

# Tibialis Anterior Tendon Transfer for Residual Dynamic Supination in Treated Clubfoot

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## **Abstract**

Clubfoot is a complex congenital deformity of the foot that may significantly impair mobility and functional activity if inadequately treated. Although the Ponseti method has become the standard treatment for idiopathic clubfoot and achieves satisfactory correction in most patients, residual or recurrent deformities may still develop during follow-up. Dynamic supination is one of the most frequent residual deformities after clubfoot treatment and is typically observed during the swing phase of gait, with the forefoot turning inward and initial contact occurring along the lateral border of the foot. The main etiology of residual dynamic supination is an imbalance between the relatively strong tibialis anterior muscle and its weaker antagonists, particularly the peroneal muscles. Persistent dynamic supination may result in abnormal gait patterns, progressive deformity, functional limitations, and difficulty with footwear. Tibialis anterior tendon transfer is a commonly used surgical procedure designed to restore muscular balance by redirecting the force of the tibialis anterior tendon toward the dorsum of the foot. The procedure aims to correct dynamic supination while preserving ankle dorsiflexion and improving overall foot alignment. Appropriate patient selection, correction of fixed deformities before surgery, accurate tendon positioning, and postoperative rehabilitation are essential for achieving satisfactory clinical and functional outcomes.

**Keywords:** Clubfoot; Residual Dynamic Supination; Tibialis Anterior; Tendon Transfer

## **Introduction**

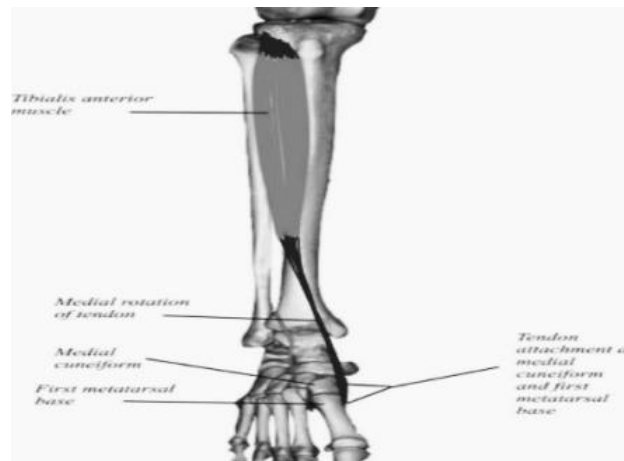
Clubfoot is a complex, congenital deformity of the foot that, if left untreated, can limit a person's mobility by making it difficult and painful to walk.

All populations show a consistent 2:1 male predominance and it occurs bilaterally in approximately 50% of cases. The most frequent residual deformity after treatment of clubfoot is dynamic supination. It is characterized by foot inversion and supination that occurs during the swinging phase of walking while the foot looks normal during standing.

The main etiology of this residual dynamic supination is the muscle imbalance between the strong tibialis anterior muscle and weak antagonists, mainly the peroneal muscles. Tibialis anterior tendon transfer aims to restore muscle balance and correct dynamic supination. The transferred tendon should be fixed centrally on the dorsum of the foot, typically into the lateral cuneiform, to achieve balanced dorsiflexion without overcorrection.

## **Anatomy and Function of the Tibialis Anterior**

The tibialis anterior is a muscle on the front of the lower leg that originates from the tibia and interosseous membrane and inserts onto the medial cuneiform bone and the first metatarsal bone. Its primary actions are dorsiflexion and inversion of the foot, and it is innervated by the deep fibular (peroneal) nerve(1).



**Figure 1. Origin and Insertion of tibialis anterior muscle.**

**Origin:**

- ◆ Lateral condyle of the tibia
- ◆ Proximal two-thirds of the lateral surface of the tibia
- ◆ Interosseous membrane of the leg
- ◆ Deep surface of the fascia cruris (the deep fascia of the leg)
- ◆ Intermuscular septum. (1)

**Insertion:**

- ◆ Medial cuneiform bone
- ◆ Base of the first metatarsal bone. (1)

**Actions:**

The tibialis anterior (TA) is the principal dorsiflexor of the ankle and a key dynamic stabilizer of the medial longitudinal arch.

Located in the anterior compartment of the leg, it plays a fundamental biomechanical role during walking by controlling foot position at heel strike, ensuring toe clearance during swing, and modulating plantarflexion after initial contact. (2)

- ◆ **Dorsiflexion:** Moves the foot upward, closer to the shin.
- ◆ **Inversion:** Turns the sole of the foot inward.
- ◆ **Support:** Helps support the medial longitudinal arch of the foot. (1)

**Innervation:**

- ◆ Deep fibular (peroneal) nerve
- ◆ Spinal nerve roots L4, L5, and S1. (1)

**Blood supply:**

Anterior tibial artery.(1)

**Definition and Etiology of Clubfoot**

**Definition:**

Traditionally, the definition of congenital clubfoot has been descriptive where the heel is inverted, the forefoot and midfoot are adducted, and the ankle is in equinus position.

However, the definition should be specific based upon the pathologic findings, which is medial and plantar displacement of the talocalcaneonavicular ball and socket joint. (3, 4)

**Incidence:**

The incidence of clubfoot varies widely with respect to race and geography. In Japan, this condition affects approximately 0.5 per 1,000 live births, while in natives of the South Pacific, the incidence is nearly 7 per 1,000 live births. In all Caucasians, the incidence is 1.2 per 1,000 live births. (5, 6)

All populations show a consistent 2:1 male predominance and occurs bilaterally in approximately 50% of cases. (5, 6)

First-degree relatives are at an increased risk compared with the general population. A sibling of a patient has a 2% to 4% chance of having clubfoot. (7)

If a child and another family member, or both parents, have clubfoot, the risk in another child increases by 10% to 20%. The more members of a family who are affected, the higher the risk of the condition occurring in other siblings, but the risk decreases significantly in second- and third-degree relatives. (7)

**Etiology:**

The exact cause of idiopathic talipes equinovarus (club foot) is unknown. There are many theories which explain the cause of clubfoot without a clear support to any one of them.

**Etiological theories:**

Hippocrates was the first to document a hypothesis to explain the etiology of congenital talipes equinovarus (club foot). He proposed that the fetal foot was forced into equinovarus posture by external mechanical forces. Today a number of hypotheses remain, and research findings do not clearly support any particular one. (5)

Proposed mechanisms are: (8)

- Uterine restriction.
- Abnormalities of joint and/or bone formation.
- Distal limb vasculature.
- Neurological development.
- Muscle migration or an underlying developmental abnormality.
- Developmental arrest.

During late human limb development (9–38 weeks), chondrification of the foot is completed, joint cavitation and ligament formation is completed, and the distal limb rotates medially. This rotation allows the sole of the foot to be placed flat on the ground, rather than being orientated with the sole facing inwards, as is seen in feet in the late embryonic period (and in the hand throughout). Pronation continues beyond birth and into postnatal development. (9)

In 1929 Bohm described the four stages in evolution of the human foot (10) (Figure 2)

### First stage (Second month):

The form of the foot is characterized by marked equinus (about 90 degree) and severe adduction of the forefoot, with the navicular lying in close proximity to the medial malleolus.

### Second stage (Beginning of the third month):

The foot rotates and is characterized by marked supination but remains in 90 degrees of plantar flexion. The first metatarsal is markedly adducted and the lateral four metatarsals are also adducted but to a lesser extent.

### Third stage (Middle of the third month):

The equinus inclination decreases to a mild degree, but the marked supination and metatarsus varus persist.

### Fourth stage (Beginning of the fourth month):

The foot is in mid-supination and there is slight metatarsus adduction. In this stage, the foot plate begins to rotate toward pronation on its long axis.

Bohm observations led him to conclude that a severe clubfoot resembles an embryonic foot at the beginning of the second month and the deformity is accompanied by underdevelopment of the bones and muscles.(10)

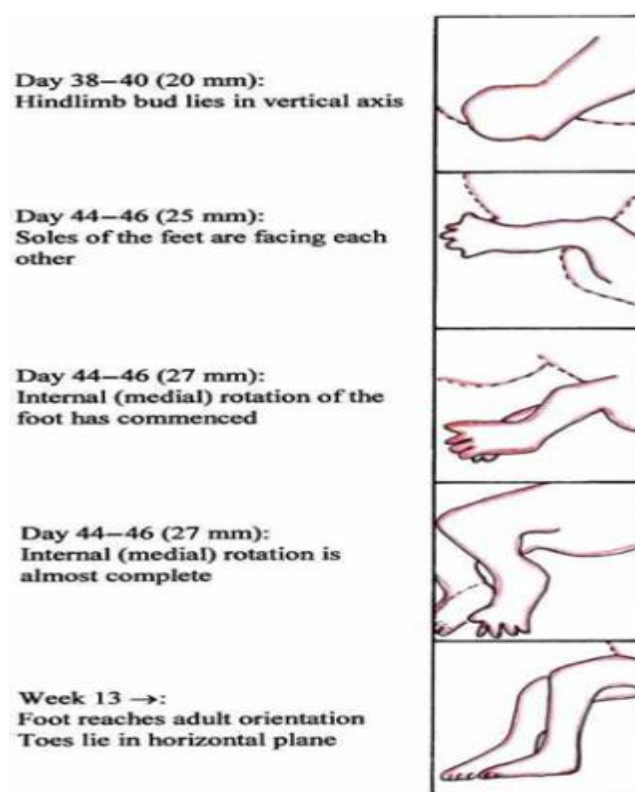


Figure 2. Development of the human foot. (9)

### Pathological Changes in Clubfoot

#### Pathological anatomy:

The pathological anatomy of idiopathic clubfoot was first described in 1818 by Scarpa who assumed that the osseous deformities of the talus is the primary cause whereas shifting of the other tarsal bones around the talus is secondary. (11)

The anatomy of the clubfoot is best understood by studying fetuses of different ages and babies after birth.

### Bony changes:

#### Navicular:

The navicular may have a normal shape but in severe cases it is wedged in shape. In all cases of clubfoot, the navicular is medially displaced and its tuberosity is large and very close to the medial malleolus. (12) (Figure 3)

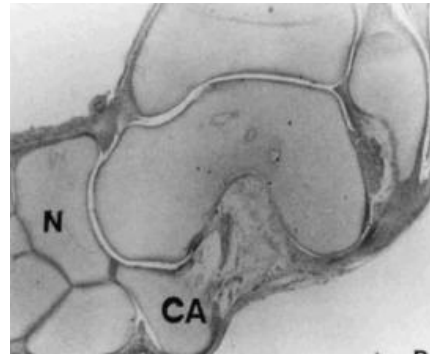


Figure 3. Wedge shaped navicular bone. (12)

#### Talus:

In all clubfeet, the talus is in severe flexion. Its body is small and altered in shape with decreased trochlea height and only the posterior part articulates with the ankle mortise. (12)

In severe cases, the posterior surfaces of the lower end of both the tibia and the fibula are in contact with the superior aspect of the posterior tuberosity of the calcaneus. Therefore, the posterior part of the body of the talus, which is not covered by joint cartilage, is intra-articular. (13)

The neck of the talus is short and wedge like, lacking its normal “waist”. It is also medially and plantarly directed. (12)

The talar neck-trochlea angle of clubfeet in comparison with normal feet was mentioned by Gunther, Irani, Howard, Waisbrod and Schlicht. Gunther found this angle ranged between 37 and 41 degrees. Irani found this angle to be up to 65 degrees, in Waisbrod's study it ranged between 30 and 46 degrees, and Howard measured 90 degrees in the most severe clubfoot. In the eight clubfoot specimens in Schlicht's study, the angle ranged between 40 and 55 degrees. (11, 14, 15, 16, 17, 18) (Figure 4)

Straus showed in a study that the talar neck–trochlea angle narrows steadily during fetal development. In the 4th month of gestation, the mean angle in normal foot is 33.4 degrees, which decreases to 26.5 degrees in newborn. (19)

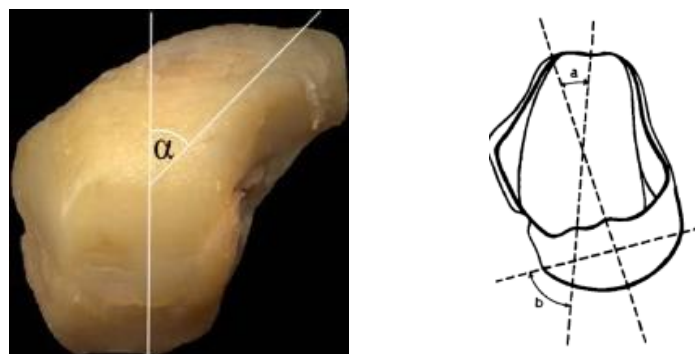


Figure 4. Neck trochlea angle (11, 12). Medial deviation of the talar neck Angle ( $\alpha$ ) (between the axis of the trochlea and the neck).

The neck of talus is directed anteromedially and downward. In a sagittal plane, the neck is deviated downward in relation to the body, and in clubfeet the inclination angle ranged from 28 to 43 degrees; in the normal feet it is 22 to 24 degrees. (Figure 5)

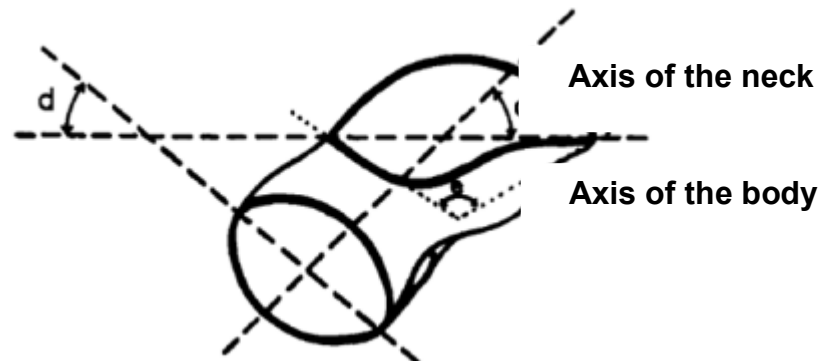


Figure 5. Inclination angle of neck talus. (11, 12)

The head is wedge-shaped with two surfaces: (20)

1. The anterolateral surface, left uncovered by the displaced navicular and is covered only by the stretched joint capsule and the skin;
2. The anteromedial surface articulates with the navicular.

Calcaneus: (Figure 6)

The body of the calcaneus is in severe flexion and slightly medially directed. In some cases it is of the same length and in others it is longer than the normal calcaneus. (13)

The calcaneus is adducted and inverted under the talus, and most of the anterior tuberosity of the calcaneus is under the head of the talus and not lateral to it as it is in normal feet. The longitudinal axes of the talus and the calcaneus are parallel unlike in normal feet. (13)

Instead of the typically saddle shaped posterior talar articular surface, the joint surface becomes triangular. In severe clubfeet, the articular surface for the cuboid is flat and medially twisted in relation to the longitudinal axis of the calcaneus; also, it is orientated upwards. (11)

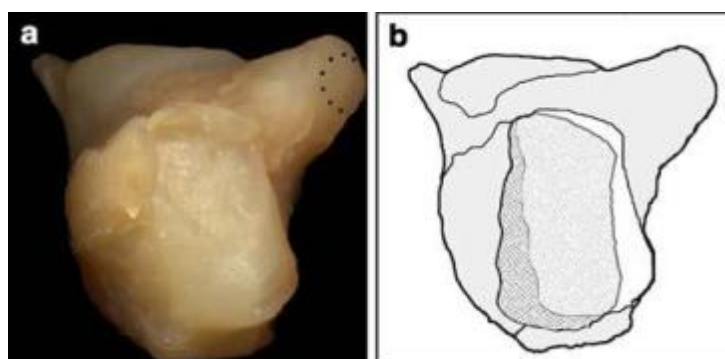


Figure 6. Anterior view of left calcaneus. (11) The articular surface for the cuboid is marked nearly white, whereas the normal orientated joint is highlighted grey.

#### Cuboid and Cuneiforms:

The cuboid and cuneiforms usually has normal shape but always adducted. (11, 13)

### Ligaments and tendons:

The soft tissues on the posteromedial aspect of the foot and ankle are shortened. All the components of the tissues participate in shortening (ligaments, capsules, muscles, tendons, tendon sheaths). The tibialis posterior tendon becomes very large and its sheath is very thick. (11, 13, 19)

Around the ankle, the tendons of the tibialis anterior, extensor digitorum longus, and extensor hallucis longus become severely displaced medially. (13, 19)

All the medial tarsal ligaments including the tibionavicular, calcaneonavicular and deltoid ligaments become very thick and shortened. (13) (Figure 7)

Laterally, the calcaneocuboid ligaments are normal while the calcaneofibular ligament is thick and short. (13, 21)

Inferiorly, the plantar fascia is thick while the long plantar ligaments are only slightly hypertrophic. (13)

The posterior segment of interosseous talocalcaneal ligament is more thickened than the anterior part and all the ligaments of the inferior tibiofibular syndesmosis become very thick. (13, 18)

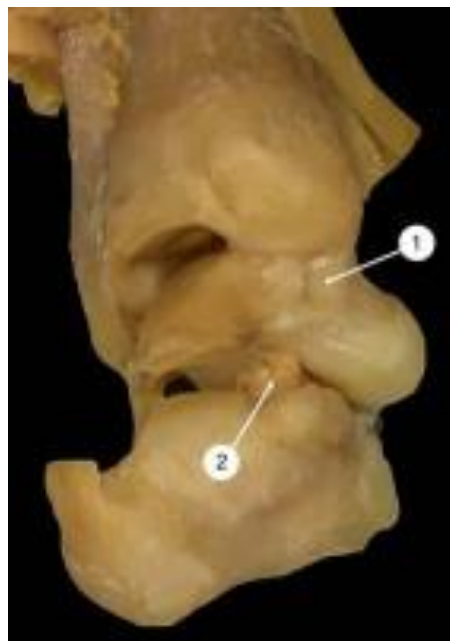


Figure 7. Posteromedial view of a left clubfoot specimen. (19), 1. Anterior and posterior tibiotalar part of the deltoid ligament, 2. Talocalcaneal interosseous ligament.

### Joints:

- The talus is firmly fitted in the ankle mortise. The navicular is medially directed with its tuberosity is nearly in contact with the medial malleolus. (11, 13)
- The talocalcaneal articulation is abnormal. (13)
- The anterior joint is very narrow or absent, whereas the middle is small.
- The medial facet of the calcaneus lies vertically, so that with the inverted calcaneus, the subtalar joint is sagittally instead of being coronally oriented.
- The calcaneocuboid joint is deformed in some clubfeet. The deformity occurs due to medial subluxation of the cuboid on calcaneus. (21)

- A system to assess the alignment of the calcaneocuboid joint is made on anteroposterior radiographs. Parallel lines are drawn on the calcaneus through the mid- longitudinal axis and along the medial border of the calcaneus (medial tangent line). (21) (Figure 8):
- When there is no malalignment, the midpoint of the cuboid ossification center situated on the longitudinal axis of the calcaneus.
- Grade I deformity occurs when the midpoint of the cuboid lies between these two parallel lines of the calcaneus.
- Grade II deformity occurs when the midpoint of the cuboid lies medial to the medial tangent line of the calcaneus.

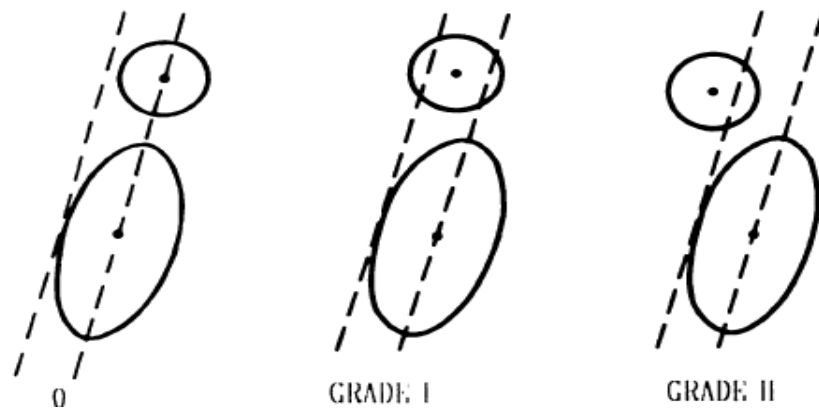


Figure 8. Grading of calcaneocuboid joint deformity in club foot. (21)

### Diagnosis and Classification of Clubfoot

#### Antenatal diagnosis:

Congenital talipes equinovarus can be diagnosed antenatally by ultrasound. (Figure 9)

There is a huge variation in the reported accuracy regarding ultrasound. A recent study found that the diagnosis of clubfoot by ultrasound had a positive predictive value of 83% with a false positive rate of 17%. Another study found that the false-positive rate was higher for unilateral (29%) than for bilateral clubfoot (7%). (22, 23)

Bar Hava et al. described a transient deformity in the early weeks of gestation resembling clubfoot which was contributed to late maturation or high flexibility of the fetal limb muscles at this stage. Ultrasound scans at 20 to 24 weeks may be more reliable for the diagnosis than those taken earlier. (24, 25)



Figure 9. Antenatal ultrasound showing fetal clubfoot.

### Clinical Features:

Clubfoot is characterized by equinus of the hindfoot, varus (or inversion) of the subtalar joint complex, cavus, and adductus of the forefoot. (26, 27)

It is difficult to miss a true case of clubfoot in a newborn. The classic appearance of the heel in marked equinus, with the inverted foot is difficult to be mistaken for anything else. Lack of correctability with absence of deep skin creases differentiates this true clubfoot from the milder postural clubfoot. (26, 27)

There is a single (occasionally double) posterior skin crease. The calcaneus (which is occasionally smaller in size) is difficult to be palpated within the fatty heel pad. A deep transverse skin crease crosses the midfoot and extends under the longitudinal arch. (26) (Figure 10)

The head of the talus can be palpated on the dorsolateral aspect of the midfoot/hindfoot just anterior to the ankle joint. This can be contributed to excessive inversion of the subtalar joint complex around the talus. (26, 27)

The severity of metatarsus adductus is measured with the use of the heel bisector method applied to a photocopy of the child's foot in the weight bearing position. But the severity does not correlate with prognosis. (20, 28) (Figure 11)

The foot and calf are smaller than the contralateral side. Little and Aiona noticed that leg-length discrepancy greater than 0.5 cm presents in 18% of children with unilateral clubfoot and in 4% with bilateral deformities. The tibia is short in 89% and the femur is short in 43% of children with unilateral deformity with limb length discrepancy. (29)

In addition, it is also essential to search for associated anomalies and neuromuscular conditions that define a non-idiopathic deformity. (26, 27)

The prognosis for a non-idiopathic and syndromic clubfoot is generally worse than that for an idiopathic clubfoot, although there are certain exceptions, such as Down syndrome or Larsen's syndrome. In these syndromes, due to the significant ligamentous laxity underlying the syndrome itself, correction may be achieved with non-operative treatment. (27)

On the other hand, patients with arthrogryposis, diastrophic dysplasia and spina bifida have clubfeet that are resistant for correction and show severe recurrence rate. (27)

Examination of the hips in a newborn is also an important part of the musculoskeletal examination, but there is no reported increased risk for developmental dysplasia of the hip in children with clubfoot.



Figure 10. Clubfoot (left) with single heel crease and normal foot (right) with multiple heel creases. (26)

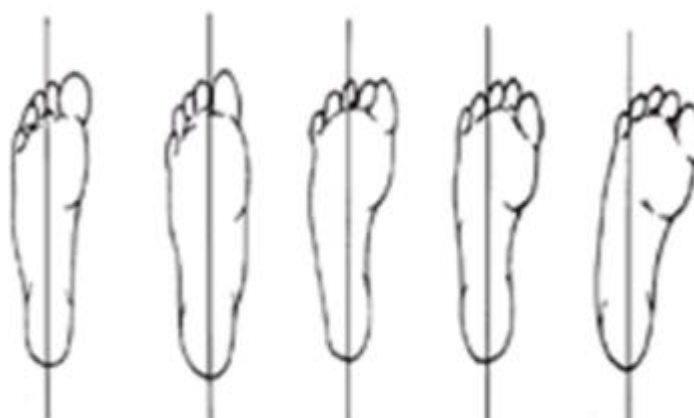


Figure 11. The heel bisector method. (28)

The severity of metatarsus adductus is determined by the relationship between the toes and the distal end of the line bisecting the heel.

#### Imaging:

Imaging in clubfoot has a limited role but it enables to understand how treatment modalities work and to assess their results.

Ultrasound and MRI also can be used to visualize the non-ossified parts of the skeleton.

#### Plain radiography:

Radiographs are useful tools for assessing alignment disorders of the foot. (30)

Malalignment of the bones of the foot may present a complex diagnostic problem for radiologists. Analytical radiography is a method for studying the four major deformities of clubfoot. (30, 31)

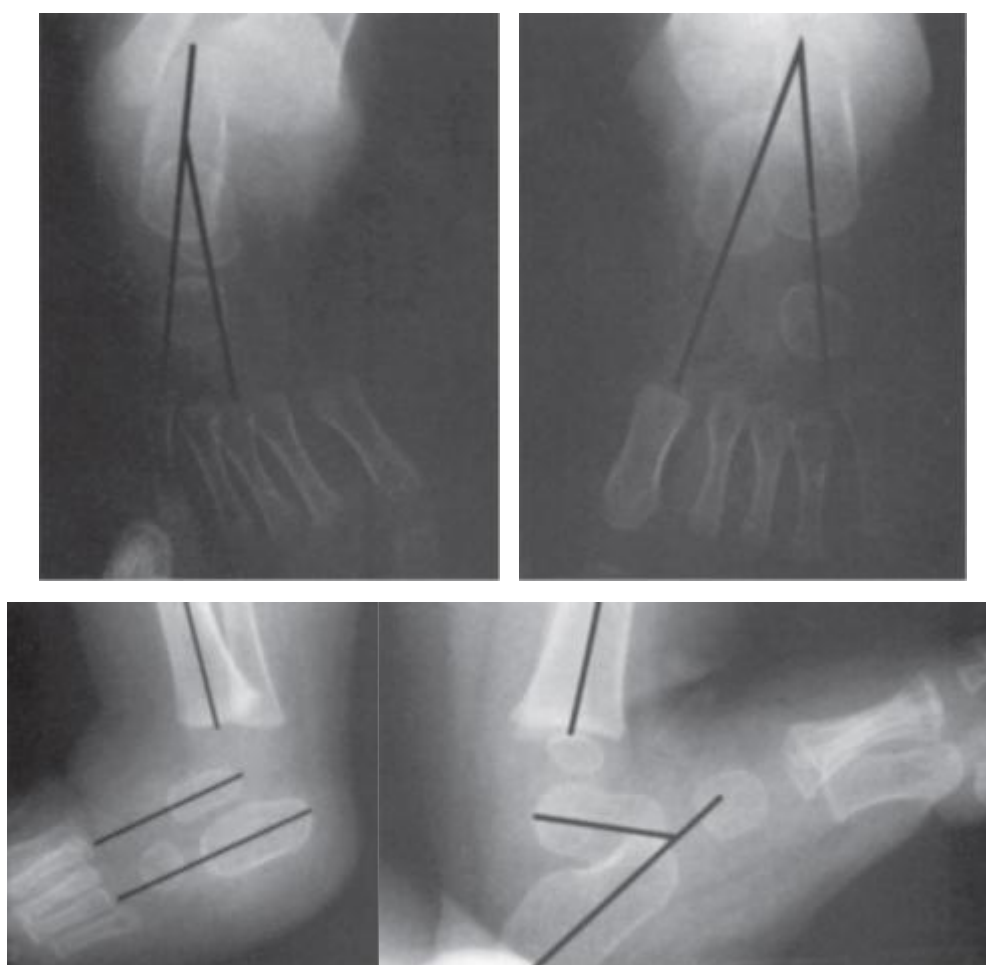
Important angles to consider in the evaluation of clubfoot are the talocalcaneal angle on the anteroposterior radiograph and, on the lateral radiograph, the talocalcaneal angle, the tibiocalcaneal angle, and the talus–first metatarsal angle (Figure 1). The anteroposterior talocalcaneal angle in normal children ranges from 30 to 55 degrees (Table.1). In clubfoot, this angle progressively decreases with increasing heel varus. On the dorsiflexion lateral radiograph, the talocalcaneal angle in a normal foot varies from 25 to 50 degrees; in clubfoot, this angle progressively decreases with the severity of the deformity to an angle of 0 degrees, or parallelism. The tibiocalcaneal angle in a normal foot is 10 to 40 degrees on the stress lateral radiograph.

In clubfoot, this angle generally is negative, indicating equinus of the calcaneus in relation to the tibia. Finally, the talus–first metatarsal angle is a radiographic measurement of forefoot adduction. This is useful in the treatment of metatarsus adductus alone but is equally important in the treatment of clubfoot to evaluate the position of the forefoot. In a normal foot, this angle is 5 to 15 degrees on the anteroposterior view; in clubfoot, it usually is negative, indicating adduction of the forefoot. <sup>(50-54)</sup>

**Table 1. Progression of Foot Angles in Normal Feet Over Average 6-Year Follow-Up**

| Angle                       | Average First Visit (Degrees) | Average Last Visit (Degrees) |
|-----------------------------|-------------------------------|------------------------------|
| <b>Anteroposterior View</b> |                               |                              |
| Talocalcaneal               | 36.3                          | 27.4                         |
| Calcaneal–second metatarsal | 14.4                          | 12.3                         |
| Talus–first metatarsal      | 16.9                          | 8.1                          |

| Lateral View               |      |      |
|----------------------------|------|------|
| Talocalcaneal              | 46   | 44.2 |
| Calcaneal–first metatarsal | 150  | 148  |
| Tibiocalcaneal             | 61.5 | 73.2 |
| Talus–first metatarsal     | 16.3 | 12.1 |
| Talocalcaneal index        | 83   | 71.6 |



**Figure 12. Radiographic evaluation of clubfoot. A, Anteroposterior view of right clubfoot with decrease in talocalcaneal angle and negative talus–first metatarsal angle. B, Talocalcaneal angle on anteroposterior view of normal left foot. C, Talocalcaneal angle of 0 degrees and negative tibiocalcaneal angle on dorsiflexion lateral view of right clubfoot. D, Talocalcaneal and tibiocalcaneal angles on dorsiflexion lateral view of normal left foot.**

#### Ultrasonography:

Sonography has become a promising imaging modality for musculoskeletal problems due to it is dynamic and due to its capability and visualization of cartilaginous structures and soft tissues. Also being radiation free, it can be repeatedly performed for monitoring response to treatment. (32)

Four standardized projections are usually taken: medial, lateral, dorsal and posterior. All measurements are obtained in neutral position and in maximum correction using simulated Ponseti maneuver. (32, 33)

### Magnetic Resonance imaging (MRI):

Recent MRI studies have enlightened the pathological abnormalities of club foot to some extent. Downey et al., described MR images in patients with idiopathic clubfoot. They also measured abnormalities of the calcaneus and talus in the transverse plane. MRI can be very helpful in visualizing the anatomy of the deformity in club foot. It gives useful information in the assessment process of the severity of the deformity and the choice of treatment modalities. (34, 35)

### Classification of congenital clubfoot:

Many classification systems are widely used in orthopedic practice for the assessment and classification of patients and comparison of treatments. (36)

It is important to be able to differentiate between various forms of congenital talipes equinovarus. Classification is difficult because the deformity is complex and partly dynamic. (36)

Many classification systems have been proposed to address this problem. An ideal system should be: (36)

1. Reliable and reproducible.
2. Account for the three-dimensional characteristics of the deformity, also simple enough to be applied in practice.
3. Include separate information for the hind foot, midfoot and forefoot as the severity of the deformity may differ at each level.
4. Include information about the flexibility and rigidity of the deformity.
5. Comprehensive enough to be usable before, during and after treatment and in children of all ages.
6. Finally, treatment should be determined by the classification with reference to the different elements of the deformity, and it should predict the prognosis of the deformity and treatment at any stage and be used to compare the results of treatment.

The systems of Ponseti and Smoley (37), Harrold and Walker (38), Catterall (39), Diméglio et al. (40) and Pirani (41) are the most commonly used.

Ponseti and Smoley classification: (37)

Ponseti and Smoley conducted the results of treatment of congenital talipes equinovarus. Their classification system is based on ankle dorsiflexion, heel varus, forefoot adduction and tibial torsion. Feet are classified on these basis as good, acceptable or poor. (Table 2)

**Table 2. The Ponseti and Smoley classification system**

| Ankle dorsiflexion | Heel varus | Forefoot Adduction | Tibial torsion | Result     |
|--------------------|------------|--------------------|----------------|------------|
| >10°               | 0°         | 0° to 10°          | 0°             | Good       |
| 0° to 10°          | 0° to 10°  | 10° to 20°         | Moderate       | Acceptable |
| 0°                 | >10°       | >20°               | Severe         | Poor       |

The system of Ponseti and Smoley was devised to assess the results of treatment of congenital talipes equinovarus.

The implication is that if one of the measurements of deformity is normal all measurements will be normal and the foot is therefore (good). This is not always the case, since one component of the deformity may be more severe than others. (36)

The authors did not give a method of classifying a foot which has different degrees of deformity in any of the four components. (36)

Harrold and Walker classification: (38)

Harrold and Walker consider the ability to correct the deformity.

**Grade 1:** The foot can be held at or beyond the neutral position,

**Grade 2:** There is fixed equinus or varus of  $<20^\circ$

**Grade 3:** There is fixed equinus or varus of  $>20^\circ$

Harrold and Walkers system was based on the first visit examination of the foot and the estimated angle of fixed inversion and fixed equinus when firm pressure, insufficient to cause pain, was applied towards the everted and dorsiflexed position.

This simple system partly quantifies the ability to correct the deformity. It may appear that this straightforward system will produce the most consistency, but reliability was not satisfactory. (36)

Catterall classification: (39)

Catterall describes four patterns depending on the evolution of the deformity which is classified as resolving, caused by tendon or joint contracture, or secondary to a false correction. Several clinical features are used for this classification. (Table 3)

**Table 3. Catterall classification system**

| Foot                     | Resolving<br>Pattern | Tendon<br>contracture | Joint<br>Contracture | False<br>correction |
|--------------------------|----------------------|-----------------------|----------------------|---------------------|
| <b>Hindfoot</b>          |                      |                       |                      |                     |
| <b>Lateral malleolus</b> | Mobile               | Posterior             | Posterior            | Posterior           |
| <b>Equinus</b>           | No                   | Yes                   | Yes                  | Yes                 |
| <b>Creases</b>           |                      |                       |                      |                     |
| - Medial                 | No                   | No                    | Yes                  | No                  |
| - Posterior              | No                   | Yes                   | Yes                  | Yes                 |
| - Anterior               | Yes                  | No                    | No                   | Yes                 |
| <b>Forefoot</b>          |                      |                       |                      |                     |
| <b>Lateral border</b>    | Straight             | Straight              | Curved               | Straight            |
| <b>Mobile</b>            | Yes                  | Yes                   | No                   | Yes                 |
| <b>Cavus</b>             | +/-                  | +/-                   | +/-                  | No                  |
| <b>Supination</b>        | No                   | No                    | Yes                  | No                  |

There is poor to slight agreement when this system is used. It may be necessary to have specific training in the application of this system before it can be used. (36)

Diméglio classification: (40)

The system of Diméglio et al was derived from a detailed scoring system based on the measurement of four parameters: (Figure 2)

- 1) Equinus in the sagittal plane.
- 2) Varus deviation in the frontal plane.
- 3) De-rotation of the calcaneoforefoot block around the talus.
- 4) Adduction of the forefoot on the hindfoot in the horizontal plane.

The scale includes four additional points for the presence of medial creases, a posterior crease, cavus and poor calf musculature.

From the score, which has a maximum of 20 points, the deformity can be graded as benign, moderate, severe or very severe.

The grading system of Diméglio is found to produce moderate to substantial agreement with very good inter-observer reliability. (36)

Pirani classification: (41)

The classification is designed of: (Figure 3)

1. Midfoot score (curvature of the outer edge of the foot, medial fold and lateral part of the talar head) and
2. Hindfoot score (dorsal fold, palpability of the calcaneal tuberosity and rigidity of the equinus deformity).

**Each parameter is rated as follows:**

0= normal; 0.5= slightly abnormal and 1= abnormal.

The classification is particularly suitable for monitoring the progress of treatment of clubfoot and timing of the need for Achilles tendon lengthening which is indicated if the midfoot score is less than 1.

Although the Dimeglio system is found to be the most reliable, the Pirani classification is more commonly used in association with the Ponseti treatment.

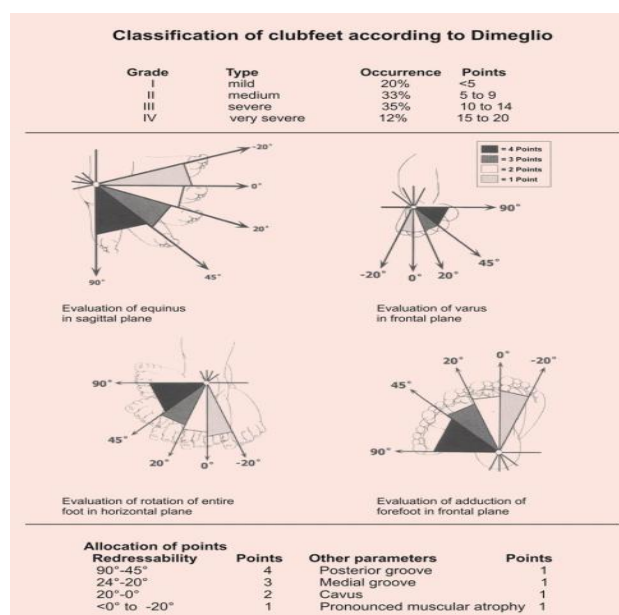
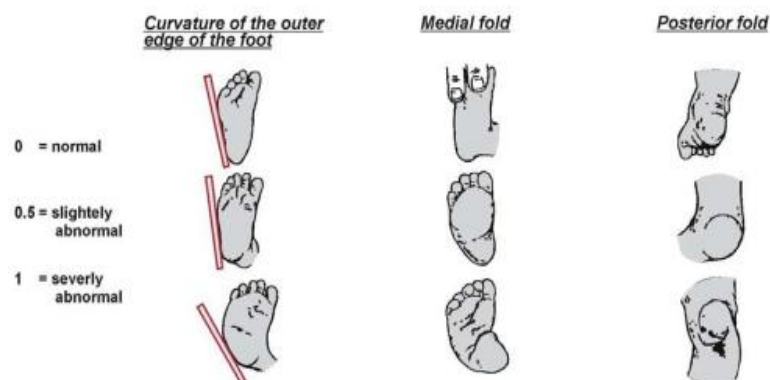
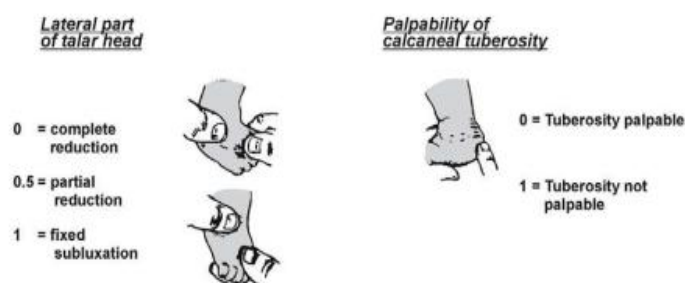


Figure 13. Diagrams of the evaluation of congenital talipes equinovarus used by Diméglio. (40)

## SEE



## FEEL



## MOVE



Figure 14. Pirani scoring system. (41)

### Treatment of Clubfoot

Congenital clubfoot is a complex deformity that is difficult to be corrected. It has a tendency to recur until the age of six or seven years.

The goal of any treatment modality is to eliminate the deformities so that the patient has a functional, pain free, plantigrade foot with good mobility. (42)

### Non-surgical Management:

Nearly all authors agree that initial clubfoot treatment should be conservatively, regardless of the severity of the deformity. Early operative treatment often results in reduced motion of the ankle and foot, on the other hand manipulation and the application of plaster casts with proper techniques would lead to greater mobility and less disability. So the successful non-operatively treated clubfoot is much better than the successful surgically treated foot. (65 - 69)

### **Ponseti technique:**

Patho-anatomy and technique of manipulation: (42, 43)

The patho-anatomy of the clubfoot must be understood before the manipulation and reduction make sense. The talus is locked in equinus in the ankle mortise by the tight tendoachilis while the tarsal bones distal to the talus are adducted and inverted and the midfoot has a cavus position as a result of pronation on the hindfoot, mainly because of plantar flexion of the first metatarsal. (42, 43)

To reduce this anatomy, the tarsal bones must be abducted with the foot in supination and all three hindfoot joints remodeled congruently. (Figure 4)

Infants are treated as soon as possible after birth. At first dorsally directed pressure on the first ray reduces the cavus, which is caused by plantarflexion of the first metatarsal. This seems more deforming; the first cast appears to be more exaggerating to the deformity, because the foot is supinated in relation to the leg. (42, 43)

From the second cast, firm pressure on the lateral head of the talus keeps it stable in the ankle mortise while the forefoot distally is abducted. The basic tenet of this technique is never touching the calcaneus during manipulation. Ponseti referred to this as Kites error, because Kite advocated counter pressure at the calcaneocuboid joint level while manipulating the forefoot. Lateral pressure on the calcaneus prevents its abduction and its rolling out from underneath the talus to reduce the heel varus and, later, the equinus. (43, 44)

Simultaneously, the navicular reduces plantarly and laterally in front of the head of the talus, the cuboid slides and moves in front of the calcaneus, and the calcaneus rolls laterally out from underneath the talus.

The reduction is gradual, with stretching of the tarsal ligaments, and is maintained by casting. The foot is reduced into its corrected position without undue force or bone and cartilage damage.

The calcaneus is ready to be dorsiflexed when the foot is abducted approximately 70 degree externally.

The typical number of manipulation and casts held until correction or tenotomy is three to seven. Infants older than 6 months and those having prior treatment usually take longer time and more casting sessions for correction. (44)

An accelerated program that decreases the time between cast changes does reduce the total length of time in casts, but not necessarily the number of casts needed. (45)

A complete percutaneous Achilles tenotomy is needed if the foot does not have at least 10 to 15 degrees of dorsiflexion. (46, 47) A recent study of 50 clubfeet demonstrated a 72% tenotomy rate. (48) Another retrospective review showed a 91% tenotomy. (49)

After the last cast removal, the feet are placed in the shoe fitted with a Denis Browne-type bar. The length of the bar is equal to the width of the patient shoulders. Regarding abduction, for the clubfoot side, the shoe is abducted 70 degrees; the normal side is abducted 45 degrees. An upward bend of 15 degrees in the middle of the bar maintains the equinus correction. The infant remains in the shoe-bar combination 24 hours a day 7 days a week for 3 to 4 months and then all night and during nap times for 3 to 4 years to prevent relapses.

The main factor leading to relapse was in compliance to use the shoes attached to the bar in external rotation for the proper length of time.<sup>(76-79)</sup>

The forefoot is supinated and abducted while counter pressure is applied to the talar head. The calcaneus is never touched during the manipulation. (43)



**Ponseti cast**

Figure 15. Ponseti technique. (43)

### **Surgical Management:**

Surgery is only indicated if nonsurgical measures fail to correct the deformity. Most authors cite failure when the affected foot fails to attain the anatomic or neutral position after 3 to 6 months of treatment. (50, 51, 52)

The goal of surgery is to restore as normal foot as possible. This involves re-establishing the anatomic relationships between the bones of the foot and ankle. Additionally, the surgeon must be careful to balance the surrounding soft tissues to help maintenance of the correction achieved with surgery. (53)

### **Timing of surgery:**

Although no ideal window for surgery has been identified, there are general guidelines. Attempts of surgical treatment within the neonatal period have not proved to be successful. Green and Lloyd-Roberts reported that surgery done before age of 6 months leads to increased risk of scar formation. (54, 55)

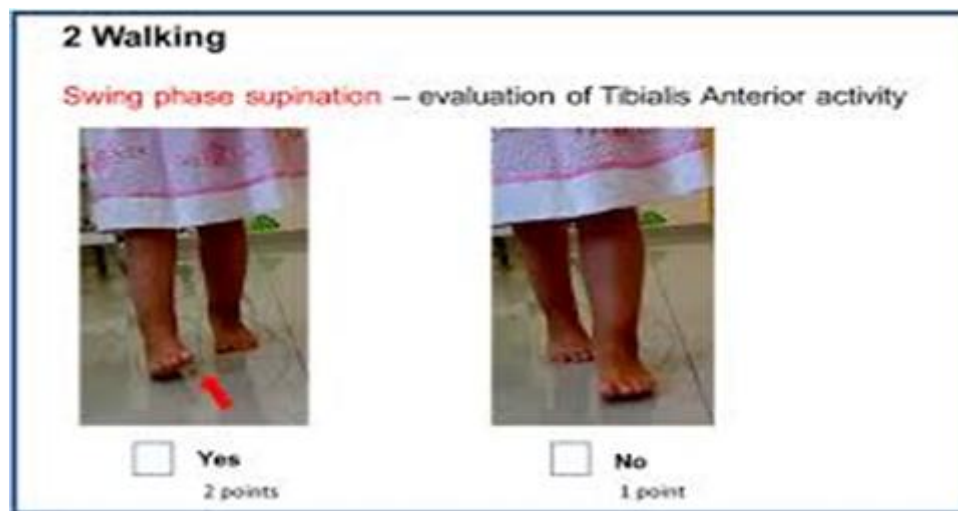
In infants between 3 to 6 months of age, foot size makes the surgery more technically demanding and may affect outcome. Some surgeons prefer to wait until the child is 9 months old. (55) Simons advocates waiting for the foot length to reach a minimum length of 8cm.(56)

However, opinion is universal in that the primary surgery should be done in the first year of life if possible (i.e, 6 to 12 months of age) because much of the potential for growth and remodeling is decreased after this period. (53)

## Residual Dynamic Supination

### Definitions:

Residual dynamic supination is a common residual deformity that may occur after treatment of congenital talipes equinovarus (clubfoot). It is characterized by supination of the forefoot during the swing phase of gait, causing the patient to strike the ground on the lateral border of the foot during initial contact. This deformity is considered dynamic rather than structural, because the foot may appear well corrected while standing but demonstrates supination during walking due to abnormal muscle forces.(57)



**Figure 16. Swinging phase supination.**

The underlying cause is usually muscle imbalance between the tibialis anterior and the peroneal muscles, leading to excessive inversion and supination forces acting on the forefoot during gait.(58)

### Etiology:

Residual dynamic supination is primarily caused by muscle imbalance around the ankle and foot, particularly overactive tibialis anterior versus weak peroneal muscles.(58)

### Other contributing factors include:

- Incomplete correction of the initial deformity
- Neuromuscular imbalance
- Poor compliance with foot abduction bracing
- Progressive growth-related biomechanical changes in the foot.(59)

### Incidence:

Residual dynamic supination is one of the most common relapse patterns following correction of idiopathic clubfoot, particularly after the Ponseti method. The reported incidence varies from 7% to 56% of treated clubfoot cases, depending on follow-up duration, adherence to bracing, and initial severity. (57)

Most cases are detected between 2 and 5 years of age, after the child begins walking and abnormal gait patterns become clinically evident. However, some mild cases may be noticed as early as 18 months, and others may present up to 7 years of age if deformity progresses or brace compliance is poor.(60)

Residual dynamic supination is more common in males (approx. 2:1 male-to-female ratio), reflecting the male predominance of idiopathic clubfoot. Geographically, the deformity incidence generally mirrors the global distribution of clubfoot, with higher rates reported in regions with elevated baseline clubfoot prevalence. (58, 59)

### **Risk Factors:**

#### **Several factors increase the risk of developing residual dynamic supination:**

1. Muscle Imbalance-Overactive tibialis anterior versus weak peroneals. (58)
2. Poor Compliance with Foot Abduction Brace – Non-compliance is one of the strongest predictors of relapse. (61)
3. Incomplete Initial Correction-Failure to fully correct cavus, adduction, or equinus during initial treatment. (59)
4. Early Discontinuation of Bracing-Children who stop bracing at a younger age are at higher risk. (60)
5. Severity of Initial Deformity-More severe clubfeet have higher relapse rates.(57)

### **Management:**

In early relapse, repeat Ponseti casting can correct residual deformities before surgery. Serial manipulation and casting help restore proper alignment in flexible deformities.(58, 59)

### **Orthotic Management:**

Braces such as ankle-foot orthoses (AFOs) can control foot position during gait and reduce inversion forces. Usually combined with physiotherapy to improve muscular balance.(60)

### **Physiotherapy and Muscle Strengthening:**

Targeted exercises to strengthen the peroneal muscles may help counteract tibialis anterior dominance. Effective mainly in mild cases.(59)

TATT is the gold standard for persistent dynamic supination. The tendon is transferred laterally to the lateral cuneiform or cuboid, converting the muscle from a strong inverter to a balanced dorsiflexor, preventing recurrent supination.(62)

Performed usually between 2–7 years after walking begins but before secondary structural deformities develop.(60)

### **Split Tibialis Anterior Tendon Transfer (STATT):**

Partial transfer of tibialis anterior allows balancing inversion and eversion without completely altering the muscle function. Used in selected cases where complete transfer is unnecessary.(63)

### **Plantar Fascia Release:**

Performed when persistent cavus deformity contributes to dynamic supination, often combined with other surgical procedures.(60)

### **Osteotomies:**

In older children or rigid deformities, midfoot or forefoot osteotomies (cuboid or cuneiform) may correct structural components not manageable by soft tissue procedures.(63)

### **Biomechanics and Techniques of Tibialis Anterior Tendon Transfer**

#### **Tibialis Anterior Tendon Transfer:**

The Standard treatment for Clubfoot is The Ponseti Method which is a series of weekly manipulations, casting and bracing of the foot. Percutaneous Achilles Tenotomy may be needed in some cases after 4 to 6 weeks to completely correct the deformity. (64)

Unfortunately, relapse of the deformity has been reported in about 5-55% of the patients treated with the Ponseti Method. Common Causes of the relapse includes inadequate short-term use of Foot Abduction

Orthosis, non-adherence to foot bracing recommendations, severe pathology, scarring and muscle imbalance. Relapses usually appear in the form of dynamic foot supination and heel varus malalignment. (64)

The most common time of presentation of the relapse is between 2.5 to 5 years of age as this is the period of rapid growth of the foot. Dynamic foot supination is the commonest form of clubfoot relapses counting around 68% of cases. The treatment of choice for dynamic foot supination is "Tibialis Anterior Tendon Transfer". (64)

In these cases of Talipes Relapse, the affected foot looks normal in standing and static phase. Dynamic supination appears during swinging phase of walking. So, diagnosis of these cases is mainly by Clinical Examination.

There have been several modifications to the procedure of transferring the tendon whether in its origin or insertion, split or complete transfer. The most recent and commonly used technique these days is transferring the whole insertion of tibialis anterior tendon from the medial cuneiform and 1st metatarsal bones to the lateral cuneiform bone. This procedure has proved great success in correcting the relapse without affecting the long-term functions of the foot. (65)

The function of the transferred tendon is to restore the muscle balance to the foot as the tibialis anterior muscle in clubfoot is typically normal while the peroneal muscles are weak. Transferring the tibialis anterior tendon to the mid-dorsum of the foot restores balance and prevents dynamic supination produced by its original medial insertion.

In our study the affected foot looks normal in standing and static phase. When the patient starts walking, Dynamic supination is detected during swinging phase. (66)

So according to the nature of this condition, Clinical assessment is the main and may be only way for diagnosis of the relapsed talipes.

Radiological evaluation may be needed by X-ray to be sure there is no other bony abnormalities or any need for other types of corrective surgeries. <sup>[96]</sup>

#### **Biomechanics of Tibialis Anterior Movement:**

##### **◆ Dorsiflexion:**

- Dorsiflexion is the primary movement generated by the TA.
- This action lifts the foot upward at the ankle joint, reducing the angle between the dorsum of the foot and the anterior leg.
- Occurs concentrically during swing phase.
- Occurs eccentrically during early stance.
- The muscle acts as the strongest dorsiflexor. (67)

##### **◆ Inversion:**

Because of its medial insertion, contraction produces inversion, turning the sole inward.

**While inversion is not the dominant action during normal gait, it contributes to:**

- Subtalar joint stabilization
- Medial arch support
- Prevention of excessive pronation.(67)

### Role of Tibialis Anterior in the Gait Cycle:

The gait cycle consists of stance phase (60%) and swing phase (40%), each with distinct TA activity patterns.

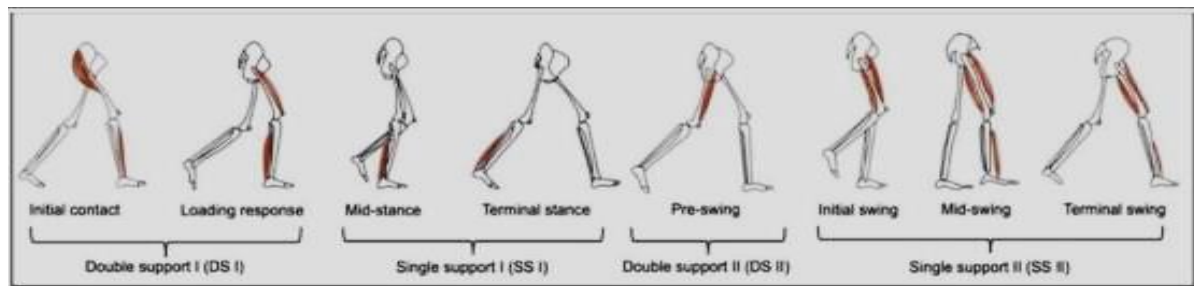


Figure 17. The Gait Cycle.

- ◆ **Initial Contact (Heel Strike):** At heel strike, the ankle is positioned in neutral or slight dorsiflexion.

Role of TA: Contracts isometrically to hold the foot in neutral, Prevents forefoot slap and Prepares the foot for controlled plantarflexion. Without TA activity, the foot would plantarflex abruptly, producing a “foot slap.”(68)

- ◆ **Loading Response:** Immediately after heel strike, the foot lowers to the ground.(68)

**TA action:** Contracts eccentrically, Controls plantarflexion and Absorbs shock. This eccentric control is critical for smooth weight transfer.

- ◆ **Mid-Stance:** During mid-stance, the tibia advances over the planted foot.

TA activity: Minimal activity, Gastrocnemius-soleus complex becomes dominant, The TA may assist slightly in medial arch stability.(68)

- ◆ **Pre-Swing (Toe-Off):** Activity is minimal. Plantar flexors generate propulsion.(68)

- ◆ **Swing Phase:** This is the most important phase for TA concentric function.

TA action: Contracts concentrically, Dorsiflexes the ankle and Ensures toe clearance.(68)

### Techniques of Transfer:

There are 3 techniques used for the transfer of tibialis anterior tendon:

1. **Total Tendon Transfer:** in which the first incision is at the tendon's origin at the medial cuneiform and base of 1st metatarsal and the second incision is at the lateral cuneiform and the new insertion of the tendon. The whole tendon is transferred from its origin to its new insertion. This is the most effective technique in cases of dynamic supination of relapsed clubfoot while the other techniques may be useful in other cases. This is the technique we used in our study.(69)



Figure 18. Total tendon transfer (70)

2. Split Tendon Transfer: same two incisions as total transfer but the tendon is split longitudinally at its origin to medial half and lateral half. The lateral half is transferred to the new insertion at lateral cuneiform as previous while the medial half is left in place. (69)



Figure 19. Split tendon transfer (71)

3. Three incisions technique: same two incisions as previous but the third incision is at extensor retinaculum to release the tendon from the surrounding soft tissues which adds more length to the tendon.(69)



Figure 20-21. Three Incision tendon transfer (71)

#### Complications:

- Overcorrection this can happen in cases where other muscles of the foot are weak or transferring the tendon to the 4th, 5th metatarsal or cuboid bone. In these cases, the foot goes into valgus instead of varus (72)(73)
- Under correction this can happen in cases of split tendon transfer or the transferred muscle is already weak before the operation. So, the tibialis anterior muscle must be at grade 5 or 4 before transferring otherwise it will not correct the deformity and achieve its needed function. (72)(73)

### **Muscle power grading**

- Grade 0 total paralysis (no contraction palpated)
- Grade 1 evidence of slight contractility but no joint movement
- Grade 2 complete range of motion with gravity eliminated
- Grade 3 complete range of motion against gravity
- Grade 4 complete range of motion against some resistance
- Grade 5 complete range of motion against maximal resistance

**Figure 22. Muscle power grading.**

- Muscle Necrosis due to vulgar manipulations during surgery to the muscle and surrounding tissues. (72)
- Surgical Site Infection by many ways as bad hygiene, bad immunity or non-sterile instruments etc. which may cause excessive scarring afterwards. So, patient should be given prophylactic antibiotics postoperatively. (72, 74)
- Bowstringing of the tendon due to release of the extensor retinaculum which should be avoided to preserve good function of the tendon. (72)
- Damage to the surrounding Neurovascular structures during manipulations to the tendon and soft tissue and specially during drilling the hole in the lateral cuneiform bone which should be done very carefully. (72, 73)
- Tendon Pull-Out from its new insertion. So, the tendon should be perfectly secured by a button, knots on skin (72)

#### **Important notes about tibialis anterior transfer:**

- The function of the transferred tendon is not to provide correction but to maintain the previously obtained correction by serial manipulations and casts
- Achilles tenotomy or lengthening is an important step to ensure good results and maintain the correction
- Tibialis Anterior muscle must be well developed and in full power before transferring to ensure a good function
- Transferring the tendon to the cuboid or 5<sup>th</sup> metatarsal results in overcorrection and should be avoided
- Avoid excessive dissection and release of the proximal part of the tendon to avoid injury to the extensor retinaculum which may result in bowstringing of the tendon.

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