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The Ludloff Metatarsal Osteotomy: Guidelines for Optimal Correction Based on a Geometric Analysis Conducted on a Sawbone Model

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ABSTRACT

Ideally, osteotomy for hallux valgus deformities corrects varus angle and pronation, while minimizing elevation, depression, and shortening. We used a serial linkage tracking device to evaluate five variations of the Ludloff osteotomy, a stable proximal metatarsal osteotomy that incorporates an oblique dorsal to plantar cut and a lateral swing or pivoting correction of the dorsal fragment. A neutral osteotomy (perpendicular to the sagittal plane) yielded the greatest correction (14°) but with shortening (average, 2.85 mm), elevation (average, 1.36 mm), and additional pronation (average, 1.88°). The same osteotomy angled 10° plantarly with 8° of correction produced an average of 1.57° of supination, 1.22 mm of depression and, 0.54 mm of shortening. Additional plantar inclination (20°) and angular correction (16°) yielded increased depression, supination, and shortening. The current findings provide guidelines to achieve the desired correction and rotation and suggest that optimal results can be obtained by performing this osteotomy angled 10° plantarly with a correction of 8° to 16°.

Key Words: First Metatarsal; Ludloff; Osteotomy; Hallux valgus

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INTRODUCTION

Hallux valgus deformity is the varus angulation of the first metatarsal with lateral displacement of the sesamoids and the extensor tendons leading to lateral rotation of the metatarsal head and pronation of the hallux. More than 130 surgical procedures have been described to treat this deformity, particularly soft-tissue release and bony correction of the deformity using proximal or distal osteotomies.[15] The ideal osteotomy would accomplish both objectives of correcting the varus angle and correcting the pronation without causing any elevation, depression, or shortening of the first metatarsal.

Although metatarsal shaft osteotomies such as the Scarf, Mau, and Ludloff procedures[14,17,23,28] have received little attention in the literature, they are relatively simple to perform and yield good results. In the Ludloff osteotomy, an oblique cut is made beginning dorsally distal to the cuneiform-metatarsal joint and proceeding distally and plantarly, ending proximal to the sesamoid complex. At two-thirds completion of the cut, a cannulated screw is inserted dorsal to plantar perpendicular to the osteotomy without completing the osteotomy. The osteotomy is then completed distally, the distal fragment is rotated laterally to achieve correction, and a second cortical screw is placed distally across the osteotomy from plantar to dorsal. The proximal and distal screws are then tightened. The Ludloff osteotomy provides the necessary correction, is mechanically stable,[27] and is technically less demanding than other commonly used osteotomies such as the proximal chevron or crescentic.

The degree of correction achieved in patients undergoing first metatarsal osteotomies can be determined clinically, subjectively or objectively, using radiographic parameters or plantar foot pressure systems.[8,16,18,21,24] However, radiographic evaluations are subject to inherent large deviations and are therefore inaccurate, and foot pressure systems cannot provide information regarding positional changes such as elevation or shortening. Mathematical models provide an accurate

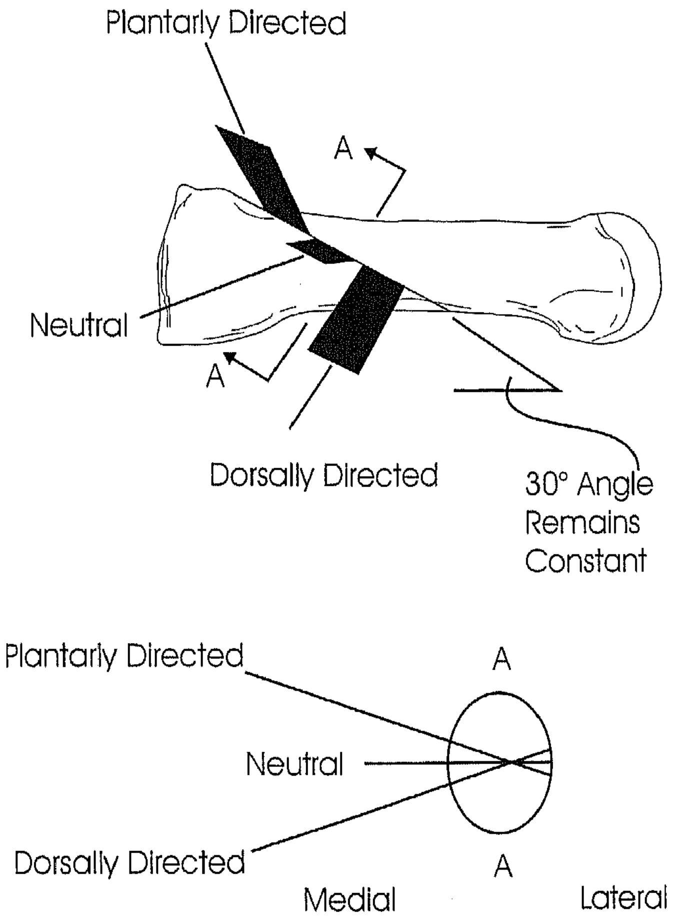

Fig. 1: Diagram showing direction of cuts in Ludloff osteotomy.

indication of the amount of correction achieved by different osteotomies,[9,10,19,22] but these studies do not consider important factors that play a role when the osteotomy is performed. Several factors involved in shortening (the width of the saw blade, displacement during the fixation method, or amount of rotation) can all have an effect on the final positioning of the osteotomy but are not included in a mathematical model. Biomechanical studies on different osteotomies usually were designed to evaluate the strength of the construct that holds the osteotomy in place and do not provide data regarding geometric changes after the osteotomy.[4,11-13,25] By comparison, a serial linkage digitizer can analyze geometric changes to an accuracy of 0.1 mm without the drawbacks of the other measurement methods.

We hypothesized that optimal geometric positioning of the osteotomy angle and the correction angle of the Ludloff osteotomy could be identified that would maximize correction while maintaining metatarsal length and avoiding excessive elevation. We used a serial linkage tracking device in sawbone models to compare the geometric changes in the metatarsal with the osteotomy angled 10° and 20° from neutral in the sagittal plane and with 8° or 16° of swing or rotation angle.

MATERIALS AND METHODS

We used sawbone models of the first metatarsal (Pacific Research Laboratories, Vashon, WA) whose dimensions were similar to the average adult bone in length (60 mm) and width (15 mm at the base and the flare of the neck).[9,10] Sawbones are synthetic anatomical specimens, consistent in size, material, and configuration. A rigid test frame provided a precise method of aiming and performing the planned osteotomy cuts. The test frame was a vertical milling machine that provided x, y, and z motion of the table on which the sawbone model was mounted. Each model had a cubical block on the proximal aspect, allowing it to be secured in a vise. The vise was mounted on a linear slide secured to the table of the test frame. Above the table, a sagittal saw was rigidly mounted to the upper arm of the milling machine, allowing it to move up and down in the z direction. The head of the milling machine could also be tilted to achieve the desired neutral, dorsally directed, and plantarly directed cuts. The sawbone models could then be positioned under the saw blade and moved in a straight line to produce accurate, reproducible cuts in any required plane. We measured the geometric changes that occurred after correcting hallux valgus deformities using different modes of the Ludloff osteotomy on the sawbone models.

A Microscribe 3D serial-linkage digitizer (Immersion Corp., San Jose, CA) was used to obtain the x, y, and z coordinates of selected points on the model. The digitizer had an accuracy of 0.1 mm. Three points on the proximal end of each sample provided a global reference frame. Three additional points over the center of the metatarsal head were used to calculate relative position changes before and after the osteotomies were performed. After securing the model in the vise, the digitizer was used to establish the global reference frame at the proximal end and obtain preoperative data. The osteotomy was then performed using a regular saw blade (Hall 5023-138 blade, 10.0 mm width, 0.4 mm thickness; Zimmer, Warsaw, IN) mounted on a regular mini Hall sagittal saw. The osteotomy started at the metatarsocuneiform line dorsally and finished 3 mm proximal to the sesamoids plantarly at a 30° angle.[23] Just before the osteotomy was completed, a proximal 3-mm cannulated screw (AO Synthes; Paoli, PA) was inserted from the dorsal cortex at 90° to the osteotomy plane and 5 mm distally from the starting point of the osteotomy. It is standard practice to place the screw before completing the rest of the osteotomy because no notable shortening results and it is critical to maintain the position of the segments during the completion of the cut. Upon completion of the osteotomy, a second screw was placed with a corrected position of 8° or 16°

to simulate correction for a moderate or a severe deformity, respectively, using a template to verify the correct angle. After the osteotomy was secured, a second set of data points was obtained. Data points for the reference frame were taken before and after the osteotomies in case the base moved during the procedure.

The osteotomy was performed at five different angles relative to the sagittal plane and measured in two corrected positions: at neutral (perpendicular to the sagittal plane) with 8° and 16° of correction, at 10° dorsally directed from neutral with 8° and 16° of correction, at 20° dorsally directed from neutral with 8° and 16° of correction, at 10° plantarly directed from neutral with 8° and 16° of correction, and at 20° plantarly directed from neutral with 8° and 16° of correction (Fig. 1). Five bones were used for each of the five different sagittal plane cuts (25 models total). For each sample we calculated change in elevation/depression of the metatarsal head, medial/lateral shift of the distal vs. the proximal segment, angular change in the transverse plane (medial/lateral), rotation of the metatarsal head in the coronal plane, and shortening/elongation of the metatarsal bone. Results were compared using a one-way analysis of variance (ANOVA) and a Student-Newman-Keuls post-hoc analysis if any observed differences were significant ($p \leq 0.05$).

RESULTS

The mean values were calculated for the different parameters measured (Table 1), and the differences were analyzed for statistical significance ($p \leq 0.05$) (Table 2).

Elevation

As expected, increasing the angle of correction along the dorsally directed plane of osteotomy caused higher elevation. Maximal elevation of 4.5 mm was found in the group with a 20° dorsally directed osteotomy and 16° of correction. This group was statistically different from all the rest of the groups. Again as expected, plantarly directed planes of osteotomy increased the angle of correction and led to more depression, which was quantified. The 3.5 mm depression in the group with a 20° plantarly directed osteotomy and 16° of correction was statistically different from all the rest of the groups.

Lateral Shift

The highest lateral shifts of 4.6 mm and 9.5 mm were obtained for the neutral 8° correction and neutral 16° correction groups, respectively. All of the 8°

Table 1: Geometric analysis of the different osteotomy planes in the Ludloff procedure

Cut/correction (°)	Elevation (mm)	Shortening (mm)	Shift (mm)	Rotation (degrees)	Angle (degrees)
Neutral 8	0.30	-1.41	4.57	1.18	6.3
Neutral 16	1.36	-2.85	9.54	1.88	14.7
10° dorsal 8	0.89	-0.92	4.01	1.64	1.1
10° dorsal 16	2.31	-1.72	7.24	2.69	5.9
20° dorsal 8	2.25	-1.31	3.39	4.49	0.9
20° dorsal 16	4.49	-2.35	6.63	6.57	6.1
10° plantar 8	-1.22	-0.54	3.84	-1.57	4.0
10° plantar 16	-1.79	-1.21	7.07	-3.78	6.9
20° plantar 8	-1.99	-0.64	4.34	-2.86	0.8
20° plantar 16	-3.50	-1.39	8.56	-6.08	6.7

Table 2: Significant differences in angle (A), elevation (E), lateral shift (L), rotation (R), and shortening (S) between the different osteotomy planes in the Ludloff procedure*

	20P16	20P8	10P16	10P8	08	10D8	016	20D8	10D16	20D16
20P16										
20P8	E,R,L									
10P16	E,R	A,L								
10P8	E,R,L		R,L							
08	E,R,L	E,R	E,R,L	E,R						
10D8	E,R,L	E,R	E,A,R,L	E,R						
016	E,A,R,S	E,A,R,L,S	E,A,R,S	E,A,R,L,S	A,I,S	A,I,S				
20D8	E,R,L	E,R	E,A,R,L	E,R	E,R	E,R	A,R,L,S			
10D16	E,R	E,R,L,S	E,R	E,R,L,S	E,L	E,L	A,S	R,L		
20D16	E,R,S	E,R,S	E,R,S	E,R,L,S	E,R,S	E,R,L,S	E,A,R,L	E,R,L,S	E,R	

P≤0.05.
*D, dorsal cut; P, plantar cut, 0, neutral cut (perpendicular to sagittal plane). Angle of cut precedes direction, and degrees of correction follow.

correction groups yielded approximately a 4 mm lateral shift. Although there was a trend for decreased lateral shift as the dorsal cut angle was increased, there were no statistically significant differences between the 8° correction groups. All 16° correction groups except the group with a 20° dorsal cut resulted in significantly greater lateral shift than in the 8° correction groups. The lateral shift in the group with a 20° dorsal cut with 16° of correction was significantly greater than in the groups with a 20° dorsal cut with 8° correction, a 10° plantar cut with 8° correction, and a 10° dorsal cut with 8° correction only.

Angle

Average correction values of 5° and 8° were obtained for the 8° and 16° correction groups, respectively. The neutral 16° correction group yielded a significantly higher angle of 14.7° compared with all the other groups. The 20° plantar cut 16° correction group had significantly higher correction (8.9°) than the rest of the 8° groups except for the 10° plantar 8° correction group. There was no statistical difference between the various 8° correction groups.

Rotation

As the angle of correction increased and the plane of the osteotomy was directed more dorsally, there was higher positive rotation (pronation), including in the neutral osteotomies. As the angle of the osteotomy was directed plantarly and the angle of correction was higher, the rotation of the head of the metatarsal was more negative (supination).

The neutral osteotomies and all dorsally directed osteotomies yielded significantly more pronation than the plantarly directed osteotomies, with the more dorsal angles resulting in greater pronation. The plantarly directed osteotomy groups all resulted in significantly more supination when compared with both the dorsally directed and the perpendicular osteotomy groups.

Shortening

There was a trend of less shortening in the plantarly directed osteotomies and more shortening in the dorsally directed osteotomies. The neutral 16° correction group and the the 20° dorsal cut 16° correction group both produced significantly more shortening than all other groups. The 10° dorsal cut 16° group yielded significantly more shortening than the 20° and 10° plantar cut 8° correction groups. No other differences between the groups were statistically significant.

DISCUSSION

Selection of the operative technique for correction of the bony deformities in hallux valgus patients is mainly based on the first to second intermetatarsal angle. Mild deformities from 12° to 15° can be corrected using distal osteotomies, moderate deformities of 16° to 20° can be corrected using proximal base osteotomies (proximal chevron, crescentic, and closing wedge osteotomy) and soft tissue procedures, and arthrodesis procedures have been advocated for severe deformities.[1] Studies have shown, however, that the base osteotomies may lead to substantial complications, including first metatarsal elevation, shortening, and altered forefoot loading that leads to transfer metatarsalgia.[26] Shortening of the metatarsal bone after the closing wedge base osteotomy has been evaluated in a sawbone model.[2] Although midshaft osteotomies such as the Scarf, Mau, and Ludloff procedures[14,17,23,28] have received little attention in the literature, they can be used to correct moderate deformities. The midshaft osteotomies may minimize the elevation and shortening found in metatarsal base osteotomies.

The most important parameter in the correction of hallux valgus deformities is reduction of the intermetatarsal angle by lateral shift of the first metatarsal. In our model, the greatest angular correction and the greatest lateral shift were obtained with the neutral osteotomy at 16° of correction. Dorsally and plantarly directed osteotomies both had significantly less angular correction than the neutral 16° correction group. The corrected angle of the neutral 16° correction group was also significantly greater than that of the neutral 8° correction group. With 8° of correction and neutral cut, there was a reduction in lateral shift, and the angular correction was smaller than that of all other groups, although the difference was significant only as compared with the neutral 16° group. Therefore, when using this osteotomy, the greatest angular correction is achieved in the neutral cut (perpendicular to the sagittal plane) with either 8° or 16° of correction, and a mild plantar cut of 10° is preferable to a dorsally directed osteotomy in terms of shortening. The higher the correction angle, the more shortening of the metatarsal occurs. Directing the plane of the osteotomy plantarly led to less shortening, whereas directing it dorsally led to more shortening. The combined results of shortening of all the plantarly-directed osteotomies were significantly ($p=0.003$) lower (0.94 mm) than the combined results of the dorsally directed osteotomies (1.54 mm).

Shuberth et al.[24] demonstrated an elevation of 6.67° of the metatarsal in a closing wedge osteotomy. Nyska et al.[18] noted central forefoot loading after a basilar osteotomy. Another study demonstrated a basilar crescentic osteotomy with a depression of 1.7° of the metatarsal to avoid transfer metatarsalgia, a common complication of this osteotomy.[16,26] In a biomechanical model, Lippert and McDermott[13] suggested rotating the saw laterally in a crescentic osteotomy to cause a slight declination of the toe. Although they showed that plantarly directed osteotomies caused a depression of the metatarsal head and that the dorsally directed osteotomy caused an elevation, they did not establish the exact relationship between those two parameters.

In the current study, we demonstrated that the 20° plantarly directed osteotomy with 8° of correction resulted in a 2 mm depression and that with 16° of correction, this osteotomy resulted in 3.5 mm of depression. Dreeban et al. showed that changes in depression of less than 4.5 mm were not likely to produce a transfer lesion,[6] but there are no data in the literature establishing the amount of depression of the metatarsal head needed to avoid central forefoot loading. However, our results for the 8° and 16° of correction may be used as predictors for postoperative depression of the metatarsal head.

One type of deformity in patients with hallux valgus is pronation of the hallux. It is secondary to lateral displacement of the sesamoids and the extensor tendons.[15] Supination of the head of the metatarsal during the osteotomy may realign the sesamoid. Although measuring the reduction of the sesamoid after hallux valgus surgery is a major radiologic parameter for success, there are no data determining how and to what extent to rotate the head of the metatarsal during fixation of an osteotomy.[1,16] Eustace et al.[7] described a method of detecting first metatarsal pronation based on the position of the inferior tuberosity of its base and showed a statistically significant relationship between first metatarsal pronation and the intermetatarsal angle. In that study, 9% of the patients with an intermetatarsal angle of less than 9° had pronation greater than 10°, and 84% of the patients with an intermetatarsal angle greater than 9° had pronation greater than 10°. In another study using a roentgen stereophotogrammetry technique, rotational correction after a basilar osteotomy could not be demonstrated.[20]

In the current study, we established a linear relationship between the direction of the osteotomy and the amount of rotation of the metatarsal head. For the 16° correction, the degrees of rotation = 0.32 x the degrees of the plantar/dorsal cut; and for the 8° correction, the degrees of rotation = 0.14 x the degrees of plantar/dorsal cut. For example, for a 20° plantarly angled cut with a 16° correction, the amount of rotation would be 6.4 degrees in supination. The plantarly directed osteotomy rotated the head into supination, leading to correction of the pronated toe. The magnitude of correction of the pronation is related to the extent of the angle to be corrected and the extent to which the osteotomy is plantarly directed. The calculated formula based on our data may predict the exact rotation of the head of the metatarsal to be expected. Kay et al.[9] demonstrated similar results in a mathematical model based on three-dimensional computerized tomographic images of a normal foot in a crescentic osteotomy. At a 15° corrective angle and at a 20° proximal-to-distal direction of the saw, the metatarsal head will supinate by 5.27°. Aiming the saw distal to proximal will pronate the head by 5.27°.

Although the Ludloff osteotomy was first described in 1918,[14] clinical experience with this osteotomy is limited. Ludloff originally used no fixation, leading to unpredictable results. Cisar et al.[5] revised 72 patients undergoing the Ludloff procedure and reported good results; those authors used screw fixation, but no radiologic data were presented in their study. Blatter and Magerl[3] noted a long healing time for this osteotomy. In a prospective series of 12 patients, Saxena and McCammon[23] demonstrated a reduction in the intermetatarsal angle of 6.5° and in the hallux valgus angle of 16.7°. They also noted a shortening of the metatarsal of 1.4 mm. Although they suggested plantarflexing the osteotomy and elongating it to avoid transfer lesions, no data regarding the amount of elevation were available in their study. Those authors also measured the tibial sesamoid position and found it to be reduced from 5.6 to 2.9 mm, but no further discussion concerning position was available.

CONCLUSIONS

The Ludloff procedure allows three-dimensional repositioning of the hallux. Based on our data, a dorsally directed osteotomy should not be used because it elevates the head of the metatarsal, rotates it into pronation, and produces shortening. A neutral (perpendicular to the sagittal plane) 30° proximal-dorsal to distal-plantar cut provides the maximum varus correction, but this cut also produces the greatest amount of shortening and results in additional head rotation (to pronation) and elevation. Greater plantar inclination and a higher correction of the angle leads to additional depression and supination of the head but may increase shortening.

These results provide guidelines for choosing the angle at which the Ludloff osteotomy is performed to meet specific needs of the patient, including the amount of elevation, the degree of rotation, the amount of shortening, and the restored hallux angle needed to correct the deformity. The current findings indicate that directing the osteotomy 10° plantarly with 8° of correction rotates the head of the metatarsal to supination, depresses it, and minimizes the amount of shortening.

REFERENCES

1. **Abidi, NA; Dhawan, S; Gruen, GS; Vogt, MT; Conti, SF**: Wound-healing risk factors after open reduction and internal fixation of calcaneal fractures. Foot Ankle Int, **19**:856-861, 1998.
2. **Banks, AS; Cargill II, RS; Carter, S; Ruch, JA**: Shortening of the first metatarsal following closing base wedge osteotomy. J Am Podiatr Med Assoc, **87**:199-208, 1997.
3. **Blatter, G; Magerl, F**: [Osteotomy of the first ray in the treatment of hallux valgus]. Ther Umsch, **48**:803-811, 1991.
4. **Campbell, JT; Schon, LC; Parks, BG; Wang, Y; Berger, BI**: Mechanical comparison of biplanar proximal closing wedge osteotomy with plantar plate fixation vs. crescentic osteotomy with screw fixation for the correction of metatarsus primus varus. Foot Ankle Int, **19**:293-299, 1998.
5. **Cisar, J; Holz, U; Jenninger, W; Uhlig, C**: [Ludloff's osteotomy in hallux valgus surgery]. Aktuelle Traumatol, **13**:247-249, 1983.
6. **Dreeben, SM; Noble, PC; Hammerman, S; Bishop, JO; Tullos, HS**: Metatarsal osteotomy for primary metatarsalgia: radiographic and pedobarographic study. Foot Ankle, **9**:214-218, 1989.
7. **Eustace, S; O'Byrne, J; Stack, J; Stephens, MM**: Radiographic features that enable assessment of first metatarsal rotation: the role of pronation in hallux valgus. Skeletal Radiol, **22**:153-156, 1993.
8. **Jahss, MH; Troy, AI; Kummer, F**: Roentgenographic and mathematical analysis of first metatarsal osteotomies for metatarsus primus varus: a comparative study. Foot Ankle, **5**:280-321, 1985.
9. **Kay, DB; Njus, G; Parrish, W; Theken, R**: Basilar crescentic osteotomy. A three-dimensional computer simulation. Orthop. Clin. North Am, **20**:571-582, 1989.
10. **Kempe, SA; Grapel, D; Hovanec, P**: A mathematical approach to closing base wedge osteotomy. J Am Podiatry Assoc; **74**:601-604, 1984.
11. **Landsman, AS; Vogler, HW**: An assessment of oblique base wedge osteotomy stability in the first metatarsal using different modes of internal fixation. J Foot Surg, **31**:211-218, 1992.
12. **Lian, GJ; Markolf, K; Cracchiolo III, A**: Strength of fixation constructs for basilar osteotomies of the first metatarsal. Foot Ankle, **13**:509-514, 1992.
13. **Lippert III, FG; McDermott, JE**: Crescentic osteotomy for hallux valgus: a biomechanical study of variables affecting the final position of the first metatarsal. Foot Ankle, **11**:204-207, 1991.
14. **Ludloff, K**: Die beseitigung des hallux valgus durch die schrage planta-dorsale osteotomie des metatarsus I. Arch Klin Chir, **110**:364-387, 1918.
15. **Mann, RA; Coughlin, MJ**: Adult hallux valgus. In Mann, R. A. and Coughlin, M. J (eds.), Surgery of the Foot and Ankle, Ed. 6. St. Louis, Mosby-Year Book Inc, 1993, pp. 167-296.
16. **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, **74A**:124-129, 1992.
17. **Mau, C; Lauber, HJ**: Die operative Behandlung des Hallux valgus (Nachuntersuchungen). Deutsche Zeit Orthop, **197**:361-377, 1926.
18. **Nyska, M; Liberson, C; McCabe, K; Linge, K; Klenerman, L**: Plantar foot pressure distribution in patients with hallux valgus treated by distal soft tissue procedure and proximal metatarsal osteotomy. Foot Ankle Surg; **4**:35-41, 1998.
19. **Palladino, SJ**: Orientation of the first metatarsal base wedge osteotomy: perpendicular to the metatarsal vs. weightbearing surface. J Foot Surg, **27**:294-298, 1988.
20. **Resch, S; Ryd, L; Stenstrom, A; Johnsson, K; Reynisson, K**: Measuring hallux valgus: a comparison of conventional radiography and clinical parameters with regard to measurement accuracy. Foot Ankle Int, **16**:267-270, 1995.
21. **Sammarco, GJ; Brainard, BJ; Sammarco, VJ**: Bunion correction using proximal Chevron osteotomy. Foot Ankle, **14**:8-14, 1993.
22. **Sarrafian, SK**: A method of predicting the degree of functional correction of the metatarsus primus varus with a distal lateral displacement osteotomy in hallux valgus. Foot Ankle, **5**:322-326, 1985.
23. **Saxena, A; McCammon, D**: The Ludloff osteotomy: a critical analysis. J Foot Ankle Surg, **36**:100-105; disc. 159-160, 1997.
24. **Schuberth, JM; Reilly, CH; Gudas, CJ**: The closing wedge osteotomy. A critical analysis of first metatarsal elevation. J Am Podiatry Assoc, **74**:13-24, 1984.
25. **Shereff, MJ; Sobel, MA; Kummer, FJ**: The stability of fixation of first metatarsal osteotomies. Foot Ankle, **11**:208-211, 1991.
26. **Thompson, FM**: Complications of hallux valgus surgery and salvage. Orthopedics, **13**:1059-1067, 1990.
27. **Trnka, H-J; Parks, BG; Ivanic, G; Chu, I-T; Easley, ME; et al**: Six first metatarsal shaft osteotomies: mechanical and immobilization comparisons. Clin. Orthop., **381**:256-265, 2000.
28. **Zygmunt, KH; Gudas, CJ; Laros, GS**: Z-bunionectomy with internal screw fixation. J Am Podiatr. Med. Assoc, **79**:322-329, 1989.