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Biomechanical Evaluation of Circumtibial and Transmembranous Routes for Posterior Tibial Tendon Transfer for Dropfoot

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Abstract

Background: Tibialis posterior tendon transfer is performed when loss of dorsiflexion has to be compensated. We evaluated the circumtibial (CT), above-retinaculum transmembranous (TMAR), and under-retinaculum transmembranous (TMUR) transfer gliding resistance and foot kinematics in a cadaveric foot model during ankle range of motion (ROM).
Methods: Eight cadaveric foot-ankle distal tibia specimens were dissected free of soft tissues on the proximal end, applying an equivalent force to 50% of the stance phase to every tendon, except for the Achilles tendon. Dorsiflexion was tested with all of the tibialis posterior tendon transfer methods (CT, TMAR, and TMUR) using a tension tensile machine. A 10-repetition cycle of dorsiflexion and plantarflexion was performed for each transfer. Foot motion and the force needed to achieve dorsiflexion were recorded.
Results: The CT transfer showed the highest gliding resistance ($P < .01$). Regarding kinematics, all transfers decreased ankle ROM, with the CT transfer being the condition with less dorsiflexion compared with the control group (6.8 vs 15 degrees, $P < .05$). TMUR transfer did perform better than TMAR with regard to ankle dorsiflexion, but no difference was shown in gliding resistance. The CT produced a supination moment on the forefoot.
Conclusion: The CT transfer had the highest tendon gliding resistance, achieved less dorsiflexion and had a supination moment.
Clinical Relevance We suggest that the transmembranous tibialis posterior tendon transfer should be the transfer of choice. The potential bowstringing effect when performing a tibialis posterior tendon transfer subcutaneously (TMAR) could be avoided if the transfer is routed under the retinaculum, without significant compromise of the final function and even with a possible better ankle range of motion.

Keywords: tibialis posterior tendon transfer, circumtibial, transmembranous, interosseous membrane, paralytic foot, dropfoot

Introduction

Tibialis posterior tendon transfer is used for different foot and ankle pathologies that need rebalancing to achieve a plantigrade foot. Injury to the common peroneal nerve is the most frequent cause of dropfoot.[9] Numerous other pathologies have dropfoot as one of their characteristics (eg, Charcot Marie Tooth syndrome, trauma, spastic syndrome, herniated disc, etc).[1,4,7] In a posttraumatic setting, it is important to differentiate whether dropfoot is secondary to tendon or neurologic damage. In almost every dropfoot case, loss of dorsiflexion has to be compensated. Initial conservative treatment for dropfoot varies greatly, but ankle foot orthoses are often prescribed. The orthosis blocks plantarflexion, which stabilizes the ankle, avoiding the equinus gait. If conservative treatment fails, operative options include arthrodesis, tenodesis, and tendon transfers.[2]

In addition to a failed conservative treatment, the following are requirements to be a candidate for a tibialis posterior tendon transfer in a dropfoot case: flexible ankle joint, normal ankle range of motion, absence of ankle joint arthritis, M4 to M5 tibialis posterior tendon strength, and a viable leg. If these requirements are not met, an ankle arthrodesis should be considered.

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In an acute traumatic setting, the dropfoot origin should be clearly identified. In cases in which no tendon or nerve damage are evident, neurapraxia is the most probable cause. After a prudent period of observation (approximately 1 year), if no neurologic improvement is demonstrated, tendon transfers can be considered.[8]

A tendon transfer procedure has to fulfill several principles to be successful. The tendon to be transferred should be a healthy tendon, restore normal anatomic relationships between the tendon and its sheath, reroute through adequate tissue to allow proper gliding, restore normal tendon tension, re-create anatomical tendon insertion, and establish proper line of tendon pull.[12] A usually preserved functioning tendon is the tibialis posterior. This tendon is frequently a deforming force too, yielding active unopposed plantarflexion and inversion. Therefore, it is a good candidate to be transferred in cases in which the function of the anterolateral compartment of the leg is compromised. Many aspects of tendon transfers are still debated, such as route of transfer, transferred tendon tension, type of bone attachment, tendon to be transferred depending on the motor unit lost, number of tendons to transfer, and so on. There are some techniques that use combined transfers for dropfoot cases. The Bridle procedure[11] combines the peroneals and flexors to balance and strengthen the tibialis posterior dorsiflexion. The study published by Vigasio et al[15] shows a similar principle as the Bridle, but with tendon to tendon tenorrhaphy instead of tendon to bone attachment.

Two main routes exist for the tibialis posterior tendon transfer (ie, transmembranous and circumtibial [CT]). There are studies that support both routes with satisfactory outcomes.[1,6] The transmembranous is performed through an interosseous membrane window, 15 cm above the ankle joint. The CT is routed through the subcutaneous fatty tissue in the distal tibia, around the medial surface of the medial malleolus, being substantially easier and faster than the transmembranous, potentially having a greater lever arm and thus better muscle strength.[6,17] Nevertheless, given its subcutaneous and oblique passage around the tibia, there could exist an increased tendon friction that may hinder a good functioning transfer. Other risks include adhesions and the possibility of a palpable tendon, given that the whole transfer is subcutaneous. The transmembranous transfer is more mechanically sound, given its more direct line of pull, but it has a smaller lever arm, having potentially less strength but better dorsiflexion capability.[13] However, a few additional risks exist (ie, narrowing of the membrane window with possible entrapment, neurovascular damage risk, tendon adhesions to the membrane, etc).[5,10]

The transmembranous transfer can be performed above and below the extensor retinaculum. The current recommendation is to perform the transfer above the extensor retinaculum.[6] Nevertheless, there is no serious biomechanical comparison among both routes.

The objective of this study was to compare and analyze the CT and transmembranous transfer routes, measuring the tendon gliding resistance and foot kinematics for each transfer in a cadaveric specimen. In addition, 2 transmembranous transfers were analyzed, above the ankle extensor retinaculum (TMAR) and under the retinaculum (TMUR). Our first hypothesis was that the transmembranous route would achieve better kinematic function with less gliding resistance than the CT route. Our second hypothesis was that the TMAR transfer would achieve less gliding resistance than the TMUR transfer.

Methods

Eight cadaveric fresh frozen foot-ankle distal tibia specimens were prepared, with at least 30 cm of tibia and fibula, identifying all extensor and flexor tendons proximally. The skin and subcutaneous tissue were kept intact. All specimens were inspected to rule out any evidence of previous trauma or decreased ankle range of motion. The mean age of the donors was 56 years (range, 52-65). Specimens were kept frozen at −20°C in a sealed plastic bag. Before testing, each specimen was thawed at room temperature one at a time, and extra care was taken to keep the specimens at a constant temperature and moisturized with saline solution. Each specimen was mounted on a special frame, and reflective markers were attached to the skin to adapt it to the Oxford Foot Model.[14]

The foot was filmed in a closed room, to determine the tridimensional change in position of every foot when subjected to testing. Any associated supination, pronation, adduction, and abduction was recorded. This was performed with 8 infrared cameras (Vicon Serie-T, Vicon Motion Systems Lt., Oxford. UK) symmetrically positioned around the room that detected (sample rate = 50 Hz) the reflective markers movement throughout the testing.

A dead weight equal to 50% of the stance phase force was applied to almost every tendon: peroneus brevis, peroneus longus, flexor digitorum longus, flexor hallucis longus, extensor digitorum longus, and extensor hallucis longus (Figure 1). No weight was applied to the Achilles tendon.

Each specimen served as its own control, testing dorsiflexion when pulling the tibialis anterior, performing a 10-repetition cycle of dorsiflexion and plantarflexion using a tensile testing machine (Kinetecnics, Santiago, Chile). The movement of the foot was recorded, and the force needed to achieve dorsiflexion was registered in every cycle.

Then, a TMAR tibialis posterior tendon transfer was performed in each specimen, through 4 incisions as in a real clinical situation. The first incision was on the medial aspect of the foot, just proximal to the insertion of the tibialis posterior tendon on the navicular bone. The tendon was obtained as long as possible and recovered from a second medial and more proximal incision 15 cm above the ankle

Figure 1. Cadaver foot in a closed room mounted on a special frame. Reflective markers attached to skin, adapting it to the Oxford foot model. Dead weight equals 50% of the stance phase applied to each tendon.

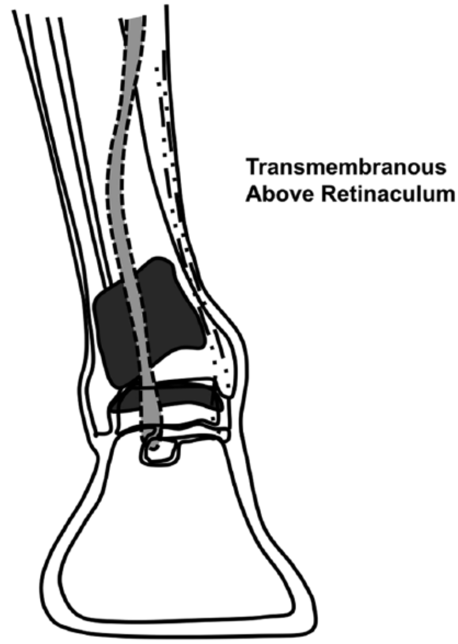

Figure 2. Anteroposterior foot drawing of the above retinaculum transmembranous tibialis posterior tendon transfer.

joint just posterior to the tibia. A third incision 12 cm above the ankle on the anterior aspect of the leg was performed, and a 5-cm-long window was performed blindly through the interosseous membrane with a Mayo scissor. The tendon was recovered from medial to anterolateral through this window. Finally, through a subcutaneous passage, the tendon was passed from this anterior incision distally to the dorsum of the foot through a fourth incision on top of the intermediate cuneiform. A biotenodesis screw was inserted in the intermediate cuneiform to fix the tibialis posterior tendon to this bone (Figures 2 and 3).

Dorsiflexion was tested through the transferred tibialis posterior tendon (TMAR, transmembranous above retinaculum transfer). A 10-repetition cycle of dorsiflexion and plantarflexion was performed by use of a tensile testing machine (Kinetecnics), recording kinematics and gliding resistance. The machine was programmed to achieve a maximum of 100 N of pull (dorsiflexion).

After performing this testing, the tibialis posterior tendon was released from its attachment proximally and recovered distally on top of the foot. It was rerouted under the extensor retinaculum, following the same transmembranous route. Then, dorsiflexion was tested with the same methodology, recording the kinematics and gliding resistance (TMUR; Figures 4 and 5).

Finally, the tibialis posterior tendon transfer tendon was released from its attachment proximally and recovered distally on top of the foot. From distal to proximal, the tibialis posterior tendon transfer tendon was routed subcutaneously in a CT way, until recovering it on the posteromedial aspect of the leg (CT transfer). In this situation, the tendon was again reattached to the testing clamp and to the testing machine. The same testing was performed again (Figures 6 and 7).

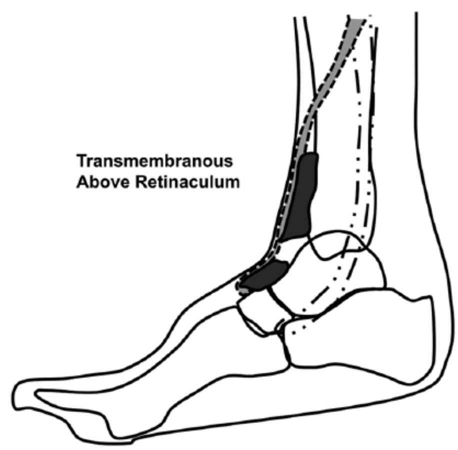

Figure 3. Lateral foot drawing of the above retinaculum transmembranous tibialis posterior tendon transfer.

Statistical analysis was performed with the SPSS software with help of a statistician. Analysis was performed using the analysis of variance test for nested measures, estimated by mixed models. The statistical differences were considered with a $P < .05$.

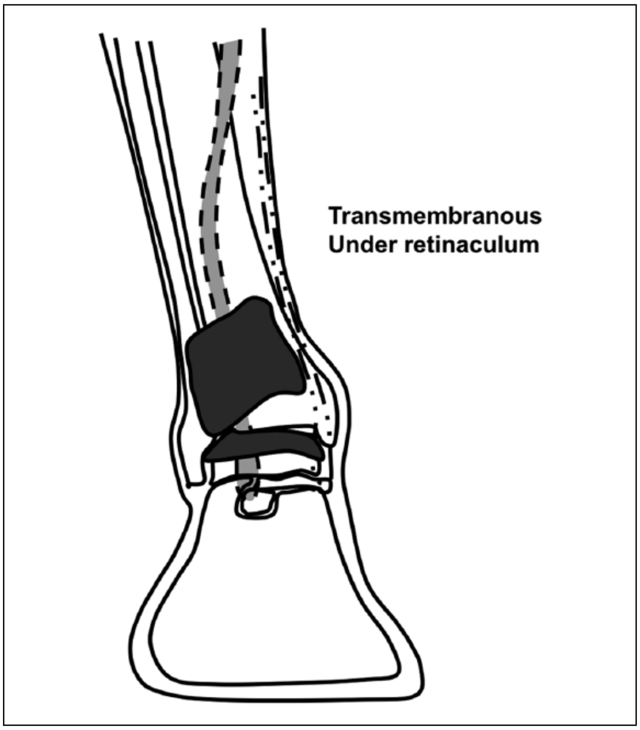

Figure 4. Anteroposterior foot drawing of the under retinaculum transmembranous tibialis posterior tendon transfer.

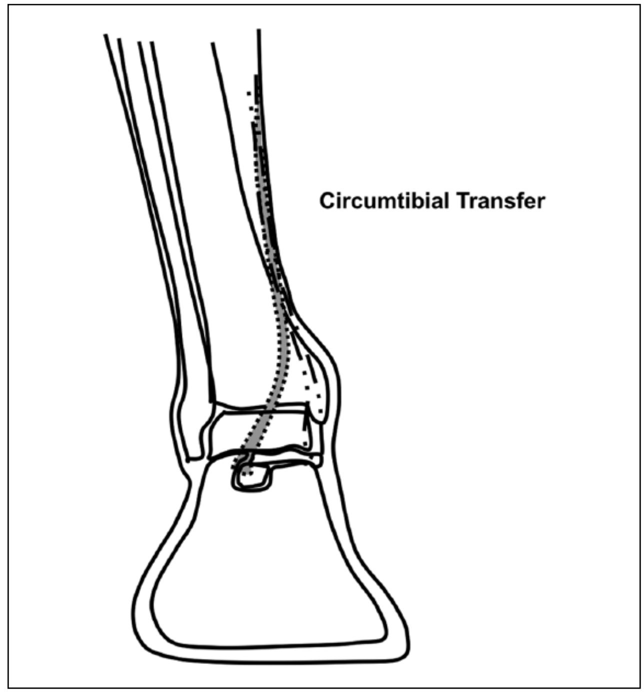

Figure 6. Anteroposterior foot drawing of the circumtibial tibialis posterior tendon transfer tendon transfer.

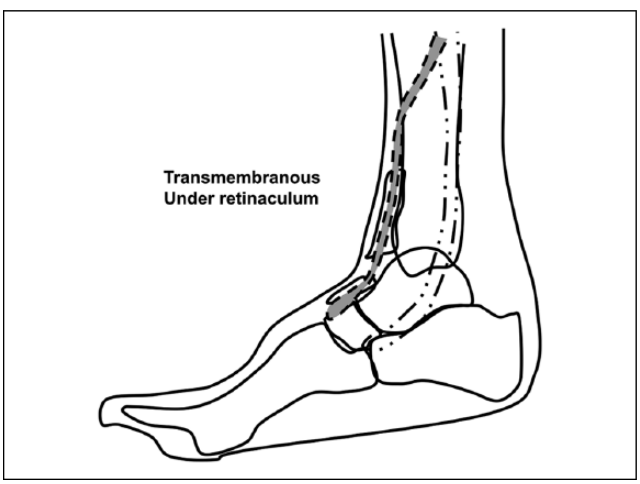

Figure 5. Lateral foot drawing of the under retinaculum transmembranous tibialis posterior tendon transfer tendon transfer.

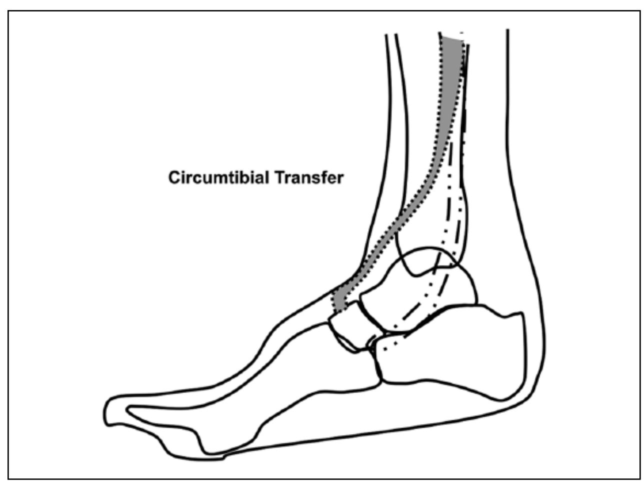

Figure 7. Lateral foot drawing of the circumtibial tibialis posterior tendon transfer tendon transfer.

Results

Regarding the gliding resistance, it was measured as a coefficient (Newtons needed to produce degree of motion, N/degree). Taking the control group as reference with a gliding resistance of 5.43 (SD, 0.78), all transfers had significantly higher gliding resistance. The CT was 12.0 (SD, 5.2; $P < .01$), the TMAR was 8.1 (SD, 2.9; $P < .05$), and the TMUR was 8.1 (SD, 2.1; $P < .05$; Table 1). The CT gliding resistance was significantly higher than all the other conditions ($P < .01$). Taking TMAR as reference, TMUR showed no difference to it ($P > .9$).

Regarding the foot kinematics after each transfer, regardless of type, all transfers significantly lost dorsiflexion in comparison with the control group (15.2 degrees; SD, 2.5), with the CT being the one with the worst performance (6.9 degrees; SD, 1.6; $P < .01$). When comparing TMAR and

Table 1. Gliding Resistance.[a]

	Gliding Resistance		
	Mean, N/degree	SD	*P* Value
Transmembranous transfer above the ankle extensor retinaculum	8.1	2.9	<.05
Transmembranous transfer under the ankle extensor retinaculum	8.1	2.1	<.05
Circumtibial	12.0	5.2	<.05
Control (healthy)	5.4	0.8	

[a]All transfers had a significantly higher gliding resistance than the control group.

Table 2. Ankle Dorsiflexion.[a]

	Dorsiflexion, degrees		
	Mean, degrees	SD	*P* Value
Transmembranous transfer above the ankle extensor retinaculum	9.1	1.7	.01
Transmembranous transfer under the ankle extensor retinaculum	11.7	2.5	.01
Circumtibial	6.9	1.6	.01
Control	15.2	2.5	

[a]All transfers showed a diminished ankle dorsiflexion compared with the control group.

Table 3. Foot Supination.[a]

	Supination		
	Mean, degrees	SD	*P* Value
Transmembranous transfer above the ankle extensor retinaculum	(–) 3.8	2.8	.856
Transmembranous transfer under the ankle extensor retinaculum	(–) 3.8	2.3	.584
Circumtibial	(–) 1.5	1.2	.001
Control (healthy)	(–) 4.4	2.5	

[a]The circumtibial transfer was the only transfer that significantly had a higher supination than the control group.

TMUR, there was a significant better performance of TMUR versus TMAR (11.7 vs 9.1 degrees, $P < .05$). Surprisingly there was no significant difference between CT and TMAR (6.9 vs 9.1 degrees, $P > .05$); nevertheless, that could be a consequence of an underpowered analysis (Table 2). When analyzing the foot axial movement, there is a significant increase in foot supination only with the CT, −1.5 degrees (SD, 1.2), in comparison with the control group, −4.4 degrees (SD, 2.5; $P < .05$; Table 3). Finally, all transfers, regardless of type, showed a significant forefoot abduction (mean of 7 degrees) in comparison with the control group ($P < .001$). There was no difference between transfers regarding abduction.

All feet were dissected at the end of the study, showing no damage of the neurovascular bundle or any other iatrogenic damage with either transfer.

Discussion

The ideal tibialis posterior tendon transfer tendon transfer route is still under discussion. The CT and transmembranous transfers are recommended by different authors.[1,2,16] Nevertheless, there is no consensus on the best way to perform the transfer. When analyzing the different routes separately, the CT transfer has been reported to successfully recover ankle dorsiflexion (9 degrees on average).

Nevertheless, 30% of cases present with symptomatic palpable tendon with fair and poor results in 16% of cases.[1] Cho et al[2] reported a similar dorsiflexion gain (11 degrees) with the transmembranous transfer, with minor complications present in 12% of cases. No mechanical comparison has been made between both routes, analyzing parameters such as gliding resistance. Some important differences between the transfers mentioned previously are the line of pull and the kinematic result. The CT route has an oblique line of pull, surrounding the distal medial tibia, that may eventually produce dorsiflexion with some foot inversion-supination. On the other hand, the transmembranous transfer has a direct line of pull producing neutral dorsiflexion without supination. In the transmembranous transfers, an additional question is whether to pass the transferred tibialis posterior tendon above or under the ankle extensor retinaculum. As Jeng et al[6] published, a subcutaneous route above the extensor retinaculum is recommended to avoid adhesions under the extensor retinaculum. Nevertheless, there is no evidence that this in fact happens. Even more, it is very unlikely that adhesions could occur between retinaculum and tendon, structures that are in constant movement under physiologic conditions.

Our study showed that all 3 transfers (TMUR, TMAR, and CT) decreased foot dorsiflexion in comparison with the healthy foot. Nevertheless, the CT route was the one that limited dorsiflexion the most with the highest gliding resistance and diminished ankle dorsiflexion. Our study demonstrated that the transmembranous tendon transfer had a lower gliding resistance, achieving better ankle dorsiflexion than the CT transfer. A possible explanation for this was the more direct line of pull of the transmembranous transfer. Another interesting finding was that supination was caused by only the CT transfer. This is explained also by the tendon oblique line of pull around the distal tibial medial surface. This observation should be taken into account when deciding on a tibialis posterior transfer, as we found the most efficient one with less kinematic alteration was the transmembranous transfer, therefore supporting our first hypothesis. It was an interesting finding that all feet had significantly more abduction than the control group. We performed the transfers to the middle cuneiform, which mechanically produces a straight line of pull. Because of this finding, we suggest that for feet with normal peroneal muscles and toe flexors, the middle cuneiform should be the preferred insertion point and not the lateral cuneiform to avoid excessive abduction. For patients with peroneal muscle paralysis, a lateral cuneiform insertion would be appropriate to compensate for the lack of eversion force. Nevertheless, this was not analyzed in our study.

Regarding the transmembranous transfers, there was no significant difference between the TMUR and TMAR (above and below the superior extensor retinaculum) regarding gliding resistance, disproving our second hypothesis. We surprisingly even found that TMUR (under retinaculum) had significantly better ankle dorsiflexion than TMAR. This contrasts the finding of D'Astous et al,[3] who showed that the above retinaculum transfer was more efficient than below the reticulum. It has to be noted that the study by D'Astous et al did not re-create a (close to) normal-anatomic stance phase like our study did. They tested only an isolated transferred tendon (not applying any force to the other tendons), used a pulley system away from the leg and used a short leg specimen. Our study included all tendons under tension (50% of the normal stance phase force) while performing the test resembling a close to in vivo situation, and all our tests were performed on a long-leg cadaver specimen, performing the tendon pull where the muscle belly is located. Finally, the differences found by D'Astous et al were very small and probably not clinically significant, a comment that was made by the authors themselves. A better performance of TMUR than TMAR is backed up by basic physics. First, TMUR glides through a retinaculum tunnel, tissue made for this purpose, in comparison to TMAR, which glides through fat and subcutaneous tissue. Second, the TMUR lever arm is much larger than the one in TMAR. TMAR was not found to have statistically better dorsiflexion than CT (9.1 vs 6.9 degrees, $P > .05$). Nevertheless, the authors think that this result was obtained secondary to an underpowered analysis.

A major limitation of our study includes the use of cadaveric specimens. Cadavers rapidly lose tissue lubrication, which could have increased tendon gliding resistance and decreased foot motion. To overcome this limitation, each specimen was dealt with one at a time, and extra care was taken to keep the specimens at a constant temperature and moisturized with saline solution. Other limitations include the specimen's inherent variability regarding different joints' range of motion, stiffness, and operative technique. Regarding the latter, this was minimized, given that the same authors performed all transfers on all feet. Finally, because there were no other studies found in the literature that were methodologically similar to this one, a power analysis could not be performed. We did a preliminary study with 2 specimens (not included in this study) to approximately calculate the minimum number of specimens needed to demonstrate a significant difference between the study groups.

In conclusion, it was clear that the CT route, given its evident mechanical disadvantages considering diminished joint range of motion, increased tendon gliding resistance and altered kinematics should not be recommended if the transmembranous route is feasible and the surgeon has experience performing it. Relative to the transmembranous (interosseous) route, it was biomechanically superior to the CT. Historically it has been taught that a transmembranous tibialis posterior tendon transfer tendon transfer should be performed above the retinaculum, because it is probably more efficient.[6] This was not confirmed in our study, where equivalent performance was found between both transmembranous transfers. Additionally, it is well known that when using a subcutaneous passage, the palpable tendon (bowstringing effect) is not cosmetic, producing patient discomfort and dissatisfaction.[4] The authors would recommend using the transmembranous route as the transfer of choice. Clinical studies comparing both transmembranous routes would be useful to provide additional information to guide our operative decision.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. ICMJE forms for all authors are available online.

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References

1. Aydin A, Topal M, Tuncer K, et al. Extramembranous transfer of the tibialis posterior tendon for the treatment of drop foot deformity in children. *Arch Iran Med*. 2013;16(11):647-651.
2. Cho BK, Park KJ, Choi SM, Im SH, SooHoo NF. Functional outcomes following anterior transfer of the tibialis posterior tendon for foot drop secondary to peroneal nerve palsy. *Foot Ankle Int*. 2017;38(6):627-633.
3. D'Astous JL, MacWilliams BA, Kim SJ, Bachus KN. Superficial versus deep transfer of the posterior tibialis tendon. *J Pediatr Orthop*. 2005;25(2):245-248.
4. Dreher T, Wolf SI, Heitzmann D, Fremd C, Klotz MC, Wenz W. Tibialis posterior tendon transfer corrects the foot drop component of cavovarus foot deformity in Charcot-Marie-Tooth disease. *J Bone Joint Surg Am*. 2014;96(6):456-462.
5. Hove LM, Nilsen PT. Posterior tibial tendon transfer for drop foot. 20 cases followed for 1-5 years. *Acta Orthop Scand*. 1998;69:608-610.
6. Jeng C, Myerson M. The uses of tendon transfers to correct paralytic deformity of the foot and ankle. *Foot Ankle Clin*. 2004;9(2):319-337.
7. Karamitopoulos MS, Nirenstein L. Neuromuscular foot: spastic cerebral palsy. *Foot Ankle Clin*. 2015;20(4):657-668.
8. King B, Ruta D, Irwin T. Spastic foot and ankle deformities: evaluation and treatment. *Foot Ankle Clin North Am*. 2014;19(1):97–111.
9. Mont MA, Dellon AL, Chen F, et al. The operative treatment of peroneal nerve palsy. *J Bone Joint Surg Am*. 1996;78(6):863-869.
10. Ozkan T, Tuncer S, Ozturk K, Aydin A, Ozkan S. Surgical restoration of drop foot deformity with tibialis posterior tendon transfer. *Acta Orthop Traumatol Turc*. 2007;41:259-265.
11. Rodriguez R. The bridle procedure for the treatment of dorsiflexion paralysis of the foot. *Tech Foot Ankle Surg*. 2009; 8:168-171
12. Schweitzer K, Jones C. Tendon transfers for the drop foot. *Foot Ankle Clin North Am*. 2014;19(1):65-71.
13. Shane A, Reeves C, Cameron J, Vazales R. Posterior tibial tendon transfer. *Clin Podiatr Med Surg*. 2016;33:29-40.
14. Theologis TN, Harrington ME, Thompson N, Benson MK. Dynamic foot movement in children treated for congenital talipes equinovarus. *J Bone Joint Surg Br*. 2003;85(4):572-577.
15. Vigasio A, Marcoccio I, Patelli A, Mattiuzzo V, Prestini G. New tendon transfer for correction of drop-foot in common peroneal nerve palsy. *Clin Orthop Relat Res*. 2008;466(6):1454-1466.
16. Wagenaar FC, Lou werens JW. Posterior tibial tendon transfer: results of fixation to the dorsiflexors proximal to the ankle joint. *Foot Ankle Int*. 2007;28(11):1128-1142.
17. Xu J, Geng X, Muhammad H, et al. Posterior tibialis tendon transfer via the circumtibial route: a cadaveric limb analysis. *J Orthop Surg Res*. 2014;9:121.