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Review

Clinical effectiveness and safety of Weil's osteotomy and distal metatarsal mini-invasive osteotomy (DMMO) in the treatment of metatarsalgia: A systematic review

Amado Rivero-Santana[a,b,c,*], Lilisbeth Perestelo-Pérez[b,c,d], Gerardo Garcés[e,f], Yolanda Álvarez-Pérez[a,b,c], Antonio Escobar[b,g], Pedro Serrano-Aguilar[b,c,d]

[a] Canary Islands Foundation of Health Research, Bco. de la Ballena, s/n, 35019 Las Palmas de GC, Spain
[b] Health Services Research on Chronic Patients Network, Camino Candelaria, 44, El Rosario, 38109 Tenerife, Spain
[c] Center for Biomedical Research of the Canary Islands, Campus Ciencias de La Salud, s/n, 38071 San Cristobal de La Laguna, Spain
[d] Evaluation Unit of the Canary Islands Health Service, Camino Candelaria, 44, El Rosario, 38109 Tenerife, Spain
[e] Department of Orthopedics, Hospital Perpetuo Socorro, C/León y Castillo, 407, 35007 Las Palmas de Gran Canaria, Spain
[f] School of Medicine, University of Las Palmas de Gran Canaria, Paseo Blas Cabrera Felipe, s/n, 35016 Las Palmas de Gran Canaria, Spain
[g] Research Unit, Hospital Basurto, Montevideo Etorb., 18, 48013 Bilbao, Spain

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ABSTRACT

Background: Weil's osteotomy (WO) is the most applied surgical treatment for metatarsalgia, a persistent pain in the lesser metatarsals' heads. We aim to review its effectiveness and safety compared to the percutaneous technique known as distal metatarsal mini-invasive osteotomy (DMMO).
Methods: Systematic review in Medline, Pubmed, Embase, Cinahl and Cochrane Library. We included studies that directly compared WO and DMMO for the treatment of primary metatarsalgia. Data on pain, function, complications and patients' satisfaction were extracted and narratively synthesized.
Results: Four retrospective studies were identified. There were no significant differences in clinical effectiveness or patients' satisfaction. Time to bone healing was significantly longer for DMMO, whereas WO showed more wound problems and metatarsophalangeal stiffness. Other complications were infrequent in the two procedures.
Conclusion: Evidence on the direct comparison of WO and DMMO is scarce and of low quality. Randomized studies are needed in order to control for potential confounders.

Contents

* Corresponding author at: Servicio de Evaluación del Servicio Canario de la Salud, Camino Candelaria, 44, 38109, El Rosario, S/C de Tenerife, Spain.
E-mail addresses: amado.riverosantana@sescs.es (A. Rivero-Santana), lilisbeth.peresteloperez@sescs.es (L. Perestelo-Pérez), ggarces@imqc.es (G. Garcés), yolanda.alvarezperez@sescs.es (Y. Álvarez-Pérez), ANTONIO.ESCOBARMARTINEZ@osakidetza.eus (A. Escobar), pseragu@gobiernodecanarias.org (P. Serrano-Aguilar).

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1. Introduction

The term metatarsalgia refers to a persistent pain experienced in the forefoot, in the metatarsals' (MTTs) heads, usually accompanied by plantar callosities. Its causes can be classified into primary (congenital or acquired anatomic–biomechanical features that produce overload in the forefoot), secondary (produced by other medical conditions through indirect mechanisms, e.g., chronic synovitis, rheumatoid arthritis, gout, neurological diseases) or iatrogenic (complications of medical procedures that may produce a load transfer between MTTs) [1,2]. Metatarsalgia is frequently associated to the presence of Hallux Valgus (HV), a lateral deformation of the first toe [2,3].

Conservative treatments for metatarsalgia include proper footwear, physiotherapy, orthotics, or analgesic medication. When these treatments fail, there are different surgical alternatives depending on the type of metatarsalgia and the anatomical and clinical characteristics of the patient (e.g., soft tissue surgery, arthrodesis, osteotomy). When metatarsalgia is accompanied by HV, in many cases the surgical correction of the hallux will be sufficient to achieve a correct load distribution and relieve the pain [4,5]. In other situations, intervention on the lesser MTTs will be necessary, for example when there are anatomical abnormalities such like abnormal MTTs inclination or length, or dislocation of the metatarsophalangeal joint. In these cases, the most common surgical intervention for the treatment of metatarsalgia is the Weil's osteotomy (WO). In this intervention a distal oblique cut is made in the neck of the MTT in order to reduce its length and set back the support area, which relieves the load on the metatarsal head and the resulting pain [6–8]. Usually, three MTTs are operated (M2, M3 and M4), although it may also be necessary to operate the M5. Usually, in order to facilitate bone union, internal fixation screws are used, generally one in each treated MTT (Table 1).

Weil's osteotomy has been shown to be an effective technique to alleviate metatarsalgia, with positive clinical results in 65%–88% of cases [6,9–15], albeit with a considerable rate of (non-serious) complications. These include the "floating toe", caused by an excess of dorsal tension that makes the finger unable to contact the floor, stiffness of the metatarsophalangeal joint with lost or decreased mobility, transfer metatarsalgia, or eventual need to remove the osteosynthesis material [16–18]. Over time, variations of the WO have been proposed to avoid these complications, such as Weil's double and triple osteotomies, or dorsal wedge resection [19–22].

One of these modifications is the distal metatarsal mini-invasive (also called *metaphyseal*) osteotomy (DMMO). It consists of a minimally invasive procedure in which, percutaneously and under local anesthesia, a metatarsal neck osteotomy is performed by means of a Shannon burr, with the help of radiographic imaging guidance, and without internal fixation [23,24] (Table 1). It has been suggested that DMMO, in addition to being less invasive, may present some advantages over WO: avoiding rigid fixation would allow the early loading after the operation to "dynamically" restore MTTs head alignment, both horizontally and in the coronal plane, thus reducing metatarsalgia and avoiding, on the other hand, the complications potentially associated with the use of screws (e.g., infection, displacement, plantar perforation). In addition, it would produce a lower stiffness in the metatarsophalangeal (MTP) joint by reducing soft tissue damage, and less interference in the blood supply to the metatarsal head that would reduce the risk of avascular necrosis [24]. Finally, it is a quick technique to apply and at a lower cost. On the side of complications, however, the use of a burr to perform the osteotomy in absence of direct vision can produce neurovascular injury and skin burns, and in the absence of fixation there is an increased risk of delayed bone union, malunion or non-union, prolonged oedema and increased time to recovery [24,25]. In uncontrolled studies, DMMO has shown a clinical effectiveness similar to that obtained by the WO, and a low rate of complications [26–28].

The aim of this study is to review the empirical evidence about the relative efficacy and safety of the WO and DMMO in the treatment of metatarsalgia.

2. Methods

We first performed a search of systematic reviews in the Center for Reviews and Dissemination (CRD) database until February 2017, with the term "metatarsalgia", and no relevant documents were found (the search yielded only one record). Then, a systematic review was carried out on studies found in the electronic databases Medline, Pubmed, Embase, Cinahl and Cochrane Library, from January 2000 (date prior to the development of the DMMO). The search strategies can be found in Appendix I in Supplementary material. Again, we first screened for systematic reviews which could be not included in the CRD database, and since no relevant publications were found we started with the selection of primary studies. A manual search was also carried out in the reference lists of the studies selected by title/abstract, as well as a non-systematic search in google.com. Finally, we consulted the archive of *Orthopedic Proceedings* (The Bone & Joint Journal), with the aim of identify abstracts that offered analyzable data.

The following inclusion criteria were applied: 1) randomized (RCT) and non-randomized (nRCT) controlled trials, or observational prospective or retrospective studies; 2) in patients of any age who present primary metatarsalgia, with or without concomitant HV presence; 3) that compare WO to DMMO; 4) and include at least one of the following outcome measures: pain, functional capacity/activities of daily living, health-related quality of life

Table 1
Main characteristics of WO and DMMO.

WO	DMMO
• Open surgery	• Percutaneous surgery, small incision
• Local/regional anesthesia	• Local/regional anesthesia
• Tourniquet is usually employed	• Tourniquet not required
• Intra-articular	• Extra-articular
• Direct vision	• Use of a motorized burr to perform the osteotomy
• Internal fixation (usually with screws)	• Radiographic imaging guidance required
	• No fixation

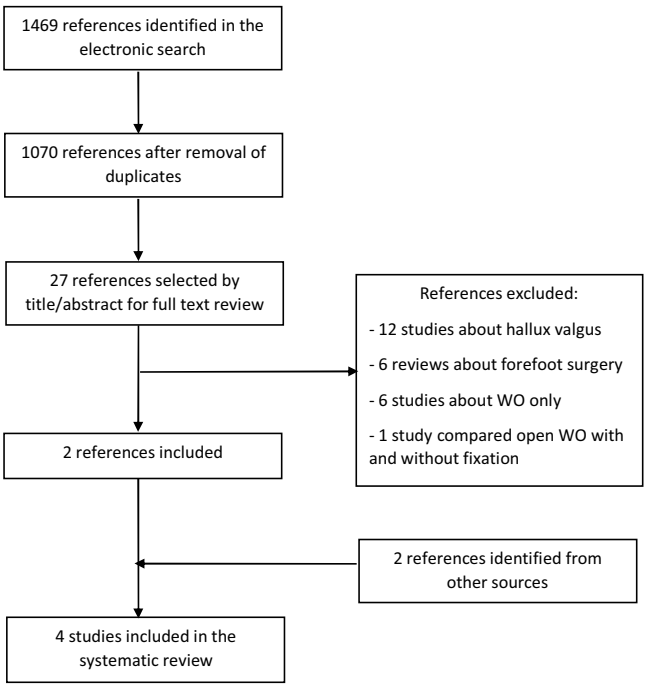

Fig. 1. Flow chart of the study selection process.

(specific to the condition studied), satisfaction or complications; 4) published in English or Spanish. Studies were excluded if: 1) they were uncontrolled; 2) included patients with metatarsalgia secondary to systemic or rheumatoid disease (e.g., rheumatoid arthritis, gout, Freiberg's disease), Morton's neuroma, or iatrogenic metatarsalgia.

Titles and summaries of references and selected articles were peer reviewed taking into account the specified inclusion criteria. The risk of bias in the included studies was assessed using the Cochrane Collaboration criteria for RCT and nRCT [29], and the Scottish Intercollegiate Guidelines Network (SIGN) criteria [30] for observational cohort studies.

3. Results

Fig. 1 shows the study selection flow. The electronic search yielded a total of 1469 references, 1070 after eliminating the duplicates. Twenty-seven references were selected by title/abstract, of which finally 2 primary studies were included [31,32]. Two more studies were identified and included, one in the search performed in google.com [33], and other published as a conference abstract in *Orthopedic Proceedings* [34]. Authors of the four studies were contacted to request data not reported in the articles, and two of them kindly provided the information.

3.1. Characteristics of included studies

Table 2 shows the characteristics of the included studies. All them were single-center, retrospective cohort studies, that included patients with primary metatarsalgia (n = 209, range 33–72), with or without intervention on M1 or metatarsophalangeal dislocation. Mean age was 60.1, 88.5% were women, and average follow-up ranged from 6 [32] to 14.4 months [31].

Henry et al. [31], Yeo et al. [32] and Castro et al. [34], used the *American Orthopedic Foot and Ankle Society* (AOFAS) scale for lesser MTTs [35], as the main measure of clinical effectiveness. It is a clinician-rated scale (although it also includes patient self-reported items), widely used in foot and ankle interventions [36,37]. It includes three sections: pain, function and alignment of MTTs. The total scale has a range of 0–100, with higher scores indicating better results. The remaining study, Miranda et al. [33] used three categories of clinical assessment (considering functionality and pain): great, partial and no improvement.

3.2. Methodological quality

Appendix II in Supplementary material shows the assessment of the methodological quality of the included studies, evaluated with the SIGN instrument [30]. The SIGN criteria establish that the rating for retrospective studies, among the three established categories (High: ++, Acceptable: +, Low: −), should not be higher than "acceptable", since usually a prospective study is subjected to a lower bias than the same study carried out retrospectively. In any case, the four studies have been rated as of low quality due to several limitations, mainly the risk of selection bias and absence of blinding. Potential confounding factors such as presence of HV, metatarsophalangeal dislocation or other clinical variables were described, but multivariate or subgroup analyzes were not performed, possibly due to the limited sample sizes. Important baseline differences were observed: the WO groups showed more interventions in M1 in Henry et al. [31] ($p = 0.04$), more patients with metatarsophalangeal dislocation in in Miranda et al. [33] ($p < 0.001$), better baseline values in the range of motion of toes and less women in Yeo et al. [32] (although the differences did not reach statistical significance, $p = 0.113$ and $p = 0.280$ respectively) and older age in Castro et al. [34] (significant p-value not reported). None of the included studies used a validated scale to assess clinical effectiveness.

3.3. Effectiveness and complications

3.3.1. Results at 3-month follow up

Henry et al. [31] observed at 3 months a significantly higher rate of residual metatarsalgia (29% vs. 7%, $p = 0.002$) and oedema (59% vs. 24%, $p = 0.008$) in the DMMO group, which also showed a lower percentage of osteotomy sites achieving bone union (79% vs. 100%).

Table 2
Characteristics of the included studies.

	Henry et al. [31]		Yeo et al.[32]		Miranda et al. [33]		Castro et al. [34]	
Groups (n)	WO (33)	DMMO (39)	WO (20)	DMMO (13)	WO (22)	DMMO (22)	WO (30)	DMMO (30)
Mean age	63.2	62.3	63.8	55.3	63.1	58.3	61	51.5
Women (%)	97%	89.7%	70%	92.3%	90.9%	81.8%	96.7%	83.3%
MTP joint dislocation	37%	31%	–	–	86.4%	18.9%	–	–
Intervention on M1	97%	84.6%	75.8%		77.3%	59.1%	90%	76.7%
Mean follow up (months)	14.8		6.0		7.7		4.0	6.8
AOFAS baseline	44.2 (14–69)[a]	46.2 (34–67)[a]	62 (49–71)[b]	69 (60–83)[b]	–	–	–	–

AOFAS: American Orthopedic Foot and Ankle Society; DMMO: distal metatarsal mini-invasive osteotomy; MTP: metatarsophalangeal; WO: Weil's osteotomy.
[a] Mean (range).
[b] Median (95% confidence interval).

Table 3
Effectiveness results at last follow-up.

	AOFAS[a]		Residual or recurrent metatarsalgia[b]		Satisfaction[c]	
	WO	DMMO	WO	DMMO	WO	DMMO
Henry et al. [31]	85.3 (63–100)	86.5 (62–100)	4 (13%)	5 (14%)	28 (93.3%)	34 (91.9%)
Yeo et al.[32]	86 (79–93)	88 (77–92)	0 (0–1)	0 (0–2)	–	–
Miranda et al. [33]	–	–	1 (4.5%)	1 (4.5%)	–	–
Castro et al. [34]	80.6	88.3	3.00	2.04	20 (68%)	24 (80%)

AOFAS: American Orthopedic Foot and Ankle Society; DMMO: distal metatarsal mini-invasive osteotomy; WO: Weil's osteotomy.
[a] Values are means (range) for Henry et al., medians (95% confidence interval) for Yeo et al., and means for Castro et al.
[b] Values represent percentage of patients with residual (Henry et al.) and recurrent (Miranda et al.) metatarsalgia. For Yeo et al., medians (95% confidence interval) in a visual analogue scale of pain (range 0–5). For Castro et al., means in a visual analogue scale of pain (range 0–10).
[c] Percentage of patients satisfied or very satisfied (versus disappointed or dissatisfied) for Henry et al.; excellent or good (versus fair or bad) for Castro et al.

In Yeo et al. [32] the rates of prolonged oedema were 15.4% (DMMO) and 0% (WO) (p = 0.18), and most patients achieved bone union within two months (numeric data not reported).

3.3.2. Results at the end of the follow up

Tables 3 and 4 show the results obtained for effectiveness variables and complications, respectively, at the end of follow up. There were not significant differences across studies in AOFAS post-scores (3 studies [31,32,34]), residual/recurrent metatarsalgia (4 studies [31–34]) or patients' satisfaction with the outcome (2 studies [31,34]). In Miranda et al. [33] a great clinical improvement was observed in 72.7% (WO) and 76.2% (DMMO) of patients, whereas the remaining participants showed a partial improvement. Yeo et al. [32] obtained a significantly better post-score for the WO group in the mental component of the RAND questionnaire [38] (p = 0.026, not shown in table), but it was mainly caused by a baseline imbalance between groups.

Time to bone healing was reported in Henry et al. [31] and Castro et al. [34] showing a significantly longer time for the DMMO group (3.7 vs. 1.5 months and 17.5 vs. 4.2 weeks, respectively). Castro et al. [37] also reported a significantly shorter time to wear comfort shoes in that group (11 vs. 18 weeks), and no significant differences in time to return to daily activities (DMMO: 12.4, WO: 10.5 weeks) or taking pain killers (5 vs. 9 weeks, respectively).

Regarding complications (Table 4), there were very few cases of prolonged oedema (one case in each group across the studies) and bone mal- or non-unions (three cases of pseudoarthrosis in the DMMO group of Castro et al. [34]). The rates of floating toe and transfer metatarsalgia, reported in two articles each, were also low (one and five cases, respectively). As expected, the WO groups showed more wound problems (e.g., infection, dehiscence), but the difference was significant only when pooling the results of the two studies that reported data (23% vs. 1.9%, p = 0.02) [33,34].

Moderate or severe MTP stiffness were more frequent in the WO group as a whole. In Yeo et al. [32] the difference was significant (p = 0.043) mainly due to the rates of severe stiffness (22% vs. 4% of operated toes). In Henry et al. [31] the difference did not reach statistical significance (p = 0.13), and was reflected in the rate of moderate stiffness (57% vs. 34% of patients).

4. Discussion

This systematic review shows that current evidence on the relative effectiveness and safety of WO and DMMO is scarce and of low quality, limited to four single-center, retrospective cohort studies with high risk of selection bias, among other limitations. Furthermore, the heterogeneity of the data reported precluded performing a meta-analyses. Taking these shortcomings in mind, results were quite consistent across studies and outcomes. The absence of internal fixation in DMMO seems to prolong the time needed to bone consolidation, and possibly to increase the likelihood of worse short-term outcomes (i.e., residual metatarsalgia, oedema). In the case of oedema, however, the observed rates in the two studies that reported data at 3 months [31,32] were considerably better for Yeo et al. [32], showing that the occurrence of oedema can be minimized. Several pre- and post-surgical factors could explain these differences, such us the vascular status of the operated limb, time to weight bearing, time walking and standing up, number of interventions on the first ray, or differences in prophylactic treatment to prevent oedema.

At the end of follow up, however, almost all patients in the DMMO groups also achieved bone union and no between-group significant differences were found in clinical assessment or patients' satisfaction in any study. Improvements were similar or better than the observed in previous uncontrolled studies about WO [6,14,39] and DMMO [28,40,41].

Regarding complications, the most noteworthy differences between groups were observed in post-operatory stiffness and wound problems, with worse results for WO. Previous uncontrolled studies have also shown high rates of moderate/severe stiffness after WO osteotomy [6,42]. These are expected results given the minimally invasive nature of DMMO, which also reduces soft tissue damage. The rate of other complications was similar and very low for both techniques, contrasting with previous findings

Table 4
Complications.

	Prolonged oedema		Floating toe		Moderate (31°–69°) and severe (<31°) MTP joint stiffness[a]		Transfer metatarsalgia		Bone malunion or non-union		Wound complications	
	WO	DMMO	WO	DMMO	WO	DMMO	WO	DMMO	WO	DMMO	WO	DMMO
Henry et al. [31]	1 (3%)	0 (0%)	–	–	17 (57%) 0 (0%)	13 (34%) 1 (2.7%)	1 (3.3%)	1 (2.7%)	0 (0%)	0 (0%)	–	–
Yeo et al. [32]	0 (0%)	0 (0%)	–	–	24 (59%) 9 (22%)	11 (50%) 1 (4%)	–	–	0 (0%)	0 (0%)	–	–
Miranda et al. [33]	0 (0%)	1 (4.5%)	1 (4.5%)	0 (0%)	– 0 (0%)	– 1 (4.5%)	–	–	0 (0%)	0 (0%)	5 (22.7%)	1 (4.5%)
Castro et al. [34]	0 (0%)	0 (0%)	0 (0%)	0 (0%)	–	–	2 (6.7%)	1 (3.3%)	0 (0%)	3 (10%)	7 (23.3%)	0 (0%)

DMMO: distal metatarsal mini-invasive osteotomy; MTP: metatarsophalangeal; WO: Weil's osteotomy.
[a] Percentage of patients in Henry et al. and Miranda et al., and percentage of toes in Yeo et al.

especially in the rate of floating toes for WO [16]. This is one of the most common complications after WO; the systematic review of Highlander et al. [16] found a pooled rate of 36% (11 studies), although with wide heterogeneity (range 6%–68%). The etiology of floating toe is not unanimously established and different adjunctive preventive interventions to avoid this complication have been described, such like resecting either a slice or a dorsally based wedge [20], or performing a plantar plate repair and extensor digitorum lengthening [44]. One study included in the mentioned review found that patients who underwent adjunctive proximal interphalangeal joint arthrodesis (for rigid hammertoes with metatarsal phalangeal joint instability) showed a higher rate of floating toe (50% vs. 15%) [17]. Transfer metatarsalgia was also infrequent in the included studies; it has been attributed to an excessive MTT shortening, but currently empirical data do not confirm this statement [16,43].

The use of the burr in absence of direct vision potentially increases the risk of neurovascular injury and skin burns in DMMO. In order to minimize these complications, the technique should be applied with low burr speeds and high torque (50–80 N cm), as well as respecting the neurovascular bundles [24]. The use of a saline irrigation of the entry point is also helpful to avoid thermal lesions [40]. The studies included in this review, as well as uncontrolled trials on DMMO [26–28,40,41,45,46], have shown that the occurrence of these complications is minimal. In any case, the procedure should be reserved for experienced surgeons well trained in open and minimal invasive surgery, and carried out with the appropriate instruments and not with tools adapted from conventional surgery [40].

The absence of differences in clinical effectiveness and the very low rate of malunions or non-unions in DMMO patients at follow up questions the use of internal fixation in WO; furthermore, a recent retrospective study comparing fixation versus no fixation in open WO osteotomy, with more than 4 years of average follow up, did not obtain significant differences in clinical effectiveness, and found more need of reoperations in the fixation group, mainly related to the removal of hardware due to plantar perforation [43].

In summary, current evidence about the relative effectiveness and complications of WO and DMMO is scarce, and the described results must be taken with caution given the low quality of the available studies; a basic limitation, in addition to the small number of patients included, is the risk of selection bias and the subsequent potential confounder effect of several variables, mainly the associated presence of Hallux valgus (and interventions performed to correct it), the relative length and inclination of the metatarsals, metatarsophalangeal joint instability, and adjunctive surgical procedures. The good results obtained with the DMMO do not imply its indication for all patients with metatarsalgia. De Prado et al. [40] point out a MTP dislocation higher than 0.5 cm as a relative contraindication for DMMO, and that this technique should not be performed in the pursuit of joint restoration. In a recent review on metatarsalgia, Besse et al. [2] recommend WO in patients with MTP dislocation or localized “propulsive” metatarsalgia combined with metatarsal length disharmony (M2 or M2M3), and DMMO for patients with diffuse “static” metatarsalgia (M2M3M4) and a rounded forefoot with no length disharmony. Future randomized trials should definitively establish the relative effectiveness of these techniques and for what subgroups of patients they should be indicated.

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Declarations of interest

None.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.fas.2018.06.004.

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