8 (3 to 5)
After surgery	1.01 (0.38 to 1.97)	0.2 [†] (0.15 to 0.28)	0.25 [†] (0 to 0.98)	4.9 [†] (4 to 6)
Split transfer of the tibialis anterior tendon				
Before surgery	0.75 (0.01 to 1.43)	0.24 (0.18 to 0.33)	0.18 (0 to 0.99)	3.73 (2 to 5)
After surgery	0.86 (0.45 to 1.53)	0.21 (0.11 to 0.38)	0.3 [†] (0 to 0.99)	4.47 [†] (4 to 6)
Reference range	2.52 to 3.51	0.11 to 0.2	n/a [‡]	n/a

* Sw V, velocity of the paretic limb during swing phase

† p < 0.038 before - after injury

‡ n/a, not available

weeks. The cast was removed only for medication and hygiene in the first three weeks and applied overnight only for the following week. During rehabilitation the physiotherapists were discouraged from using ankle/foot orthoses to control ankle dorsiflexion during the swing phase.

At discharge, patients were advised to carry on with stretching and strengthening exercises at home, if possible, and to walk as much as possible. However we had no control on the frequency and intensity of this training. Post-operative pain was controlled with oral NSAIDs and oral paracetamol/codeine.

One year after operation all patients were reassessed in a standard way. They were asked to walk barefoot with the aids they customarily used at home or outside and not necessarily those used during the first evaluation.

Several outcome measurements were undertaken. The Walking Handicap Score was assessed according to the functional walking categories¹⁵ of a therapeutic walker, limited household walker, unlimited household walker, most-limited community walker, least-limited community

walker and community walker. Each category was assigned a score from 1 (therapeutic walker) to 6 (community walker).

Self-selected speed, cadence, swing velocity, step length of the healthy limb, stride length of the paretic leg and the step width were evaluated from the gait analysis data. The maximum ankle dorsiflexion during the swing phase was also assessed. This is the angle of maximal dorsiflexion between the tibia and the foot, expressed in degrees. If the foot is in plantar flexion the angle is negative. We used this parameter because it represents the position of maximum ability to dorsiflex the ankle actively during the swing phase. The normal value is around 4°.¹⁶

The paretic propulsion is a quantitative measure of the coordinated output of the paretic leg that is sensitive to hemiparetic severity.¹⁷ It is the propulsive impulse of the paretic leg divided by the sum of the paretic and healthy propulsive impulses; where the impulse is the time integral of the posteroanterior ground reaction force. The result is an adimensional measurement.

The number of patients normally using orthoses during walking and the aids or assistance required during walking was recorded.

The self-selected speed and the maximum ankle dorsiflexion during the swing phase were chosen as the main outcome parameters.

Statistical analysis. This was performed using Wilcoxon's test to analyse data from within the same group. Inter-group comparisons were made using the Mann-Whitney U test. An α error value of 0.05 was chosen. This value was corrected for multiple comparisons with the false discovery rate method considering two primary outcome variables and thereafter two null-hypotheses. We obtained a new α error value of 0.038. Data were analysed with GraphPad Prism software version 4.00 (GraphPad Software, San Diego, California).

Results

Pre-operatively, the two groups did not differ statistically, except for cadence, which was higher in patients in the EHL transfer group ($p = 0.02$, Table II).

Post-operatively, patients treated by either EHL transfer or SPLATT showed statistically significant improvements in self-selected speed ($p = 0.027$ and $p = 0.035$, respectively), paretic limb stride length ($p = 0.004$ and $p = 0.02$) and paretic propulsion ($p = 0.037$ and $p = 0.003$). Gait disability was significantly reduced in both groups, as evidenced by the improvement in the walking handicap score ($p = 0.004$ and $p = 0.002$ for EHL transfer and SPLATT respectively). The maximum dorsiflexion angle in the swing phase ($p = 0.006$), the anterior step length of the healthy side ($p = 0.004$) and step width ($p = 0.002$) improved significantly in the EHL transfer group only (Tables II and III).

One year after operation the patients in both groups had similar results for all outcome measures. Comparison with the Mann-Whitney U test showed no significant difference between the groups (Tables II and III).

No patient had recurrence of forefoot varus in the swing phase and no complications were observed post-operatively. One patient in the EHL transfer group abandoned the stick after surgery. Two patients changed aids from a four-legged frame to a simple stick (one in the SPLATT and one in the EHL transfer group). Pre-operatively, four patients in the former group and two in the latter group used ankle-foot orthoses. None needed an orthosis after their operation.

Discussion

Our data support the hypothesis that EHL transfer can be a valid alternative to SPLATT in patients without overactivity of tibialis anterior in the swing phase. Both groups improved in most parameters, and no significant difference was found between the two groups post-operatively. It should also be noted that, even if an overall trend towards improvement is clearly evident in both groups, statistical significance was not

reached for all variables, in particular for maximum dorsiflexion of the ankle during the swing phase in the SPLATT group. The fact that maximum dorsiflexion of the ankle during the swing phase was still lower than normal in both groups should not be considered as an under-correction, as all patients underwent lengthening of the tendo Achillis, which allowed the foot to be placed in dorsiflexion during the stance phase. However, the extent of dorsiflexion during the swing phase is due to the combination of the internal moment produced by either the dorsiflexors acting against the moment produced by the mass of the foot and the residual resistance of plantar flexors. Therefore, any residual lack of dorsiflexion is more likely due to the remaining relative imbalance between plantar- and dorsiflexor moments, rather than under-correction of the contracture of the calf.

Since neither group differed in the parameters evaluated post-operatively, we support the hypothesis that EHL transfer in patients with forefoot varus and without tibialis anterior overactivity is a valuable surgical option.

Another important observation is the improvement in walking speed and paretic propulsion, combined with an improvement in gait. Also, reduction of step width is an indirect indicator of increased stability during walking.

A possible limitation of our study is the low number of patients. However, it should be noted that no data are available about EHL transfer at present and no studies have directly compared different surgical solutions for the varus foot during the swing phase in stroke patients.

Another limitation is that we did not measure foot varus during the swing phase. Unfortunately, the biomechanical model in our study is not able to produce reliable data on the position of the foot in the frontal plane and there are no validated, reliable and simple models to measure forefoot varus in stroke patients. However, we have an indirect measure of correction of the varus foot from the improvement of other kinematic and spatiotemporal data, including the stride length and step width, and the reduced need for orthoses.

Additionally, the design of the study could not exclude selection and observer biases. The limitations of observational studies are well-known,¹⁸ and a randomised trial would have provided more accuracy. However, we believe that such a design would have raised ethical concerns.

Another limitation is the length of follow-up. We limited it to one year for organisational reasons. However, we cannot exclude a higher rate of recurrence in the longer term. It might be argued that, because patients underwent a rehabilitative programme post-operatively, the results could be partially altered because of physiotherapy. However, there is no evidence that physiotherapy alone can produce long-term modifications in gait velocity in patients with chronic stroke.¹⁹

Transfer of the EHL can be a valid alternative to split transfer of the tibialis anterior tendon to correct equinovarus foot, when associated with lengthening of the tendo Achillis, in stroke patients without overactivity of the tibialis anterior.

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