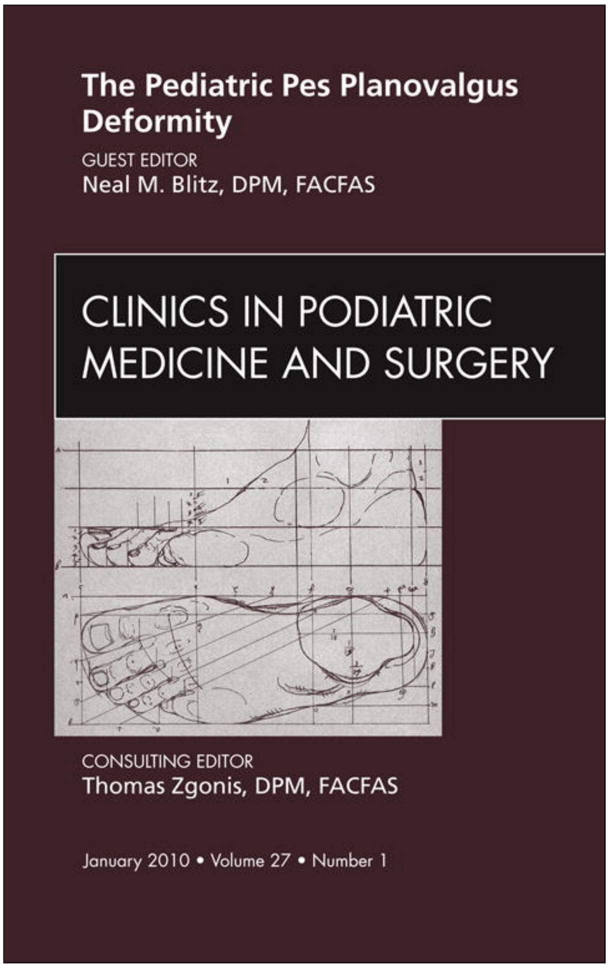
The Pediatric Pes Planovalgus Deformity
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Flexible Pediatric and Adolescent Pes Planovalgus: Conservative and Surgical Treatment Options

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KEYWORDS

• Flexible flatfoot • Pes planovalgus • Equinus

Symptomatic flexible pediatric pes planovalgus is a common problem encountered in the foot and ankle practice. There is a wide range of clinical presentations, both objectively and subjectively. Structurally, the feet may be mildly flat to severely flat, and may occur in a single plane or multiple planes. In this patient population, growth plates are typically open (skeletally immature) or near closure, which directly affects the treatment recommendations and pathways. The treatment goals are directed first at resolution of pain, and second at the realignment of the foot. Conservative management should be attempted before surgical intervention. Surgical reconstruction and the procedure selection are based on the physical examination, radiographs (standing), planal dominance, and resultant biomechanical compensations.[1] This article provides an overview of the common treatment pathways that highlight methods to structurally realign the pediatric and adolescent flatfoot.

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CONSERVATIVE MANAGEMENT

The conservative management of flexible flatfoot begins with education of the patient and the parents. Education should consist of the biomechanical findings that support the diagnosis of a flatfoot and the purpose of corrective devices if used. Different severities of deformity are present ranging from mild to the very severe symptomatic flatfoot. Some cases may be so mild that no treatment is indicated at the time; normal development and strengthening of the foot may be all the treatment indicated. Obtaining a family history, particularly of the parents and the patient's siblings about any similar problems, may be insightful about the genetic structure of the child's foot and provide a realm of familiarity to the parents concerning treatment for their child's condition.

Promoting and discussing proper supportive shoe gear is an important first-line treatment in the flexible flatfoot. Typically, an enclosed sneaker offers structural support to the skeletally immature foot. The sneaker should comfortably support an orthotic device if that is to be the next line of treatment. The shoe should have a firm sole to prevent the orthosis from compressing the medial side of the shoe.[2] High-top sneakers may be indicated if a large amount of instability is present within the ankle and subtalar joints. Certain types of shoes such as sandals and moccasin styles should be discouraged because they may fail to provide the structural support that the skeletally immature patient needs.

Passive stretching of the tendo-Achilles complex can be done if an equinus deformity exists, and the stretching should be part of the conservative approach to flexible flatfoot. Equinus can be a strong deforming force in the sagittal plane and also influences the frontal and transverse plane position. Statically and dynamically, an equinus contracture can result in the breakdown of the midfoot, clinically seen as flattening of the arch and abduction of the midfoot. One may visualize equinus dynamically as an early heel-off in gait. Multiple exercises for stretching the Achilles tendon can be easily taught to the patient. Active strengthening exercises do not provide any benefit to an equinus condition unless a muscle weakness is noted.

Nonsteroidal anti-inflammatory drugs may be used if symptoms of inflammation are present. Medial column collapse and strain may present as an inflammatory process and warrant the use of anti-inflammatory medications in conjunction with resting and icing to alleviate the symptoms. Apophysitis is common in the skeletally immature patient and requires similar treatment.

Orthotic therapy in the pediatric flexible flatfoot helps restore structure and support to the medial column. The purpose of a functional orthosis is to control the amount of pronation across the subtalar joint, thereby restoring the support and alignment to the talocalcaneal joint. Either an increase in the supination moment or a decrease in the pronation moment will achieve the desired result on weight bearing.[2] According to Valmassy,[3] a functional orthosis device is only appropriate for use in a pediatric patient after a heel-to-toe gait has begun. According to Jay and colleagues,[4] a pediatric orthotic device should attempt to accommodate the intrinsic and extrinsic structural deformities, provide rigidity for control but accommodate the natural foot shape, create postural alignment of the foot to the leg, and finally contain materials that enhance the patient-orthoses interface. As a first-line orthotic treatment, the dynamic stabilizing innersole system serves to control hyperpronation in young children via stabilization of the medial and lateral columns and to control calcaneal eversion through a deep heel seat. This device is typically used in the first few years after ambulation has begun.[4] The University of California at Berkeley Laboratory (UCBL) orthotic device is another example of a device that can control the flexible flatfoot deformity demonstrating hyperpronation and to be used early in the child's life. The advantage of the UCBL orthotic device is its high medial and lateral flanges to provide control of the rearfoot and midfoot complexes, especially when increased transverse plane deformity is seen. Other foot orthoses types that have been used in the pediatric population are Whitman-Roberts orthoses, heel stabilizers, and Schaffer type orthoses.[4]

Compliance can become an issue with these devices and may require thorough explanation and education to the parents. A discussion of how the orthotics function to help support and provide realignment to the foot may be beneficial in helping the parents understand why such a treatment is necessary. In addition, visual aids, such as a skeleton foot model placed over an actual orthotic device, can demonstrate the ability of the device to capture the foot and prevent arch collapse. It allows the patient and parents to visualize the purpose of the prescribed device.

For the more severe flatfooted deformity or the ligamentous laxed patient, in whom ankle instability, posterior tibial tendon symptoms, or early arthrosis has developed, an ankle-foot orthosis (AFO) or a more proximal device can be more appropriate. The adolescent, skeletally mature patient may benefit somewhat from these types of orthoses or as a last line of nonsurgical treatment. The goal of these devices is to facilitate the transmission of deforming forces onto external materials, and to assist normal ground reactive forces through corrected functional anatomy and alignment.[5] In case of equinus, in which there is restriction of ankle joint range of motion, specific devices such as rocker bottom shoe soles, torque absorbing AFOs, and proximal weight-bearing AFOs can be used.

SURGICAL TREATMENT

Surgical intervention for the flexible pediatric flatfoot is typically reserved for symptomatic feet that have not responded to conservative measures. The goals of surgery are simple: pain reduction or resolution and realignment of the foot. Although attaining these goals may be difficult because there are such a wide variety of clinical presentations ranging from mild flatfeet to severe flatfeet with a multitude of planal dominance contributions, that surgical realignment may be challenging. A variety of surgical methods have been described to correct the flexible pediatric flatfoot, and they are categorized in 3 types: (1) reconstructive osteotomies (extra-articular), (2) arthroereisis, and/or (3) arthrodesis.[6,7] Less commonly considered as a distinct category are the medial column soft tissue procedures (**Box 1**).

Flatfoot procedure selection often involves a combination of these types of procedures and it is critical to understand the pathomechanics and planal dominance of each individual foot as a separate entity when considering surgical intervention and developing a strategic surgical plan. Although many of the surgical procedures may be performed individually, often reconstructions involve a combination of soft tissue and osseous procedures (osteotomies and/or fusions) to achieve correction. In addition to the level and degree of deformity, surgeons must also consider age and skeletal maturity.

SURGICAL MANAGEMENT OF EQUINUS

Equinus correction is almost universally performed along with a pediatric flatfoot correction. The contribution of gastrocnemius, soleus, and/or both the muscle groups to equinus dictates the surgical management. The Silfverskiold test is necessary to determine the location of contracture, and is covered elsewhere in this issue. Isolated gastrocnemius contracture may be resolved with a gastrocnemius recession and multiple techniques may be used.[8] A Strayer recession involves completely transecting the gastrocnemius aponeurosis, thus eliminating gastrocnemius contribution,[9,10] although surgical reattachment, or scaring down of this aponeurosis, may provide

Box 1
Surgical treatment categories for flexible flatfoot

Arthroereisis

- Subtalar

Soft tissue medial column procedures

- Kidner procedure
- Young tenosuspension
- Modified Kidner-Cobb

Osteotomies

- Medial column
  - Cotton medial cuneiform
- Rearfoot
  - Medializing calcaneal osteotomy
  - Evans calcaneal osteotomy
  - Double calcaneal osteotomy

Arthrodesis

- *Medial column*
  - Lapidus
  - Hoke
  - Miller
- *Rearfoot*
  - Isolated talonavicular joint
  - Isolated subtalar joint
  - Isolated calcaneocuboid joint and/or distraction
  - Double rearfoot fusion
  - Triple arthrodesis

some return of gastrocnemius function in a lengthened state. Gastrocnemius equinus may also be managed by lengthening only the muscular bound gastrocnemius aponeurosis (gastrocnemius intramuscular aponeurotic recession or Baumann), which theoretically only weakens the gastrocnemius pull while preserving the natural anatomic insertional attachment of gastrocnemius onto soleus.[11–14] When concomitant soleus equinus exists, aponeurotic lengthening of soleus may also be performed. Endoscopic gastrocnemius recession has also been used.[15] The Vulpius procedure and Baker tongue-in-groove recession are other methods to manage gastrosoleal equinus above the Achilles tendon (**Fig. 1**).[8,16,17] Alternatively, surgeons may perform a tendo-Achilles lengthening through an open or percutaneous technique.

Arthroereisis

Subtalar arthroereisis describes a procedure where a spacer is placed into the sinus tarsi, restricting pronation.[6] Pronatory forces can be reduced by limiting the contact of the lateral talar process against the calcaneal sinus tarsi floor, therefore maintaining a more neutral position of the talocalcaneal joint. It is a means of reducing joint motion

Fig. 1. Tongue-in-groove gastrocnemius recession for gastrosoleus equinus in pediatric patient.

without sacrificing total loss of motion (ie, arthrodesis) to provide stability to the rearfoot. It should be noted that arthroereisis is used as an adjunctive procedure, which can be powerful in correcting frontal plane deformity.

Historically, arthroereisis involved extra-articular bony blocks.[18–20] Nowadays, most arthroereisis procedures involve implants (removable, if necessary) that are less invasive and do not require cutting, drilling, or direct implantation into the calcaneus. Several products currently exist on the market for this procedure, and differences in the design of these implants are not discussed in this article, but the purpose of the implant is to be "well-seated" within the sinus tarsi, thus preventing collapse of this space (ie, pronation).

A distinct advantage of the arthroereisis procedure in the pediatric population is that the implant provides structural realignment of the rearfoot complex during skeletal growth, which may become a permanent correction as the child reaches and surpasses skeletal maturity. As such, the implant may be removed as the child skeletally matures. According to Giannini,[21] surgery performed during growth provides an optimal and lasting correction of the deformity, restoring the talocalcaneal alignment with remodeling of the subtalar joint.

More contemporary are the bioabsorbable implants that obviously do not require removal. However, potential limitations include foreign body reaction and surgical challenges when placing the radio-translucent implant. The bioabsorbable and metallic implants have been reported to occasionally cause symptoms requiring explantation of the device, however these reports occurred in adults.[22,23] It is possible that pediatric patients may better tolerate a sinus tarsi implant because skeletal immaturity may adapt to a changing environment.

Proper sizing and placement of the implant, whether it is absorbable or metallic, is crucial to the success of the arthroereisis procedure. Too large an implant may result in lateral symptoms and too small may result in under correction.[22] Assessment of the range of motion should be performed on the talocalcaneal joint intraoperatively after insertion of the trial implants to achieve a neutral position. Pronation of the subtalar joint should be restricted but not eliminated. Intraoperative fluoroscopy to visualize the transverse position of the implant within the sinus tarsi is also used. The leading (medial) edge of the implant should be placed at the bisection of the talus.

Arthroereisis may be used in isolation for flexible flatfoot repair or in combination with other reconstructive flatfoot procedures, such as soft tissue procedures of the medial column, osteotomies, and/or fusions. The individuality of these procedures are discussed later, but the theoretical concept is that the "pronation blockade" by arthroereisis helps support the subacute postsurgical healing of medial column procedures (soft tissue and/or osseous) by preventing collapse from premature weight bearing. In addition, while the subtalar arthroereisis corrects the rearfoot malalignment, it may uncover a concomitant forefoot varus once the rearfoot is aligned (**Fig. 2**) and surgeons may want to consider combining the reconstruction with a medial column procedure that brings the medial column into alignment.

SOFT TISSUE MEDIAL COLUMN RECONSTRUCTIONS

The Kidner Procedure

The Kidner procedure is best known for its place in removal of a symptomatic accessory navicular (os tibiale externum) or hypertrophic navicular, which may often be a pathologic component of pediatric flexible pes planovalgus.[24] The presence of this accessory bone has been implicated in transmitting a functional disadvantage to the posterior tibialis tendon (the most significant inverter of the foot). One study reported that the presence of an accessory navicular plays no role in the development of a flatfoot.[25] An accessory navicular may be a pain producer if enlarged and/or synchondrotic with the navicular. Advanced imaging with computed tomography (CT) and/or magnetic resonance imaging (MRI) may be invaluable in making this distinction, whereas bone scan has not been shown to be useful.[26] The main role of

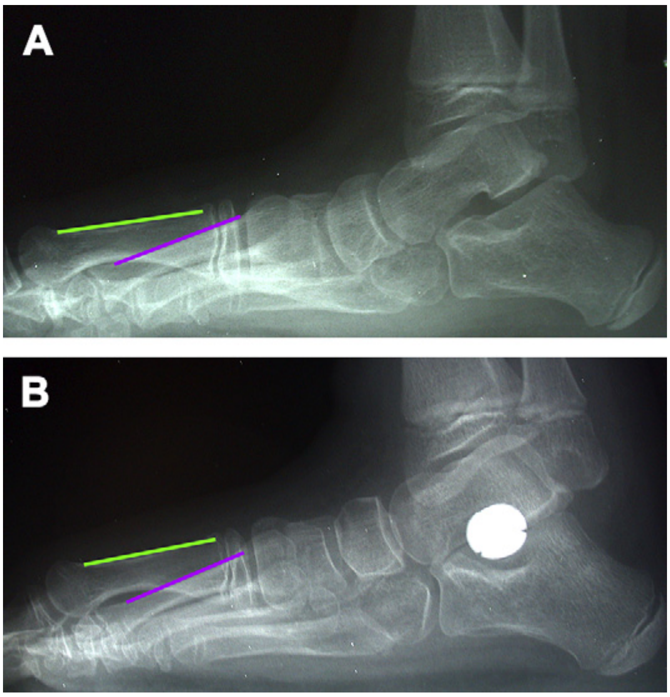

Fig. 2. Preoperative (*A*) and postoperative (*B*) lateral weight-bearing radiographs of subtalar arthroereisis in skeletally immature patient. The forefoot varus is evident after the arthroereisis realigns the rearfoot. Note the elevation of the first ray (dorsal cortex of the first metatarsal joint, *green line*) compared with the second metatarsal joint (dorsal cortex of the second metatarsal, *purple line*). A flexible forefoot varus should correct over time.

the Kidner procedure (a soft tissue medial column procedure) is to restore the mechanical advantage of the posterior tibial tendon. Other procedures that balance and/or structurally realign the foot may be required, especially procedures involving the rearfoot and/or lateral column (**Fig. 3**).

Bennett and colleagues[27] reported their retrospective review of 50 consecutive patients (75 feet) with symptomatic accessory navicular or prominent navicular tuberosity who underwent simple excision without alteration of the tibialis posterior course. Good or excellent results were reported by 90% of the patients. Koop and Marcus[28] retrospectively reviewed the Kidner procedure on 13 consecutive patients (14 feet) for simple resection of symptomatic accessory navicular bones, in a slightly older patient population (mean age 28.2 years), demonstrating an average postoperative American Orthopaedic Foot and Ankle Society (AOFAS) score of 94.5. Tan and colleagues[29] compared simple ossicle resection versus the Kidner procedure in 18 patients, over an average follow-up time of 3.1 years, and they demonstrated that both procedures alleviated symptoms in 15 of the 18 patients. Prichasuk and Sinphurmsukskul,[30] in their review of 28 patients, identified that the isolated Kidner procedure itself did not significantly restore the medial longitudinal arch,. These studies support the contention that the main purpose of the Kidner procedure is to manage the protuberance of the navicular and/or accessory ossicle and that it should not be considered as a major reconstructive procedure to restore the medial longitudinal arch when performed in isolation.

The surgical approach involves a medially based incision directly over the hypertrophic navicular tuberosity and/or os tibialis externum. Esthetically, surgeons should consider a concave incision (keeping in mind the relaxed skin tension lines) because this orientation gives the appearance of an arch when healed, which is advantageous when correcting a flatfoot deformity. The posterior tibialis is detached from the accessory navicular maintaining as much length of the tendon as possible. Once the ossicle is removed, any enlargement or prominence of the navicular tuberosity is also removed. The posterior tibialis tendon may be advanced on the navicular tuberosity, and placed inferiorly to restore its native attachment. Reattachment is most routinely performed with bone anchors, placing the foot in an inverted and plantar flexed position. Postoperative course involves non–weight bearing until the tenodesis has healed, a process that may take 6 to 8 weeks.

Modified Kidner-Cobb

The modified Kidner-Cobb procedure is a modification of the Kidner procedure, where a section of tibialis anterior is used to reinforce the insertion of the posterior tibial repair (**Fig. 4**).[31–34] Because the section of the tibialis anterior that is transferred is no longer connected to the pulling action of the tibialis anterior, the adjunctive nature of this procedure is merely to support other medial column soft tissue work. In 2003, Viegas[35] reviewed 17 consecutive pediatric patients (34 feet), over a 5-year period, who underwent reconstruction of flexible pediatric pes planus using a medial split tibialis anterior tendon in conjunction with a Kidner, Evans, and tendo-Achilles lengthening. Radiographic measurements improved statistically with the aforementioned reconstruction.

It is the authors' opinion that this modification be considered when (1) significant degeneration of the posterior tibialis tendon has occurred, (2) there is difficulty reattaching the posterior tibial tendon after a large os tibiale externum is removed and/or a large navicular tuberosity is resected, and (3) it is necessary for a spring ligament support.

Young Tibialis Anterior Tenosuspension

This soft tissue procedure, first described in 1939, involves inferior transpositioning of the tibialis anterior tendon through a slit or a hole in the navicular tuberosity, while

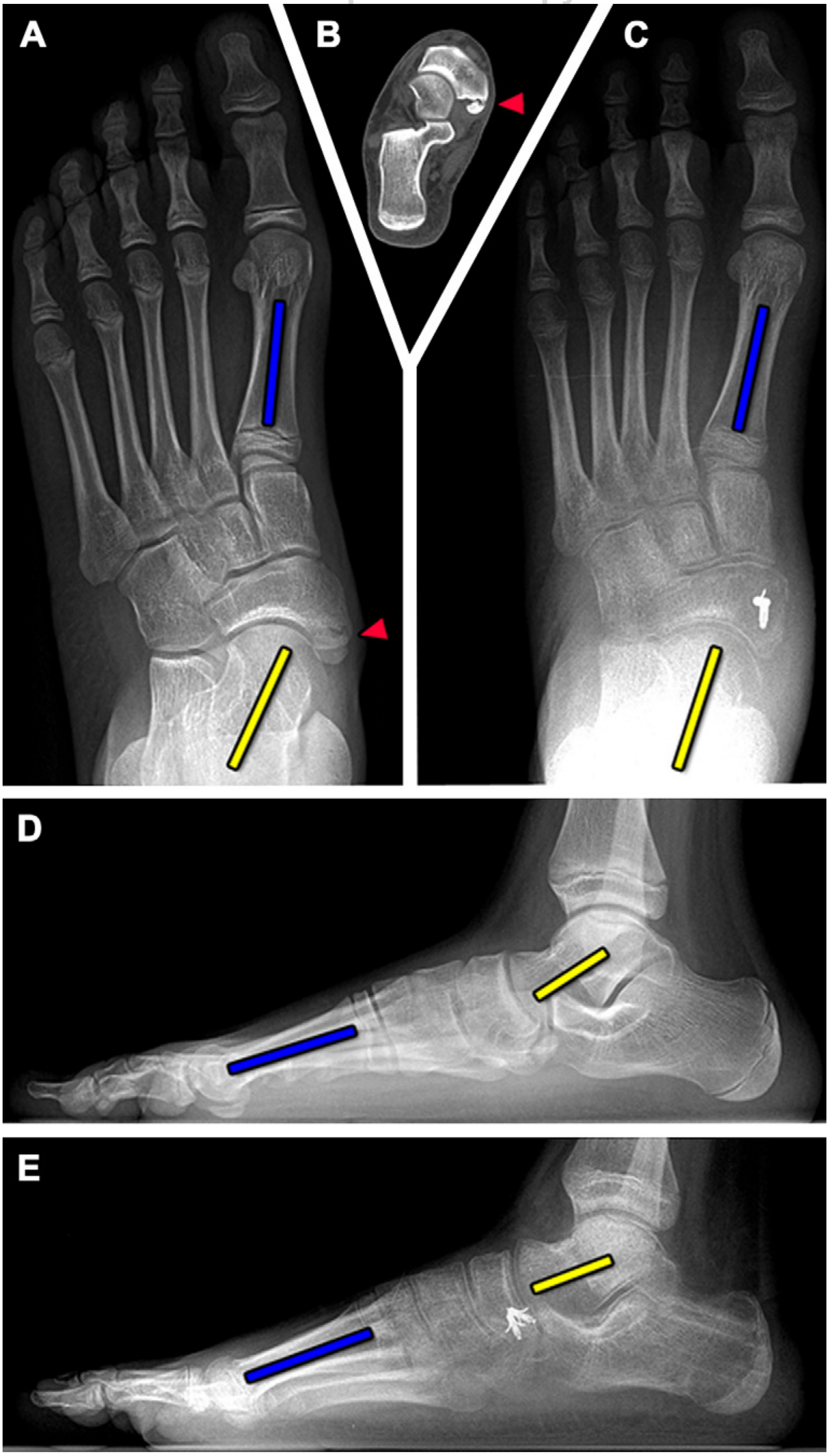

Fig. 3. 12-year-old skeletally immature girl with a symptomatic painful pes planovalgus and accessory navicular. Flatfoot reconstruction involved Kidner procedure with bone anchors and a medializing calcaneal osteotomy. (*A, D*) Preoperative weight-bearing radiographs. (*B*) Preoperative CT scan illustrates the synchondrosis (*red arrowhead*) between the accessory bone and the navicular. A fragmented interface suggests that the union may be interrupted. (*C, E*) Postoperative weight-bearing radiographs. In addition to excising the accessory bone, the enlarged navicular was also resected. The calcaneal osteotomy was fixated with smooth Steinmann pins (removed) as the calcaneal apophysis was open at the time of surgery. Realignment of this foot is evident as the talo-first metatarsal angle is restored in the transverse and the sagittal planes (*yellow* and *blue lines*). Patient is pain free.

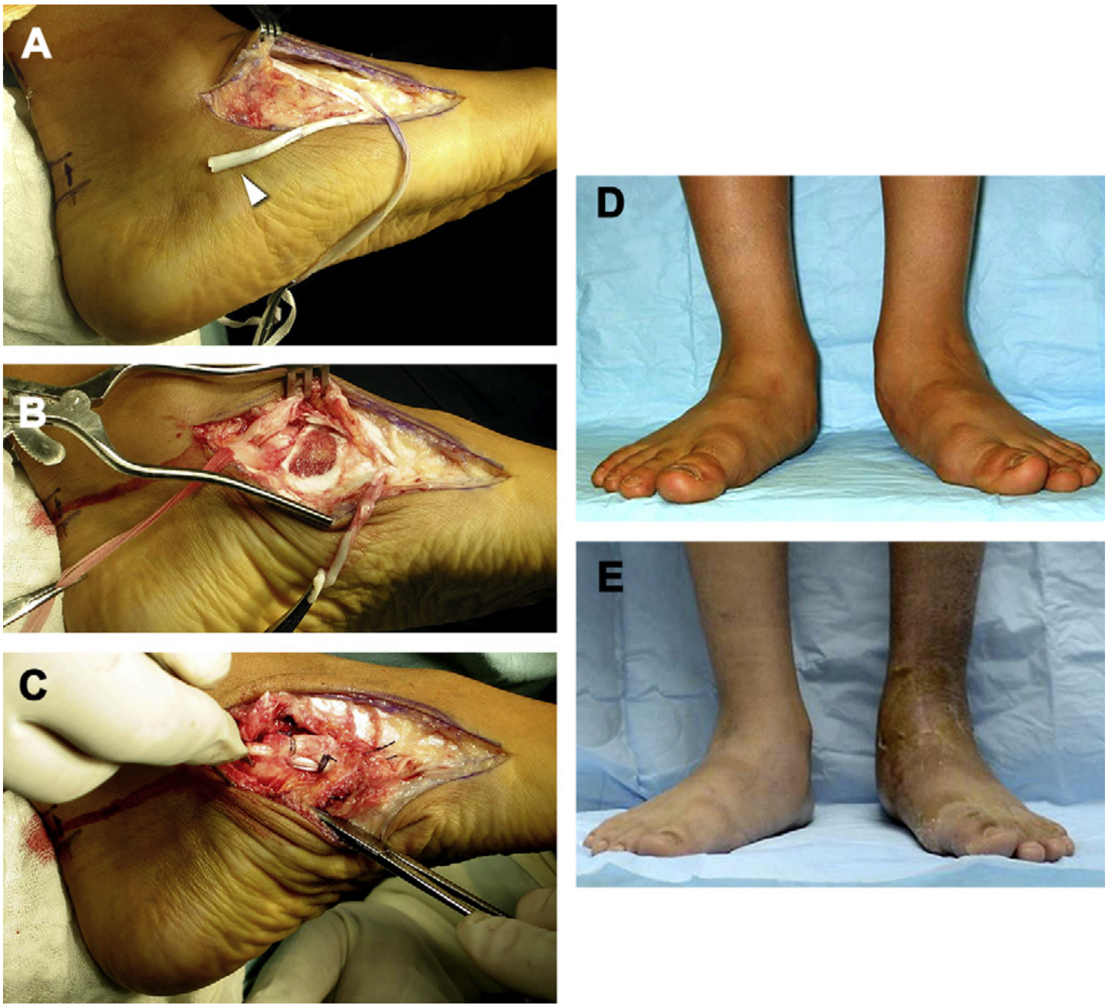

Fig. 4. Intraoperative series demonstrating the modified Kidner-Cobb technique. (*A*) The inferior portion of tibialis anterior is split. Proximally, the inferior half of the tendon is transected, and distally the attachment remains intact. (*B*) An enlarged navicular tuberosity is resected exposing cancellous bone. (*C*) Kidner procedure is performed (reattachment of the tibilais posterior to the navicular tuberosity) and reinforced with the split tibialis anterior tendon. (*D*) Clinical images before left foot reconstruction involving percutaneous tendo-Achilles lengthening, modified Kidner-Cobb, and subtalar joint arthroereisis. (*E*) Postoperative clinical image demonstrating improved medial arch height.

keeping its native attachment onto the first metatarsocuneiform joint intact.[36] This procedure has fallen out of favor with more advanced techniques available, but nonetheless, surgeons may see indications for its use on a case-by-case basis. In 1995, Cohen-Sobel and colleagues[37] performed the modified Young tenosuspension in conjunction with Evans calcaneal osteotomy and tendo-Achilles lengthening in 10 patients (12 feet) for severe flatfeet. In 1997, Dragonetti and colleagues[38] reported their retrospective results by comparing subtalar arthroereisis and tendo-Achilles lengthening with or without Young tenosuspension in 2 series of 15 feet. With regard to outcomes, the only statistically significant difference between the groups was the reduction of forefoot supination in the group that underwent Young tenosuspension.[38]

RECONSTRUCTION INVOLVING OSTEOTOMIES

Medializing Calcaneal Osteotomy

The medial calcaneal osteotomy is a common procedure in flatfoot reconstruction.[39,40] It is most useful when frontal plane deformity of the posterior calcaneal tuberosity exists (valgus of the heel). The procedure structurally realigns the calcaneus beneath the leg, which restores the biomechanical advantage of the Achilles tendon as a rearfoot inverter. Several techniques have been described.[41,42] Classically, the procedure involves an oblique lateral incision over the tuber, such that the sural nerve is avoided and the lateral aspect of the calcaneus is accessed at a level posterior to the subtalar joint and distal to the insertions of the Achilles tendon and plantar fascia. A through and through osteotomy of the heel allows the posterior tuber to be transposed medially. Although an obliquely linear osteotomy seems to be most popular, surgeons have also described other osteotomy orientations, such as a calcaneal scarf.[43] More contemporary is the percutaneous technique that involves a Gigli saw (**Fig. 5**).[44] The advantages of this method include (1) avoidance of the sural nerve, thus lessening the chance for iatrogenic sural nerve complications, (2) potentially less soft tissue complications (such as wound dehiscence), (3) cosmetically considerate, and (4) limited dissection around the lateral rearfoot allowing for less stress of the soft tissue for other concomitant nearby procedures to be performed within the same surgical setting.

Evans Calcaneal Osteotomy

Evans calcaneal osteotomy is used mainly for transverse plane flatfoot deformity by lengthening the lateral column.[45] The procedure is popular because it allows for

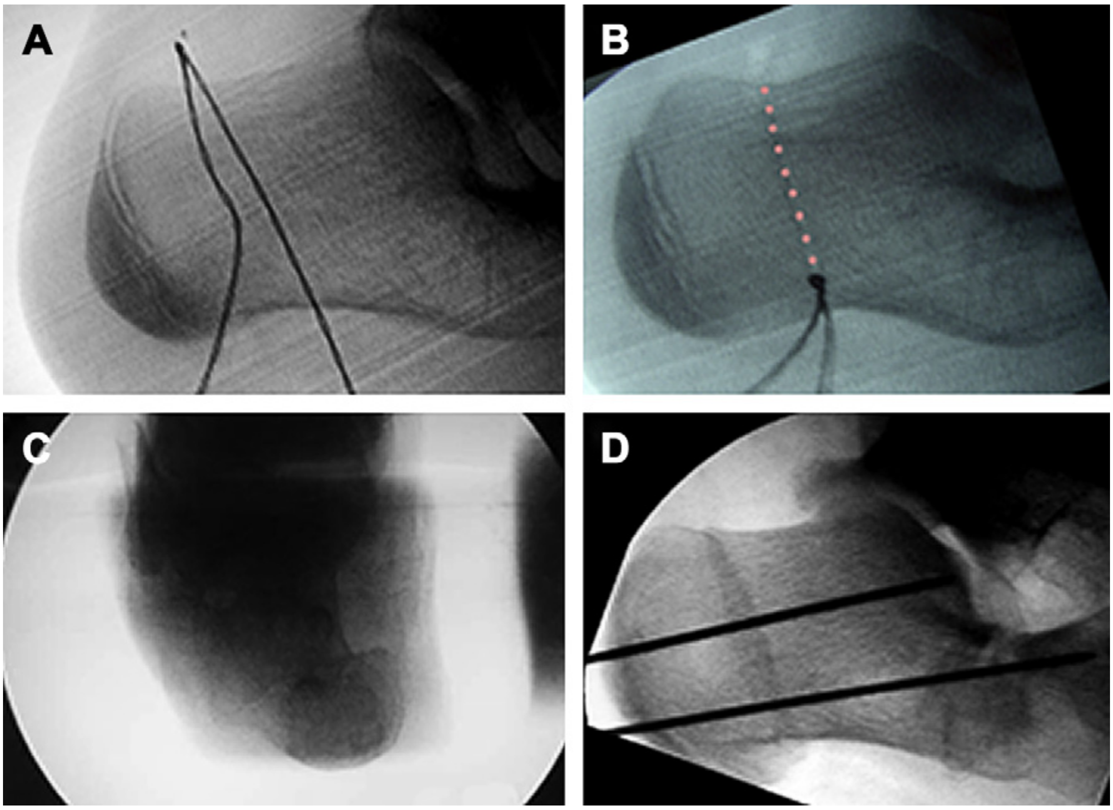

Fig. 5. Intraoperative fluoroscopic series demonstrating the technique for percutaneous calcaneal displacement osteotomy. (*A*) Gigli saw placement verified before performing the osteotomy. The osteotomy should be within the body of the calceaneal tuber, anterior to Achilles tendon insertion (and/or physis), and posterior to the subtalar joint. (*B*) The osteotomy is performed from superior to inferior direction. Here the Gigli saw is just about to penetrate the inferior calcaneal cortex for a through and through osteotomy. (*C*) Axial view demonstrating medial displacement of posterior fragment of tuber. (*D*) Fixation with 2 smooth K wires (or Steinmann pins), when the physis is open.

extra-articular correction of flatfoot deformity, which is especially desirable in the adolescent patient (**Fig. 6**). Traditionally, lengthening is achieved by inserting a bone graft into the anterior aspect of the calcaneus through a transverse osteotomy. Surgeons have varied the orientation of the osteotomy, the graft material (autograft, allograft, and synthetic), the absence and/or presence of a medial hinge, and the fixation constructs.[46,47] The amount of lengthening varies and is determined by the clinical scenario (ie, degree of deformity), and it is often an intraoperative decision as the surgeon can dial-in the amount of lengthening. Graft sizes of 5 to 15 mm have been used. Complications of the Evans procedure include delayed union, nonunion, malunion, subluxation of the calcaneocuboid joint, and persistent lateral column pain. The cause of lateral column pain may be related to jamming of the calcaneocuboid joint as contact characteristic studies after Evans procedure demonstrated increased pressure and altered contact patterns.[48,49] A cadaveric study by DiNucci and colleagues[50] measured strain on the long plantar ligament with sequentially increasing graft size with Evans procedure. They concluded that grafts more than 6 mm have no additional corrective capacity without compromising the long plantar ligament. Either larger graft size or loss of the long plantar ligament could compromise the intrinsic stability of the lateral column of the foot.[50] Another cadaveric study performed by Tien and colleagues[51] suggested that lateral column lengthening caused increased lateral forefoot plantar pressure, which was more pronounced during calcaneocuboid distraction arthrodesis than the Evans procedure. A more contemporary approach at lengthening is callus distraction with external fixation,[52] which allows for gradual lengthening (both the bone and soft tissue) with time, but it is criticized for the need for an external fixator.

Mosca[53] performed flatfoot reconstructions (or skew foot reconstructions) in 20 patients with Evans calcaneal osteotomy for symptomatic severe flatfoot. In 5 patients with skew foot, a Cotton medial cuneiform osteotomy was also performed. Follow-up was from approximately 5 to 16 years from the index operation. Satisfactory clinical

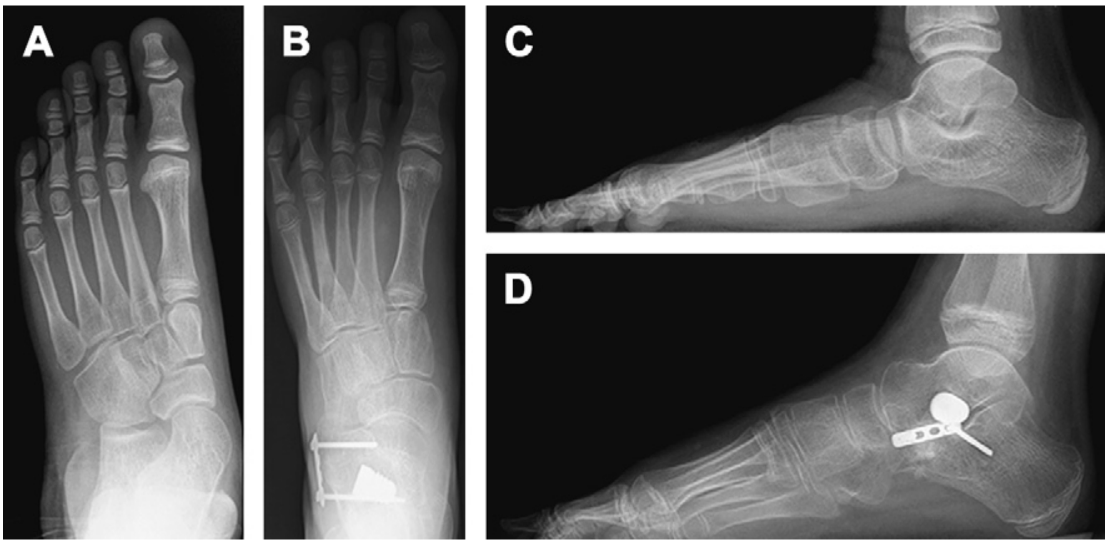

Fig. 6. Evans calcaneal osteotomy combined with subtalar arthroesis in an 11-year-old boy with flexible pes planus. (*A, C*) Preoperative weight-bearing images demonstrate transverse plane and sagittal plane deformity at the talonavicular joint. Dorsilateral peritalar subluxation and calcaneal cuboid abduction is present. (*B, D*) Postoperative images. Comparison of the anteroposterior views illustrate how the Evans osteotomy is capable of correcting the cuboid abduction. The lateral postoperative image is non–weight bearing. (*Courtesy of* Dan Choung, DPM, San Rafael, CA.)

and radiographic correction was achieved in all but 2 patients. He concluded that the aforementioned extra-articular reconstruction resolved the flatfoot-associated symptoms and avoided the need for arthrodeses procedures.[53] Davitt and colleagues[54] performed distal calcaneal lengthenings in children and adolescents (11 feet, 9 patients) and demonstrated improved radiographic values (talonavicular coverage angle and talo-first metatarsal angle, in a mean follow-up of 11.1 months). Ten of the 11 feet had excellent or good postoperative AOFAS scores.

Double Calcaneal Osteotomy (Medializing Calcaneal Osteotomy and Evans Calcaneal Osteotomy)

Surgeons have combined the benefits of the transverse plane correction achieved with Evans osteotomy and the frontal plane correction achieved with the medializing calcaneal osteotomy of the tuber, by performing a double calcaneal osteotomy for adolescent and adult flatfoot.[55] Catanzariti and colleagues[42] used the procedure in 8 patients with either adolescent flatfoot or adult late stage II posterior tibial tendon dysfunction. Moseir-LaClair and colleagues[56] performed 28 adult flatfoot reconstructions using a double calcaneal osteotomy combined with flexor tendon transfer and tendo-Achilles lengthening. The mean postoperative ankle-hindfoot AOFAS score was 90 with a mean follow-up of 5 years.[56]

A major advantage of the double calcaneal osteotomy in adolescent patients is that multiple planes of deformity can be corrected with preservation of the growth plates. In addition, the procedure is a joint sparing procedure. When performing the double calcaneal osteotomy, surgeons must be considerate of the incisional approach because accessing the anterior and posterior aspect of the calcaneus through a lateral approach may strain the soft tissue and result in dehiscence. A minimally invasive approach to the medializing calcaneal osteotomy component of the double calcaneal osteotomy may be beneficial.

Cotton Medial Cuneiform Osteotomy

The Cotton medial cuneiform osteotomy[57] is a procedure known for its use in pediatric and adolescent flexible flatfoot, and it is used for medial column collapse. The procedure calls for the insertion of an opening wedge bone graft (apex plantar) into the midsubstance of the medial cuneiform for the main purpose of sagittal plane correction of the collapsed medial column, although mild transverse plane correction may also be achieved. The procedure seems to be most advantageous in children and the adolescent population with flexible pes planovalgus deformities because it preserves the growth plate of the first metatarsal base in the skeletally immature patient, when medial column arthrodesis may otherwise be contraindicated.

Use of medial cuneiform osteotomies date back to 1908, when Riedel used a closing wedge osteotomy for hallux abducto valgus deformities to address the "atavistic" cuneiform.[58,59] In 1910, Young[60] reported on the opening wedge osteotomy for the correction of hallux abducto valgus, although Fowler[61] popularized the osteotomy for correction of forefoot adduction associated with a cavovarus deformity. In 1935, Cotton[57] (after whom the procedure is named) reported on opening wedge osteotomy using an allogenic femoral head graft as a sagittal plane structural correction for a depressed medial column in pes planus.

The Cotton osteotomy is rarely used as an isolated procedure in flatfoot reconstructions, however (**Fig. 7**) it is often combined with procedures that realign the rearfoot. It is well known that a compensatory forefoot varus exists in flexible flatfoot deformities, which becomes accentuated with correction of the rearfoot. The Cotton osteotomy corrects this deformity by plantar flexing the medial column, establishing an

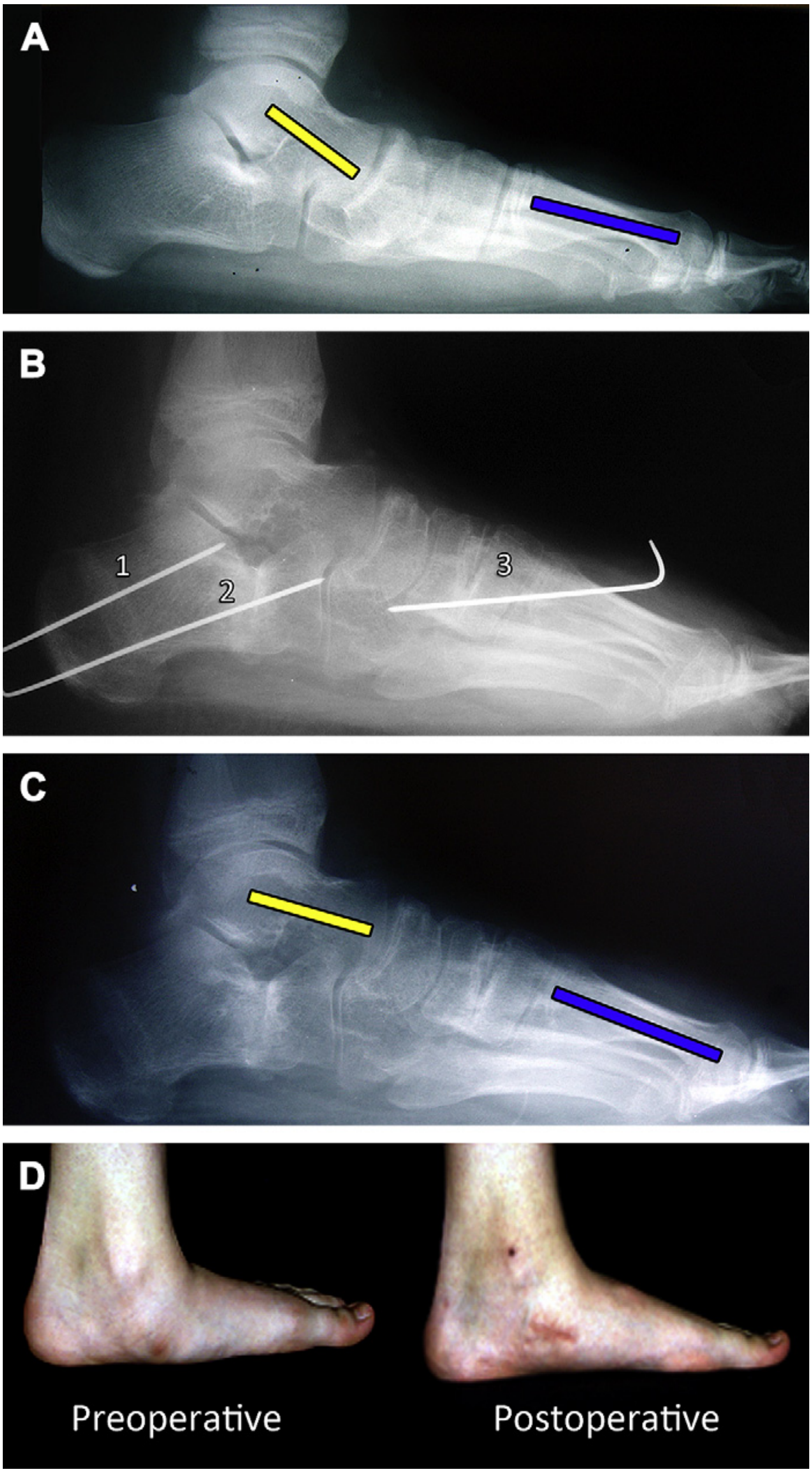

Fig. 7. Flatfoot reconstruction involved the following procedures: endoscopic gastrocnemius recession, double calcaneal osteotomy, Cotton osteotomy, and first metatarsal base osteotomy. (*A*) Preoperative weight-bearing lateral radiograph demonstrating the disruption of the talo-first metatarsal alignment (*yellow* and *blue lines*) with naviculocuneiform sag. Note the open physis demonstrating skeletal immaturity. (*B*) Postoperative lateral radiograph demonstrating the extra-articular osteotomies and fixation placement: (1) medial calcaneal displacement osteotomy, (2) Evans calcaneal osteotomy, and (3) Cotton medial cuneiform osteotomy and first metatarsal base osteotomy. (*C*) Postoperative weight-bearing radiographs demonstrating healing of all osteotomies and restoration of proper talo-first metatarsal alignment (*yellow* and *blue lines*). (*D*) Clinical preoperative and postoperative images of the aforementioned procedures demonstrating obvious visual improvement of the medial longitudinal arch.

immediate appropriate forefoot to rearfoot relationship.[57] The advantages of this technique (compared with first tarsometatarsal arthrodesis) include predictable union, preservation of first ray mobility, preservation of the open growth plate, and the ability to easily vary the amount of correction. However, the procedure should only be performed after ossification of the medial cuneiform (typically in children more than 6 years of age). Napiontek[62] has performed the Cotton procedure in 25 children less than 4 years of age.

The surgical approach for Cotton osteotomy involves a dorsomedial incision over the medial cuneiform (**Fig. 8**). The tibialis anterior and extensor hallucis longus are avoided. It is best to visualize the dorsal and medial aspects of the medial cuneiform, and use intraoperative fluoroscopy to identify the center of the cuneiform, as the optimal site for the osteotomy. A vertical osteotomy is made, all the way through the plantar cortex and a laminar spreader is used to open the medial cuneiform in the desired plane or planes to make the appropriate anatomic correction. A wedge-shaped tricortical cancellous graft is inserted to maintain the aforementioned desired anatomic correction. The goal is to bring the medial column down, limit the dorsal sagittal plane motion and, in some cases, to adjunctively correct transverse plane pathology. Because the procedure is most often used in the pediatric population with open growth plates, the bone graft is stabilized with smooth wires, although surgeons have used staples also. Complications of the Cotton procedure include tibialis anterior tendon injury, graft extrusion, irritation to the surrounding soft tissues, malalignment, nonunion, and delayed union.

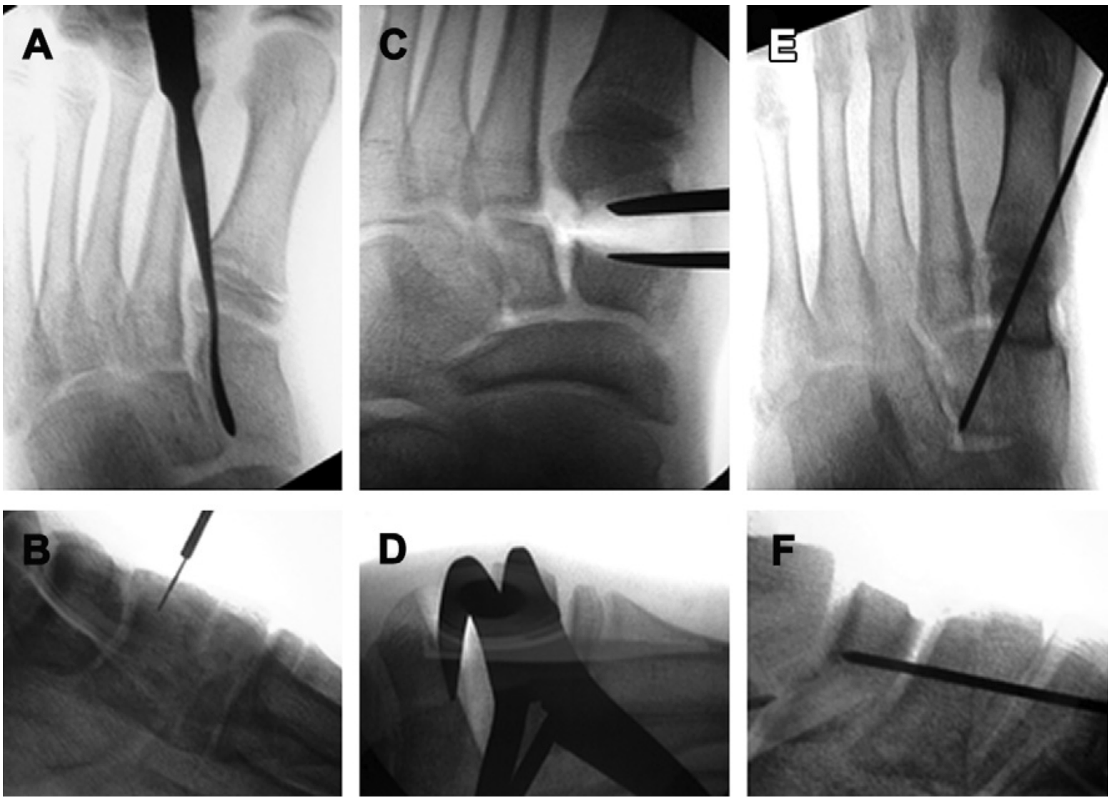

Fig. 8. Intraoperative fluoroscopic series demonstrating the technique for Cotton medial cuneiform osteotomy. (*A, B*) The position of the osteotomy should be verified before making the medial cuneiform. A freer elevator may be used to define the interval between the medial cuneiform and intermediate cuneiform. (*C, D*) A lamina spreader is used to create a wedge within the medial cuneiform with the base dorsal and apex plantar. (*E, F*) After the bone graft is placed fixation should be performed; in this case a smooth K wire was used.

RECONSTRUCTION INVOLVING ARTHRODESIS

Medial Column Arthrodesis (Lapidus ± Navicular Cuneiform)

Medial column arthrodesis procedures are considered when the flexible flatfoot is associated with skeletal maturity or when the growth plates are near closed (**Figs. 9** and **10**). The procedures are indicated for medial column instability that results in collapse. The radiographic location of the collapse determines the level/location of fusion. Isolated fusions of the first tarsometatarsal joint (Lapidus)[63] or the navicular cuneiform joint (Hoke)[64] have been used. The first tarsometatarsal and navicular cuneiform joint may be concomitantly fused, often referred to as the Miller procedure.[65]

Dockery[66] advocated medial column fusion to correct medial column instability as an adjunctive procedure in the surgical treatment of symptomatic juvenile flexible flatfoot. el-Tayeby[7] combined medial column fusion (naviculocuneiform joint) along with Evans, tendo-Achilles lengthening, and plantar rerouting of the tibialis anterior tendon in 11 patients (19 feet) with an average age of 10.7 years. Naviculocuneiform fixation was achieved with 2 crossing Kirschner wires (K wires) and nonunion occurred in 2 cases. Statistically significant improvement in radiographic alignment was achieved with this technique.[7]

Rearfoot Arthrodesis

The use of rearfoot arthrodesis for the treatment of symptomatic flexible juvenile flatfoot is limited. Selective arthrodeses or triple arthrodesis may be performed in the case of severe painful deformity, although selective arthrodeses should be strongly considered over triple arthrodesis. In general, rearfoot fusion of essential joints is not entirely a mainstream approach because the goals of reconstruction in the pediatric and adolescent patient are to preserve major rearfoot joint motion. In the cases of severe deformity where perfect postreconstruction alignment may not be achieved, it should be considered that improved alignment offers symptom resolution. Young patients may undergo osseous remodeling that may result in

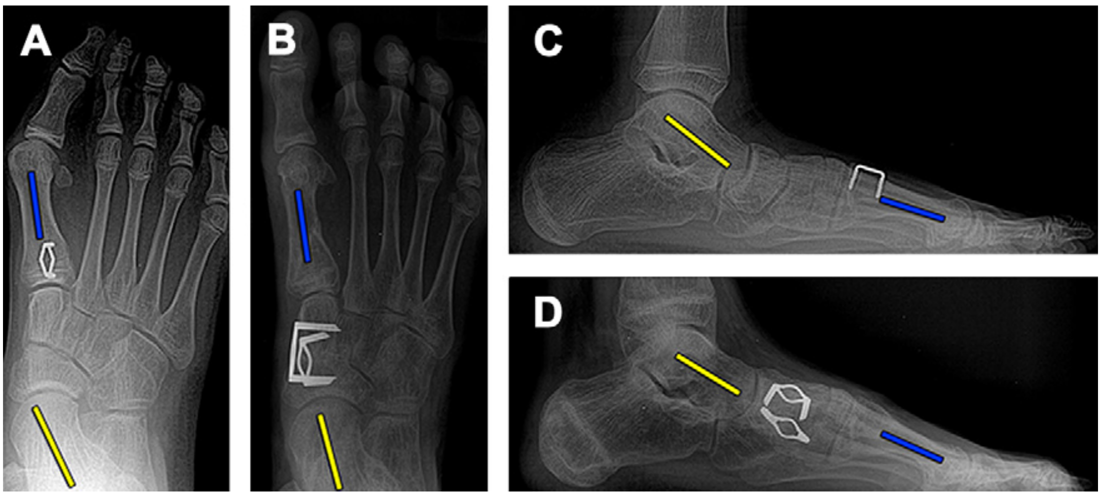

Fig. 9. 12-year-old boy, skeletally immature, with symptomatic flexible pes planus. (*A, C*) Preoperative weight-bearing images demonstrate multiplanar deformity. A retained staple is present from a failed previous epiphysiodesis for bunion correction. Note the significant medial column collapse with apex at the navicular cuneiform joint. (*B, D*) Healed postoperative weight-bearing images after navicular cuneiform fusion (with staples), first metatarsal closing base wedge, first metatarsal head osteotomy, medializing calcaneal osteotomy, and gastrocnemius recession. Restoration of proper talo-first metatarsal alignment (*yellow* and *blue lines*) is achieved. (*Courtesy of* Luke Cicchinelli, DPM, Mesa, AZ.)

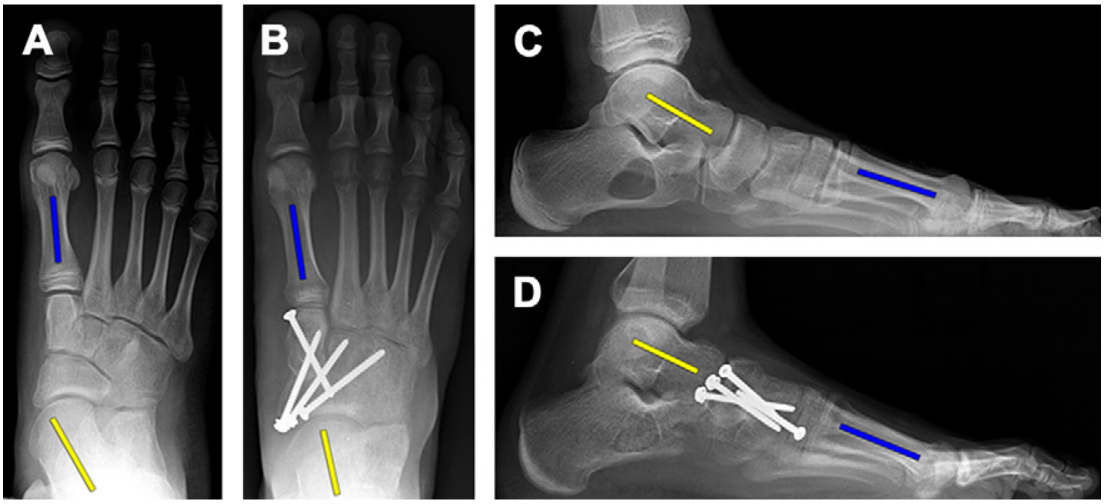

Fig. 10. 16-year-old boy, skeletally immature with near closed physis, with flexible pes planus who underwent reconstruction involving navicular cuneiform fusion. (*A, C*) Preoperative weight-bearing images demonstrate transverse plane deformity at the talonavicular joint (nearly 50% joint uncovering) and sagittal plane deformity (medial column collapse) with apex at the navicular cuneiform joint. An incidental benign calcaneal cyst is present. (*B, D*) Healed postoperative weight-bearing images after navicular cuneiform fusion is performed. Restoration of proper talo-first metatarsal alignment (*yellow* and *blue lines*) is achieved. Note that all 3 cuneiforms are incorporated into the fusion for the purpose of adducting and plantar flexing the midfoot to restore the arch. The return to talonavicular joint congruency is evident in the transverse plane, and illustrates the dramatic effect that a medial column fusion can have on the rearfoot complex. (*Courtesy of* Dan Choung, DPM, San Rafael, CA.)

improvement of the foot with time. Perhaps staged procedures can be considered with severe deformity. Rearfoot fusion is best indicated for the failed reconstruction.

SUMMARY

Pediatric and adolescent flexible flatfoot is a pathomechanically complex deformity. Conservative and surgical treatment is directed at realigning the foot and alleviating symptoms. When surgical intervention is considered, there are various methods and techniques that may be performed to realign the foot. A specific treatment algorithm does not exist, although planal dominance influences direct the surgeons when considering surgical intervention. Open physis often dictates the direction of the reconstruction. Attempts at essential joint preservation should be strongly considered in this young patient population.

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