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# Radiographic Outcomes of Minimally Invasive Distal Metatarsal Metaphyseal Osteotomy (DMMO) for primary central metatarsalgia

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**Objective is to investigate the potential of DMMO to restore a harmonious forefoot morphotype according to Maestro criteria.**

**Retrospective study investigated 51 feet in 48 patients with central primary metatarsalgia between the 2nd and 4th metatarsal. Associated procedures included hallux valgus and lesser toe corrections. Patients were evaluated radiographically with comparison of their forefoot morphotypes after the DMMO procedure to their preoperative state regarding the Maestro criteria. A subgroup of 17 patients was evaluated for union in 3 months and functionally by the AOFAS and VAS scale.**

**Ten percent of the 48 patients were male and ninety percent were female with a mean age of 52.1 ± 11.7 (range 23 to 70) years. In total 148 DMMOs were performed in 51 feet. Osteotomies were localized on M2 and M3 in 10% and on three metatarsals (M2-M3-M4) in 90%). In 84% associated procedures were performed. All radiographic parameters of the Maestro criteria were significantly different preoperative compared to postoperative ($p<0.05$). In 94% patients of the subgroup there was a bony consolidation at three months. There was a mean AOFAS-score of 76.8 ± 15.1 (range 49-95) and a mean VAS-score of 2.7 ± 1.7 (range 1-6). There were late complications in 8% of the patients.**

**DMMO is effective for treating primary central metatarsalgia unless the ideal harmonious forefoot was not restored. For DMMO the Maestro criteria have no predictive value for clinical outcome in preoperative planning. Further studies are necessary to correlate the functional improvement.**

**Level of evidence: Level IV retrospective case series**

**Keywords:** DMMO, Maestro criteria, forefoot morphotypes, radiographic.

## INTRODUCTION

Central metatarsalgia is a common problem in the orthopaedic foot and ankle practice, where the pain is situated on the plantar forefoot region between the 2nd and 4th metatarsal heads[1-3]. Associated deformities of the first, fifth ray and the lesser toes can be present. Metatarsalgia is a frequent condition that affects 10% of the general population throughout the course of their lifetime and mostly women[4,5].

There can by several contributing factors of the metatarsalgia syndrome which can be classified as primary or biomechanical and secondary or iatrogenic[2,6,7]. Primary metatarsalgia is present in approximately 90% of the cases and is caused by intrinsic abnormalities in metatarsal anatomy with a resultant overload in the forefoot[1,3]. The most common anatomic abnormality is a long second metatarsal bone[5]. Anatomical variance in the forefoot can cause imbalance in weight bearing leading to mechanical overload followed by pain and plantar callosities of the affected metatarsal heads[8]. Other causes of primary metatarsalgia include a congenital short first metatarsal or severe hallux valgus (HV) with transfer metatarsalgia, disproportionate length of the third metatarsal, congenital deformity of the metatarsal heads, tightness of the triceps surae, fixed equinus, pes cavus or any hindfoot deformity resulting in overloading of the forefoot[9].

Maestro and Besse studied forefoot morphology and defined precise criteria for the ideal morphology[5]. The first step in the treatment of metatarsalgia is conservative such as physiotherapy and stretching for gastrosoleus tightness, shoe modifications, functional

orthoses, debridement of painful callosities and injection of corticosteroids[10]. Before considering surgery, conservative measures should always be explored, as they yield satisfactory results in 85% of the cases[2,6].

When conservative treatment fails, surgery could be proposed with or without treatment of the first ray[11,12]. The goal of surgery is to relieve pain by restoring an ideal forefoot morphology with normalisation of pressure distribution in the forefoot[13-15]. Many surgical procedures have been described for this pathology, from which the Weil osteotomy has been the preferred technique for many years[16-19]. However, this procedure has become controversially and only indicated in cases where there exist an (sub)luxation of the metatarsophalangeal (MTP) joint because of its main complication postoperative stiffness[20,21].

DMMO has gained popularity in the last decade, which is a percutaneous extra-articular osteotomy without internal fixation[16,17,22]. The metatarsal lengths are set automatically upon weight bearing and results in less postoperative stiffness compared to the Weil osteotomy[14]. Because risk of wound healing problems in diabetic patients, this percutaneous procedure is also used in a modified way to reduce plantar pressure of metatarsal bones over chronic plantar ulcers[23].

The primary purpose of this retrospective study was to evaluate the potential of DMMO in restoring a harmonious foot morphotype according to Maestro's criteria and if these radiographic parameters are correlated with clinical outcomes. To tell us whether to maintain the predictive value of these criteria during preoperative planning, also for this percutaneous surgery.

## MATERIALS AND METHODS

In our hospital AZ Sint-Lucas Brugge, between January 2018 until September 2021, 51 feet in 48 consecutive patients with the diagnosis of central primary metatarsalgia were enrolled in this retrospective study.

All patients underwent DMMO performed by two surgeons PD and FT, both trained together in minimally invasive surgery (MIS). This study was approved by the Institutional Ethics Committee.

Inclusion criteria were patients with central primary metatarsalgia between the 2nd (M2) and 4th metatarsal (M4). Patients were excluded if they had previous foot surgery or trauma or when they had secondary or iatrogenic metatarsalgia, when there was arthritis of the metatarsophalangeal (MTP) joint, hallux rigidus, congenital deformities, infection and neurologic pathology. Only symptomatic patients with failed conservative treatment underwent DMMO. Associated forefoot pathologies included hallux valgus (HV) deformity, MTP joint instability and flexible or fixed lesser toe deformities.

Preoperative the patients were evaluated both clinically and radiographically. Clinical evaluation consisted of documentation of the affected side, presence of plantar callosities, pain on palpation, shortening of the triceps surae, symptomatic MTP instability and presence of lesser toe deformities or hallux valgus. Radiographically a normal or harmonious forefoot shows a geometrical progression of M2 regarding the relative lengths of the lesser metatarsals compared to the SM4 line and all patients were classified regarding the Maestro criteria (Figure 1)[24]. The DMMO was done only for the symptomatic metatarsals, but in the case the neighbouring metatarsal became too long after this shortening, this metatarsal was also shortened because of the high risk of transfer metatarsalgia. When associated deformities were present, they were corrected in the same surgical procedure. HV corrections were done by a Chevron-Akin or Scarf-Akin procedure. For lesser toe deformities the approach was tailored based, existing of percutaneous tenotomies of flexor and extensor tendons and percutaneous and open interphalangeal (IP) plasties.

The operative technique for the DMMO was performed according to the same general principles as described by De Prado[17]. The patient is positioned supine, with the contralateral foot lowered with the adjustable table end. The mini c-arm is used for every step of the procedure to objectify the position of the osteotomy (Figure 2). If a thigh tourniquet was applied for related procedures such as HV correction, it was deflated for the DMMO procedure. Prophylactic antibiotics were administered before the surgery. The anaesthetist performed a popliteal block preoperative.

The bandage technique is very important to maintain the metatarsal head position as there is no osteosynthesis material for this operation technique. A Pehahaft bandage was used between all intermetatarsal spaces and with gentle traction the toe was maintained in light hypercorrection and plantar inclination (Figure 3). During every clinical follow-up the bandage was reapplied by the surgeon.

The postoperative protocol was the same for every patient and was standardized and identical for both surgeons. The operations were done in day surgery and the patients were allowed to weight bear immediately as much they could tolerate with a rigid flat-soled orthopaedic shoe for the following 6 weeks.

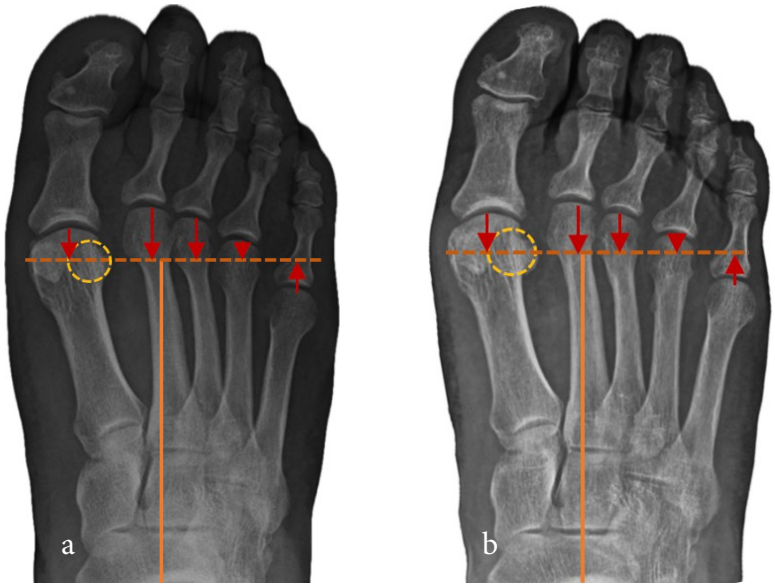


*Fig. 1 — Maestro criteria.*
*The vertical foot axis (orange solid line) runs from the midpoint of the Chopart joint to the second metatarsal head. The SM4 line (orange dashed line) is the line perpendicular to the previous one bisecting the lateral sesamoid. Relative length to the SM4 line of the lesser metatarsal heads is measured (red arrow lines) to determine the morphotype and calculate the number of metatarsals to be shortened during the DMMO procedure.*
*1a. Preoperative, non-harmonious 2*
*1b. 8 months postoperative, non-harmonious 2.*


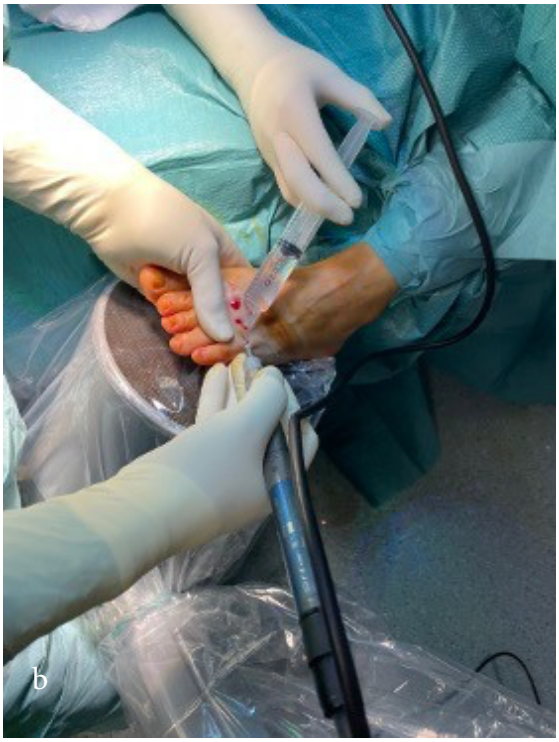


*Fig. 2 — Surgical procedure of DMMO.*
*2a. Beaver knife is used to make stab incision after determination of position by mini c-arm.*
*2b. Position of osteotomy is objectified again by mini c-arm and Shannon burr is cooled with Saline and blood by operating without a tourniquet.*

No thromboprophylaxis was prescribed. The patients were seen clinically at 2 weeks for a wound check and reapplication of a bandage by the surgeon. At 6 weeks the postoperative shoe was weaned off and an anteroposterior and lateral weightbearing X-ray was performed. After 3 months a final X-ray was performed to confirm consolidation. Postoperative an online questionnaire was sent to the patients to assess functional outcome with the American Orthopaedic Foot & Ankle Society (AOFAS) scale 25 and the Visual

*Fig. 3 — Bandage technique with Pehahaft.*

Analogue Scale (VAS). Unfortunately, only a subgroup of 17 patients completed the questionnaire and had their x-ray at the 3-months follow-up because of restrictions in the COVID19 period. Any complications were recorded.

The clinical and radiographic assessment were carried out by a registrar orthopaedic surgery LL and documented in an anonymized database together with patients' demographics (Table I). Radiographs were obtained preoperative and postoperative at the 6-weeks and 3-months follow-up. The radiographs were analysed in a standardized manner using the Maestro measurements (Figure 1) and classified according to the Maestro and Besse criteria (Table II): harmonious morphotype (normal forefoot), nonharmonious morphotype-1, non-harmonious morphotype-2, non-harmonious morphotype-3 and unclassified nonharmonious. Union was confirmed on X-ray of the 3-months follow-up.

The data are presented as mean plus standard deviation or median with range for continuous variables and as numbers for categorical data. The

**Table I.** — Demographics and comorbidities.

| | |
|---|---|
| Gender | |
| Male | 5 /51 (9.8) |
| Female | 46/51 (90.2) |
| Age (years) | 52.1 ± 11.7 |
| Smoking | |
| Yes | 9/51 (17.6) |
| No | 42/51 (82.4) |
| Side | |
| Right | 30/51 (58.8) |
| Left | 21/51 (41.2) |
| Comorbidities | |
| Hypertension | 5/51 (9.8) |
| Vascular disease | 7/51 (13.7) |
| BMI | 26.2 ± (3.8) |
| >30 kg/m$^2$ | 6/51 (11.8) |
| ASA | |
| 1 | 42 (82.4) |
| 2 | 9/51 (17.6) |
| 3 | 0/51 (0) |

**Table II.** — Morphotypes: pre- and postoperative, normal population[33].

| | Normal population | Preoperative | Postoperative |
|---|---|---|---|
| Harmonious | 31% | 0 | 2.0% (1/51) |
| Non-harmonious 1 | 30% | 41.2% (21/51) | 17.6% (9/51) |
| Non-harmonious 2 | 37% | 52.9% (27/51) | 78.4% (40/51) |
| Non-harmonious 3 | 2.4% | 5.9% (3/51) | 0 |
| Unclassified non-harmonious | 0 | 0 | 2.0% (1/51) |

Chi-square test was used to analyse the radiological classification regarding the Maestro criteria preoperatively compared to postoperatively. The Wilcoxon test was used to assess the relationship between complications and comorbidities (smoking, hypertension, vascular disease, Body Mass Index (BMI) and American Society of Anaesthesiologists (ASA)). Statistical significance was considered for $p < 0.05$.

## RESULTS

In our institution 51 feet in 48 patients with the diagnosis of primary central metatarsalgia were treated by DMMO by two foot- and ankle surgeons. All patients were evaluated clinically and radiologically initially, but only 17 patients were assessed functionally by a questionnaire and with a radiograph 3 months postoperatively.

Five (10%) of the patients were male and forty-six (90%) were female. The mean age was 52.1 ± 11.7 (range 23 to 70) years. 30 patients (59%) were operated on their right foot and 21 (41%) on their left foot.

Regarding risk factors 18% were smokers, 12% were obese and 24% had significant comorbidities (hypertension or vascular disease). According to the ASA classification there were 42 ASA 1 patients (82%), 9 ASA 2 patients (18%) and no ASA 3 patients. (Table I)

In total 148 DMMOs were performed in 51 feet. Osteotomies were localized on M2 and M3 in 5 (10%) and on three metatarsals (M2-M3-M4) in 46 (90%) (Table III). In 43 (84%) of the 51 feet associated procedures were performed. In 2 feet a Scarf-Akin procedure was performed, in 27 a Chevron-Akin and in 29 feet a correction of a toe deformity was carried out.

In our study all radiographic parameters of the Maestro criteria were significantly different preoperative compared to postoperative ($p<0.05$). The harmonious morphotype was present in none of the cases preoperatively and only in 1 case (2%) postoperatively. A nonharmonious morphotype-1 was present in 21 (41%) patients preoperatively compared to 9 (18%) postoperatively. A nonharmonious morphotype-2 was identified in 27 (53%) cases preoperatively with respect to 40 (78%) cases postoperatively. A nonharmonious morpotype-3 was identified in 3 (6%) preoperative patients and in none of the postoperative patients. An unclassified morphotype was present in 1 (2%) postoperative patient and in none of the preoperative patients. (Table II). From the 17 patients who had their radiography at the 3 months follow-up, 16 (94%) patients achieved bony consolidation. The one patient had a delayed union of her 3rd metatarsal after a trauma with her dog.

For the 17 patients who completed the questionnaire at their 3 months follow-up, there was a mean AOFAS-score of 76.8 ± 15.1 (range 49-95) and a mean VAS-score of 2.7 ± 1.7 (range 1-6).

There were early complications in 9 (18%) of the 51 feet operated. Three patients experienced complex regional pain syndrome, one patient had hypoesthesia of 2 digits, two patients had persistent metatarsalgia, two patients had stiffness in their MTP

**Table III.** — Distribution and number of metatarsal osteotomies done in a single surgical procedure.

| | Normal population | Preoperative | Postoperative |
|---|---|---|---|
| Harmonious | 31% | 0 | 2.0% (1/51) |
| Non-harmonious 1 | 30% | 41.2% (21/51) | 17.6% (9/51) |
| Non-harmonious 2 | 37% | 52.9% (27/51) | 78.4% (40/51) |
| Non-harmonious 3 | 2.4% | 5.9% (3/51) | 0 |
| Unclassified non-harmonious | 0 | 0 | 2.0% (1/51) |

joints and 1 patient had delayed union. At one year postop there were still residual complications in 4 (8%) of the patients. Smoking showed a significant correlation with complications ($p < 0.0032$). All the other comorbidities were not considered significant: hypertension ($p > 0.9587$), vascular disease ($p > 0.5916$), ASA > 1 ($p > 0.9384$) and BMI > 30 kg/m2 (0.5814).

## DISCUSSION

In the last decade DMMO became more popular in Europe as an alternative for the more traditional Weil osteotomy. Currently there is a preference of DMMO over open osteotomies because of the well-known postoperative stiffness and floating toe[16,24]. Distal Metatarsal Metaphyseal Osteotomy (DMMO) is a relative safe and effective minimally invasive method for the treatment of primary central metatarsalgia. Smoking is a possible contraindication. The ideal harmonious forefoot was only found in one case postoperative. Hence for DMMO the Maestro criteria have no predictive value for clinical outcome in preoperative planning.

Further studies are necessary to correlate the functional improvement[26]. Distal Metatarsal Metaphyseal Osteotomy (DMMO) is a relative safe and effective minimally invasive method for the treatment of primary central metatarsalgia. Smoking is a possible contraindication. The ideal harmonious forefoot was only found in one case postoperative. Hence for DMMO the Maestro criteria have no predictive value for clinical outcome in preoperative planning.

Further studies are necessary to correlate the functional improvement.

This study showed that the ideal harmonious forefoot type was not restored apart from one case. This is also stated by literature that the optimal treatment and restoration of the ideal forefoot morphotype remains controversial[1,2]. Rivero-Santana et al. stated that time to bone healing was longer for DMMO and Weil osteotomy had more wound problems and stiffness[27]. A recent meta-analyses showed that Weil osteotomy and DMMO are equally safe and effective for the treatment of metatarsalgia[28].

As shown be our study smoking was related to complications in DMMO. A study of Bettin and al. revealed that cigarette smoking is a risk factor for forefoot surgery in general and that surgeons should consider convincing their patients for a cessation[29]. The mean age in our study was 52 years and the oldest patient was 70 years. Vermersch et al. mentioned that there weren't more complications in elderly in forefoot surgery if major surgical procedures were avoided in this age group[30]. Obesity was not related to complications in our study which was also confirmed by a study of Stewart in al. for forefoot procedures, however in case of diabetes there were more wound healing problems1[3].

In 57% of the operated feet in our series there was a related procedure to correct a hallux valgus deformity. Instability of this first ray can be a provoking or exacerbating factor of metatarsalgia. Bevernage made the conclusion that radiographic preoperative planning only in the anteroposterior plane is not sufficient as these pathologies require corrections in three- dimensional planes[21]. A three-dimensional correction for the DMMO procedure is on the other hand difficult to assess completely as there is a potential proximal shift of the metatarsal heads in both the sagittal and coronal planes and the displacement is not only peroperative, but also postoperative with weight bearing. In contrast to the Weil osteotomy, where there is a fixed position of the osteotomies by screw fixation.

Radiographic morphotypes regarding the Maestro criteria were significantly different preoperative compared to postoperative. In only one case postoperative the harmonious morphotype was restored. Previously, Jardé et al. proved that patients with restoration of postoperative alignment close to the Maestro criteria after Weil osteotomies had better results[15]. However the Maestro criteria were not met in our review, there were acceptable clinical outcome scores with a mean AOFAS-score of 77 and a mean VAS-score of 2.7. Further studies are imperative to prove the redundancy to restore a harmonious forefoot type after a DMMO procedure despite good clinical outcome scores.

A limitation of our study is that we don't know the exact healing time of most of our patients because of restricted follow-up during the COVID19 pandemia. Nevertheless, there was a union rate of 94% of the subgroup of patients who had their 3 months postoperative x-ray. As mentioned earlier, it was stated in a recent meta-analysis that DMMO requires a longer time to union, but has better results compared to Weil osteotomy[28]. Distal Metatarsal Metaphyseal Osteotomy (DMMO) is a relative safe and effective minimally invasive method for the treatment of primary central metatarsalgia. Smoking is a possible contraindication. The ideal harmonious forefoot was only found in one case postoperative. Hence for

DMMO the Maestro criteria have no predictive value for clinical outcome in preoperative planning.

Further studies are necessary to correlate the functional improvement.

There were late complications in 8% of the patients. Persistent metatarsalgia resolved with insoles, stiffness improved with physiotherapy and the delayed union was resolved in the 16- weeks follow-up. Complications of DMMO are reported in the literature and Redfern does not recommend DMMO in presence of arthritis or stiffness of MTPs[16,18]. The most common long-term complication in our series was complex regional pain syndrome (CRPS). However, CRPS is an uncommon complication, it was shown by a retrospective review of 390 cases that in half of the patients who developed CRPS the forefoot was involved[32].

Our review revealed that unless the ideal harmonic forefoot type regarding the Maestro criteria was not restored, there were good functional outcomes scores. This could be potentially explained by redistributing the plantar forces by a DMMO not only as measured on the anteroposterior view, but three-dimensional planes. Further review is necessary to correlate functional outcomes with measurements for example with weightbearing CT-scan and potentially to revise specific preoperative planning criteria for DMMO.

## CONCLUSION

Distal Metatarsal Metaphyseal Osteotomy (DMMO) is a relative safe and effective minimally invasive method for the treatment of primary central metatarsalgia. Smoking is a possible contraindication. The ideal harmonious forefoot was only found in one case postoperative.

Hence for DMMO the Maestro criteria have no predictive value for clinical outcome in preoperative planning. Further studies are necessary to correlate the functional improvement.

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