Abstract: The aim of the surgical treatment of metatarsalgia is to decrease the pressure under the metatarsal (MT) head. Percutaneous surgery of the foot, also known as minimal invasive surgery, allows interventions to be carried out through extremely small incisions without direct exposure of the surgical field under radiologic monitoring. The current authors present their experience with the distal MT osteotomy, in the context of the indications, the technique, postoperative management, and the outcome. Percutaneous osteotomy has proven to be a valid technique, providing satisfactory clinical and anatomic results, similar to open osteotomy, for the treatment of metatarsalgia and other forefoot problems.

Level of Evidence: Diagnostic Level 5. See Instructions for Authors for a complete description of levels of evidence.

Key Words: metatarsalgia, osteotomy, DMMO, percutaneous, forefoot

(Tech Foot & Ankle 2015;00: 000–000)

HISTORICAL PERSPECTIVE

Metatarsalgia is a vague term defining a symptom instead of a specific condition. It is a complaint that can interfere with normal ambulation, work, fitness, and recreation; it is more common in middle-aged women, with a prevalence around 10% in the general population.1 Defined as a pain in the plantar foot, it is usually associated with MT overload of the lesser ray, which is a fairly common pathology, mainly caused by a morphologic abnormality in the length or the position of the MT,2 which leads to an incorrect stance and alters the biomechanics of gait.

The aim of the surgical treatment of metatarsalgia is to decrease the pressure under the MT head, shortening and/or raising the MT, thus removing the overload and preserving the joint integrity.3 It has been somewhat controversial, with >25 different lesser MT osteotomies described to date. Historically, Meisenbach3 first described in 1916 an osteotomy to manage metatarsalgia: a diaphyseal osteotomy with considerable dissemination and good results. Years later, in 1940, Mau described a proximal metaphyseal osteotomy and Borgeve, in 1949, a distal MT osteotomy.4,5 Other authors such as Davidson, Sgarlato, and Helal modified the former techniques, but it was not until 1992 when Weil described a technique7 that enabled perfect control of the planned proximal migration of the MT head,4 consisting of an intra-articular oblique osteotomy of the MT neck and shaft. The Weil osteotomy, popularized in Europe by Barouk, is the most widely used surgical treatment in open distal MT surgery.6,7 Its popularity was based on the simple technique, stable fixation, excellent union rates, and predictable results.

According to the principles of traditional surgery, surgical maneuvers requiring large incisions and aggressive techniques should be needed to effectively resolve the different pathologic elements producing the deformity to eliminate this serious injury. These principles concern surgeons such as Withe,9 who described a modification of distal metaphyseal osteotomy in the neck through a percutaneous approach without visualization and without internal fixation to obtain an MT in the optimal weight-bearing position.3

Percutaneous surgery of the foot, also known as minimal invasive surgery (MIS), allows interventions to be carried out through extremely small incisions without direct exposure of the surgical field under radiologic monitoring, thus causing minimal injury to the adjacent tissues and reducing the surgical trauma.10 These techniques were pioneered by Morton Polokoff, who applied a subdermal surgical system for treating subungual exostosis. His ideas were later used by other foot surgeons: Prowler11 introduced new tools and described more aggressive techniques in the 1960s and Weinstock started using an electric motor. In the 1970s, several surgeons advanced these techniques, such Perrone or Pritz,12 who introduced new instruments and broadened the indications of MIS.

Nevertheless, the development and the expansion of these techniques in the following years had several complications due to its invasivity; in some cases, disabling sequelae occurred in a number of patients who underwent percutaneous foot surgery in the United States in the 1980s when the technique was rapidly gaining ground, being referred at that time as “the Surgical foot cripple” by Johnson,13,14 and it was considered ill-advised by a number of specialists since then. It was largely abandoned by most podiatric and orthopedic surgeons. During several years, MIS was suspended, considered a bad surgical method, except for a small group associated with the Academy of Ambulatory Foot and Ankle Surgery that continued to use and perfect these techniques.

It was not until the early 1990s when Stephen Isham described percutaneous techniques based on solid pathophysiological criteria, with careful design of the osteotomies and the surgical strategy, that yielded excellent results and provided an effective approach to resolve forefoot problems by MIS. Therefore, this technique showed high efficiency to solve problems of the forefoot without causing complications such as his predecessors.14 Techniques and principles used in the United States were applied and modified by European surgeons such as De Prado and colleagues15,16 during several years, broadening the indications, and other surgeons such as Bösch et al,17 Magnan et al,18 or Maffulli19 began to use these techniques in different European countries. In France, in 2002,
De Lavigne, Laffnètre, and Guillo, supported by De Prado, created the GRECMIP group, which is now considered to be one of the most important groups for the development, the validation, and the research of minimally invasive surgery of the foot and ankle.

Over the last few years, foot surgery has come to be recognized as a major orthopedic subspecialty, where percutaneous surgery plays an important role. Nowadays, percutaneous osteotomy has proven to be a valid technique that yields results similar to open osteotomy for the treatment of metatarsalgia and other forefoot problems.

INDICATIONS AND CONTRAINDICATIONS

The clinical appearance includes pain over the MT heads, which is exacerbated by weight-bearing, accompanied by plantar hyperkeratosis. Indications for surgery are basically clinical, including all static metatarsalgias of the lateral rays with plantar hyperkeratosis; length pattern alterations, transverse plane deformities, subluxation of the metatarsophalangeal joint (MTFJ), and intractable plantar skin lesions. The distal metatarsal minimal invasive osteotomy (DMMO) technique is indicated in patients with metatarsalgia and functional impairment, wherein medical treatment is unable to eliminate the pain symptoms and hyperkeratosis. DMMO can be performed on multiple metatarsals with lesser chance of producing elevation of 1 MT head as compared with diaphyseal osteotomies.

Specific contraindications of DMMO are active infection and the inability to complete postoperative management. An MTFJ dislocation higher than 0.5 cm is a relative contraindication, wherein DMMO should not be performed in the pursuit of joint restoration, but it could be performed as a decrease in symptomatic gesture.

PREOPERATIVE PLANNING

A precise understanding of the biomechanics, which may explain numerous problems affecting the feet, is extremely important for preoperative planning. The surgeon should mentally formulate a strategy that defines the most precise and effective manner to carry out the surgical intervention. Three conditions are essential to undertake DMMO safely: (i) thorough familiarity with the foot’s anatomy, to enable the creation of a percutaneous access route without iatrogenic lesions; (ii) adequate surgical instruments, to allow each step to be performed skillfully and effectively; and (iii) imaging guidance, to monitor the instrument’s position, follow the course of surgery, and confirm the results. With these premises, the surgeon will minimize the complications that are a byproduct of a lack of direct vision of the surgical field.

A complete radiography study is performed, including standard weight-bearing dorsoplantar, lateral, and oblique views, and an axial view of the MT heads, beneficial in...
evaluating the structure and the position of the central MT heads.

Surgical management of metatarsalgia with plantar keratosis is based on the characteristics of the callus, depending on the gait phase where they have their origin. On the basis of the “Rocker concept,” the second-rocker occurs once foot flat is achieved, and a discrete callus with a central keratotic core beneath the MT head can appear when there is increased plantar flexion of one or more MT heads leading to localized forefoot overload. The third-rocker occurs during heel rise, and the callus is linked to the MT length, causing a propulsive metatarsalgia, and a diffuse callus appears without a keratotic core. With MT osteotomy, we look forward to the ideal repositioning of the head, shortening and elevating it, achieved without internal fixation (Fig. 1). The osteotomy’s angle of cut, usually 45 degrees, may vary with the function of the type of callus, being slightly more vertical than 45 degrees in second-rocker callus, obtaining more shortening, and being slightly more horizontal in third-rocker ones looking for a higher elevation.

The number of osteotomies required is a decision based on clinical criteria and radiologic findings. The osteotomy is most often used on the second MT, but we prefer to perform it on the second, the third, and the fourth MT routinely. Exceptions should be considered, such as isolated fifth-ray metatarsalgia or cases with well-localized callus, where we follow the criteria of the Leventen formula: second and third MT should be performed when plantar hyperkeratosis is located at the second MT head; in cases in which the hyperkeratosis is located at the third MT head, which may or may not be associated with the second and/or the fourth MT heads, we recommended to perform osteotomies in the second, the third, and the fourth MT concomitantly. Only in cases with isolated fourth MT head hyperkeratosis, we recommend performing only a third and fourth osteotomy, but not in the second MT.

The osteotomy should be performed in the MT neck as the site of choice in our opinion. In cases of metatarsalgia secondary to diabetes, or other diseases involving vascular insufficiency, we prefer to perform it in the middle or the proximal third of the MT to obtain greater MT elevation, addressing only the affected MT instead of the 3 DMMO performed routinely.

TECHNIQUE

The surgical tools required to perform a DMMO are those used for percutaneous forefoot procedures: a straight burr, an MIS blade, elevators, rasp (large and small), a low-speed and high-torque drill, and a fluoroscope. MIS should never be carried out with mechanized or manual instruments adapted from conventional surgery; major complications can occur if inappropriate instruments are used.

The patient’s foot is scrubbed using disinfectant soap and painted with antiseptic solution. Block anesthesia (total ankle block or MT block) is performed and the patient is placed in the supine position with the foot free over the end of the table (Fig. 2). Ischemia, achieved with a pneumatic tourniquet or another method to obtain a blood-free working area, is never used.

A 0.5-cm longitudinal incision is made with an MIS blade in the intermetatarsal space immediately behind the dorsal interdigital fold (Fig. 3). Care should be taken to avoid the venous network at this level, which is usually visible owing to
vasodilation secondary to the ankle block. The incision is made parallel to the extensor tendon and the neurovascular structures (Fig. 4), and the scalpel is advanced at an oblique angle of about 45 degrees until it reaches the dorsal aspect of the MT neck to undergo osteotomy. A small rasp is then inserted and slid along the lateral or the medial cortical of the MT to be osteotomized, and the periosteum is separated over a small area (Fig. 5). The absence of soft tissue between the bone and the rasp is verified by the scraping of the instrument’s teeth on the bone. Fluoroscopy is used to confirm the correct position of the osteotomy site on the MT neck and the angle of cut, which should be 45 degrees relative to the long axis of the MT and in a dorsal-distal to proximal-plantar direction (Fig. 6). The osteotomy is started on the dorsal cortical where the cartilage of the MT head begins. The straight burr 2-15 is introduced into the space where the periosteum has been removed from the MT neck (Fig. 7) and the cutting is started.15

Once the cut has been marked clearly, the direction of osteotomy cannot be changed without breaking the burr. Thus, it is necessary to start a “twisting” rather than a lateral movement, using skin incision as a pivot point (Fig. 8). The lateral cortical surface is cut first, followed by the plantar cortical, the medial, and finally, the dorsal cortical. During the procedure, the forefoot is held in the other hand, with the first toe positioned on the plantar surface of the MT head being osteotomized and the other toes on the dorsal surface of the

MT shaft. Once the osteotomy is completed, the surgeon shall note that the head resistance to dorsal displacement will yield. This movement should be sparingly gentle, both when using the burr and when exerting pressure on the MT to avoid producing excessive displacement. Subsequently, under fluoroscopic vision, the toe that has been treated is placed gently in traction and the bone is seen to shift position, thereby confirming complete osteotomy (Fig. 9).

Osteotomies scheduled preoperatively are then performed, repeating the same procedure for each ray needing an osteotomy. Once all are completed, the incisions are closed with a 4/0 monofilament suture (Fig. 10) and the forefoot is wrapped with an MT strap using a self-adhesive bandage (Fig. 11).

RESULTS

In the author’s practice, this technique has been used for >15 years. We analyzed the results of a retrospective case series study, performed on patients operated with DMMO between 2002 and 2005 in our center, including patients with mechanical metatarsalgia without conservative treatment response after 6 months. Exclusion criteria were traumatic metatarsalgia, secondary metatarsalgia (diabetes, rheumatoid arthritis, or general diseases), equinus contracture, and previous forefoot surgeries. Sixty-two patients (84 feet) were included, with a mean age of 58 years (range, 21 to 79 y), including 54 women and 8 men. In all patients, a second, third, and fourth DMMO was performed, combined with different surgical procedures in the presence of associated deformities: (i) Reverdin-Isham osteotomy29 for hallux valgus (HV) deformity; and (ii) flexor and extensor tenotomies with distal phalangeal percutaneous osteotomy for lesser toe deformities. The preoperative American Orthopaedic Foot and Ankle
Society (AOFAS) score and the radiologic MT formula were recorded. The postoperative AOFAS score, clinical results of the scale evaluated subjectively (highly satisfactory, satisfactory, somewhat satisfactory or unsatisfactory), and radiologic osteotomy consolidation results were recorded at the 3-month follow-up. In our patients, associated deformities to metatarsalgia were as follows: 12 (14.28%) cases had no deformities, 20 (23.80%) had accompanying HV deformity, 21 (25%) had associated lesser toe deformities, and 31 (36.9%) had HV and lesser toe deformities concomitantly, with the index minus formula in 75 feet (89.28%) and the index plus minus in 9 (10.71%). The mean follow-up was 26 months (range, 12 to 35 mo), where the AOFAS score increased from a mean of 46 points preoperatively to a mean of 89 points ($P < 0.05$). Highly satisfactory results were obtained in 54 patients (64.28%), satisfactory results in 22 patients (26.19%), somewhat satisfactory results in 6 patients (7.14%), and unsatisfactory results in only 2 (2.38%) patients, both with hallux valgus-associated surgery. Radiologic consolidation was observed (Fig. 12) at 3 months postoperatively in 78 feet (92.85%). Unfortunately, there were 5 feet (5.95%) with delayed union, achieving radiologic consolidation at 12 months (Fig. 13), and 1 nonunion case (1.19%) in 2 of the 3 osteotomies performed (second and third MT). Postoperative complications were noted in 12 patients (14.28%): 2 cases of transfer metatarsalgia (2.38%), 1 case of persistent edema after 12 months (1.19%), 5 (5.95%) cases of residual hyperkeratosis (2 of them without clinical manifestation), and 1 case of floating toe (1.19%). No cases of Metatarsophalangeal joint (MTPJ) stiffness were recorded.

**COMPLICATIONS**

Before the decade of the 90s, MIS surgery yielded poor results due to incorrect indications and the use of nonspecific tools. Nowadays, DMMO complications are rare and can be avoided with appropriate care, controlling the shortening, while avoiding plantar depression of the head. They include nonunion and malunion, skin burn, wound infection, transfer metatarsalgia, MTPJ stiffness, MT head osteonecrosis, floating toes, and recurrent deformity. A skin burn can appear, but the risk of it decreases with the learning curve, and it is possible to minimize thermal lesions with saline irrigation of the entry point while performing an osteotomy. Transfer metatarsalgia is caused by a lack of harmonious forefoot reconstruction, mainly produced by technical imperfections (performing incomplete osteotomies or shaft osteotomies) or abnormal postoperative weight-bearing, which alters the normal shortening and

![FIGURE 12. Radiologic osteotomy follow-up.](image)

![FIGURE 13. Delayed union achieving radiologic consolidation at 12 months.](image)
elevation of the MT head. MTPJ stiffness is avoided by performing the osteotomy slightly more proximal than Weil osteotomy and extra-articular. Nonunion is an extremely rare condition, being described by surgeons as very rare, even without fixation of the osteotomy.5

POSTOPERATIVE MANAGEMENT
Surgery is performed on an outpatient basis. A surgical shoe is fitted, and walking is allowed immediately (Fig. 14) according to the usual postoperative guidelines. The first follow-up visit is performed at 7 days, when sutures are removed (Fig. 15). Weight-bearing dorsoplantar, lateral, and oblique radiographs of the foot are taken, and the patient is taught how to apply the MT strap (Fig. 16) after foot hygiene. Walking without the strap or the surgical shoe is prohibited for 1 month, because weight-bearing without a rigid sole would cause excessive extension of the MTFJ, favoring displacement and rotation of the osteotomized MT head.

One month after the surgery, there is enough fibrous callus around the osteotomy to permit the use of other types of shoes. The shoe should be wide, with a rigid sole and laces to provide a close fit. Pain and inflammation on the dorsal forefoot may persist for up to 2 or 3 months, particularly if there is an insufficient venous return, as is often the case.

POSSIBLE CONCERNS, AND THE FUTURE OF THE TECHNIQUE
Modern orthopedic surgery tends to use minimal invasive techniques to solve, or at least minimize, some of the problems raised in open surgery.31 The absence of direct visualization of the surgical field increased the risk of potential complications; this is the reason why the scientific community was very hesitant to use these techniques as standard procedures. Percutaneous surgery for metatarsalgia using DMMO is simple, effective, and reproducible,22 but it is a relatively new technique, with only a minimal number of reports on this topic available in the English literature.1 Henry et al32 compared DMMO with Weil’s osteotomy in 72 feet, showing a similar outcome in both the groups, and Mifsut et al,5 in his study with the first 28 DMMO they performed, obtained 81% good to excellent functional results, with 89% excellent cosmetic results. DMMO for static metatarsalgia provides satisfactory clinical and anatomic results, avoiding medium-term stiffness and pain typical of open surgery.4

DMMO indications should be accurate; the good results achieved do not imply that all foot interventions should be performed by MIS. Minimally invasive surgery is a method available to the surgeon, but not the end in itself; this method should be reserved for experienced surgeons in open and MIS surgery.31 We can reduce the complication rate by conducting training courses with opinion leaders on cadaveric anatomic specimens, allowing the surgeon to get used to the tools needed to perform MIS and to determine the right indications, thus smoothing the demanding learning curve and improving the initial results.

REFERENCES


