A pictorial review of reconstructive foot and ankle surgery: evaluation and intervention of the flatfoot deformity

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ABSTRACT

This pictorial review focuses on basic procedures performed within the field of podiatric surgery, specifically for elective reconstruction of the midfoot and rearfoot with focus on the flatfoot deformity. Our goal is to demonstrate objective radiographic parameters that surgeons utilize to initially define the deformity, lead to procedure selection, and judge post-operative outcomes. We hope that radiologists will employ this information to improve their assessment of post-operative radiographs following reconstructive foot surgeries. First, relevant radiographic measurements are defined and their role in procedure selection explained. Second, the specific surgical procedures of the Evans calcaneal osteotomy, medial calcaneal slide osteotomy, Cotton osteotomy, subtalar joint arthroeresis, and arthrodeses of the rearfoot are described. Finally, specific plain film radiographic findings that judge post-operative outcomes for each procedure are detailed.

REVIEW ARTICLE

PICTORIAL REVIEW

The intention of this review is to present radiologists with a basic overview of common procedures performed within the field of podiatric foot and ankle reconstructive surgery. This article specifically focuses on elective procedures of the midfoot and rearfoot used for correction of the flatfoot deformity. Our goal is to emphasize radiographic findings that surgeons utilize to judge post-operative outcomes, but we will also review the pre-operative radiographic parameters that initially define the deformities and lead to procedure selection. It is our hope that radiologists will employ this information to improve their ability to assess post-operative radiographs following reconstructive foot surgeries.

Flatfoot Deformity Presentation

Flatfoot deformity, also referred to as “pes valgus,” “pes plano valgus,” “pes planus,” or “peritalar subluxation,” is commonly characterized by a relatively simple and subjective “collapse” of the medial longitudinal arch of the foot (Figure 1). In fact, however, it is a complex deformity involving osseous, articular, and soft tissue pathology with both clinical and radiographic signs potentially evident in three cardinal body planes – transverse, sagittal, and frontal [1,2]. A thorough clinical examination is paramount in fully assessing the extent and various components of the deformity, and is at least as important as the radiographic evaluation. The patient is examined non-weight bearing, weight bearing in stance, and during gait in order to fully appreciate the biomechanical and dynamic nature of the deformity. Clinical evaluation may

reveal findings including, but not limited to, an everted or valgus-positioned heel, abduction of the forefoot relative to the rearfoot, collapse of the medial longitudinal arch, equinus deformity of the ankle, abductory twist within the forefoot during gait, and early heel rise during gait. Some deformities are flexible and reducible with physical manipulation, while some types of flatfeet may be rigid, indicating a fixed arthritic condition or the presence of an osseous coalition. Only after a comprehensive clinical exam is complete may weight bearing radiographs be performed in order to further assess and objectively analyze the deformity.

A systematic series of radiographs are performed to characterize the deformity in all three planes. Because nearly all foot and ankle deformities have a dynamic biomechanical component, it is important to always evaluate these feet with only weight-bearing radiographs taken in the angle and base of gait [3]. Non-weight bearing views will often underestimate the degree of deformity and are generally considered to be inappropriate if used for procedural selection.

Transverse plane radiographic evaluation

The anterior-posterior (AP) or dorsal-plantar (DP) foot radiograph is most useful for assessment of the transverse plane component of the deformity. Several angular measurements are performed and calculated to define transverse plane deformity [3-5]:

- The talocalcaneal angle (TCA; also known as Kite's angle) is defined as the resultant angulation between the longitudinal axis of the talar head and neck and a tangent drawn to the lateral side of the calcaneus, with a normal angle being between 25-40 degrees (Figure 2). An angle greater than 40 degrees is indicative of flatfoot deformity, while values less than 25 degrees indicate cavus deformity.

- The calcaneocuboid angle (CCA) is defined as the resultant angular relationship between a tangent drawn along the lateral side of the cuboid and a tangent drawn along the lateral side of the calcaneus, with a normal angle between 0-5 degrees (Figure 2). An angle greater than 5 degrees is considered abnormal and represents a relatively abducted forefoot.

- A final radiographic parameter to evaluate with the AP radiograph is the amount of talar head coverage. This is determined by specific evaluation of the talar-navicular joint. In a rectus (or normally aligned) foot, most if not all of the talar head is "covered" by the navicular (75-100%). In a flatfoot, as the deformity progresses, the medial aspect of the head of the talus becomes "uncovered", and does not fully articulate with the navicular (Figure 3).

With all three of these radiographic parameters, it may be useful to consider the talus as distinct from the remainder of the foot. With increasing transverse plane flatfoot deformity, the forefoot, midfoot and calcaneus are essentially transposed in a relatively lateral direction while the talus diverges relatively medially. The observed change seen with all three of these transverse plane radiographic parameters can be conceptualized within this paradigm. For this reason, another term often used to describe the flatfoot deformity is "peritalar subluxation," as the foot seems to "sublux" off the talus with progressive deformity [6].

Sagittal plane radiographic evaluation

The lateral foot/ankle radiograph is most useful for assessment of the sagittal component of the deformity. Several angular measurements are performed and calculated to define sagittal plane deformity [3-5,7]:

- The talar declination angle (TDA) is defined as the resultant angulation between the supporting surface and the longitudinal axis of the talar head and neck. A normal value is between 18-24 degrees, with an angle greater than 24 degrees being characteristic of flatfoot deformity and an angle less than 18 degrees being characteristic of cavus deformity (Figure 4).

- The calcaneal inclination angle (CIA) is defined as the resultant angulation between the supporting surface and a line tangential to the plantar aspect of the calcaneus. As with the talar declination angle, the normal range is 18-24 degrees; however flatfoot deformity would be characterized by an angle of less than 18 degrees and cavus greater than 24 degrees (Figure 4).

- The talo-first metatarsal angle, also known as Meary's angle, is defined by the angular relationship between the longitudinal bisection of the first ray and the longitudinal axis of the talar head and neck. In a rectus foot type, these lines would be parallel with an angle of zero degrees. An angle of greater than 4 degrees with the apex oriented inferiorly indicates a flatfoot deformity whereas an angle of greater than 4 degrees with the apex oriented superiorly indicates a cavus foot type (Figure 4).

There are several other more subjective features that may be evaluated from the lateral radiograph for frontal plane deformity including the appearance of the sinus tarsi. In a flatfoot, the sinus tarsi is not clearly defined or may appear "obliterated" as the lateral talar process fills the space of the sinus tarsi. Conversely, a "bullet hole" sinus tarsi is characteristically seen in a cavus foot type (Figure 5)[3]. One may also take note of the Cyma line or an "S" formed on the lateral view at Chopart's joint. An anterior break in the Cyma line, meaning an anterior shift of the talonavicular joint line causing a discontinuity of the apparent "S", is indicative of flatfoot deformity (Figure 6)[3]. Finally, one can assess for a relative "break" or "fault" within the various medial midfoot joints (talonavicular, naviculocuneiform, cuneometatarsal). These faults may indicate an anatomic level of collapse within the medial column (Figure 7)[3].

Frontal plane radiographic evaluation

The frontal plane is poorly defined with standard radiographic views and therefore ancillary projections should also be obtained, most commonly a long leg calcaneal axial which can identify the talus and calcaneus in a rectus, varus or valgus position relative to the tibia (Figure 8)[5,8]. The resultant angulation between the longitudinal axis of the tibia and the calcaneus is observed, with a relatively valgus orientation of the calcaneus expected in a flatfoot deformity. One may also extend the tibial axis and note the relative

location of where the calcaneal tuber is expected to come into contact with the weight-bearing surface. This is known as the "calcaneal strike position," and should be within approximately 5mm of the extended tibial axis.

This view may also be used to assess the subtalar joint, in particular for the presence of a coalition which would produce a rigid flatfoot deformity. A coalition is defined as the presence of osseous or fibrocartilagenous bridging where a joint space would normally be present. Specifically, subtalar joint coalitions can be present within any of the three articular facets. On the lateral projection, the presence of a "halo sign," or a sclerotic, radiodense ring about the posterior aspect of the subtalar joint, may be indicative of a posterior facet subtalar joint coalition (Figure 9)[9-11]. Calcaneonavicular joint coalitions may present with the characteristic "anteater sign" on the lateral view as an elongated anterosuperior calcaneal process (Figure 10). This is further confirmed with the medial oblique foot projection or advanced imaging such as a CT scan [10].

Flatfoot Deformity Surgical Correction

Once the clinician has made the appropriate diagnosis based on clinical and radiographic findings, there are a variety of surgical treatment options available depending on the severity and plane(s) of the deformity. Flatfoot deformity may primarily occur within a single plane as defined above, but is usually within a combination of the three cardinal planes. In other words, a given flatfoot may be determined to be "triplanar," or involving the transverse, sagittal and frontal planes, or simply could involve deformity primarily in a single plane or a combination of two planes. Surgical procedures are generally thought to provide correction in a single plane, so correction of deformity often involves a combination of procedures. These procedures also commonly involve a combination of soft tissue and osseous work, so it is possible that only a portion of the procedure may be visible or apparent on the post-operative radiographs.

Transverse plane surgical correction

One of the most common osseous procedures performed in flatfoot reconstruction is the Evans calcaneal osteotomy [2,12,13]. Although the Evans calcaneal osteotomy has been described to achieve angular correction in all three cardinal body planes, it is primarily thought of as a transverse plane corrective procedure. It consists of the insertion of a wedge-shaped bone graft into the lateral aspect of the anterior calcaneus approximately 1.0-1.5cm proximal to the calcaneocuboid joint (Figure 11). The laterally based wedge is inserted to effectively "lengthen" the lateral column and "push" the midfoot and forefoot into a more adducted position. When considering the peritalar subluxation paradigm, the wedge is essentially transposing the midfoot back on top of the talus and increasing talar head coverage. This is expected to provide correction and normalization of the talocalcaneal angle, calcaneocuboid angle and talar head coverage on the AP radiograph.

On radiographs this procedure is evidenced by the presence of the bone graft in the anterior calcaneus. Surgeons attempt to tamp the graft into an anatomic position without prominence, but usually at least some small step-off can be appreciated with a different radiodensity observed (Figure 12). This is an inherently stable procedure, so often no internal fixation is utilized, however, one may observe a wire, screw or plate utilized to hold the graft in place.

Another common transverse plane procedure involves advancement of the posterior tibial tendon on the navicular tuberosity or transfer of the flexor digitorum longus tendon to the navicular tuberosity [2,14,15]. This is evidenced post-operatively by the presence of a bone anchor within the navicular tuberosity (Figure 12), and possibly the resection of a portion of the navicular tuberosity or os tibiale externum. One should verify that this fixation is not within the talar-navicular joint or navicular-cuneiform joint post-operatively.

Sagittal plane surgical correction

The primary surgical intervention for correction of the sagittal plane component of a flatfoot deformity is soft tissue in nature, and therefore, not visible on post-operative radiographs. This comes in the form of either an Achilles tendon lengthening or gastrocnemius recession (Figure 13). This will decrease the plantarflexory pull on the calcaneus and help restore the calcaneal inclination angle and talar declination angle. One osseous procedure that does involve sagittal plane correction is the Cotton osteotomy [2,13,15]. In this procedure a dorsally based wedge of bone graft is inserted into the medial cuneiform (Figures 12 and 14). The wedge shape of the graft effectively plantarflexes the first metatarsal and may restore Meary's (lateral talo-first metatarsal) angle to it's normal parallel relationship. Similar to the Evan's calcaneal osteotomy, the graft is intrinsically stable and often inserted without internal fixation, although a screw or wire may be utilized.

Frontal plane surgical correction

There are two procedures primarily used for correction of a frontal plane component to flatfoot deformity. The first is the medial calcaneal slide osteotomy which involves a through-and-through osteotomy through the calcaneal tuber with medial translation of the posterior fragment [2,12,13,16,17]. This translation is best viewed with a calcaneal axial view (Figure 15). This is nearly always stabilized with internal fixation, most commonly two screws or a laterally oriented plate.

Primarily in pediatric patients, a subtalar joint arthroeresis may be inserted into the sinus tarsi to control frontal plane motion (Figure 16). This is a biomaterial implant that literally provides a "stop" or limitation of subtalar joint motion in the direction of pronation/eversion [2,9,18,19]. This is best visualized on the lateral view with the implant visible in the sinus tarsi, but may also be seen on the AP view near the talar neck.

Arthrodesis procedures

In end-stage flatfoot deformity or in cases where there is significant pain or arthritic changes noted to the affected joint(s), joint arthrodesis is indicated [2,8,20,21]. Most commonly with flatfoot, the subtalar, talonavicular, and calcaneocuboid joints are involved. These joints may be fused

individually or as a unit known as the triple arthrodesis (Figure 17). The medial column may also be fused involving the first metatarsocuneiform joint and/or naviculocuneiform joints to achieve stability of the medial column in a relatively plantarflexed, fixed position. Arthrodesis procedures will nearly always involve the use of internal fixation including screws and plates.

TEACHING POINT

The preceding was a basic review of common procedures utilized by foot and ankle surgeons for correction of the flatfoot deformity. We attempted to emphasize which specific radiographic findings and measurements lead to procedure selection, as well as provide a basic visual understanding of the most commonly performed procedures (Table 1). It is our hope that radiologists will employ this information to improve their ability to assess post-operative radiographs following foot and ankle reconstructive surgeries.

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FIGURES

Figure 1: Clinical picture of a 46 y/o male with a symptomatic right flatfoot deformity. Although the deformity is most easily defined as a "collapse" of the medial column longitudinal arch as pictured, it is actually a complex deformity involving bone, joint and soft tissue abnormality in the transverse, sagittal and frontal planes. Picture courtesy of Dr. Jason Piraino, DPM.

Figure 2 (left): Weight bearing AP view of a 46 y/o male with a symptomatic flatfoot deformity demonstrating a transverse plane component to the deformity. The talocalcaneal angle is defined as the resultant angulation between the longitudinal axis of the talar head and neck (Line A) and a tangent drawn to the lateral side of the calcaneus (Line B), with a normal angle ranging between 25-40 degrees. The calcaneocuboid angle (CCA) is defined as the resultant angular relationship between a tangent drawn along the lateral side of the cuboid (Line C) and a tangent drawn along the lateral side of the calcaneus (Line B), with a normal angle between 0-5 degrees. Both angles increase with progressive transverse plane flatfoot deformity.

Figure 3 (top): Cropped AP view of a left foot of a 55 y/o female highlighting the talar-navicular joint. Another measure of transverse plane alignment is the talar head coverage which estimates what percentage of the relativley convex talar head is "covered" by the relativley concave proximal navicular. Normally approximately 75-100% of the talar head articular surface would be expected to be covered by the articular surface of the proximal navicular, with less coverage noted with progressive transverse plane deformity. The image above designates the most medial and lateral aspects of the cartilage on the talar head with "X"s and the most medial aspect of the navicular indicated with an "O". Only approximately 60% of the talar head articular cartilage is "covered" by the articular cartilage of the proximal navicular in this image.

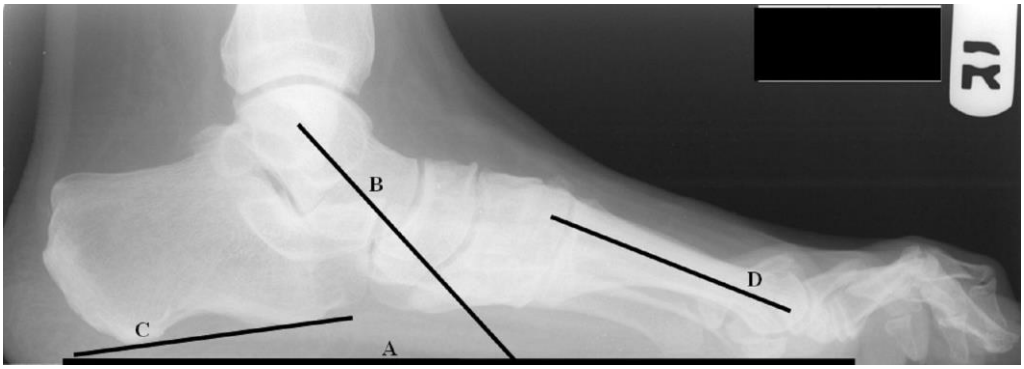

Figure 4: Weight bearing lateral view of a 46 y/o male with a symptomatic flatfoot deformity indicating sagittal plane component of the deformity. The talar declination angle is the resultant angulation between the supporting surface (Line A) and the longitudinal axis of the talar head and neck (Line B). The calcaneal inclination is the resultant angulation between the supporting surface (Line A) and a line tangential to the plantar aspect of the calcaneus (Line C). The talo-first metatarsal angle is defined by the angular relationship between the longitudinal bisection of the first metatarsal (Line D) and the longitudinal axis of the talar head and neck (Line B).

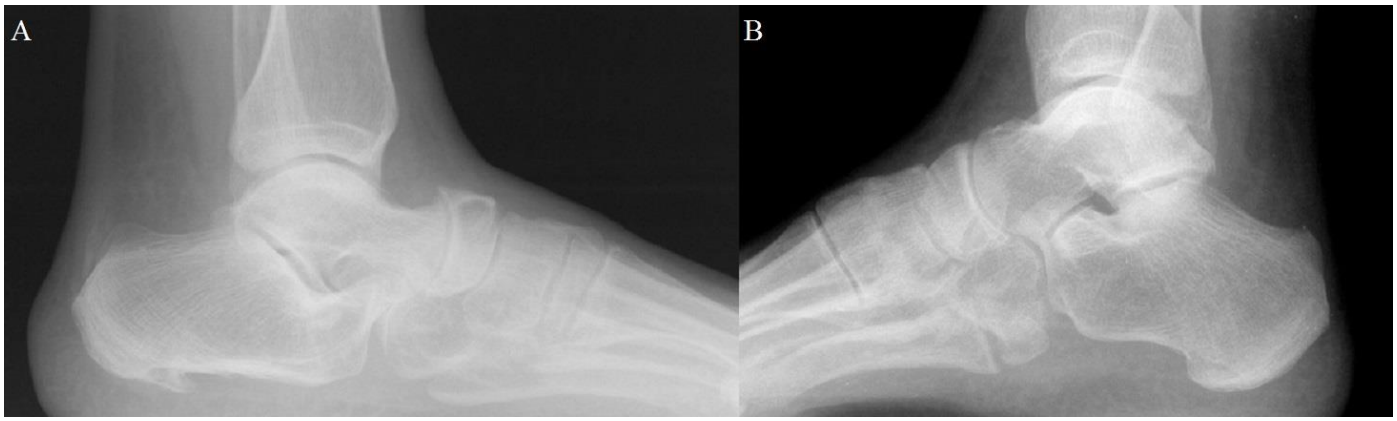

Figure 5: These cropped lateral radiographic views highlight differences appreciated in the appearance of the sinus tarsi between flatfeet and cavus feet. The sinus tarsi of the subtalar joint in Figure 5A of a 60 y/o male is not well visualized and may be termed "obliterated" when described in a flatfoot as the lateral talar process fills the space, while the sinus tarsi in Figure 5B of a 32 y/o male is very well visualized and may be termed "bullet hole" when describing a cavus foot.

Figure 6: These cropped lateral radiographic views highlight assessment of the midtarsal or Chopart's joint. In a rectus, or normally aligned, foot (Figure 6A of a 56 y/o female) one may expect to see a relative "S" shape formed by the outline of the calcaneocuboid and talonavicular joints. This continuous line is also referred to as the Cyma line. In a flatfoot (Figure 6B of a 42 y/o male), this "S" shape is displaced with the talonavicular joint found relatively anterior to the calcaneocuboid joint. This may be described as an "anterior break" in the Cyma line.

Figure 7: This cropped lateral view of a 29 y/o male highlights the medial column of the foot with an associated "break" or "fault" in the navicular-cuneiform joint. One can appreciate a relative depression along the dorsal aspect of the bones (highlighted with the overlying white lines) at the level of the "fault" at the navicular-cuneiform joint.

Figure 8: These long leg calcaneal axial views demonstrate a relatively rectus (Figure 8A of a 32 y/o female) and valgused (Figure 8B of a 46 y/o female) rearfoot. On the left one can appreciate a relative parallel relationship between the long axis of the tibia and the calcaneus compared to the valgused orientation of the calcaneal axis on the right. Further, the tibial axis can be extended to see where the calcaneal tuber strikes the ground relative to this landmark. On the left one can appreciate that the calcaneal tuber strikes the ground in close proximity to the extension of the tibial axis, whereas the calcaneal tuber strikes the ground well lateral to this line on the right.

Figure 9 (bottom): These cropped lateral and calcaneal axial views of a right foot of a 48 y/o male demonstrate a posterior facet subtalar joint coalition which may result in a rigid flatfoot deformity. On the lateral view (Figure 9A), one can appreciate extra radiodensity extending along the posterior and superior aspects of the subtalar joint (black arrow) which may be referred to as a "halo sign" and suspicious for coalition. This finding is confirmed with the calcaneal axial view (Figure 9B) which demonstrates a lack of joint space at the posterior facet (black arrow).

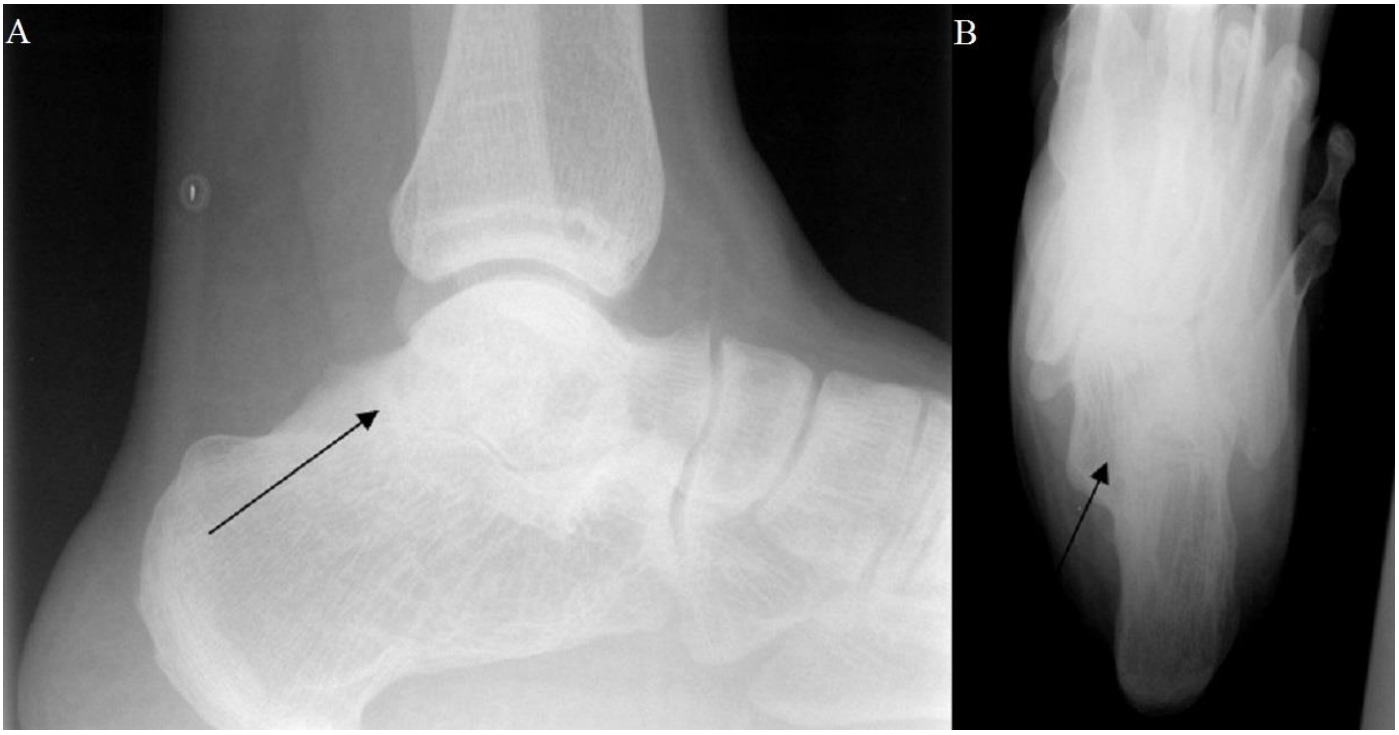

Figure 10: This lateral radiograph of a 26 y/o male is suspicious for a calcaneal-navicular coalition secondary to an elongated anterior process of the calcaneus (arrow) commonly referred to as an "anteater sign."

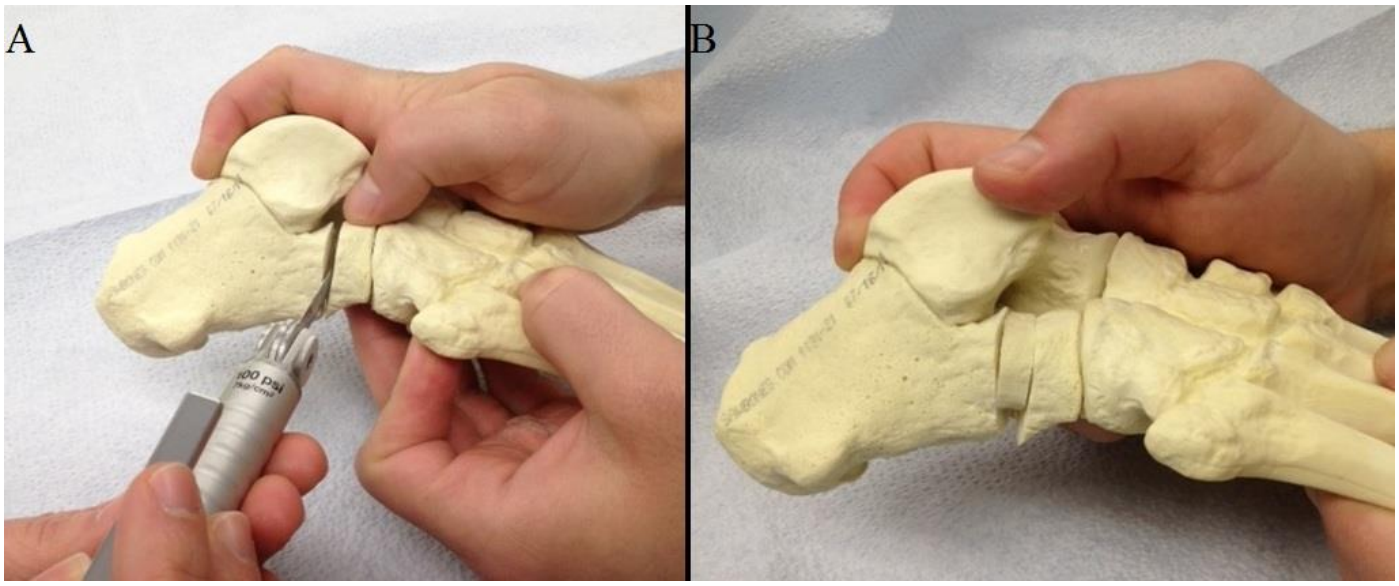

Figure 11: These bone models demonstrate performance of the Evans calcaneal osteotomy. First a sagittal saw or osteotome is used to cut through the anterior aspect of the calcaneus approximately 1cm proximal to the calcaneal-cuboid articulation from lateral to medial (left) . Then a wedge of bone graft approximately 1cm in diameter is inserted into the osteotomy effectively "lengthening" the calcaneus (right).

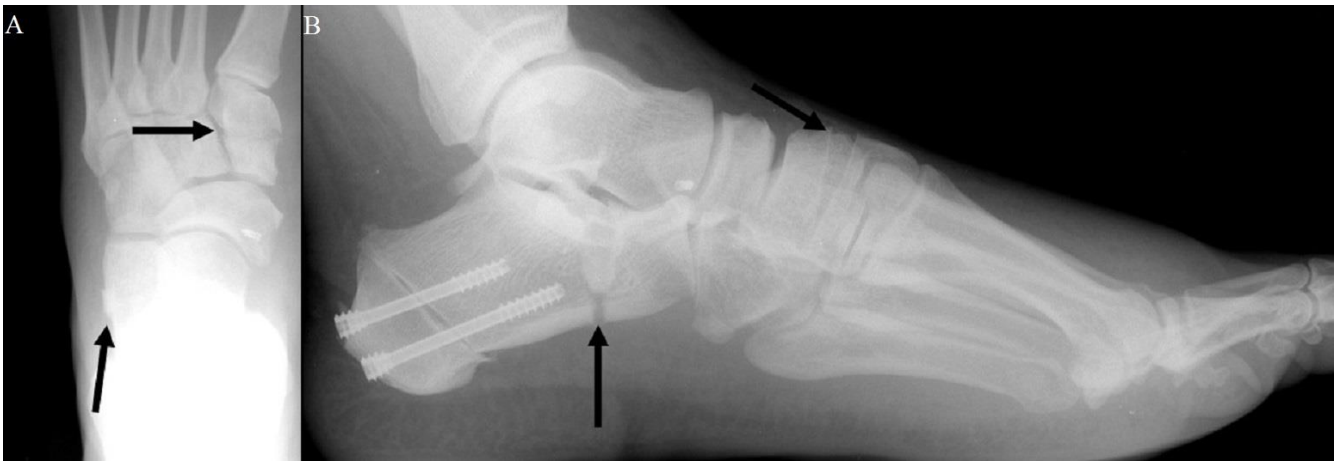

Figure 12: These cropped AP (Figure 12A) and Lateral views (Figure 12B) of a 46 y/o male demonstrate a patient following an Evans calcaneal osteotomy and Cotton medial cuneiform osteotomy (among other procedures). One can appreciate the location of the osteotomies and the presence of bone graft as highlighted by the arrows in the anterior calcaneus and medial cuneiform. An anchor in the navicular is also visible indicating a posterior tibial tendon advancement or flexor digitorum longus tendon transfer.

Figure 13 (left): The primary surgical intervention for correction of a sagittal plane component to a flatfoot deformity is soft tissue in nature and in the form of either an Achilles tendon lengthening (pictured here) or gastrocnmeius recession. These are completely soft tissue in nature, and therefore, not visible on plain film radiographs. Picture courtesy of Dr. John Steinberg, DPM.

Figure 15 (top): This calcaneal axial view of a 46 y/o male demonstrates a medial calcaneal slide osteotomy used for correction of a frontal plane component to a flatfoot deformity. A through-and-through osteotomy is performed through the calcaneal tuber with medial translation of the posterior fragment. This is nearly always held in place with internal fixation. This osteotomy will literally pull the calcaneal axis out of a valgus orientation and the tuber closer to an extension of the tibial axis extension (see Figure 8).

Figure 14 (bottom): These bone models demonstrate performance of the Cotton medial cuneiform osteotomy. First a sagittal saw or osteotome is used to cut the dorsal aspect of the medial cuneiform from dorsal to plantar in line with the first metatarsal-medial cuneiform articulation (Figure 14A). Then a wedge of bone graft is inserted into the osteotomy effectively plantarflexing the first metatarsal (Figure 14B).

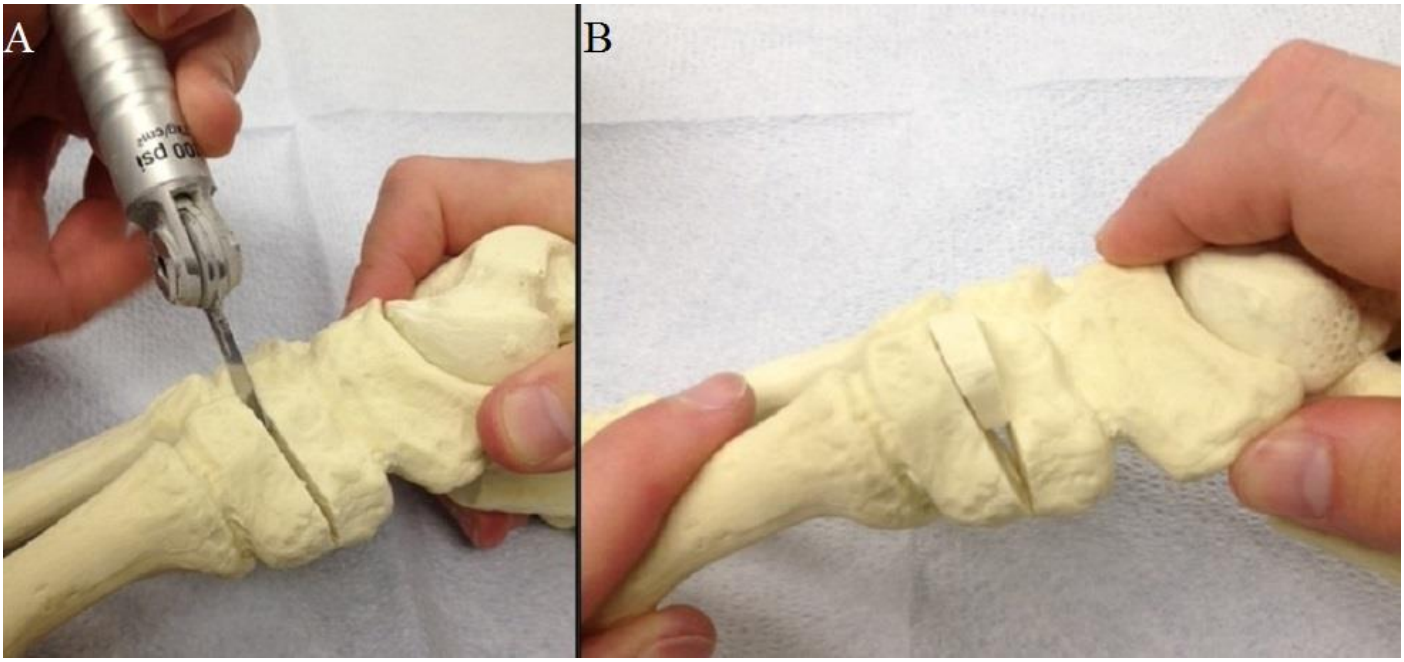

Figure 16: This lateral view of a 13 y/o male of a post-operative patient demonstrates implantation of a subtalar joint arthroeresis within the sinus tarsi. This is primary used on pediatric patients and provides a "stop" to excession subtalar joint motion in the direction of pronation.

Figure 17: This post-operative lateral radiograph of a 42 y/o male demonstrates the so-called "triple arthrodesis," or fusion of the subtalar, calcaneal-cuboid, and talar-navicular joints of the rearfoot. These joints can be fused individually for correction of deformity, or as a unit as demonstrated here. The joints are surgically prepared in such a way as to correct for triplanar angular deformity, and help in place with multiple internal fixation options.

Plane of Deformity; Radiographic Projection	**Radiographic Analysis**	**Surgical Procedures**

Transverse Plane; AP/DP view	• Talocalcaneal angle (Kite's angle)
	  ○ Normal 25-40 degrees
	• Calcaneocuboid angle
	  ○ Normal 0-5 degrees
	• Talar head coverage
	  ○ Normal 75-100%
		• Evan's calcaneal osteotomy
		• Posterior tibial tendon advancement
		• Flexor digitorum longus tendon transfer

Sagittal Plane; Lateral view	• Talar declination angle
	  ○ Normal 18-24 degrees
	• Calcaneal inclination angle
	  ○ Normal 25-40 degrees
	• Lateral talo-first metatarsal angle (Meary's angle)
	  ○ Normal parallel relationship
		• Achilles tendon lengthening
		• Gastrocnemius recession
		• Cotton medial cuneiform osteotomy

Frontal Plane; Long leg calcaneal axial view	• Frontal plane alignment of the talus and calcaneus relative to the long axis of the tibia • Position of the calcaneal tuber relative to an extension of the long axis of the tibia	• Medial calcaneal slide osteotomy • Subtalar joint arthroeresis

Table 1: Summary table of flatfoot radiographic evaluation and procedure selection.

ABBREVIATIONS

AP = anterior-posterior
CCA = calcaneocuboid angle
CIA = calcaneal inclination angle
DP = dorsal-plantar
TCA = talocalcaneal angle
TDA = talar declination angle

KEYWORDS

Podiatric surgery; Flatfoot; Calcaneal Osteotomy; Cotton osteotomy; Coalition