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Modified Lapidus vs Scarf Osteotomy Outcomes for Treatment of Hallux Valgus Deformity

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Abstract

Background: The Lapidus procedure and scarf osteotomy are indicated for the operative treatment of hallux valgus; however, no prior studies have compared outcomes between the procedures. The aim of this study was to compare clinical and radiographic outcomes between patients with symptomatic hallux valgus treated with the modified Lapidus procedure versus scarf osteotomy.
Methods: This retrospective cohort study included patients treated by 1 of 7 fellowship-trained foot and ankle surgeons. Inclusion criteria were age older than 18 years, primary modified Lapidus procedure or scarf osteotomy for hallux valgus, minimum 1-year postoperative Patient-Reported Outcomes Measurement Information System (PROMIS) scores, and minimum 3-month postoperative radiographs. Revision cases were excluded. Clinical outcomes were assessed using 6 PROMIS domains. Pre- and postoperative radiographic parameters were measured on anteroposterior (AP) and lateral weightbearing radiographs. Statistical analysis utilized targeted minimum-loss estimation (TMLE) to control for confounders.
Results: A total of 136 patients (73 Lapidus, 63 scarf) with an average of 17.8 months of follow-up were included in this study. There was significant improvement in PROMIS physical function scores in the modified Lapidus (mean change, 5.25; $P < .01$) and scarf osteotomy (mean change, 5.50; $P < .01$) cohorts, with no significant differences between the 2 groups ($P = .85$). After controlling for bunion severity, the probability of having a normal postoperative intermetatarsal angle (IMA; <9 degrees) was 25% lower ($P = .04$) with the scarf osteotomy compared with the Lapidus procedure.
Conclusion: Although the modified Lapidus procedure led to a higher probability of achieving a normal IMA, both procedures yielded similar improvements in 1-year patient-reported outcome measures.
Level of Evidence: Level III, retrospective cohort.

Keywords: hallux valgus, bunionectomy, Lapidus, scarf osteotomy, PROMIS

Introduction

Hallux valgus is the most common cause of forefoot pain and affects approximately 20% of patients over the age of 18 years.[30] When operative management is pursued, the goal is to correct the pathology and maintain forefoot function. However, almost 10% of patients do poorly after surgery.[3,12] Variation in the management of hallux valgus may contribute to some of these failures. Despite over 100 different techniques described for bunion correction, there is no one accepted procedure or algorithm for the operative

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management of hallux valgus.[14,37] Therefore, there is a need to compare and critically evaluate commonly used operative techniques to determine if there are notable differences in patient-reported outcomes or postoperative radiographic measurements between these procedures.

Two techniques frequently employed to treat hallux valgus deformities are the modified Lapidus procedure, a first tarsometatarsal joint arthrodesis to correct the deformity and stabilize the first ray, and the scarf osteotomy, a Z-cut osteotomy of the first metatarsal with a dorsal distal limb and a plantar proximal limb. A major complication of the scarf osteotomy is troughing, or collapsing height with or without rotation of the metatarsal due to interlocking cortices, and it has been reported as a complication up to 35% of the time.[8] The benefit of a scarf osteotomy over the modified Lapidus procedure is the shorter recovery time.[29] In contrast, the modified Lapidus procedure has been shown to have a high nonunion rate, may result in transfer metatarsalgia, and requires a substantial period of nonweightbearing.[9,22,34,37] However, a commonly cited benefit of the modified Lapidus procedure is that it stabilizes the first tarsometatarsal joint, which may be hypermobile in patients with hallux valgus and may eventually lead to recurrent widening of the intermetatarsal angle between first and second metatarsals (IM1-2) in patients treated with a first metatarsal osteotomy.[21]

Although multiple studies have directly compared other operative techniques, including the scarf osteotomy and the distal chevron osteotomy, for the treatment of hallux valgus,[13,19,27] no study has compared outcomes following the scarf osteotomy and modified Lapidus procedure. The primary purpose of this study was to compare clinical outcomes and complications at a minimum of 1 year postoperatively between the scarf osteotomy and the modified Lapidus procedure in patients indicated for operative correction of their hallux valgus deformity. A secondary purpose of this study was to compare radiographic outcomes based on 9 measurements on preoperative and most recent postoperative radiographs, including hallux valgus angle (HVA), intermetatarsal angle (IMA), distal metatarsal articular angle (DMAA), tibial sesamoid, Meary's angle, Horton index, Seiberg index, first metatarsal declination angle, and sagittal IMA. We hypothesized that patients who underwent a modified Lapidus procedure would have better clinical and radiographic outcomes than those patients who underwent a scarf osteotomy.

Methods

This was a retrospective cohort study from a prospectively collected database in which patients treated by 1 of 7 fellowship-trained foot and ankle orthopedic surgeons at the authors' institution from July 2016 to December 2018 were identified. Data including demographic information, operative and office notes, complications and reoperations, radiographic studies, and patient-reported outcome scores were collected from an institutional review board (IRB)–approved foot and ankle orthopedic registry after obtaining approval from the registry's steering committee. Patients were eligible to be included in this study if they were older than 18 years of age at the time of surgery, were indicated for and underwent a primary modified Lapidus procedure or scarf osteotomy for hallux valgus, had preoperative and a minimum of 1-year postoperative Patient-Reported Outcomes Measurement Information System (PROMIS) scores, and had preoperative and at least 3-month postoperative anteroposterior (AP) and lateral weightbearing radiographs of the foot. Patients were excluded if the hallux valgus correction was performed concomitantly with other major midfoot or hindfoot procedures such as hindfoot fusion or flatfoot reconstruction, if lesser metatarsal osteotomy was performed, or the patient was undergoing a revision procedure to address their hallux valgus deformity. Lesser metatarsal osteotomies were excluded due to the potential for confounding in both the radiographic and clinical outcomes. Additionally, the participating surgeons used a variety of techniques to shorten the metatarsals, which would have added another layer of confounders to the analysis. Surgeon patient selection for either procedure was generally chosen by surgeon preference and familiarity to the specific procedure. If tarsometarsal hypermobility was documented in the chart, the modified Lapidus procedure was chosen. For this study, we define modified Lapidus as a corrective arthrodesis of the first tarsometatarsal joint without involvement of the base of the second metatarsal. In general, the postoperative protocol for Lapidus was 5 or 6 weeks of nonweightbearing, followed by 4 weeks of gradual protected weightbearing. The postoperative protocol for scarf osteotomy was surgeon dependent: either immediate weightbearing as tolerated in a shoe or 2 weeks of nonweightbearing followed by 4 weeks of gradual protected weightbearing.

An a priori power analysis was performed in G*Power (version 3.1.9.3; Düsseldorf, Germany).[15] The power analysis was based on achieving a minimum difference in the PROMIS physical function score of 5.0 between the scarf osteotomy and the modified Lapidus procedure groups with a standard deviation of 10 in the PROMIS physical function domain, an alpha of 0.05, and a power of 0.8, and yielded a recommended number of 64 patients per cohort. A total of 397 patients were identified who underwent primary hallux valgus correction with either scarf or Lapidus methods during this time period. Patients were excluded if they underwent lesser metatarsal shortenings (n = 191), due to potential confounding for postoperative lateral radiographic measurements. Out of the remaining 206 surgeries (102 scarf, 104 Lapidus), 136 had the minimum 3-month postoperative radiographs and 1-year postoperative PROMIS scores. A total of 131 patients (136 feet; 63

scarf, 73 Lapidus) with an average follow-up of 17.8 months (range, 12-36 months) constituted our study cohort.

Clinical Outcome Assessment

Patient-reported outcomes were prospectively collected preoperatively and at a minimum of 1 year postoperatively. PROMIS is a computerized adaptive test (CAT) that has been previously validated for foot and ankle surgery.[2,16,17] The following PROMIS domains were evaluated: physical function, pain interference, pain intensity, global physical health, and global mental health. Scores are reported as *t* scores and have a standardized mean of 50, which represents the average of the U.S. population, and a standard deviation of 10. Higher scores indicate more of the domain being studied (ie, better physical function, greater severity of pain, and better global health).

Postoperative and change in clinical outcome scores between the 2 cohorts were compared. This was done in order to determine if any differences in postoperative PROMIS domain were due to preoperative differences in the 2 operative groups. In order to determine clinical significance of improvement, changes in PROMIS domains were compared with previously published minimal clinically important differences (MCIDs) for PROMIS in foot and ankle procedures, which have been reported as 4.5 for the PROMIS physical function domain and 4.1 for the PROMIS pain interference domain using a distribution-based method.[18,31]

Radiographic Assessment

Pre- and postoperative radiographic parameters were measured by an orthopedic surgery foot and ankle fellow (M.R.) on AP and lateral weightbearing plain radiographs of the foot. On the AP view, the HVA (normal, $<$15 degrees), first-second IMA (normal, $<$9 degrees), DMAA (normal, $<$10 degrees), and tibial sesamoid (normal, 1-4) were measured.[6] On the lateral view, the measurements included the lateral talo–first metatarsal angle (Meary's; normal, 0-5 degrees), Horton index (normal, 3.4 $\pm$ 1.9 mm),[38] Seiberg index (normal, 0-1 mm),[38] sagittal IMA (normal, -1 to 1 degree),[38] and first metatarsal declination angle (normal, 20.6 $\pm$ 4.2 degrees).[20] Postoperative radiographic measures were dichotomized into "normal" versus "not normal" using the reference values cited above.

While all patients had a minimum of 1-year clinical follow-up, a minimum 3-month radiographic follow-up was determined appropriate as it was not standard of care to collect radiographs after the 3-month follow-up unless indicated. Furthermore, previous studies have demonstrated complete healing with a mean radiographic union of 11.1 weeks, with no variation of radiographic parameters at 3 months compared with later time points.[4,22,34]

Statistical Analysis

We estimated postoperative mean counterfactual PROMIS scores and the probability of normal radiographic parameters if patients underwent a scarf osteotomy versus if patients underwent a modified Lapidus procedure using a cross-validated targeted minimum-loss estimation (CV-TMLE) and super learning. TMLE requires regression of the outcome variables on the operative procedure and confounders, and regression of the operative procedure on confounders. The CV-TMLE is a doubly robust estimator that remains consistent with model misspecification of, at most, either the outcome regression or the propensity model. We included the following set of confounders: age at operation, body mass index (BMI), if the patient had concomitant procedures, the respective preoperative PROMIS domain score, and all preoperative radiographic parameters; CV-TMLE was performed using 15 folds. The specific surgeon was considered as a confounder, but since the procedures were skewed per surgeon preference, we found this to lead to practical positivity violations with the data. We included 4 candidate estimators in the super learner for both the outcome regression and treatment regression: main terms generalized linear models, multivariate adaptive regression splines, random forests, and extreme gradient boosting (XGBoost). We tested the null hypothesis that average counterfactual postoperative PROMIS scores were the same if patients underwent scarf osteotomy versus if patients underwent the Lapidus procedure (presented as the average treatment effect), and if the counterfactual probability of having normal postoperative radiographic parameters was the same (presented as relative risk), using 2-sided, alpha-level 0.05 Wald tests. *P* values were adjusted for multiple comparisons using the Benjamini and Hochberg method, and all estimates are accompanied by 95% confidence intervals. Analyses were performed in R version 4.0.3 (R Foundation for Statistical Computing, Austria, Vienna)[33] using the SuperLearner and lmtp R packages.[32,40]

Results

Demographics

The average ages were 55.4 years (SD, 17.1 years) and 53.5 years (SD, 16.8 years) in the scarf and Lapidus groups (P = .32), respectively. The average BMIs were 25.1 kg/m^2 (SD, 4.7 kg/m^2) and 24.6 kg/m^2 (SD, 4.1 kg/m^2) in the scarf and Lapidus groups (P = .52), respectively. There were 52 of 63 (83%) females in the scarf group, and 69 of 73 (95%) females in the Lapidus group (Table 1).

Clinical Outcomes

Unadjusted pre- and postoperative PROMIS scores for each domain by procedure are presented in Table 2. Both the

Table 1. Patient Demographics by Operative Procedure.[a]

Variable	Scarf osteotomy (n = 63)	Lapidus (n = 73)
Age at surgery	55.40 (17.09)	53.46 (16.81)
Body mass index	25.08 (4.72)	24.58 (4.07)
Sex, F/M (% female)	52/11 (83)	69/4 (95)

[a]Data are presented as mean (SD) unless otherwise indicated.

Table 2. Mean Unadjusted PROMIS Domains by Operative Procedure.[a]

Domain	Time	Scarf osteotomy (n = 63)	Modified Lapidus procedure (n = 73)
Physical function	Preop	45.08 (7.30)	47.66 (8.02)
	Postop	51.69 (9.21)	52.05 (7.69)
Pain interference	Preop	57.33 (6.21)	55.74 (7.48)
	Postop	48.67 (8.70)	48.13 (8.33)
Pain intensity	Preop	47.25 (7.29)	46.38 (7.23)
	Postop	39.04 (8.67)	38.88 (7.59)
Global physical health	Preop	47.89 (7.07)	49.07 (8.70)
	Postop	52.27 (9.88)	55.33 (7.96)
Global mental health	Preop	52.96 (7.79)	55.11 (8.80)
	Postop	53.00 (8.75)	56.99 (9.15)
Depression	Preop	46.09 (6.73)	47.62 (8.19)
	Postop	46.03 (7.49)	45.42 (8.00)

Abbreviations: PROMIS, Patient-Reported Outcomes Measurement Information System.
[a]Data are presented as mean (SD).

scarf osteotomy and modified Lapidus procedure resulted in discernable changes in the PROMIS physical function, pain interference, pain intensity, and global physical health domains (all $P < .01$) (Table 3). Discernible changes in the PROMIS depression and global mental health domains were also found for the modified Lapidus procedure ($P = .035$ and $P = .047$). The estimated increases in the PROMIS physical function domain using TMLE were 5.50 (95% CI, 3.31-7.70; $P < .01$) and 5.25 (95% CI, 3.19-7.31; $P < .01$) in the scarf and Lapidus cohorts, respectively. No evidence was found of a discernible difference in the change in PROMIS physical function domain between the 2 groups. The estimated mean decreases in the PROMIS pain interference domain were 7.65 (95% CI, −9.77 to −5.54; $P < .01$) and 8.35 (95% CI, −10.54 to −6.17; $P < .01$) in the scarf and modified Lapidus cohorts, respectively. The estimated mean decreases in the PROMIS pain intensity domain were 7.41 (95% CI, −9.87 to −4.94; $P < .01$) and 8.16 (95% CI, −10.21 to −6.10; $P < .01$) in the scarf and Lapidus cohorts, respectively. The estimated mean increases in the PROMIS global physical health domain were 4.25 (95% CI, 1.77-6.73; $P < .01$) and 6.45 (95% CI, 4.31-8.59; $P < .01$) in the scarf and modified Lapidus cohorts, respectively. There was no evidence of any difference in the change of the PROMIS pain interference, pain intensity, or global physical health domains between the 2 groups. Similarly, there were no differences in postoperative patient-reported outcome scores between the scarf osteotomy and modified Lapidus procedure for any of the PROMIS domains (all $P > .05$) (Table 4).

Radiographic Outcomes

Unadjusted pre- and postoperative radiographic outcomes by procedure are presented in Table 5. The radiographic measurements were evaluated using the probability of achieving normal postoperative parameters (Table 6). Since normal tibial sesamoid can be position 1, 2, 3, or 4,[6] and there was no variation in this outcome, the analysis could not be performed for this data point. When comparing the probability of achieving normal radiographic parameters between the scarf osteotomy and modified Lapidus procedure with the Lapidus group as the reference group, we found that patients who had a scarf osteotomy had a 25% lower probability of achieving a normal IMA (<9 degrees) compared with patients who underwent the modified Lapidus procedure (relative risk, 0.75; 95% CI, 0.62-0.92; $P = .04$). For all other AP and lateral radiographic measurements, the probability of achieving normal postoperative parameters was not statistically different between the two operative procedures (Table 6).

Complications

In the scarf cohort, 1 patient developed recurrence of hallux valgus deformity with plan for future revision and 1 patient

Table 3. Results of TMLE on Change Between Postoperative and Preoperative PROMIS by Operative Procedure.

	Scarf osteotomy			Modified Lapidus procedure			Average treatment effect[a]		
PROMIS domain	Estimate	P value	95% CI	Estimate	P value	95% CI	Estimate	P value	95% CI
Physical function	5.50	<.01	(3.31-7.70)	5.25	<.01	(3.19-7.31)	0.25	.85	(−2.43 to 2.94)
Pain interference	−7.65	<.01	(−9.77 to −5.54)	−8.35	<.01	(−10.54 to −6.17)	0.70	.79	(−2.08 to 3.48)
Pain intensity	−7.41	<.01	(−9.87 to −4.94)	−8.16	<.01	(−10.21 to −6.10)	0.75	.79	(−2.12 to 3.61)
Global physical health	4.25	<.01	(1.77-6.73)	6.45	<.01	(4.31-8.59)	−2.20	.79	(−5.33 to 0.93)
Global mental health	0.22	.86	(−2.18 to 2.62)	1.85	.047	(0.02- 3.68)	−1.63	.79	(−4.60 to 1.34)
Depression	−1.15	.32	(−3.19 to 0.88)	−1.71	.035	(−3.24 to −0.17)	0.55	.79	(−1.90 to 3.01)

Abbreviations: PROMIS, Patient-Reported Outcomes Measurement Information System; TMLE, targeted minimum-loss estimation.
[a]Average treatment effect corresponds to E(Y_post – Y_pre [Scarf osteotomy]) – E(Y_post – Y_pre [Lapidus procedure]).

developed hallux rigidus deformity of the involved joint and underwent a cheilectomy procedure. One patient developed dermatitis around the wound site that resolved with observation. One patient developed a second metatarsal stress fracture, which resolved with modified weightbearing.

In the Lapidus cohort, 1 patient developed asymptomatic pseudarthrosis at the tarsometarsal joint and 1 patient developed recurrence of hallux valgus deformity; neither patient opted for reoperation. Three patients developed symptomatic hardware that resolved after hardware removal, and 1 patient developed hallux varus deformity that did not require operative intervention. Three patients developed delayed wound healing, which resolved with expectant management. One patient developed a fifth metatarsal stress fracture that resolved with modified weightbearing. One patient developed a symptomatic superficial venous thrombosis, which was managed by the vascular medicine team.

Discussion

Despite wide variations in the management of hallux valgus, no studies have directly compared patient-reported and radiographic outcomes between the modified Lapidus procedure and scarf osteotomy. Our study found postoperative improvements in multiple PROMIS domains including PROMIS physical function, pain interference, pain intensity, and global physical health for both cohorts. The modified Lapidus procedure also had discernible changes in the PROMIS depression and global mental health domains, but these changes are likely not clinically important with regard to MCID. We also found that the modified Lapidus procedure was more likely to result in a "normal" IMA, as patients who underwent a scarf osteotomy had a 25% lower probability of achieving an IMA less than 9 degrees. However, this did not appear to affect clinical outcome measures at 1 year postoperatively. Other studies have also not found a difference between IMA and patient-reported outcome measures.[7,28]

The scarf osteotomy for bunion correction has produced excellent results for deformity correction, even in severe deformities.[1,24,29] Although troughing has been reported, a prevalent concern with the scarf osteotomy, we did not find evidence of first ray elevation on our postoperative lateral radiographs, indicating that troughing was not a considerable overall complication in the scarf group. From a technical standpoint, it has been recommended to make the short arms of the Z osteotomy 2 to 3 mm deep and angle the long arm of the Z to adjust the height of the metatarsal head.[10] Although studies have not compared the scarf osteotomy with the modified Lapidus procedure, comparisons between the scarf osteotomy and distal chevron osteotomy have resulted in similar patient outcomes in terms of stiffness, pain, and satisfaction.[13,19,39] Although most of the radiographic outcomes were similar between the scarf and distal chevron osteotomies, a meta-analysis showed that IMA improved by 0.88 degrees in scarf osteotomy compared with the chevron osteotomy.[36] The scarf osteotomy has been compared with the Ludloff osteotomy in a prospective comparative study, which showed similar patient satisfaction, activity level, and American Orthopaedic Foot & Ankle Society scores, but better long-term radiographic outcomes were found in the scarf group.[35]

The modified Lapidus, in contrast, corrects the hallux valgus deformity more proximally but has a risk of nonunion at the arthrodesis site and dorsiflexion of the first ray resulting in transfer metatarsalgia.[5] Previous studies have found the nonunion rate at this joint to be between 2% and 10%.[9,22,34,37] The modified Lapidus procedure has been shown to improve the pronation deformity in hallux valgus.[11] The modified Lapidus procedure is also the procedure of choice for patients with first ray instability by stabilizing the first tarsometatarsal joint through arthrodesis. We found a low nonunion rate in our study with only 1 patient developing a pseudarthrosis, which did not require operative intervention, and no instances of transfer metatarsalgia required reoperation. Even young, active patients have been shown to benefit from a first tarsometarsal arthrodesis without substantial postoperative limitations.[26] One study assessed the

Table 4. Results of TMLE Modeling for the Effect of Operative Procedures on Postoperative PROMIS Domains, Between Operative Procedures.

PROMIS domain	Scarf osteotomy		Modified Lapidus procedure		Average treatment effect[a]		
	Estimate	95% CI	Estimate	95% CI	Estimate	*P* value	95% CI
Physical function	51.73	(49.46-54.00)	52.00	(50.09-53.91)	−0.27	.85	(−3.12 to 2.58)
Pain interference	48.73	(46.67-50.79)	47.95	(45.90-50.00)	0.78	.75	(−2.06 to 3.62)
Pain intensity	39.38	(37.02-41.75)	38.65	(36.87-40.43)	0.73	.75	(−2.23 to 3.70)
Global physical health	52.52	(49.84-55.19)	54.98	(53.03-56.94)	−2.47	.39	(−5.66 to 0.72)
Global mental health	53.62	(51.22-56.01)	56.04	(53.99-58.10)	−2.43	.39	(−5.35 to −0.49)
Depression	45.92	(43.86-47.98)	45.22	(43.44-47.00)	0.70	.75	(−1.77 to 3.16)

Abbreviations: PROMIS, Patient-Reported Outcomes Measurement Information System; TMLE, targeted minimum-loss estimation.
[a]Average treatment effect corresponds to E(Y [Scarf osteotomy]) – E(Y [Lapidus procedure]).

Table 5. Mean Radiographic Values by Operative Procedure and Time Frame.[a]

Domain	Time	Scarf osteotomy (n = 63)	Modified Lapidus procedure (n = 73)
DMAA	Preop	28.44 (10.42)	32.43 (11.21)
	Postop	8.80 (6.86)	10.43 (7.38)
Horton	Preop	2.53 (1.87)	2.68 (2.27)
	Postop	2.48 (2.16)	2.13 (1.97)
HVA	Preop	30.15 (8.50)	32.49 (8.89)
	Postop	9.34 (6.03)	9.27 (7.49)
IMA	Preop	15.14 (3.33)	15.79 (3.37)
	Postop	7.35 (3.20)	5.66 (2.66)
Meary's	Preop	8.79 (7.20)	5.83 (6.79)
	Postop	7.37 (6.54)	2.83 (6.72)
1st MT declination	Preop	20.46 (4.09)	19.82 (3.52)
	Postop	19.89 (4.39)	20.93 (5.35)
Sagittal IMA	Preop	1.07 (2.45)	0.29 (3.06)
	Postop	1.13 (2.21)	−1.01 (2.93)
Seiberg	Preop	0.50 (1.29)	0.18 (1.44)
	Postop	0.42 (1.13)	−0.42 (1.52)
Tibial sesamoid	Preop	5.87 (1.07)	6.15 (1.26)
	Postop	2.56 (1.10)	2.51 (1.21)

Abbreviations: DMAA, distal metatarsal articular angle; HVA, hallux valgus angle; IMA, intermetatarsal angle; MT, metatarsal.
[a]Data are presented as mean (SD).

activity level and satisfaction in patients under 50 years of age and found that 4 out of 5 young patients were satisfied with their ability to return to activities postoperatively, including some high-impact activities.[26] Although not directly compared with the scarf osteotomy, the modified Lapidus procedure has been retrospectively compared with the distal chevron osteotomy and a closing wedge base osteotomy.[23] The authors found no difference between the 3 procedures, but they did note that reoperations for nonunions were more likely in the modified Lapidus group and reoperations for symptomatic hallux varus were more likely in the chevron-Austin osteotomy group.[23]

Multiple studies have compared the complication rates and outcomes between multiple procedures for hallux valgus. A systematic review of numerous procedures used to operatively manage patients with hallux valgus deformities found that the modified Lapidus procedure had the highest infection rate and highest nonunion rate among the treatments studied.[3] However, many outcomes were similar among the 9 techniques that were compared, including recurrence of hallux valgus deformity, need for second surgery, rate of nerve damage, and persisting postoperative pain.

Our results also suggested that patients undergoing operative correction for hallux valgus had substantial clinical improvement. Previous studies, although looking at foot and ankle procedures overall, determined a PROMIS physical function MCID of 4.5 and a PROMIS pain interference MCID of 4.1 using the standard deviation and one-half method.[18,31] A more recent study reported bunion-specific

Table 6. Results of TMLE Modeling for the Effect of Operative Procedure on Postoperative Radiographic Parameters.[a]

	Scarf (n = 63)		Lapidus (n = 73)				
Measure	Absolute risk	95% CI	Absolute risk	95% CI	Relative risk	*P* value	95% CI
DMAA	0.65	(0.53-0.77)	0.53	(0.41-0.66)	1.23	.28	(0.92-1.64)
Horton	0.50	(0.37-0.63)	0.56	(0.43-0.68)	0.90	.70	(0.65-1.25)
HVA	0.75	(0.64-0.87)	0.76	(0.66-0.85)	1.00	.97	(0.82-1.21)
IMA	0.70	(0.57-0.82)	0.92	(0.85-1.00)	0.75	**.04**	(0.62-0.92)
Meary's	0.40	(0.27-0.53)	0.37	(0.25-0.48)	1.09	.80	(0.71-1.68)
1st MT declination	0.80	(0.70-0.90)	0.68	(0.56-0.81)	1.17	.28	(0.93-1.46)
Sagittal IMA	0.55	(0.42-0.68)	0.43	(0.32-0.55)	1.27	.28	(0.90-1.80)
Seiberg	0.63	(0.51-0.75)	0.46	(0.35-0.60)	1.33	.28	(0.96-1.84)

Abbreviations: DMAA, distal metatarsal articular angle; HVA, hallux valgus angle; IMA, intermetatarsal angle; MT, metatarsal; TMLE, targeted minimum-loss estimation.

[a]The reference level for relative risk is the Lapidus procedure. Risk is defined as the probability of having a normal postoperative value. The results suggest that the probability of having a normal postoperative IMA is 25% ($P = .04$) lower with the scarf osteotomy compared with the Lapidus procedure. Boldface type indicates statistical significance ($P < .05$).

MCIDs as an increase in the PROMIS physical function MCID of 3.9 or greater, a decrease in the PROMIS pain interference domain of 4.65 or greater, and a decrease in the PROMIS depression domain of 3.1 or greater.[25] In our cohort, the estimated improvements in PROMIS physical function scores were 5.50 (95% CI, 3.31-7.70) for the scarf osteotomy group and 5.25 (95% CI, 3.19-7.31) for the modified Lapidus group, which were both greater than the previously cited MCIDs for the PROMIS physical function domain in foot and ankle patients. The estimated decreases in PROMIS pain interference scores were 7.65 (95% CI, −9.77 to −5.54) for the scarf osteotomy group and 8.35 (95% CI, −10.54 to −6.17) for the modified Lapidus group, which would also indicate that both groups had a decrease in pain interference score that reached the MCID based on prior studies. Similarly, the PROMIS global physical health domain also improved following both the scarf osteotomy (mean change, 4.25; 95% CI, 1.77-6.73) and modified Lapidus procedure (mean change, 6.45; 95% CI, 4.31-8.59), but there was no difference between the 2 groups ($P = .79$). Although there is no MCID for the PROMIS global physical health domain in foot and ankle surgery, the MCID for this domain has been found to be between 2.3 and 2.5 in patients undergoing total knee arthroplasty, which suggests that both procedures for hallux valgus lead to clinical improvement in this domain. The domains of depression and global mental health had statistical but not likely clinical improvements following modified Lapidus surgery. Overall, our work suggests that the scarf osteotomy and modified Lapidus procedure result in the most clinically relevant improvements in the PROMIS physical function, pain interference, and global physical health domains, and both procedures result in changes that are not clinically different from each other.

The strengths of this study include a large cohort of prospectively collected data. We exceeded the power for our study, which was an initial recommended cohort of a minimum of 64 patients with regard to PROMIS scores. The cohort included surgeries from 7 different foot and ankle fellowship-trained orthopedic surgeons. In general, the surgeons at our institution have similar indications for a scarf osteotomy or modified Lapidus procedure, and therefore patients with more severe deformity are not necessarily more likely to undergo a modified Lapidus procedure in this cohort. The decision for which procedure is primarily based on surgeon familiarity with the respective technique. However, patients with first tarsometatarsal instability or those undergoing a revision surgery would be more likely to undergo a modified Lapidus procedure. Patients undergoing a revision surgery were excluded from this analysis. Additionally, we used an advanced, nonparametric statistical methodology (CV-TMLE), paired with machine learning, that offers greater protection again model misspecification compared with typical analysis strategies.

The limitations of this study include a short minimum radiographic follow-up of 3 months postoperatively. Longer follow-up may show further degradation of radiographic results, although some previous studies have demonstrated complete healing with a mean radiographic union of 11.1 weeks, with no variation of radiographic parameters at 3 months compared with later time points.[4,22,34] A postoperative computed tomography (CT) scan would have been the gold standard to assess for nonunion in a tarsometatarsal arthrodesis, but in this study, postoperative CT scans were only performed with patients who had symptoms of nonunion, such as persistent pain or broken hardware. Future directions of the study could include a comparison of the radiographic outcomes between the 2 procedures, extrapolated to 3-dimensional postoperative correction measurements, utilizing weightbearing CT scans. Another limitation is that different surgeons have a propensity for one procedure, and their indications for either surgery, operative technique, and operative experience were not investigated. As discussed above, many surgeons in our group primarily employ either a scarf osteotomy or modified Lapidus procedure for similar indications, and any gross differences in severity of hallux valgus deformities should have been accounted for using the TMLEs. This study excluded patients who had lesser metatarsal osteotomies, and therefore our results may only be applicable to patients with hallux valgus deformity who are not indicated for lesser metatarsal osteotomies for metatarsalgia. A final limitation is the differences in postoperative protocols between the surgeons, including the amount of time patients were made nonweightbearing, which may potentially influence short-term outcomes.

Conclusion

The scarf osteotomy and modified Lapidus procedure are 2 commonly used techniques to operatively manage patients with hallux valgus deformities. In our study, although the modified Lapidus procedure led to a higher probability of achieving a normal IMA, both procedures yielded similar improvements in 1-year patient-reported outcome measures. These findings suggest that surgeons may utilize either technique with satisfactory clinical results.

Declaration of Conflicting Interests

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References

1. Adam SP, Choung SC, Gu Y, O'Malley MJ. Outcomes after scarf osteotomy for treatment of adult hallux valgus deformity. *Clin Orthop Relat Res*. 2011;469(3):854-859.
2. Anderson MR, Houck JR, Saltzman CL, et al. Validation and generalizability of preoperative PROMIS scores to predict postoperative success in foot and ankle patients. *Foot Ankle Int*. 2018;39(7):763-770.
3. Barg A, Harmer JR, Presson AP, Zhang C, Lackey M, Saltzman CL. Unfavorable outcomes following surgical treatment of hallux valgus deformity: a systematic literature review. *J Bone Joint Surg Am*. 2018;100(18):1563-1573.
4. Biz C, Fosser M, Dalmau-Pastor M, et al. Functional and radiographic outcomes of hallux valgus correction by mini-invasive surgery with Reverdin-Isham and Akin percutaneous osteotomies: a longitudinal prospective study with a 48-month follow-up. *J Orthop Surg Res*. 2016;11(1):157.
5. Busch A, Wegner A, Haversath M, Brandenburger D, Jager M, Beck S. First ray alignment in Lapidus arthrodesis—effect on plantar pressure distribution and the occurrence of metatarsalgia. *Foot (Edinb)*. 2020;45:101686.
6. Chen JY, Rikhraj K, Gatot C, Lee JY, Singh Rikhraj I. Tibial sesamoid position influence on functional outcome and satisfaction after hallux valgus surgery. *Foot Ankle Int*. 2016;37(11):1178-1182.
7. Chong A, Nazarian N, Chandrananth J, Tacey M, Shepherd D, Tran P. Surgery for the correction of hallux valgus: minimum five-year results with a validated patient-reported outcome tool and regression analysis. *Bone Joint J*. 2015;97-B(2):208-214.
8. Coetzee JC. Scarf osteotomy for hallux valgus repair: the dark side. *Foot Ankle Int*. 2003;24(1):29-33.
9. Coetzee JC, Resig SG, Kuskowski M, Saleh KJ. The Lapidus procedure as salvage after failed surgical treatment of hallux valgus. Surgical technique. *J Bone Joint Surg Am*. 2004;86-A(suppl 1):30-36.
10. Coetzee JC, Rippstein P. Surgical strategies: scarf osteotomy for hallux valgus. *Foot Ankle Int*. 2007;28(4):529-535.
11. Conti MS, Willett JF, Garfinkel JH, et al. Effect of the modified Lapidus procedure on pronation of the first ray in hallux valgus. *Foot Ankle Int*. 2020;41(2):125-132.
12. Coughlin MJ. Hallux valgus. *Instr Course Lect*. 1997;46:357-391.
13. Deenik A, van Mameren H, de Visser E, de Waal Malefijt M, Draijer F, de Bie R. Equivalent correction in scarf and chevron osteotomy in moderate and severe hallux valgus: a randomized controlled trial. *Foot Ankle Int*. 2008;29(12):1209-1215.
14. Easley ME, Trnka HJ. Current concepts review: hallux valgus part II: operative treatment. *Foot Ankle Int*. 2007;28(6):748-758.
15. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39(2):175-191.
16. Ho B, Houck JR, Flemister AS, et al. Preoperative PROMIS scores predict postoperative success in foot and ankle patients. *Foot Ankle Int*. 2016;37(9):911-918.
17. Hung M, Baumhauer JF, Latt LD, et al. Validation of PROMIS (R) Physical Function computerized adaptive tests for orthopaedic foot and ankle outcome research. *Clin Orthop Relat Res*. 2013;471(11):3466-3474.
18. Hung M, Baumhauer JF, Licari FW, Voss MW, Bounsanga J, Saltzman CL. PROMIS and FAAM minimal clinically important differences in foot and ankle orthopedics. *Foot Ankle Int*. 2019;40(1):65-73.

19. Jeuken RM, Schotanus MG, Kort NP, Deenik A, Jong B, Hendrickx RP. Long-term follow-up of a randomized controlled trial comparing scarf to chevron osteotomy in hallux valgus correction. *Foot Ankle Int*. 2016;37(7):687-695.
20. Jones M, Sanders A, DaCunha R, et al. Assessment of various measurement methods to assess first metatarsal elevation in hallux rigidus. *Foot Ankle Orthop*. 2019;4(3):1-9.
21. Kimura T, Kubota M, Taguchi T, Suzuki N, Hattori A, Marumo K. Evaluation of first-ray mobility in patients with hallux valgus using weight-bearing CT and a 3-D analysis system: a comparison with normal feet. *J Bone Joint Surg Am*. 2017;99(3):247-255.
22. Kopp FJ, Patel MM, Levine DS, Deland JT. The modified Lapidus procedure for hallux valgus: a clinical and radiographic analysis. *Foot Ankle Int*. 2005;26(11):913-917.
23. Lagaay PM, Hamilton GA, Ford LA, Williams ME, Rush SM, Schuberth JM. Rates of revision surgery using chevron-Austin osteotomy, Lapidus arthrodesis, and closing base wedge osteotomy for correction of hallux valgus deformity. *J Foot Ankle Surg*. 2008;47(4):267-272.
24. Law GW, Tay KS, Lim JWS, et al. Effect of severity of deformity on clinical outcomes of scarf osteotomies. *Foot Ankle Int*. 2020;41(6):705-713.
25. MacDonald A, Houck J, Baumhauer JF. Role of patient-reported outcome measures on predicting outcome of bunion surgery. *Foot Ankle Int*. 2020;41(2):133-139.
26. MacMahon A, Karbassi J, Burket JC, et al. Return to sports and physical activities after the modified Lapidus procedure for hallux valgus in young patients. *Foot Ankle Int*. 2016;37(4):378-385.
27. Mahadevan D, Lines S, Hepple S, Winson I, Harries W. Extended plantar limb (modified) chevron osteotomy versus scarf osteotomy for hallux valgus correction: a randomised controlled trial. *Foot Ankle Surg*. 2016;22(2):109-113.
28. Matthews M, Klein E, Youssef A, et al. Correlation of radiographic measurements with patient-centered outcomes in hallux valgus surgery. *Foot Ankle Int*. 2018;39(12):1416-1422.
29. Molloy A, Widnall J. Scarf osteotomy. *Foot Ankle Clin*. 2014;19(2):165-180.
30. Nix S, Smith M, Vicenzino B. Prevalence of hallux valgus in the general population: a systematic review and meta-analysis. *J Foot Ankle Res*. 2010;3:21.
31. Norman GR, Sloan JA, Wyrwich KW. Interpretation of changes in health-related quality of life: the remarkable universality of half a standard deviation. *Med Care*. 2003; 41(5):582-592.
32. Polley E, LeDell E, Kennedy C, van der Laan M. SuperLearner: super learner prediction. R package version 2.0-26. Accessed April 25, 2021. https://cran.r-project.org/web/packages/SuperLearner/index.html
33. R Development Core Team. *R: A Language and Environment for Statistical Computing*. Austria; 2019.
34. Rink-Brune O. Lapidus arthrodesis for management of hallux valgus—a retrospective review of 106 cases. *J Foot Ankle Surg*. 2004;43(5):290-295.
35. Robinson AH, Bhatia M, Eaton C, Bishop L. Prospective comparative study of the scarf and Ludloff osteotomies in the treatment of hallux valgus. *Foot Ankle Int*. 2009;30(10): 955-963.
36. Smith SE, Landorf KB, Butterworth PA, Menz HB. Scarf versus chevron osteotomy for the correction of 1-2 intermetatarsal angle in hallux valgus: a systematic review and meta-analysis. *J Foot Ankle Surg*. 2012;51(4):437-444.
37. Smyth NA, Aiyer AA. Introduction: why are there so many different surgeries for hallux valgus? *Foot Ankle Clin*. 2018; 23(2):171-182.
38. Usuelli F, Palmucci M, Montrasio UA, Malerba F. Radiographic considerations of hallux valgus versus hallux rigidus. *Foot Ankle Int*. 2011;32(8):782-788.
39. Vopat BG, Lareau CR, Johnson J, Reinert SE, DiGiovanni CW. Comparative study of scarf and extended chevron osteotomies for correction of hallux valgus. *Foot Ankle Spec*. 2013;6(6):409-416.
40. Williams NT, Diaz I. lmtp: non-parametric causal effects of feasible interventions based on modified treatment policies. R package version 0.9.0. Accessed April 25, 2021. https://cran.r-project.org/web/packages/lmtp/index.html