Managing Complications of Foot and Ankle Surgery

Reconstruction of the Progressive Collapsing Foot Deformity

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KEYWORDS

• PCFD • PTTD • AAFD • osteotomy • fusion • complications • nonunion • malunion

KEY POINTS

- Progressive collapsing foot deformity is a complex spectrum of disease that can be clinically and technically challenging to evaluate and treat. Successful treatment begins with appropriate staging and picking the surgical techniques necessary to completely correct the deformity.
- A thorough physical examination with muscle testing, standing and dynamic evaluation of deformity, and adequate imaging that includes weight-bearing radiographs of the ankle and foot or a weight-bearing CT is necessary to create an adequate preoperative plan.
- Careful intraoperative assessment of deformity correction and motion is necessary to adequately address the pathology and avoid complications such as overcorrection or undercorrection.
- Complications have been reported as high as 20% following surgical correction of flatfoot deformity. Most of these complications are secondary to local neurovascular injury, nonunion, malunion, or inadequate deformity correction.
- With recent advancements in surgical techniques, implants, and biological augmentation, the rate of complications has improved; however, poor outcomes still remain common in high-risk populations such as patients who smoke, have diabetes, have a connective tissue disorder, or have unrecognized osteoarthritis and poorly understood deformities. Additional assessment and risk stratification is necessary in these populations.

INTRODUCTION

The progressive collapsing foot deformity (PCFD) is a common condition treated by foot and ankle surgeons, and the deformity has been associated with multiplanar progressive collapse of the medial longitudinal arch.[1,2] This collapse leads to the classic

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Abbreviations	
PCFD	Progressive collapsing foot deformity
PTTD	Posterior Tibial Tendon Deficiency
AAFD	Adult acquired flatfoot deformity

picture of flatfoot deformity, which is characterized by hindfoot valgus, midfoot abduction, and forefoot supination, and possible ankle joint valgus due to attenuation of the ankle ligamentous complex. Previous works have suggested several factors associated with its cause, with the primary focus on posterior tibial tendon dysfunction (PTTD) as the most accepted throughout the literature.[2–9] However, improved understanding of the deformity based on gait analysis, advances in MRI, and weight-bearing computed tomographic (WBCT) imaging over the past decade have demonstrated a wide array of tissues that are involved in addition to the posterior tibial tendon (PTT) including the spring ligament complex, the deltoid ligament, and the intraosseous ligaments within the subtalar joint. The changes in these tissues are more likely secondary changes to the stresses of the deformity rather than a primary cause of the deformity.

The first classification system for PTTD was described in 1989 by Johnson and Strom[10] and described the continuum of anatomic and clinical characteristics of each stage of disease while also proposing potential treatment strategies. Their classification system served as the foundation for many of the modified classification systems proposed in subsequent years. However, as understanding of this widely variable deformity has improved, and the observation that the deformities did not always follow a continuum of progression, a new classification system has recently been introduced to allow clinicians to better characterize the components of the deformity and provide recommendations for treatment[11] (**Table 1**).

In most cases, patients are initially managed nonoperatively with immobilization, foot orthotics, braces, physical therapy, and nonsteroidal antiinflammatory drugs with good outcomes.[12–16] However, when conservative modalities fail, operative intervention is warranted, and several effective operative options exist for treatment.[3,15] In general, the surgical treatment of choice is guided by multiple factors including the stage of disease, the magnitude of each component of the deformity, flexibility of the deformity and the existence of osteoarthritis, as well as skin condition, vascularity, and overall health of the patient. Given the wide spectrum of pathology and complexity involved in the decision-making process, choosing the “correct” procedure, or set of procedures, can be difficult and is beyond the scope of this article. In this article, the authors discuss the common surgical treatment options in adult flatfoot reconstruction and highlight the complications encountered with each procedure and provide treatment options for complication management.

Posterior Tibial Tendon Debridement

In patients with early-stage disease, and no significantly evident clinical deformity, tenosynovectomy, repair, or debridement of the PTT can be performed.[17] This procedure is uncommonly performed in isolation because most patients have some degree of preexisting gastroc-soleus contracture, hindfoot valgus, or abduction deformity; therefore, deformity correction and gastrocnemius-soleus muscle complex lengthening is often added to the tendon debridement procedure. Debridement alone has been advocated for younger patients with seronegative inflammatory arthropathy as the primary cause of the disease that has not responded to pharmaceutical and

Table 1
Consensus group classification of progressive collapsing foot deformity

	Stage of the Deformity	
	Stage 1 (Flexible)	**Stage II (Rigid)**
	Types of Deformity (Classes: Isolated or Combined)	
	Deformity Type/Location	**Consistent Clinical/Radiographic Findings**
Class A	Hindfoot valgus deformity	Hindfoot valgus alignment
		Increased hindfoot moment arm. hindfoot alignment angle, foot and ankle offset
Class B	Midfoot/forefoot abduction deformity	Decreased talar head coverage
		Increased talonavicular coverage angle
		Presence of sinus tarsi impingement
Class C	Forefoot varus deformity/medial column instability	Increased talus-first metatarsal angle
		Plantar gapping first TMT joint/NC joints
		Clinical forefoot varus
Class D	Peritalar subluxation/dislocation	Significant subtalar joint subluxation/subfibular impingement
Class E	Ankle instability	Valgus tilting of the ankle joint

Abbreviations: NC, naviculocuneiform; TMT, tarsometatarasal.

From Myerson MS, Thordarson DB, Johnson JE, et al. Classification and nomenclature: progressive collapsing foot deformity. Foot Ankle Int. 2020;41(10):1271–6.

bracing treatments.[18] In a study of 19 patients who underwent synovectomy and debridement for tenosynovitis, the investigators reported complete pain relief in 74% of patients and 84% of patients reported feeling “much better” and experienced return of function of their PTT.[19] In most cases when PTT procedures are performed in isolation, however, there have been significant long-term failure rates reported in previous studies.[3,15] The procedure can be performed open or endoscopically, and the choice should be based on surgeon preference and training. Consideration should also be given to performing adjunctive procedures in combination, such as flexor digitorum longus (FDL) transfer and gastrocnemius or gastrocnemius-soleus muscle complex lengthening.

Indications

- Tenosynovitis, without tendon attenuation

Contraindications

- Significant deformity
- Posterior tendon or spring ligament complex involvement

Summary of complications

- Recurrent tendon inflammation, progressive deformity, and pain
- Medial neurovascular structure injury
- Inadvertent injury to flexor hallicus longus (FHL) or FDL
- Secondary PTT rupture or subluxation
- Infection and wound complications

The incidence of major complications after PTT debridement and synovectomy remains quite low; however, success of the procedure highly depends on appropriate patient selection. Recurrent tenosynovitis, pain, and progressive deformity can develop if surgery is done inadequately or for incorrect indications. The PTT lies near the posterior tibial artery (PTA), vein, and nerve at the level of the ankle joint, and although the tendon is superficial to these structures, care must be taken to avoid their injury during dissection. Similarly, the FDL and FHL are located close to each other in the tarsal tunnel, and errors in tendon identification may occur during surgery. Inadvertent injury to the FDL occurs more commonly compared with the FHL given that the FHL is located deep to the neurovascular bundle; however, damage to either may result in loss of lesser toe or hallux function, compromising push-off strength.[20] Adequate examination and debridement often requires opening the retinaculum that secures the PTT in its groove behind the medial malleolus. Failure to adequately repair this structure may lead to anterior subluxation of the tendon (**Fig. 1**). Many surgeons leave a 1- to 2-cm portion of the distal retinaculum intact and debride the tendon above and below this section, as needed, to prevent this complication. Finally, secondary rupture of the PTT can occur with overly aggressive debridement or inadvertent laceration intraoperatively.[20]

Flexor Digitorum Longus Transfer

Transfer of the FDL was first described in the treatment of talipes equinovalgus deformity in 1974, after the investigators observed insufficient restoration of the medial arch with PTT plication alone.[21] The investigators reported improved results with FDL transfers done in combination with spring ligament imbrication and tendo-Achilles lengthening. Given the similar line of pull between the FDL and PTT, the FDL transfer has become the tendon of choice in treating PTT deficiency, although there are other

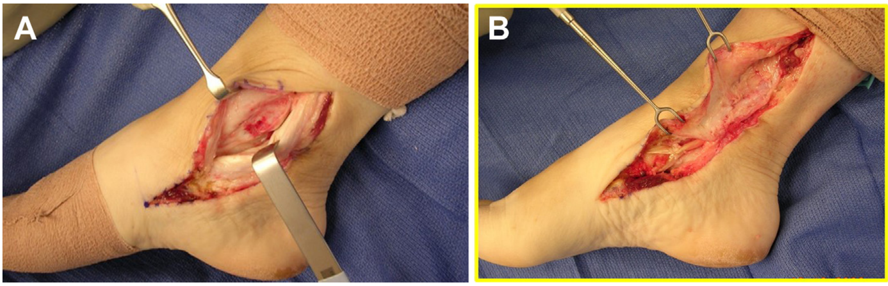

Fig.1. (*A*) Posterior tibial tendon anterior subluxation with progressive tendinopathy following isolated tendon debridement in a 35-year-old female. Note the erosion on medial malleolus from chronic anterior subluxation of the tendon. (*B*) Repair of tendon subluxation with excision of the dysfunctional posterior tibial tendon, reconstruction with FDL tendon transfer to the navicular, and repair of the retinaculum. (Images copyrighted by Jeffrey E Johnson, MD.)

options.[3,22] Previous studies have investigated the balance and excursion of muscles around the foot and ankle and found the FDL to be nearly 3 times weaker in strength than the PTT.[23] It is often recommended that FDL transfer be performed in combination with adjunctive procedures, such as a medial displacement calcaneal osteotomy or a lateral column lengthening (LCL), to improve correction and also protect the transfer from the increased biomechanical stresses of a hindfoot valgus or abduction deformity by restoring the varus-directed moment across the ankle and hindfoot that was previously provided by the posterior tibialis muscle-tendon unit.[24] It has also been suggested in imaging studies that the FDL may undergo hypertrophy postoperatively,[25] yet it is unlikely that it will hypertrophy enough to adequately counteract the pull of the peroneus brevis. There are 2 common techniques used when transferring the FDL, and those include transfer of the FDL to an intact PTT or distal stump and transfer of the FDL to the navicular bone. Results are generally good with either method, and choice of treatment is often dictated by surgeon preference.

Indications

- Flexible PCFD stage 1A through C deformity with PTT attenuation or rupture
- Adjunctive procedure to deltoid ligament repair/reconstruction for ankle valgus deformity (PCFD Class 1D or E) or spring ligament reconstruction to help balance the valgus-directed moment across the ankle and hindfoot from the loss of the posterior tibialis and/or when there is early valgus tilt of the tibiotalar joint

Contraindications

- Rigid flatfoot deformity. Typically, rigid deformity requires arthrodesis or osteotomy for correction. An FDL transfer may be used as an adjunctive procedure, but not as the primary means of correction.

Summary of complications

- Recurrent deformity and pain
- Graft pull-out and/or fracture of navicular bone at tenodesis site
- Medial neurovascular structure or FHL injury during harvest of FDL tendon
- Lesser toe flexion weakness
- Infection and wound complications

The most common complication following FDL transfer is inadequate relief or recurrence of preoperative symptoms and dysfunction.[22] This complication is usually associated with inadequate correction of the deformity with bony procedures. Although most studies reporting on outcomes are positive, a study in 1992 following reconstruction of flexible PCFD deformities reported relatively high failure rates (6 of 20 patients) after PTT debridement with side-to-side anastomosis of the FDL (but without bony correction with osteotomy or fusion) at an average of 15 months. Owing to persistent symptoms and dysfunction, each of those patients subsequently underwent triple arthrodesis.[26] Therefore, most surgeons favor a secure tendon to bone attachment as well as correction of the deformity with osteotomies or selected arthrodesis. Depending on how much tendon length is available for transfer, the technique may be performed by suturing the FDL tendon back on itself through an intraosseous tunnel through the navicular tuberosity or to surrounding soft tissues or the remaining PTT stump (ie, tendon-to-tendon repair) or via interference screw fixation with or without adjunctive suture to the periosteum or PTT stump. Initially, only large-diameter bioabsorbable screws designed for ACL reconstruction were available. These screws required oversized pilot holes relative to tendon diameters,[27,28] which could lead to unanticipated complications of graft pull-out and/or fracture of the bony tunnels used for graft passage. In response to this problem, smaller screws were designed for foot and ankle procedures and these have subsequently decreased the rate of complications. The authors are not aware of any series reporting injury to the medial neurovascular structures during tendon harvest; however, there is a plexus of vessels beneath the navicular in the knot of Henry and careful dissection should be carried out to avoid bleeding complications. The medial plantar branch of the tibial nerve also lies superficial to the distal extent of the FDL and can be injured during the surgical approach. Finally, lesser toe flexion weakness is not a significant problem following FDL transfer, especially if the FDL tenotomy is made proximal to the master knot of Henry because FDL function is often adequately preserved due to the FHL, flexor hallucis brevis, and quadratus plantae muscle attachments distally. Some surgeons perform a tenodesis of the distal FDL tendon to the FHL tendon at the knot of Henry with the objective to help retain lesser toe flexion power.

Medial Displacement Calcaneal Osteotomy

The medial displacement calcaneal osteotomy (MDCO) was first described by Gleich in 1893 and has since proved to be an effective option for correcting the hindfoot valgus component of flatfoot deformity. Biomechanically, it shifts the vector of Achilles tendon pull medially, thus reducing its contribution to deformity progression.[29,30] In addition to hindfoot valgus correction, it aids in decreasing strain on the medial ligamentous structures (ie, PTT and deltoid/spring ligaments), which theoretically prevents or slows their attenuation. For these reasons, in some cases an MDCO is added to a subtalar or triple arthrodesis to aid in the correction of the hindfoot valgus deformity when reduction of the joint is not adequate for full correction of the deformity.[31] In cadaveric models with hindfoot valgus deformity, the force of the Achilles tendon has been shown to increase progression of flatfoot deformity, which can be significantly decreased with utilization of the MDCO.[30] However, the MDCO has not been shown in previous studies to effectively correct the concomitant forefoot abduction and peritalar subluxation deformities.[32,33] Several previous investigators have reported positive results following the procedure; yet, their interpretation can be difficult because the MDCO is rarely performed in isolation.[3,30,32–34]

Indications

- Flexible PCFD Class 1A
- Adjunct to other procedures for correction of Class 1B, 1D, and 1E deformities with associated hindfoot valgus
- Residual hindfoot valgus following undercorrection with prior MDCO or hindfoot arthrodesis

Contraindications

- Isolated forefoot abduction deformity without hindfoot valgus
- When used in isolation with subtalar arthritis and painful/limited subtalar joint motion

Summary of complications

- Sural nerve injury
- Medial neurovascular structure (ie, tibial artery, tibial nerve) injury
- Nonunion, malunion, or loss of osteotomy correction
- Recurrence of deformity or inadequate correction
- Infection and wound complications

The sural nerve transverses across the lateral aspect of the calcaneus to provide cutaneous sensation to the lateral aspect of the foot, and its branches can be injured during the surgical approach. The authors recommend sharply incising skin and then bluntly dissecting through the subcutaneous tissues to protect the sural nerve. Similarly, the medial neurovascular structures are at risk when completing the osteotomy through the medial cortex, especially the more anterior the osteotomy is placed in the tuberosity. In a cadaveric study that examined the medial neurovascular anatomy and its relation to the calcaneal osteotomy, an average of 4 neurovascular structures were found crossing the osteotomy site.[35] Branches of the lateral plantar nerve (LPN) and PTA were among the most common structures. With regard to the LPN, the calcaneal sensory branch crossed in 86% of cadavers, and the second branch of the LPN (Baxter nerve) crossed in 95% of specimens. The medial plantar nerve did not cross in any of the specimens, but it could be crushed or placed under significant traction with medial displacement of the tuberosity fragment.

- Nonunion and malunion are relatively rare complications after MDCO, and in most cases they are observed in patients with underlying medical comorbidities (ie, diabetes, smoking, malnutrition).[29] It is important to optimize patients preoperatively and use good surgical technique and avoid thermal necrosis of the bone at the osteotomy site. In a recent retrospective review of 160 patients treated with MDCOs for flatfoot correction, the investigators reported a 7% rate of complications related to healing of the osteotomy site, 3% with wound dehiscence, and 2% with surgical site infection.[36] Patients with concurrent tobacco usage and higher body mass index were at higher risk for complications. Finally, when using a minimally invasive surgical (MIS) technique with a power cutting tool it is important to avoid prolonged use of the saw or burr because it can lead to thermal necrosis of the bone and subsequent osteotomy nonunion. It is recommended to use irrigation fluid to prevent overheating at the saw/burr-bone interface.[36] The use of a smaller incision over the lateral heel with the MIS technique may avoid a traction injury to the sural nerve from retractors that could occur with a wider dissection.

Evans Lateral Column Lengthening Osteotomy

- The Evans osteotomy, or LCL osteotomy, was first described in 1975 in the context of pediatric “calcaneo-valgus deformity” and its surgical management.[37] Typically, the osteotomy is performed in the anterior calcaneal neck with insertion of a trapezoidal-shaped wedge of allograft/autograft bone or a metallic wedge or plate to hold the osteotomy in its lengthened position. The idea of medial and lateral column imbalance, as it applied to talipes equinovarus, was initially introduced by Evans in 1961 in the setting of the relapsed clubfoot; this rendered the idea that mismatch of the columns was a significant driver of deformity in these 2 different foot conditions. As written in the 1975 article, Evans largely attributed the flatfoot deformity to relative shortening of the lateral column compared with the medial, and to achieve correction the columns needed to be “equalized.”[37,38] A technique for elongation of the lateral column was thus described, and this became the advent for a new surgical treatment option in these adolescent patients. Although subsequent observations have noted that the lateral column is not anatomically shortened in adult individuals with PCFD, it functionally and radiographically appears shortened due to a rotatory subluxation of the talus in relation to the calcaneus, and correction of this subluxation occurs with LCL in the flexible foot.[39] Therefore, in contemporary adult flatfoot deformity correction, LCL is used to correct forefoot abduction and improve talar head uncoverage.[40–44]

Finally, the LCL-type osteotomies are rarely performed in isolation and are more commonly used in conjunction with other osseous and soft tissue procedures.

Indications

- PCFD Class 1B deformity with talar head uncoverage

Contraindications

- Rigid, painful flatfoot deformity
- Preexisting calcaneocuboid (CC) osteoarthritis

Summary of complications

- Nonunion, malunion, or loss of osteotomy correction
- Injury to sural nerve and peroneal tendons
- Laceration of FHL tendon or medial plantar nerve with saw blade
- Injury to subtalar joint complex with misplaced osteotomy
- Injury to the CC joint
- Dorsal displacement of anterior calcaneal tuberosity fragment
- CC joint arthritis
- Stress fracture of fifth metatarsal
- Overcorrection causing limited subtalar joint eversion and lateral column overload
- Undercorrection and relapse of deformity
- Infection

The reported rates of nonunion across the literature range between 1.4% and 5.26%, which includes osteotomies performed both with and without internal fixation[45–48] (**Fig. 2**). This low incidence is thought to be secondary to the highly vascularized anatomy of the calcaneus, as well as the natural compression of the bone graft at the osteotomy site.[38] A recent systematic review of 172 patients found a nonunion rate

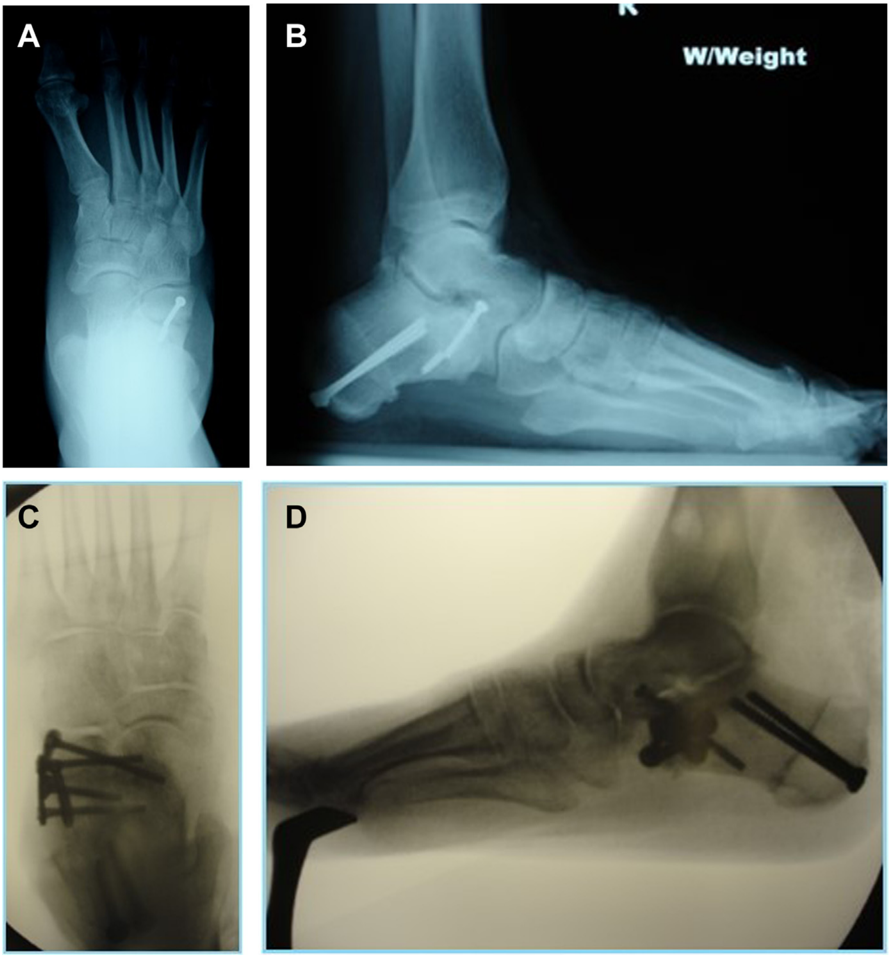

Fig. 2. (*A, B*) Anteroposterior and lateral radiographs of 58-year-old male with painful calcaneal nonunion 6 months following Evans LCL osteotomy with allograft interposition. (*C, D*) Postoperative radiographs following autogenous bone grafting and plate fixation. (Images copyrighted by Jeffrey E Johnson, MD.)

just less than 9.5% in patients who underwent an Evans LCL osteotomy. Nonunion rate was associated more commonly with grafts larger than 8 mm and use of allograft (14.5% nonunion with allograft vs 9.3% with autograft).[49]

In an effort to minimize nonunion rates a “Z”-osteotomy modification of the Evans LCL has been described.[50] In this technique, a “Z” shape is created at the neck of the calcaneus. Starting 10 to 12 mm posterior to the CC joint, the dorsal one-third of the neck is cut vertically. At the apex of this cut, a horizontal limb is created to a point just anterior to the peroneal tubercle. An additional vertical cut is made aiming inferiorly through the plantar cortex.[50,51] To perform this osteotomy, the peroneals first need to be retracted plantarly and posteriorly to perform the anterior and horizontal cuts; they then need to be retracted dorsally with the sural nerve through additional subcutaneous dissection to perform the inferior cut. This additional exposure and dissection risks injuring these structures; nevertheless, by rotating the neck in addition to lengthening it, this osteotomy has the potential advantages of decreased lateral column overload by using smaller wedges. This osteotomy is also believed to result in improved union rates because of the longer surface area contact of native bone.[52] In a retrospective review of 111 patients comparing a standard Evans LCL to a "Z"-osteotomy, nonunion rates were significantly lower and time to union was faster in the "Z"-osteotomy group; yet, Foot and Ankle Outcome Scores (FAOS) and lateral column pain were equivalent in both groups. One superficial infection was found in the standard Evans group and 2 in the "Z"-osteotomy group. In the "Z"-osteotomy group, 2 patients underwent tenosynovectomy of the peroneal tendons and 3 underwent repair of peroneal tendon splits at the same time as hardware removal.[52]

In a series of 49 feet that underwent a standard Evans osteotomy, the rate of sural nerve injury was reported at 11%, whereas injury to the peroneal tendons occurred less frequently.[43] Most osteotomies are made 12 to 17 mm from the CC joint, and universally the sural nerve and peroneus brevis tendons can be observed overlying the site.[38] In contrast, the peroneus longus tendon is often only found to be at risk if the osteotomy is less than 10 mm from the joint. The FHL tendon lies close to the medial side of the distal calcaneus and can be lacerated if the saw blade penetrates through the medial cortex of the calcaneal osteotomy. Using an osteotome to complete the osteotomy will help avoid this complication. Regardless of osteotomy location, careful subcutaneous dissection, identification, and proper protection of these structures can avoid their injury.

Some clinicians choose to use a porous metal wedge in performing an Evans-type LCL. The advantages of using such a device are decreased surgical time, trial implants that can allow the surgeon to intraoperatively assess the optimal graft size for deformity correction, and lack of donor site morbidity if using autograft. The literature is limited regarding the efficacy of these implants; however, the amount of deformity correction and nonunion rates with a porous metal wedge are comparable to autograft and allograft. Moreover, no major complications were reported in either study.[53,54]

The risk of invading the subtalar joint or including the sustentaculum tali in the osteotomy has also been elucidated in previous anatomic studies. The risk of including one of the calcaneal facets in the osteotomy cut (ie, anterior or medial) ranges between 37% and 44%.[55–57] As a result, varying recommendations exist regarding the start point and trajectory of the osteotomy in relation to the CC joint. However, even if the anterior facet is involved, the risk of subtalar joint incongruity or instability remains low because the lateral ligaments are posterior to the osteotomy.[57]

Dorsal subluxation of the calcaneal anterior tuberosity is also quite common, with incidences between 11.8% and 100% in studies.[43,58] Dorsal subluxation is likely due to overstretch of the already shortened soft tissues that subsequently become tensioned with lengthening. Excessive soft tissue stripping of the anterior calcaneus may also lead to dorsal subluxation or avascular necrosis of the distal fragment or nonunion of the osteotomy. Dorsal subluxation can be reduced by using an osteotome to complete the cut through the medial cortex or pinning the CC joint before completing the osteotomy.

Lateral column overload, pain, and fifth metatarsal stress fractures can also occur, and these are likely related to the increase in the joint contact pressures distributed throughout the column and CC joint (**Fig. 3**). The increased intra-articular pressure has been associated with onset of CC joint arthritis, fifth metatarsal stress fractures, and lateral column pain in up to 11.2% of patients.[38,59] Graft size may play a role in lateral column overload, and in most studies the reported graft size ranges between 8 and 10 mm.[46,60,61] However, in a previous cadaveric study the CC joint pressure was not observed to increase until graft sizes were greater than 8 mm, and thus it is

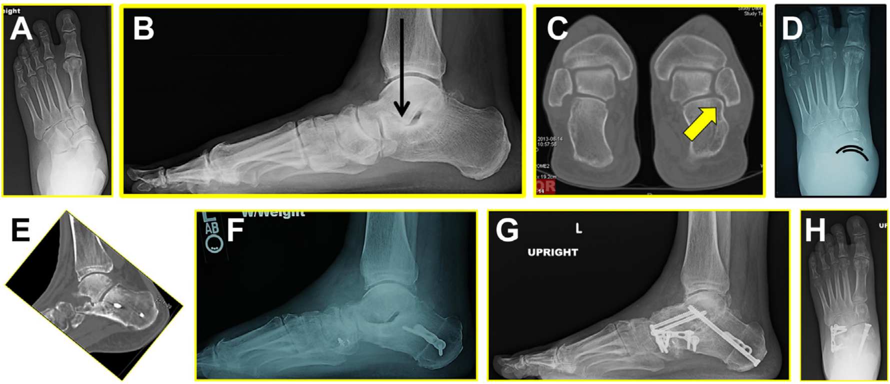

Fig. 3. (*A–C*) Radiographs of a 58-year-old male with flexible PCFD, accessory navicular and medial midfoot pain, and lateral sinus tarsi pain. Note the subtalar joint subluxation with lateral talocalcaneal and calcaneofibular impingement as indicated by the black and yellow arrows. (*D–F*) Radiographs and CT scan of the same patient following excision of accessory navicular, FDL transfer, Evans lateral column lengthening, and MDCO. Note that although significant deformity correction was obtained, the patient had persistent sinus tarsi pain and talocalcaneal impingement with osteoarthritis. (*G, H*) Salvage triple arthrodesis was used to correct residual subtalar subluxation and treat osteoarthritis pain. (Images copyrighted by Jeffrey E Johnson, MD.)

recommended to combine the osteotomy with other procedures if grafts larger than 8 mm are required.[60] Smaller graft sizes may be used as well to correct forefoot abduction and minimize lateral column overload.

Finally, loss of correction, overcorrection, and undercorrection are all possible outcomes of this osteotomy. Loss of correction due to soft osteoporotic calcaneal bone may occur in select patients, and several modifications to osteotomy technique and graft fixation have been described.[38] These include modifications to the shape of the osteotomy (ie, step-cut or Z-osteotomy) and stronger fixation techniques such as with wedge locking plates.[38] Overcorrection and undercorrection are infrequently encountered and can often be mitigated while in the operating room (**Fig. 4**). Overcorrection is often associated with flexible flat feet of spastic origin,[62] whereas undercorrection is commonly seen in rigid valgus feet (ie, tarsal coalitions), which highlights the importance of appropriate patient selection and surgical technique. In the author's experience, overcorrection is a significantly more difficult problem to manage clinically secondary to patient pain, deformity, and lateral column overload. Therefore, we recommend erring on the side of undercorrection and potentially adding an adjunctive MDCO when needed to perform adequate correction.

Cotton Osteotomy

The Cotton osteotomy was first described in 1936, when Cotton described a procedure to assist in correction of the flatfoot deformity that used a dorsal opening wedge medial cuneiform osteotomy with insertion of a wedge-shaped piece of allograft or autograft bone to plantarflex the first ray.[63] The theory was that through this procedure the surgeon is able to restore the "triangle of support" to the foot and allow the patient to have improved function by restoring the mechanics of weight-bearing.[63] In the subsequent years since Cotton's original text, additional technical studies have been written on the use of this medial cuneiform osteotomy as part of flatfoot deformity

Fig. 4. Intraoperative anterioposterior image demonstrating overcorrection of the talonavicular joint from excessive distraction of the Evans calcaneal lengthening osteotomy. Note the subluxation of the talonavicular joint with medial gapping and subluxation. This was recognized intraoperatively, and the graft size was reduced. (Images copyrighted by Jeffrey E Johnson, MD.)

correction.[63–66] Generally, it is recommended that the Cotton osteotomy be used in combination with other reconstructive procedures rather than in isolation. Cotton osteotomy is primarily used to correct forefoot varus when the medial column elevation deformity is primarily located at the first tarsometatarsal (TMT) joint or naviculocuneiform joint.[15,65,67] The Cotton osteotomy will also correct medial column elevation when it is associated with mild forms of first TMT instability. Most commonly, the Cotton osteotomy is performed after all hindfoot osteotomies have been made so the amount of residual forefoot varus can be assessed to determine if a Cotton osteotomy is required for further correction. A Cotton osteotomy may also be used to balance the forefoot following a triple arthrodesis when there is residual forefoot varus, from medial column elevation, despite reduction of the hindfoot joints.

Indications

- Forefoot varus deformity isolated to the medial column, associated with any of the classes of PCFD
- Residual first ray elevation following hindfoot arthrodesis for PCFD correction

Contraindications

- Significant medial column hypermobility, degenerative changes of the first TMT joint, or sag with plantar gapping at the first TMT joint
- Deformity greater than what a 5- to 10-mm bone block can correct
- Fixed deformity through transverse tarsal joints or naviculocuneiform joints

Summary of complications

- Nonunion, malunion, or loss of osteotomy correction
- Symptomatic hardware
- Bony exostosis
- Plantar/sesamoid pain
- Lateral column overload
- Fracture extending into the first TMT joint
- Violation of the plantar cortex and instability of the osteotomy
- Infection

Perhaps the most common error in the use of this procedure is performing it for the wrong indication, especially when the forefoot varus is greater than a Cotton osteotomy can correct or the medial column is too stiff. Performing the osteotomy in these cases causes an undercorrection of the foot deformity. In cases of significant deformity or stiffness, a naviculocuneiform fusion combined with a reduction maneuver to plantarflex the first ray may be a more powerful correction than a Cotton osteotomy for these deformities.[68]

Overall, technical complications are relatively rare following this procedure (**Fig. 5**). In a series of 16 feet after Cotton osteotomy, only 1 patient had a symptomatic screw that was removed, and no nonunions or residual pain was reported.[64] In a larger series, 10 postoperative complications were reported with 30% being symptomatic screws.[67] Important technical tips in performing a Cotton osteotomy include (1) smoothing down the prominent boney ridge that occurs at the dorsal aspect of the osteotomy to prevent pain with dorsal pressure from footwear, (2) completion of the osteotomy all the way to the plantar cortex of the cuneiform to prevent TMT-1 intra-articular fracture, and (3) avoidance of complete osteotomy through the plantar cortex that could induce instability or displacement of the distal fragment.[65,69] Given the stability of the osteotomy, some surgeons avoid using hardware in this prominent area and have still shown high union rates.[39,67,70,71] Furthermore, symptomatic hardware can be avoided with use of low-profile plate fixation, or percutaneous pins that can then be removed in the postoperative outpatient setting. The incidence of plantar/

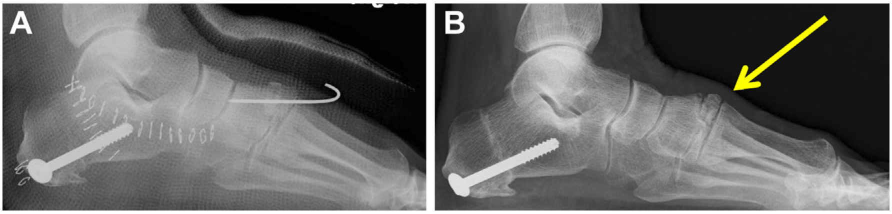

Fig. 5. (*A*) Postoperative lateral radiograph demonstrating technical error in performing Cotton osteotomy. (*B*) The osteotomy is placed too close to the first TMT joint and was distracted without completing the osteotomy to the plantar cortex of the cuneiform. The resultant distraction caused a fracture into the first TMT joint and dorsal subluxation of the graft as indicated by the yellow arrow. (Images copyrighted by Jeffrey E Johnson, MD.)

sesamoid pain or pain secondary to lateral column overload can also be decreased by avoiding overcorrection (ie, excessive plantarflexion) of the first ray and carefully assessing the foot intraoperatively to ensure appropriate restoration of the "triangle of support."[26,65]

Hindfoot Arthrodesis

When significant arthritis, instability, or deformity is present, hindfoot arthrodesis will provide a more stable and predictable outcome than osteotomies and soft tissue reconstruction. Selective joint fusions have been recommended by many investigators, although triple arthrodesis has been the most common procedure recommended when fusion is warranted.

The triple arthrodesis was first described in 1923 by Ryerson,[72] for correction of rigid hindfoot deformities secondary to paralytic conditions. This procedure remains a valuable and frequently used treatment of flatfoot deformity in patients with subtalar arthritis, severe hindfoot rigidity, or deformity. Some surgeons also prefer arthrodesis for obese or older low-demand patients, although several investigators have reported that results with traditional reconstructive techniques in these groups are not inferior.[73] Throughout the literature, good outcomes are reported in greater than 85% of patients who undergo the procedure. There have been numerous studies reporting on varying surgical techniques, and their associated outcomes. Given the complexity of the procedure, it is critical to adhere to techniques that align with surgeon skillset and experience to avoid complications of nonunion, malunion, and recurrent deformity. A triple arthrodesis is a technically demanding procedure when deformity is involved. Accurate reduction of all the components of the multiplanar deformity, as well as preparation and fixation of the joints, are equally important factors that determine success following triple arthrodesis. Because motion at the hindfoot joints is eliminated, creation of a plantigrade foot is even more important when performing a triple arthrodesis than with other procedures where subtle amounts of overcorrection or undercorrection may be accommodated by adjacent joint mobility.

Isolated talonavicular fusion or LCL fusion have been advocated for correction of hindfoot deformity, even in the absence of significant osteoarthritis.[74,75] However, correction without fusion is possible in most patients with flexible deformities.

With the advent of WBCT, subtle subluxation of the subtalar joint is now easily visualized and has led to an increase in use of a repositional subtalar fusion to correct hindfoot valgus and forefoot abduction deformity by correction and stabilization of the subtalar subluxation[76]; this is commonly performed with adjunctive soft tissue or other boney procedures such as FDL transfer, MDCO, and naviculocuneiform reduction/fusion or Cotton osteotomy.[68,77]

Indications

- PCFD Class 2A, B, C, and D deformity
- PCFD Class E, when foot deformity requires arthrodesis in conjunction with ankle correction
- Painful osteoarthritis of the talonavicular and subtalar joints. Gross instability or hyperflexibility associated with PCFD
- Salvage procedure following failed flatfoot surgery

Contraindications

- PCFD Class 1 (flexible) deformity, amenable to correction with osteotomies and soft tissue reconstruction.

Summary of complications

- Nonunion and malunion
- Progressive ankle valgus deformity and ankle arthritis
- Cutaneous nerve injury
- Lateral wound breakdown and infection

Nonunion is by far the most common reported complication observed after triple arthrodesis, with rates ranging from 10% to 23%, and mostly involving the talonavicular joint.[15,78] These rates have significantly decreased to approximately 5% in recent years with improved hardware design and the use of biologic augmentation. Unfortunately, rates of malunion, undercorrection, and overcorrection of deformity remain common sources of poor outcomes and are likely underreported in the literature (**Fig. 6**). These complications can be mitigated by accurate correction of the deformity and are aided by adjunctive procedures such as a Cotton osteotomy (for residual forefoot varus), MDCO (for residual hindfoot valgus), deltoid ligament repair/allograft reconstruction (for significant deltoid insufficiency), or FDL transfer (for mild forms of deltoid laxity and valgus talar tilt). Malunion of a triple arthrodesis has reported rates as high as 6% across the literature, and undercorrection resulting in residual hindfoot valgus, residual forefoot varus, or potential rocker-bottom deformities account for the most common positions of malunion.[78] Overcorrection with residual hindfoot varus is less common and a greater risk when the hindfoot deformity is hyperflexible. Reduction of the talocalcaneal subluxation and realignment of the transverse tarsal joints is technically demanding in severe deformities and release of joint contractures and thorough joint preparation are important components of the procedure. Detailed

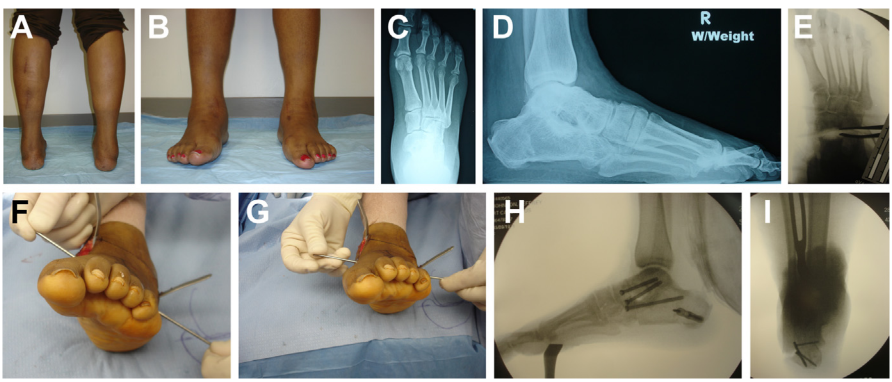

Fig. 6. (*A, B*) Clinical photographs of a 43-year-old female with malunion of bilateral triple arthrodesis for PCFD. Note the overcorrection with residual hindfoot and forefoot varus with elevation of the right first metatarsal. (*C, D*) Anterioposterior (AP) and lateral radiographs of overcorrected right foot. Note the overcorrected position of the talonavicular joint on the AP radiograph and the elevation of the first ray on the lateral. (*E*) Intraoperative radiograph demonstrating the transverse tarsal joint osteotomy for correction of fixed forefoot varus. (*F, G*) Intraoperative photographs demonstrating the fixed forefoot varus and the subsequent forefoot reduction maneuver using a smooth transverse pin to aid the derotation of the forefoot. (*H*) Lateral radiograph demonstrating correction of varus malunion with transverse tarsal joint derotation osteotomy and lateral displacement calcaneal osteotomy with internal fixation. (*I*) Axial radiograph demonstrating lateral shift of the calcaneal tuberosity for correction of varus malunion of hindfoot. (Images copyrighted by Jeffrey E Johnson, MD.)

intraoperative attention to the accuracy of the reduction, both clinically and radiographically, and meticulous surgical technique during joint preparation and fixation are critical to avoiding injury to surrounding structures and ensuring good outcomes.[79] Finally, the progression of ankle arthritis after triple arthrodesis has been observed and patients should be counseled regarding this possibility.[80,81] In many cases, this remains largely out of surgeon control, however, avoidance of malunion during the operation may decrease the overall risk. It is the author's opinion that significant preexisting ankle arthritis is best managed with a staged triple arthrodesis followed by total ankle replacement.

Deltoid and Spring Ligament Repair

As the PCFD deformity progresses in severity, the medial soft tissue structures including the spring ligament complex and deltoid ligament complex will become chronically attenuated due to the increased biomechanical stresses; this allows the foot to drift into hindfoot valgus and forefoot abduction.

The spring ligament is poorly visualized on MRI scans and is typically evaluated intraoperatively. When a tear or significant attenuation is noted, repair or reconstruction is indicated and numerous techniques have been described using local tissue with suture augmentation and autograft or allograft tendon reconstruction.[82] Most investigators recommend some type of repair, but the contribution of the repair to the overall deformity correction is difficult to determine.

The deltoid ligament is an important structure that resists the valgus stresses on the ankle caused by PCFD. These increased stresses on the medial supporting structures ultimately contribute to the gradual onset of lateral talar tilt at the ankle as the deep portions of the deltoid ligament become attenuated resulting in a variable amount of pes planovalgus foot deformity and ankle valgus. Regardless of what procedure is performed on the ankle deformity, the underlying foot deformity must also be corrected, either concurrently or in a staged manner.

Patients with valgus instability of the ankle joint that is flexible and reducible with any class of deformity, without significant osteoarthritis or medial joint space narrowing (especially PCFD Class 1E), would benefit from a medial soft tissue reconstructive procedure in conjunction with the appropriate deformity correction procedure for the underlying foot deformity. In contrast, patients who display a fixed valgus tilt at the ankle, or who have significant lateral joint space narrowing and osteoarthritis (PCFD 2E) are not able to be treated with a joint-sparing procedure. Depending on multiple factors, the options for correction of the arthritic ankle in valgus include a total ankle arthroplasty with a deltoid repair or without a deltoid repair using a larger polyethylene bearing as a spacer to tension the native deltoid ligament. As total ankle replacement evolves, more constrained implants may help reduce the need for deltoid reconstruction in combination with ankle arthroplasty. In some patients with gross instability or joint destruction a tibiotalar or tibiotalocalcaneal arthrodesis with correction of the foot deformity distal to the level of the arthrodesis may be needed. The goal of any of these procedures is to create a plantigrade foot and preserve as much motion as possible.[56] In most cases, a pantalar arthrodesis can be avoided.

Several deltoid ligament reconstructive techniques have been described, including tendon allografts, tendon autografts, and soft tissue repair constructs with suture tape augmentation.[83–85] In a study using peroneus longus tendon autograft, the investigators reported improved valgus tilt from 7.7° preoperatively to 2.1° at 9-year follow-up.[83] Similar results were reported in a separate study in which combined spring and deltoid ligament reconstruction was completed with flexor digitorum transfer and internal brace augmentation with suture tape, and no complications or loss of correction were reported at the time of follow-up.[85] Haddad and colleagues[84] studied cadaveric specimens following deltoid reconstruction using an anterior tibial tendon graft and demonstrated that under low torque, their technique was able to restore eversion and external rotation stability to the talus, which was statistically similar to the intact deltoid ligament.

Deltoid ligament reconstruction is technically demanding, and each technique carries its own technical considerations; therefore, the choice of treatment is best guided by surgeon experience and the goals for each individual patient.[82]

Indications

- PCFD Class 1E
- PCFD Class 2E, when combined with total ankle arthroplasty
- Any other class of deformity in which deltoid insufficiency is a component of the deformity

Contraindications

- PCFD Class 2E deformity when used alone, because a soft tissue reconstruction alone is not indicated for fixed deformity without additional procedures.

Summary of complications

- Poor initial tensioning of tendon graft, allowing persistent valgus deformity
- Graft elongation and/or failure
- Graft pull-out from osteopenic medial malleolus bone
- Recurrent valgus talar tilt secondary to unrecognized lateral joint space narrowing
- Injury to saphenous nerve
- Injury to the medial flexor tendons (FHL or FDL) during graft insertion into sustentaculum
- Fracture of the sustentaculum
- Infection

Deltoid reconstruction is an important component to overall management of the PCFD deformity when the ankle is amenable to reconstruction; however, it is only successful when the valgus-directed biomechanical forces on the ankle are reduced with a concomitant procedure to correct the collapsed foot deformity. Therefore, its use is generally only recommended in combination with additional procedures to avoid graft failure and recurrence of lateral talar tilt. The results of deltoid reconstruction when associated with PCFD are relatively unpredictable,[82] and accurate correction of the hindfoot valgus deformity is critical to avoid recurrent talar tilt.[83,86] The most common complication is persistent residual valgus of the tibiotalar articulation after final correction and can be due to either technical or decision-making errors. Technical factors that contribute to persistent valgus include (1) inadequate tensioning of the tendon graft; (2) failure of bone at the graft insertion site due to osteopenia; (3) improper placement of the insertion points of the graft, too proximal in the talus or too medial in the tibia, which may reduce the mechanical advantage of the graft; and (4) failure to adequately reduce the valgus-directed thrust on the ankle with accurate correction of the underlying collapsed deformity. To avoid these sequelae, previous investigators have proposed having a low threshold for adding an MDCO to the hindfoot reconstruction to offload the deltoid reconstruction.[86] In addition, in patients with osteopenic bone, tendon grafts can be fixed to the lateral cortical bone of the tibia with suture buttons rather than anchored to the soft cancellous bone of the medial malleolus. When drilling osseous tunnels for graft placement, the tibial and sural nerves, and the FHL tendon, each can be at risk during drilling and graft passage and need to be protected. Finally, improper placement of the calcaneal tunnel can lead to fracture of the sustentaculum or poor placement of the graft, and this can be avoided with careful use of fluoroscopy to guide correct insertion point on lateral radiographs before drilling.

Errors in decision making include failure to recognize lateral joint space narrowing or a stiff/irreducible ankle as contributing factors to the lateral talar tilt. When these factors are present, deltoid reconstruction will not correct the valgus deformity and a joint-sacrificing procedure, such as a total ankle replacement, possibly with a deltoid reconstruction, is indicated.

CLINICS CARE POINTS

- Preoperative planning with a careful physical examination including standing alignment, joint range of motion, and muscle strength testing is critical to understanding PCFD and creation of a surgical plan
- Appropriate preoperative imaging studies should include weight-bearing radiographs and additional imaging studies as needed. WBCT is a new modality that offers promise as an aid in surgical decision making.
- Careful intraoperative examination of foot position and joint range of motion is needed to avoid overcorrection, which is more disabling than undercorrection. Typical displacement for an MDCO is 7 to 15 mm; typical graft sizes for an Evans LCL osteotomy range from 5 to 10 mm, and for Cotton osteotomy, from 5 to 10 mm.[87]
- Preoperative evaluation should include weight-bearing radiographs of the ankle to evaluate for possible valgus talar tilt position, osteoarthritis, and presence of deltoid or spring ligament insufficiency that may require reconstruction in addition to accurate PCFD correction.
- Patients with obesity, excessive hindfoot instability, osteopenia, and pain in the sinus tarsi area require special attention to determine if a joint fusion procedure might provide a more successful result than joint-preserving reconstructions.
- Surgical correction of PCFD is a complex and evolving field of foot and ankle surgery. Additional research is needed to help minimize complications and improve outcomes.

DISCLOSURES

The authors have received nothing of value in the preparation of this manuscript. The senior author is a paid consultant for Medline Industries and has been compensated for speaking on behalf of Arthrex. The second author (J.E.J.) is a paid consultant for Arthrex.

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