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Original Article

Minimally invasive distal metaphyseal metatarsal osteotomy (DMMO) for symptomatic forefoot pathology – Short to medium term outcomes from a retrospective case series

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ABSTRACT

Background: Minimally invasive distal metaphyseal metatarsal osteotomy (DMMO) may be used to treat metatarsalgia and forefoot pathology. Few large series report its results or examine the degree of metatarsal shortening with this technique. The clinical and radiographic results of a cohort of patients treated with DMMOs at our unit are reported.

Methods: This was a single-centre retrospective study looking at the outcome of consecutive patients undergoing DMMOs. Demographics, radiological and clinical outcomes, complications and patient reported outcome measures (PROMs) were analysed.

Results: DMMOs on 106 toes in 43 feet were included. Mean age was 60.2 ± 10.2 years and median follow-up was 38 months. Concurrent procedures were performed in 26 cases (60%). DMMO was performed on multiple toes in 42 cases (97%). Mean shortening achieved was 3.6 ± 2.2 mm, 4.1 ± 1.6 mm, and 3.6 ± 1.6 mm for the second, third and fourth metatarsals respectively. Mean time to fusion was 11.4 ± 7.8 weeks and union occurred in 105 toes (99%). The single non-union was asymptomatic at 12 months. Two patients required a subsequent additional DMMO for transfer metatarsalgia. Minor complications were seen in 11 patients (26%). At final follow-up PROMs data was available for 42 cases: mean MOxFQ was 28.8 ± 27.6, mean EQ-5D was 0.789 ± 0.225, mean EQ-VAS was 68.5 ± 20.3, mean VAS-Pain score was 3.1 ± 2.8, and patients were satisfied overall in 40 cases (95%).

Conclusions: The authors demonstrate excellent radiological and clinical outcomes in the short to medium term with DMMOs and present data on metatarsal shortening achieved with this technique.

1. Introduction

The morphology of the forefoot and its impact on gait has long been a topic of interest for the orthopaedic surgeon. During stance, there is a transfer of load from hindfoot to forefoot and from the lateral to the medial rays [1,2]. In the normal foot, the differing lengths of the metatarsals form a parabola whereby there is balanced, progressive loading of the metatarsal heads such that approximately 50% of the forefoot load is borne by the lesser metatarsals and 50% by the 1st metatarsal [3]. Imbalances in the lengths or positions of the metatarsals may result in one or more rays being relatively longer. The longer metatarsals may come into contact with the ground earlier, resulting in increased loading [2,3]. This increased pressure can result in callosities, pain, and rupture of the plantar plate with associated subluxation of the metatarsophalangeal joint (MTPJ) [4,5].

Pain under the lesser metatarsal heads is termed metatarsalgia and when it is due to the relative lengths of the metatarsals it is termed primary metatarsalgia [3]. Maestro et al. described an ideal or harmonious foot morphotype where the metatarsal parabola allowed smooth progression of forces throughout gait and did not result in increased plantar pressures [2]. Where the morphotype had one or more relatively longer metatarsals, it was termed inharmonious. As described above, an inharmonious morphotype has been associated with increased localized plantar pressures [2,5] and many authors recommended shortening of the metatarsals to recreate the normal parabola and balance forefoot loading [6–8].

A number of osteotomies are described to restore the metatarsal parabola, and the Weil's osteotomy in particular has been widely used as it provides the ability to fix the length of the metatarsals according to a preoperative plan [2,3,8–10]. However, the Weil's osteotomy is not

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without complications: it is an intra-articular osteotomy which can result in stiffness, floating toes, and is frequently an open procedure [11]. More recently, surgeons have performed minimally invasive distal metaphyseal metatarsal osteotomies (DMMO) with the perceived advantages of a minimal incision, reduced operative time, and allowing the length of the metatarsal to be set automatically according to soft-tissue tension and pressures generated during weightbearing. Common indications include primary metatarsalgia or MTPJ subluxation with a relative lengthening of the lesser metatarsals [9]. Criticisms of the technique include persistent swelling and lack of fixation which may not recreate the ideal foot morphotype [12,13].

Although DMMOs have been performed for a number of years, the number of clinical studies reporting their results are limited and most series have small numbers of patients with short durations of follow-up. Furthermore, few studies examine the degree of metatarsal shortening achievable with this technique. In the present study, a series of DMMOs with clinical and radiological outcomes and short to medium term follow-up are discussed. In addition, the degree of metatarsal shortening achieved was examined. The aim of this study is to demonstrate that DMMO has good results in the short to medium term and that sufficient shortening can be achieved using this technique.

2. Materials and methods

This is a single-centre, single surgeon, retrospective series looking at consecutive percutaneous DMMOs performed at our unit over a 52-month period (between 2012 and 2017). Institutional review board approval was obtained prior to conducting this study. Demographic data was obtained on all patients and review of radiographs and clinical notes was performed. All patients undergoing the procedure were included with no exclusions. All patients had preoperative and postoperative weightbearing radiographs of their foot.

2.1. Surgical technique

All procedures were performed as day case procedures, under general anaesthesia, using an upper thigh tourniquet. Patients were supine and intra-operative fluoroscopy was used to identify the appropriate location for the osteotomies. If surgery on the 1st ray was required, this was performed first, followed by the DMMO. Any subsequent procedures to the lesser toes were performed last.

For the DMMOs dorsal stab incisions were made on the medial side of the metatarsals and the soft tissue surrounding the metatarsal was cleared percutaneously. A 2 mm × 12 mm Shannon burr (WG Healthcare UK Limited, Letchworth, Hertfordshire, UK) was used to perform the osteotomy. Osteotomy of the 2nd metatarsal was performed first, followed by the 3rd and 4th as required. The osteotomy was performed at an angle of 45° to the metatarsal axis starting at the extra-articular subcapital region of the metatarsal, in a proximal-plantar to distal-dorsal direction. In most cases, care was taken to ensure that the osteotomy finished dorsally with the burr perpendicular to the metatarsal shaft to ensure there was no medial or lateral obliquity to the cut. However, where varus or valgus angulation was present at the distal metatarsal, the cut was finished slightly oblique to the metatarsal shaft to allow lateral or medial translation to correct the deformity. The burr runs with continuous saline irrigation to wash out debris and prevent thermal necrosis.

Postoperatively the wounds were washed out with saline prior to being closed with absorbable interrupted sutures and dressed. Patients were allowed to mobilize weightbearing as tolerated in a flat postoperative shoe, unless they had a concomitant 1st ray procedure which required an initial period of heel-weightbearing. The wound was reviewed at 2 weeks postoperatively and weightbearing radiographs were taken at 6 weeks postoperatively. Where union was not achieved at 6 weeks, most patients had further radiographs 12 weeks postoperatively. However, the exact timing of further follow-up and the number of subsequent radiographs performed over the course of follow-up were determined according to the individual clinical and radiological parameters.

2.2. Clinical and patient reported outcome measures

Clinical outcome was determined from clinical notes and patient questionnaires. This included indication, concomitant procedures, complications, persistent oedema, time to union, and return to activity. At our unit it is standard practice to record these factors, whether present or absent, in our clinical notes which allowed a retrospective review of this nature.

The present study focussed on patient reported outcome measures (PROMs) as there is a current trend toward recording and presenting this data and it reflects what is important to the patients. The EuroQol 5-dimensions 5-Likert scale (EQ-5D) which includes the EuroQol visual analogue health thermometer (EQ-VAS) was used. Additionally, the visual analogue pain score (VAS-Pain) and the Manchester-Oxford Foot Questionnaire (MOxFQ) were recorded. The MOxFQ is a well validated scoring system which examines pain (MOxFQ-P), ability to walk (MOxFQ-W) and social activity (MOxFQ-S), as well as summary index score (MOxFQ-I) [14–17]. The interpretation of scores are summarized in Table 1. Finally, patients were asked if they were satisfied with the result of their operation overall.

As this was a retrospective study PROMs were only assessed postoperatively and no pre-operative scores were available for comparison. PROMs were measured for all patients at the time of initiating the study. The reported PROMs were therefore assessed between 10 and 62 months postoperatively at a median time of 38 months after surgery.

2.3. Radiological measurements

All patients had digital preoperative and postoperative weightbearing anterior–posterior radiographs of their foot. These were standardized with the patient asked to stand normally with both feet on the digital receiver plate with the source directly above and angled 10° toward the heel. The leg was kept perpendicular to the floor and weight evenly distributed between both feet. The beam was centred on the base

Table 1
Results of patient reported outcome measures. The Manchester-Oxford Foot Questionnaire (MOxFQ) has 3 domains which measure pain (MOxFQ-P), walking ability (MOxFQ-W), and social activities (MOxFQ-S). Additionally, the scores can be presented as an aggregate index score (MOxFQ-I). For the MOxFQ a lower score reflects a better health state. The EuroQol 5-dimensions (EQ-5D) consists of 5 questions examining patient's health state. A score of 1.000 suggests a state of perfect health, and a score of 0.000 represents the worst possible health state. The EQ-VAS is a health thermometer scale where a score of 100 represents the best health state imaginable and 0, the worst health state imaginable. The visual analogue pain scale (VAS-Pain) is from 1 to 10 with 10 being the worst pain imaginable and 0 being no pain.

	EQ-5D	EQ-VAS	MOxFQ-P	MOxFQ-W	MOxFQ-S	MOxFQ-I	VAS-Pain
Mean	0.789	68.5	30.6	29.3	25.8	28.8	3.1
SD	0.225	20.3	25.9	30.0	30.3	27.6	2.8
Min	0.153	15	0	0	0	0	0
Max	1.000	98	85	100	100	89	9

of the 3rd metatarsal. All images were stored on our digital Patient Archiving and Communication Software (PACS, Agfa Healthcare, Greenville, South Carolina, USA) after correcting for magnification. Postoperative radiographs were used to determine radiological union. Measurements were taken to determine the degree of shortening of the metatarsals following union as described below.

Numerous methods of determining metatarsal length and shortening have been proposed. These include various methods using computed tomography (CT) scans or laser scanning [18,19]. Protrusion of the 2nd metatarsal has been calculated by measuring the height the metatarsal head projects above a tangential line drawn between the 1st and lesser metatarsal heads [20–23]. Other authors have determined the midpoint of the hindfoot and drawn arcs from this point to determine and compare metatarsal length [24]. A number of these studies have used the diaphyseal axis of the 2nd metatarsal as the main reference point as it represents the axis around which the foot rotates during gait. Finally, Maestro et al. drew the axis of the 2nd metatarsal to the midpoint of the hindfoot and then drew the perpendicular line which passed through the midpoint of the lateral sesamoid [2].

These methods were adapted for our purposes for a number of reasons. Firstly, the hindfoot was not adequately visible in all of our radiographs and therefore we used the diaphyseal axis of our 2nd metatarsal for our main axis line (Line L1). Secondly, because we performed 1st ray surgery in a number of cases, the position of the lateral sesamoid may have shifted. In order to calculate shortening of the metatarsals we required a fixed point and none of our patients had surgery to the 5th metatarsal. Therefore, the most distal point of the articular surface of the 5th metatarsal was used as the reference point for the perpendicular line to the 2nd metatarsal axis (Line L2). The height of each metatarsal was measured as the perpendicular distance (in millimetres) from Line L2 to the most distal articular surface.

Additionally, the length of the 5th metatarsal on the preoperative and postoperative radiographs were measured to compare them. This served the purpose of allowing us to adjust for any magnification differences, as being of a fixed length between radiographs any difference in length observed would be due to differences in magnification. The postoperative radiograph measurements were then adjusted by this magnification factor. Finally, the corrected measurements taken on both the immediate preoperative and final postoperative radiograph were compared to find the difference in metatarsal length produced by the DMMO. The difference in metatarsal lengths where DMMO was not performed was expected to be 0 mm and this served as a further in-built validation of the method. The method is summarized in Fig. 1.

The relationship between the length of the 1st and lesser metatarsals was not measured as a number of patients had procedures on the 1st ray which did not allow accurate estimation of changes in relative length: for example, when patients had a hallux MTPJ fusion.

A pilot series on 10 feet was performed to determine intraobserver and interobserver reliability. This was performed by 2 of the authors. Subsequently all measurements were made by a single author with two measurements taken for each foot and the average taken as the final measurement.

2.4. Statistical analysis

Statistical analysis was carried out using SPSS 22.0 (IBM, Armonk New York, USA). Data are presented as means with standard deviations. Shapiro–Wilks test for normality was performed and found that all measurements were normally distributed and therefore parametric testing was performed where required. Differences between measurements taken preoperatively and postoperatively were compared using a 2-tailed paired Student's *t* test. Statistical significance was considered to be a p-value of < 0.05.

Intraclass correlation (ICC) was used to determine intraobserver and interobserver agreement. For both measures we utilized absolute agreement, single measure models. For intraobserver agreement we used a two-way mixed model, but for interobserver agreement we used a two-way random model to improve applicability to future studies [25]. ICC values greater than 0.800 were considered to indicate excellent agreement, values between 0.600 and 0.800 indicated good agreement, and values between 0.400 and 0.600 were considered to indicate moderate agreement [26]. ICC values are presented along with 95% confidence intervals.

3. Results

In total DMMOs were performed on 106 toes in 43 feet, in 40 patients. The female to male ratio was 41 to 2. The mean age of all patients was 60.2 ± 10.2 years (range 39–79 years). Surgery was performed on the left foot in 21 cases and the right foot in 22 cases. Two patients were diabetic (5%), and 1 patient was taking glucocorticoids (2%). The indication for DMMO was primary metatarsalgia in 20 out of 43 cases (46%), transfer metatarsalgia (after previous hallux surgery or with current severe hallux valgus deformity) in 11 out of 43 cases (26%) and MTPJ subluxation with associated inharmonious foot morphotype in 12 out of 43 cases (28%). The mean duration of follow-up was 37.7 ± 15.8 months (range 10–62 months). Greater than 24-months follow-up data was available for 34 out of 40 patients (85%).

3.1. Procedures performed

Concurrent procedures included hallux valgus correction (either scarf or chevron osteotomy) in 16 out of 43 cases (37%), hallux MTPJ fusion in 4 out of 43 cases (9%), and other lesser toe procedures (such as interphalangeal joint fusion) in 11 out of 43 cases (26%). All cases with transfer metatarsalgia due to hallux valgus had concomitant correction or fusion of deformity prior to DMMO being performed.

DMMO was performed on the 2nd metatarsal in 42 out of 43 feet (98%), on the 3rd metatarsal in 41 out of 43 feet (95%), and on the 4th metatarsal in 21 out of 43 feet (49%). In total DMMO was performed on 2 toes in 24 out of 43 cases (56%), on 3 toes in 18 out of 43 cases (42%), and in only one toe in 1 case (2%).

3.2. Complications

The mean time to both clinical and radiological union was 11.4 ± 7.8 weeks (range 6–45 weeks, median: 8 weeks). There was 1 non-union out of 106 toes (1%). This patient was asymptomatic at 1 year suggesting fibrous union had occurred. No major complications were experienced - as the non-union was eventually asymptomatic it was not considered a major complication. In total there were 11 minor complications in 43 feet (26%). These are summarised in Fig. 2 and include 2 superficial infections (5% of operated feet) which were managed with antibiotics but did not require a return to theatre, and 2 cases of persistent swelling beyond 3 months, both of which had settled by 1 year (5% of operated feet). In addition, 2 out of the 24 patients (8%) who had DMMOs of the 2nd and 3rd metatarsals, but not the 4th, developed transfer metatarsalgia, which settled after a further DMMO of the 4th metatarsal – this represents a 5% rate of transfer metatarsalgia across all operated feet. Finally, 4 patients (9% of operated feet) had some degree of persistent forefoot pain beyond healing of the osteotomies. In 2 cases this improved by 1 year post-operatively, and in 1 case the patient's symptoms were manageable with orthotics. In the final patient, no cause for ongoing persistent symptoms could be established.

3.3. Patient reported outcomes

PROMs scores were available for 39 out of 40 patients (42 out of 43 cases, 98%), the 1 patient whose PROMs' data was missing died of unrelated causes prior to completing PROMs, although the patient did unite and was doing well at final follow-up. The mean postoperative

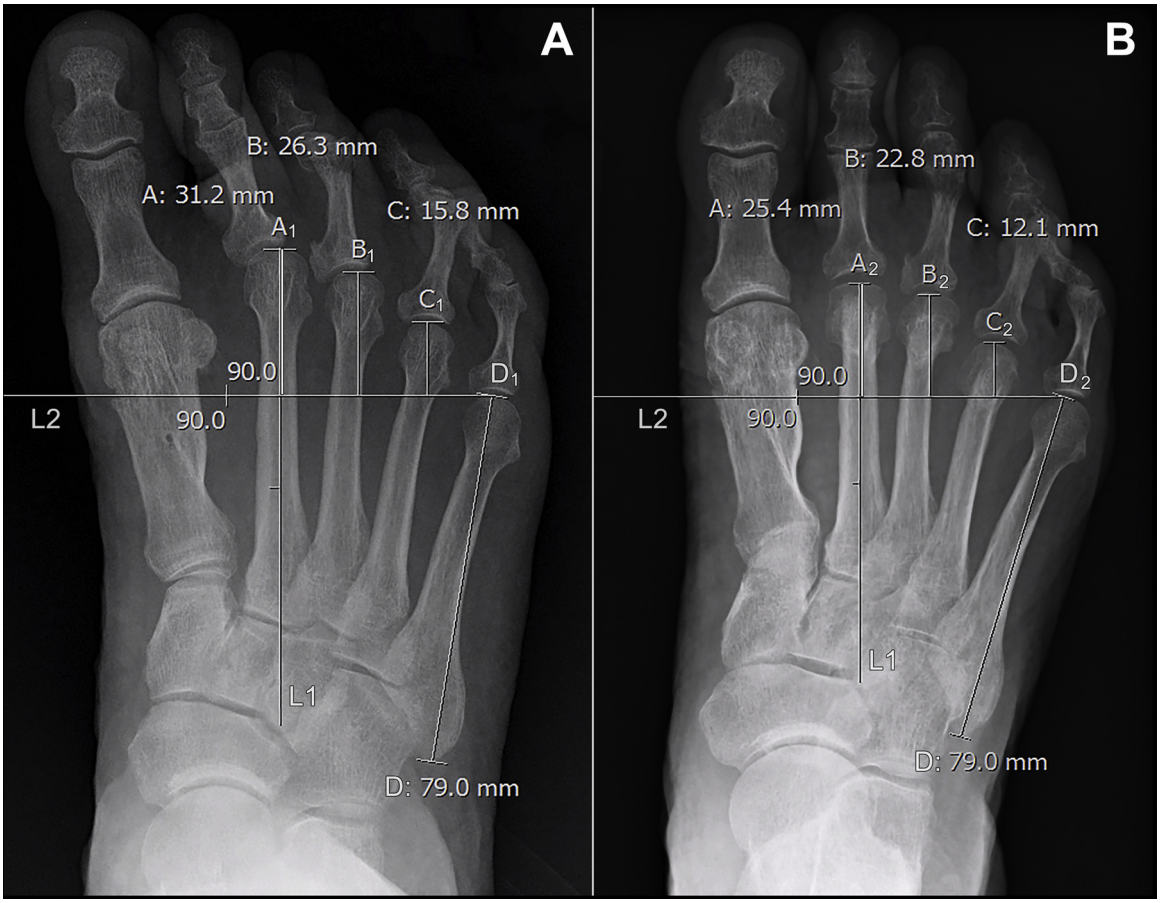

Fig. 1. Technique of measurement for determining metatarsal shortening. (A) The preoperative, anteroposterior, weightbearing radiograph and (B) the post-operative, weightbearing radiograph. Firstly, Line L1 is constructed along the second metatarsal diaphyseal axis (axis of the foot). Line L2 is constructed perpendicular to this from the distal articular surface of the 5th metatarsal. Line L2 is therefore represents a constant position across radiographs. Next measurement D is drawn and compared between (A and B) to determine any differences in magnification. Finally, the perpendicular distances from Line L2 to the distal articular surfaces of the 2nd, 3rd and 4th metatarsals are measured as A–C respectively. The shortening of the metatarsals is calculated as $A_1 - A_2$, $B_1 - B_2$, and $C_1 - C_2$: in this example, shortening of 5.8 mm, 3.5 mm and 3.7 mm for the 2nd, 3rd and 4th metatarsals has been achieved.

EQ-5D was 0.789 ± 0.225, the mean EQ-VAS was 68.5 ± 20.3, the mean VAS-Pain score was 3.1 ± 2.8, and the mean MOxFQ-I was 28.8 ± 27.6. These are summarized in Table 1.

In total 37 out of 39 patients (95%) returned to their desired level of activity, including sporting activities, and patients reported they were satisfied with their outcome in 40 out of 42 cases (95%).

3.4. Radiological measurements

The radiographs of 43 feet were analysed using our measurement

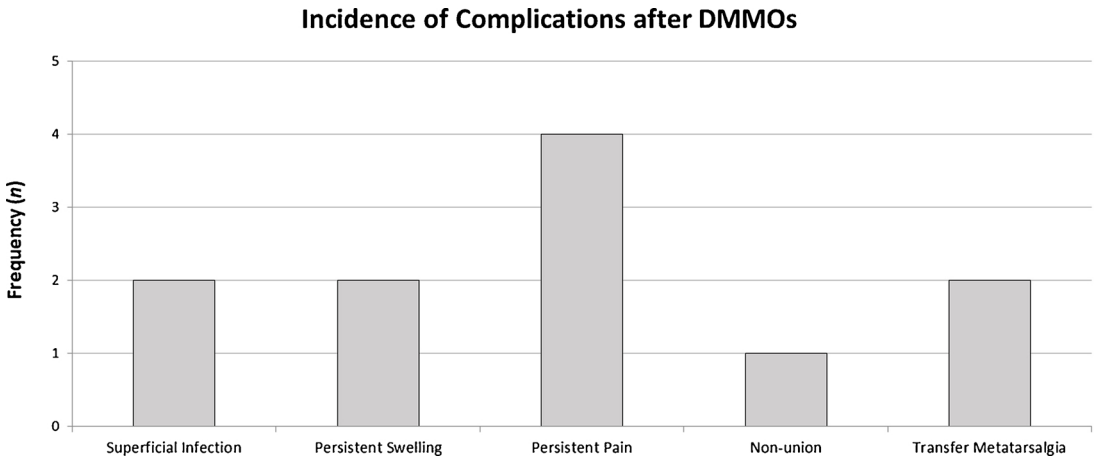

Fig. 2. Figure illustrating the frequency of complications seen in this series, where *n* is the number of feet in which the complication was seen. Persistent swelling refers to swelling which was present for longer than 3 months following procedure. Persistent pain refers to pain which persisted after union had occurred and swelling had settled.

Table 2
Results of intraclass correlation (ICC) for intraobserver and interobserver agreement. Presented as ICCs with 95% confidence intervals in parentheses. The results indicate excellent intraobserver and interobserver agreement for all measurements (ICC > 0.800).

	Intraobserver agreement (two-way mixed, absolute agreement, single measure)		Interobserver agreement (two-way random, absolute agreement, single measure)
	Observer – 1	Observer – 2	
2nd metatarsal	0.993 (0.972–0.998)	0.986 (0.946–0.997)	0.921 (0.655–0.975)
3rd metatarsal	0.991 (0.967–0.998)	0.989 (0.961–0.997)	0.925 (0.704–0.975)
4th metatarsal	0.986 (0.947–0.997)	0.967 (0.867–0.992)	0.837 (0.518–0.940)
5th metatarsal	0.998 (0.992–0.999)	0.991 (0.965–0.999)	0.854 (0.541–0.947)

system as described above. The ICCs obtained for intraobserver and interobserver agreement are detailed in Table 2. We demonstrated excellent intraobserver and interobserver agreement using this measurement system. For toes not operated on, the mean difference in length measured on the radiographs was 0.0 ± 0.5 mm (range −0.7 to 1.0 mm) indicating that our expected error in measurement would be less than 1 mm.

The mean preoperative 5th metatarsal length was 72.9 ± 5.7 mm and the mean postoperative length was 72.8 ± 5.9 mm, with no statistical difference ($p = 0.855$). The mean calculated magnification factor error was −1 ± 2.5% (range −5% to 5%). The mean corrected shortening achieved was 3.6 ± 2.1 mm for the 2nd metatarsal ($p < 0.001$), 4.1 ± 1.6 mm for the 3rd metatarsal ($p < 0.001$), and 3.6 ± 1.6 mm ($p < 0.001$) for the 4th metatarsal. This is summarized in Table 3.

Finally, our preoperative foot morphotype were compared with our postoperative foot morphotype and these results are summarized in Table 4. The mean difference between the lengths of the 2nd and 3rd metatarsals increased by 0.5 mm, whilst the mean differences between the lengths of the 3rd and 4th metatarsals, and the 4th and 5th metatarsals decreased by 2.1 mm and 1.8 mm respectively. Although all metatarsals shortened, this indicates that the 3rd and 4th metatarsals shortened relatively more than the 2nd. Fig. 3 shows an example of a successful procedure that fused well.

4. Discussion

Due to the inclination of the metatarsals to the ground, as little as 2 mm of relative change in metatarsal length may be associated with increased forefoot pressures and callosities [2,18]. Offloading with orthotics is the first stage in treatment, but should surgery be required, shortening the lesser metatarsals by 3–4 mm can sufficiently reduce plantar pressures (by up to 10,300 N/m^2) [8]. Conversely, over-shortening (of 5–6 mm) may result in subsequent transfer of load to the adjacent toes as shortening by 5 mm also elevates the metatarsal head by approximately 2.8 mm [6,27].

Given differences of a few millimetres can make a significant difference to forefoot pressures, inaccurate reproduction of the pre-operative plan may potentially result in ongoing symptoms. Despite careful planning, it can be challenging to recreate an ideal foot morphotype, particularly when planning with radiographs [28,29]. Metatarsal osteotomies without fixation have therefore gained popularity as they allow length and position to be set in accordance with soft-tissue tension and weightbearing pressures. Indeed, previous studies have shown good results with Weil's osteotomies performed without fixation [30]. DMMOs have the added advantage of being minimally invasive, and although associated with a significant learning curve, minimally invasive techniques are safe [31–33]. DMMOs have been compared to Weil's osteotomies in a number of studies and found to offer similar results at final follow-up [12,34,35].

Although there have recently been a number of studies looking at outcomes of DMMOs, only one major study looks at shortening achieved [12]. This series by Henry et al. found that in their DMMO group each metatarsal was shortened by about 4–5 mm which was different than in their Weil's osteotomy group where the length was set according the harmonious foot morphotype. They also found less shortening of the 2nd metatarsal compared to the 3rd and 4th [12]. Our findings are similar and we report a mean shortening of between 3.6 and 4.1 mm for our metatarsals. Furthermore, our final foot morphotype would not be considered ideal by the criteria of Maestro et al. and the relative difference in length between the 2nd and 3rd metatarsals in our series increased postoperatively [2]. Nevertheless, our patients' symptoms resolved in the vast majority of cases. The present authors speculate that (in line with findings of previous studies [5,7,36,37]) this may be because the length of the 2nd metatarsal and function of the 1st ray are more important than the ideal foot morphotype. However, as the relationship between the length of the 1st and 2nd metatarsals was not measured, no firm conclusions can be drawn and further work will be required in this regard.

Our clinical outcomes and complication rate are in keeping with previously published studies which report an overall non-union rate of 0–3% (1% in our study), transfer metatarsalgia in 2.4–6.2% (8% of the subgroup in our study), persistent forefoot pain in 5.8–19.4% (9% in our study), persistent oedema beyond 3 months in up to 59% (5% in our study), and a patient satisfaction rate of 89–99% (95% in our study) [12,13,28]. Persistent oedema has been variably reported after DMMOs and some authors report no cases of this in their series [34]. The cause is unclear but may relate to ongoing movement at the osteotomy site whilst healing occurs. We routinely counsel patients that swelling takes longer to settle after DMMOs compared to other foot operations, but that it will usually resolve by 6–12 months. We had 2 cases of transfer metatarsalgia and both of these were in patients who had DMMOs to only the 2nd and 3rd metatarsals. Although this number is not large enough to draw firm conclusions, as it represents 8% of the subgroup, counselling patients in whom DMMO of only 1 or 2 metatarsals is planned is recommended.

This study has few limitations. As a retrospective study only post-operative scores were recorded and additionally depend on the adequacy and accuracy of clinical notes. The notes reviewed all included documentation of presence of absence of the various complications/post-operative symptoms discussed in this paper, but nevertheless we cannot quantify the impact of PROMs on patients' symptoms and there

Table 3
Relative lengths of the lesser metatarsals compared to the Line L2 preoperatively and postoperatively.

	Preoperative mean (range) (mm)	Postoperative mean (range) (mm)	Difference mean (range) (mm)	*p*-Value
2nd metatarsal	27.6 ± 4.6 (13.1–35.9)	24.1 ± 4.2 (13.1–31.2)	3.6 ± 2.1 (1.4–9.8)	< 0.001
3rd metatarsal	22.8 ± 3.3 (16.6–31.5)	18.8 ± 3.1 (12.3–24.4)	4.1 ± 1.6 (1.7–8.1)	< 0.001
4th metatarsal	13.6 ± 2.1 (9.4–17.9)	11.8 ± 2.4 (7.4–17.7)	3.6 ± 1.6 (1.5–6.7)	< 0.001

Table 4
Relative lengths of the lesser metatarsals to each other preoperatively and postoperatively and compared to the ideal harmonic foot described by Maestro et al. [2].

	Preoperative mean (mm)	Postoperative mean (mm)	Maestro et al. [2] 'Harmonic Foot' (mm)
2nd–3rd metatarsal difference	4.9 ± 2.4	5.4 ± 2.3	3.4 ± 1.0
3rd–4th metatarsal difference	9.2 ± 2.1	7.0 ± 2.7	6.5 ± 1.0
4th–5th metatarsal difference	13.6 ± 2.1	11.8 ± 2.4	12.0 ± 1.9

is the possibility of failing to pick up other complications and concerns which were not documented. Scores may also be affected by concomitant foot and ankle pathology. Nevertheless, our PROMs are reported as a baseline for future studies to compare to. The results obtained for postoperative scores for the MOxFQ are also similar to those obtained by Haque et al. [28]. As a retrospective series the reliance is on clinical notes to monitor progress and any inaccuracies in this cannot be determined. As patients were not randomised to treatment there may have been a selection bias in this reported group. This was a single surgeon series and the results may not be generalisable to other surgeons. Our series reports on 106 toes in 43 feet, and is one of the larger series on DMMOs with the longest mean follow-up period. However, this is still a relatively small number and results of longer term follow-up would be desirable.

The present study is one of only two series to report the radiological outcome after DMMO with regard to the shortening achieved. However, plain radiographs were used and this method has inherent errors. Nevertheless, plain radiographs have been shown to be relatively accurate as the standard weight-bearing anteroposterior projection does not modify the relative lengths of the metatarsals [2]. Furthermore, this is a method of imaging which is cheap, and readily accessible to most surgeons and therefore our results have wider applicability. A validated method for calculating metatarsal shortening was not used, and our reasons for this was discussed in the methods section. The principles of our measurements are, however, based upon well-established and previously validated criteria and landmarks. Our system is easy to use, using only measurement and angle tools which should be widely available on most digital imaging software. Our method also does not need to have the hindfoot included in the radiograph and uses the fixed point of the 5th metatarsal so that it can be used even when intervening surgery is performed to the 1st ray. Finally, this study has shown that this method has excellent intraobserver and interobserver reliability.

5. Conclusions

This study demonstrates that excellent patient satisfaction can be achieved in the short to medium term with DMMO in the treatment of primary metatarsalgia. Excellent union rates may also be achieved along with a mean shortening of 3–4 mm, which appears to be sufficient to improve symptoms. Patients undergoing DMMO of the 2nd and 3rd metatarsals, but not the 4th appear to have a higher incidence of transfer metatarsalgia and this should be taken into account when planning surgery and counselling patients. A set of baseline PROMs at final follow-up is provided.

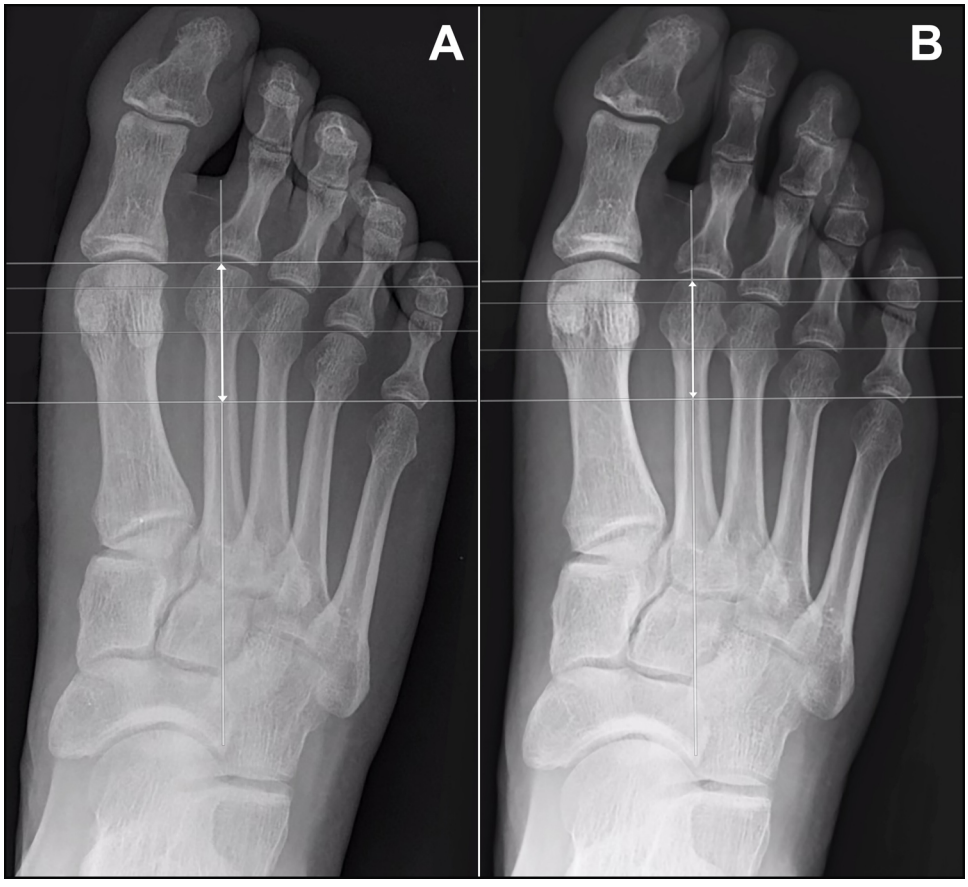

Fig. 3. (A) The preoperative radiograph of a patient undergoing DMMOs. The relative lengths of the metatarsals can be noted. (B) The same patient after undergoing DMMOs to the 2nd, 3rd and 4th metatarsals. The osteotomies have completely healed and it can be seen that although the relative lengths of the osteotomised metatarsals remain relatively unchanged compared to each other, their length has reduced.

6. Brief summary

What is known on the subject:

- DMMOs may be used to treat metatarsalgia caused by relatively long metatarsals.
- The goal of surgery is to restore the relative metatarsal lengths and normal parabola.
- Although some studies have looked at the short term outcome following DMMO, no studies have examined the degree of shortening achieved.

What this study adds:

- DMMOs can produce excellent radiological and clinical outcomes in the medium term.
- The mean shortening achieved with DMMOs in this series was 3–4 mm per metatarsal, which was sufficient to alleviate symptoms in majority of cases.
- DMMOs of only the 2nd and 3rd metatarsals may result in transfer metatarsalgia of the 4th metatarsal.

Conflicts of interest

The authors have no conflicts of interest to declare.

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