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AMERICAN ORTHOPAEDIC FOOT & ANKLE SOCIETY

Foot & Ankle International®
2015, Vol. 36(8) 919–927

DOI: 10.1177/1071100715576918
fai.sagepub.com

Optimal Position of the Heel Following Reconstruction of the Stage II Adult-Acquired Flatfoot Deformity

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Abstract

Background: While previous work has demonstrated a linear relationship between the amount of medializing calcaneal osteotomy (MCO) and the change in radiographic hindfoot alignment following reconstruction, an ideal postoperative hindfoot alignment has yet to be reported. The aim of this study was to identify an optimal postoperative hindfoot alignment by correlating radiographic alignment with patient outcomes.

Methods: Fifty-five feet in 55 patients underwent flatfoot reconstruction for stage II adult-acquired flatfoot deformity (AAFD) by 2 fellowship-trained foot and ankle orthopedic surgeons. Hindfoot alignment was determined as previously described by Saltzman and el-Khoury.[23] Changes in pre- and postoperative scores in each Foot and Ankle Outcome Score (FAOS) subscale were calculated for patients in postoperative hindfoot valgus (≥0 mm valgus, n = 18), mild varus (>0 to 5 mm varus, n = 17), and moderate varus (>5 mm varus, n = 20). Analysis of variance and post hoc Tukey's tests were used to compare the change in FAOS results between these 3 groups.

Results: At 22 months or more postoperatively, patients corrected to mild hindfoot varus showed a significantly greater improvement in the FAOS Pain subscale compared with patients in valgus ($P = .04$) and the Symptoms subscale compared with patients in moderate varus ($P = .03$). Although mild hindfoot varus did not differ significantly from moderate varus or valgus in the other subscales, mild hindfoot varus did not perform worse than these alignments in any FAOS subscale. No statistically significant correlations between intraoperative MCO slide distances and FAOS subscales were found.

Conclusions: Our study indicates that correction of hindfoot alignment to between 0 and 5 mm of varus on the hindfoot alignment view (clinically a straight heel) following stage II flatfoot reconstruction was associated with the greatest improvement in clinical outcomes following hindfoot reconstruction in stage II AAFD.

Level of Evidence: Level III, comparative series.

Keywords: adult-acquired flatfoot deformity, reconstruction, hindfoot alignment, outcome studies, calcaneal osteotomy

Stage II adult-acquired flatfoot deformity (AAFD) is characterized by a range of passively correctible deformities including collapse of the medial longitudinal arch, forefoot abduction, increased talonavicular uncoverage, and hindfoot valgus.[5,17] These changes are the result of dysfunction of the posterior tibial tendon in combination with the progressive failure of ligaments that support the arch of the foot.[5] Proper operative treatment of stage II AAFD remains controversial but typically involves both bony and soft tissue procedures that are chosen according to the severity of the deformity. For the correction of hindfoot valgus in AAFD, the medializing calcaneal osteotomy (MCO) is the most common procedure performed in the United States.[14] Current biomechanical and clinical outcomes literature has shown that the MCO can be used to restore foot alignment, decrease load on the medial arch, normalize force at the talonavicular joint, reposition the Achilles tendon to function as a heel inverter, and improve patient outcomes.[1,9,11,13,18-21,25,26]

Despite the frequent use of the MCO procedure in flatfoot reconstruction, there are few established principles guiding the amount of medial displacement to be performed. A commonly cited amount of intraoperative medial displacement is 10 mm,[2,9,10,13,18,19,21,26] and one biomechanical study has supported this amount of heel translation.[1] However, because patients present preoperatively with different severities of hindfoot deformity, postoperative hindfoot alignments can vary significantly with the same amount of

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Table 1. Patient Demographics and Procedures by Postoperative Hindfoot Moment Arm Group.

Hindfoot Moment Arm	Total No.	Body Mass Index	Age, y	Percentage Male	Lateral Column Lengthening	First Tarsometatarsal Fusion	Cotton Osteotomy	Spring Ligament Reconstruction
Valgus	18	27.8	60.5	50.0	15	13	4	2
Mild varus (0-5 mm)	17	29.0	61.9	29.4	9	9	6	3
Moderate varus (>5 mm)	20	27.7	62.3	30.0	15	6	9	0

Table 2. Preoperative Abduction and Adduction Radiographic Measurements[a].

Hindfoot Moment Arm	Total No.	Preoperative Incongruency Angle, degrees (range)	Preoperative AP Talonavicular Coverage Angle, degrees (range)	Preoperative AP First Talometatarsal Angle, degrees (range)
Valgus	17	43.4 (–75.9 to 147.6)	33.0 (4.8 to 69.6)	17.0 (–24.0 to 36.4)
Mild varus (0-5 mm)	17	25.3 (–42.4 to 91.0)	27.2 (2.9 to 36.0)	12.6 (–3.5 to 35.8)
Moderate varus (>5 mm)	20	9.2 (–92.6 to 92.0)	26.1 (1.6 to 40.6)	12.8 (–11.5 to 32.9)

[a]There were no statistically significant differences between the 3 hindfoot moment arm groups.

heel slide. In addition, difficulties in assessing hindfoot alignment in the operating room may cause the amount of heel slide performed to vary among surgeons. This variability can lead to suboptimal outcomes. It is our experience that in patients with insufficient correction of the calcaneus, residual hindfoot valgus deformity can result in continued symptoms and eventual collapse of the reconstructed foot. Overcorrection of hindfoot alignment, meanwhile, may shift plantar pressures laterally and has the potential to cause discomfort in the lateral foot.[13]

While a prior study demonstrated an association between the amount of MCO performed intraoperatively and the change in hindfoot alignment following reconstruction, an ideal postoperative hindfoot alignment based on clinical outcomes has not yet been reported.[4] Indeed, it is unclear what position of the heel the surgeon should aimed for when he or she is sliding the heel. The goal of this study was to evaluate the relationship between postoperative hindfoot alignment following an MCO for stage II AAFD and patient outcomes using the Foot and Ankle Outcome Score (FAOS), previously validated for patients with flatfoot deformity.[16] Our hypothesis was that patient outcomes would be highest in the cohort that was corrected to a mild varus hindfoot alignment postoperatively.

Methods

For this retrospective study, we identified all patients who underwent flatfoot reconstruction for stage II AAFD by 2 surgeons fellowship-trained in foot and ankle surgery between January 2008 and March 2011. The protocol used data from an institutional review board–approved foot and ankle registry at the investigators' institution and was approved by the registry's steering committee. Data collected from the registry database included demographic information, postoperative hindfoot alignment view radiographs, preoperative FAOS, and postoperative FAOS. Operative notes were reviewed to identify the use of various flatfoot reconstructive procedures including MCO, lateral column lengthening (LCL), first tarsometatarsal (TMT) fusion, Cotton osteotomy, and spring ligament reconstruction.

Fifty-five feet (26 right, 29 left) in 55 patients met the inclusion and exclusion criteria. The cohort consisted of 20 men and 35 women with a mean age of 61.6 years (range, 42-84 years) and a mean body mass index (BMI) of 28.1 (range, 18.5-40.7). There were no statistically significant differences between BMI, gender, or age between the groups (Table 1). Additionally, preoperative measurements of the lateral talonavicular incongruency angle, talonavicular coverage angle, and talo–first metatarsal angle did not differ significantly between the hindfoot moment groups, indicating similar preoperative abduction deformity (Table 2).[7] Postoperative hindfoot alignment radiographs were taken at an average of 23.5 months (range, 12-47 months), and FAOS results were obtained after an average of 3.1 years postoperatively (range, 1.8-4.4 years).

Inclusion and Exclusion Criteria

The inclusion criteria for this study required patients to have (1) a diagnosis of stage II AAFD at the time of reconstruction, (2) an MCO performed as part of the flatfoot reconstruction, (3) an FAOS preoperatively and greater than 22 months postoperatively, and (4) a hindfoot alignment

Table 3. Number of Patients by Postoperative Hindfoot Moment Arm Group Who Answered a Sufficient Number of Questions in Each FAOS Subscale[a].

Hindfoot Moment Arm	Total	Pain	Symptoms	Daily Activities	Sports Activities	Quality of Life
Valgus	18	18	18	18	9	18
Mild varus (0-5 mm)	17	17	16	15	12	17
Moderate varus (>5 mm)	20	16	19	19	17	20

[a]Patients are not required to respond to all of the questions in the FAOS survey, and consequently, some patients may not have a score in every subscale. All values are numbers of patients.

radiograph greater than 48 weeks postoperatively.[23] Patients were excluded if (1) they underwent a contralateral flatfoot reconstruction and/or (2) talonavicular, calcaneocuboid, or subtalar fusions were performed as these were judged to be possible confounders. In our initial search, 60 patients with stage II AAFD undergoing an MCO as part of a flatfoot reconstruction from January 2008 through December 2012 were identified who met all inclusion criteria. Of these 60 patients, 1 patient was excluded for a subsequent contralateral triple arthrodesis, and 4 patients were excluded for a subsequent contralateral MCO. Fifty-five patients met all inclusion and exclusion criteria.

Clinical Outcome Evaluation

Clinical outcomes were evaluated using the FAOS, a self-administered, subjective foot and ankle–specific questionnaire that has been validated for AAFD.[16] The survey is composed of 42 questions grouped into 5 subscales: pain, symptoms, daily activities, sports activities, and quality of life. Patients grade the magnitude of their symptoms as none, mild, moderate, severe, or extreme. Additionally, the frequency of their symptoms was selected from the following choices: (1) never, rarely, sometimes, often, or always or (2) never, monthly, weekly, daily, or always. The survey is scored from 0 (extreme symptoms) to 100 (no symptoms) for each of the subscales with no total score calculated. To control for within-subject variability, the change in FAOS preoperatively to postoperatively was calculated. The preoperative FAOS was chosen for each patient using the survey completed closest to the time of reconstruction. Postoperatively, the most recent FAOS questionnaire administered at least 22 months postoperatively was selected from the registry to ensure adequate follow-up time. Because patients are not required to answer every question in the FAOS survey if they feel that particular questions are not applicable, the number of scored subscales can vary between patients resulting in differences in the number of patients included in the analysis for each subscale (Table 3).

Radiographic Evaluation

To determine final postoperative heel alignment, the hindfoot moment arms were measured by a single orthopedic resident on postoperative hindfoot alignment radiographs, as previously described by Saltzman and el-Khoury with the exception that our radiographs were taken using a bilateral view of the hindfoot.[23] Interobserver reliability of the measurement of the hindfoot moment arm has previously been found to be excellent ($r = 0.96$).[23] To summarize, the hindfoot moment arm is defined as the shortest distance between the midtibial axis and the most inferior aspect of the calcaneus (Figure 1). This measurement was chosen as it has been found to be reliable in prior studies.[3,20,22,23] All radiographs were taken at more than 48 weeks postoperatively.

Postoperative position of the heel was classified into 3 groups based on the hindfoot moment arm: valgus (≥0 mm valgus, n = 18), mild varus (>0 to 5 mm varus, n = 17), and moderate varus (> 5 mm varus, n = 20). Because of the lack of evidence supporting a normal range for the hindfoot moment arm, the 3 moment arm groups were defined by the senior author (J.D.) to test the hypothesis that a position of the heel in slight varus would result in improved outcomes taking into consideration the concerns for both over- and undercorrection of the hindfoot. Patients were initially divided into varus and valgus hindfoot alignment groups as the Achilles tendon may be able to assist the posterior tibial tendon with inversion of the heel when the insertion point on the calcaneus is medial to the midtibial axis. However, overcorrection with too much medial translation of the heel may result in persistent symptoms due to lateral weightbearing and/or excessive stiffness. Patients in varus hindfoot alignment were therefore subdivided into mild and moderate cohorts.

Operative Technique

Two surgeons fellowship-trained in foot and ankle surgery at the investigators' institution performed all of the flatfoot reconstructions. Reconstruction included either an MCO

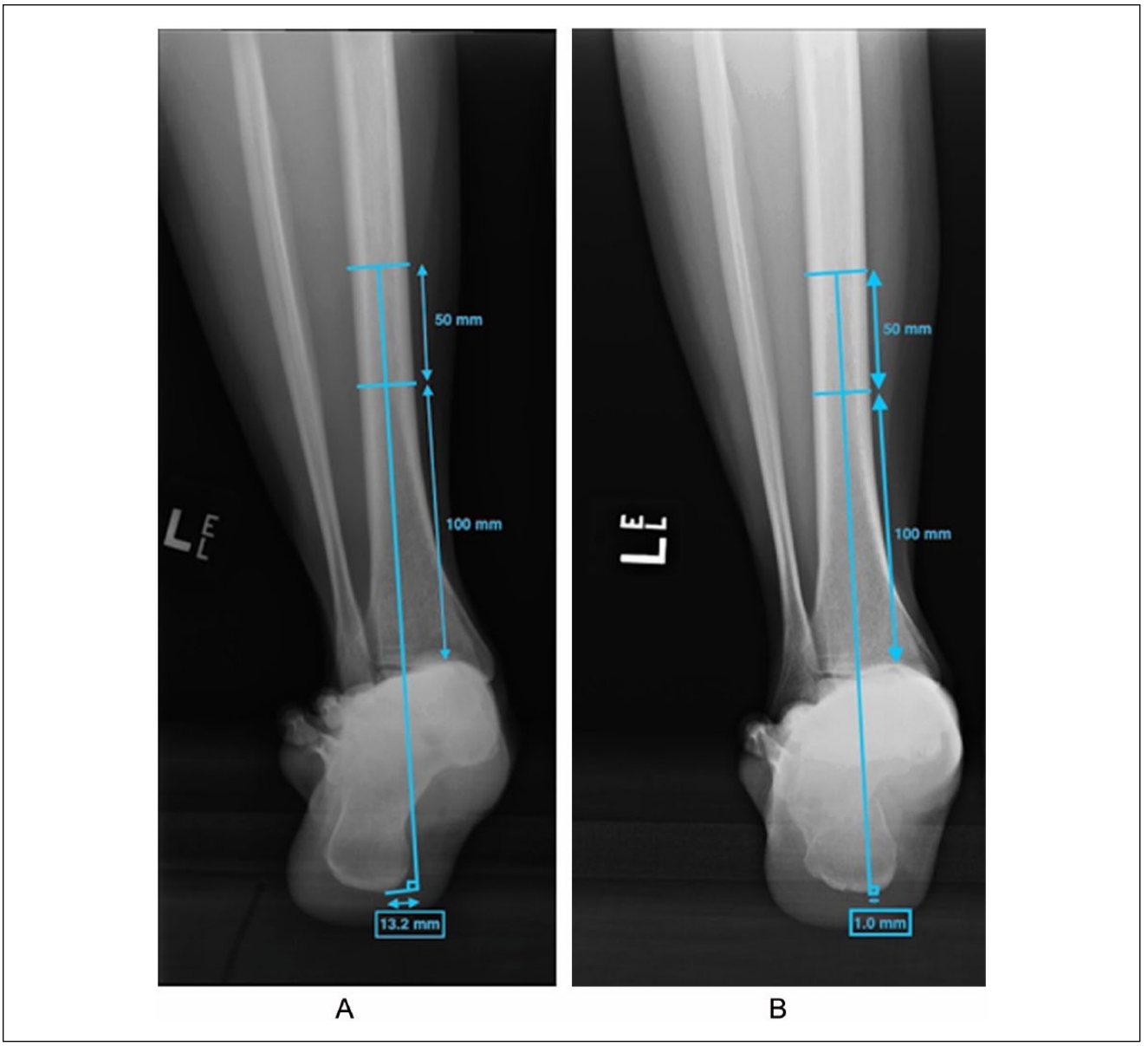

Figure 1. (A) Pre- and (B) postoperative hindfoot moment arm. The hindfoot moment arm is measured on a hindfoot alignment view radiograph. It is defined as the shortest distance from the midtibial axis to the most inferior aspect of the calcaneus.

(n = 16) or a combination of MCO with LCL (n = 39). The MCO was completed via a lateral incision and transverse cut of the calcaneus. The posterior segment was translated medially and secured with 4.5, 6.5, or 7.3 cannulated screws. Lateral column lengthening was performed with either a Vander Griend (Stepcut)-type or Evans-type osteotomy through a lateral incision over the anterior calcaneus.[8,24] The osteotomy site was then filled with autograft and bone marrow aspirate from the ipsilateral iliac crest and fixed with 2 fully threaded cortical screws or a claw plate.

Other procedures performed concomitantly to reconstruct the foot included the Cotton osteotomy (n = 24), first TMT fusion (n = 28), and spring ligament reconstruction (n = 5) (Table 1). All patients except 1 received either a Cotton osteotomy or first TMT fusion. The Cotton osteotomy was completed through a dorsal approach, and the osteotomy site was filled with autogenous or allograft bone and fixed with a small plate and screws. The first TMT fusion was performed using a modified Lapidus technique in which the joint surfaces were prepared and then fixed with a combination of fully threaded, cortical cross screws. When performed, spring ligament reconstruction was completed using an allograft tendon placed through drill holes in the navicular, tibia, and fibula and secured to 3.5-mm

screw posts in the plantar navicular and lateral fibula. The amounts of MCO, LCL, and Cotton osteotomy were determined intraoperatively by the attending surgeon in order to give adequate correction of the deformity. Postoperative treatment for all patients began with 6 to 8 weeks of nonweight-bearing in a cast or removable boot and progressed to full weight-bearing by 10 to 12 weeks.

Statistical Analysis

An analysis of variance (ANOVA) was used to compare the change in the FAOS subscales between the 3 hindfoot moment arm groups. Statistically significant effects identified by the ANOVA were evaluated using post hoc Tukey's tests to determine which group varied significantly from the others. This method enabled the identification of hindfoot moment arm groups that had significantly different changes in any of the FAOS subscales. Similarly, preoperative FAOS results were compared between the groups to examine whether there were significant differences in patient condition before surgery. ANOVA was also used to explore any differences between the 3 hindfoot moment arm groups in BMI or age as well as preoperative AP radiographic measurements of incongruency, talonavicular coverage, and first talometatarsal angles. A chi-square test was used to determine whether there were any differences in gender between the groups.

To explore the possibility that differences in the change in FAOS subscales between groups were due to heel slide distance rather than final heel alignment, the relationship between the amount of MCO performed intraoperatively and FAOS subscales was investigated. For the patients with the MCO slide amount documented in their operative note (n = 41), Spearman's rank correlation coefficients were calculated to determine whether any correlation between the amount of MCO performed intraoperatively and FAOS subscales existed.

Finally, concomitant procedures including LCL, first TMT fusion, Cotton osteotomy, and spring ligament reconstruction were analyzed to determine whether specific procedures had an effect on FAOS results. For each procedure, patients were divided into cohorts based on whether they had the procedure. Changes in FAOS results were compared between the 2 groups using a Wilcoxon rank sum test.

Results

Statistically significant differences in the FAOS Pain and Symptoms subscales were found between hindfoot alignment groups. The mean change in the FAOS Pain subscale was 27.9 (range, –8.3 to 63.9) for the moderate varus group (n = 16), 41.2 (range, 5.6 to 66.7) for the mild varus group (n = 17), and 22.3 (range, –58.3 to 63.9) for the valgus group (n = 18). Post hoc Tukey's tests indicated that patients corrected to mild hindfoot varus showed a significantly greater improvement in the FAOS Pain subscale compared with patients in valgus ($P = .04$) (Figure 2). Although the mean change in the FAOS Pain subscale was higher for mild varus than moderate varus, this did not reach significance ($P = .20$).

For the FAOS Symptoms subscale, the mean change in score was 6.6 (range, –40.7 to 46.4) for the moderate varus group (n = 19), 25.9 (range, 3.6 to 78.6) for the mild varus group (n = 16), and 11.0 (range, –32.1 to 46.4) for the valgus group (n = 18). Patients corrected to mild varus improved significantly more in the Symptoms subscale than patients in the moderate varus group ($P = .03$). Additionally, patients in the mild varus demonstrated higher clinical outcomes than those in the valgus group, but this difference was not statistically significant ($P = .11$). There were no differences between groups in the change in scores for the Daily Activities ($P = .26$), Sports Activities ($P = .06$), or Quality of Life ($P = .17$) subscales of the FAOS. However, the mean change in scores for patients in the mild hindfoot varus group were not lower than those in valgus or moderate varus for any subscale.

There were no differences between groups in the preoperative FAOS for all subscales ($P > .10$ for all analyses). None of the other procedures performed during flatfoot reconstruction (LCL, TMT fusion, spring ligament reconstruction, or Cotton osteotomy) showed a significant association with change in FAOS results ($P > .05$ for all analyses).

Finally, intraoperative MCO slide distances were recorded for 41 patients. Spearman's rank correlation coefficients showed that the amount of MCO performed intraoperatively did not correlate with any of the FAOS subscales (all $P > .10$).

Discussion

This study indicates that a postoperative radiographic hindfoot moment arm between 0 and 5 mm in varus results in the greatest clinical improvement for patients undergoing an MCO as part of a flatfloot reconstruction for stage II AAFD. Patients in the mild varus hindfoot alignment group showed significantly greater improvement than the valgus group in the FAOS Pain subscale and significantly greater improvement than the moderate varus group in the FAOS Symptoms subscale. Because one of the primary indications for flatfoot reconstruction is the relief of pain and symptoms, these subscales provide an important guide for the success of the procedure. In addition, in no subscale was the valgus or moderate varus better than the mild varus group.

When Koutsogiannis[15] reintroduced the concept of a medializing calcaneal osteotomy as part of flatfoot reconstruction in 1971, he recommended sliding the posterior

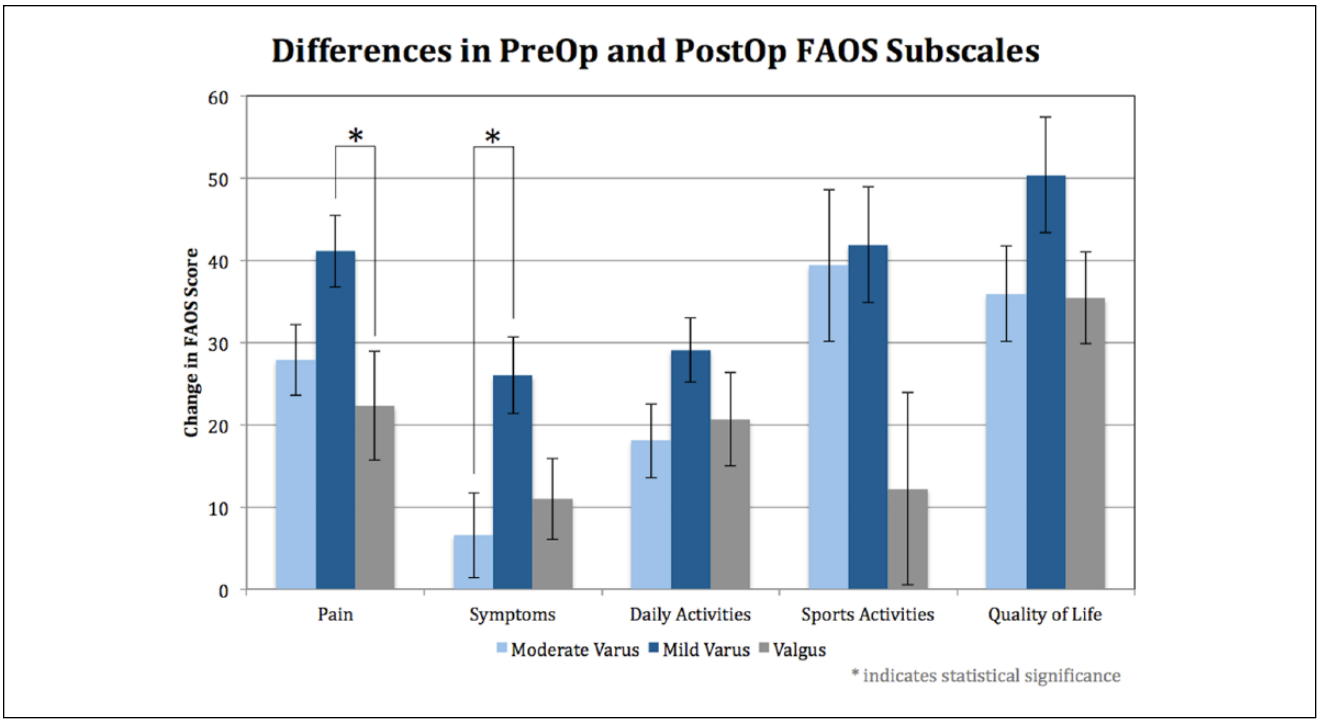

Figure 2. Differences in pre- and postoperative Foot and Ankle Outcome Score (FAOS) subscales. Change in FAOS subscales were compared between patients in hindfoot valgus, mild varus (0-5 mm), and moderate varus (>5 mm) following flatfoot reconstruction with an MCO procedure. Patients corrected to mild varus showed a significantly greater improvement in the Pain subscale over patients corrected to valgus (P = .04) and in the Symptoms subscale compared with patients corrected to moderate varus (P = .03).

segment of the calcaneus one-third to a half of the width of the calcaneus. Later studies quantified this recommendation and suggested translating the posterior segment approximately 10 mm medially.[1,10,12,18,19]

In practice, our work may be used by the surgeon to estimate the appropriate amount of medial heel slide for an individual during a flatfoot reconstruction. Chan et al[4] in 2013 described a model relating the amount of MCO performed and the change in hindfoot moment arm. Their results indicated that each millimeter of medial translation in the operating room corresponded to approximately a 1.5-mm change in the radiographic moment arm measured with the patient standing in the clinic.[4] Medial translation in the operating room is measured using a ruler extending from the lateral-most aspect of the proximal segment of the calcaneus to the lateral-most aspect of the displaced distal segment of the calcaneus during the osteotomy.

Defining the amount of heel slide that is appropriate for each patient depends on knowing where the final position of the heel should be. This study found evidence to support a final heel alignment of 0 to 5 mm in varus. Therefore, if the surgeon measures the preoperative hindfoot moment arm and determines the amount from the preoperative deformity to the optimal postoperative heel alignment, then the surgeon can calculate the amount of intraoperative slide necessary to achieve the greatest improvement in clinical outcomes. For example, if a patient has a preoperative moment arm of 4 mm in valgus, our study in addition to the previous work by Chan et al[4] discussed above suggests that the patient would need to be medially translated approximately 4 mm intraoperatively to achieve a hindfoot moment arm of about 2 mm varus resulting in a final heel alignment in mild varus. Thus, the surgeon could use the following formula to predict the amount of intraoperative medial heel translation necessary: [1.5 × (Intraoperative Medial Slide Distance) = Preoperative Hindfoot Moment Arm – Postoperative Moment Arm] with moment arms in valgus being positive and those in varus being negative. Although the equation was validated by comparing the amount of heel slide performed with the postoperative heel alignment, we are in the process of testing it to achieve a desired postoperative heel alignment. Therefore, clinicians should use this equation only as an estimate and should confirm a "straight heel alignment" in the operating room by raising the leg with the foot in neutral and viewing back of the heel to calf from distal to proximal.

To our knowledge, the optimal position of the heel following flatfoot reconstruction for stage II AAFD has not yet been reported. It is important not to confuse clinical varus with radiographic varus (Figure 3). Normal alignment of the heel is in mild clinical valgus. On standing clinical view, the straight heel (Figure 3B) is therefore likely to be in mild

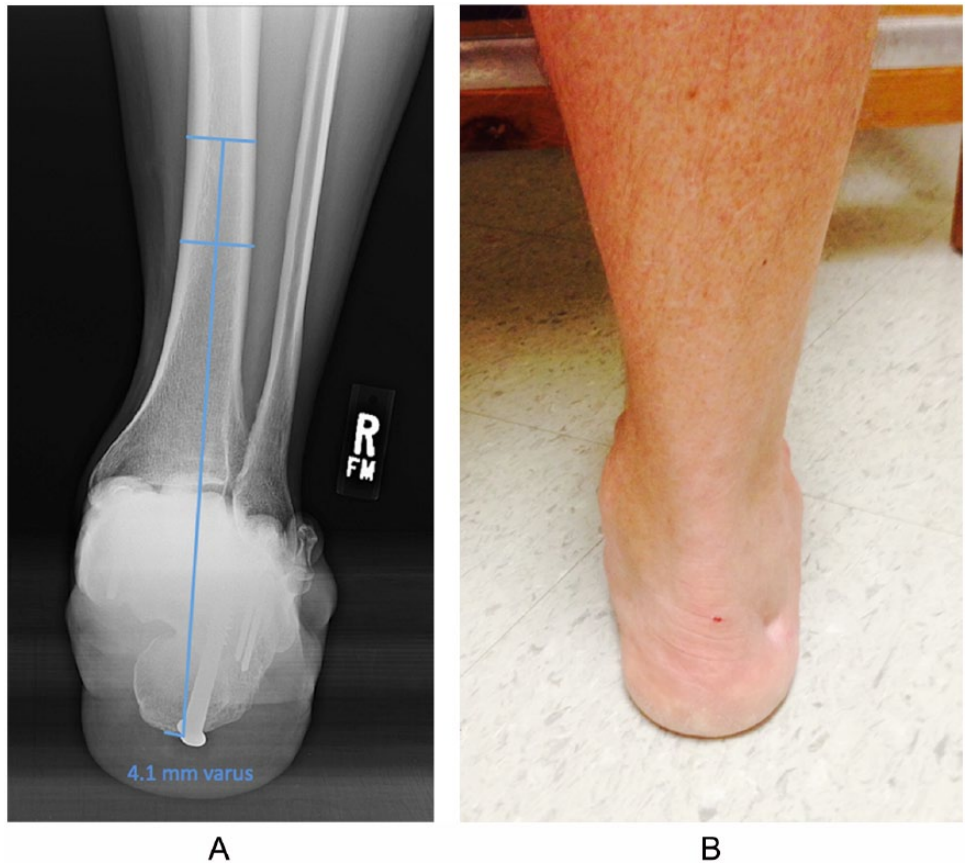

Figure 3. Postoperative (A) radiographic and (B) clinical alignments of a patient corrected to 4.1 mm varus (mild varus) on the hindfoot alignment view. The clinical heel alignment shows that the heel is straight or clinically in very mild varus.

varus on the radiographic view (Figure 3A). These patients had the best results in the present study. Patients placed in clinical varus are likely to be in moderate radiographic varus and in this study were not as likely to have favorable results. Therefore, we presently aim for a clinically straight heel (mild radiographic varus).

Displacing the calcaneus to a position of mild varus via an MCO procedure during flatfoot reconstruction provides static support to the posterior tibial tendon by positioning the Achilles tendon to pull the heel into varus, which locks the transverse tarsal joint during toe-off.[10] This has the potential to improve patient outcomes. For example, patients in the mild varus hindfoot alignment group in our study show improved responsiveness in all FAOS subscales compared with the average stage II AAFD patient reported by Mann and Thompson.[16]

In contrast, undercorrection of the hindfoot in valgus can lead to persistent flatfoot symptoms.[12] Patients who have valgus postoperative hindfoot moment arms may continue to suffer from the everting pull of the Achilles tendon and high loads along the medial longitudinal arch, as suggested by their lower improvement in the FAOS Pain subscale. Patients who are corrected into moderate varus postoperative hindfoot moments, in contrast, may have excessive inversion of the foot, leading to increased loads along the lateral column. These higher loads can result in increased symptoms of discomfort or pain, given that patients with lateral plantar pain following LCL for stage II AAFD have been shown to have greater lateral plantar pressures than those without pain.[6] We believe this could account for the significantly smaller improvement in the FAOS Symptoms subscale for patients with postoperative hindfoot alignments in moderate varus compared with those in mild varus.

While the FAOS is a region-specific instrument, not all subscales will be relevant to stage II AAFD patients. In particular, patients in this study often found the Sports Activities subscale to be not applicable, which is evident by the low number of respondents (n = 38) for this category. Patients undergoing flatfoot reconstruction also tend to have good functional improvement generally. This may explain why the Quality of Life subscale and Daily

Activities subscale do not show statistically significant differences between the postoperative hindfoot alignment groups. Furthermore, the amount of medial translation performed did not show any correlation with the improvement in FAOS outcomes. This suggests that medializing heel slides should not uniformly be 1 cm but should instead be tailored to each patient's preoperative deformity.

Because flatfoot reconstructions involve a variety of procedures, the concomitant use of LCL, Cotton osteotomy, first TMT fusion, and/or spring ligament reconstruction could potentially affect postoperative hindfoot alignment and clinical outcomes in addition to the MCO. It was not the purpose of this study to determine how much of an effect additional procedures have on hindfoot alignment, although the study by Chan et al[4] suggested that hindfoot alignment was determined primarily by the amount of MCO performed. Instead, the present study focused on clinical outcomes, and our results did not reveal any association between concomitant procedures and FAOS results (all P values > .05).

This study was limited by the retrospective design and small sample sizes for the hindfoot moment arm groups. The requirement for 48-week postoperative radiographic and 22-month clinical outcome scores follow-up times curtailed the number of patients eligible to be included in this study. Additional power would have helped to decrease the risk of a type II error. While we would have preferred a longer radiographic follow-up time, a recent study on AAFD indicated that postoperative hindfoot alignments remain unchanged after 3 months following surgery.[20]

In summary, patient outcomes following flatfoot reconstruction for stage II AAFD were determined by proper correction of the deformities present. In this study, we have identified a hindfoot alignment range corresponding to higher clinical outcomes as measured by the FAOS, a score previously validated in flatfoot patients. As a result, we believe that this radiographic hindfoot alignment range of mild varus, which corresponds to the clinical observation of a straight heel, represents the optimal position of the heel following flatfoot reconstruction. Our work may allow the surgeon to estimate an individualized amount of intraoperative medial heel translation for each patient in order to achieve the greatest improvement in clinical outcomes. Now that an optimal position has been suggested, further studies can be done to confirm it using the equation by Chan et al[4] to determine whether the equation, along with clinical judgment, consistently achieves the desired position of the heel.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This project was supported in part by funds from the Clinical Translational Science Center (CTSC), National Center for Advancing Translational Sciences (NCATS) (grant number UL1-RR024996). The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding source NCATS, based in Rockville, Maryland.

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