Angular correction and complications of proximal first metatarsal osteotomies for hallux valgus deformity

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Abstract

Purpose Proximal first metatarsal osteotomies are recommended for the surgical treatment of moderate to severe hallux valgus deformity. This study aimed to compare correction of intermetatarsal and hallux valgus angles and complications of proximal crescentic, Ludloff, proximal opening wedge, proximal closing wedge, proximal chevron and other proximal first metatarsal osteotomies.

Methods A systematic search for the keywords “(bunion OR hallux) AND (proximal OR crescentic OR basilar OR opening OR closing OR shelf OR Ludloff) AND osteotomy” in the online databases MEDLINE, Embase, CINAHL, Cochrane Central Register of Controlled Trials and Cochrane Database of Systematic Reviews was performed.

Results There was a mean correction of hallux valgus angle of 20.1° [confidence interval (CI) 18.7–21.4] and of intermetatarsal angle of 8.1° (CI 7.7–8.9). The overall complication rate reached 18.7 %.

Conclusions The results of this study reveal higher corrective power of proximal osteotomies compared to meta-analysis data on diaphyseal osteotomies.

Introduction

Hallux valgus deformity is characterised by lateral deviation of the great toe and medial deviation of the first metatarsal,

leading to subluxation of the respective joint [1, 2]. More than 200 different surgical methods have been described to address this pathological condition. Correctional metatarsal osteotomies are the surgical treatment of choice for symptomatic hallux valgus deformity [3]. They can be performed at the distal, diaphyseal or proximal aspect of the first metatarsal. Osteotomies of the first metatarsal typically create three-dimensional effects on the distal fragment, affecting alignment in the axial and sagittal planes as well as rotationally [4].

The severity of deformity is classified by radiological criteria [5]. Mild deformity has less than 15° intermetatarsal 1–2 angle (IMA), moderate deformity has 15–20° IMA and severe deformity has more than 20° IMA [6]. Mathematical analysis revealed that distal metatarsal osteotomies (DMO) provide less corrective power than proximal metatarsal osteotomies (PMO). Therefore, DMO are preferred to correct mild to moderate hallux valgus deformities. For severe hallux valgus deformity with an IMA in excess of 20°, a PMO is indicated.

Fixation in PMO is critical and complications due to high lever forces acting on the osteotomy site are common. The complications include shortening and dorsiflexion malunion leading to first ray insufficiency. Due to this fact, its use is limited in spite of its theoretically superior corrective power compared to DMO [3, 6, 7].

The most common proximal osteotomies are the crescentic osteotomy, the Ludloff osteotomy, the proximal chevron osteotomy, the proximal opening wedge osteotomy and the proximal closing wedge osteotomy. The proximal crescentic osteotomy achieves correction by angular rotation after performing a cut dorsal to plantar with a crescentic saw blade at the proximal aspect of the first metatarsal. The Ludloff osteotomy is an oblique osteotomy starting 1.5 cm distal to the metatarsocuneiform joint on the dorsal aspect of the metatarsal base. The proximal chevron osteotomy represents a V-shaped displacement osteotomy with 60° of angulation

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between the dorsal and the plantar cut. Proximal opening and closing wedge osteotomies both correct the IMA by rotation of the metatarsal bone. Whereas opening wedge osteotomy provides lengthening, closing wedge osteotomy shortens the first metatarsal bone (Fig. 1) [7, 8].

Many authors have studied the clinical and radiographic results of PMO. However, there exist only a few comparative studies with a limited number of patients. Therefore, the aim of this study was to compare (1) the efficacy of PMO in terms of corrective power and (2) the complication rate of PMO.

Methods

Search method

A systematic search for the keywords “(bunion OR hallux) AND (proximal OR crescentic OR basilar OR opening OR closing OR shelf OR ludloff) AND osteotomy” in the online databases MEDLINE, Embase, CINAHL, Cochrane Central Register of Controlled Trials and Cochrane Database of Systematic Reviews was performed. English and German language studies previous to August 2012 were included in the analysis. A manual reference check of all accepted papers and recent reviews was performed to supplement the electronic searches and to identify any additional potentially relevant studies. Literature search and selection were performed according to the Cochrane Handbook for Systematic Reviews (http://hiv.cochrane.org/sites/hiv.cochrane.org/files/uploads/Ch13_NRS.pdf).

The titles and abstracts were reviewed in duplicate and independently for eligibility. Two reviewers then independently extracted all relevant information about outcome-related demographic data. For a study to satisfy the criteria for inclusion, the authors had to have reported on (1) pre- and

post-operative IMA and hallux valgus angle (HVA), (2) number of feet, (3) length of follow-up and (4) type of procedure and method of fixation.

We included systematic reviews of randomised controlled trials (RCTs) and prospective and retrospective case-control and case-series studies. There was no restriction to RCTs because our aim was to establish the angular correction obtained by the aforementioned osteotomies when used for the surgical correction of hallux valgus deformity. There was no criterion for minimum length of follow-up because radiographic angular correction can be established early after the operation [1]. The level of evidence for each study was assigned according to the guidelines of the American Academy of Orthopaedic Surgeons (AAOS) [9].

Outcome parameters

The two target outcomes analysed were the differences in HVA and in IMA before and after surgery (delta HVA and delta IMA). These outcome measures were to be compared between the six surgical methods “Ludloff” (method 1), “proximal crescentic osteotomy” (method 2), “proximal opening wedge osteotomy” (method 3), “proximal closing wedge osteotomy” (method 4), “proximal chevron osteotomy” (method 5) and “other methods” (method 6).

As a secondary outcome parameter, the rate of overall, major and minor complications was compared between the surgical methods and separately between fixation methods 1 to 7 (1=screw, 2=plate, 3=locking plate, 4=wire, 5=pin, 6=external fixation and 7=combination screw/wire). Major complications were defined as complications that might require revision surgery. These included nonunion, dorsiflexion malunion, recurrence, hallux varus, fracture, deep infection and implant failure. Minor complications included superficial infection or numbness.

Fig. 1 Dorsoplantar and lateral views of different proximal first metatarsal osteotomies. *From left to right:* Ludloff osteotomy, proximal crescentic osteotomy, proximal opening wedge osteotomy, proximal closing wedge osteotomy and proximal chevron osteotomy

Data analysis

For those studies where the range (in terms of minimum and maximum observed values) was reported as measure of variance, the standard deviation was estimated by a maximum likelihood method making use of the reasonable assumption of normally distributed values and the available mean, minimum and maximum values. The correlation between pre- and post-treatment values was estimated from all studies where an estimate for the standard deviation was available for pre- and post-treatment and for the mean difference. This estimate was 0.43 for HVA and 0.23 for IMA.

Using the estimated correlations, the standard deviations for the pre- to post-treatment differences were calculated. For studies where no measure of variance was reported, the standard deviation of the pre- to post-treatment difference was estimated as the pooled standard deviation of all other studies.

A random effects model was fit for each surgical method separately to calculate the mean treatment effect in terms of delta IMA or delta HVA and to estimate the variability between studies. The reported value I^2 is an estimate of the relative amount of total variability accounted for by the heterogeneity between studies. Confidence intervals (CI) for the group mean effects were calculated. Funnel plots were drawn to check for publication bias. Inspection of the funnel plots showed no sign of publication bias.

Multiple random effects models were fit including surgery type as moderator. From these models the hypothesis of equal mean effects in each surgery group was tested. These calculations were performed using the library metafor (<http://www.jstatsoft.org/v36/i03>) in the statistical computing environment R2.14.2 [10].

The negative binomial distribution was used to model the complication rates in the different studies. Generalised linear models were fit to explain the complication rate per treated feet by type of surgery or type of fixation for overall, major and minor complications separately. In these models, the study values were weighted by the respective sample sizes. Likelihood ratio tests were calculated to test the hypothesis of no difference between the surgery or fixation types, respectively. Estimated mean values for the complication rate per feet and 95 % CI were calculated. These calculations were done using PROC GENMOD in SAS 9.3.

Results

The initial search yielded 808 citations. The final database included 62 primary studies eligible for meta-analysis [11–68]. Four of these were identified as kinship studies. The studies included a total amount of 2,843 feet. Detailed

distribution is presented in Table 1. Study attrition is shown in Fig. 2.

Analysis of level of evidence of the selected studies revealed that the majority of studies were case series (level IV) ($n=43$). Ten studies were level III, three studies level II and two studies level I (Fig. 4).

There were 974 feet that underwent proximal crescentic osteotomy, 596 feet proximal closing wedge osteotomy, 326 feet proximal opening wedge osteotomy, 446 feet proximal chevron osteotomy, 402 feet Ludloff osteotomy and 99 feet where other types of proximal first metatarsal osteotomies were performed (Fig. 4).

For all proximal first metatarsal osteotomies the mean correction of HVA was 20.1° (CI 18.7 – 21.4) and of IMA 8.1° (CI 7.7 – 8.9). Subgroup analysis revealed an average angular correction of HVA of 22.4° (CI 19.3 – 25.7° , $I^2=93\%$) for Ludloff osteotomy, 23.3° (CI 21.4 – 25.2° , $I^2=92\%$) for proximal crescentic osteotomy, 16.2° (14.0 – 18.0° , $I^2=87\%$) for proximal opening wedge osteotomy, 19.6° (CI 16.4 – 22.9° , $I^2=95\%$) for proximal closing wedge osteotomy, 21.0° (18.4 – 24.2° , $I^2=93\%$) for proximal chevron osteotomy and 17.1° (CI 16.0 – 19.1° , $I^2=50\%$) for other osteotomies. The difference was statistically significant ($p=0.0056$).

Correction of IMA averaged 8.2° (CI 6.2 – 9.2° , $I^2=95\%$) for Ludloff osteotomy, 9.2° (CI 8.2 – 10.2° , $I^2=89\%$) for proximal crescentic osteotomy, 8.2° (CI 7.2 – 9.0° , $I^2=85\%$) for proximal opening wedge osteotomy, 7.2° (CI 6.2 – 9.2° , $I^2=96\%$) for proximal closing wedge osteotomy, 8.2° (CI 7.2 – 10.0° , $I^2=91\%$) for proximal chevron osteotomy and 7.2° (CI 3.2 – 8.2° , $I^2=56\%$) for other osteotomies. However, the intergroup difference was not statistically significant ($p=0.144$) (Fig. 3).

A total of 534 complications (18.7 %) occurred with 364 major (12.8 %), 92 minor (3.2 %) and 78 other complications (2.7 %). The most common major complications were hallux varus ($n=121$, 4.3 %), recurrence ($n=99$, 3.5 %) and dorsiflexion malunion ($n=59$, 2.5 %) respectively. Results of the GENMOD procedure to compare complications are presented in Tables 2 and 3. We found statistically significant differences for major complications between the different surgical methods ($p=0.025$). The mean major complication rates were 17.5 % (CI 12.8 – 23.9) in patients who underwent Ludloff osteotomy, 11.7 % (CI 7.2 – 18.0) for proximal crescentic osteotomy, 14.3 % (CI 8.1 – 25.1) for proximal opening wedge osteotomy, 15.7 % (CI 10.4 – 23.4) for proximal closing wedge, 6.1 % (CI 3.6 – 10.2) for proximal chevron osteotomy and 24.6 % (CI 10.1 – 57.8) for other methods. From these mean values and CI the main difference was observed for proximal chevron osteotomy with major complication rates smaller than for the other methods (Fig. 4).

Analysis of methods of fixation revealed statistically significant differences for total ($p=0.027$) and minor complications

Table 1 Detailed information about the studies included regarding first author, year of publication, level of evidence, number of feet, surgical methods, IMA correction (mean, 95 % CI), HVA correction (mean, 95 % CI) and total number of complications

First author (year)	Level of evidence	Number of feet (patients)	Type of surgery	Delta IMA (95 %CI)	Delta HVA (95 %CI)	Complications
Bar-David (1991) [11]	III	20 (18)	Basilar (Balacescu or Juvara)	9.30 (7.44–11.16)	15.60 (12.81–18.39)	1
Cedell (1982) [12]	IV	46 (43)	Proximal closing wedge	5.80 (4.58–7.02)	20.30 (17.76–22.84)	8
Chiang (2012) [13]	III	30 (30)	Modified Ludloff	4.60 (3.20–6.00)	21.00 (17.89–24.11)	12
Chiodo (2004) [14]	IV	82 (75)	Ludloff	9.00 (8.09–9.91)	20.00 (18.10–21.90)	15
Choi (2009) [15]	III	52 (52)	Ludloff	10.00 (9.04–10.96)	26.40 (22.40–28.76)	4
Choi (2009) [15]	III	46 (46)	Proximal chevron	10.70 (7.95–13.45)	27.20 (24.09–30.31)	3
Chow (2008) [16]	IV	32 (26)	Proximal crescentic	6.60 (5.15–8.06)	17.20 (14.16–20.24)	3
Cooper (2007) [17]	IV	23 (23)	Proximal opening wedge	7.00 (6.00–8.00)	15.00 (13.16–16.81)	4
Coughlin (2007) [19]	IV	122 (103)	Proximal crescentic	9.10 (8.35–9.85)	20.00 (18.44–21.56)	21
Coughlin (2005) [18]	IV	33 (27)	Proximal crescentic	8.40 (6.96–9.84)	23.00 (20.00–26.00)	
Day (2011) [20]	IV	70 (57)	Proximal closing wedge	8.80 (8.03–9.57)	20.00 (18.48–21.52)	7
Dreeben (1996) [21]	IV	28 (20)	Proximal crescentic	11.30 (9.53–13.07)	22.70 (18.94–26.46)	6
Easley (1996) [22]	I	41 (29)	Proximal crescentic	9.00 (7.71–10.29)	22.00 (19.31–24.69)	7
Easley (1996) [22]	I	43 (37)	Proximal chevron	9.50 (8.24–10.76)	20.10 (17.47–22.73)	9
Fadel (2008) [23]	IV	40 (32)	Proximal closing wedge	6.10 (4.83–7.37)	22.00 (18.84–25.16)	2
Fox (1999) [24]	IV	29 (27)	Proximal crescentic	13.50 (11.96–15.04)	22.60 (19.40–25.80)	5
Gallentine (2007) [25]	IV	20 (16)	Proximal chevron	7.60 (6.36–8.84)	16.00 (12.66–19.34)	2
Glover (2008) [26]	IV	24	Mau osteotomy	6.79 (5.56–8.02)	18.34 (15.37–21.31)	17
Granberry (1995) [27]	II	31 (22)	Proximal closing wedge	9.20 (7.71–10.69)	24.00 (21.24–26.76)	11
Haas (2007) [28]	III	20 (19)	Proximal closing wedge	7.85 (6.96–8.74)	19.90 (16.66–23.14)	
Hofstaetter (2006) [29]	IV	70 (67)	Ludloff	10.00 (9.01–10.99)	25.00 (22.94–27.06)	14
Hyer (2008) [30]	II	10 (10)	Proximal crescentic	5.80 (3.00–8.60)	16.50 (10.26–22.74)	23
Hyer (2008) [30]	II	24 (24)	Mau osteotomy	6.70 (5.47–7.93)	18.34 (15.37–21.31)	12
Jensen (1989) [31]	IV	41 (27)	Proximal closing wedge	11.00 (9.37–12.63)	26.00 (23.32–28.68)	7
Lee (2008) [33]	I	85 (65)	Proximal chevron	7.60 (6.68–8.52)	22.60 (20.70–24.50)	5
Lee (2007) [34]	IV	35 (29)	Proximal chevron	11.80 (10.56–13.04)	27.80 (25.05–30.55)	5
Lee (2009) [32]	III	69 (52)	Proximal chevron	10.20 (9.35–11.05)	24.05 (22.28–25.82)	3
Limbird (1989) [35]	III	22 (15)	Proximal opening wedge	7.00 (5.23–8.77)	14.40 (10.73–18.07)	
Lüthje (1990) [36]	IV	59 (44)	Proximal closing wedge	4.00 (2.92–5.08)	6.00 (3.76–8.24)	
Mann (1992) [37]	IV	109 (75)	Proximal crescentic	8.00 (7.19–8.81)	21.30 (19.44–23.16)	37
Markbreiter (1997) [38]	III	25 (18)	Proximal crescentic	10.20 (8.54–11.86)	26.20 (22.76–29.64)	4
Markbreiter (1997) [38]	III	25 (18)	Proximal chevron	9.70 (8.04–11.36)	19.70 (16.26–23.14)	3
Nedopil (2010) [39]	IV	86 (66)	Proximal closing wedge	11.10 (10.22–11.98)	22.10 (20.44–23.76)	6
Okuda (2005) [41]	III	55 (36)	Proximal crescentic	10.00 (9.02–10.98)	24.00 (21.86–26.14)	6
Okuda (2000) [40]	IV	47 (33)	Proximal crescentic	10.70 (9.46–11.94)	24.20 (21.89–26.51)	3
Okuda (2008) [42]	IV	54 (41)	Proximal crescentic	9.30 (8.46–10.14)	24.00 (22.35–25.65)	11
Paczesny (2009) [43]	IV	20 (16)	Proximal closing wedge	5.00 (3.29–6.71)	14.10 (11.25–16.95)	1
Pearson (1991) [44]	IV	31 (27)	Proximal curved	6.30 (4.17–8.43)	18.80 (15.11–22.49)	7
Pehlivan (2004) [45]	IV	26 (26)	Proximal oblique crescentic	9.90 (8.54–11.26)	22.10 (20.29–23.91)	1
Petratos (2008) [46]	IV	39 (32)	Proximal crescentic	7.30 (5.97–8.63)	14.00 (11.24–16.76)	2
Randhawa (2009) [47]	IV	31 (29)	Opening wedge	10.30 (7.67–12.93)	13.70 (11.31–16.09)	
Resch (1989) [48]	IV	27 (25)	Proximal closing wedge	3.00 (1.41–4.59)	13.00 (9.69–16.31)	8
Ritschl (1999) [49]	IV	80	Proximal crescentic	9.60 (8.77–10.43)	27.70 (25.63–29.77)	
Robinson (2009) [50]	II	57	Ludloff	6.00 (4.90–7.10)	16.00 (13.72–18.28)	3
Sammarco (1998) [52]	IV	72 (55)	Proximal chevron	6.00 (5.07–6.93)	15.00 (13.26–16.74)	11
Sammarco (1993) [51]	IV	51 (43)	Proximal chevron	7.30 (6.33–8.27)	19.30 (16.82–21.78)	9
Saragas (2009) [53]	IV	64 (46)	Opening wedge	6.40 (5.64–7.16)	14.70 (12.94–16.46)	9

Table 1 (continued)

First author (year)	Level of evidence	Number of feet (patients)	Type of surgery	Delta IMA (95 %CI)	Delta HVA (95 %CI)	Complications
Seiberg (1994) [54]	III	31 (25)	Proximal closing wedge	12.10 (10.98–13.22)	31.80 (28.50–35.10)	8
Señaris-Rodríguez (1998) [55]	III	10 (9)	Proximal closing wedge	5.62 (3.39–7.85)	17.25 (9.67–24.83)	3
Shurnas (2009) [56]	IV	84 (78)	Opening wedge	9.90 (9.09–10.71)	20.00 (18.52–21.48)	20
Smith (2009) [57]	IV	49 (47)	Proximal opening wedge	8.00 (7.09–8.91)	19.80 (18.55–21.05)	14
Takao (2007) [58]	IV	27 (22)	Proximal oblique-domed	8.40 (7.53–9.27)	28.50 (26.59–30.41)	
Tanaka (2008) [59]	IV	48 (37)	Proximal spherical (crescentic)	13.10 (12.05–14.15)	34.00 (31.62–36.38)	22
Thordarson (1992) [60]	IV	46 (32)	Proximal crescentic	10.20 (8.98–11.42)	23.70 (21.16–26.24)	6
Treadwell (2005) [61]	IV	5	Proximal closing wedge			4
Trnka (1999) [63]	IV	60 (42)	Proximal closing wedge	9.40 (8.20–10.60)	19.00 (16.14–21.86)	23
Trnka (2008) [62]	IV	111 (99)	Ludloff	9.00 (8.21–9.79)	26.00 (24.37–27.63)	32
Veri (2001) [64]	IV	37 (25)	Proximal crescentic	10.00 (8.75–11.25)	24.00 (20.50–27.50)	16
Walther (2008) [65]	IV	35 (35)	Opening base wedge	9.00 (8.13–9.87)		3
Wukich (2009) [66]	IV	18 (16)	Opening base wedge	9.00 (7.38–10.62)	13.50 (6.08–20.92)	6
Zembsch (1998) [67]	IV	50 (34)	Proximal closing wedge	10.00 (8.83–11.17)	19.00 (16.56–21.44)	25
Zettl (2000) [68]	IV	86 (70)	Proximal crescentic	10.00 (8.99–11.01)	26.50 (23.63–29.37)	25

($p < 0.001$). For screw fixation there was a total complication rate of 24.3 % (CI 18.9–31.4) and a minor complication rate of 2.9 % (CI 1.9–4.5), and for plate fixation we found 16.2 % (CI

10.8–24.4) and 1.1 % (CI 0.4–3.5), respectively. For locking plate fixation the overall complication rate reached 9.1 % (CI 2.5–32.6) and minor complication rate reached 1.8 % (CI 0.2–

Fig. 2 Flow diagram outlining study search methods and selection

Fig. 3 Forest plots presenting the results of IMA correction for different surgical methods. *RE* random effects model

16.4), wire fixation showed 11.5 % (CI 7.7–17.0) and 2.9 % (CI 1.6–5.3), pin fixation showed 30.5 % (CI 18.5–50.1) and 14.4 % (CI: 8.0–25.7), external fixation showed 23.9 % (CI 7.4–77.6) and 8.7 % (CI 2.0–37.8) and combined screw/wire

Table 2 Complication rate for each surgical method, rate of major complications and rate of minor complications (95 % CI indicate the lower and upper limits of a 95 % CI for the mean)

Complication rates			
Type of surgery	Mean	SE	95 % CI
Total complications			
Proximal crescentic osteotomy	19.900	4.297	13.033–30.386
Ludloff osteotomy	23.741	3.481	17.811–31.646
Proximal opening wedge osteotomy	20.513	5.354	12.299–34.212
Proximal closing wedge osteotomy	21.857	4.112	15.117–31.602
Proximal chevron osteotomy	11.211	2.526	7.209–17.435
Others	37.374	15.210	16.833–82.981
Major complications			
Proximal crescentic osteotomy	11.692	2.858	7.241–18.878
Ludloff osteotomy	17.506	2.790	12.810–23.924
Proximal opening wedge osteotomy	14.286	4.098	8.142–25.067
Proximal closing wedge osteotomy	15.667	3.221	10.471–23.442
Proximal chevron osteotomy	6.054	1.621	3.582–10.233
Others	24.242	10.785	10.137–57.977
Minor complications			
Proximal crescentic osteotomy	2.985	1.458	1.146–7.776
Ludloff osteotomy	3.836	1.249	2.026–7.265
Proximal opening wedge osteotomy	2.197	1.381	0.640–7.536
Proximal closing wedge osteotomy	4.061	1.666	1.817–9.078
Proximal chevron osteotomy	4.035	1.784	1.696–9.601
Others	3.030	2.974	0.442–20.756

Table 3 Rate of total complications for each method of fixation, rate of major complications and rate of minor complications (95 % CI indicate the lower and upper limits of a 95 % CI for the mean)

Complication rates			
Type of fixation	Mean	SE	95 % CI
Total complications			
Screw	24.368	3.149	18.916–31.392
Plate	16.197	3.383	10.756–24.391
Locking plate	9.091	5.931	2.531–32.655
Wire	11.456	2.321	7.702–17.041
Pin	30.453	7.739	18.506–50.113
External fixation	23.913	14.362	7.369–77.600
Screw/wire	25.253	5.929	15.939–40.008
Major complications			
Screw	16.684	2.461	12.494–22.278
Plate	12.207	2.880	7.686–19.385
Locking plate	5.455	4.280	1.172–25.392
Wire	7.379	1.753	4.631–11.756
Pin	15.638	4.697	8.679–28.176
External fixation	8.696	6.666	1.935–39.069
Screw/wire	21.549	5.616	12.929–35.914
Minor complications			
Screw	2.932	0.649	1.899–4.526
Plate	1.174	0.567	0.455–3.028
Locking plate	1.818	2.042	0.201–16.435
Wire	2.913	0.895	1.593–5.323
Pin	14.403	4.268	8.057–25.746
External fixation	8.696	6.524	1.998–37.841
Screw/wire	1.010	0.624	0.300–3.391

fixation showed 25.3 % (CI 15.9–40.0) and 1.0 % (CI 0.3–3.4), respectively. Regarding minor complications it appears that pin fixation is associated with an increased rate while all other methods exhibit a similar level.

Discussion

The aim of this study was to assess corrective power and complications of proximal first metatarsal osteotomies for hallux valgus deformity. This was achieved by comparing pooled data of 2,834 operated feet. The evaluated surgical methods included proximal crescentic osteotomy, Ludloff osteotomy, proximal chevron osteotomy, proximal opening wedge osteotomy, proximal closing wedge osteotomy, and a few other proximal first metatarsal osteotomies. We found a mean correction of IMA of 8.1°. HVA showed an average improvement of 20.4°. Additionally, we evaluated the complication rate and we found a total of 18.7 %. There was a statistically significant difference concerning reduction of HVA and overall major complications between the different surgical methods. Overall and minor complications differed statistically significantly between the methods.

There are some limitations associated with this study. First, a direct comparative meta-analysis of the different methods was not possible due to the fact that there were few head-to-head studies. Therefore, we were only able to perform a pooled meta-analysis across all studies. Second, the quality of meta-analysis depends on the quality of the studies included. In our analysis the majority of included studies were uncontrolled case series. This is not uncommon in clinical musculoskeletal research. However, it illustrates the need for further prospective comparative studies. Basically, proximal osteotomies are recommended for the treatment of moderate to severe deformities [3, 5–7]. The studies included in this meta-analysis also contained patients who suffered from mild to moderate hallux valgus deformity. Therefore, the comparison of corrective power might be affected.

In this study, proximal crescentic osteotomy revealed the best results in terms of correction of HVA (23.3°) followed by Ludloff osteotomy (22.4°) and proximal chevron osteotomy (21.0°). Opening and closing wedge osteotomies provided less HVA correction. In fact, it was 16.2 and 19.6°, respectively. For IMA correction, proximal crescentic

Fig. 4 **a** Number of studies for different levels of evidence. **b** Number of feet for each surgical method

osteotomy revealed the most favourable results with a mean correction of 9.2° , followed by proximal chevron, opening wedge and Ludloff osteotomies (8.2°). Proximal closing wedge osteotomy and other methods accomplished less angular correction (7.2°). However, changes in IMA were not statistically significant.

The heterogeneity between studies (compare the I^2 values and the forest plots) is considerably large. This indicates that beyond the mean differences between surgical methods, the outcome may strongly depend on further factors that vary between study areas.

In a recent meta-analysis Smith et al. [1] investigated the corrective power of distal chevron and Scarf osteotomy, respectively. For the distal chevron osteotomy, they found in 1,028 feet a mean correction of IMA of 5.33° . Analysis of 300 feet that underwent Scarf osteotomy showed a mean correction of IMA of 6.21° . The difference was statistically significant. With a mean correction of 8.2° (range 7.2 – 9.6°), the results of our study indicate that proximal osteotomies provide a higher corrective power than distal or diaphyseal osteotomies. This represents the clinical proof for the mathematical theory.

In one of the few comparative studies on this topic Easley et al. [22] prospectively investigated proximal crescentic and proximal chevron osteotomies in patients (84 feet) with moderate to severe deformity. According to this meta-analysis they found no statistically significant difference in correction of IMA. However, chevron osteotomy showed shorter healing time and less dorsiflexion malunion. This also corresponds to the results of this study in which proximal chevron osteotomy showed the lowest number of major complications. The difference of this parameter was significant compared to the other proximal first metatarsal osteotomies.

Recently, Park et al. compared proximal and distal chevron osteotomies in 77 feet [69]. In contrast to the results of our study compared with the meta-analysis of Smith et al. they found no statistically significant difference for correction of HVA and IMA. However, there was more shortening in the distal chevron osteotomy group. The radiographic results in terms of corrective power might be affected due to the circumstance that not only severe deformities had been included.

With 6.1 %, proximal chevron osteotomy showed the lowest rate of major complications in our study. It was followed by proximal crescentic osteotomy (11.7 %), proximal opening wedge osteotomy (14.3 %), proximal closing wedge osteotomy (15.7 %), Ludloff osteotomy (17.5 %) and the other osteotomies (24.2 %). The differences were statistically significant. The overall complication rate in proximal chevron osteotomy (11.2 %) also revealed the most favourable results compared to other osteotomies. However, these differences were not statistically significant.

The method of fixation is an important issue in PMO due to the high lever forces acting on the osteotomy site and the risk of dorsiflexion malunion. This is associated with functional

impairments in terms of transfer metatarsalgia. In contrast to the clinical literature, many studies exist that compare different methods of fixation in PMO. Scott et al. compared construct stability of locking plate fixation for proximal chevron osteotomy with Ludloff osteotomy fixed with two screws and found superior results for the Ludloff construct [70]. Hofstaetter et al. found that construct stiffness of proximal opening wedge osteotomy fixed with a plate is inferior to Ludloff osteotomy with screw fixation. For proximal crescentic osteotomy dorsal plate fixation provides more stability than single screw fixation [71]. These results indicate that rigid fixation is biomechanically important for proximal osteotomies [70, 72]. In our study, we found statistically significant differences with respect to method of fixation. Pin fixation revealed inferior results concerning complications compared to more rigid methods of fixation. Plate and locking plate fixation, however, showed the most favourable results. Therefore, the latter should be recommended as the method of fixation of first metatarsal osteotomies.

This study exposed the major lack of objective, prospective and controlled data on either procedure. The findings demonstrate that the majority of available data on the results of these procedures are based on retrospective uncontrolled case series. The sample sizes in many of the studies were small and follow-up period limited. Therefore, prospective studies are needed to compare the procedures in similar patient groups.

Conclusion

To the best of our knowledge, this is the first meta-analysis on corrective power and complications of proximal first metatarsal osteotomies for hallux valgus deformity. The results of this study indicate that proximal first metatarsal osteotomies achieve a correction of IMA of 8.1° and a correction of HVA of 20.1° . The overall complication rate is 18.7 %. The proximal crescentic osteotomy provided the highest amount of HVA correction. However, regarding angular correction as well as complications the proximal chevron osteotomy revealed the most favourable results. Rigid fixation is mandatory in order to reduce complications, and further high-quality prospective comparative studies are required and might change the observed effects.

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