Tibialis posterior tendon transfer for foot drop: Strength of interference screw fixation to the cuboid versus Pulvertaft weave to peroneus brevis

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ABSTRACT

Introduction

Tibialis posterior (TP) tendon transfer is an effective treatment for foot drop. Currently standard practice is to immobilise the ankle in a cast for six weeks nonweightbearing, risking profound postoperative stiffness. To assess whether early active dorsiflexion and protected weightbearing could be safe, the current study assesses tendon displacement under cyclic loading and load to failure, comparing the Pulvertaft weave (PW) with interference screw fixation (ISF) in a cadaveric foot model.

Methods

Twenty-four cadaveric ankles had TP tendon transfer performed, 12 with the PW technique, and 12 with ISF to the cuboid. The TP tendon was cycled 1000 times at 50 to 150 N, and then loaded to failure in a materials testing machine. Tendon displacement at the insertion site was recorded every 100 cycles. An independent t-test and two way ANOVA were performed to compare techniques, with a significance level of $p < 0.05$.

Results

Mean tendon displacement was similar in the PW group (2.895 +/- 2.529 mm (mean +/- SD) compared with the ISF group (2.368 +/- 1.117 mm), $p = 0.35$. One specimen in the ISF group failed early by tendon pullout. None of the PW group failed early, although displacement of 8.910 mm was observed in one specimen. Mean load to failure was 419.095 +/- 82.614 N in the PW group in comparison to 499.394 +/- 109.641 N in the ISF group, $p = 0.06$.

Conclusion
For TP tendon transfer, ISF and PW techniques were comparable, with no differences in tendon displacement after cyclical loading or load to failure. Greater variability was observed in the PW group suggesting it may be a less reliable technique.

Clinical Relevance

The results indicate that early active dorsiflexion and protected weightbearing may be safe for clinical evaluation, with potential benefits for the patient compared with cast immobilisation.

Keywords

Foot drop; Tendon transfer; Tibialis posterior; Interference screw; Pulvertaft weave; Rehabilitation

INTRODUCTION

Anterior transfer of the tibialis posterior (TP) tendon is an established surgical technique for the treatment of foot drop secondary to several inherited and acquired neuromuscular conditions. The most important factor to achieve a good outcome following surgery is foot posture and the ability to actively dorsiflex beyond neutral. Secure fixation at the insertion site is therefore required whilst maintaining a mobile joint. The optimal fixation of tendon transfers in the foot remains unknown. In principle tendon transfer directly to bone is preferable. Potential benefits include secure fixation and an effective pull on the foot during muscle contraction, especially important because the TP tendon has a short excursion. Methods previously reported include barbed staples, interference screws and suturing tendon to tendon. Potential advantages of interference screw fixation (ISF)
are the ability to harvest a shorter graft, and the need for less dissection at the both the
harvest and transfer sites.\textsuperscript{9}

When patients have significant weakness of eversion, the TP tendon is transferred to the
lateral side of the foot.\textsuperscript{15,17} A commonly used technique is to secure the tendon transfer via
a Pulvertaft weave technique,\textsuperscript{31} suturing to either the peroneus brevis or peroneus tertius
tendons.\textsuperscript{10} For tendon to bone transfers, typically the cuneiforms or cuboid are chosen
according to the pattern of muscle weakness.\textsuperscript{1,15,17,38}

At present, standard practice is to immobilise the ankle in a cast for four to eight weeks,
however this can cause adhesions and profound stiffness.\textsuperscript{19,32,40} In one case series of
patients with foot drop secondary to leprosy, early active motion commenced on day five
led to an earlier return to independent walking compared with patients who had standard
immobilisation.\textsuperscript{32} Early active range of motion and protected weight bearing could have
potential advantages including improved patient satisfaction and neuromuscular
function.\textsuperscript{19,26,40} Furthermore, the risk of venous thromboembolism (VTE) would be lower
and a shorter period of immobilisation would reduce the need for chemical VTE prophylaxis.
The question remains whether early rehabilitation is safe. The main risk would be tendon
slippage at the insertion site, leading to a significant increase in tendon length, muscle
atrophy and weakness leading to recurrence of foot deformity.\textsuperscript{16}

The purpose of the current study was to biomechanically assess two techniques for anterior
transfer of the TP tendon in a cadaveric model, to assess their ability to withstand early
postoperative rehabilitation. In the absence of evidence to the contrary, the primary null
hypothesis was that under cyclic loading tendon displacement would not differ after
interference screw fixation (ISF) to the cuboid compared with a Pulvertaft weave (PW)
suturing technique to the peroneus brevis tendon. The secondary null hypothesis was that
ultimate load to failure would not differ between the PW and ISF groups.
METHODS

Specimen preparation

Twenty-four cadaveric fresh frozen below knee specimens 39 +/- 9 (27 to 63) [mean +/- SD (min to max)] years (10 male, 14 female), with no history of disease or previous surgery were obtained from a tissue bank after obtaining local institutional ethics approval. Specimens consisting of whole feet (13 right, 11 left) and approximately 400 mm of tibia, were stored in a freezer at -20°C before use and thawed on the day of experimentation. Testing on each specimen took place in a single day.

The tendon transfer was performed using an established technique via an interosseous window with the tendon end prepared with a 2/0 Ethibond whipstitch (Ethicon, Johnson and Johnson, NJ, USA). The TP tendon was subcutaneously tunnelled to the dorsolateral foot, superficial to the extensor retinaculum.

In the PW group (n=12, 39 +/- 11 (27 – 63) years), the TP tendon was sutured to the peroneus brevis tendon approximately 50 mm proximal to the peroneus brevis insertion into the base of the fifth metatarsal (Figure 1). In all cases the TP tendon was woven through the peroneus tendon twice and sutured using interrupted 2/0 Ethibond sutures. One specimen was chosen for a pilot test on which a load to failure test was performed; this left 11 specimens for cyclic testing.

A 5.5 mm x 15mm interference screw (Biotenodesis screw, Arthrex, Naples, FL, USA) was used in all specimens in the ISF group (n=12, 38 +/- 9 (29 – 48) years. Screw insertion was performed according to the manufacturer’s guidelines. The TP tendon diameter was sized using sleeves with 0.5mm increments. A guidewire was then inserted into the cuboid perpendicular to the dorsal surface of the bone. A bicortical pilot hole was then made
matching the tendon diameter, which ranged from 5.5mm to 7mm. Using the whipstitch, the
tendon was pulled through the cuboid bone tunnel, and the suture pulled out through the
sole of the foot. The tendon was then tensioned by hand whilst the interference screw was
inserted over a guidewire (Figure 2).

Following completion of the tendon transfer, each foot was placed in a custom made
aluminium tray taking care to ensure the hindfoot was in a neutral position. Each foot was
secured in the tray using two Steinmann pins through the calcaneum and one Steinmann pin
across the forefoot via the metatarsals. The tray was then filled with acrylic cement (Simplex
rapid PMMA, Kemdent Medical, UK), encasing the foot to prevent sliding within the tray
(Figure 3).

Using a marker pen, points were drawn on the tendon and at the insertion site on either the
peroneus brevis (PW group) or the cuboid (ISF group) depending on which technique was
used, allowing subsequent measurement of displacement of the tendon transfer relative to
the insertion point. Given the short excursion of the TP muscle, displacement greater than
5mm was considered excessive and likely to represent failure of the fixation in the clinical
setting.

Specimen testing

Specimens were loaded onto a servohydraulic materials testing machine (Instron, High
Wycombe, UK). The proximal TP tendon was identified and dissected from the muscle belly.
The proximal tendon end was held in a freeze clamp attached to the actuator of the testing
machine. The specimen was positioned on the machine under the actuator so that the load
would be applied in line with the physiological line of pull of the TP tendon.
The TP tendon was preloaded to 100 N (ramp rate 10 N/s for 10 seconds). Baseline digital photographs were taken of the tendon insertion point, with a ruler included to allow subsequent scaling of the images. A pilot test using the PW technique showed load to failure of 401 N. A previous study had suggested that 50 N tendon tension was required to achieve maximum ankle dorsiflexion, although modern estimates suggest that the TP muscle can generate greater force. Considering previous estimates and our pilot results, we chose 150 N as the maximum cyclic load, which we felt would realistically simulate two postoperative conditions: 1) partial weightbearing immobilised in a boot; 2) nonweightbearing active ankle dorsiflexion. Cyclic loading from 50 N to 150 N was commenced at a rate of 1 Hz, for 1000 cycles. Digital photographs were taken every 100 cycles until completion of testing. Displacement was measured using a digital software program. Following cyclic loading, a load to failure test was performed, at a rate of 1000 mm per minute.

**Statistical analysis**

Using load to failure as the endpoint, to show a mean difference of 131 N between groups (SD +/- 81 N), power analysis (p=0.05, power 0.80) suggested that the required sample size would be seven specimens per group. Since matched pairs were not used, the sample size was increased to 12 specimens per group, a larger number than other studies. Two way ANOVA was performed to compare displacement of the tendon transfer during cyclic loading for each technique at 10 different cycle intervals. An independent samples t-test was used to compare mean load to failure forces. Data were analysed in SPSS (IBM SPSS Statistics for Windows, version 24.0; IBM, Armonk, NY), with significance set at p<0.05.
RESULTS

Cyclic testing

All 11 specimens in the PW group survived cyclical testing, during which the mean tendon displacement was $2.895 \pm 2.529 \ (0.020 \ - \ 8.910) \ mm$. In the ISF group, 11 out of 12 specimens survived cyclic testing, with a mean tendon displacement of $2.368 \pm 1.117 \ (0.800 - 3.770) \ mm$. In both groups significant tendon displacement occurred compared with baseline ($p<0.001$), however the differences between techniques were not statistically significant ($p=0.35$). Only one specimen in the PW group displaced more than 5mm, measuring 8.91 mm at 1000 cycles. Displacement was less than 4 mm in all 11 specimens which survived cyclic testing in the ISF group. Figure 4 shows the change in displacement, measured every 100 cycles.

In the specimen that did not survive cyclic testing (30 year old male), failure occurred within the first 100 cycles. The TP tendon measured 6.5 mm in diameter and a 6.5 mm pilot hole was drilled. There were no technical difficulties during screw insertion. Post testing examination revealed tunnel deformity, with eccentric expansion at the site of screw insertion (Figure 5).

Load to failure

The mean load to failure was $419.095 \pm 82.614 \ (291.702 \ - \ 601.895) \ N$ in the PW group in comparison to $499.394 \pm 109.641 \ (333.270 \ - \ 702.670) \ N$ in the ISF group, $p=0.06$. The mode of failure was consistent. All PW specimens failed at the tendon to tendon repair site. All specimens in the screw group failed by tendon pullout, leaving the screw in situ in some cases (n=6), pulling the screw out in others (n=5). Post-test examination revealed tunnel deformity or fracture in all specimens (Figures 5 to 7). Pilot hole diameter did not affect
tendon pullout strength significantly: specimens with pilot holes ranging from 5.5 to 6.0
mm had a mean load to failure of 504.521 N; those with pilot holes 6.5 to 7.0 mm had a
mean load to failure of 493.242 N (p=0.9).

DISCUSSION

The current cadaveric study has shown that tendon displacement under cyclic loading and
load to failure were comparable for both the ISF and PW techniques, accepting our null
hypotheses that there was no difference between groups. Our results suggest that both the
ISF and PW fixation methods may have sufficient strength to resist early postoperative
protected weightbearing and active ankle dorsiflexion. If supported by clinical experience,
the likely benefits of early rehabilitation compared with plaster immobilisation could include
improved patient satisfaction, less stiffness, reduced risk of VTE and shorter duration of
chemical VTE prophylaxis.

Although early rehabilitation is feasible, it is not risk free. The normal excursion of the TP
muscle is only 1.75 cm, but even 4mm elongation of the tendon is estimated to cause
dysfunction. For the purposes of the current study, considering measurement error, we
defined displacement of more than 5mm as failure. All 11 of the PW specimens survived
1000 cycles, with mean displacement of 2.9 mm. Displacement of more than 5 mm
occurred in only one specimen, measuring 8.9 mm after 1000 cycles. Given the short
excursion of the TP muscle, this amount of displacement is probably undesirable. In
comparison, one out of 12 ISF specimens failed prematurely, within 100 cycles. In the
remaining 11 specimens, mean displacement was 2.4mm, and in all specimens was less than
4mm. Displacement was observed to occur earlier in the PW group. Mean displacement of
2 mm had occurred by 300 cycles in the PW group, but took 900 cycles to reach this
threshold in the ISF group. We observed greater variation in displacement in the PW group compared with ISF (SD 2.5 and 1.1 mm respectively). Screw fixation may therefore be preferable over tendon to tendon repair as it is more consistently reproducible compared with tendon to tendon repair.

Data on cyclical testing of tendon fixation in the foot is limited, especially in comparison to the extensive literature in the knee. The displacements we observed for TP tendon transfer appear similar to that observed in some studies of hamstrings graft interference screw fixation for reconstruction of the anterior cruciate ligament (ACL).\textsuperscript{22,27} For example, Kousa et al showed that cyclic loading of ACL hamstring grafts fixed with a 7 mm RCI screw, displaced 3.9 mm after 1500 cycles at 200 N.\textsuperscript{22} Micucci et al recorded hamstring graft slippage in a 9 mm tunnel at 250 N for 1500 cycles, noting mean displacements of 2.65 mm with a 9 mm diameter interference screw, and 7.83 mm with an 11 mm screw.\textsuperscript{27} However, another study of ACL graft fixation found a mean displacement of 0.7 to 1.3 mm among five hamstrings tendon fixation methods after 1000 cycles from 70 to 200 N, and mean ultimate strengths of 490 to 945 N.\textsuperscript{4} In theory, tendon transfer directly to bone is preferable. The single failure we observed in the ISF group, is similar to rates observed in previous biomechanical studies.\textsuperscript{9,22} In the foot for example, Drakos et al reported early failure in three out of 10 specimens following ISF (5.5 mm diameter biotenodesis screw) for FHL transfer to the calcaneus, at 60 N loads. Simulating ACL reconstruction, Kousa et al observed one out of 10 specimens failed early.\textsuperscript{22}

The physiological force required for active dorsiflexion is unclear. Although in an unloaded foot model 50 N tension was required to achieve maximum dorsiflexion,\textsuperscript{17} modern estimates based on muscle cross sectional area suggest that greater physiological forces are encountered.\textsuperscript{6,7,20,37} During normal gait, Delp et al estimated that the tibialis anterior and tibialis posterior muscles generate peak forces of 600 N and 1270 N respectively.\textsuperscript{7} Even with
an anticipated loss of one grade of strength following anterior transfer of the TP, it is likely
that more than 50 N tension would occur at the fixation point.\textsuperscript{6,7,17,20} We therefore chose to
cyclically load the tendon at 150 N to simulate likely physiological forces encountered during
protected partial weight bearing with the ankle immobilised in a boot, and also
nonweightbearing active ankle dorsiflexion.

Both techniques demonstrated similarly high load to failure tests. In all specimens, the PW
consistently failed at the tendon-suture interface. In the ISF group all specimens failed at
the tendon-screw interface, similar to biomechanical studies assessing FDL and FHL tendon
transfers.\textsuperscript{9,24} In the current study, the screw was placed inferior to the tendon within the
pilot hole. Upon loading, due to the direction of tendon pull, the superior edge of the pilot
hole was loaded, fracturing in some cases (Figures 5 to 7). In future studies it may be useful
to assess whether proximal placement of the screw relative to the tendon would increase
pullout strength.

In vivo management of an early tendon transfer failure would pose particular difficulties for
both techniques. For the PW technique, after load to failure testing, the peroneus brevis
tendon consistently sustained damage due to the sutures tearing out, which would make it
hard to re-suture the TP tendon using the original technique. A side to side tendon repair
would be more feasible as a revision procedure or alternatively use a different transfer site.
Failure following the ISF method might be even more difficult to revise. We consistently
noted tunnel deformity or small fractures through part of the tunnel wall. Furthermore the
tendon lying within the pilot hole flattened due to compression by the screw. Over reaming
to a larger pilot hole and use of a larger diameter interference screw might be possible if the
navicular had sufficient bone stock. If the pilot hole deformity was too severe to revise, a
different transfer site would be required.
Interference screw fixation in the foot has gained popularity for several conditions. Screw fixation might be preferable to a tendon to tendon repair as it is less dependent upon surgeon technique. The load to failure forces we report are greater than for other tendon transfers in the foot. In one study, split anterior tibialis tendon transfer to the cuboid using an 8mm biotenodesis screw had a mean load to failure of 150 N. Sabonghy et al reported that FDL transfer to the navicular using a 7 mm x 20 mm interference screw with a 6.4 mm diameter pilot hole, failed at a mean of 148 N. Louden performed a similar study using FDL and FHL tendons but with smaller pilot holes of 3.9 and 4.5 mm diameters. In that study pull-out forces were approximately 170 and 75 N for 7 mm and 5 mm diameter screws respectively. Similarly, in two separate studies, FHL transfer to the calcaneum had loads to failure of 172 N and 170 N with 5.5 mm and 7 mm diameter screws respectively. The greater pull-out strengths we report are likely to be related to the large diameter of the TP tendon. Furthermore, we also used a whipstitch, proven to increase pullout strength.

For smaller diameter tendon transfers in the foot which are less than 5 mm (such as FDL or split anterior tibialis tendons), the drill hole is often oversized to accommodate a larger screw. The advantage of using a whole tendon transfer rather than split tendon is that oversizing of the pilot hole is not necessary. We drilled the tunnel to match the TP tendon, which has been shown to increase pullout strength. In all but two specimens the bone tunnel was 6.5 mm or less. In the two specimens which required 7 mm holes, the pullout strengths were 513 and 485 N. We found no difference in loads to failure comparing 5.5 to 6.0 mm pilot tunnels (504 N) versus 6.5 to 7 mm tunnels (493 N). For consistency we chose to use the same diameter screw for all specimens. Although screw diameter seems to be less important compared with the tendon to tunnel diameter ratio, it is possible that use of a larger diameter screw in our own study may have affected the pullout strength.
must also consider the risk of using a large diameter screw in a relatively small bone in the foot, which could lead to damage to the tendon graft or fracture.

**Limitations**

Several limitations exist inherent to an in vitro cadaveric study. We were not able to simulate the effects of tendon remodelling, or tendon-bone interface healing which usually occur within the first six weeks. Our findings therefore are only relevant to the early postoperative period before this process has occurred. We did not measure bone mineral density prior to testing. The mean age of the specimens used was relatively young, which represent the typical population receiving tendon transfers for foot drop. Other studies have used elderly osteoporotic specimens. Although we conducted a priori power analysis based upon load to failure, post hoc analysis using mean tendon displacement during cyclic testing showed that the power was 0.14 and that 194 specimens in each group would be required to show a significant difference between techniques.

The current study only compared two techniques for anterior transfer of the TP. We chose transfer to the lateral side of the foot as would be required in a foot drop which included peroneal tendon weakness. Our findings cannot necessarily be applied to other sites of tendon transfer such as the cuneiforms, or techniques using smaller diameter tendons, including split TP tendon transfer.

**CONCLUSIONS**

The current study supports early postoperative active dorsiflexion and early protected partial weightbearing. For anterior transfer of the TP tendon, ISF and PW techniques were comparable with relatively small displacements during cyclic loading, and similar loads to failure. The variability of displacement however was greater in the PW group, suggesting it
may offer less reliable fixation. The potential benefits of early rehabilitation include improved patient satisfaction, reduced stiffness and reduced risk of VTE and need for chemical prophylaxis. We recommend future clinical trials to determine the functional outcomes of early rehabilitation versus cast immobilisation after TP tendon transfer.

REFERENCES


FIGURES
Figure 1  A lateral view of a right foot specimen showing a Pulvertaft weave suturing of the tibialis posterior tendon to the peroneus brevis tendon. P.brevis – Peroneus brevis

Figure 2  A lateral view of a right foot specimen showing an interference screw fixation of the tibialis posterior tendon into the cuboid. P. brevis – Peroneus brevis

Figure 3  Specimen set up.

Figure 4  Graph to show mean tendon displacement during cyclic loading. In both groups statistically significant displacement occurred compared with baseline (p<0.001), but there was no significant difference comparing groups (p=0.35)

Figure 5  Lateral view of a left foot specimen. Tunnel deformity observed in the specimen which failed during cyclic testing after interference screw fixation

Figure 6  Lateral view of a right foot specimen. Deformity after completion of a load to failure test is noted on the inferior side of the pilot hole, correlating to the site of the screw insertion. In this specimen, the interference screw pulled out with the tendon

Figure 7  Pilot hole fracture after a load to failure to test. The interference screw remains in situ