Tibialis Anterior Tendon Transfer.

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INTRODUCTION

Tendon transfer procedures have long been used for the correction of complex foot deformities in adults and children. Because many deformities coexist, however, concomitant bony and soft tissue procedures are often necessary for successful correction. Transfer of the tibialis anterior tendon is used commonly to treat recurrent clubfoot and to restore muscle balance in patients with cerebral palsy. Recurrent clubfoot deformities are often attributable to an overactive tibialis anterior muscle and weak antagonists. Although many techniques have been proposed for the correction
of recurrent clubfoot deformities, the most common treatments include the complete and split transfer of the tibialis anterior tendon.

Complete transposition of the anterior tibial tendon was first described by Garceau in 19401,2 and later modified by Ponseti. The Ponseti technique popularized and is largely accepted as the standard treatment for the management of idiopathic clubfoot.3,4 The technique aims to correct dynamic supination by transferring the tibialis anterior tendon laterally.

Several decades later, the split tibialis anterior tendon transfer (STATT) was introduced by Hoffer and colleagues.5 The STATT is a variation of the complete tibialis anterior tendon transfer where the tibialis anterior tendon is split and the lateral half is secured into the lateral cuneiform or cuboid. When initially introduced, the STATT procedure was used to treat children with cerebral palsy and spastic equinovarus deformity. Since then, the indications have expanded to include the treatment of residual clubfoot deformity as well as spastic equinovarus deformity in adults.5–7 As with the complete transfer of the tibialis anterior tendon, the STATT procedure attempts to neutralize the varus pull of the tibialis anterior muscle.5 Both the complete and split transfers have proven safe and effective means of achieving deformity correction, restoring muscle balance, and improving functional autonomy.6,9 The present report discusses the key aspects of both the complete transfer of the tibialis anterior tendon and the STATT, including the operative indications and contraindications, key aspects of preoperative planning, operative techniques and rehabilitation protocols, and lastly, published outcomes are reviewed.

Pathomechanics

Weak evertors allow the tibialis anterior muscle to have an unopposed pull creating a dynamic supination of the forefoot.10 Transferring the tendon laterally balances inversion and eversion and reduces the talo-first metatarsal angle.11

Indications

Successful outcomes depend on appropriate patient selection. Table 1 outlines the indications for both the tibialis anterior tendon transfer and the STATT.

Contraindications

There are very few absolute contraindications to tibialis anterior tendon transfer. The procedure should be avoided when muscle strength of the tibialis anterior is less than 4+ or 515 and when severe contraction limits tendon length and prevents the transfer.

Table 1

<table>
<thead>
<tr>
<th>Tibialis Anterior Tendon Transfer</th>
<th>Split Tibialis Anterior Tendon Transfer</th>
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</thead>
<tbody>
<tr>
<td>Spastic rearfoot varus12,13</td>
<td>Recurrent clubfoot10,12–14</td>
</tr>
<tr>
<td>Spastic equinovarus12,13</td>
<td>Flexible forefoot equinus12,13</td>
</tr>
<tr>
<td>Excessive inversion power12</td>
<td>Dynamic forefoot supinatus13</td>
</tr>
<tr>
<td>Forefoot equinus with swing-phase extensor substitution12</td>
<td>Dropfoot12</td>
</tr>
<tr>
<td>Flexible cavovarus12</td>
<td>Tarsometatarsal amputation12</td>
</tr>
<tr>
<td>Excessive supination in gait12</td>
<td>Charcot–Marie–Tooth deformity12,14</td>
</tr>
<tr>
<td>Dorsiflexor weakness12</td>
<td></td>
</tr>
</tbody>
</table>

In rigid deformity indications, the tendon transfer should be performed in conjunction with bony procedures. Data from Refs.10,12–14
of the distal end laterally. In rigid deformities, the procedure should not be performed in isolation.

**SURGICAL TECHNIQUE**

**Preoperative Planning**

Detailed preoperative planning is critical to proper deformity correction. The information garnered can be used to identify the underlying pathology as well as the origin and cause of the deformity. As part of the preoperative planning process, a thorough patient history and clinical examination should be conducted. The patient’s pain, sensory deficits, and ambulatory status should be taken into consideration. The clinical examination should include both a static evaluation of foot position and a dynamic evaluation with gait analysis. Tools are available to enhance the study of patient biomechanics. For example, dynamic pedobarography can be employed to measure the pressure distribution patterns during gait, instrumented 3-dimensional gait analysis provides visualization of foot movements in all 3 planes, and electrophysiologic examination can assist in the detection of muscle or nerve dysfunction.

Muscle strength of the tibialis anterior must be accurately quantified. An initial strength of 4+ or greater is required to retain functionality, as one grade of muscle strength is typically lost following tendon transfer (Table 2). Weight-bearing lateral and anteroposterior radiographs of the foot and ankle should be obtained. In cases of severe deformity, additional studies, such as magnetic resonance imaging or computed tomography, may be necessary to evaluate the deformity fully. These imaging modalities will allow the surgeon to identify any superimposed bony deformities that may require correction during the index procedure.

Kuo and colleagues suggest that the most appropriate point of fixation is the lateral cuneiform in the full tendon transfer and the cuboid bone in the split tendon transfer.

<table>
<thead>
<tr>
<th>Table 2</th>
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<tbody>
<tr>
<td><strong>Evaluation of muscle strength. A 4+/-5 or a 5/5 muscle strength is required for successful transfer.</strong></td>
</tr>
<tr>
<td><strong>Grade</strong></td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>4+</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>4-</td>
</tr>
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<td>3+</td>
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<td>1</td>
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<td>0</td>
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</tbody>
</table>

transfer. This is not a hard-and-fast guideline, because selection of the anchoring bone is based on clinical evaluation, particularly the strength of the peroneals and the amount of correction necessary to balance the foot. The greater the correction, the more laterally the fixation must be placed.

As stated by Lampasi and colleagues,11 “in feet with a rigid or partially correctable deformity, transfer of the [tibialis anterior tendon] should not be expected to provide much improvement, except for reduction of adduction in more flexible feet, and correction should be provided by other procedures.” For this reason, the transfer of the tibialis anterior tendon is rarely performed in isolation. Most commonly, a gastrocnemius recession is required to address equinus deformity.12,13 If spasticity of the posterior tibial tendon exists, a myotendinous lengthening may be necessary to reduce associated heel varus.18 Fixed deformities may require calcaneal osteotomy, subtalar or triple arthrodesis, extensor tendon lengthening, or tenotomies for digital correction. These procedures should always be considered during the preoperative evaluation.

Despite an overwhelming acceptance of the procedure, there is no defined temporal indication. It is generally agreed that transfer of the tendon alone or with a gastrocnemius recession may be more effective in children, whereas bony procedures are often required in older patients. In any event, a comprehensive operative approach is needed, tailored specifically to the deformity and the patient.

**Preparation and Patient Positioning**

Patient positioning must permit exposure to the medial foot, lateral foot, and anterior leg. Therefore, the patient should be supine with an ipsilateral bump to position the leg rectus with the tibial tuberosity forward. A combination of general and regional anesthesia is preferred, but spinal anesthesia can also be used. A pneumatic thigh tourniquet is insufflated after exsanguination of the lower leg.

**Operative Approach**

A 3-incision approach is used for both the tibialis anterior tendon transfer and the STATT, with incision placement as follows (Fig. 1):

1. Dorsal–medially on the foot overlying the tibialis anterior tendon insertion at the medial side of the medial cuneiform and base of the first metatarsal;

![Fig. 1. Incision placement for transfer of the tibialis anterior tendon. Incisions 1 and 2 provide exposure to the tendon (A), whereas incision 3, located laterally on the dorsal aspect of the foot, represents the point of tendon stabilization (B). The technique shown provides stabilization through fixation into the lateral cuneiform.](image)
2. Anteriorly within the lower leg, just proximal to the extensor retinaculum; and
3. Dorsal–laterally on the foot, overlying the lateral cuneiform or cuboid.

**Operative Procedure**

**Tibialis anterior tendon transfer**

The sheath is incised in a linear fashion (incision 1; [Fig. 2]). The tendon is identified and sharply released from its insertion. Through the incision on the anterior leg (incision 2), the tibialis anterior tendon is identified and gently pulled proximally along its sheath through the incision. The end of the tendon is “tagged” with a suture in a whip-stitch fashion. A tendon passer is inserted through the dorsal-lateral foot incision (incision 3), and retrieved through the anterior leg (incision 2). Care must be taken to ensure that the tendon passer remains within the long extensor sheath, underneath the extensor retinaculum. The tendon is retrieved and delivered through the dorsal–lateral

![Fig. 2](image-url)

**Fig. 2.** Complete tibialis anterior tendon transfer. The tendon is identified and isolated through incisions 1 and 2 (A). The tendon is released completely from its insertion point through incision 1 (B) and drawn out through the anterior lower leg incision (incision 2; C). The end of the tendon is whipstitched and retrieved with the use of a hemostat from incision 3 underneath the extensor retinaculum (D, E).
foot incision. The tendon is then secured to the lateral cuneiform or the cuboid to appropriately balance the foot. Two methods of fixation exist.

- **Interference screw (Fig. 3):** A guidewire is placed from dorsal to plantar through the anchoring bone and retrieved through the plantar aspect of the foot. The tendon is sized, and the appropriate reamer for the interference screw is used over the previously placed guidewire. The tendon is passed through the prepared canal and out the plantar aspect of the foot. The foot is held in neutral dorsiflexion with slight eversion while appropriate physiologic tension is placed on the tendon. The interference screw is advanced from dorsal to plantar, securing the tendon. The suture is cut flush with the plantar aspect of the foot.

- **Tendon anchor (Fig. 4):** A tendon anchor of the surgeon’s choice is placed from dorsal to plantar into the anchoring bone. The suture attached to the anchor is used to secure the tendon to the bone using a suture technique of the surgeon’s choice. Excess tendon must be trimmed before suturing. To ensure that the appropriate amount of tendon is trimmed, the foot is held in neutral dorsiflexion with slight eversion, appropriate physiologic tension is placed on the tendon, and the tendon is trimmed accordingly.

![Fig. 3. Stabilization of the tendon with an interference screw. A: Guidewire for the appropriate sized interference screw is placed from dorsal to plantar through the anchoring bone exiting the plantar foot. This technique shows stabilization into the lateral cuneiform. B: The corresponding reamer is used over the guidewire, and the tendon is passed through the prepared hole exiting the plantar foot. C: With the foot dorsiflexed and slightly everted, the tendon is appropriately tensioned and the interference screw is advanced from dorsal to plantar, securing the tendon into the cuneiform.](image-url)
Split tibialis anterior tendon transfer

Similar to the complete tibialis anterior tendon transfer described, the tendon is identified in the dorsal–medial foot and anterior leg incisions (Fig. 5). Once the tendon is identified within the anterior leg (incision 2), the tibialis anterior tendon is incised in a linear fashion. Umbilical tape is thread through the split and retrieved with the use of a tendon passer from proximal to distal, exiting through the medial foot incision (incision 1). This maneuver splits the tendon in half longitudinally. The lateral fibers of the tibialis anterior are released from the insertion point, and the freed portion of the tendon is pulled gently out of the anterior leg incision. The remainder of the procedure mirrors that of the tibialis anterior tendon transfer, as described.

Surgical Closure

After thorough irrigation of the surgical incisions, layered closure is performed in the standard fashion.

Immediate Postoperative Care

Patients are placed in a postoperative splint, with care taken to ensure that the foot is dorsiflexed in a neutral position with slight eversion. Strict non–weight-bearing status is initiated and maintained for 6 weeks. Suture removal occurs between 2 and 3 weeks, based on the extent of edema and incision coaptation.

REHABILITATION AND RECOVERY

Non–weight-bearing begins immediately after surgery. A postoperative splint is applied to maintain the desired foot position and adjusted accordingly over the course of 6 weeks. The patient is then graduated to a controlled ankle motion boot with progressive weight bearing. At this juncture, rehabilitation is initiated. Therapy focuses on tibialis

Fig. 4. Stabilization of the tendon with an anchor. An appropriately sized tendon anchor is inserted into the anchoring bone from dorsal to plantar (A). This technique shows stabilization into the lateral cuneiform. After the tendon is trimmed appropriately, the suture from the anchor is used to secure the tendon to the bone (B). The foot is held in dorsiflexion with slight eversion and appropriate tension is placed on the tendon.
anterior muscle retraining, gait training, and progressive strengthening. The in-phase transfer of the tibialis anterior is beneficial to recovery, because the original function of the tendon is preserved and functional gains can be more rapidly achieved. Return to full activity depends on functional improvements with rehabilitation. Complete functional recovery is typically achieved within three to five months. The rehabilitation course should be altered in accordance with the performance of concomitant procedures. If non–weight-bearing is anticipated beyond six weeks, it is still recommended that the patient begin physical therapy with active, open chain motion, and muscle training.

**COMPLICATIONS**

Morbidity associated with this procedure is relatively low; however, complications can occur. Table 3 provides a list of potential complications.

**CLINICAL RESULTS IN THE LITERATURE**

Tibialis anterior tendon transfers are used to address soft tissue imbalances and instabilities. With nonreducible deformities, however, bony procedures are often needed to
Fig. 5. (continued).

<table>
<thead>
<tr>
<th>Complication</th>
<th>Iatrogenic Factors</th>
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<tbody>
<tr>
<td>Infection</td>
<td>Transfer of the tendon too far laterally\textsuperscript{12} or use of a split</td>
</tr>
<tr>
<td>Overcorrection</td>
<td>transfer over a full transfer\textsuperscript{16}</td>
</tr>
<tr>
<td>Undercorrection</td>
<td>Inappropriate or absence of necessary concomitant procedures</td>
</tr>
<tr>
<td>Instability</td>
<td>Unopposed extensor hallucis longus and peroneus longus</td>
</tr>
<tr>
<td>Muscle necrosis</td>
<td></td>
</tr>
<tr>
<td>Rupture of tendon transfer</td>
<td></td>
</tr>
<tr>
<td>Damage to neurovascular structures</td>
<td></td>
</tr>
<tr>
<td>Transient tenosynovitis\textsuperscript{12,13}</td>
<td></td>
</tr>
<tr>
<td>Cocked-up hallux\textsuperscript{20}</td>
<td></td>
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</tbody>
</table>

\textit{Data from Refs.}\textsuperscript{12,13,16,19,20}
address the structural abnormalities. Consequently, the procedure is often tailored specifically to the deformity and the patient. Further complicating the interpretation of the results, numerous variations of the tibialis anterior tendon transfer have been reported since its initial introduction. Surgeons have described subcutaneous transfer of the tibialis anterior,\textsuperscript{10} transfer through a 2-incision approach,\textsuperscript{21} transfer through a 3-incision approach,\textsuperscript{21} and split transfer.\textsuperscript{22} The tendon can be rerouted above or below the extensor retinaculum\textsuperscript{23} with variable sites of fixation and methods of fixation.\textsuperscript{9,10,14,24,25}

Given the similar indications for the transfer of the tibialis anterior, the complete and split procedures are often used for the management of the same or similar conditions, both providing consistent results. Even so, the two procedures are often examined separately. In 2009, Thompson and colleagues\textsuperscript{10} sought to determine whether subcutaneous tibialis anterior tendon transfer effectively treats recurrent clubfoot and whether the presence of structural deformities influenced the outcomes. Using a subjective rating system, the study confirmed that the tibialis anterior tendon transfer effectively restores muscle balance in recurrent clubfeet with resultant improvements in function. Balance was restored in 87% to 88% of patients with data to suggest that the tibialis anterior tendon transfer may prevent secondary osseous alteration.\textsuperscript{10}

More recently, in 2014, Gray and colleagues\textsuperscript{9} conducted a prospective, comparative study to evaluate the effectiveness of the tibialis anterior tendon transfer at restoring the balance between eversion and inversion strength. The treatment group consisted of children with idiopathic congenital talipes equinovarus indicated for tibialis anterior tendon transfer, and the control group consisted of age-matched children with congenital talipes equinovarus who, after Ponseti casting, were not eligible for tibialis anterior tendon transfer. The study found that the tibialis anterior tendon transfer procedure effectively restored the inversion to eversion balance one year after surgery.\textsuperscript{9} Furthermore, the treatment group demonstrated similar plantar loading, function, and satisfaction outcomes compared with the control group.

The STATT procedure has also demonstrated favorable results. In an initial study, Vogt\textsuperscript{6} evaluated patient outcomes after STATT and found a significant improvement in patient autonomy, demonstrated by an improved ability to ambulate independently and a decreased need to wear orthopedic shoes and orthoses, as well as an increased ability to wear normal shoes. The authors concluded that the procedure is safe and yields good results with minimal complications.\textsuperscript{6} In 2011, Vogt and colleagues\textsuperscript{7} retrospectively evaluated the functional results associated with the STATT procedure. Patients with spastic equinovarus deformity that were treated with the STATT procedure were asked to complete a questionnaire. The results showed a strong relationship between the preservation of deep foot sensitivity and the level of functional autonomy.\textsuperscript{7}

There are a select number of comparative investigations evaluating the complete transfer of the tibialis anterior and the STATT. In 1998, Hui and colleagues\textsuperscript{26} used a cadaveric model to determine if one procedure was more efficacious than the other. Despite the variation in techniques, the two procedures achieved similar maximum dorsiflexion. Also using a cadaver model, Knutsen and colleagues\textsuperscript{21} found that the 2-incision complete transfer, the 3-incision complete transfer, and the split transfer produced varying forefoot pronation and hindfoot valgus motion. Notably, the 3-incision complete transfer and the split transfer demonstrated greater forefoot pronation compared with the 2-incision complete transfer.\textsuperscript{21} Although both studies provide interesting insight, their cadaveric nature limits clinical translation. A cadaveric model cannot take into account the relative imbalance between the invertors and evertors to determine the appropriate amount of correction.
In 2001, Kuo and colleagues\textsuperscript{17} conducted an in vivo study to compare the results of the complete transfer of the tibialis anterior tendon with the STATT in patients with residual dynamic clubfoot deformity. Both techniques provided satisfactory correction of the deformity. Employing Garceau’s criteria, the two groups showed similar results. Moreover, both groups demonstrated a similar increase in dorsiflexion, plantar flexion, eversion, and motion at the tibiotalar joint. However, the STATT group demonstrated better preservation of inversion. With regard to muscle strength, both groups demonstrated similar increases in plantar flexion strength and eversion strength. There was no improvement in dorsiflexion strength for either group. The radiographic analysis revealed similar improvements in the anteroposterior talo-first metatarsal angle, the lateral talo-first metatarsal angle, and the overlap ratio. No significant correction in the lateral first to fifth metatarsal angle was observed for either group.\textsuperscript{17}

Regardless of the operative approach, complete or STATT, the surgeon must decide whether to transfer the tendon above or below the extensor retinaculum. Ezra and colleagues\textsuperscript{23} advocate the transfer of the tendon above the extensor retinaculum. Although this technique is thought to address the deformity appropriately, investigators have theorized that transferring the tendon underneath the retinaculum will decrease the incidence of postoperative transient tendonitis as well as the prominence of the tendon along the anterior leg. For these reasons, the authors advocate the transfer of the tendon beneath the extensor retinaculum.

Throughout the literature, a number of surgeons have described various sites for tibialis anterior tendon stabilization, including the lateral cuneiform, cuboid, and base of the fifth metatarsal. The evidence suggests that the ideal insertion site of the tibialis anterior tendon is onto the third metatarsal axis and the fourth metatarsal axis for the total tendon transfer and the split tendon transfer, respectively.\textsuperscript{26} These sites were identified based on the maximum motion achieved at the foot and ankle, when the tendon was anchored and tension was applied. The same protocol was repeated serially from the second through the fifth metatarsals. As with many operative procedures, however, surgeon preference and the extent of deformity correction necessary often dictate insertion site selection.

Over the last 70 years, multiple methods of fixation have become available. Trephine plugs,\textsuperscript{24} stabilization with a suture button and without osseous fixation,\textsuperscript{9,10} interference screws,\textsuperscript{22} bone anchors\textsuperscript{25} and suture into the peroneus brevis\textsuperscript{14} have proved viable. In a strength comparison, however, interference screws demonstrated superior strength compared with bone anchors for fixation during an STATT procedure.\textsuperscript{25}

Despite a growing body of evidence, there is insufficient evidence to advocate one procedure over another. This is attributable in part to isolated examination of each procedure as opposed to direct comparisons, and in part to slight variations in the techniques and patient populations, which preclude direct comparisons. Be that as it may, many surgeons have described the STATT procedure as more reliable\textsuperscript{12,17} and have recognized the STATT procedure for achieving adequate inversion to eversion muscle balance, presumably reducing the incidence of overcorrection.\textsuperscript{16}

**SUMMARY**

With dynamic deformity correction, restoration of muscle balance can achieve improvements in function and prevent deformity progression. Both the complete transfer and STATT procedures result in similar improvements in ankle and foot range of motion and muscle function. However, the split transfer resulted in better
preservation of the inversion motion. Kuo and colleagues\textsuperscript{17} recognize that both procedures “are an excellent method of correcting residual dynamic clubfoot deformity,” but prefer the split technique under the premise that it is less likely to result in overcorrection. However, considering the results, surgeon preference and patient presentation should dictate procedure selection.

REFERENCES


