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# Plantar Plating for Medial Naviculocuneiform Arthrodesis in Progressive Collapsing Foot Deformity

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**Abstract**

**Background:** Medial column procedures are commonly used to treat progressive collapsing foot deformity (PCFD) reconstruction. The aim of this research is to present the clinical results of plantar plating for medial naviculocuneiform (NC) arthrodesis when NC joint pathology contributes to medial arch collapse. The authors hypothesized that lag screws with a plantar neutralization plate would result in a satisfactory NC joint fusion rate.

**Methods:** A single-surgeon, retrospective case series was performed on patients with flexible PCFD who underwent NC arthrodesis using lag screws and a contoured neutralization plate applied plantarly across the medial NC joint as part of PCFD reconstruction. Thirteen patients (11 females, 2 males; mean age 53.1 [34-62] years) between 2016 and 2019 were identified for inclusion. Mean follow-up was 25.2 $\pm$ 12.7 months. Preoperative and postoperative anteroposterior talo–first metatarsal angle, lateral talo–first metatarsal angle, talonavicular coverage angle, and calcaneal pitch were measured. Union was evaluated radiologically. AOFAS midfoot scores were recorded at final follow-up.

**Results:** All parameters demonstrated a significant improvement. Fusion was confirmed in 11 of 13 patients (85%) at a mean 5.7 $\pm$ 2.1 months. One patient required a revision of their NC fusion because of symptomatic nonunion. There were no cases of symptomatic plantar hardware.

**Conclusion:** The results of this small cohort series suggest that lag screw with plantar plate NC arthrodesis yielded generally improved short-term radiographic and clinical outcomes in PCFD patients with medial arch collapse through the NC joint.

**Level of Evidence**: Level IV, retrospective case series.

**Keywords:** PCFD, naviculocuneiform, arthrodesis, fusion rate, plantar plating

## Introduction

Progressive collapsing foot deformity (PCFD), previously termed adult acquired flatfoot deformity (AAFD), is a 3-dimensional pathology that involves hindfoot valgus, forefoot abduction, and midfoot varus.[29] PCFD encompasses varying degrees of dysfunction of the posterior tibial tendon, calcaneonavicular (spring) ligament, and deltoid ligament, as well as deformity of the subtalar, talonavicular, naviculocuneiform (NC), and/or first tarsometatarsal (TMT) joints.[10,14,16,18] An important component of the pathophysiology is painful collapse along the medial longitudinal arch, which can result in medial midfoot and hindfoot pain and swelling.[24,28,30]

Collapse of the medial arch at the level of the NC joint can be a challenge to treat during PCFD reconstruction. Historically, NC arthrodesis was thought to be less reliable than arthrodesis of more proximal or distal joints in the medial column.[17] A recent systematic review of 139 patients who underwent NC arthrodesis reported a nonunion rate of

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6.5%.[6] The fixation method for NC arthrodesis is typically carried out via a combination of cannulated partially threaded lag screws and a locking plate that spans either the dorsal, medial, or medioplantar aspect of the joint.[1,3,7,37] Prior authors have promoted a medioplantar plate to stabilize motion not only in the sagittal plane but also in the horizontal plane against abduction.[37] A cadaver biomechanical study comparing dorsal vs plantar plating for extended midfoot arthrodesis (TMT and NC combined) demonstrated no difference in construct stiffness and number of loads to failure.[36]

The authors propose that application of a plantar neutralization plate during NC arthrodesis should function like a tension-band construct to resist plantar-sided gapping and reduce the risk of deformity recurrence. This concept has been used in other areas of foot and ankle surgery with successful clinical outcomes.[4,27] Additionally, plantar plating potentially increases the soft tissue envelope around the plate to reduce the risk of prominent hardware and tendon irritation. The purpose of this study was to determine the (1) fusion rate; (2) change in radiographic parameters of PCFD correction; and (3) change in clinician-reported outcomes following a lag screw with plantar plating technique for medial NC joint arthrodesis. Based on the current literature for midfoot fusion rates, the authors hypothesized that >90% of patients treated with plantar plating NC arthrodesis as part of PCFD correction will achieve NC joint union with significant improvement in both radiographic parameters and clinical outcomes.

## Methods

### Study Population and Design

A retrospective case series was performed on 13 consecutive patients treated by the senior author between January 2016 and December 2019. Inclusion criteria consisted of patients with flexible PCFD with varying degrees of hindfoot valgus deformity, midfoot/forefoot abduction deformity, and forefoot varus deformity/medial column instability. Patients were diagnosed by clinical and radiologic parameters and were required to have persistent hindfoot and midfoot symptoms despite 6 months of conservative management with oral anti-inflammatory medication, shoe wear adjustments, and activity modification. Included patients had medial arch collapse through the NC joint and were operatively treated with NC arthrodesis using lag screws and a contoured neutralization plate applied plantarly across the medial NC joint. Further inclusion criteria were a minimum of 6 months clinical follow-up and complete preoperative and postoperative anteroposterior (AP) and lateral weightbearing foot radiographs. Exclusion criteria consisted of patients undergoing NC arthrodesis for a diagnosis other than PCFD, PCFD with significant peritalar subluxation and/or ankle instability, rigid PCFD, Charcot arthropathy, peripheral vascular disease, patients undergoing revision NC arthrodesis, uncontrolled diabetes mellitus type 1 or 2, and known active infection. All aspects of this study received institutional review board (IRB) approval.

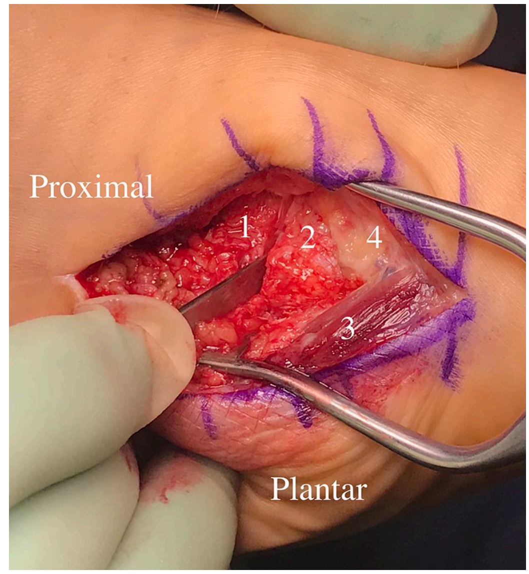


**Figure 1.** Intraoperative photograph demonstrating exposure and preparation of the naviculocuneiform joint of a left foot with proximal and plantar aspects of the foot labeled. The navicular (1), medial cuneiform (2), abductor hallucis muscle belly (3), and insertion of tibialis anterior tendon (4) are all visible.

### Surgical Technique

Operative technique for medial NC plantar plating arthrodesis entailed an incision medially from the navicular tuberosity to the mid aspect of the medial cuneiform. The NC joint was prepared by using a lamina spreader and the articular cartilage was removed using a combination of osteotomes and curettes (Figure 1). Each articular surface was drilled with a fluted 2-mm drill bit to fenestrate all the surfaces and were then fish scaled with a 3-mm osteotome. If needed, autograft cancellous bone was percutaneously harvested from the calcaneus using an 8-mm core reamer (Acumed LLC) and packed into the prepared joint. No other biologic augmentation was used. With the joint manually held in compression, 1 or 2 (depending on patient anatomy and bone quality) partially threaded 3.0-mm cannulated titanium lag screws (Arthrex or In2Bones) were placed from medial to lateral across the joint. Next, depending on patient anatomy, either a 4-hole or 5-hole 3.0-mm titanium plate (Arthrex or In2Bones) was contoured and applied in compression mode to the plantar aspect of the NC joint. To achieve a plantigrade foot, additional procedures to correct peritalar subluxation, hindfoot valgus, or forefoot abduction were concomitantly performed.


**Figure 2.** Preoperative weightbearing (A) AP foot radiograph demonstrating the AP talo–first metatarsal angle (left foot) and talonavicular angle (right foot) and (B) lateral right foot radiograph demonstrating Meary angle and the calcaneal pitch. AP, anteroposterior.

### *Postoperative Course*

Standard postoperative protocols were used for all patients, which included 6 weeks of nonweightbearing immobilization. At the 6-week postoperative visit, weightbearing AP and lateral foot radiographs were obtained and patients were transitioned into a walking cast. Subsequent visits with weightbearing radiographs were performed every 6-8 weeks until joint fusion was confirmed radiographically (presence of visible bone formation across the joint on orthogonal views) and clinically (lack of pain along the medial arch, preserved medial longitudinal arch structure, and lack of motion through the NC joint). Computed tomography (CT) scans were obtained postoperatively only when the status of NC joint fusion in question (4 patients) or revision surgery was planned for pathology not associated with the NC joint (1 patient). A CT scan demonstrating greater than 50% bony bridging across the NC joint was considered a union.[9] All patients received vitamin $D_3$ supplementation at a dose of 50 000 international units weekly for 12 weeks postoperatively. All operative procedures and follow-up examinations were performed by the senior author in person, up until the patient successfully healed and was granted full release or required a reoperation. Telemedicine follow-up was performed after 6 months on patients who had successfully fused and been granted full release.

Demographic data, perioperative data, American Orthopaedic Foot & Ankle Society (AOFAS) midfoot scores, complications and reoperations were recorded from electronic medical records. Preoperative AOFAS midfoot scores were calculated at the initial clinic visit and then again at the patients' most recent follow-up visit. In the case of most recent follow-up occurring prior to 6 months postoperatively, a telemedicine visit was performed to obtain updated AOFAS midfoot scores and inquire about any complications or reoperations that were managed by an outside surgeon.

### *Radiographic Measurements*

Preoperative and 6-week postoperative AP and lateral talo–first metatarsal (Meary) angle, talonavicular coverage angle, and calcaneal pitch (Figure 2) were measured independently by 3 of the authors (AEW, DMK, JSA) and their means calculated. Intraclass correlation coefficients were calculated for radiographic parameter readings (excellent reliability, $>0.9$; good reliability, 0.75-0.9; fair reliability, 0.5-0.75; poor reliability, $<0.5$).[23] These radiographic angles were chosen based on prior literature demonstrating their utility in assessing PCFD deformity.[11,33] The authors considered a decrease in the talonavicular coverage angle, an increase in the talo–first metatarsal angle, and an increase in the calcaneal pitch to be indicative of improvement in the alignment of the PCFD deformity.[5,20]

### *Statistical Analysis*

Descriptive statistics were calculated for demographic and perioperative data and reported as mean ± standard deviation. Categorical data were collected and reported as frequencies with percentages. A 1-tailed paired Student *t* test was used to analyze changes in radiographic parameters and AOFAS scores before and after surgery. Significance was set at $\alpha = 0.05$.

## Results

### *Demographic Data*

Thirteen consecutive patients with a diagnosis of flexible PCFD consisting of NC instability or arthritis with medial arch collapse who met inclusion criteria were available for review (Table 1). There were 11 females and 2 males

**Table 1.** Patient Demographics.

| Patient | Age, y | Sex | BMI | DM | Laterality | Prior Ipsilateral Flatfoot Surgery? | Follow-up, mo | Telemedicine Used? |
|---|---|---|---|---|---|---|---|---|
| 1 | 62 | F | 31.0 | N | R | None | 29.3 | Y |
| 2 | 39 | F | 21.8 | N | R | None | 18.2 | N |
| 3 | 60 | F | 29.1 | N | L | None | 16.0 | N |
| 4 | 55 | F | 38.7 | N | R | PTT repair | 44.9 | Y |
| 5 | 58 | M | 24.1 | N | L | None | 42.1 | Y |
| 6 | 60 | F | 27.1 | N | R | None | 37.2 | Y |
| 7 | 55 | F | 40.0 | Y, Type 2 | L | None | 37.9 | Y |
| 8 | 46 | F | 30.9 | N | L | None | 13.1 | N |
| 9 | 34 | F | 43.1 | N | R | None | 33.0 | Y |
| 10 | 49 | F | 25.4 | N | R | None | 11.7 | N |
| 11 | 56 | F | 35.0 | Y, Type 2 | R | None | 17.4 | Y |
| 12 | 59 | F | 24.0 | Y, Type 2 | L | None | 19.7 | N |
| 13 | 57 | M | 27.2 | N | R | None | 6.0 | Y |

Abbreviations: DM, diabetes mellitus; F, female; L, left; M, male; N, no; PTT, posterior tibialis tendon; R, right; Y, yes.

**Table 2.** Radiographic Outcomes.

| | Preoperative | | Postoperative | | |
|---|---|---|---|---|---|
| Angle Measurement | Average ± SD | ICC (95% CI) | Average ± SD | ICC (95% CI) | *P* Value |
| AP talo–first metatarsal angle, degrees | 20.4 ± 9.5 | 0.96 (0.89, 0.99) | 4.4 ± 8.2 | 0.89 (0.73, 0.96) | <.001 |
| AP talonavicular coverage angle, degrees | 32.2 ± 13.6 | 0.98 (0.95, 0.99) | 6.6 ± 7.4 | 0.97 (0.92, 0.99) | <.001 |
| Lateral talo–first metatarsal (Meary) angle, degrees | –21.9 ± 7.8 | 0.92 (0.79, 0.97) | –5.0 ± 2.5 | 0.80 (0.48, 0.93) | <.001 |
| Calcaneal inclination angle (calcaneal pitch), degrees | 13.6 ± 4.2 | 0.95 (0.88, 0.98) | 19.9 ± 4.1 | 0.94 (0.85, 0.98) | <.001 |

Abbreviations: AP, anteroposterior; CI, confidence interval; ICC, intraclass correlation coefficient.

with an average age of 53.1 ± 8.6 years at the time of surgery. Mean BMI was 30.6 ± 6.7. Mean follow-up was 25.2 ± 12.7 months after surgery. Overall, there was a mean of 3.8 ± 1.1 concomitant procedures performed per surgery in addition to NC arthrodesis. Telemedicine follow-up visits were necessary for 8 patients who had been granted full release after achieving radiographic and clinical union at their 6-month postoperative appointment or shortly thereafter.

## *Clinical Results*

Radiographic parameters, which included AP talo–first metatarsal angle (20.4 ± 9.5 degrees to 4.4 ± 8.2 degrees), lateral talo–first metatarsal angle (–21.9 ± 7.8 degrees to –5.0 ± 2.5 degrees), talonavicular coverage angle (32.2 ± 13.6 degrees to 6.6 ± 7.4 degrees), and calcaneal pitch (13.6 ± 4.2 degrees to 19.9 ± 4.1 degrees), all demonstrated significant improvements when comparing the final preoperative visit to the first postoperative visit ($P < .001$). The intraclass correlation coefficients were excellent for 6 of the radiographic parameter readings and good for 2 (Table 2).

Out of 13 cases, there were 11 confirmed unions (85%) at a mean time of 5.7 ± 2.1 months. Fusion was confirmed in 9 patients by radiographs alone. In 2 patients with broken hardware and inconclusive radiographs, fusion was confirmed by CT scan. AOFAS midfoot scores demonstrated significant improvement from preoperative evaluation to most recent follow-up (53.3 ± 11.4 to 84.7 ± 9.1, $P < .001$). Regarding the 2 nonunion cases, one patient with broken hardware was symptomatic and CT confirmed nonunion, for which the patient went on to require revision NC arthrodesis at 16 months. Another patient with nonunion and broken hardware has been followed for 18 months but is asymptomatic and has not required a reoperation. There were no wound complications. There were no complaints of prominent plantar hardware (Table 3).

## Discussion

This short-term retrospective case series suggests that a lag screw and plantar plating technique for medial NC arthrodesis is an effective method to radiographically and functionally correct medial arch collapse through the NC joint during

**Table 3.** Clinical Outcomes and Complications.

| Patient | Preoperative AOFAS Midfoot Score | Postoperative AOFAS Midfoot Score | Time to NC Fusion, (months) | CT Scan | Broken Hardware | Complications/Reoperations |
|---|---|---|---|---|---|---|
| 1 | 53 | 90 | 6.4 | Y | N | Symptomatic lateral column hardware that required a reoperation at 16 mo |
| 2 | 64 | 82 | – | Y | Y | Nonunion with broken screws, but asymptomatic, and has not required a reoperation |
| 3 | 56 | 88 | 9.7 | Y | Y | Broken screws, asymptomatic |
| 4 | 49 | 88 | 4.9 | N | N | None |
| 5 | 58 | 88 | 3.2 | N | N | None |
| 6 | 45 | 88 | 3.1 | N | N | None |
| 7 | 64 | 80 | 6.5 | N | N | None |
| 8 | 73 | 69 | 6.2 | Y | N | Broken screws, asymptomatic |
| 9 | 32 | 98 | 3.3 | N | N | None |
| 10 | 36 | 88 | 8.0 | N | N | None |
| 11 | 48 | 90 | 6.4 | N | N | None |
| 12 | 60 | 64 | – | Y | Y | Revision at 13 mo for NC nonunion with hardware failure |
| 13 | 55 | 88 | 5.2 | N | N | None |
| Mean ± SD | 53.3 ± 11.4 | 84.7 ± 9.1 | 5.7 ± 2.1 | | | |

Abbreviations: AOFAS, American Orthopaedic Foot & Ankle Society; CT, computed tomography; N, no; NC, naviculocuneiform; NR, not recorded; Y, yes.

PCFD reconstruction. Although the union rate of 11 of 13 cases (85%) fell short of the authors' hypothesis, the significantly increased AOFAS midfoot scores support that this procedure can provide reliable functional outcomes in carefully selected patients with PCFD and NC joint pathology contributing to medial arch collapse. Symptomatic hardware was not reported in this cohort, but there were 2 instances of asymptomatic broken hardware. The results of the current series demonstrate significant radiographic improvement in talonavicular coverage angles, lateral and AP talo–first metatarsal angles, and calcaneal pitch (Figure 3).

Options for medial column procedures during PCFD reconstruction include an opening-wedge medial cuneiform (Cotton) osteotomy, first TMT arthrodesis, NC arthrodesis, or combined TMT and NC arthrodesis (Miller procedure).[8,19,21,22,26,34,35] NC arthrodesis can be considered when degeneration or instability at the NC joint contributes to medial arch collapse.[3,7,25,37] Moreover, when restoring the native arch of the medial column, PCFD reconstruction with NC arthrodesis preserves hindfoot motion to protect surrounding joints from increased load.[5,31] NC arthrodesis sacrifices 50% of the first-ray sagittal plane range of motion, but preserves hindfoot motion.[32] In contrast, talonavicular arthrodesis results in >90% loss of subtalar motion.[2]

Several advantages to plantar plating for NC arthrodesis exist. Plates located along the plantar surface of the joint can potentially reduce the risk for recurrence of deformity by way of functioning as a tension-band construct, that is, to resist plantar-sided gapping and promote compression dorsally. Additionally, the plantar location of the hardware places it safely away from both the tibialis anterior tendon insertion and course of the extensor hallucis longus tendon, eliminating cause for irritation, while taking advantage of a thicker soft tissue envelope. The biomechanical advantage of NC arthrodesis rests in the motion spared at the other essential hindfoot (subtalar, talonavicular) and midfoot (TMT) joints.[14,15]

Similar to the present study, union rate following plantar implant positioning for midfoot arthrodesis that included the NC joint has recently been shown to be 83% in a series of 23 patients.[12] This is in contrast to a technique using lag screw with medial plating of the NC joint, which typically results in fusion rates higher than 90%.[1,3,13] A technique using medioplantar plating for the NC joint combined with subtalar arthrodesis yielded a 94% fusion rate at 1 year in 34 feet of 31 patients.[37] In these cases, the added stability at the subtalar joint likely compensates for a deficient PTT to better resist deforming forces than NC fusion alone. Moreover, this medioplantar plating technique included fixation from the navicular tuberosity to the intermediate cuneiform, which may further enhance stability.

In the current study, clinical and radiographic union at the NC joint was achieved in 11 of 13 (85%) patients at a mean of 5.7 months. Given the 2 cases of union with broken hardware in addition to the 2 cases of nonunion with broken hardware, the authors hypothesize that a plantar plating

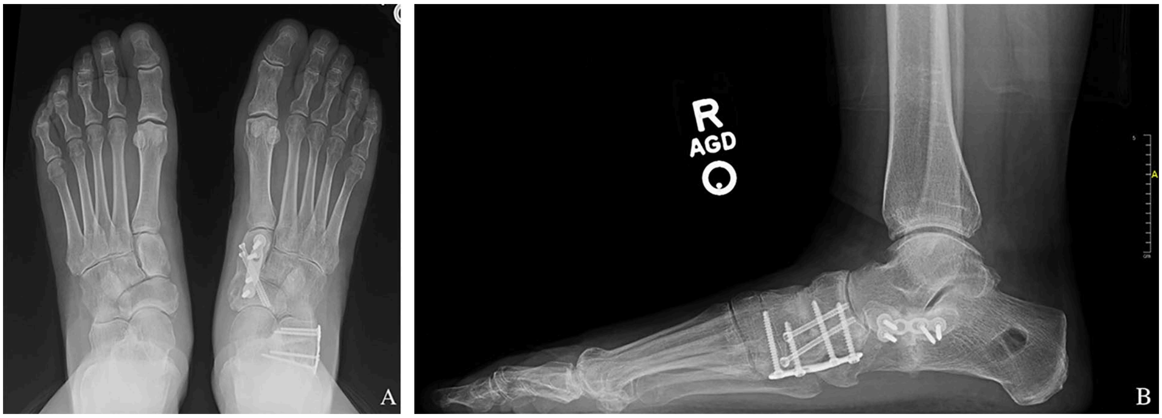


**Figure 3.** (A) Anteroposterior and (B) lateral foot postoperative radiographs demonstrating plantar plating hardware for medial naviculocuneiform arthrodesis.

technique may not provide robust enough neutralization required for midfoot stabilization. An alternative explanation is that incomplete surface preparation along the lateral NC joint leads to limited apposition and increased motion, which places stress on the screw/plate construct and prevents lateral fusion. Although this study demonstrates a substantial increase in outcome scores and radiographic parameters, a union rate that falls short of the existing literature for NC arthrodesis has prompted the authors to adopt an alternative approach moving forward (lag screws with a medial plate). The authors suggest that a larger plantar plate thickness (>3.0 mm) with greater bending rigidity is one possible solution implemented in future work. A stouter plate would likely be well tolerated given this study had no cases of symptomatic hardware.

Limitations of the present study include being a single-author retrospective case series with short-term follow-up. Analysis of a single surgeon's technique may not extrapolate well to other surgeons with differing levels of experience and resources. The number of patients included in the current study was small, and a larger randomized controlled trial of this technique would provide better insight in comparison to alternative techniques of NC arthrodesis, including comparison of techniques that include fixation of the intermediate cuneiform. Furthermore, no power analysis was performed nor was there a nonoperative control group included for comparative analysis. All included patients denied a history of tobacco/nicotine use; however, this was not objectively confirmed with further laboratory testing prior to inclusion in the study. Using plain radiographs to monitor for arthrodesis could be seen as a limitation because it is less accurate than a CT scan.[9] Lastly, telemedicine follow-up was used for some patients after radiographic union had been confirmed, which carries limitations regarding accuracy of the physical examination component of the AOFAS midfoot score. Moreover, the AOFAS surveys are clinician-based and not validated patient-reported outcome measures.

## Conclusion

In this small series, we found that lag screw with plantar plating for NC arthrodesis resulted in a 15% nonunion rate. Nonetheless, at short-term follow-up, the technique proved capable of correcting medial arch collapse through the NC joint when used in conjunction with adjunct soft tissue and bony procedures for a flexible deformity. Addressing medial arch collapse with plantar plate NC arthrodesis resulted in significant improvement of both radiographic parameters of PCFD correction and clinician-reported outcome measures.

### Ethics approval

Ethical approval for this study was obtained from the Houston Methodist Research Institute (IRB ID: PRO00025960).

### Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Jason S. Ahuero, MD, has stock or stock options for In2Bone. Kevin E. Varner, MD, reports royalties or licenses, consulting fees, and patents planned, issued or pending from In2Bone. ICMJE forms for all authors are available online.

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## References


1. Ajis A, Geary N. Surgical technique, fusion rates, and planovalgus foot deformity correction with naviculocuneiform fusion. *Foot Ankle Int*. 2014;35(3):232-237. doi: 10.1177/1071100713517098
2. Astion DJ, Deland JT, Otis JC, Kenneally S. Motion of the hindfoot after simulated arthrodesis. *J Bone Joint Surg Am*. 1997;79:241-246. doi: 10.2106/00004623-199702000-00012
3. Barg A, Brunner S, Zwicky L, Hintermann B. Subtalar and naviculocuneiform fusion for extended breakdown of the medial arch. *Foot Ankle Clin*. 2011;16:75–76. doi: 10.1016/j.fcl.2010.11.004
4. Bernstein DT, Mitchell RJ, McCulloch PC, Harris JD, Varner KE. Treatment of proximal fifth metatarsal fractures and refractures with plantar plating in elite athletes. *Foot Ankle Int*. 2018;39(12):1410-1415. doi: 10.1177/1071100718791835
5. Chi TD, Toolan BC, Sangeorzan BJ, Hansen ST. The lateral column lengthening and medial column stabilization procedures. *Clin Orthop Relat Res*. 1999;365:81-90. doi: 10.1097/00003086-199908000-00011
6. Chu AK, Wilson MD, Lee J, So E, Prissel MA, Hyer CF. The incidence of nonunion of the naviculocuneiform joint arthrodesis: a systematic review. *J Foot Ankle Surg*. 2019;58:545-549. doi: 10.1053/j.jfas.2018.09.014
7. Cohen BE, Ogden F. Medial column procedures in the acquired flatfoot. *Foot Ankle Clin*. 2007;12:287-299. doi: 10.1016/j.fcl.2007.03.002
8. Cotton FJ. Foot statistics and surgery. *N Engl J Med*. 1936;214:353-362.
9. Coughlin MJ, Grimes JS, Traughber PD, Jones CP. Comparison of radiographs and CT scans in the prospective evaluation of the fusion of hindfoot arthrodesis. *Foot Ankle Int*. 2006;27(10):780-787. doi: 10.1177/107110070602701004
10. Deland JT, de Asla RJ, Sung IH, Ernberg LA, Potter HG. Posterior tibial tendon insufficiency: which ligaments are involved? *Foot Ankle Int*. 2005;26(6):427-435.
11. Dyal CM, Feder J, Deland JT, Thompson FM. Pes planus in patients with posterior tibial tendon insufficiency: asymptomatic versus symptomatic foot. *Foot Ankle Int*. 1997;18(2):85-88. doi: 10.1177/107110079701800208
12. Fraser TW, Miles DT, Huang N, Davis FB, Dunlap BD, Doty JF. Radiographic outcomes, union rates, and complications associated with plantar implant positioning for midfoot arthrodesis. *Foot Ankle Orthop*. 2021;6:24730114211027115. doi: 10.1177/24730114211027115
13. Gerrity M, Williams M. Naviculocuneiform arthrodesis in adult flatfoot: a case series. *J Foot Ankle Surg*. 2019;58:352-356. doi: 10.1053/j.jfas.2018.08.027
14. Greisberg J, Assal M, Hansen ST, Sangeorzan BJ. Isolated medial column stabilization improves alignment in adult-acquired flatfoot. *Clin Orthop Relat Res*. 2005;435:197-202. doi: 10.1097/01.blo.0000157658.17056.46
15. Greisberg J, Hansen ST, Sangeorzan B. Deformity and degeneration in the hindfoot and midfoot joints of the adult acquired flatfoot. *Foot Ankle Int*. 2003;24(7):530–534. doi: 10.1177/107110070302400704
16. Guelfi M, Pantalone A, Mirapeix RM, et al. Anatomy, pathophysiology and classification of posterior tibial tendon dysfunction. *Eur Rev Med Pharmacol Sci*. 2017;21(1):13-19.
17. Hiller L, Pinney SJ. Surgical treatment of acquired flatfoot deformity: what is the state of practice among academic foot and ankle surgeons in 2002? *Foot Ankle Int*. 2003;24(9):701-705. doi: 10.1177/107110070302400909
18. Jack EA. Naviculo-cuneiform fusion in the treatment of flat foot. *J Bone Joint Surg Br*. 1953;35:75-82. doi: 10.1302/0301-620X.35B1.75
19. Johnson JE, Cohen BE, Digiovanni BF, Lamdan R. Subtalar arthrodesis with flexor digitorum longus transfer and spring ligament repair for treatment of posterior tibial tendon insufficiency. *Foot Ankle Int*. 2000;21(9):722-729. doi: 10.1177/107110070002100902
20. Jordan TH, Rush SM, Hamilton GA, Ford LA. Radiographic outcomes of adult acquired flatfoot corrected by medial column arthrodesis with or without a medializing calcaneal osteotomy. *J Foot Ankle Surg*. 2011;50:176-181. doi: 10.1053/j.jfas.2010.12.008
21. Kadakia AR, Haddad SL. Hindfoot arthrodesis for the adult acquired flat foot. *Foot Ankle Clin*. 2003;8:569-594. doi: 10.1016/s1083-7515(03)00048-2
22. Knupp M, Stufkens SA, Hintermann B. Triple arthrodesis. *Foot Ankle Clin*. 2011;16:61-67. doi: 10.1016/j.fcl.2010.11.006
23. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15(2):155-163. Erratum in: J Chiropr Med 2017;16:346. doi: 10.1016/j.jcm.2016.02.012
24. McCormick JJ, Johnson JE. Medial column procedures in the correction of adult acquired flatfoot deformity. *Foot Ankle Clin*. 2012;17:283-298. doi: 10.1016/j.fcl.2012.03.003
25. Metzl JA. Naviculocuneiform sag in the acquired flatfoot: what to do. *Foot Ankle Clin*. 2017;22:529-544. doi: 10.1016/j.fcl.2017.04.007
26. Miller OL. A plastic flatfoot operation. *J Bone Joint Surg*. 1927;9:84–91.
27. Mitchell RJ, Duplantier NL, Delgado DA, et al. Plantar plating for the treatment of proximal fifth metatarsal fractures in elite athletes. *Orthopedics*. 2017;40:e563-e566. doi: 10.3928/01477447-20170327-04
28. Myerson MS. Adult acquired flatfoot deformity: treatment of dysfunction of the posterior tibial tendon. *Instr Course Lect*. 1997;46:393-405.
29. Myerson MS, Thordarson DB, Johnson JE, et al. Classification and nomenclature: progressive collapsing foot deformity. *Foot Ankle Int*. 2020;41(10):1271-1276. doi: 10.1177/1071100720950722
30. Pedowitz WJ, Kovatis P. Flatfoot in the adult. *J Am Acad Orthop Surg*. 1995;3:293-302. doi: 10.5435/00124635-199509000-00005
31. Pinney SJ, Lin SS. Current concept review: acquired adult flatfoot deformity. *Foot Ankle Int*. 2006;27(1):66-75. doi: 10.1177/107110070602700113
32. Roling BA, Christensen JC, Johnson CH. Biomechanics of the first ray. Part IV: the effect of selected medial column

arthrodeses. A three-dimensional kinematic analysis in a cadaver model. *J Foot Ankle Surg*. 2002;41:278-285. doi: 10.1016/s1067-2516(02)80045-x
33. Saltzman CL, Brandser EA, Berbaum KS, et al. Reliability of standard foot radiographic measurements. *Foot Ankle Int*. 1994;15(12):661-665. doi: 10.1177/107110079401501206
34. Sammarco VJ, Magur EG, Sammarco GJ, Bagwe MR. Arthrodesis of the subtalar and talonavicular joints for correction of symptomatic hindfoot malalignment. *Foot Ankle Int*. 2006;27(9):661-666. doi: 10.1177/107110070602700901
35. Sangeorzan BJ, Smith D, Veith R, Hansen ST. Triple arthrodesis using internal fixation in treatment of adult foot disorders. *Clin Orthop Relat Res*. 1993;294:299-307.
36. Simons P, Sommerer T, Zderic I, et al. Biomechanical investigation of two plating systems for medial column fusion in foot. *PLoS One*. 2017;12:e0172563. doi: 10.1371/journal.pone.0172563
37. Steiner CS, Gilgen A, Zwicky L, Schweizer C, Ruiz R, Hintermann B. Combined subtalar and naviculocuneiform fusion for treating adult acquired flatfoot deformity with medial arch collapse at the level of the naviculocuneiform joint. *Foot Ankle Int*. 2019;40(1):42-47. doi: 10.1177/1071100718800295