surgical techniques development

MDPI

Systematic Review

Minimally Invasive Distal Metatarsal Osteotomies for Metatarsalgia Treatment: A Review

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Abstract: Introduction: Metatarsalgia is a very common pathology in podiatric consultations, whose main aetiological factor is biomechanical alterations. Given the failure of conservative treatments, minimally invasive osteotomies of the distal metatarsal are becoming more popular, providing comparable results to open surgical techniques and with a lower rate of complications. Objectives: To determine clinical improvement and patient satisfaction after minimally invasive distal metatarsal osteotomy (DMMO) as a surgical treatment for central metatarsalgia at present. Methodology: The databases used for this systematic review were PubMed, Scielo, Cochrane Library, WOS and Scopus. We included articles that studied the efficacy of DMMO for primary metatarsalgia and excluded studies whose patients had more than one pathology or used other surgical techniques. Results: We identified 10 articles, 5 prospective studies, 4 retrospective studies and 1 cross-sectional, non-randomized, analytical study published between 2015 and 2021. The total number of subjects was 366, with a mean age of 61 years. The majority of subjects were women. They presented with symptomatology compatible with primary metatarsalgia for a minimum of 6 months and had failed conservative treatment. Conclusions: DMMO osteotomies for central metatarsals offer excellent post-surgical results for the treatment of central metatarsalgia in the assessment scales (AOFAS, MOXFQ etc.) of the articles analyzed and therefore an evident clinical improvement with benefits in terms of MTF mobility and reduction of surgical time, as well as a high degree of satisfaction in the patients who received this intervention that can be considered as excellent.

Keywords: minimally invasive distal metatarsal osteotomy; DMMO; metatarsalgia; surgical technique

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1. Introduction

Metatarsalgia is a pathology that causes localized pain in the forefoot, specifically in the support area of the metatarsal heads and toes [1]. This pathology is related to imbalances in the length and position of the metatarsals, resulting in increased plantar pressure on one or more of them [2]. If the pathology does not respond to conservative treatments (physiotherapy and stretching exercises for gastrosoleus tension, plantar foot orthoses, footwear modifications to reduce forefoot pressure, debridement of calluses, use of infiltrations), which are satisfactory in 85% of cases, a surgical approach with or without first metatarsal (M1) procedure is necessary [3].

Distal central radial osteotomies are one of the best surgical treatments for this pathology, as they allow a displacement of the distal capital fragment in three dimensions, modifying the weight supported by the metatarsal head and, in turn, the functional impact on the rest of the metatarsal heads. The use of this technique appeared for the first time

in the United States by specialists in podiatric medicine, among them the precursor, Dr. Morton M. Polokoff in 1945 and its use has been developed by other American podiatrists such as Dr. Stephen Isham [4]. Minimally invasive distal metatarsal osteotomies (DMMO) have currently gained popularity as an alternative technique to traditional Weil's osteotomy (WO) due to the perceived potential advantages of dynamic correction and the low cost of not using osteosynthesis materials. The main differences between the two techniques are therefore that DMMO is performed extra-articularly, without internal fixation, by percutaneous or minimal-incision surgery and therefore does not require ischemia; however, (WO) is located intra-articularly, using osteosynthesis material and ischemia tourniquet as it is open-field surgery.

Clinical indications for DMMO include pain under or around the metatarsal head (especially weight bearing), presence of plantar heloma, abnormal metatarsal parabola and metatarsal phalangeal joint subluxations (MTPJ). They allow a displacement of the distal fragment of the capitellum in three dimensions with the aim of reducing the length of the metatarsal, elevating the head, correcting the metatarsal parabola and reducing forefoot overload. Therefore, it achieves correct load distribution, which is a factor in relieving metatarsal pain [5,6].

The osteotomy is performed just at the widening junction where the diaphysis ends and the metaphysis begins, at the distal level of the lesser metatarsal. It is an extracapsular osteotomy but does not usually have any type of fixation, which can lead to greater than desired and uncontrolled displacement. It is performed on a 45° plane, with respect to the axis of the metatarsal in the sagittal plane. By performing the osteotomy at this point, the proximal fragment avoids overcorrection, limiting dorsal displacement (due to ground forces) and limiting shortening (due to soft tissue tension). With experience, the plane can be adjusted to achieve the desired elevation or shortening [7].

Currently, there are several surgical osteotomies to treat persistent metatarsalgia and among them, traditional WO by open surgery, DMMO and proximal osteotomies are the usual choice. Several studies have shown that DMMO offers comparable results to WO at the cost of fewer complications and far fewer technical difficulties. The percutaneous tool is an alternative that offers, for smaller radii, a different concept based on self-adjustment [8].

The articles published in recent years speak of the Maestro studies, which consider as their surgical objective the importance of re-establishing the metatarsal formula in this pathology, but the reality is that the length of the metatarsals is not the only thing responsible for biomechanical alterations in the forefoot [9].

This systematic review (SR) aims to comprehensively analyze the available evidence on the clinical improvement over time and the degree of satisfaction following DMMO central metatarsal osteotomies.

2. Materials and Methods

A SR was carried out following the criteria and according to the recommendations of PRISMA or 'Preferred reported items of SR and meta-analysis' [10]. The databases used were PubMed, Scielo, Cochrane Library, Web of Science and Scopus. The PICO strategy was followed to search for articles in the different databases.

The PICO question is composed of:

P-Patient: Patient diagnosed with central radial metatarsalgia with failure of conservative treatment.

I-Intervention: DMMO.

C-Comparison: Clinical improvement of patients before and after the intervention and degree of satisfaction.

O-Outcome (Results): Reduction of symptomatology and improvement in quality of life.

The term used for the research articles was Distal Minimally Invasive Metatarsal Osteotomy, 'DMMO', lesser toe. The search strategy used in PubMed, Scielo, Cochrane Library, WOS and Scopus databases was: ('DMMO') in open access articles. Boolean

operators were not used. The research was conducted between 22 January 2024 and 1 April 2024.

2.1. Inclusion Criteria

The criteria established for the inclusion of this systemic review were:

- SR;
- Randomized controlled trials (RCTs) and non-randomized controlled trials (nRCTs);
- Retrospective or prospective observational studies;
- Articles in English and Spanish;
- Patients with primary metatarsalgia without the presence of Hallux abducto valgus (HAV);
- Patients should be treated with the DMMO technique;
- Maximum time: 10 years.

2.2. Exclusion Criteria

The criteria were:

- Patients undergoing DMMO at M1 or M5 (fifth metatarsal);
- Patients with metatarsalgia secondary to systemic, rheumatoid, Morton's neuroma, or iatrogenic disease.

2.3. Study Selection Process

The selection of the studies was made by a single researcher. When the search strategy was performed in each database, the articles that met the inclusion criteria were selected. Subsequently, those that were duplicates were eliminated. Each title was read and, based on whether or not it fit our research on the DMMO technique, it was discarded or saved for further reading. The articles were then read in their entirety and discarded if they were irrelevant to the study or did not meet the inclusion criteria.

2.4. Data Extraction

After collecting the articles, they were classified according to their different characteristics. These were composed of author, date of publication of the article, sample size, age, sex and surgical technique. Finally, the different results of each study and the conclusions were collected.

2.5. Risk of Bias Assessment Tool

The Risk of Bias (Robbins-I) proposed by the Cochrane manual was used to collect the level of evidence and the risk of bias.

3. Results

3.1. Process of Identification and Selection of Studies

First, a search was carried out in the aforementioned databases with the terms 'DMMO', lesser toe and Distal Minimally Invasive Metatarsal Osteotomy, obtaining a total of 147 articles. After applying the inclusion criteria (maximum age of 10 years, articles in English or Spanish and open access), there were a total of 39 articles. After discarding duplicate articles, the result was 18 articles. Therefore, these 18 relevant articles were selected for full-text evaluation. After reading, eight articles were discarded, many of them repeating the same information. Finally, 10 articles were used in the development of this systematic review (Figure 1).

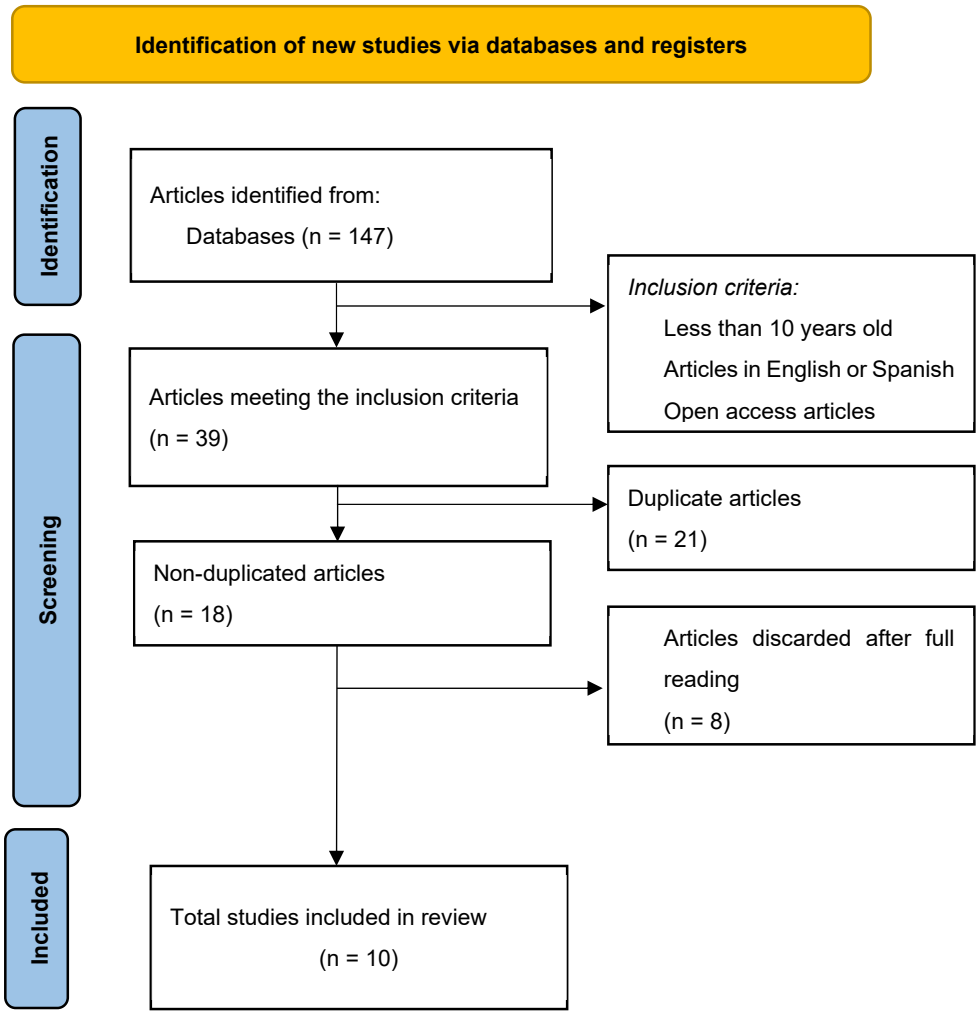

Figure 1. Flow chart of the searching strategy and final studies included.

3.2. Risk of Bias Found in the Studies

The risk of bias of the 10 articles was estimated using the Robbins-I tool for nonrandomized interventional studies. Seven articles received a low risk of bias (LR). There were three articles that showed a moderate risk of bias (MR) because the authors of the articles displayed evidence of treatment effects but further research may change and show different effects, opening a new door to other methods (Table 1).

Table 1. Risk of Bias.

Author	Confusion Bias	Bias on the Selection of Participants	Bias on the Classification of Interventions	Bias due to Deviations from Planned Interventions	Bias due to Lack of Data	Bias on the Measurement of Results	Bias on the Selection of the Reported Outcome
McMurrich et al. [11]	MR	LR	LR	LR	LR	LR	LR
Magnan et al. [12]	LR	LR	LR	LR	LR	LR	LR
Haque et al. [13]	LR	LR	LR	LR	LR	LR	LR
Malhotra et al. [2]	LR	LR	LR	LR	LR	LR	LR
Eng Meng Yeo et al. [14]	MR	LR	LR	LR	LR	MR	LR
Martínez-Ayora et al. [8]	LR	LR	LR	LR	LR	LR	LR

Table 1. *Cont.*

Author	Confusion Bias	Bias on the Selection of Participants	Bias on the Classification of Interventions	Bias due to Deviations from Planned Interventions	Bias due to Lack of Data	Bias on the Measurement of Results	Bias on the Selection of the Reported Outcome
De Prado Ripoll et al. [1]	LR	LR	LR	LR	LR	LR	LR
Biz et al. [3]	LR	LR	LR	LR	LR	LR	LR
Naranjo-Ruiz et al. [15]	LR	LR	LR	LR	LR	LR	LR
Tournemine et al. [6]	MR	LR	LR	LR	LR	LR	LR

3.3. Characteristics of the Selection Studies

Publication dates range from 2015 to 2021, the oldest being Haque et al. [13] and the most recent being Prado-Ripoll et al. [1]. The articles come from different countries: Spain, France, Italy, the UK and Singapore.

3.4. Study Design

Of the 10 articles used in the SR, five studies are prospective studies, four are retrospective studies and one article is a cross-sectional analytical study.

3.5. Level of Evidence

The level of evidence was not specified for any of the articles reviewed, except for the ones by McMurrichb et al. [11] and Haque et al. [13], which were rated as level 4. The SIGN guidelines [16] were used to assess the level of evidence of the articles based on their bias level score and type of scientific research article. Four studies were rated as 2+ level of evidence, five studies as level 1+ and one study as level 1++ on the SIGN scale.

3.6. Sample Characteristics

3.6.1. Sample Size

A total of 366 subjects were found in the 10 articles [1–3,6,11–15,17]. The study with the largest sample was that of Biz et al., with 93 subjects [3]. Martínez-Ayora et al. [8] had the smallest sample size, with 10 subjects.

3.6.2. Age and Sex

The mean age in all studies was 61 years. The youngest subjects included were 31 years old in the studies by Biz et al. [3] and Eng et al. [14]. The oldest age was 79 years, in the study by Malhotra et al. [2]. In total, more women were included than men. The 10 studies included 297 women and 59 men. The study by Biz et al. [3] showed the largest difference between men and women, 14 vs. 79. The oldest age was 89 years and that study was conducted by Tournemine et al. [6].

3.6.3. Development of the Inclusion Criteria

The 10 studies included subjects who had been symptomatic with isolated primary metatarsalgia, precisely located below the metatarsal heads of M2 (second metatarsal), M3 (third metatarsal) and M4 (fourth metatarsal), for at least 6 months and who had failed conservative treatment (Table 2). There was only one study which did not present the same inclusion criteria as the previous ones because the surgical technique was performed on cadavers and the anonymity of the body donation program did not allow information on previous pathologies, cause of death, age and sex of the specimens to be obtained [8].

3.6.4. Development of the Exclusion Criteria

As for exclusion criteria, patients who had already undergone several previous surgeries or asymmetries in the lower limbs, paralysis of any muscle group, HAV, M5 deformities, rearfoot alterations, MTPJ dislocation, diabetes mellitus, nerve entrapment or

rheumatic diseases and all those with secondary metatarsalgia were excluded from the study [1–3,6,8,11–15,17].

Table 2. Table of results for the systematic review.

Articles	Author and Year	Design	Level of Evidence (SIGN)	Sample/ Sex	Average Age	Surgical Technique	AOFAS Results	MOXFQ Results
'MIS Distal Metatarsal Metaphyseal Osteotomy in the treatment of metatarsalgia: MOXFQ patient reported outcomes'	W. McMurrich, A. Peters, M. Ellis, H. Shalaby G. Baer, D. MacDonald, J.C. McKinley. (2020) [11]	Observational, descriptive and retrospective study.	2++	24 patients 20 women 4 men	64 years	DMMO	79%	24.3
'Percutaneous distal osteotomy of lesser metatarsals (DMMO) for treatment of metatarsalgia with metatarsophalangeal instability'	Bruno Magnan, Ingrid Bonetti, Stefano Negri, Tommaso Maluta, Carlo Dall'Oca, Elena Samaila. (2017) [12]	Retrospective study.	2+	57 patients 55 women 2 men	60.2 years	DMMO	88.6%	-
'Outcome of Minimally Invasive Distal Metatarsal Metaphyseal Osteotomy (DMMO) for Lesser Toe Metatarsalgia'	Syed Haque, Rajesh Kakwani, C. Chadwick, Mark Bowen Davies, and Chris M. Blundell. (2015) [13]	Observational, descriptive and retrospective study.	2++	30 patients 17 women 13 men	60 years	DMMO	-	31
'Minimally invasive distal metaphyseal metatarsal osteotomy (DMMO) for symptomatic forefoot pathology—Short to medium term outcomes from a retrospective case series'	Karan Malhotra, Nikita Jojia, Simon Mordecaib, Ben Rudgea. (2018) [2]	Retrospective study.	2+	43 patients 41 women 2 men	60.2 years	DMMO	-	31
Comparison of early outcome of Weil osteotomy and distal metatarsal mini-invasive osteotomy for lesser toe metatarsalgia'	Nicholas Eng Meng Yeo, Bryan Loh, Jerry YongQiang Chen, Andy Khye Soon Yew, Sean YC Ng. (2016) [14]	Systematic review.	1+	33 patients 21 women 12 men	63.8 years	WO VS DMMO	88%	-
'Ultrasound-guided distal minimally invasive metatarsal osteotomies (US-DMMO): A cadaveric study about its safety and accuracy'	Alvaro Martínez-Ayora, Manuel Cuervas-Mons, Ana Fajardo-Ruiz, Tamara Rodríguez-López, Javier Vaquero, Luis Sanz-Ferrando. (2021) [8]	Analytical cross-sectional study.	1++	10 patients	-	US-DMMO	-	-
'Medium-Long-Term Clinical and Radiographic Outcomes of Minimally Invasive Distal Metatarsal Metaphyseal Osteotomy (DMMO) for Central Primary Metatarsalgia: ¿Do Maestro Criteria Have a Predictive Value in the Preoperative Planning for This Percutaneous Technique?'	Carlo Biz, Marco Corradin, Wilfried Trepin Kuete Kanah, Miki Dalmau-Pastor, Alessandro Zornetta, Andrea Volpin, Pietro Ruggieri. (2018) [3]	Prospective study.	1+	93 patients 79 women 14 men	62.4 years	DMMO	81.4%	-
'Clinical results of treatment of mechanical metatarsalgia without first metatarsal involvement'	De Prado-Ripoll J, De Prado M, Forriol F. (2021) [1]	Continuous prospective study.	1+	29 patients 27 women 2 men	58 years	DMMO	76%	-
'Influence of Foot Type on the Clinical Outcome of Minimally Invasive Surgery for Metatarsalgia. A Prospective Pilot Study.'	Carmen Naranjo-Ruiz, Alfonso Martínez-Nova, María de los Ángeles Canel-Pérez, Miguel López-Vigil, Javier Ferrer-Torregrosa, Carlos Barrios. (2021) [15]	Prospective study.	1+	28 patients 22 women 6 men	57.8 years	DMMO	92.9%	-
'Shortening efect infuence of Distal Minimally Invasive Metatarsal Osteotomy in primary metatarsalgia.'	Simon Tournemine, Fabien Calé, Cyrille Cazeau, Thomas Bauer, Yves Stiglitz. (2021) [6]	Observational, descriptive and retrospective study.	2++	19 patients 15 women 4 men	64 years	DMMO	-	-

3.7. Complications

The incidence of recurrence or transfer injury was negligible (three cases) and resolved with a second intervention by DMMO osteotomy, and the only long-term complication was persistent stiffness in 9.7% of patients [3].

Some patients had prolonged post-surgery edema due to early ambulation, which resolved spontaneously after 3 months. No rehabilitation treatment was recommended and the return to sports practice was 3 months after surgery [14].

4. Discussion

From the results it appears that metatarsal surgery, specifically the DMMO technique, offers optimal clinical and functional results, with improvement in the clinical scales performed between 6 [14] and 58.7 months on average [3]. The clinical scales used were mainly the AOFAS scale [1,3,12,14,15,17] and the MOXFQ. The AOFAS scale measures both objective parameters (ranges of motion) and subjective parameters such as pain or adaptation to footwear. The MOXFQ scale, as a scoring system, is validated to measure all foot and ankle surgeries and is collected in 16 items, comprising three blocks: walking/standing (7 items), foot pain (5 items) and social interaction (4 items). The scores of this system are comprised between 0–100 where 0 is the best possible score and represents an excellent result [13].

In relation to the AOFAS scale, the studies obtain increases in the score of between 27 (48.6 ± 7.3 and 75.6 ± 12.1) [3] and 52.11 points (42.82–15.6 and 92.93 ± 8.6 at 12 months) [16]. It seems to be observed that as the follow-up time is longer, the improvement increases in the AOFAS scale [1,3,12,14,15,17]. All the studies achieve clinical results of "excellent" or very good, indicating that DMMO osteotomy produces a clear clinical improvement. Both patients and surgeons appear to be very satisfied [1].

This clinical improvement would be related to the re-establishment of the imbalance between soft tissue and bone tissue as the cause of mechanical metatarsalgia, which is corrected by the shortening of the affected metatarsal or metatarsals [6]. Another factor that could explain the surgical success would be related to the absence of post-surgical stiffness and the fact of preserving the flexor plate [17]. In reference to the recovery of the activities of daily living, the gait recovers its normality twelve months after the intervention, as the residual edema and any type of pain disappear [15]. Moreover, in all cases, pain improves or disappears in an average follow-up of forty-five months [12].

The improvement obtained is reflected in all the scales analyzed (AOFAS, MOXFQ, SF36, EVA) as well as the reduction of hyperkeratosis and MTF instability; however, this is not related to a harmonious metatarsal formula, according to Maestro [9] (only in 3.2% of the cases) [3].

In the comparison of the results of the WO versus the DMMO group, 30% of the WO patients presented some degree of MTPJ stiffness and two patients in the DMMO group presented prolonged edema up to 3 months post-surgery [14]. The WO is recommended in cases of MTPJ dislocation or dynamic metatarsalgias and the use of DMMO in purely static metatarsalgias and it is determined that an average shortening of 3–4 mm per metatarsal obtains good medium-term results [11].

DMMO osteotomies are usually performed in conjunction with other procedures in forefoot surgery, including hallux valgus and hammer toes or claw toes, yielding results that do not differ from those of performing DMMO alone in terms of recovery and patient satisfaction [13], also being an alternative that has the advantage of speed, with the absence of ischemia, in a multiple and prolonged procedure.

In cases where there is a subluxation, DMMO can be used successfully, but if the dislocation is complete, the technique of choice is Weill osteotomy (WO) [11].

DMMO presents benefits in terms of surgical time and hospitalization, including recovery and a low risk of complications with respect to other alternative techniques by open surgery, but we must plan the technique correctly to avoid transfers mainly to M4 [3,12]. A modification of DMMO, where fluoroscopy is replaced by ultrasound (US-DMMO), avoids soft tissue damage and is a safe alternative to fluoroscopy because it

eliminates ionizing radiation exposure to both staff and patients This technique does not modify the approach route and by being able to visualize them by ultrasound it avoids damage to soft tissues. Therefore, ultrasound allows the obtainment of a large number of planes, a three-dimensional orientation and no overlapping of planes, thus improving the location and angulation of the incision and approach point in DMMO [8].

5. Conclusions

The results show that the DMMO technique for metatarsal surgery offers optimal clinical and functional results with improvement in the scales analyzed, observing that the longer the follow-up time, the greater the improvement in the AOFAS scale. The clinical improvement seems to be related to the shortening of the affected metatarsals and the re-establishment of the imbalance between soft tissue and bone tissue; however, this is not related to a harmonic metatarsal formula. In turn, patients and surgeons report a high degree of satisfaction. DMMO is recommended over OT in the surgical treatment of static metatarsalgia with a lower degree of stiffness.

It seems that future lines of research could be directed towards the use of ultrasound as a reliable method in achieving the desired clinical results but eliminating the risk of ionizing radiation. In general, the recent emergence of MIS surgery in relation to traditional techniques makes it lacking in long-term studies and also in the number of publications.

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