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Radiological and Clinical Outcome After Reversed L-Shaped Osteotomy: A Large Retrospective Swiss Cohort Study

Thorsten Jentzsch, Dr Med, MSc[1]*, Niklas Renner, Dr Med[1], Richard Niehaus, Dr Med[2], Jan Farei-Campagna, Dr Med[2], Marcel Deggeller, Pract Med[3], Fabrice Scheurer, Cand Med[4], Katie Palmer, PhD[5], Stephan H. Wirth, Dr Med[6]

[1] Attending Physician, Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Zurich, Switzerland
[2] Resident, Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Zurich, Switzerland
[3] Resident Physician, University of Zurich, Zurich, Switzerland
[4] Medical Student, University of Zurich, Zurich, Switzerland
[5] Epidemiologist, Fondazione Ospedale San Camillo IRCCS, Venice, Italy
[6] Chief-of-Service, Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Zurich, Switzerland

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ABSTRACT

The objective was to report radiological and clinical outcomes after reversed L-shaped osteotomy (ReveL) for hallux valgus (HV). A retrospective cohort study was performed between January 2004 and December 2013. The primary outcome was radiological recurrence of HV (HV angle [HVA] >15°). There were various exposure and secondary outcome variables. The results showed a median follow-up of 12.0 months (N = 827). Radiological recurrence, limited patient satisfaction, complication, revision surgery, and elective hardware removal were found in 25.0%, 15.3%, 4.6%, 2.5%, and 26.7%. Median pre- to postoperative changes were highest for HVA (delta = −16.7°). Recurrence was more likely in cases with preoperative HVA ≥40° (adjusted odds ratio [$OR_{adjusted}$]) 3.63, $p < .001$). Revisions were more likely with concomitant diseases and bilateral surgery ($OR_{adjusted}$ 12.53, $p = .010$; $OR_{adjusted}$ 3.35, $p = .030$). Hardware removal was less likely in patients ≥50 years ($OR_{adjusted}$ 0.67, $p = .014$). In conclusion, ReveL was a good surgical option for HV because of the relatively low rates of unfavorable outcomes.

Hallux valgus deformity (HV) is a common and often progressive musculoskeletal disease (1). In this deformity of the foot, the great toe (hallux) deviates laterally (valgus). This leads to a medial bony prominence of the metatarsophalangeal joint, which causes pain. Older age and the use of constrictive shoe wear are considered risk factors for HV (2–5). Pooled prevalence estimates for HV are 23.0% for individuals aged 18 to 65 years, and 35.7% for individuals ≥66.0 years (6). Although surgical treatment is mainly based on the level of pain and clinical examination, severity of the deformity can be graded radiologically using the hallux valgus angle (HVA) (7–9). Exact cutoffs for the HVA differ between studies, but mild, moderate, and severe HV can be defined as HVA <20.0°, 20.0 to 39.9°, and ≥40.0° (10). Radiological recurrence of HV after surgical treatment is relatively high and occurs in up to 73.0%. Patient satisfaction after HV surgery is acceptable and usually around 77.4%, but is lower than other common orthopedic procedures, such as total hip and knee arthroplasty (91.9% and 90.5%) (11); therefore, the search for the best surgical technique continues.

There are numerous surgical techniques for HV. They used to only involve soft-tissue procedures; now, they largely favor osteotomies of the first metatarsal bone, involving a deformity correction by cutting and realignment of bone (12). The most common surgical techniques can be categorized as proximal metatarsal (e.g., proximal chevron), mid-shaft metatarsal (e.g., scarf), and distal metatarsal (e.g., distal chevron) osteotomies (13, 14). The more recent distal metatarsal, (biplanar) reversed L-shaped osteotomy (ReveL) uses an osteotomy cut in the form of an L as illustrated in Figure 1 and is a modification of the established distal metatarsal chevron osteotomy, which was first introduced by Austin in 1962. It combines advantages of more proximal and distal metatarsal osteotomies, which are high corrective power and intrinsic mechanical stability, respectively (15, 16). Instead of using a V-shaped osteotomy (17), the ReveL osteotomy uses a short dorsal vertical and long plantar horizontal arm (18).

Although ReveL is almost always used at the current study's institution for all types of HV severity, it is used by only 3.5% of surgeons in

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Address correspondence to: Thorsten Jentzsch, Dr Med, MSc Epidemiology, Physician Attending, Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Forchstrasse 340, 8008 Zurich, Switzerland.
E-mail addresses: thorsten.jentzsch@gmail.com, thorsten.jentzsch@balgrist.ch (T. Jentzsch).
* orcid.org/0000-0002-6133-3314

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Switzerland for the treatment of mild to moderate HV (19, 20). So far, to the best of our knowledge, only half a dozen other clinical studies with a similar surgical technique of a distal metatarsal osteotomy using a long plantar arm can be identified (20-25). The sample sizes were mostly <100, ranging from 23 to 183 cases. Most pre- to postoperative reductions in HVA were <15°, ranging from 8.0° to 27.9°. Where reported, patient satisfaction, complication, and hardware removal rates ranged from 83.3% to 93.0%, 0.0% to 12.8%, and 0.0% to 13.0%, respectively. Moreover, statistical analysis did not involve any adjustment for confounders.

The objective of the current study is to report radiological and clinical outcome after ReveL for HV. The novelty of this study is that actual objective radiological recurrence rates of HV are provided in addition to more subjective limited patient satisfaction rates for long plantar arm osteotomies in a very large patient cohort. Furthermore, subgroup analyses are performed to identify risk factors for unfavorable outcomes. The sub aims are to identify the rate of radiological recurrence, limited patient satisfaction, complication, revision, and elective hardware removal after ReveL, to study if these outcome variables are influenced by age, concomitant disease, side of surgery, bilateral surgery and preoperative severity of HV, and to report the pre- to postoperative change of HVA, intermetatarsal angle (IMA), and distal metatarsal articular angle (DMAA).

Patients and Methods

Study Design

A retrospective cohort study was carried out as part of a Master's thesis; findings about different study aims are presented elsewhere (26–28).

Setting

Patient charts from a single institution, the Balgrist University Hospital in Switzerland were studied. The study period was between January 2004 and December 2013. Data comprised various radiological and clinical information.

Ethics

Ethics approval was obtained from the local ethics committee (cantonal ethics committee Zurich 2015-0480), which permitted this study without the need for individually signed informed consent because of its retrospective nature and the large number of patients.

Surgical Technique

Indications for surgery were based on a clinically painful HV. Surgical steps involved a longitudinal medial skin incision over the first metatarsophalangeal joint; sharp release of the plantar capsule avoiding vessel injury at the metatarsal head, partially by limiting the exposure posterolaterally on the dorsal side; systematic lateral soft-tissue release of the capsule of the metatarsophalangeal joint (through the medial incision); ReveL with a short dorsal vertical and long plantar horizontal osteotomy (Fig. 1), starting dorsally and 1 cm proximal to the metatarsophalangeal joint before changing to a proximally directed cut in the middle of the dorsoplantar distance of the metatarsal bone and exiting the plantar cortex approximately 4 cm proximal to the metatarsophalangeal joint; optional resection of a medial wedge if biplanar resection was used to decrease the distal metatarsal articular angle; lateral displacement of the distal head fragment between 50% and 67% of the metatarsal width depending on the needed correction; fixation with 1 or 2 2.4-mm cortex screws in a dorsoplantar direction; resection of the medial osseous prominence; capsular trimming; and layered skin closure (20). Postoperative care consisted of specific dressings for medialization of the great toe (mainly with compresses in between the first and second toe pulling the great toe medially) for (4 to) 6 weeks and unrestricted ambulation in a postoperative shoe equipped with a rigid sole for (4 to) 6 weeks as well.

Participants

The inclusion criteria were primary ReveL for HV (M20.1 according to the International Classification of Diseases) in patients of at least 18 years of age (29). The local database (KISIM; CISTEC AG, Zurich, Switzerland) was explored for the key term "hallux valgus." Exclusion criteria consisted of refusal to participate in any research, missing documentation (e.g., missing surgical report), other surgery (i.e., no actual surgery for HV, such as calcaneal osteotomy or metatarsophalangeal arthrodesis), primary revision (e.g., previous surgery for HV), no use of ReveL for HV (e.g., chevron osteotomy), and a specific reason for the chosen screw number (e.g., weak hold of 1 screw and intentional placement of an additional screw). Metatarsophalangeal arthrodesis was excluded because this procedure often involves the additional presence of hallux rigidus and arthritis (30). In addition to the different surgical technique, which involves fusion of the metatarsophalangeal joint with a plate, this technique directly affects the HVA and adds another level of disease resulting from arthritic pain. This is in contrast to a tarsometatarsal arthrodesis, which uses screws, only indirectly affects the HVA, is performed because of hypermobility of the tarsometatarsal joint, and does not add another level of disease. After consideration of these criteria, 827 cases were included in the study. Patients were always invited for at least 1 follow-up, usually around 1.5 to 3 months postoperatively. They usually did not require longer follow-up because they were satisfied with the outcome and conventional radiographs showed a good correction of the deformity with a consolidated osteotomy. This led to the fact that some patients only had 1 follow-up at 1.5 months; however, it is the standard of care at our institution that we continue scheduling further follow-up visits in case of dissatisfaction or an unfavorable outcome. We also tell patients that we would like to be contacted again should any problems or questions arise; therefore, short-term follow-up was unlikely to be a major bias for the results of this study.

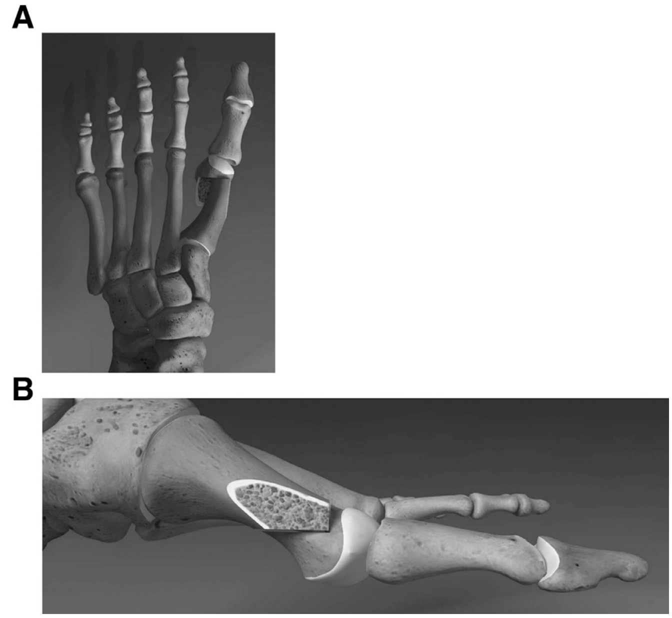

Fig. 1. Illustration of the reversed L-shaped osteotomy planes during hallux valgus surgery of the left foot. (A) Dorsoplantar view. (B) Lateral view.

Variables

The exposure variables were age, concomitant disease, side of surgery, bilateral surgery, HVA, IMA, and DMAA. All self-reported current concomitant diseases were extracted from the admission report. These included, but were not limited to, current or history of psychiatric (e.g., depression), cardiovascular (e.g., arterial hypertension), pulmonary (e.g., asthma), gastrointestinal (e.g., gastroesophageal reflux), endocrine (e.g., osteoporosis), and neurologic diseases (e.g., Parkinson's disease). Bilateral surgery for HV was defined as any surgery for HV on both feet during the study period. In addition to the HVA, the IMA and DMAA were provided because they are a measure of HV severity (31) (Fig. 2).

The primary outcome variable was the radiological recurrence of HV at last radiological follow-up (Fig. 3). This was defined as HVA >15° (no or yes) (10). Secondary clinical outcome variables were limited patient satisfaction (no or yes) at last clinical follow-up as well as complication (no or yes), revision surgery (no or yes), and elective hardware removal (no or yes) throughout the postoperative follow-up period.

Patient satisfaction was defined according to the history in patient charts. During follow-up visits, orthopedic surgeons usually documented the level of self-reported satisfaction. According to the history, patient satisfaction was categorized as dissatisfied, improved, satisfied, or very satisfied, in line with previous literature (25). To ease analysis and reduce measurement error, dissatisfaction and improvement were categorized as limited patient satisfaction, whereas satisfied and very satisfied cases were categorized as patient satisfaction. Complication consisted of infection, osseous necrosis, nonunion, complex regional pain syndrome, and revision. These were included because they are common major complications that influence the radiological recurrence of HV and limited patient satisfaction. Because revision surgery is particularly burdensome for patients, this was also investigated as a standalone variable. Revision surgery referred to any surgical procedure that was performed to treat a complication of ReveL for HV that was not amenable to conservative treatment. Mandatory hardware removal consisted of infection

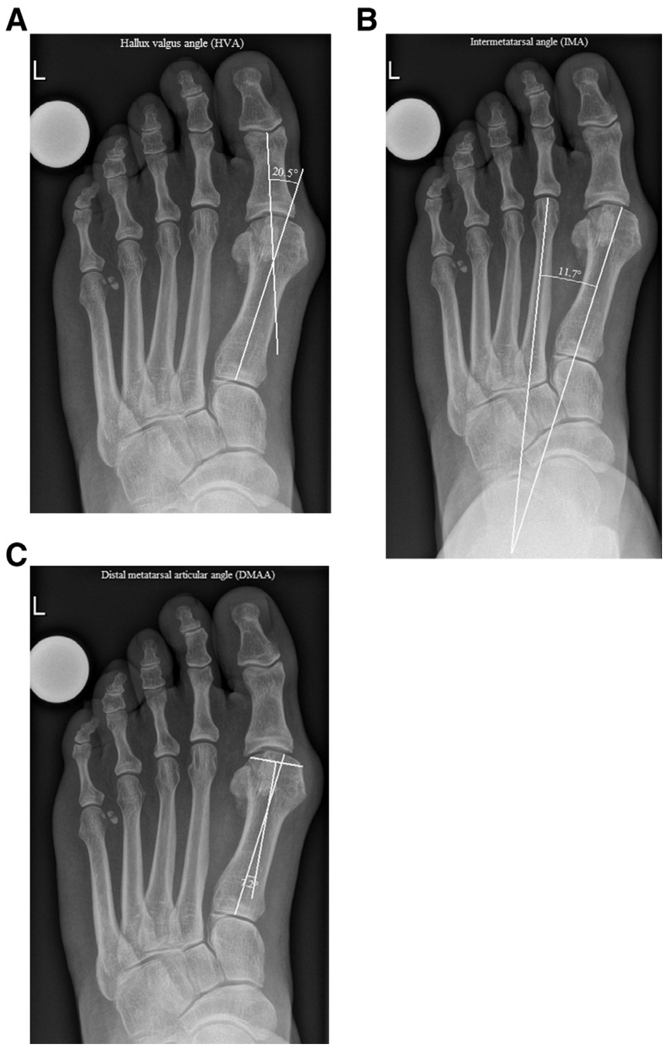

Fig. 2. Hallux valgus–specific measurements on conventional dorsoplantar radiographs of the left foot. (A) Hallux valgus angle. (B) Intermetatarsal angle. (C) Distal metatarsal articular angle.

or implant failure and was included in revision surgery. Elective hardware removal included foreign body sensation or sensitivity to weather changes. Patients sometimes opted for elective hardware removal after healing of their osteotomy or fracture site at a time when changes to the radiologic and clinical result became negligible (32). This was considered as elective hardware removal.

Data Sources and Measurements

Patient charts were studied using the local database (KISIM) and imaging software (IMPAX 6.4.0.6010 and IMPAX Orthopaedic Tools, Agfa-Gevaert N.V. [Agfa], Mortsel, Belgium). Data were collected by 6 investigators. Clinical data were retrieved before radiological data. The hypotheses were known to the investigators. Before the start of the study, a manual was handed out to all investigators. Several meetings were set up to discuss and practice data collection on cases. Data were collected in an anonymous fashion using REDCap (version 6.11.5; Vanderbilt University, Nashville, TN) and only the principal investigator had the key to the data. The data were cleaned with Microsoft Excel (version 2010; Microsoft Corporation, Redmond, WA) and Stata/IC (version 13.1; StataCorp LP, College Station, TX).

Bias

Measures to limit bias consisted of a sample size calculation (type II error), and all investigators responsible for data collection received instruction with a manual and several meetings (detection bias, nondifferential and differential misclassification), choosing a precise primary outcome (detection bias and measurement error), and providing missing values (selection bias).

Fig. 3. Illustration of 2 cases after reversed L-shaped osteotomy (and Akin osteotomy) for hallux valgus. (A) Without recurrence. (B) With recurrence.

Study Size

A sample size calculation was based on the primary outcome variable (i.e., radiological recurrence of HV [HVA >15°]). According to a previous study comparing an isolated distal metatarsal osteotomy with an additional proximal phalanx osteotomy, mean postoperative HVA and standard deviations were 18.0 (6.1)° and 14.1 (4.2)° (33). Assuming a significance level of 5% and power of 80%, the minimum sample size was ≥60 cases.

Statistical Methods

The distribution of data was tested with the skewness and kurtosis test for normality (34). Because data were not normally distributed, values are presented as medians (interquartile range [IQR]). Continuous data were transformed into binary data to ease analysis. Groups were chosen according to previous literature. Two different categories were chosen for age to test this variable for linear trend. Age was transposed into a binary (<50.0 or ≥50.0 years) and categorical variable (<40.0, 40.0 to 49.9, 50.0 to 59.9, or ≥60.0 years), preoperative HVA into a binary variable (<40.0 or ≥40.0°), IMA into a binary variable (<10.0 or ≥10.0°), and DMAA into a binary variable (<8.0 or ≥8.0°).

Table 1
Exposure variables of HV deformity cases treated with ReveL (N = 810)

Variable	Category	N_{total} (%)	$N_{category}$ (%)	Median (IQR)
Age (years)		810 (100.0)		50.0 (38.0–60.0)
	<50.0		394 (48.6)	
	≥ 50.0		416 (51.4)	
Concomitant disease		810 (100.0)		
	No		308 (38.0)	
	Yes		502 (62.0)	
Side		810 (100.0)		
	Left		411 (50.7)	
	Right		399 (49.3)	
Bilateral surgery for HV		810 (100.0)		
	No		375 (46.3)	
	Yes		435 (53.7)	
HVA (°) preoperatively		810 (100.0)		27.3 (21.6–33.6)
	<40.0		727 (89.8)	
	≥ 40.0		83 (10.3)	
IMA (°) preoperatively		810 (100.0)		12.9 (10.5–15.0)
	<10.0		160 (19.7)	
	≥ 10.0		650 (80.3)	
DMAA (°) preoperatively		810 (100.0)		17.5 (11.5–25.9)
	<8.0		101 (12.5)	
	≥ 8.0		709 (87.5)	

Abbreviations: DMAA, distal metatarsal articular angle; HV, hallux valgus; HVA, hallux valgus angle; IMA, intermetatarsal angle; IQR, interquartile range; ReveL, reversed L-shaped osteotomy.

Table 2
Outcome variables of HA deformity cases treated with ReveL (N = 810)

Variable	Category	$N_{category}$ (%)	Median (IQR)
Follow-up (months)			12.0 (4.0–19.0)
	<12.0	336 (41.5)	
	≥ 12.0	474 (58.5)	
Radiological recurrence of HV* (HVA [°] at last radiological follow-up)			10.8 (6.2−-15.1)
	No (≤ 15.0)	607 (75.0)	
	Yes (>15.0)	203 (25.0)	
IMA (°) at last radiological follow-up			5.0 (3.1–7.2)
	<10.0	764 (94.3)	
	≥ 10.0	46 (5.7)	
DMA (°) at last radiological follow-up			5.0 (2.1–9.3)
	<8.0	555 (68.5)	
	≥ 8.0	255 (31.5)	
HVA (°) change from pre- to postoperatively			−16.7 (−22.2 to −10.8)
IMA (°) change from pre- to postoperatively			−7.8 (−10.0 to −5.3)
DMAA (°) change from pre- to postoperatively			−12.1 (−18.8 to −6.3)
Limited patient satisfaction†			
	No	686 (84.7)	
	Yes	124 (15.3)	
Complication‡			
	No	773 (95.4)	
	Yes	37 (4.6)	
	Time to complication		6.0 (2.5–15.0)
Revision surgery			
	No	790 (97.5)	
	Yes	20 (2.5)	
	Time to revision		11.0 (3.0–20.3)
Elective hardware removal			
	No	594 (73.3)	
	Yes	216 (26.7)	
	Time to elective hardware removal		13.0 (8.0–25.0)

Abbreviations: DMAA, distal metatarsal articular angle; HV, hallux valgus; HVA, hallux valgus angle; IMA, intermetatarsal angle; IQR, interquartile range; ReveL, reversed L-shaped osteotomy.

* HVA >15.0°.

† Limited patient satisfaction was defined as dissatisfied or improved, whereas patient satisfaction was defined as satisfied or very satisfied.

‡ Defined as infection, osseous necrosis, nonunion, complex regional pain syndrome, and revision.

The chi-squared test (and score test for trend of odds) was used for categorical variables. The odds ratio (OR) and 95% confidence interval (95% CI) were computed. Confounders were defined as variables with differences in crude and adjusted estimates by ≥ 10%. Effect modification was also taken into account by a test for heterogeneity. Adjusted Mantel-Haenszel estimates were also calculated. A causal model was computed by logistic regression (Wald test), and interaction terms and linear trends were considered. The statistical significance level was defined as 5%. Stata/IC was used to perform the analysis (StataCorp LP).

Results

Participants

The patient selection consisted of assessment for eligibility (n = 1,977), and exclusion of 1,150 cases. Causes for exclusion were refusal to participate in any research (n = 9), missing documentation (n = 43), other surgery (n = 789), primary revision (n = 69), no use of ReveL for HV (n = 218), and a specific reason for the chosen screw number (n = 22). Seventeen (2.1%) cases were lost to follow-up and 810 (97.9%) were analyzed. The median follow-up was 12.0 (IQR 4.0–19.0, range 1.5–114) months. All cases had at least 1 follow-up consultation. Most cases (n = 474 [58.5%]) were followed for >12 months. Few cases (n = 45 [5.6%) had a follow-up of 1.5 months.

Exposure Variables

The median age of all cases was 50.0 (IQR 38.0–60.0) months (Table 1). Most cases had concomitant diseases (n = 502 [62.0%]). Both sides were treated in a similar frequency (left: n = 411 [50.7%] vs right: n = 399 [49.3%]). Bilateral surgery was performed in a few more cases (n = 435 [53.7%]). The median preoperative HVA, IMA, and DMAA values were 27.3° (IQR 21.6–33.6), 12.9° (IQR 10.5–15.0), and 17.5° (IQR 11.5 –25.9).

Outcome Variables

The minority of cases had radiological recurrence of HV at last follow-up (n = 203 [25.0%]) (Table 2). The median HVA, IMA, and DMAA values at last radiological follow-up were 10.8° (IQR 6.2–15.1), 5.0° (IQR 3.1–7.2), and 5.0° (IQR 2.1–9.3). Median pre- to postoperative changes were highest for HVA (Δ −16.7° [IQR −22.2 to −10.8]), followed by those for DMAA (Δ −12.1° [IQR −18.8 to −6.3]) and IMA (Δ -7.8° [IQR −10.0 to −5.3]). Limited patient satisfaction was found in 124 cases (15.3%). Only a few complications (n = 37 [4.6%]) and revision surgeries (n = 20 [2.5%]) were observed. Elective hardware removal was seen in about every fourth case (n = 216 [26.7%]).

Table 3
Logistic regression model for different factors associated with radiological recurrence of HV deformity (HVA >15°) and age as well as preoperative severity of HV after ReveL for HV (n = 799)

Main Effect of Variable	Stratum-Specific Effect of Variable	Category	Adjusted OR (95% CI)*	*p* Value†
Age (years)				
		<50.0	1.00 (reference)	
		≥ 50.0	1.08 (0.77–1.52)	.640
HVA (°) preoperatively				
		<40.0	1.00 (reference)	
		≥ 40.0	3.63 (2.19–6.00)	<.001

Abbreviations: CI, confidence interval; DMAA, distal metatarsal articular angle; HV, hallux valgus; HVA, hallux valgus angle; IMA, intermetatarsal angle; IQR, interquartile range; OR, odds ratio; ReveL, reversed L-shaped osteotomy.

* Adjusted for confounders and effect modifiers: age, sex, preoperative hallux valgus angle, number of screws, additional surgical technique for hallux valgus, time period, and body mass index.

† Wald test.

Multivariate Analysis of Primary Outcome

The logistic regression model did not show an association between radiological recurrence of HV after ReveL and age (Table 3). It demonstrated strong evidence that radiological recurrence of HV was 263% more likely with preoperative HVA ≥40° than preoperative HVA <40° ($OR_{adjusted}$ = 3.63 [95% CI 2.19–6.00], $p < .001$).

Multivariate Analysis of Secondary Outcomes

No evidence of an associations of limited patient satisfaction with age ($OR_{adjusted}$ = 1.00 [95% CI 0.68–1.45], p = .992) and preoperative HVA ($OR_{adjusted}$ = 0.99 [95% CI 0.52–1.92] p = .986) were observed. There was no evidence for associations of complications with age ($OR_{adjusted}$ = 1.57 [95% CI 0.78–3.15], p = .207) and preoperative HVA ($OR_{adjusted}$ = 0.78 [95% CI 0.30–2.02] p = .601).

Strong evidence was seen that revision surgery was 1.15% more likely with concomitant diseases than without concomitant diseases ($OR_{adjusted}$ = 12.53 [95% CI 1.57–99.91], p = .017) and 235% more likely with bilateral surgery for HV than unilateral surgery for HV ($OR_{adjusted}$ = 3.35 [95% CI 1.12–9.96], p = .030). No evidence for associations of revision surgery with age ($OR_{adjusted}$ = 1.80 [95% CI 0.63–5.13], p = .270) and preoperative HVA was found ($OR_{adjusted}$ = 1.01 [95% CI 0.28–3.59] p = .987).

There was strong evidence that elective hardware removal was 33% less likely with older (≥50 years) age than younger (<50 years) age ($OR_{adjusted}$ = 0.67 [95% CI 0.48–0.92], p = .014). No evidence of an association of elective hardware removal with preoperative HVA ($OR_{adjusted}$ = 0.78 [95% CI 0.44–1.40], p = .410) was recorded.

Discussion

This is, to the best of knowledge, the first study to provide actual radiological recurrence rates in addition to the clinical outcome after ReveL for HV in addition to the large cohort. Radiological recurrence of HV, limited patient satisfaction, complications, and revisions were relatively uncommon, and markedly radiologic correction of HV by ReveL was observed in this single-center cohort study. There was evidence that higher preoperative radiological severity of HV is independently associated with increased radiological recurrence of HV after ReveL for HV. Having concomitant diseases and having undergone bilateral surgery for HV was associated with increased revision surgeries. The wish for elective hardware removal was present in approximately every fourth patient. Being older was independently associated with less elective hardware removal.

The literature about long plantar arm osteotomies for HV (e.g., ReveL) is very limited and studies often lack power and, to the best of knowledge, only half a dozen other studies were identified (20–25). Our sample size calculation illustrates that most previous studies about this surgical technique are likely underpowered for a radiological outcome because at least 60 cases were needed per group to determine differences.

The radiological recurrence of HV of 25.0% is lower in our study than many previous studies using other surgical techniques for HV. In a randomized controlled trial, radiological recurrence of HV was 54.2% without differences between scarf and chevron osteotomies (35). It was even higher (73%) after distal chevron osteotomy for HV in another study (10). Although there are other studies that reported lower rates (e.g., 13.9%) for radiological recurrence of HV following proximal metatarsal osteotomies, radiological recurrence of HV was often defined more liberally (i.e., HVA >20°) (8). This potentially suggests higher intrinsic stability after ReveL.

A previous study from our institution reported preliminary results about ReveL for HV from a different period (2000–2001) (n = 39) (20). Their radiological correction of HV (change in pre- to postoperative HVA) was lower than the one presented herein (Δ = 11.0° vs Δ = 16.7°). In their study, limited patient satisfaction and complication rates were similar to the ones found in our study (13.0% vs 15.3% and 6.4% vs 4.6%, respectively). Furthermore, they reported lower elective hardware removal (16.1% vs 26.7%). This could be attributed to their postoperative follow-up time, which was restricted to two years.

Another study reported that radiologic recurrence of HV did not occur (n = 42) (21). Yet, it was not described how this was assessed and 64.3% cases were lost to radiologic follow-up, rendering the radiologic results prone to selection bias. Their radiological correction of HV of Δ = 8.0° was lower than ours. This may be attributed to the fact that their dorsal arm was not chosen in a vertical direction to the ground but angulated as in the original Chevron osteotomy, which may have limited corrective power. Their limited patient satisfaction was similar to ours (16.7% vs 15.3%).

In a different study, radiological correction of HV was Δ = 11.0° (n = 54) (22). The reason for the lower reduction in HVA may be explained by using a shorter planter arm than the one used in our study. Of patients that were followed for 2 years, 5.6% reported undercorrection of HV and limited patient satisfaction, which led to revision surgery. Another 7.4% underwent hardware removal. The lower rate of limited patient satisfaction may be misleading if their patients were entirely dissatisfied. The actual dissatisfaction rate in our study was similar (6.5%), but we opted to report a broader limited patient satisfaction by combining improvement and dissatisfaction since surgery for HV should be performed with the goal to achieve at least satisfactory results.

Another study reported a mean radiological correction of HV of Δ = 14.0°, as well as limited patient satisfaction in 8.7%, minor complications in 13.0%, and major complications in 0% (n = 23) (23). Their slightly better clinical results could potentially be attributed to a different patient population, in which all patients were female and concomitant diseases were unknown.

Another previous study also did not report radiological recurrence of HV, but it can be assumed that it was low because of the mean postoperative HVA of 5.0° and high radiological correction of HV (Δ = 27.0°) (n = 86) (24). They reported limited patient satisfaction in 8.0%, minor complications in 12.8%, revision in 1.2%, and hardware removal in 8.0% of cases. Aside from the different surgical technique using a more angled plantar arm, their superior results may be explained by a different patient population that included fewer males than ours (3.4% vs 11.5%), less additional surgery of the foot than ours (19.8% and exclusion of hindfoot procedures vs 35.8% and no exclusion of hindfoot procedures), and a different frequency of bilateral surgeries (not reported vs 53.7%).

A recent study described a large mean radiological correction of HV (Δ = 27.9°) (n = 184) (25). Limited satisfaction was found in 7% and minor complications were found in 0.9%. These superior results may be due an unreported high rate of low concomitant diseases, low bilateral surgeries for HV, low additional techniques for HV, or because only 1 surgeon performed surgeries.

The relatively low radiological recurrence, infrequent limited patient satisfaction, low complication rate, low revision surgery rates, and high corrective power of ReveL for HV show that ReveL is a good option for patients with HV. Lower radiological recurrence of HV in our study in comparison to other surgical techniques for HV could be explained by the higher intrinsic stability of a short dorsal vertical and long plantar horizontal arm during distal metatarsal osteotomy. It could, however, be possible that differences in soft-tissue handling and capsulotomy may have confounded these findings. An increased rate of elective hardware removal manifests that patients often have symptoms of foreign body sensation or the subjective wish for elective hardware removal. Our rate of hardware removal (26.7%) was relatively high and could be attributed to the fact that patients are encouraged to have their hardware removed if they feel that this could be associated with any residual discomfort around the screw(s) and if they present with painful palpable screw head(s). Also, specific results about patient satisfaction after hardware removal are not presented in this study; it is our subjective feeling that patients benefit from this with correct indications.

The preoperative severity of HV (i.e., increased HVA) is likely associated with higher rates of radiological recurrence of HV since larger bony deformities are more difficult to correct, soft tissue is increasingly constricted, and a memory of the deformity has developed in the brain. Furthermore, it is plausible that concomitant diseases are associated with increased revision surgery rates because wound and osseous healing are commonly negatively affected by diseases, such as rheumatoid arthritis and osteoporosis. Moreover, intrinsic factors may contribute to the fact that bilateral surgery is associated with increased revision surgery rates. In the future, elective hardware removal could potentially be reduced by using Herbert screws instead of cortical screws, because they do not have a prominent head and may lead to less tissue irritation.

Limitations

Because of the retrospective nature of this study, cases differed in their follow-up time. The standard algorithm involved outpatient visits after 1.5, 3, and 12 months. This was not always adhered to for miscellaneous reasons. If the final outcome was excellent before 12 months, patients were not asked to return for a follow-up visit. This may have introduced surveillance bias because many recurrences of HV are not immediate. However, in Switzerland, the follow-up of patients is very good (as illustrated by the low rate of loss-to-follow-up in this study) and it can be assumed that the last follow-up depicts the final result. This also limited missing data and non-differential misclassification. Furthermore, clinical data were retrieved before radiological data to avoid detection bias.

Radiographic measurements are prone to small measurement errors of approximately 3° (36). The intra- and interobserver reliabilities of the measurements of this study have mostly been reported as very strong except for the DMAA (intraobserver reliabilities: intraclass correlations for HVA of 0.99, IMA 0.91, and DMAA 0.78 as well as interobserver reliabilities: intraclass correlations for HVA 0.99, IMA 0.90, and DMAA 0.38) (37). Although a small risk of measurement error remains in our study, it therefore, seems reasonable that only 1 investigator perform each measurement. Moreover, choosing a radiological variable, which is easy to measure, as the primary outcome of HVA in this study, measurement and differential errors that could arise from recall bias if more subjective clinical outcomes had been used, are limited. Overall, it is important to note that pre-, intra-, and postoperative decision-making and assessment not only involves the HVA, which was the focus of this study for clarity purposes, but also the IMA and DMAA. Although the exact cutoff values are debatable, patients with a milder HV (HVA <30 and IMA $<15°$) can usually be sufficiently treated with a single distal osteotomy (e.g., ReveL), whereas more severe HV (HVA $\geq 30°$ and IMA $\geq 15°$) require a tarso-metatarsal-I-arthrodesis or more proximal osteotomy (e.g., Scarf) (20,38). Usually, an additional biplanar distal osteotomy (e.g., ReveL) is performed if the DMAA is $>15°$ and an additional Akin osteotomy is performed if the hallux valgus interphalangeus is $>10°$.

Retrospective assessment of limited patient satisfaction was difficult in some cases. Although a 4- point scale was initially chosen similar to previous literature, during data collection it became obvious that a 2-point scale (limited patient satisfaction vs patient satisfaction) would reflect reality more accurately (25). Therefore, a binary variable was chosen for analysis to avoid misclassification, nondifferential errors, and underestimation of the strength of association. Furthermore, self-reporting of concomitant diseases is prone to reporting bias. This may be particularly true for psychiatric diseases, such as depression, which may be associated with social stigma.

Although an interesting topic for future studies, this study did not evaluate if the ReveL osteotomy is superior to other osteotomies; however, one may compare the results of this study to other well-conducted studies focusing on other osteotomies, such as the randomized controlled trial of 96 patients regarding the Scarf versus Chevron osteotomy in HV by Deenik et al (35). At a follow-up of 27 months, the HVA and IMA were found to be corrected from 29° to 18° ($\Delta = -11°$) and 13° to 10° ($\Delta = -3°$) in the Scarf group and 30 to 17° ($\Delta = -13°$) and 13 to 10° ($\Delta = -3°$) in the Chevron group (without significant differences between groups). Our retrospective study had a shorter follow-up, but resulted in better correction of the HVA and IMA. To draw comparative conclusions, future studies with direct comparisons of ReveL versus Scarf and/or Chevron osteotomies are needed. A superiority randomized controlled trial could be set up to directly compare the radiological recurrence and clinical outcome of HV after ReveL versus other commonly used osteotomies, such as chevron or scarf osteotomy at one-year follow-up. Randomization can minimize confounding and selection bias, while blinding can minimize reporting and observer bias. Furthermore, powerful evidence for a causal relationship according to Bradford Hill criteria could be obtained.

Another opportunity for a future study is to conduct similar studies with a longer follow-up (e.g., ≥ 10 years), perhaps undertaken to find a potentially higher rate of recurrence. The findings of the current study will affect future patient decision-making regarding the choice for or against surgical treatment of their HV and orthopedic surgeons in selection of the best surgical technique for each patient.

In conclusion, in this cohort, ReveL was a good surgical option for adult patients with HV because of relatively low rates of radiological recurrence of HV and limited patient satisfaction, as well as low rates of complications and revision surgeries. Earlier surgical treatment of milder deformities may be indicated if the disease is progressive to prevent unfavorable outcomes with larger deformities and concomitant diseases. Uneventful healing of unilateral ReveL for HV may precede contralateral surgery for HV. Comparative clinical studies with this surgical technique are suggested.

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