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Management Lines of Residual Forefoot Adduction Deformity

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Abstract: Idiopathic clubfoot, scientifically known as congenital talipes equinovarus, which is a complex three-dimensional deformity affecting the joints. Typically, this condition involves hindfoot plantar flexion (equinus), inversion (varus), and forefoot adduction deformity. It is imperative to accurately provide historical details about the presentation, progression, current status, and response to prior parental interventions regarding deformities. Patients manifest with progressive deformities impacting their gait (exhibiting an in-toeing gait). They experience pain and locomotor challenges, particularly over extended distances. Notably, a thickened callous and sizable bursa may manifest over the dorsolateral aspect of the foot, often accompanied by deep fissures and subsequent infection, leading to an inability to wear shoes. To evaluate anatomical measurements of clubfoot deformity, anteroposterior and lateral roentgenograms should be obtained. If the deformity is unilateral, the contralateral foot can be utilized as a control for measurements. Efforts to correct residual forefoot adduction in idiopathic clubfoot encompass a range of approaches, including conservative and surgical interventions. Invariably, osseous procedures are conducted alongside or preceded by soft tissue release. Even in cases of advanced rigid clubfoot, where single-step procedures are generally avoided, initial surgical phases commonly involve soft tissue release. They facilitate the stretching, elongation, and relaxation of critical soft tissue structures, such as vascular and nerve elements, preceding the substantial correction achieved through osseous surgery. A combination of osseous and soft tissue maneuvers is typically employed for persistent or residual forefoot adduction following clubfoot repair.

Keywords: Residual Forefoot Adduction Deformity

Introduction: It is imperative to accurately provide historical details about the presentation, progression, current status, and response to prior parental interventions regarding deformities.

Patients manifest with progressive deformities impacting their gait (exhibiting an in-toeing gait). They experience pain and locomotor challenges, particularly over extended distances. Notably, a thickened callous and sizable bursa may manifest over the dorsolateral aspect of

the foot, often accompanied by deep fissures and subsequent infection, leading to an inability to wear shoes. (1)

B. Past medical history:

1. Prenatal: A comprehensive pregnancy review is essential, encompassing gestational duration, maternal exposure to medicinal or recreational substances, and any illnesses or traumas encountered. (1)

2. Perinatal: Critical aspects of labor and delivery merit scrutiny, including the duration of anesthesia, instances of neonatal seizures or apnea, and complications. (1)

3. Growth and development: Parents' elucidation of significant developmental milestones, such as the age of head lifting, rolling over, grasping, sitting up, and walking, is valuable. However, it is crucial to acknowledge the considerable variance in average developmental trajectories among individuals and families. (1)

II. Examination:

A. Musculoskeletal:

When evaluating a patient's musculoskeletal system, it is important to assess any equino-adducto-varus foot deformity with calf atrophy carefully. The severity of the deformity is typically linked to the degree of articular malalignments, while the rigidity of the surrounding soft tissue determines the resistance to correction.

It is also crucial to thoroughly examine the patient's back and hips, keeping an eye out for sacral abnormalities, pigmented skin lesions, and congenital hip dislocation, which is more prevalent in those with idiopathic clubfoot and must be ruled out. (1)

Rotational Profile:

Staheli's rotational profile addresses the diagnosis of specific rotational deformities in the lower limb. This involves assessing several factors, including the foot progression angle, medial and lateral hip rotation, the thigh-foot angle, and any foot deformities present. (2, 3)

The foot progression angle (FPA) is a crucial measure that determines the angle between the foot's longitudinal axis and the direction of gait progression**.** It is a general indicator of whether the individual toes in or out and is influenced by factors such as femoral and tibial version and any foot adduction deformities present. An in-toeing gait is assigned a minus value. The average FPA for children aged 4-16 is +10°, with a normal range of 0° to +20°. (2, 3)

To estimate the **femoral version**, the patient is placed in a prone position with their knees flexed at a 90° angle while their hip internal (IR) and external rotation (ER) are measured**.** The greater trochanter is palpated while the leg is moved medially and laterally to rotate the hip. Once the trochanter is most prominent, the leg is positioned to bring the head/neck axis to a horizontal position. The femoral version is then determined by measuring the angle

between the leg and the true vertical. If the hip internal rotation exceeds 70°, it may indicate excessive femoral anteversion. (2, 3)

One can measure either the thigh-foot or the trans-malleolar angle to determine **tibial rotation**. The thigh-foot angle (TFA) is calculated by measuring the angle between the longitudinal axes of the thigh and foot while observing from behind with the knee flexed at a 90-degree angle. This measurement provides information about the rotational status of the tibia and hindfoot. The trans-malleolar angle (TMA), also measured with the patient in the same position, is the angle between the thigh axis and a line perpendicular to the trans-malleolar axis, which provides insight into tibial rotation. The difference between the TMA and TFA is used to gauge hindfoot rotation**.** (2, 3)

During an evaluation, **the foot** is assessed for forefoot adduction deformity (FFA) by examining the position of the forefoot in relation to the mid-line axis of the hindfoot. Typically, the hindfoot axis should project to the interspace between the second and third toes, but with the metatarsus adductus, it becomes displaced laterally. (2, 3)

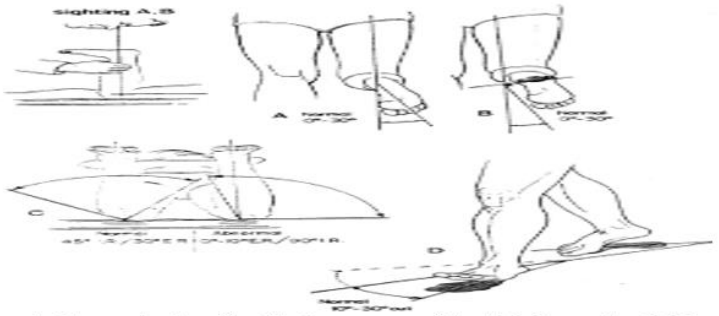

Figure 1: The rotational profile: **(A)** Measurement of the thigh-foot angle, **(B)** Measurement of the angle of the trans-malleolar axis, **(C)** Measurement of hip internal and external rotation, **(D)** Foot progression angle. *(3)*

Bleck (1982) outlined a clinically reproducible technique for quantitatively assessing forefoot deformity. By bisecting the heel and extending the bisection line through the forefoot, a normal alignment should have the line extending between the second and third toes. Any deviation that results in the line of bisection falling through the third, between the third and fourth, or between the fourth and fifth toes indicates mild, moderate, or severe deformity, respectively. (4)

To assess the flexibility of the forefoot, the foot should be gently stroked both the lateral and medial borders of the foot. If the child does not spontaneously straighten their foot, a proper technique should be used to evaluate any potential forefoot deformity. Stabilizing the hindfoot in varus and slight plantar flexion is essential to prevent hindfoot motion. To correct any deformity, apply pressure with the thumb of the opposing hand to push the medial aspect of the first metatarsal head into abduction while recording the amount of correction and the degree of force required. The taut tendon of the abductor hallucis can be observed

and felt with the index finger, where it is stretched like a bowstring near its insertion. Based on the degree of abduction beyond the midline of the heel bisector, the foot can be classified as flexible, partly flexible, or inflexible (rigid), with no abduction possible. (4)

During a foot examination, it is important to observe its appearance thoroughly, paying attention to any

signs of adduction and/or varus deformities. The heel should also be examined for any visible deformities, as well as its size, severity, mobility, and hypoplasia. If there is a deep skin crease on the medial aspect of the foot, this may indicate a more rigid deformity. Additionally, it is essential to take note of the skin condition, including any callosities, scars, or ulcers. Evaluate the passive and active motion of the forefoot, including abduction and peroneal function, as well as the ankle. Finally, note any anterior tibial tendon or abductor hallucis muscle contracture. (4)

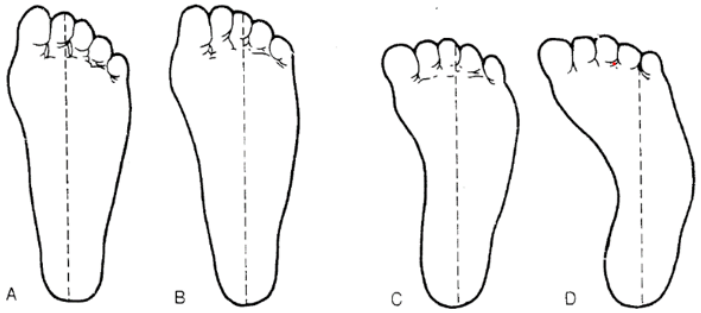

Figure 2: Bleck's clinical method of recording the severity of forefoot adduction deformity: **(A)** Normal child foot, **(B)** Mild adduction, **(C)** Moderate adduction, **(D)** Severe adduction. *(4) 2*

When assessing the cavovarus deformity, it is crucial to evaluate its flexibility. One way to assess hindfoot flexibility is through the **Coleman block test**, where the patient stands with their heel and the lateral half of the affected foot supported by a block. This allows the first metatarsal to hang freely. If the hindfoot deformity is flexible, the heel varus should correct itself when the patient stands on the block. (5)

B. Neurophysiologic:

In order to accurately determine the type of clubfoot present, a comprehensive assessment of the patient's neurophysiological status is necessary. This assessment should include an evaluation of three key areas: **(1)** muscle tone and motor function, **(2)** sensation and reflex activity, and **(3)** motion and gait. (1)

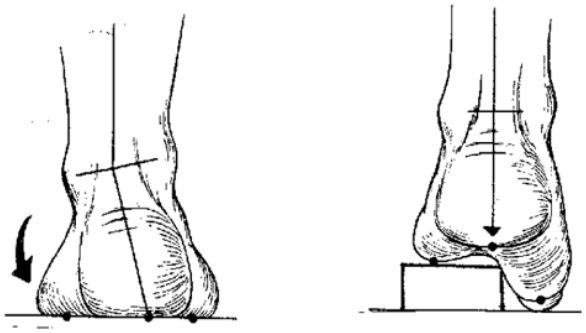

Figure 3: Coleman block test. *(5)*

2-RADIOGRAPHIC EVALUATION:

To evaluate anatomical measurements of clubfoot deformity, anteroposterior and lateral roentgenograms should be obtained. If the deformity is unilateral, the contralateral foot can be utilized as a control for measurements.

For the anteroposterior view, the patient is seated with knees and hips flexed, forefoot maximally abducted, and ankle maximally dorsiflexed to allow for a plantigrade foot. The X-ray beam should be at a 30° angle from perpendicular**.** When capturing the lateral view, the hindfoot should be parallel to the cassette, the ankle maximally dorsiflexed without raising the heel, and the X-ray beam should be at a 90° angle from perpendicular**.** Standing anteroposterior and lateral roentgenograms can be obtained for older children. **(6)**

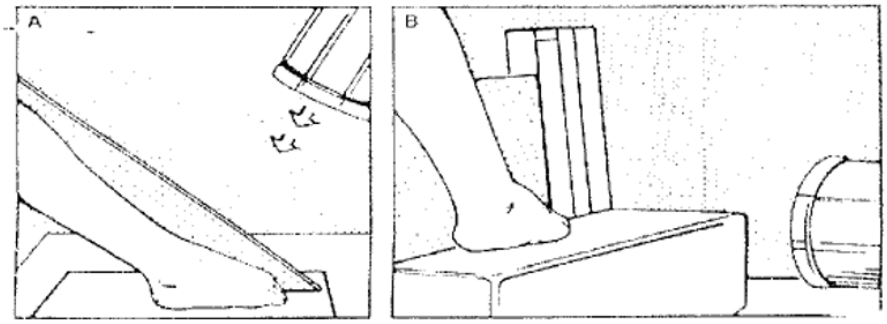

Figure 4: The position of the patient and the tube in: **(A)** standard anteroposterior, and **(B)** lateral radiographs. (6)

I. Anteroposterior Weightbearing Radiography:

(A) Anterior talocalcaneal angle (Kite's angle) (TCA1):

This angle is determined by bisecting the talus and calcaneus longitudinally**.** Typically, a normal range for this angle is between 20° to 40°. However, in cases of clubfoot, this angle tends to decline progressively as heel varus increases. The talocalcaneal angle does not give information about forefoot adduction. (7, 8)

(B) Anterior talo-first metatarsal angle (TFMA1):

This angle is obtained by drawing a bisector through the talus and the first metatarsal on an anteroposterior view**.** A normal foot typically features a metatarsal axis positioned laterally

to the talar axis and measuring between 0° and -10°. However, if the bisection of the first metatarsal is located medially to the talar bisector, a positive value is assigned, indicating that the foot is adducted. (7, 8)

(C) Calcaneo-fifth metatarsal angle (CFMA):

This is the angle between the long axis of the calcaneus and the fifth metatarsal. Typically, this angle measures between 0° and 5°, with the long axis of the calcaneus pointing toward the fifth metatarsal**.** (7, 8)

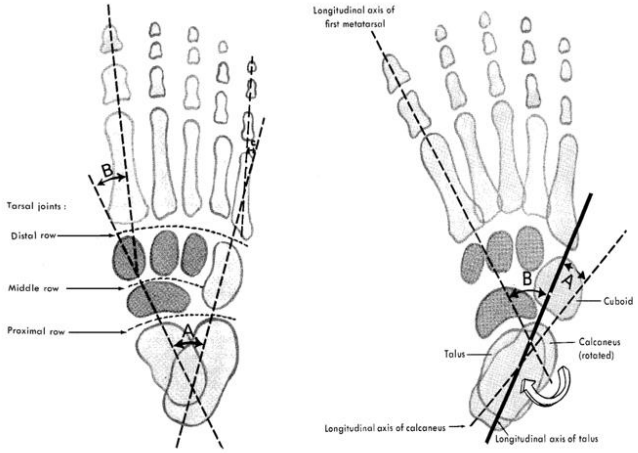

Figure 5: The anteroposterior radiographic measurements for a normal foot **(left)** and a foot with talipes equinovarus **(right)**: **(A)** the talocalcaneal angle, **(B)** anterior talo-first metatarsal angle, and **(C)** calcaneo-fifth metatarsal angle. *(7, 8)*

II. Lateral Weightbearing Radiography:

(A) Lateral talocalcaneal angle (TCA2):

This angle is formed by a line that bisects the talus and another line that runs along the lower portion of the calcaneus**.** This angle indicates varus and can be considered normal in cases of metatarsus adductus and varus. However, it tends to be reduced in cases of clubfoot. If the lines are parallel, this may suggest that residual heel varus is present. It normally falls within a range of 25 to 50 degrees. (7, 8)

(B) Lateral talo-first metatarsal angle (Meary' s angle) (TFMA2):

This is the angle between the first metatarsal's long axis and that of the talus**.** This angle provides important insights into the presence of cavus. Typically, it ranges between 0° and 5°. (7, 8)

The sum of the talocalcaneal angles in the AP and lateral views is called the talocalcaneal index. Its normal range is 40° to 85°.

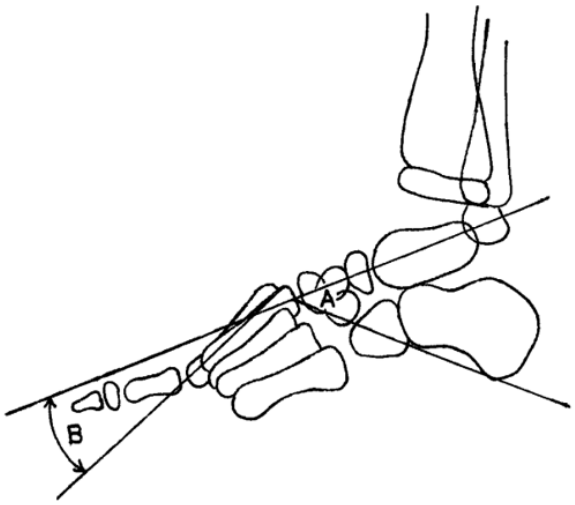

Figure 6: The lateral radiographic measurements: **(A)** the lateral talocalcaneal angle, and **(B)** the talo-first metatarsal angle. *(7, 8)*

TREATMENT OF RESIDUAL FOREFOOT ADDUCTION DEFORMITY

Efforts to correct residual forefoot adduction in idiopathic clubfoot encompass a range of approaches, including conservative and surgical interventions.

1-Conservative Approaches:

When residual metatarsus adductus remains minimal, functionality and normal footwear are typically unaffected, obviating the need for elective foot surgery. Passive stretching exercises and manipulation involving stabilizing the hindfoot with the tibia while abducting the forefoot represent viable strategies. Additionally, casting or utilizing shoe therapy may be employed. (9)

2-Surgical Interventions:

Invariably, osseous procedures are conducted alongside or preceded by soft tissue release. Even in cases of advanced rigid clubfoot, where single-step procedures are generally avoided, initial surgical phases commonly involve soft tissue release. They facilitate the stretching, elongation, and relaxation of critical soft tissue structures, such as vascular and nerve elements, preceding the substantial correction achieved through osseous surgery. (9)

A combination of osseous and soft tissue maneuvers is typically employed for persistent or residual forefoot adduction following clubfoot repair.

I. Soft Tissue Procedures:

Soft tissue procedures are indicated for mild to moderate flexible forefoot adduction deformity in idiopathic clubfoot and cases where the deformity arises mainly from soft tissue contractures rather than bony abnormalities. (9)

Advantages:

1. They are less invasive, involving manipulation, release, and lengthening of the soft tissues around the foot and ankle, without bone osteotomies, thus preserving the natural bone structure.
2. They generally entail a quicker recovery, enabling earlier weight-bearing and a return to normal activities.
3. They can be performed at a younger age, facilitating early intervention and correction of deformities.

Disadvantages:

1. Soft tissue procedures may offer limited correction for severe or fixed deformities, especially when bony abnormalities are present, potentially leading to a higher risk of recurrence compared to osseous procedures.
2. Achieving the desired correction with soft tissue procedures can be challenging, increasing the risk of over-correcting or under-correcting the deformity.
3. Successful outcomes often rely on the patient's compliance with post-operative rehabilitation and the use of orthoses or splints.

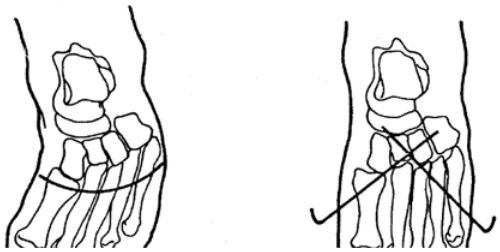

Figure 7: Surgical incision and fixation recommended for Heyman tarsometatarsal soft tissue release. [48]

Types:

Tarsometatarsal Soft Tissue Release:

Before the ossification and squaring of the bases of metatarsals, soft tissue procedures such as those outlined by **Heyman and associates** offer a means to address persistent metatarsus adductus or residual clubfoot adduction deformity. Corrections are sought through a dorsal incision, complete capsulotomies, and ligament releases of the tarsometatarsal joint. Historically, abductor hallucis release was advocated for hallux varus

and medial ray adduction deformity, typically recommended between 18 months and four years of age. However, due to frequent reports of postoperative stiffness and pain, this approach is now discouraged. (4, 10)

Tibialis Anterior Tendon Transfer:

Transfer of the tibialis anterior insertion, either as the entire tendon or as a split transfer to the lateral cuneiform, is warranted in cases of dynamic adduction and supination deformity, particularly during the swing phase, leading to weight-bearing on the lateral aspect of the foot during initial stance. Extensive utilization of tibialis anterior tendon transfer in clinics like Baja suggests its efficacy lies in negating the tendon's deforming influence rather than augmenting dorsiflexion and eversion. Optimal outcomes are achieved when the transfer is performed between the third and sixth years. (11)

Tibialis Posterior Tendon Transfer:

The utility of tibialis posterior tendon transfer in clubfoot cases is constrained. There is a risk of overcorrection, resulting in a valgus foot type if the tendon is transferred excessively laterally. It is often more prudent to Z-lengthen the tendon to weaken it rather than opt for transfer. (11)

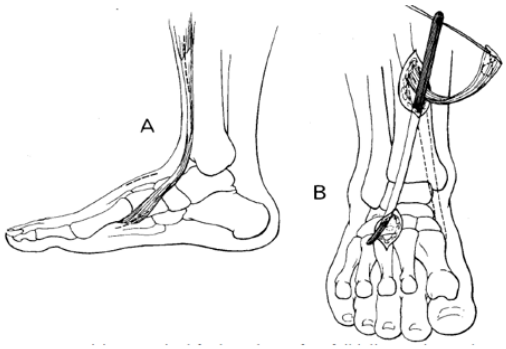

Figure 8: (A) Incisions required for lateral transfer of the tibialis anterior tendon are made over the medial side of the foot, the anterior aspect of the leg, and the dorsum of the foot. **(B)** After removing the tibialis anterior tendon from its insertion and delivering it into the proximal incision over the tibia, a tendon passer is used to thread the tendon to the lateral incision in the foot for insertion into the bone. (10)

II. Osseous Procedures:

The osseous procedures are indicated for children aged 3-10 with moderate to severe fixed forefoot adduction deformity, midfoot supination, and cavovarus deformities associated with idiopathic clubfoot, especially when soft tissue techniques fail to correct the condition adequately. Additionally, surgery is indicated when the adduction deformity extends distally to the navicular, necessitating metatarsal osteotomies, or when lateral column shortening or lengthening is required to address hindfoot varus or cavus deformities. It is also warranted for residual or recurrent clubfoot deformities that are unresponsive to conservative treatment and severe forefoot adduction, causing functional impairment and pain. (12)

Advantages:

1. They enable comprehensive correction by addressing the involved bony structures.

2. They enhance stability by realigning and repositioning the bones, thus reducing the likelihood of relapse.
3. These procedures aim to restore normal foot anatomy and biomechanics, resulting in improved functional outcomes such as pain relief, enhanced gait, and better tolerance to orthoses and footwear.

Disadvantages:

1. They are invasive with inherent risks and potential complications.
2. They entail a longer recovery time and rehabilitation period compared to conservative measures and soft tissue procedures.
3. They possess risks of complications, including infection, delayed healing, nerve and blood vessel injury, bone fracture, and overcorrection.

Types:

A) Metatarsal Osteotomies:

Peabody and Muro demonstrated an osseous surgery involving an abductory osteotomy carried out on the base of the fifth metatarsal, removal of the central bases of the three metatarsals, and medial mobilization to reduce the joint of the first metatarsal with cuneiform. (13, 14)

Steytler and Van der Walt presented a V-shaped metatarsal osteotomy involving metatarsals one through five. The "V" was executed obliquely with the apex directed towards the hindfoot, with the medial arm being vertical and the lateral arm being more horizontal. By refraining from using fixation, they believed they could enhance the stability of the osteotomy. (14, 15)

Berman and Gartland described dome-shaped osteotomies through the bases of all metatarsals, with the apex of the dome positioned proximally to fix persistent adduction of the metatarsals. In cases where the adduction deformity originates distal to the navicular, this procedure is indicated. However, it is vital to exercise caution during the procedure to prevent harm to the first metatarsal physis through osteotomy or periosteal stripping, as this may lead to shortening the first metatarsal. (12, 16)

B) Tarsal Osteotomies:

Lateral Column Shortening:

Evans described lateral column shortening by calcaneocuboid joint fusion. It is indicated in paralytic clubfoot, in which stability of the lateral column of the foot is desired. However, it should be avoided for children below eight years of age due to the risk of overcorrection and valgus deformity. (17)

According to **Lichtblau**, a wedge of bone on the anterior calcaneus can be removed laterally while keeping the articular surface intact. This is recommended for patients with a relatively long lateral column of the foot and no malalignment of the calcaneocuboid joint. Opting for

this method helps prevent hindfoot stiffness in the long run, which can occur with Evans's procedure. (18)

The traditional cuboid decancellation procedure has been modified at the **Baja project**, where a laterally based triangular wedge of bone is removed from the cuboid and lateral cuneiform**.** This procedure is performed when there is only a fixed varus inclination of the midfoot. (19)

One potential method to address residual heel varus in clubfoot is calcaneal osteotomy. According to **Dwyer**, a medial opening wedge osteotomy may be advantageous as it can elongate the typically small, underdeveloped heel often present in residual clubfoot deformity. However, it can occasionally result in tight skin sloughing along the incision over the calcaneus. A **modified Dwyer** lateral closing wedge osteotomy can be performed through the lateral incision. It is important to note that this procedure is typically recommended for children over three years of age. (20)

Medial Column Lengthening:

Fowler outlined a groundbreaking technique for lengthening the shortened medial column in residual clubfoot or cavovarus presentation cases. An autogenous bone graft is inserted through an osteotomy in the medial cuneiform . (21)

Combined Lateral Column Shortening and Medial Column Lengthening:

McHale and Lenhart have developed a variation of the Fowler procedure, in which they perform a closing wedge osteotomy of the cuboid bone and use the wedge as a graft for a medial cuneiform osteotomy . This method is particularly effective for older children between 3 and 12 who have a residual adduction or varus deformity in the forefoot or midfoot. (23)

They recommended the following sequence of procedures:

Step 1: Perform a bone wedge osteotomy extraction from the cuboid.

Step 2: Conduct a soft tissue release encompassing the plantar fascia, the abductor hallucis, or the tibialis anterior tendon.

Step 3: Initiate an opening wedge medial cuneiform osteotomy.

Step 4: Reinsert the extracted bone wedge at the medial cuneiform osteotomy and close the cuboid osteotomy.

This method allows for maximum lengthening and angular correction of the medial cuneiform, along with the removal of additional bone from the cuboid. The cuboid is approached through a dorsolateral curvilinear incision from the calcaneus to the fourth metatarsal shaft. The sural nerve may be encountered during minimal traumatic anatomic dissection and should be carefully retracted . A sharp osteotome or power saw removes a laterally based wedge or truncated wedge from the cuboid . It is important to keep the size of the wedge conservative to avoid any difficulty in approximating the cut surfaces later. The wedge of the removed bone is then used as the opening graft in the medial cuneiform osteotomy. (23)

The medial column is then approached by a dorsomedial curvilinear incision, or a previous scar can be used, beginning just behind the tuberosity of the navicular and extending down to the proximal one-fourth of the first metatarsal. If the saphenous nerve or vein is encountered, it may be reflected dorsally. The plantar aspect of the tibialis anterior tendon needs to be mobilized and reflected or partially detached . A vertical osteotomy of the medial cuneiform is performed using a sharp osteotome or power saw. The intermediate cuneiform may also be opened if necessary. A baby lamina spreader is used to open the osteotomy and thoroughly inspect the cuboid. Additional bones may be removed as needed. (23)

Next, the broadest possible bone graft is inserted medially . If required, each osteotomy may be internally stabilized. A lateral staple and a threaded Kirschner wire on the medial side are recommended to provide compression without bulk and prevent graft extrusion. The threads of the Kirschner wire also help prevent the graft from collapsing . (23)

Postoperative care:

After the wounds are closed and dressed, the patient should be placed in a non-weight-bearing short-leg cast. Immediate postoperative and follow-up radiographs are crucial. After six weeks, the cast and pins can be removed once healing is adequate to resume weight-bearing.

Indications of combined cuboid-cuneiform osteotomy procedure is indicated for severe fixed forefoot adduction deformity that does not respond to conservative treatment, previous unsuccessful surgeries, persistent or recurring forefoot adduction deformity, moderate to severe fixed forefoot adduction deformity and midfoot supination in children aged 3-12 not helped by orthotic treatment, cavovarus deformity, intolerance to footwear or orthoses causing skin issues, persistent or walking-related pain, and presence of other associated deformities like hindfoot varus or cavus. (24, 25)

Double osteotomy has several **advantages** over metatarsal and other tarsal osteotomies: **(A)** It avoids the first metatarsal physis completely; **(B)** The broad contact area and greater blood supply provide better conditions for bone healing; (**C)** Multiplanar correction of deformity may be easier due to the tall profile of the cuneiform. (22)

A biplane wedge is used to correct cavovarus deformity, with the wider end placed plantarly to correct a plantarflexed medial column and medially to correct adduction. Supination correction is achieved through forefoot rotation at the midfoot transverse osteotomy.

However, the procedure also has some **disadvantages** to consider. Firstly, the anterior tibial tendon is present in the operative field, which requires careful attention. Secondly, there are inherent risks associated with bone grafting. (*22*)

Complications of the combined cuboid-cuneiform osteotomy procedure for clubfoot encompass a range of potential issues, including infection, delayed or nonunion of bones, nerve or blood vessel damage, malalignment or recurrence of deformity, hardware-related problems, pain, difficulties with wound healing, rare occurrences of avascular necrosis of the talus, flat-topped talus, migration of k-wires, residual deformity, anesthesia-related complications, and cosmetic concerns. (24, 25)

Köse described trans-midtarsal osteotomy. The procedure involves a complete midfoot osteotomy following the lateral shortening procedure. The osteotomy is carried out transversely, freeing the forefoot from the hindfoot by passing through all the cuneiforms. Osteotomy on the intermediate and lateral cuneiforms can better correct rotational and cavus deformities. In cases where the foot has a fixed heel varus, either a repeat subtalar release or a lateral slide osteotomy of the calcaneus through the medial incision combined with the cuboid-cuneiform osteotomy can prevent growth arrest and fusion. (26)

III. Salvage Procedures:

These procedures serve various purposes, such as addressing failed prior surgeries, nonunion or delayed union, infection, chronic pain, residual deformity, post-treatment complications, functional limitations, and skin issues. (32)

Triple arthrodesis:

It is a salvage procedure used in children over ten years old. It is still valuable for stabilizing neglected clubfoot. (32)

Talectomy:

This procedure has been used for stiff, arthrogrypotic, and neuromuscular clubfeet by inducing hindfoot laxity for correction in both the sagittal and frontal planes. This procedure maintains the plantigrade position of the foot while ensuring a stable, congruous foot-to-leg relationship. While the foot is notably shortened, there is a risk of the forefoot deformity persisting. As such, triple arthrodesis is often considered the preferred alternative. (27)

The Ilizarov:

This apparatus can correct deformities in multiple planes simultaneously using a circular frame. **Distraction histogenesis** is a technique that stimulates skin, muscle, nerve, vascular structure, connective tissue, and bone formation by applying a distraction force. There are two approaches to correcting contractures using the Ilizarov method. The non-constrained closed technique involves soft tissue stretching without osteotomies and is suitable for children under eight. The constrained technique combines various osteotomies and is typically used for children over eight. However, there are potential complications to consider, including pin tract infection, toe flexion contractures, anterior subluxation of the ankle, distal tibial epiphysiolysis, wires cutting out, osteoporosis, and the recurrence of the deformity. (27)

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