The Ludloff osteotomy: a review of current concepts

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Abstract The Ludloff osteotomy is a technique option to address hallux valgus in patients with a moderately to significantly increased first-second intermetatarsal angle. The Ludloff osteotomy is an oblique osteotomy of the first metatarsal extending dorsal-proximal to plantar-distal when viewed in the sagittal plane. The dorsal-proximal portion of the metatarsal is cut with the saw while maintaining the plantar-distal surface intact. A screw is inserted across the proximal aspect of the osteotomy, then the osteotomy is extended across the plantar surface distally. The metatarsal is rotated around the axis of the screw to the desired correction. In order to perform the osteotomy correctly, the surgeon must not only effectively complete the nuances of the technique, but also understand the limitations and contraindications of the Ludloff osteotomy. This review of current concepts for the Ludloff osteotomy reviews recent literature as well as technique pearls and pitfalls in the application of this powerful osteotomy.

Keywords Ludloff osteotomy · Hallux valgus · Current concepts review

Introduction

Hallux valgus is varus angulation of the first metatarsal with lateral displacement of the sesamoids and extensor tendons resulting in lateral rotation of the metatarsal head and pronation of the hallux. The Ludloff osteotomy is a surgical option for treating a moderate to severe hallux valgus deformity. The Ludloff osteotomy is an oblique osteotomy of the first metatarsal in the transverse plane extending dorsal-proximal to

plantar-distal when viewed in the sagittal plane. It is particularly useful for correcting large intermetatarsal angles. As originally described in 1918, the osteotomy was performed without any fixation. In the mid-1990s, Myerson et al. re-introduced the procedure, focusing on a technique which stabilizes the osteotomy during the rotation to prevent any loss of correction during fixation [1]. This modification has persisted and is currently the method that is used worldwide for performing the osteotomy. In this technique, the dorsal and proximal metatarsal is cut but only two thirds of the distance toward the plantar surface, and a screw is inserted in the proximal metatarsal to fix the partially cut metatarsal. In this manner, control of the metatarsal is not lost, and fixation is stable. Once the first, proximal screw has been inserted, the osteotomy is completed distally on the remaining plantar surface. The metatarsal is then rotated around the axis of the screw until the desired position of the metatarsal is obtained. Correction of the metatarsal is performed around the axis of the proximal screw, and correction is not lost during fixation.

Contraindications

Contraindications for a modified Ludloff include first metatarsocuneiform joint instability, symptomatic first metatarsophalangeal arthritis, severe osteopenia, and an abnormal distal metatarsal articulation angle. Metatarsocuneiform instability is not addressed by this osteotomy and will persist if not addressed in the reconstruction. In such scenarios, arthrodesis at the metatarsocuneiform joint will both treat the instability and can correct the varus angulation of the first metatarsal. If a patient has both first metatarsophalangeal arthritis and hallux valgus deformity, addressing the arthritis is the priority as compared to treating the valgus deformity alone. If the severity of the degenerative changes at the joint is sufficiently symptomatic in a moderate to severe deformity, arthrodesis at the metatarsophalangeal joint is the treatment of choice. Much of the success of the

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Ludloff technique is intimately linked to secure internal fixation. By definition, solid fixation is challenging to establish in an osteopenic patient and therefore this procedure should be avoided in such patients. The Ludloff osteotomy is a rotational osteotomy and therefore does not address an abnormal distal metatarsal articulation angle. Other procedures, such as a Scarf or Chevron osteotomy, better address both deformities.

Reliability

The Ludloff osteotomy is a reliable method to address a moderate to severe hallux valgus deformity caused by an increased first intermetatarsal angle. Chiodo et al. reviewed the clinical results of seventy Ludloff osteotomies, noting a mean improvement in the first intermetatarsal angle from 31 degrees to 11 degrees [2]. In addition to the radiographic improvement, the mean American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score improved from 54 to 91 in these patients.

Numerous osteotomy choices exist for the first metatarsal to address hallux valgus. Examples include a proximal chevron osteotomy, a scarf osteotomy, opening wedge osteotomy and others. Researchers continue to study the advantages and disadvantages, both biomechanically and clinically, of the different options [1–16].

Despite the popularity of the modified Ludloff osteotomy, there are studies that suggest a Ludloff osteotomy stabilised with two screws has inferior biomechanics compared to other techniques. Unal et al. compared a Ludloff osteotomy with a Mau osteotomy, scarf osteotomy, offset V osteotomy and modified Mau osteotomy using a Sawbones model [3]. They found that the Ludloff osteotomy stabilised with two compression screws was a less stiff construction.

Recent studies

Many clinical series have evaluated the Ludloff osteotomy

Choi et al. in 2009 published a clinical comparison between proximal chevron and Ludloff osteotomies in the treatment of hallux valgus deformities. Patients were evaluated by preoperative and postoperative weight bearing radiographs and the AOFAS hallux metatarsophalangeal score. Both groups had similarly high AOFAS scores and good correction by radiographic parameters. No statistically significant differences were found with respect to correction of hallux valgus angle (HVA) and intermetatarsal angle (IMA) between the two groups. Of note, radiographic measurements demonstrated significant first metatarsal shortening of approximately 2.6 mm (4 % of preoperative length) with the Ludloff osteotomies ($p < 0.05$), indicating that this procedure may not be best for patients with a short metatarsal or metatarsalgia [4].

Robinson et al. in 2009 compared Scarf and Ludloff osteotomies in a prospective cohort of 57 patients. Overall,

patients who underwent a Scarf osteotomy had a superior outcome at both six and 12 months as compared to the Ludloff patients with regard to clinical outcomes (subjective satisfaction, AOFAS score, improvement in functional activities and motion) and radiological outcomes (intermetatarsal angle, hallux valgus angle, distal metatarsal articular angle and sesamoid position). Interestingly, there were three cases of delayed union in the Ludloff group, two of which resulted in dorsiflexion malunion [5]. Trnka et al. published a large series in 2008 evaluating the intermediate term outcome of the modified Ludloff osteotomy. They found, in a review of 99 patients (111 feet), that the procedure (in combination with a distal soft-tissue procedure) achieves significant correction of moderate-to-severe hallux valgus deformity, significant reduction in forefoot pain and significant improvement in functional outcome. In comparison to Robinson's study, all osteotomy sites united without dorsiflexion malunion [6].

Although not a clinical series, Scott et al. compared the mechanical properties of a proximal chevron osteotomy fixed with a medial locking plate and a Ludloff osteotomy fixed with two screws in a cadaveric model. The authors found that using a plantar-to-dorsal cantilever bending model, two of ten Ludloff osteotomies stabilised with two screws failed prior to the 1000th loading cycle by fracture at the distal screw site, whereas six of ten proximal chevrons failed. In addition, the bending stiffness of the Ludloff osteotomy exceeded that of the proximal chevron at all measurement points between the first and 200th load cycle ($p < 0.05$) [7].

When evaluating different osteotomies to correct an increased first intermetatarsal angle, it is important to consider the specifics of each technique. Addressing the importance of the geometric parameters of the bone cuts while performing a Ludloff osteotomy, Beischer et al. studied the spatial geometry using three-dimensional computer modelling software and determined that in order to limit first metatarsal shortening, elevation, and sagittal plane rotational mal-alignment, the optimal Ludloff osteotomy starts at the dorsum of the first metatarsal base at the first tarsometatarsal joint and extends distally and plantarwards to a point just proximal to the sesamoid articulation. In addition, a tilt of 10° in the coronal plane of the osteotomy is necessary to limit first metatarsal head elevation and the best axis of rotation is within five millimetres of the proximal end of the osteotomy [8].

Depending on the quality of bone and stability of the osteotomy, many surgeons allow their patients to begin heel-weight bearing as tolerated immediately after surgery. Traditionally, between four and six weeks after surgery, the osteotomy is healed and patients may progress to full weight bearing in a firm, flat accommodating shoe.

Despite the overall success of Ludloff osteotomies, there are potential complications including loss of fixation, malunion and nonunion, among others. Loss of reduction of proximal metatarsal osteotomies may result from poor bone

quality, suboptimal fixation, and limitations inherent in the bony geometry of the osteotomy. Fracture of the dorsal fragment is possible in osteopenic bone or if the proximal screw is inserted too close to the proximal end of the dorsal fragment. Additionally, failing to countersink the screw head may also increase fracture risk. Dorsal malunion may result if while making the osteotomy, the saw blade is angled upward relative to the sagittal plane of the metatarsal. This will force the metatarsal head into an elevated and pronated position. Persistent pronation of the hallux increases the risk of recurrent deformity. An excessively shortened or elevated first metatarsal also increases the risk of transfer metatarsalgia.

Hallux varus may develop if the intermetatarsal angle is overcorrected, the medial capsule is overpllicated or the medial eminence is excessively resected. If clinically symptomatic, soft tissue balancing including transfer of the extensor hallucis brevis is a viable option to address the complication. As with any surgery, infection as and/or symptomatic hardware may require subsequent surgery. Transient neuritis of the medial cutaneous branch of the superficial peroneal nerve has been reported and in the few with persistent symptoms, treatment may require neurectomy and nerve transposition.

Although some of the complications listed may be the result of technical error, post-operative non-compliance with weight-bearing restrictions may be an additional factor. Advances in fixation, including the use of locking plates to improve stability, have been developed in an attempt to decrease the incidence of loss of fixation and malunion. Additionally, more stable hardware will allow patients to resume normal patterns of gait more quickly.

Tsilikas et al. in 2011 performed a cadaver study comparing the load to failure, stiffness and absorbed energy to failure of fixation with two screws alone versus two screws augmented with a mini locking plate. Both the load to failure and absorbed energy to failure improved with the addition of the plate. The improvements were statistically significant [9].

Stamatis performed a cadaveric study in order to find an alternative method of fixation in cases where a short osteotomy occurs and in cases where subsequent screw fixation is precarious due to inadequate bone stock. They found that a threaded pin provided adequate strength for fixation [10]. Schon et al. described the use of Kirschner wires to supplement fixation in poor quality bone without good fixation after a second screw. Recommendations included using one or two 0.062-inch or 0.045-inch Kirschner wires inserted from the proximal medial aspect of the first metatarsal down the shaft of the distal segment engaging the distal cortex. The wires are then bent, cut, and tamped against the bone. If fixation is a persistent concern, two or three additional Kirschner wires can be inserted from the distal medial aspect of the first metatarsal head into the second metatarsal head

Fig. 1 A low-profile locking plate/screw, designed for fixation of the Ludloff osteotomy

[11]. A follow-up cadaveric study confirmed the biomechanical validity of the described technique [12].

Hofstaetter et al. in a cadaver study examined the mechanical properties of corrective opening-wedge osteotomies and Ludloff oblique osteotomies under simulated weight bearing. Their results indicate that screw type for Ludloff fixation may be left to surgeon preference and that opening-wedge plate osteotomies stabilised with plates are mechanically inferior to the Ludloff osteotomy stabilised with two headless screws [13].

Recently, a specific Ludloff osteotomy locking plate has been developed on the hypothesis that a locked plate with compression screws will better stabilise a first metatarsal osteotomy allowing for safe and early weightbearing. Neufeld et al. performed Ludloff osteotomies in 89 patients, stabilising the osteotomies with their low-profile locking plate/screw (Figs. 1 and 2). Patients were allowed immediate full weight bearing in a post-op shoe. Average hallux valgus and intermetatarsal angles of 27.58° and 14.35° respectively corrected to 6.12° and 5.95° at final follow-up (Fig. 3). At their six-week follow-up they were allowed to return to activities as tolerated. None of the cases resulted in hardware failure, nonunion, delayed union or lesser metatarsal transfer lesions [14].

Fig. 2 Demonstration of the low-profile locking plate on a cadaver model

Fig. 3 Radiographs and photographs, respectively, prior to surgery (a, b) and after osteotomy (c, d) with fixation using a locking plate

Studies have documented well the efficacy of the Ludloff osteotomy in addressing moderate to severe hallux valgus deformities in patients without instability of the first metatarsocuneiform joint or deformity of the metatarsophalangeal articulation. Nonetheless, continued exploration of the biomechanics surrounding such a correction and ingenuity with regard to fixation methods will only serve to benefit patients in the future.

Advantages and technique tips

The major advantage of the Ludloff osteotomy is that control of the metatarsal position is maintained throughout the procedure.

Place Hohmann retractors dorsal-proximally and plantar-distally to the metatarsal prior to creating the osteotomy. The plantar-distal Hohmann retractor protects the plantar artery to the metatarsal head, and the dorsal-proximal retractor protects the extensor hallucis longus tendon and the interosseous branch of the dorsalis pedis artery.

The initial metatarsal osteotomy cut should extend only two-thirds the length of the metatarsal, maintaining the distal plantar cortex intact. Once the proximal screw is placed across the osteotomy, the distal bone cut is completed.

Rotation of the metatarsal osteotomy occurs around a single axis point established by the more proximal screw. The further proximal the osteotomy is performed or the closer the axis of rotation is to the tarsometatarsal joint, the less the angular correction is distally.

Fig. 4 a Radiographs, three views of the left foot, demonstrate moderate hallux valgus deformity with a hallux valgus angle of 26degrees, and first-second intermetatarsal angle of 17degrees. b Postoperative radiographs demonstrate fixation using two 3.5mm cortical screws to compress the osteotomy. A dorsal-to-plantar directed screw was first inserted in standard lag fashion. The screw was slightly loosened, the distal, plantar limb saw cut was complete and a second screw placed from plantar to dorsal. Finally, a 2.7mm neutralisation screw was placed obliquely across the osteotomy. Both the hallux valgus and first-second intermetatarsal angles improved to neutral alignment.

The axis of rotation of the metatarsal must be as proximal as possible to facilitate correction. If the screw is inserted too far distally, the corrected metatarsal will have a banana shape, and although the alignment of the hallux with the centre of the metatarsal head may be adequate, the result may be an incongruent centre of rotation, with subsequent development of arthritis.

The angle of the saw blade to the sagittal plane of the metatarsal affects the degree of shortening and ultimate rotation. A perpendicular saw blade creates the greatest varus

correction. If the handle of the saw is raised, the first metatarsal head will be depressed, and the metatarsal head will rotate into slight supination, which is desirable. The converse applies with a plane of the osteotomy in which the handle of the saw is dropped down, whereupon the metatarsal head will tilt up. The result may be a dorsal malunion with pronation of the metatarsal head, associated with an increased likelihood of recurrent hallux valgus.

The angle of the osteotomy must be as oblique as possible taking care not to violate the sesamoid apparatus distally

Fig. 5 The patient underwent staged procedures on both feet to address her symptomatic hallux valgus deformity. In each foot, two FRS cannulated compression screws were used for fixation. In order to better stabilise the left, a K-wire was used to supplement. (**a** and **b**, radiographs of the right foot pre- and post-operative, respectively; **c** and **d**, radiographs of the left foot pre- and post-operatively, respectively.)

Fig. 6 During placement of the proximal 3.0mm FRS screw across the osteotomy site, a fracture was noted. The screw was removed, the fracture reduced and held in position with a pointed reduction clamp. Provisional K-wires were used to maintain the reduction followed by placement of an FRS screw again across the osteotomy. An F3 Fragment plate was applied to the medial aspect of the metatarsal. (a, pre-operative foot radiograph series; b, post-operative radiographs)

and the tarsometatarsal joint proximally. An angle that is too steep results in an irregular correction, associated with an increased incidence of delayed union.

Consider countersinking the proximal screw to reduce its prominence and minimise the risk of dorsal metatarsal cortical fracture.

The second, more distal screw is inserted plantar to dorsal, and perpendicular to the osteotomy.

Discrepancy in philosophy exists among surgeons regarding screw placement technique across the osteotomy. Some use a compression/lag technique. Others use fully-threaded cortical screws, noting that lag technique is not possible because screw placement perpendicular to the osteotomy is not possible with the Ludloff technique. With advancement of a fully threaded screw, compression is held at the osteotomy site with a towel clamp.

Fig. 7 Two FRS headless screws were applied in standard fashion across the osteotomy site. Due to generalised osteopenia and lack of strong fixation with the screws as assessed intraoperatively, a decision was made to include an L-shaped FRS plate with combination of locking and non-locking screws (a- pre-operative radiographs; b- postoperative radiographs)

If fixation with screws alone is poor, consider using one or two 0.062-inch or 0.045-inch Kirschner wires inserted from the proximal medial aspect of the first metatarsal down the shaft of the distal segment, ideally engaging the distal cortex. If fixation concerns persist, two or three Kirschner wires may be inserted from the distal medial aspect of the first metatarsal head into the second metatarsal head.

Medial eminence exostectomy is performed after the osteotomy has been rotated, in-line with the metatarsal shaft.

Intraoperative deformity between the first and second metatarsals may persist after the osteotomy is performed. This is an indication of unrecognised instability of the tarsometatarsal joint, in which this instability may be in the transverse rather than sagittal plane. The tarsometatarsal joint cannot be stabilised with arthrodesis at this late stage. The treatment options are as follows: [1] insert sutures between the first and second metatarsals distally; [2] insert a transverse screw between the first and second metatarsals proximally. The second technique places the second metatarsal at increased risk for stress fracture. Postoperative strapping of the foot at weekly intervals is important to stabilise the overall alignment of the first and second metatarsals.

Lengthen a contracted extensor hallucis longus tendon.

If the ability of screws to maintain the stability of the osteotomy is of concern, then the screws should be supplemented by K-wires or a plate.

If periosteal bone formation is present at the osteotomy site in early postoperative radiographs, it is an indicator that the osteotomy site is loose, and although union of the osteotomy will occur, slight elevation and dorsal malunion also may occur simultaneously. If periosteal bone formation is noted, weight bearing should be controlled in a boot, and the foot carefully strapped.

Postoperatively, with screw fixation, patients may heel weight-bear immediately for four to six weeks, until evidence of bone healing is appreciated on radiographs. Progressive weightbearing as tolerated on the medial foot is allowed between six and 12 weeks.

If fixation is less than optimal and there are concerns that clear evidence of bone healing are lacking, extend and enhance postoperative immobilisation and delay weight-bearing.

Strapping the forefoot and midfoot to enhance the position of the reconstruction can be beneficial up to six weeks postoperatively.

Conclusion

The Ludloff osteotomy is a powerful tool to correct a wide first–second intermetatarsal angle. As with any osteotomy directed at correcting hallux valgus, execution

of proper technique is critical to the success of the procedure. In addition, patient selection is paramount. The modified Ludloff is contraindicated in patients with first metatarsocuneiform joint instability, symptomatic first metatarsophalangeal arthritis, severe osteopenia, and an abnormal distal metatarsal articulation angle. Studies continue to support the effectiveness of the Ludloff osteotomy. In addition, development of fixation techniques that optimise patient outcome and reduce recovery time remain of interest to surgeons and researchers (Figs. 4, 5, 6, 7).

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