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Radiographic Outcomes of Adult Acquired Flatfoot Corrected by Medial Column Arthrodesis with or without a Medializing Calcaneal Osteotomy

Thomas H. Jordan, DPM [1], Shannon M. Rush, DPM, FACFAS [2], Graham A. Hamilton, DPM, FACFAS [3], Lawrence A. Ford, DPM, FACFAS [4]

[1] *Submitted Post Graduate Year 3, Kaiser Permanente San Francisco Bay Area Foot and Ankle Residency Program, Kaiser Permanente Medical Center, Oakland, CA*
[2] *Staff Podiatric Surgeon, Podiatric Surgery, The Palo Alto Medical Foundation, Mountain View Center, Mountain View, CA*
[3] *Staff Podiatric Surgeon, Department of Orthopedics and Podiatric Surgery, Kaiser Permanente Medical Center, Antioch, CA*
[4] *Staff Podiatric Surgeon, Department of Orthopedics and Podiatric Surgery, Kaiser Permanente Medical Center, Oakland, CA*

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ABSTRACT

Medial column arthrodesis and calcaneal osteotomies are commonly used for adult acquired flatfoot surgical reconstruction. In this retrospective study, 41 patients (47 feet) with a mean age of 55 ± 13.5 years underwent a medial column arthrodesis, with or without calcaneal osteotomy, between 1999 and 2007. The indication for surgery was a painful flatfoot deformity with peritalar subluxation, and a fault in the naviculocuneiform joint. At a mean of 9.6 (range 3–43) months postoperatively, in patients who underwent a medial column arthrodesis, radiographs showed a mean decrease in the talonavicular coverage angle of 10.2° ± 8.7° ($P < .001$), and mean increases in the lateral talometatarsal and calcaneal inclination angle of 10.7° ± 5.1° ($P < .001$) and of 3.2° ± 2.7° ($P < .001$), respectively. In patients who underwent a combined medial column arthrodesis and a medializing calcaneal osteotomy, the talonavicular coverage angle decreased by a mean of 12.1° ± 6.1° ($P < .001$), while the lateral talometatarsal angle and calcaneal inclination angle increased by a mean of 12.3° ± 6.1° ($P < .001$) and 3.1° ± 2.7° ($P < .001$), respectively, from preoperative values. Four nonunions (4 of 47, 8.51%) occurred at the naviculocuneiform joint and 1 nonunion (1 of 32, 3.13%) occurred at the tarsometatarsal joint. These findings demonstrate marked improvement of radiographic flatfoot parameters following a medial column arthrodesis with or without a medializing calcaneal osteotomy.
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The adult acquired flatfoot is a triplanar deformity characterized by progressive collapse of the medial longitudinal arch, abduction of the forefoot, and eversion of the calcaneus (1–4). Various degrees of sagittal, frontal, and transverse plane deformity are responsible for different manifestations of the collapsed foot. The etiology is thought to be a combination of factors, including the congenital configuration of the anatomical osseous structure, preexisting equinus deformity, and insufficiency of the dynamic and static soft tissue stabilizers of the arch (5–14). The medial column of the foot acts as a stable buttress to allow for even distribution of forefoot pressure on forward propulsion, which resists medial deflection of body weight and prevents continued overpronation of the midfoot (15). Equinus deformity, along with medial column instability, overloads the column and causes collapse of the longitudinal arch and dorsolateral peritalar subluxation (8, 16–18). The terms *lateral* and *dorsolateral peritalar subluxation* are used to describe the acquired flatfoot deformity as the midfoot rotates about the relatively fixed talus in the ankle mortise (17). Reducing pain and improving function are the goals of treatment for adult acquired flatfoot, which can be accomplished through medial column arthrodesis. Greisberg et al (18) showed, in a small series of 14 patients, that medial column arthrodesis corrects the radiographic alignment of peritalar subluxation in the sagittal and transverse planes.

The purpose of this retrospective cohort study was to assess the effectiveness of medial column arthrodesis, with or without calcaneal osteotomy, as demonstrated by the degree of alignment change of the hindfoot from preoperative to postoperative radiographs. Medial calcaneal osteotomies were used as ancillary procedures in some patients with significant hindfoot valgus. It was our intention to measure these changes in an effort to further our understanding of the influence with this form of flatfoot reconstruction on radiographic parameters that are commonly used by surgeons in the evaluation and management of acquired pes valgus with medial column collapse.

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Address correspondence to: Lawrence A. Ford, DPM, FACFAS, Department of Orthopedics and Podiatric Surgery, Kaiser Permanente Medical Center, 280 West MacArthur Boulevard, Oakland, CA 94611.
E-mail address: Lawrence.Ford@kp.org (L.A. Ford).

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Furthermore, we believe that this information is necessary to formulate a basis on which randomized controlled trials and prospective cohort studies focusing on the surgical repair of flatfoot deformity can be developed.

Patients and Methods

This study was a retrospective review of consecutive patients who underwent arthrodesis of the medial column (naviculocuneiform and tarsometatarsal joints) for correction of a painful adult acquired flatfoot at Kaiser Permanente Medical Centers in Oakland and Walnut Creek, California, from December 1999 to May 2007. The Kaiser Foundation Research Institutional Review Board approved the investigation. All of the medical charts of potentially eligible patients were reviewed by a single investigator (T.H.J.). Inclusion criteria included all patients who underwent a medial column arthrodesis for symptomatic adult acquired flatfoot, and whose medical records, including operative reports, contained the following clinical and radiographic information: patient age, sex, diagnosis, surgical procedure, and weight-bearing preoperative and postoperative radiographs.

All surgical procedures involved arthrodesis of the naviculocuneiform (NC) joint. An arthrodesis of the first tarsometatarsal (TMT) joint was also performed if this joint demonstrated a fault, dorsal subluxation, or metatarsus primus varus similar to that described by Miller (19). If a moderate to severe hindfoot valgus deformity was appreciated preoperatively, an ancillary medial displacement calcaneal osteotomy (MDCO) was performed. All of the patients also underwent either a gastrocnemius recession or an Achilles tendon lengthening (TAL) to address the associated equinus contracture. Flexor digitorum tendon transfers to the posterior tibial tendon were performed if significant degeneration was observed in the posterior tibial tendon intraoperatively.

Standard anteroposterior (AP) and lateral radiographs were taken preoperatively and postoperatively with the patient fully weight bearing. Radiographs used to measure outcome angles were the latest available postoperative weight-bearing radiographs for each patient. A nonunion was defined radiographically as persistent lucency, sclerosis, or lack of trabeculation across the arthrodesis site. Radiographic analysis of the hindfoot was assessed using the talonavicular (TN) coverage, calcaneal inclination, and the lateral talometatarsal angles. On the lateral view, the calcaneal inclination angle and the talometatarsal angles were measured to determine sagittal plane deformity. Calcaneal inclination was defined as the angle formed between the weight-bearing surface and a line extending from the inferior tuberosity to the inferior aspect of the anterior process of the calcaneus. The lateral talometatarsal angle was formed by the intersection of the bisection of the first metatarsal to the bisection of the body and neck of the talus. This angle establishes the sagittal plane deformity where a fault in the medial column results in an increased dorsal position of the first metatarsal in relation to the bisection of the talus. The normal foot reportedly has a lateral talometatarsal angle of –4° to +4° (20). The TN coverage was determined as previously described by Sangeorzan et al (21), wherein the relative coverage of the talus by the navicular is described by an angular measurement based on the relationship of the center of the talus to the center of the navicular. One line connects the proximal navicular articular margins, lateral to medial, and a second line connects the articular margins on the head of the talus. The TN coverage angle is formed by the intersection of these two lines. The higher the value of this angle represents more significant hindfoot abduction in the transverse plane or lateral peritalar subluxation.

A single investigator (T.H.J.) performed all radiographic measurements. A digital caliper (Stentor Intelligent Informatics, iSite Version 3.3.1, Philips Electronics, Amsterdam, The Netherlands) was used to measure the angles on the digital radiographs. Preoperative vales for each measurement were compared with postoperative values. Paired Student's *t* tests were used to compare values that were normally distributed and Wilcoxon signed ranks tests were used for values with a non-normal distribution. Statistical significance was defined at the 5% ($P \leq .05$) level. A biostatistician who did not participate in any of the surgeries performed the statistical analyses.

Operative Technique

Either a gastrocnemius recession or a percutaneous TAL was performed based on the patient's preoperative Silfverskiold test. A TAL was used for more significant equinus deformities. This procedure was performed using 2 or 3 stab incisions, alternating from the medial to the lateral aspect of the tendon, each incision 2 cm apart. The gastrocnemius recession was performed as previously described at the inferior aspect of the medial head of the gastrocnemius muscle belly (22).

An ancillary calcaneal osteotomy was used if the surgeon noted substantial hindfoot valgus deformity preoperatively. The MDCO was made through a standard lateral approach, displaced medially and fixed in retrograde fashion with interfragmental compression screws.

The NC joint was accessed through a straight medial approach as described by Hansen (17). Access to the joint was facilitated with either a lamina spreader or Weinraub retractor. Articular cartilage and subchondral bone were resected, preserving the joint contour, after which the prepared surfaces were fish scaled with an osteotome. Care was taken to debride all 3 articular facets of the NC joint. Reduction of the NC joint was effected either by engaging the windlass mechanism or by using a large bone tenaculum. The forefoot was aligned relative to the hindfoot at the NC joint, essentially plantarflexing and adducting the first ray. Fixation was achieved using lag and positional screws or a medially placed plate with screws. The first TMT arthrodesis, if indicated, was fixed with 2 crossed lag screws, one antegrade and the second retrograde. A third lag screw was sometimes used and placed from the medial aspect of the base of the first metatarsal to the second cuneiform or from the medial cuneiform to the second cuneiform. If substantial degeneration was observed in the posterior tibial tendon, either by means of preoperative magnetic resonance imaging or direct surgical inspection at the time of the operation, then flexor digitorum longus tendon was transected deep and distal to it, and anastamosed in a side-to-side fashion.

Postoperatively, all of the patients were placed in a non–weight-bearing compression splint for 10 to 14 days, after which time the sutures were removed. Subsequently, patients were given a short-leg non–weight-bearing cast for the next 4 to 6 weeks, then gradually converted to a removable walking boot once radiographs showed satisfactory consolidation of the arthrodesis sites, and finally to regular supportive shoe gear as tolerated.

Table 1
Ancillary procedures (n = 47 extremities in 41 patients)

Procedure	Count (% of extremities)
Medial displacement calcaneal osteotomy	24 (51.06)
First tarsometatarsal arthrodesis	32 (68.09)
Flexor digitorum longus transfer	16 (34.04)
Gastrocnemius recession	39 (82.98)
Percutaneous tendoAchilles lengthening	8 (17.02)

Results

Forty-one patients (47 extremities) met the criteria for inclusion. Six (14.6%) patients underwent bilateral corrections. The mean age of the patients at the time of the surgery was 52 ± 13.5 (range 21–78) years. Surgeries were performed on 26 (60.47%) females and 15 (34.88%) males, and each of the operations was performed by one of the senior authors (S.M.R., G.A.H., or L.A.F.). Table 1 depicts the count and proportion results for the ancillary procedures that were performed. An ancillary MDCO was performed in 24 extremities (51.06%), and first TMT joint fusion was performed in 32 (68.09%) of the 47 extremities in this study. In 16 (34.04%) extremities, flexor digitorum tendon transfers to the posterior tibial tendon were performed. A gastrocnemius recession was done in 39 (90.7%) extremities, while an Achilles tendon lengthening (TAL) was done in 8 (18.6%) extremities to address the associated equinus contracture. Postoperative radiographs used to measure outcome angles were taken at a mean of 9.6 ± 11.1 (3–43) months. All mean radiographic parameters showed statistically significant improvement ($P < .05$) from preoperative values, regardless of whether medial column arthrodesis was performed with or without MDCO. Table 2 shows the results for the 23 extremities that underwent medial column arthrodesis without MDCO. In

Table 2
Comparison of preoperative and postoperative radiographic angles after a medial column arthrodesis (n = 23 extremities in 21 patients)

Radiographic Angle (°)	Preoperative*	Postoperative*	Difference	*P* Value
Talonavicular coverage	27.5 ± 7.7 (12 to 41)	17.3 ± 8.3 (0 to 33)	10.2 ± 8.7	< .0001
Talar–first metatarsal	−15.4 ± 6.9 (−28 to −4)	−4.7 ± 5.9 (−15 to 7)	10.7 ± 5.1	< .0001
Calcaneal inclination	15.6 ± 4.5 (7 to 24)	18.8 ± 4.9 (8 to 27)	3.2 ± 2.7	< .0001

* Results for the preoperative and postoperative measurements shown as mean ± standard deviation (minimum to maximum range).

Table 3
Comparison of preoperative and postoperative radiographic angles after a medial column arthrodesis with a medializing displacement calcaneal osteotomy (n = 24 extremities in 20 patients)

Radiographic Angle (°)	Preoperative*	Postoperative*	Difference	*P* Value
Talonavicular coverage	29.9 ± 8.3 (16 to 51)	17.8 ± 9.0 (0 to 40)	12.1 ± 6.1	< .0001
Talar–first metatarsal	−17.5 ± 6.4 (−30 to −6)	−5.1 ± 6.9 (−16 to 7)	12.3 ± 6.1	< .0001
Calcaneal inclination	16.3 ± 3.3 (11 to 24)	19.4 ± 3.7 (13 to 26)	3.1 ± 3.0	< .0001

* Results for the preoperative and postoperative measurements shown as mean ± standard deviation (minimum to maximum range).

these cases, the TN coverage angle on the AP view decreased by 10.2° ± 8.7° ($P < .001$), the lateral talometatarsal angle improved by 10.7° ± 5.1° ($P < .001$), and the calcaneal inclination angle increased by 3.2° ± 2.7° ($P < .001$) (Figures 1 and 2). Table 3 shows the results for the 24 extremities that underwent medial column fusion with MDCO. In these cases, the AP TN coverage angle decreased by 12.1° ± 6.1° ($P < .001$), the lateral talar–first metatarsal angle increased 12.3° ± 6.1° ($P < .001$), and the calcaneal inclination increased by 3.1° ± 3.0° ($P < .001$) (Figure 3). Patients who underwent MDCO did not display a significantly greater amount of angular change for each of the measured variables, on average a decrease of 1.9° for the TN coverage angle ($P = .185$), 1.6° ($P = .546$) for the lateral talar–first metatarsal angle, and 0.1° ($P = .501$) for the calcaneal inclination angle ($P = .501$) (results not shown in the tables).

An isolated nonunion occurred at the NC joint in 3 (6.38%) of 47 cases and combined nonunion of the NC and TMT joints occurred in 1 case (3.13% of TMT arthrodesis, 2.13% of 47 cases). Hence, we observed a total of 4 (8.51%) NC nonunions and 1 (2.13%) TMT nonunion. All of the nonunions observed in this study were pseudoarthroses, and no loss of radiographic angular correction was seen. The patient who experienced nonunion at both the NC and the TMT joints was asymptomatic and therefore did not require a revision procedure; whereas, each of the other 3 isolated NC fusion nonunions was clinically symptomatic and warranted revision surgery. Radiographic angular measurements of the revision procedures were not included in this study.

Discussion

Various treatments have been described for an acquired flatfoot deformity with a fault in the medial column and valgus of the heel. A combination of arthrodesis, osteotomy, and tendon transfer performed independently or in combination is most often used (3–8, 17, 18). Although arthrodesis of the hindfoot joints can adequately correct the deformity, motion is sacrificed, increased stress is placed on adjacent joints, and the normal mechanics of the foot are altered. It has been shown that motion exists along the entire medial column of the foot. In a cadaveric study, Roling et al (23) demonstrated that the NC joint had the most motion of any joints in the medial column, contributing an average of 50% total first ray sagittal plane range of motion while the MC and TN joint contribute 41% and 9%, respectively. A cadaveric study demonstrated that arthrodesis of the TN joint eliminates motion of the hindfoot by 80% to 90% (24). When performing surgical correction of the adult acquired flatfoot, restoration of motion in the triple joint complex (subtalar, talonavicular, and calcaneocuboid joints) should be maintained if at all possible (7).

Fusion of distal joints along the medial column provides an option for correcting a medial column fault while preserving essential joint motion of the triple joint complex. In this study, arthrodesis of the NC joint was performed for feet with a sag or fault in the medial column on preoperative weight-bearing radiographs. As the flatfoot deformity progresses, a fault often occurs at the NC joint, as indicated by gapping at the inferior aspect of this joint with or without involvement of the TMT joint, which may also sublux dorsally (8). Throughout the stance phase of gait, the ground reactive force produces a dorsal vector on the foot, specifically the first ray. Stokes et al (15) showed that the medial longitudinal arch is subject to an upward shear force and bending moment in the dorsiflexion direction throughout forefoot contact with the ground, and these calculated forces were found to be highest for the first metatarsal. Because of the action of these forces on the first metatarsal, joints along the medial column are subject to

Fig. 1. Weight-bearing preoperative and postoperative radiographs of a patient who underwent naviculocuneiform arthrodesis, flexor digitorum longus transfer, and percutaneus tendoAchlillis lengthening. Talar coverage, lateral talometatarsal, and calcaneal inclination angles are depicted. Preoperative anteroposterior (*A*), postoperative anteroposterior (*B*), preoperative lateral (*C*), and postoperative lateral (*D*).

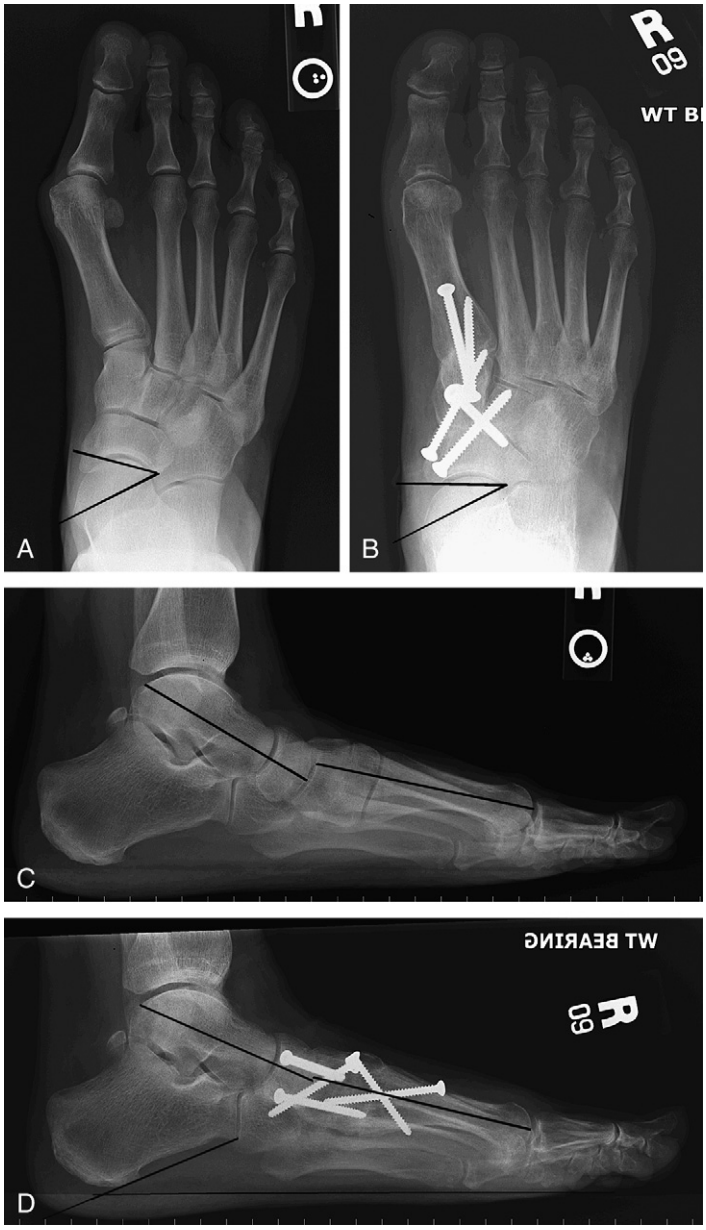

Fig. 2. Weight-bearing preoperative and postoperative radiographs of a patient who underwent a naviculocuneiform arthrodesis, tarsometatarsal arthrodesis, and gastrocnemius recession. Talar coverage, lateral talometatarsal, and calcaneal inclination angles are depicted. Preoperative anteroposterior (*A*), postoperative anteroposterior (*B*), preoperative lateral (*C*), and postoperative lateral (*D*).

Fig. 3. Weight-bearing preoperative and postoperative radiographs of a patient who underwent naviculocuneiform arthrodesis, medializing calcaneal osteotomy, and gastrocnemius recession. Talar coverage, lateral talometatarsal, and calcaneal inclination angles are depicted. Preoperative anteroposterior (*A*), postoperative anteroposterior (*B*), preoperative lateral (*C*), and postoperative lateral (*D*).

tensile forces prohibiting the proper locking motion of the first ray and the midtarsal joint, just before heel-off in the gait cycle. A contracted gastrocnemius or Achilles tendon caused by increased force transmitted through the midfoot structures further contributes to the fault in the arch and compromises soft tissue integrity (6, 7). Biomechanical studies have demonstrated medial column flattening represented by plantarflexion of both the talus and navicular with concomitant dorsiflexion of the first metatarsal when Achilles load is increased (16). Therefore, addressing equinus is a powerful adjunct to correction of the flatfoot.

This study supports the concept that arthrodesis of the insufficient medial column directly alters hindfoot radiographic angular measurements. For the purposes of this investigation, and based on our understanding of the existing literature, as well as our own personal experiences, we considered a decrease in the talonavicular coverage angle, an increase in the talar–first metatarsal angle, and an increase in the calcaneal inclination angle, to be indicative of improvement in the alignment of the adult acquired flatfoot.

Statistically significant improvement of the TN coverage angle and the lateral talometatarsal angle after fusion of the medial column was demonstrated in our cohort. In addition, pronounced correction of the transverse plane deformity after a medial column arthrodesis occurred. This coincides with the findings of Chi et al (6), who showed a decreased lateral talometatarsal angle and TN coverage angle by 20° and 10°, respectively, in 5 feet that underwent arthrodesis of the NC and/or first TMT joints. Greisberg et al (18) reported improvements in the lateral talometatarsal angle and TN coverage angle by 16° and 14°, respectively, in 13 feet that underwent arthrodesis of both the NC and first TMT joints, and 3 feet that underwent an isolated arthrodesis of the first TMT joint. In concordance with the aforementioned studies, our results support the notion that by addressing the medial column alone, hindfoot deformity can be improved and its essential motion maintained without performing a procedure on the triple joint complex itself.

It is not entirely clear why subluxation of the TN joint improves with arthrodesis of the NC joint. In the sagittal plane, the improved alignment is explained by increased plantarflexion of the first ray, aligning its axis closer to that of the talus, thus creating an intrinsically stable fixed locking mechanism of the first ray. This is similar to the biomechanics of a cavus foot deformity where a plantarflexed first ray is known to cause a supinatory effect of the heel (25). Johnson and Christensen (26) proved that the peroneus longus creates an eversion locking moment on the first ray that can stabilize the medial column and resist further medial deflection of body weight. Greisberg et al (18) hypothesized that hindfoot valgus has a forefoot origin that occurs with TN subluxation, explaining that the medial column acts as a post for the talus. When a breach in the medial column occurs, the TN joint destabilizes into dorsolateral subluxation with subsequent forefoot abductovarus and eversion of the subtalar joint. Therefore, the hindfoot valgus that results from the insufficient medial column can be considered a forefoot-driven hindfoot valgus. The data from this study support these findings.

Medial displacement calcaneal osteotomies increase the varus moment arm of the heel, which limits the amount of rearfoot eversion before forefoot loading (27, 28). The exact mechanism by which medial translation of the calcaneus improves rearfoot angular relationships is not completely understood, but surgical results have been favorable. Myerson et al (13) demonstrated significant radiographic improvement in both the anteroposterior TN coverage angle and the lateral talometatarsal angle in 129 patients when a medializing calcaneal osteotomy was used in combination with a flexor digitorum longus tendon transfer. Wacker et al (29) reported improvement of American Orthopaedic Foot & Ankle Society (AOFAS) scores, after 3- to 5-year follow-up; from 48.8 to 88.8 in 51 patients who underwent a medializing calcaneal osteotomy with a flexor digitorum longus tendon transfer. However, it has been speculated that this procedure is insufficient at restoring the longitudinal arch and maintaining correction over longer periods of time (2). No studies to date have evaluated the contribution that a medializing calcaneal osteotomy has to a medial column arthrodesis.

In this study, similar degrees of correction were seen in cases where a calcaneal osteotomy was performed. This supported the surgeons' assessments for this ancillary hindfoot procedure. Although not evaluated in this study, most of the correction from this osteotomy was in the coronal plane, which places the heel in its proper anatomical position in line with the axis of the tibia, completing the functional tripod of the heel with the first and fifth metatarsal as described by Cotton (30). When this occurs, the talus responds with a decrease of both plantarflexion and adduction within the ankle mortise (8). Additionally, a medializing calcaneal osteotomy contributes to the inversion moment of the hindfoot before heel rise, locking the midtarsal joints where the midfoot becomes a rigid lever on which the body can push off (30). Without this inversion, the midtarsal joint axes remain parallel and the joints remain flexible (31).

Nonunion is a possible complication that occurs with any arthrodesis. In this study, 4 (8.51%) of 47 NC fusions and 1 (3.13%) of the 32 TMT fusions developed a nonunion. Results of nonunion occurring at the NC joint are sparse in the literature. In one study, 2 of 13 patients developed a nonunion of the NC joint when a combined arthrodesis of both the NC and TMT joint was performed (18). In another study, where compression of the NC fusion was provided by a distal advancement of the osteoperiosteal flap, 8 (21%) of 38 nonunions occurred in an adolescent patient population (19). Nonunion rates of the TMT joint have been reported in the range of 3.3% to 12.0% (32–35). At our facilities, this rate was reported to be 5.3%, based on 227 feet that underwent an isolated first TMT arthrodesis (36).

We recognize that a number of methodological shortcomings could have influenced the results upon which we made our conclusions. For instance, the osseous procedures were not performed in isolation, and the use of soft tissue procedures such as the gastrocnemius recession, TAL, and flexor digitorum longus transfer were likely to have influenced the radiographic measurements as well. We did not undertake an explanatory analysis that may have enabled us to identify the influence of the independent variables, and enabled us to determine effect modification and confounding. Another potential limitation was the relatively short and variable duration of follow-up, which was 9.6 (range 3–43) months. However, in this retrospective cohort study, we feel that even by the 3-month postoperative point in time, absence of a nonunion would enable us to measure the angles of interest and provide information useful to our aims. Further, this study did not attempt to correlate patient satisfaction to radiographic improvement. It is unclear why some adult flatfeet are symptomatic while others are not, and we understand that pain in the flatfoot does not necessarily correlate with radiographic measurement and previous studies do not indicate the amount of radiographic correction that is necessary for a good result (6, 8).

In conclusion, we believe that it is important to appreciate the deformity as it occurs in all 3 cardinal planes, when surgically reconstructing the adult acquired flatfoot. The results of this study support the notion that subluxation of the TN joint in the adult acquired flatfoot can be improved by isolated arthrodesis of the medial column. Further studies are needed to correlate clinical improvement and patient satisfaction with these radiographic changes.

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