⟨ Clinical Research ⟩

Immediate Weight Bearing After Hallux Valgus Correction Using Locking Plate Fixation of the Ludloff Osteotomy

A Retrospective Review

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Abstract: Background. *A Ludloff osteotomy is a common procedure used to correct hallux valgus deformities. Traditionally, the osteotomy is stabilized with screws only, thus requiring the patient to be non–weight bearing until healed. There have been no outcome studies analyzing immediate weight bearing after Ludloff osteotomy for hallux valgus.* Methods. *Of the 350 patients (390 feet) who underwent a Ludloff osteotomy fixed with a locking plate and prescribed an immediate weight-bearing postoperative protocol, 288 patients (326 feet) were included in the analysis. Average radiographic follow-up was 8 months, and hallux-valgus angle (HVA), intermetatarsal angle (IMA), and any hardware failures or hypertrophic callus formation were recorded. The Foot Function Index (FFI) was assessed in 103 patients at an average of 44 months postoperatively.* Results. *Average IMA and HVA correction were 7.6° and 21.6°, respectively ($P < .0001$). Loss of HVA and IMA correction of 4.6° and 2.3°, respectively, were noted between the initial postoperative films and final weight-bearing films. The average FFI score calculated for the 103 respondents was 10.4 out of a possible 100, indicating relatively low pain and disability. Complication rates were consistent with most other published postoperative protocols, with the most commonly seen being superficial infection (4.9%) and symptomatic hardware (4.6%).* Conclusion. *An immediate weight-bearing protocol for Ludloff osteotomies fixed with locking plates results in recurrence rates that are similar to those found with other protocols. Patient function is quite high and pain low following this protocol. The most commonly observed complications were superficial infection and symptomatic hardware requiring removal.*

Levels of Evidence: *Level IV*

Keywords: Ludloff osteotomy; hallux valgus

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Introduction

Hallux valgus has long plagued both patients and surgeons. It is a common

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presentation in the orthopaedic clinic and may lead to significant disability in advanced stages, at which point surgical correction often becomes necessary. One of the more common and versatile surgical procedures is the Ludloff osteotomy, which is an oblique first metatarsal osteotomy used to treat moderate to severe hallux valgus deformity. The osteotomy begins dorsal/proximal approximately 1 cm from the joint and continues plantar/distal at an optimal 30° angle. The initial bone cut extends two-thirds of the length of the metatarsal and is traditionally secured proximally by a screw placed just distal to the metatarsocuneiform joint. The distal cut is then completed and the osteotomy is rotated before it is then locked in place with a second distal screw.[1,2] Lateral soft-tissue releases are also performed routinely. Usually, patients are kept non—weight bearing for at least 2 weeks postoperatively, at which point some surgeons transition them to heel weight bearing, whereas others keep the patient non–weight bearing for up to 6 weeks. Complications include superficial infection, malunion (1%-5%), nonunion (1%-2%), and loss of correction. There is even more concern of these complications occurring in osteopenic bone. In one study, 28% of cases of dorsal angulation malunion went on to develop transfer metatarsalgia.[3-5] Often, malunion occurs because of poor compliance with non–weight bearing protocols.[6,7] Because issues with weight-bearing protocols are often to blame for the postoperative complications listed above, especially with obese and elderly patients, more robust methods of fixation have been developed to mitigate the risks of these complications occurring. It is felt that the locking plate moves some of the weight-bearing stresses from the osteotomy site to the plate construct. The biomechanical literature endorses this as a possible use for locking plates to provide more durable fixation. We hypothesize that anatomical locking plates offer more robust fixation and stability at the osteotomy site, making weight bearing safe for most patients, and especially safer in those with osteopenic bone.

Materials and Methods

In this retrospective cohort study, we analyzed the clinical data of all Ludloff osteotomies performed between 2010 and 2015. This study period was chosen because of convenience and because of the fact that an anatomical locking plate was used almost universally in this time frame. Preoperative radiographic data were collected, including intermetatarsal angle (IMA) and hallux valgus angle (HVA). The study was approved by our institutional review board.

All patients were instructed to be weight bearing as tolerated immediately postoperatively. Our objectives were to determine the effect that immediate weight bearing has on (1) radiographic outcomes, (2) pain and function outcomes, and (3) the complication rate. These outcomes can be compared with similar literature to determine the potential risks and benefits of an immediate weight-bearing protocol.

A total of 390 feet in 350 patients were examined. Of these, 43 feet in 41 patients had incomplete films and were excluded from analysis. Also, 21 patients underwent Ludloff osteotomies that were fixed with only 2 screws (as opposed to a locking plate) and followed restricted postoperative weight-bearing protocols, and were thus excluded. In all, 326 feet in 288 patients were included, all of whom underwent a Ludloff osteotomy fixed with an anatomical locking plate; 41 patients (14.2%) underwent bilateral procedures; all bilateral surgeries were staged with no less than 3 months intervening. Six patients (2.1%) were male. The Ludloff procedures were performed by 3 different surgeons at the Orthopaedic Foot and Ankle Center in Falls Church, VA. Radiographic analysis was conducted by a senior orthopaedic resident (JJM) who was not involved in any of the preoperative, intraoperative, or postoperative clinical care of any of the patients.

Indications for a Ludloff osteotomy in our series included the following: (1) symptomatic hallux valgus deformity with an intermetatarsal angle (IMA) of greater than 10°, (2) HVA of greater than 20°, (3) failure of conservative management, and (4) normal preoperative range of motion at the hallux metatarsophalangeal joint. Exclusion criteria were the following: (1) radiographic or clinical first tarsometatarsal joint instability, (2) peripheral neuropathy, (3) peripheral vascular disease, (4) congruent bunion deformity, and (5) first metatarsophalangeal joint arthritis.

Postoperatively, patients were administered the Foot Function Index (FFI) via phone, email, or regular mail. The 22-question survey aimed to measure the impact of foot pathology on function in terms of 3 subscales—pain, disability, and activity limitation. It is a self-administered index with scores ranging from 0 to 100, with 0 representing no disability. It has been proven in the literature to be a reliable method for evaluation of subjective outcomes.[8] This was administered an average of 44 months after the index surgical procedure. This lag is a result of the fact that early in the series we were not collecting clinical scores routinely. Radiographic analysis included anteroposterior, lateral, and oblique views. Preoperative views were weight bearing; initial postoperative views were non–weight bearing; and follow-up views were weight bearing. IMA and HVA were recorded, as were any obvious hardware failures or the formation of hypertrophic callus. The initial radiographs were taken with a portable X-ray machine, transported into the patient's clinic room, and were used to confirm hardware placement and rule out any initial complication.

Concomitant procedures and complication data were gleaned from the patients' electronic medical record retrospectively from clinic notes dictated or written by the treating surgeon. These are listed in Table 1. Importantly, all patients followed the same protocol regardless of secondary surgeries.

Table 1.

Additional Procedures.

Additional Procedures	Total
Second metatarsal osteotomy (Weil type)	102
Proximal phalanx osteotomy (Aiken)	71
Hammertoe correction (PIP joint)	69
Cheilectomy	11
Neuroma excision	9
MTP open reduction and internal fixation	8
Bunionette deformity correction	8
DuVries condylectomy	6
Proximal metatarsal osteotomy	5
Adductor tendon contracture release	4
Extensor tendon tenotomy	4
Ganglion excision	2
Keller procedure	2
DIP arthrodesis	2
DIP resection	2
Peroneus brevis repair	2
Bone cyst excision	1
Chevron/Austin distal metatarsal osteotomy	1
Metatarsal open reduction and internal fixation	2
Calcaneal osteotomy	1
Ankle arthroscopy	1
Ankle arthroplasty	1
Brostrom repair	1
Fibular sesamoidectomy	1
Sum	316

Abbreviations: PIP, proximal inter-phalangeal joint; MTP, metatarsal-phalangeal joint; DIP, distal inter-phalangeal joint.

Surgical Technique

The patient is placed in a supine position. A lateral release is carried out through a small incision in the first interspace. The Ludloff osteotomy is performed through a medial skin incision with care taken not to disrupt the dorsal medial cutaneous nerve. The first tarsometatarsal joint is identified, and the osteotomy is marked out at a 30° angle starting about 1 cm distal to the joint. Initially, 75% of the proximal bone is ostetotomized through and through, with care taken not to disrupt the distal 25%. The 4-hole anatomical locking plate is placed over the osteotomy, and a K-wire is used to fix the plate in place. Fluoroscopic guidance is used to ensure that the dorsal-proximal wire passes across the osteotomy site. A nonlocking cannulated screw is then placed over this wire. The osteotomy is then completed and rotated until the desired correction is achieved. The proximal nonlocking screw is then tightened. Another guided K-wire is advanced across the second dorsal-distal nonlocking hole and a cannulated screw is placed, providing compression at the osteotomy site. Finally, 2 locking screws are placed at the most proximal and distal holes, respectively (Figures 1 and 2).

A total of 316 additional procedures were performed, the most common being claw toe/hammertoe repairs ("Weil" osteotomy and/or PIP fusions) and proximal phalanx osteotomies (Akin procedure). See Table 1 for a complete listing of associated procedures.

In the immediate postoperative period, patients were fitted with a rigid-sole shoe and a CAM walker boot and told to use a silicone spacer between the first and second toes. Weekly bunion strapping was not done. All patients underwent the same postoperative protocol: age, bone density, body weight, or predicted level of activities was considered. For the first 7 postoperative days, the patient was instructed to ambulate as tolerated in the rigid-sole shoe but to elevate and ice the foot as much as possible. At postoperative day 7 to 10, the patient returned to the office for a dressing change. Portable radiographs were taken, and the patient remained in either a rigid-sole shoe or CAM boot, with instructions to keep a spacer in between the first 2 toes. The patients were then allowed to undertake normal activities of daily living (driving, walking). The patients were allowed to wear either the CAM boot or the postoperative shoe,

Figure 1.

First metatarsal Ludloff locking plate construct.

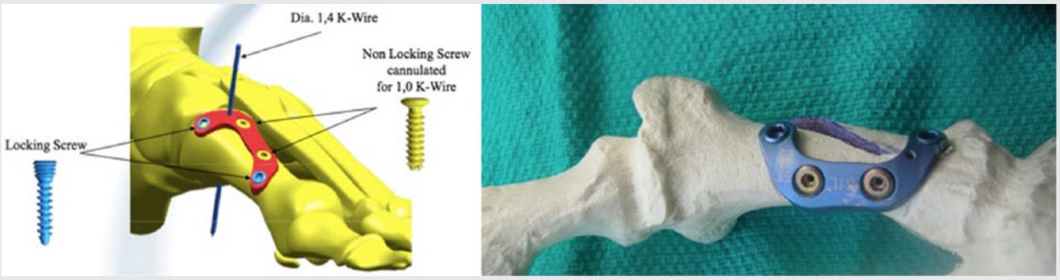

Figure 2.

Preoperative and postoperative weight-bearing X-rays of a Ludloff osteotomy stabilized with a locking plate construct.

based on comfort and personal preference. Patients were encouraged to remove the CAM boot and rigid shoe when they were not walking. Elevation was still encouraged, and plantarflexion and dorsiflexion range-of-motion exercises were initiated once the incision was healed. Patients were instructed to avoid abduction or adduction. At 6 to 7 weeks postoperatively, radiographs were repeated. With radiographic evidence of healing, the patient was allowed to wean from the rigid shoe or boot into a normal flat shoe (ie, sneaker, tennis shoe) and advance activities as tolerated. If the first MTP joint was felt to be stiff, physical therapy was prescribed. The patients were discharged from care once radiographic union was demonstrated and range of motion returned.

Data Analysis

Preoperative and postoperative HVA and IMA, and postoperative FFI scores were recorded. *P* values for the HVA and IMA were calculated using a commercially available, free online calculator (GraphPad Software, graphpad.com). A total of 103 patients (36%) responded to the FFI. All complications were recorded.

Results

Radiographic results demonstrated an average correction of the HVA by 21.6° ($P < .0001$) and the IMA by 7.6° ($P < .0001$) when comparing initial preoperative

Table 2.

Preoperative and Postoperative Radiographic Measurements.

Pre-IMA	Post-IMA No. 1 (NWB)	Post-IMA No. 2 (WB)	Average IMA Correction
16.44	6.55	8.87	7.57 (46.1%)
Pre HVA	**Post-HVA No. 1 (NWB)**	**Post-HVA No. 2 (WB)**	**Average HVA Correction**
35.27	9.03	13.68	21.6 (61.3%)

Abbreviations: IMA, intermetatarsal angle; NWB, non–weight bearing; WB, weight bearing; HVA, hallux valgus angle.

weight-bearing images with final postoperative weight bearing images (an average of 8 months postoperatively, ranging from 2 to 43 months; Table 2). Another radiographic feature that was recorded was the presence of hypertrophic callus; 15 feet (4.6%) were noted to have radiographic evidence of a hypertrophic callus (ie, the formation of hypertrophic bone beyond the contour of the native bone). Of these, 2 were patients listed among those requiring hardware removals for symptomatic hardware (see below). It was noted that there was a statistically significant loss of correction of IMA of 2.3° ($P < .0001$) and HVA of 4.6° ($P < .0001$) between the initial postoperative films and the final postoperative films (see Table 2).

A total of 103 patients completed the FFI an average of 44 months postoperatively. The average score was 10.4 out of a possible 100, indicating relatively low pain and disability, with 100 being the worst. The minimum score reported was 0, and the maximum was 78 (see Table 3); 12 patients had scores greater than 20.

All complications are listed in Table 4. The most commonly recorded complication was superficial wound infection or cellulitis around the incision site (n = 16, 4.9%). Of those, only 3 required debridement in the office. The rest were treated with topical agents and/or oral antibiotics. All resolved without requiring hardware removal. There were no cases of deep infection. A total of 15 (4.6%) feet required hardware removal for symptomatic hardware, including broken or prominent screws. These were in older women with especially thin feet. No broken plates were observed. Other complications included symptomatic hallux varus (n = 5, 1.5%), symptomatic recurrent hallux valgus (n = 3, 0.9%), nonunion (n = 1, 0.3%), wound dehiscence (n = 2, 0.6%), extensor hallucis longus (EHL) rupture (n = 1, 0.3%), deep-vein thrombosis (DVT)/pulmonary embolism (n = 1, 0.3%), and second metatarsal stress fracture (n = 1, 0.3%).

Table 3.

Foot Function Index Scores.

Statistic	FFI
Average	10
Median	4.1
Minimum	0
Maximum	79

Abbreviation: FFI, Foot Function Index.

Table 4.

Complications.

Complication	Total
Superficial wound infection	16
Removal of hardware	15
Malunion	8
Nonunion	1
Superficial wound dehiscence	2
EHL rupture	1
DVT/PE	1
Metatarsal stress fracture	1

Abbreviations: DVT, deep-vein thrombosis; PE, pulmonary embolism.

Discussion

Several previous studies have reported on outcomes of Ludloff osteotomies with varying postoperative protocols. However, none of these studies specifically evaluated an immediate weight-bearing protocol in osteotomies fixed with an anatomical locking plate.

Our study, which is to date the only series of its kind, demonstrates that anatomical locking plate fixation of the Ludloff osteotomy with an immediate weight-bearing postoperative protocol results in good long-term pain and function outcome scores, a low rate of symptomatic malunion (2.5%), a low rate of superficial infection (4.9%), and a relatively low rate of hardware removal (4.6%). Radiographically, excellent rates of deformity correction and maintenance of that correction were achieved with a relatively low rate of hypertrophic callus formation. Hypertrophic callus formation suggests that there was some motion at the osteotomy site during the postoperative course. Despite this obvious motion, the locking plate construct held the alignment until union was achieved without catastrophic loss of correction. This series represents a real-world population including patients with multiple concomitant procedures, making the study population reliable and realistic. Outcomes were excellent despite the numerous secondary procedures performed, which one might imagine would only slow progress down. Additionally, it was the authors' experience that the anatomical-shaped locking plate served as a valuable template for positioning of the first metatarsal osteotomy. This was especially true in cases when the bone was osteopenic and cracked during manipulation and correction of the deformity. Because osteopenia was not a factor in success or failure in this series, its presence was not recorded.

Several recent studies have evaluated outcomes following Ludloff osteotomies. Their heterogeneity highlights a widespread disagreement on both fixation methods and postoperative protocols. Some maintain non–weight bearing status for prolonged periods, whereas others allow faster, if not immediate, weight bearing.

In 2013, Saxena and St Louis evaluated the 119 Ludloff osteotomies in 112 patients. The osteotomies were stabilized with either lag screws or a locking plate. They assessed pain and function using the American Orthopaedic Foot and Ankle Society (AOFAS) score and Roles and Maudsley scores preoperatively and postoperatively. All patients were kept non–weight bearing in a below-the-knee cast for 3 weeks postoperatively. They found no significant differences between the groups with regard to age, preoperative and postoperative AOFAS scores, and preoperative Roles and Maudsley scores. The postoperative Roles and Maudsley score for the lag screw group was 1.8 ± 0.6 and 2.2 ± 0.7 for the locking plate group ($P < .009$). The AOFAS scores improved for both groups postoperatively. A statistically insignificant difference in rates of recurrent hallux valgus was found between the screw and locking plate fixation groups: 4.2% in the screw group and 0.8% in the locking plate group ($P = .57$). Of note, all cases of recurrent hallux valgus occurred in women older than 48 years. There was 1 case of dorsal malunion in the lag screw group (1.1%); 18% of patients required plate removal. All their "athletic" patients returned to their desired sports, whereas 94% of their "active" patients maintained their desired level of activity. They conclude that locking plate fixation of Ludloff osteotomies is superior in the athletic and active populations when compared with lag screw fixation.[9]

More conservative postoperative protocols such as these produce good results in terms of pain and function. However, return to activities of daily living and work may be delayed when compared with more aggressive protocols. Recently, faster advancement of weight bearing has become apparent in the literature. In 2008, Trnka et al[10] published their intermediate-term results following Ludloff osteotomy fixed with 2 lag screws in 111 feet. They found that the osteotomy produced a correction of the hallux valgus deformity, reduced pain in the forefoot, and improved patient function with greater improvement in patients under 60 years old. Their postoperative protocol included applying ice to the foot to reduce swelling immediately after surgery. With sufficient bone quality and fixation, the patient walked in a postsurgical forefoot offloading type shoe beginning immediately postoperatively for 6 weeks. Those in whom fixation was questionable were placed in a cast. Weekly dressing changes and bunion strapping were used for this time period. Radiographs were taken during the operation and again at 6 weeks, and with radiographic evidence of union the patient was allowed to use a stiff-soled dress shoe and to begin to full weight bearing for 6 weeks. Unrestricted full weight bearing was usually allowed after this. Sports activity was allowed after 10 to 12 weeks. If there was questionable fixation, a fracture boot or short leg walking cast was utilized for 6 weeks after surgery. Overall, their patients' AOFAS scores improved from an average of 53 to 88 points ($P < .0001$), a result that was particularly significant in patients older than 60 years. Radiographic recurrence occurred in 4.5%, hallux varus in 8%, prominent hardware in 4.5%, and superficial infection in 2.7%.[10]

In 2009, Robinson et al[11] prospectively compared the Scarf and Ludloff osteotomies for correction of moderate to severe metatarsus primus varus. They fixed their Ludloff osteotomies with 2 lag screws. Postoperatively patients were allowed full heel weight bearing in a heel wedge shoe for 6 weeks. They were advanced at that point based on clinical and radiographic data. With 57 patients in each group, they found no statistically significant difference between the groups in terms of subjective satisfaction, AOFAS score, improvement in functional activities, and range of motion. With the Scarf osteotomy, there was significant improvement in pain at 12 months ($P < .05$). There were 3 cases of delayed union (5.3%) in the Ludloff group, 2 of which resulted in dorsiflexion malunion (3.5%). No delayed union, malunion, or nonunions were observed in the Scarf group. In summary, they found the Scarf osteotomy to have a better outcome at 6 and 12 months, likely as a result of the greater bony stability imparted by the Scarf osteotomy as compared with the Ludloff. The average patient age was 54.3 years, and the study was predominantly composed of female patients (83 female, 4 male), a similar demographic to our study.[11] We experienced no dorsal malunions and a 0.3% nonunion rate, perhaps because of the increased stability provided by the locking plate as compared with compression screws.

The biomechanical literature supports the notion that locking plates provide more stability than screws alone. Tsilikas et al[12] compared screw fixation and screw fixation with a medially positioned locking plate augmentation in bone substitute models. The models were loaded to failure. There was an insignificantly increased average stiffness in the locking plate group (172.7 vs

193.3 N, $P = .21$). The average load to failure in newtons (kg.m/sec^2) was significantly higher in the locking plate group (278.4 vs 356.2, $P = .025$), as was the mean average energy absorbed before failure (506.7 vs 769.8 N mm, $P = .05$). Although not stiffer, the group augmented with a locking plate required significantly more energy to fail than did the group fixed with screws alone.[12]

There are several potential complications of the Ludloff osteotomy, including loss of fixation, malunion, and nonunion. Noncompliance with postoperative weight-bearing restriction on an unstable osteotomy has been implicated as the leading cause of these complications, especially dorsal angulation of the first metatarsal with subsequent transfer metatarsalgia.[13] The effect of osteopenic bone is not to be dismissed: Hofstaetter et al[14] conducted a biomechanical evaluation of the Ludloff osteotomy and found that there was a significant positive correlation between bone mineral density and osteotomy stiffness when undergoing repetitive plantar-to-dorsal bending loads. We believe that anatomical locking plates provide more durable fixation, especially in patients with osteopenic bone. This is supported by our relatively low rate of nonunion and the fact that we experienced no dorsal malunions. Although we did not specifically analyze our cohort to determine a specific rate of osteopenia or osteoporosis, the theoretical benefits of locking plate fixation apply in this scenario. Many of our patients are elderly, with osteopenic bone, and their surgeries were handled the same as nonosteopenic bone. Locking plate fixation carries with it many potential benefits, including but not limited to earlier normalization of gait, earlier return to work and daily activities, reduced DVT rate, and reduced operative extremity atrophy.

The present study has several strengths, including a large patient cohort (288 patients, 326 feet), an independent radiographic observer, and data gleaned from procedures conducted by 3 surgeons. The fact that 3 surgeons contributed to the data makes the results more generalizable. To date, this is the largest series of its kind.

Limitations include the retrospective nature of the study. Additionally, although all patients were permitted to bear weight as tolerated postoperatively, not all patients are equally aggressive in bearing weight. They were not restricted beyond being advised to minimize ambulation for soft-tissue protection, and activity cannot be standardized. Nevertheless, we believe that it is representative of the population at large. Finally, there was a relatively low response rate to the FFI, likely in large part as a result of the length of time that elapsed between the index procedure and the administration of the survey in a large portion of our study population. Another limitation is the additional concomitant procedures performed—an issue difficult to resolve when studying bunion surgery of any kind but that, nonetheless, may affect weight bearing. Alternatively, the resolution of concomitant foot pathology via those concomitant procedures may account for a portion of the patients' improvement, which would also be exposed by the FFI. Thus, we cannot say with certainty that the FFI scores reflect a clinical improvement solely as a result of the Ludloff osteotomy. Although our patients were allowed early weight bearing, which may allow earlier return to activities of daily living, we cannot draw any conclusions therein based on our analysis. Finally, the initial postoperative radiographs were non–weight-bearing views because of the aforementioned clinic protocol. This, we believe, is compensated for by 2 subsequent consecutive weight-bearing radiographs.

In conclusion, we believe that our data support the use of an immediate weight-bearing protocol for Ludloff osteotomies fixed with anatomical locking plates. Patients and surgeons can expect healing and complication rates similar to osteotomies fixed with screws and a non–weight-bearing postoperative protocol. Furthermore, because of the increased stability imparted by the anatomical locking plate, the authors feel that it would be a good option for osteopenic bone and revision bunion surgery. Further study is needed to prove that this protocol would make a functional difference in time to return to work or activities of daily living.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Steven K Neufeld, MD has a consulting/royalty agreement with Merete, the manufacturer of the plate used in this study.

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Ethical Approval

Not applicable, because this article does not contain any studies with human or animal subjects.

Informed Consent

Not applicable, because this article does not contain any studies with human or animal subjects.

Trial Registration

Not applicable, because this article does not contain any clinical trials. FAS

References

1. Bae SY, Schon LC. Surgical strategies: Ludloff first metatarsal osteotomy. *Foot Ankle Int*. 2007;28:137-144.
2. Castaneda DA, Myerson MS, Neufeld SK. The Ludloff osteotomy: a review of current concepts. *Int Orthop*. 2013;37:1661-1668.
3. Easley ME, Kiebazak GM, Davis WH, Anderson RB. Prospective, randomized comparison of proximal chevron osteotomies for correction of hallux valgus deformity. *Foot Ankle Int*. 1996;17:307-316.
4. Mann RA, Rudicel S, Graves SC. Repair of hallux valgus with a distal soft-tissue procedure and proximal metatarsal

osteotomy: a long-term follow-up. *J Bone Joint Surg Am*. 1992;74:124-129.

5. Zettl R, Trnka HJ, Easley M, Salzer M, Ritschl P. Moderate to severe hallux valgus deformity: correction with proximal crescentic osteotomy and distal soft-tissue release. *Arch Orthop Trauma Surg*. 2000;120:397-402.
6. Acevedo JI, Sammarco VJ, Boucher HR, Parks BG, Schon LC, Myerson MS. Mechanical comparison of cyclic loading in five different first metatarsal shaft osteotomies. *Foot Ankle Int*. 2002;23:711-716.
7. Pearson SW, Kitaoka HB, Cracchiolo A, Leventen EO. Results and complications following a proximal curved osteotomy of the hallux metatarsal. *Contemp Orthop*. 1991;23:127-132.
8. Budiman-Mak E, Conrad KJ, Roach KE. The Foot Function Index: a measure of foot pain and disability. *J Clin Epidemiol*. 1991;44:561-570.
9. Saxena A, St Louis M. Medial locking plate versus screw fixation for fixation of the Ludloff osteotomy. *J Foot Ankle Surg*. 2013;52:153-157.
10. Trnka HJ, Hofstaetter SG, Hofstaetter JG, Gruber F, Adams S, Easley ME. Intermediate-term results of the Ludloff osteotomy in one hundred and eleven feet. *J Bone Joint Surg Am*. 2008;90:531-539.
11. Robinson A, 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;30:955-963.
12. Tsilikas SP, Stamatis ED, Kourkoulis SK, Mitousoudis AS, Chatzistergos PE, Papagelopolous PJ. Mechanical comparison of two types of fixation for Ludloff oblique first metatarsal osteotomy. *J Foot Ankle Surg*. 2011;50:699-702.
13. Hofstaetter SG, Glisson RR, Alitz CJ, Trnka HJ, Easley ME. Biomechanical comparison of screws and plates for hallux valgus opening-wedge and Ludloff osteotomies. *Clin Biomech (Bristol, Avon)*. 2008;23:101-108.
14. Hofstaetter SG, Riedl M, Glisson RR, Trieb K, Easley M. The influence of patient age and bone mineral density on osteotomy fixation after hallux valgus surgery: a biomechanical study. *Clin Biomech (Bristol, Avon)*. 2016;32:255-260. doi:10.1016/j.clinbiomech.2015.11.002