Clinical Research

Subtalar Fusion for Correction of Forefoot Abduction in Stage II Adult-Acquired Flatfoot Deformity

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Abstract: Background. *Correction of talonavicular uncoverage (TNU) in adult-acquired flatfoot deformities (AAFD) can be a challenge. Lateral column lengthening (LCL) traditionally is utilized to address this. The primary study objective is examining stage II AAFD patients and determining if correction can be achieved with subtalar fusion (STF) comparable to LCL.* Methods. *Following institutional review board approval, retrospective chart review performed identifying patients meeting criteria for stage IIB AAFD who underwent either STF with concomitant flatfoot procedures (but not LCL) to correct TNU, or who underwent LCL as part of their flatfoot reconstruction. Patients indicated for STF had one or more of the following: higher body mass index (BMI), were older, had greater deformity, lateral impingement pain, intraoperative spring ligament hyperlaxity. Patients without 1-year follow-up or compete records were excluded. All other patients were included. A total of 27 isolated STFs identified, along with 143 who underwent LCL. Pre-/postoperative radiographic parameters obtained as well as PROMIS (Patient-Reported Outcomes Measurement Information System) and FAOS (Foot and Ankle Outcome Score) scores. Radiographic and patient reported outcomes both preoperatively and at 1-year follow-up evaluated for both groups.* Results. *STF patients were older ($P < .05$), with higher BMIs ($P < .004$). STF had significantly worse TNU ($P < .001$) than LCL patients, and average change in STF TNU was larger than LCL change postoperatively ($P = .006$), after adjusting for age, BMI, gender. PROMIS STF improvement reached statistical significance in Physical Function (P 0.011), for FAOS Pain (P 0.025) and Function ($P = 0.04$).* Conclusions. *STF can be used in appropriately indicated patients to correct flatfoot deformity without compromising radiographic or clinical, correcting not only hindfoot valgus, but also talonavicular uncoverage (TNU) and corresponding medial arch collapse.*

Levels of Evidence: *Level III: Retrospective chart review comparison study (case control)*

> "Operative management of stage IIB AAFD [adult-acquired flatfoot deformity] continues to be controversial . . ."

Keywords: obesity; comorbid conditions; foot surgery techniques; diagnostic and therapeutic techniques; reconstructive foot and ankle surgery; flat foot; forefoot; toe; midfoot; geriatric podiatry; age-related problems; biomechanical abnormalities; complex foot and ankle conditions; surgical complications

Adult-acquired flatfoot deformity (AAFD) is classified into 4 stages based on the types of deformity

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present.[1] Stage II flatfoot is divided into stage IIA and IIB based on the amount of flexible talonavicular uncoverage present along with flexible hindfoot valgus, with stage IIB group being defined by flexible deformity having greater than 40% talonavicular uncoverage on a standing anteroposterior (AP) radiograph of the foot.[2] Operative management of stage IIB AAFD continues to be controversial, particularly with regard to appropriately addressing talonavicular uncoverage and associated forefoot abduction.

Lateral column lengthening (LCL) has been well described and examined in the literature and remains a mainstay of correcting forefoot abduction and associated talonavicular subluxation in the operative reconstruction of the stage IIB flexible flatfoot along with other procedures.[3] Correction of talonavicular uncoverage and associated forefoot abduction has been shown biomechanically to transfer plantar loads from the first metatarsal head to the lateral column by adduction and plantarflexion through the talonavicular joint[4-8] and has translated to improved patient-reported outcomes.[9-15] functional outcomes,[12,16] and radiographic alignment.[16,17] Concerns with the LCL procedure involve the potential for overcorrection, which can lead to the development of hindfoot eversion stiffness, lateral overload, and fifth metatarsal stress fractures. Distraction arthrodesis through the calcaneal cuboid joint is also fraught similar risks and suboptimal outcomes.[9,10,18-20] Along with overcorrection, graft collapse and nonunion are concerning possible complications of performing the LCL, with nonunion rate ranging from 6% to 30%.[2,21-25]

Talonavicular subluxation correction and the associated forefoot abduction and talonavicular uncoverage in flexible flatfoot patients without significant subtalar arthrosis, has generally been addressed with LCL, though subtalar arthrodesis has been described at well.[26] The potential effect that arthrodesis, including subtalar fusion (STF), has on increasing adjacent joint forces and risk for progression of adjacent joint arthritis has been well described in the literature.[27,28] Mann et al[27] demonstrated that isolated subtalar arthrodesis resulted in transverse tarsal motion being diminished by 40%, dorsiflexion by 30%, and plantarflexion by 9%. Furthermore, there was a 36% and 41% incidence of mild radiographic progression of arthrosis in the ankle and transverse tarsal joint, respectively, at average follow-up of 5 years in isolated subtalar arthrodesis.[27] Yet this was not correlated with symptoms or need for reoperation. Due to this, the historical mainstay of surgical treatment of reconstruction of the stage IIB flexible flatfoot has been to employ joint preserving procedures to retain hindfoot joint motion. Subtalar arthrodesis has traditionally been reserved for more rigid deformities (stage III or above), and our current study will elucidate the utility of repositional subtalar arthrodesis in more flexible severe preoperative deformity (stage II), talonavicular hypermobility/spring ligament hyperlaxity, combined with significant subfibular/lateral impingement symptoms, relatively older patients, and patients with relatively higher body mass indices (BMIs).

Measuring forefoot abduction via talonavicular uncoverage has shown to correlate well with correction of the flatfoot deformity and outcomes.[6,29] It has been shown that subtalar arthrodesis without talonavicular arthrodesis leads to excellent results clinically and restores talonavicular coverage during flatfoot correction in ways not previously appreciated or thought possible, but alluded to in prior data.[26,30] Advanced imaging in the form of weightbearing computed tomography (CT) has brought an improved understanding of the structural anatomy of flatfoot deformity and correction in illustrating how patients with a flexible flatfoot demonstrate possess an innate valgus in the posterior facet of the subtalar joint, which may be associated with operative failure.[31,32] It is our experience; however, that correction of talonavicular uncoverage/forefoot abduction can be achieved with repositional subtalar arthrodesis that is satisfactory and comparable to results achieved with LCL. The authors consider utilization of the STF over LCL particularly in patients with worse radiographic preoperative deformity, severe intraoperative talonavicular hypermobility/spring ligament hyperlaxity, combined with significant subfibular/lateral impingement symptoms, relatively older patients, and patients with relatively higher BMIs. We have observed that this offers a more reproducible outcome when resolving lateral impingement and is felt to be more resistant to postoperative collapse of the heel back into valgus.

The primary objective of our study is to assess a cohort of patients undergoing subtalar arthrodesis utilized in the correction of stage IIB flexible flatfoot deformity in combination with other concomitant procedures, but not LCL, to assess primarily radiographic correction of abduction and talonavicular coverage. Our secondary study goal was to assess clinical outcomes in these patients with previously validated outcome measures.[33-36] We hypothesize that the subtalar arthrodesis cohort will have comparable radiographic outcomes with regard to correction of forefoot abduction and talonavicular uncoverage, and comparable clinical outcomes, compared to the group undergoing LCL instead.

Methods

A retrospective chart review intervention comparison study was utilized. Following approval by the institutional review board, data were collected via a patient registry database search at the Investigators' institution to identify patients meeting criteria of stage IIB adult-acquired flatfoot deformity who underwent either subtalar arthrodesis to correct forefoot abduction and talonavicular subluxation (with or without medializing calcaneal osteotomy and concomitant secondary flatfoot procedures; Table 1) or those patients who underwent an LCL as part of their flatfoot reconstruction to address forefoot

Table 1.

Repositional Subtalar Arthrodesis Indications.

Indications for STF	No. of patients (%)				
Age >60 y	16/27 (59.3)				
BMI >30 kg/m^2	17/27 (63.0)				
Severe deformity (TNU >50%)	23/27 (85.2)				
Spring ligament hypermobility	10/27 (37.0)				
Lateral impingement	17/27 (63.0)				
Patients with more than 1 STF indication	1	2	3	4	5
	3 (11)	7 (26)	7 (26)	7 (26)	3 (11)

Abbreviations: BMI, body mass index; TNU, talonavicular uncoverage; STF, subtalar fusion.

abduction and talonavicular uncoverage. The patients were found via institutional database search for stage II flexible flatfoot and not stage III. The STF patients included in the STF group had completely mobile/flexible subtalar joints on clinical preoperative exam without pain from subtalar motion, but many patients had pain because of their lateral subtalar/subfibular impingement. The subtalar impingement due to pinching at the angle of Gissane is extra-articular, and different than frank subtalar arthritis. These patients' preoperative images were reviewed for recording measurements of radiographic parameters, and none of the included STF patients had significant subtalar arthritis which would move them into a stage III category.

The database search yielded 27 subtalar arthrodesis patients, along with 143 patients who underwent LCL. The STF cohort consisted of 27 patients with surgical undergoing surgery from 2007 to 2018 with surgery performed by 1 of 6 fellowship-trained foot and ankle orthopaedic surgeons. The authors consider utilization of the subtalar arthrodesis over LCL particularly in patients with worse radiographic preoperative deformity of talonavicular uncoverage >50%, significant subfibular/lateral impingement pain which is typically accompanied by severe spring ligament hyperlaxity determined by the operating surgeon intra-operatively. Relatively older patients over age 60 years, or patients with relatively higher BMIs >30 kg/m^2 (Table 1). Subjective intraoperative spring ligament hyperlaxity was never the only single criteria used to indicate the patient for subtalar arthrodesis. It was always associated with significant lateral/subtalar/subfibular impingement pain symptoms which was the primary indication for the repositional subtalar arthrodesis recorded in the patient record. The 3/27 patients that were indicated for STF with only one of the aforementioned indications has severe significant lateral/subtalar/subfibular impingement pain as the primary indication for repositional subtalar arthrodesis. In all, 24 of 27 (88.88%) of patients indicated for STF had at least 2 or more of the listed indications. The mean age and BMI of the subtalar arthrodesis group were 61 years and 31 kg/m^2, respectively.

The LCL cohort consisted of patients from 2 fellowship-trained foot and ankle surgeons performed between 2006 to 2012 also assess in a previous study at our institution.[37] The group consisted of 111 patients (143 total feet). A total of 65 feet, from 45 women and 20 men with a mean age of 58.0 years (range, 21.7-71.2 years) and a mean follow-up of 4.4 years (range, 2.0-8.5 years), underwent an Evans osteotomy between 2006 and 2012. A total of 78 feet, from 51 women and 27 men with a mean age of 54.5 years (range, 18.6-81.6 years) and a mean follow-up of 3.1 years (range, 2.0-5.7 years), underwent step-cut LCL between 2009 and 2013. The Evans and step-cut LCL patients were both grouped into one LCL group for the comparison with the repositional subtalar arthrodesis patients. The patient demographics and comorbidities of these 2 cohort groups are outlined in Table 2.

Charts were retrospectively reviewed. Patients were included regardless of the presence of bilateral reconstructions or deformities, previous operation, or comorbid conditions. Patients younger than 18 years were excluded because of their increased likelihood to heal the osteotomy and likely different nature of the etiology of the deformity. Minimum follow-up for both the lateral column group and the STF group was 1 year.

Preoperative and most recent postoperative AP and lateral weightbearing foot radiographs were reviewed to assess the correction in talonavicular uncoverage and resultant forefoot abduction following reconstruction, and hindfoot alignment weightbearing views. Five radiographic

Table 2.

Patient Demographics.

	STF (n = 142)	LCL (n = 142)	*P*
Age, y, mean (SD)	60.6 (11.9)	55.3 (12.6)	.050
BMI, kg/m^2, mean (SD)	31.3 (5.9)	27.6 (5.4)	.004
Female, n (%)	16 (64.0)	95 (66.9)	.777
Bilateral, n (%)	0 (0.0)	32 (22.5)	.005
Comorbidities, n (%)			
Hypertension	5 (18.5)	33 (23.1)	NA
Diabetes type II	5 (18.5)	7 (4.9)	NA
Rheumatoid arthritis	4 (14.8)	2 (7.4)	NA
Smoker	2 (7.4)	3 (11.1)	NA
Obesity (BMI >30 kg/m^2)	15 (55.6)	39 (27.3)	NA

Abbreviations: STF, subtalar fusion; LCL, lateral column lengthening; BMI, body mass index; NA, not applicable.

parameters of forefoot abduction were measured: lateral incongruency angle,[38] talonavicular coverage (TNC) angle,[17] talonavicular uncoverage percent,[38] and talus–first metatarsal (T-1MT) angle,[39] on the AP view. Hindfoot alignment view was utilized for measuring Hindfoot moment arm.[40] For each parameter, the change in any give parameter was calculated as the difference between the values measured preoperatively and postoperatively.

For both the subtalar arthrodesis group and LCL group, patients failed bracing, orthotics, and physical therapy and had persistent pain for more than 6 months before being scheduled for surgery. In addition to LCL or repositional subtalar arthrodesis to correct talonavicular subluxation, the patients included in our study underwent concomitant flatfoot correction procedures as shown in Table 3.

Patient-reported outcomes both preoperatively and at 1-year follow-up were also reviewed and evaluated for both groups with either the Foot and Ankle Outcome Score (FAOS) or Patient-Reported Outcomes Measurement Information System computerized adaptive tests (PROMIS CATs) based on when a patient had surgery and was enrolled in the hospital registry. For FAOS, we recorded patient rated scores for Pain, Symptoms, Daily Activities, Sports, Quality of Life. For PROMIS, we recorded Physical Function, Pain Interference, Pain Intensity, Global Mental Health, Global Physical Health, Depression note the registry changed from the FAOS to PROMIS CATs in March of 2016. Of the 27 subtalar arthrodesis patients, 12 patients had post FAOS scores; but 3 were missing a preoperative FAOS score. Thus, 9 patients (33.3%) were summarized for the changes in FAOS. For the LCL patients, 112 of the 143 (78.3%) had FAOS scores available. Twelve of the 27 subtalar arthrodesis patients had PROMIS scores (44.4%). Our institution changed from FAOS to PROMIS in March 2016. Due to this change, the LCL patient cohort did not have PROMIS measurement available for comparison to the STF group. Two subtalar arthrodesis patients were lost to follow-up within the first year and did not have postoperative X-rays. One patient in the original LCL group did not have complete radiographic data and was excluded from the statistical analysis. These 3 patients were still included in the overall patient demographic data for completeness but had to be excluded from the analysis results for the aforementioned reasons. Thus, the total number of patients in the STF and LCL groups for statistical analysis was 25 and 142, respectively.

Nonunion was identified both clinically and radiographically. Clinically at a minimum of 6 months out from the index procedure, patients complained of persistent pain and swelling on the lateral border of the foot after weightbearing for LCL and in the area of the sinus tarsi for the STF cohort. Radiographically, lucency was identified on plain radiographs, and for the STF cohort, CT scans were available for all nonunion patients demonstrating lack of bridging bone at the joint interface or broken hardware at minimum of 6 months out from the initial surgical procedure and without evidence of infection.

Table 3.

Concomitant Flatfoot Procedures.

Concomitant flatfoot procedures	STF (n = 27), n (%)	LCL (n = 143), n (%)
Medializing heel slide	17 (62.9)	143 (100)
Posterior tibialis tendon repair	2 (7.4)	142 (99.3)
FDL transfer	21 (77.8)	128 (89.5)
Spring ligament repair	5 (18.5)	118 (82.5)
Spring ligament reconstruction with Achilles allograft	5 (18.5)	15 (10.5)
Gastrocnemius recession	13 (48.2)	125 (87.4)
Percutaneous teno-Achilles lengthening	9 (33.3)	0
Cotton osteotomy	7 (25.9)	48 (33.6)
Lapidus first TMT plantarflexion arthrodesis	15 (55.6)	85 (59.4)
Proximal tibia autograft	5 (18.5)	0
Calcaneal autograft	17 (62.9)	0
Allograft (demineralized bone matrix)	5 (18.5)	0
Iliac crest autograft (ipsilateral tricortical)	0	120 (83.9)
Allograft (tricortical)	0	23 (16.1)

Abbreviations: STF, subtalar fusion; LCL, lateral column lengthening; TMT, tarsometatarsal; FDL, flexor digitorum longus.

Statistical Analysis

Two-sample *t* test was performed for continuous normal-distributed variable; Fisher's exact test was performed for categorical variable. Generalized estimating equation models adjusted for age, BMI, gender, and bilateral (n = 163 in all models; 4 patients with BMI missing were excluded).

Surgical Technique Repositonal Subtalar Arthrodesis

A sinus tarsi approach is performed. Care is taken to protect branches of the sural nerve and the peroneal tendons. The posterior facet is typically well visualized. The talocalcaneal ligament is the released which allows better exposure of the joint surfaces and the middle and anterior facets. As the subtalar joint is undergoing arthrodesis, there is no need for repair of the talocalcaneal ligament. The calcaneal fibular ligament is preserved. Using curved osteotomes and/or curettes, the articular cartilage is removed from the superior calcaneus and inferior talus and the facet joints. Next utilizing either a 2.5-mm drill followed by osteotomes, or a 3.0-mm burr, vascular channels are created via creation of small perforations in the subchondral bone to aid in the fusion. A laminar spreader is placed with one tong on the floor of the sinus tarsi, and the other tong on the lateral process of the talus (Figure 1A).

It is also imperative not to overcorrect it and supinate the foot, which can be assessed utilizing intraoperative fluoroscopy to check a Harris heel view, mortise ankle and lateral foot views, as well as with visual assessment of hindfoot position. Such overcorrection can be avoided by performing a medializing calcaneal osteotomy concomitantly with the STF. The authors first derotate and reduce the talus back on top of the calcaneus (which relieves the subfibular impingement), and then hold up the heel to make sure it is under the mechanical axis of the tibia. If the talonavicular joint is reduced with reducing the subtalar joint, but the calcaneus is still too lateral from the tibial mechanical axis, a concomitant medializing calcaneal osteotomy is subsequently performed. Additionally, it is important to verify on the AP foot view that the lateral talonavicular incongruency angle is not overcorrected, as demonstrated by lateral talar head uncoverage as demonstrated on an AP foot intraoperative image (Figure 2) and to also clinically evaluated the forefoot eversion motion to further assess and avoid overcorrection.

If a simultaneous medializing heel slide calcaneal osteotomy is deemed necessary, a separate 4- to 5-cm incision is made in the lateral aspect of the posterior calcaneal tuberosity, a

Figure 1.

Laminar spreader positioning and deformity reduction through the subtalar joint. (A) Intraoperative laminar spreader position placed with one tong on the floor of the sinus tarsi, and the other tong on the lateral process of the talus. (B) The reduction and deformity correction as the laminae spreader is opened, the talus reduces back to its appropriate position back onto to calcaneus as the talus slides upwards along the slope of the calcaneus at the posterior facet.

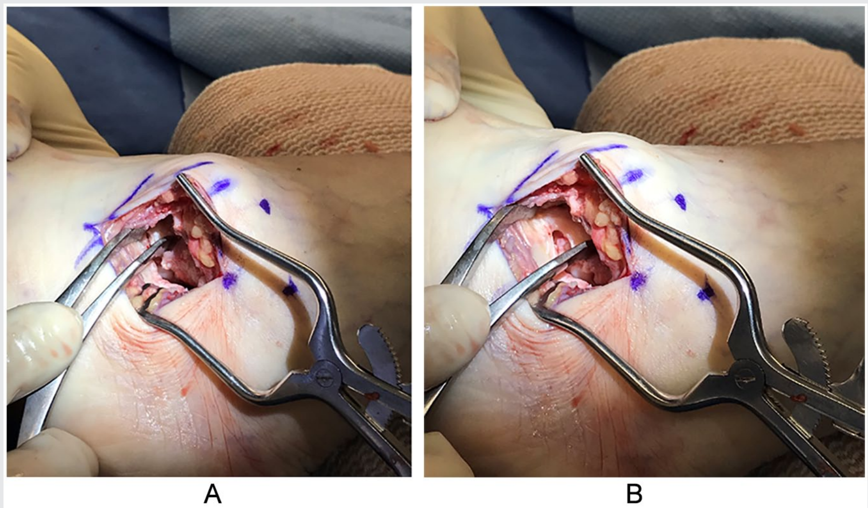


Figure 2.

An example of talonavicular overcorrection on intraoperative anteroposterior foot X-ray.

transverse osteotomy is made, and the heel is then shifted medially to correct any residual hindfoot valgus position that is not entirely corrected through the subtalar joint position. The subtalar joint, and concomitant heel slide when present, are provisionally pinned and then fixed with either solid or cannulated screws placed from the tuber of the calcaneus into the talar head and neck.

Surgical Technique Lateral Column Lengthening

The operative technique used for both the Evans osteotomy and step-cut LCL have been described previously.[22,37] The postoperative protocol is then identical for both the STF and LCL groups, which consists of splinting for 2 weeks, followed by casting for 3 weeks, after which the patients are transitioned into a CAM boot and remain nonweightbearing until progressive weightbearing in the boot begins between 8 and 10 weeks after surgery.

Results

Review of the measured radiographic parameters demonstrated patients that underwent STF were found to have worse radiographic preoperative deformity with regard to talonavicular uncoverage with $P < .001$ (Table 3), and to also be older ($P < .05$), have higher BMIs ($P < .004$), and preoperative TN coverage angle ($P < .006$), and incongruency angle ($P < .004$) in STF group were significantly higher than patients in LCL group (Table 4).

In univariate analysis, the difference preoperative radiographic parameters were found to be statistically significant in the following parameters; TN coverage angle ($P = .006$), the mean change in TN uncoverage ($P < .001$), and mean change in TN incongruency angle ($P = .004$). Statistically significant difference was found preoperatively neither in AP T-1 MT angle ($P = .869$) nor in Meary's angle ($P = .323$). Incomplete radiographs of preoperative hindfoot alignment view were available to measure preoperative hindfoot moment arm (Table 5).

Comparison of postoperative radiographic parameters demonstrates statistically significant radiographic changes in both LCL and STF cohorts in change in TN coverage angle ($P = .028$), change in TN uncoverage percent ($P < .001$), change in TN incongruency angle ($P = .035$), change in Meary's angle ($P = .029$), and change in hindfoot moment arm ($P < .001$). No significance was found in change of AP T-1 MT angle ($P < .504$) (Table 5).

On multivariate analysis after adjusting for BMI, age, gender, and bilaterality, the

Table 4.

Radiographic Outcomes: Pre- and Postoperative.[a]

	STF (n = 25), mean (SD)	LCL (n = 142), mean (SD)	*P*
Preoperative outcomes			
TN coverage angle	40.2 (12.3)	33.4 (11.1)	.006
TN uncoverage	50.4 (10.9)	42.2 (9.2)	<.001
TN incongruency angle	78.3 (38.2)	60.5 (40.0)	.004
Talus–first metatarsal angle	20.3 (11.9)	20.7 (9.6)	.869
Meary's angle	24.8 (8.8)	22.7 (9.8)	.323
Hindfoot moment arm	NA	NA	NA
Postoperative outcomes			
Change in TN coverage angle	–24.8 (11.7)	–19.3 (11.6)	.028
Change in TN uncoverage	–25.9 (11.2)	–17.8 (9.9)	<.001
Change in TN incongruency angle	–74.5 (46.2)	–54.5 (42.8)	.035
Change in talus–first metatarsal angle	–12.5 (11.7)	–10.8 (7.8)	.504
Change in Meary's angle	–16.9 (8.4)	–12.6 (9.1)	.029
Change in hindfoot moment arm	7.7 (5.1)	3.2 (5.5)	<.001

Abbreviations: TN, talonavicular; STF, subtalar fusion; LCL, lateral column lengthening; NA, not applicable.
[a]Two-sample *t* test was performed for continuous normal-distributed variable; Fisher's exact test was performed for categorical variable.

2 radiographic parameter changes between the LCL and STF groups that reached statistical significance were TN uncoverage percentage ($P = .006$) and hindfoot moment arm ($P < .001$) (Table 6).

Looking at differences in clinical outcomes scores for STF patients, there was significant improvement in FAOS pain ($P = .025$) and daily activities ($P = .040$). For LCL patients, there were improvement on all 5 FAOS categories ($P < .001$). Between STF and LCL patients, the improvement in each FAOS category was similar and without statistical significance. Preoperative PROMIS data were not available for the LCL cohort, but for STF patients, there was significant improvement in PROMIS function score ($P = .011$) (Table 7).

Reviewing results of complications in the form of nonunion and removal of hardware, nonunion was higher in the STF group 3/27 (11.1%) than the LCL group 6/143 (4.2%), yet removal of symptomatic hardware was more prevalent in the LCL group 70/143 (49.0%), versus 6/27 (22.2%) in the STF cohort (Table 8). Of the 17 (of 27) patients who had both STF and medializing calcaneal osteotomy, none of these patients were among the 3 recorded nonunions.

Discussion

The data demonstrate that in appropriately selected stage IIB patients, repositional subtalar arthrodesis has equivalent or better correction of talonavicular uncoverage/forefoot abduction even in older, heavier, and more severe flatfoot patients, along with similar improvement in patient-reported outcomes than correction via LCL when performed at the time of flexible flatfoot reconstruction (Figures 3-7). This has significant implications with regard to indications in the utility of STF in treating stage IIB flexible flatfoot deformity particularly selecting patients with worse radiographic preoperative deformity and talonavicular uncoverage >50%, severe spring hypermobility/hyperlaxity intraoperatively, combined with significant subfibular/lateral impingement symptoms, relatively older patients over age 60 years, and patients with higher BMIs.

Talonavicular uncoverage has been described as one of the best indicators for measuring severity of forefoot abduction deformity. The data reinforce that not only worse preoperative deformity patients (in this study >50% talonavicular uncoverage preoperatively)

Table 5.

Average Postoperative Radiographic Parameter Absolute Values and Ranges.

Group	n	Variable	Mean	SD	Lower 95% CL for mean	Upper 95% CL for mean	*P*
LCL	142	Postoperative TN coverage angle	14.11	10.78	12.33	15.90	.73
STF	25	Postoperative TN coverage angle	15.36	8.18	11.98	18.74	.73
LCL	142	Postoperative TN uncoverage %	24.39	10.26	22.68	26.09	.09
STF	25	Postoperative TN uncoverage %	24.48	9.38	20.61	28.35	.09
LCL	142	Postoperative TN incongruency Angle	5.97	29.99	1.00	10.95	.24
STF	25	Postoperativve TN incongruency angle	3.77	26.40	7.12	14.67	.24
LCL	142	Postoperative AP talar–first MT angle	9.65	7.01	8.49	10.82	.97
STF	25	Postoperative AP talar–first MT angle	7.88	6.51	5.19	10.57	.97
LCL	142	Postoperative Meary's angle	10.09	8.14	8.74	11.44	.58
STF	25	Postoperative Meary's angle	7.89	5.47	5.63	10.00	.58

Abbreviations: STF, subtalar fusion; LCL, lateral column lengthening; CL, confidence limit; AP, anteroposterior; TN, talonavicular; MT, metatarsal.

Table 6.

Multivariate Analysis.[a]

Outcomes	STF vs LCL (ref), (95% CI)	*P*
Change in TN coverage angle	−5.1 (−10.4, 0.1)	.053
Change in TN uncoverage	−6.1 (−10.5, −1.7)	.006
Change in TN incongruency angle	−23.0 (−46.5, 0.5)	.055
Change in talus–first metatarsal angle	2.5 (−23.8, 28.9)	.850
Change in Meary's angle	−3.4 (−7.5, 0.7)	.101
Change in hindfoot moment arm	10.5 (8.0, 13.0)	<.001

Abbreviations: STF, subtalar fusion; LCL, lateral column lengthening; ref, reference; TN, talonavicular.
[a]Generalized estimating equation models adjusted for age, body mass index (BMI), gender, and bilateral (n = 163 in all models; 4 patients with BMI missing were excluded).

but also, in particular, lateral impingement pain (which is not always visible on radiographs but can be detected best on weight bearing CT) can be successfully corrected with repositional subtalar arthrodesis, and given these patients had worse preoperative deformity, this accounts for the greater postoperative correction found on statistical analysis. While this does introduce an unavoidable selection bias, if anything this bias should presumably make the STF group at a clinical outcome result disadvantage, but that was not found to be the case. The authors feel that despite the dissimilarities between the STF and LCL groups, having an LCL cohort to compare the clinical and radiographic outcomes against repositional subtalar arthrodesis is imperative to expounding the results of the correction of STF, and when to consider sacrificing a nonarthritic subtalar joint over LCL in appropriately selected patients. Particularly as the authors are indicating repositional STF in a stage II patient population, which is

Table 7.

Changes in FAOS and PROMIS Scores.

	STF (n = 25)				LCL (n = 142)				STF vs LCL
	n	Mean	SD	*P*[a]	n	Mean	SD	*P*[a]	*P*[b]
Change in FAOS									
Pain	9	30.3	32.9	.025	112	22.3	30.4	<.001	.453
Symptoms	9	12.3	27.1	.210	112	11.9	24.2	<.001	.961
Daily activities	9	24.5	30.0	.040	112	17.5	36.4	<.001	.576
Sport	9	6.0	40.1	.667	112	25.5	42.4	<.001	.185
Quality of life	9	27.8	37.1	.056	112	36.7	28.5	<.001	.381
Follow-up time (years)	9	2.6	1.7	NA	112	3.7	1.7	NA	.041
Change in PROMIS									
Physical function	12	10.2	11.6	.011					
Pain interference	12	–2.8	18.5	.607					
Pain intensity	12	11.9	31.3	.214					
Global mental health	12	2.4	18.6	.664					
Global physical health	12	5.4	16.8	.288					
Depression	12	2.1	26.2	.784					
Follow-up time (years)	12	1.6	0.8	NA					

Abbreviations: FAOS, Foot and Ankle Outcome Score; PROMIS, Patient-Reported Outcomes Measurement Information System; STF, subtalar fusion; LCL, lateral column lengthening.
[a]One-sample t-test was performed for testing the zero mean hypothesis.
[b]*P* value from 2-sample *t* test or Wilcoxon sum-rank test (for follow-up years).

Table 8.

Nonunion and Removal of Hardware.

Secondary surgical complication	STF (n = 27)	LCL (n = 143)
Nonunion	3 (11.1%)	6 (4.2%)
Removal of symptomatic hardware	6 (22.2%)	70 (49.0%)

typically treated with joint preservation procedures, having the LCL cohort adds much more value to the study than a simple case series of the STF patients alone. Overall, the data note improvement in radiographic parameters in both LCL and STF cohort groups and implicates the power of correction of repositional subtalar arthrodesis.

Regarding patient-reported outcome scores for STF patients, there was significantly improvement in FAOS pain and daily activities. For LCL patients, there was improvement on all 5 FAOS categories. Between STF and LCL patients, the improvement in each FAOS category was similar, although LCL patients were measured with longer

Figure 3.

Weightbearing anteroposterior (AP) foot X-rays before and after repositional subtalar arthrodesis. (A) A preoperative weightbearing AP view of the foot. (B) a postoperative weightbearing AP view of the foot at 1-year follow-up.

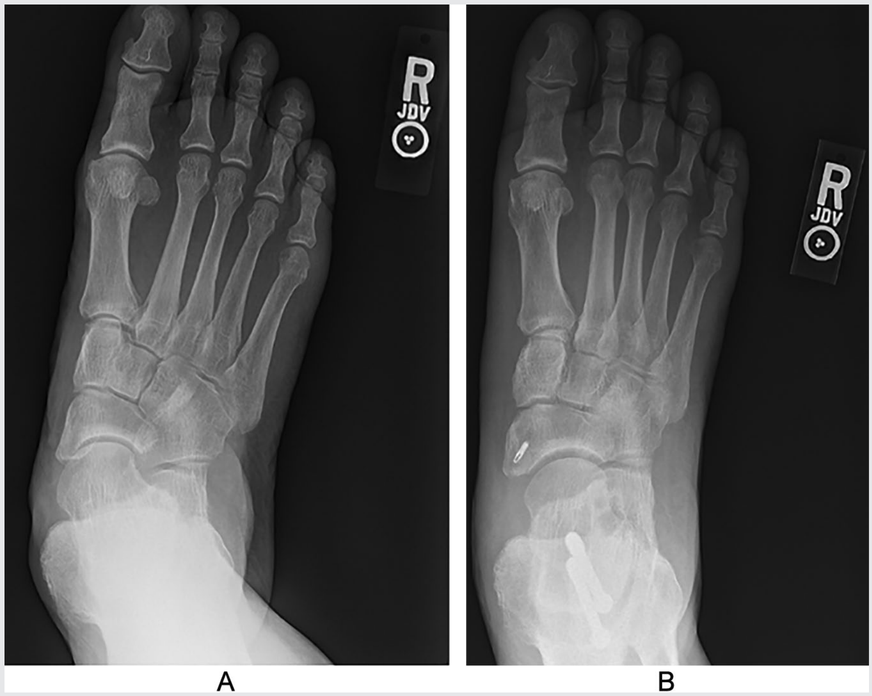
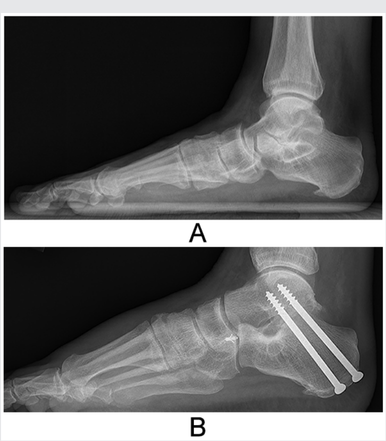


Figure 4.

Weightbearing lateral foot X-ray before and after repositional subtalar arthrodesis. (A) A preoperative weightbearing lateral X-ray of the foot. (B) A postoperative weightbearing lateral X-ray of the foot at 1-year follow-up.



follow-up times. For STF patients, there was significantly improvement in PROMIS function score. For those nonsignificant changes in STF, we likely lack of power to find an improvement due to small sample size. Both FAOS and PROMIS have been independently validated and are both useful determinants of clinical outcome following orthopaedic foot and ankle surgeries.[33-36]

A review of the literature demonstrates a prior retrospective review which examined radiographic results of subtalar arthrodeses, without LCL, combined with spring ligament repair/reefing and flexor digitorum longus (FDL) transfer to the navicular in 17 feet, and found that the talonavicular coverage angle significantly improved postoperatively along with other standard flatfoot measurements.[26] Additionally, this study suggested considering repositional subtalar arthrodesis over LCL for addressing talonavicular uncoverage and resultant forefoot abduction and medial arch collapse, especially for flatfoot deformities in patients with severe flexible deformity combined with hypermobility and obesity. This study did not have an LCL and looked only at radiographic parameters without clinical outcome score aside from AOFAS hindfoot score.

To our knowledge, this is the first study of its kind to demonstrate the power of talonavicular uncoverage correction in a head to head comparison with traditional LCL. The only 2 prior studies to document the improvement of talonavicular uncoverage via subtalar arthrodesis without talonavicular fusion or LCL did not have a control/comparison cohort as in the present study.[26,30]

Nonunion was higher in the STF group 3/27 (11.1%) than the LCL group 6/143 (4.2%), yet removal of symptomatic hardware was more prevalent in the LCL

Figure 5.

Weightbearing mortise foot X-rays in a patient with lateral subtalar impingement before and after repositional subtalar arthrodesis. (A) A preoperative weightbearing mortise view of the ankle. (B) A postoperative weightbearing mortise view at 1-year follow-up.

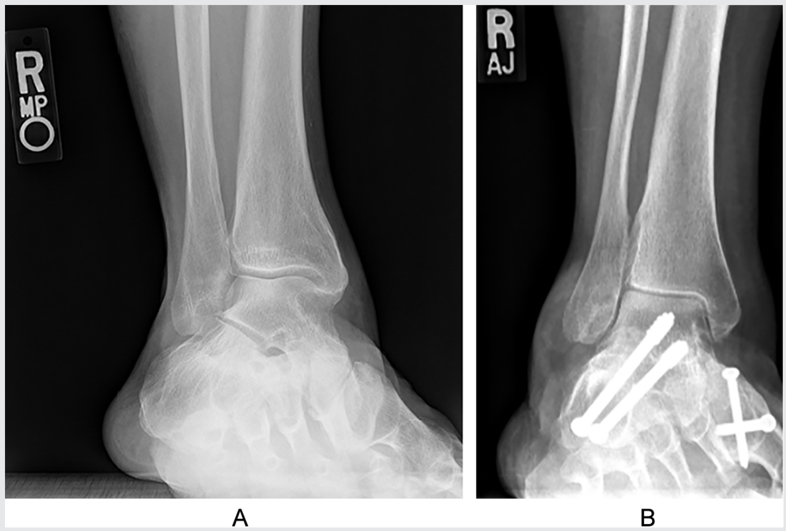
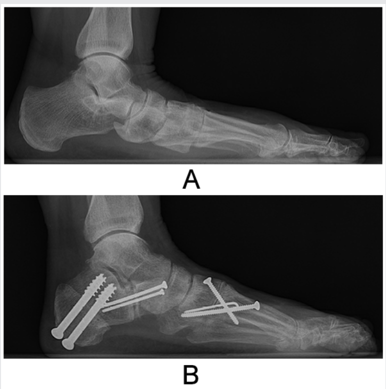


Figure 6.

Weightbearing anteroposterior (AP) foot X-rays before and after lateral column lengthening. (A) A preoperative weightbearing AP view of the foot. (B) A postoperative weightbearing AP view at 1-year follow-up.

Figure 7.

Weightbearing lateral foot X-rays before and after lateral column lengthening. (A) A preoperative weightbearing lateral view of the foot. (B) A postoperative weightbearing lateral view of the foot at 1-year follow-up.



group 70/143 (49.0%), versus 6/27 (22.2%) in the STF cohort. The nonunion rate was higher in this cohort at 11.1% compared with the LCL cohort group at 4.2%. A closer look at the 3 subtalar nonunion patients showed that 2 of the 4 were older (both 76 years old at time of surgery), had higher BMI (32 and 36 kg/m^2), and both had hypertension. These 2 patients had the lateral shelf of calcaneal bone remaining following medializing heel slide osteotomy utilized in the subtalar joint as calcaneal autograft. One of the patients was found to have severe hypovitaminosis D with level of 13 ng/mL (range 30-80 ng/mL) and high BMI of 32 kg/m^2, and proximal tibial bone graft was utilized during the time of initial surgery. Two of these 3 subtalar nonunions ultimately went on to undergo a revision STFs, iliac crest autograft was utilized in one, and in the other iliac crest bone marrow aspirate was combined with BMP-2 (bone morphogenetic protein–2; Infuse) and demineralized bone matrix (Graft-On). Both these patients went on to successful union following their revision. One of the 3 nonunion patients was found to have persistent nonunion at just after 1 year postoperatively with complaints of mild to moderate lateral hindfoot/sinus tarsi pain, but after discussion of options, the patient decided that he did not with for further surgical intervention/revision and opted to defer surgical intervention at the last clinic follow-up note available.

Literature review of subtalar arthrodesis nonunion demonstrated a large study of subtalar arthrodesis nonunion rates and complications reported at nonunion rate of 16% in 30 of 184 patients undergoing isolated subtalar arthrodesis.[41] After the authors eliminating the nonunion that had been treated with revision arthrodesis, structural bone graft, and subtalar arthrodesis adjacent to the site of a previous ankle arthrodesis, the union rate improved by only 6%, from 84% (154 of 184) for the overall group to 90% (104 of 116). However, when the patients who smoked were also eliminated, the union rate improved to 96% (73 of 76).[41] Literature review of LCL nonunion rates range from 5% to 10% in several large reviews.[23] Our data compare to the reported literature complication rates for nonunion and clinical/radiographic outcomes for both STF and LCL groups.

This study has several limitations. The main limitation of this study, yet a necessary one, is selection bias represented by the difference between the 2 cohort groups. The authors' indications for STF were older, had higher BMIs, and worse preoperative deformity, which is what the data demonstrate. Interestingly, after univariate analysis between groups, the only preoperative radiographic parameter which reached statistical significance between the LCL and STF groups was worse talonavicular uncoverage parameters in the STF group. At the same time, the STF group also showed greater improvement in mean change in talonavicular coverage angle ($P = .006$), mean change in talonavicular uncoverage ($P < .001$), and mean change in TN incongruency angle ($P = .004$). This makes sense in that the STF patients were selected for worse preoperative deformity through the TN joint, but that the overall final correction postoperative parameters between the LCL and STF groups were similar, even given the STF group had worse preoperative deformity. This illustrates the significant talonavicular uncoverage correction power of the STF compared with LCL; which was the main purpose of our study. While the authors accept the inherent selection bias in the indications for the groups, inclusion of LCL group for comparison with the recommended STF technique is necessary to demonstrate its radiographic corrective power of forefoot abduction and clinical outcome scores, and better exemplifies the results compared to a case report study of just the STF patients alone.

Second, a larger sample size for the repositional subtalar arthrodesis group would have been beneficial. Additional power would also decrease the probability of a type II error for variables that did not reach significance. Unfortunately, due to the nature of this type of procedure, it is difficult to capture a large study cohort of flexible flatfoot patients undergoing STF, as demonstrated by chart review of 6 fellowship-trained orthopaedic foot and ankle surgeons at our large tertiary referral center institution over an 11-year period yielded only 27 patients. Despite this, the present study offers the largest such known cohort to date.

Another limitation of our study is multiple surgeons (6) all perform these procedures slightly differently from a technical standpoint, such as differing joint preparation techniques, hardware fixation, and choice of graft. Of note, all surgeons in the study have similar training and approach both the bony and soft tissue procedures in very similar fashions.

An additional limitation and potential confounding variable is the difference in the surgical technique between the Evan's and step-cut techniques in the LCL cohort. The reason they are both grouped together is to have more data comparison points for the STF group. This limitation is often necessary and ubiquitous one in studies reviewing flatfoot reconstructions. The number of accessory procedures performed, such as heel slides, cotton osteotomies, FDL transfer, spring ligament tightening/reconstruction, gastrocnemius recession, and so on, during flatfoot reconstruction adds another difficult variable to control, not to mention technique differences in how these procedures are performed between surgeons. Due to the manner in which the Hospital for Special Surgery database provides the raw data, a multivariate analysis on these secondary procedures performed between these 2 groups could not be performed for *P* values, but is listed as succinctly as the data allowed in Table 3 for proportional comparison. In particular, the concomitant bony procedures such as Cotton osteotomies and plantar flexion Lapidus arthrodesis were performed in similar proportions between the cohorts; Cotton osteotomy (STF 25.9%; LCL 33.6%) and Lapidus first TMT plantarflexion arthrodesis (STF 55.6%; LCL 59.4%). FDL transfers were also performed in comparable proportions (STF 77.8%; LCL 89.5%). While having a *P* value for concomitant procedures would be ideal, it was not possible with the data. Despite this limitation, having the LCL cohort is imperative to appropriately evaluating the STF group against the historical standard of care for these selected repositional subtalar arthrodesis patients, and adds significant value to the results overall.

The different times frames of the LCL cohort data having been collected and identified from a prior study from 2006 to 2012, and the STF group data ranging from 2007 to 2018 adds another confounding variable, but overall timeframe is similar, and was larger in the STF group in order to include as many STF patients as possible to improve the power of the study.

The primary indication for repositional subtalar arthrodesis was preoperative talonavicular uncoverage >50%; which over 85% of the indicated STF patients had. The second most common indication was lateral subtalar/subfibular impingement pain (63%). Admittedly, intraoperative spring ligament hyperlaxity/hypermobility of the talonavicular joint is subjective to the surgeon. Every patient who underwent STF with reported "hyperlaxity" on the operative report by the individual surgeons also had concomitant lateral subtalar/subfibular impingement. This subjective indication presumably introduces another variable into the STF indications; however, spring ligament hyperlaxity was never used in isolation as a primary singular indication for STF. It was always associated with significant lateral/subtalar/subfibular impingement pain symptoms, which was the primary indication for the repositional subtalar arthrodesis recorded in the patient record. Of the 3 (of 27) patients indicated for STF with only one of the aforementioned indications, significant lateral/subtalar/subfibular impingement pain was the primary indication for repositional subtalar arthrodesis. In all, 24 of 27 (88.88%) of patients indicated for STF had at least 2 or more of the listed indications.

Last, this is a retrospective study, but did investigate clinical outcomes in association with the correction in forefoot abduction obtained. A future prospective study could be performed to assess clinical and radiographic outcomes in a larger group of patients, assess longer term outcomes, and to assess deformity with more novel weightbearing CT.

This study has several meaningful strengths. While there is numerically a smaller cohort of STF patients, this is a difficult patient cohort to evaluate, and our present study includes 27, which is the largest in the literature to date. Our study required demonstrated follow up with both clinical and radiographic outcome measurements in both the STF and LCL groups between 2 and 3 years (STF FAOS 2.6-year average, STF PROMIS 1.6-year average, LCL FAOS 3.7-year average), which is one of the longest reported in the literature. Additionally, our study is novel in that it represents a case control study with LCL comparison cohort for both clinical outcome and both validated radiographic and validated clinical outcome measurements. Having multiple surgeons included also demonstrates that this technique is reproducible amongst providers.

In conclusion, to the authors' knowledge this study is the first case control comparison to examine the role for repositional subtalar arthrodesis in the setting of correction of stage II adult-acquired flatfoot deformity in appropriately selected patients, and demonstrates the utility of repositional subtalar arthrodesis to restore hindfoot position with equivalent or better radiographic outcomes, and similar patient reported clinical outcomes compared with our cohort of LCL patients. This this technique offers another viable tool for surgeons to consider in operative treatment of this difficult problem.

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Not applicable.

Informed Consent

Not applicable.

Trial Registration

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