

## Ultrasound-Guided Bone Surgery: A New Perspective

Álvaro Martínez-Ayora<sup>1\*</sup>, Manuel Cuervas-Mons<sup>2</sup>, Javier Vaquero<sup>2</sup>

<sup>1</sup>Department of Orthopaedics and Traumatology, Hospital Universitario de Torrejón, Madrid, Spain

<sup>2</sup>Department of Orthopaedics and Traumatology, Hospital General Universitario Gregorio Marañón, Madrid, Spain

\*Correspondence should be addressed to Álvaro Martínez-Ayora; [amartinezay@torrejonsalud.com](mailto:amartinezay@torrejonsalud.com)

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We would like to thank Archives of Orthopedics for inviting us to comment on our recent publication “Tips, quips and pearls: Ultrasound-guided distal metatarsal minimal invasive osteotomy (US-DMMO)”[1].

Metatarsalgia is a frequent cause of forefoot pain [2]. Surgical treatment is based on the performance of osteotomies at the level of the minor radii to restore a normal distribution of pressure within the forefoot and improve the biomechanics during gait. In recent years, percutaneous surgery of the foot, and specifically distal metatarsal minimal invasive osteotomy (DMMO), have proven to be a valid technique, providing satisfactory clinical results, similar to open osteotomy with reduced operation time and less soft tissue damage [3-6]. In a context in which economic savings and the surgical time use are paramount, it is expected that the boom in percutaneous forefoot surgery will continue to develop in the coming years. Although quality cost-effectiveness studies are needed to confirm that DMMO is cost-effective compared to traditional Weil osteotomy, some authors report a 40% reduction in cost per procedure compared to open surgery, with no difference in post-surgical medical care costs [7]. Other minimally invasive techniques have shown a decrease in costs compared to their open variants, such as Achilles tendon repair [8], endoscopic carpal tunnel release [9], or traumatic and degenerative spinal pathology treatment [10,11]. Among the causes of economic savings, there is the decrease in surgical time and better use of operating rooms, the decrease in the implants used, the decrease in hospital stay and shorter recovery times with a faster return to work activity.

One of the disadvantages of percutaneous surgery compared to open surgery is the increased exposure

to ionizing radiation by the patient and the operating room staff. We consider radiological control essential to avoid some of the most devastating complications of percutaneous forefoot surgery. Nonunion occur when the osteotomy is performed too proximally and/or too vertical; on the other hand, articular damage and metatarsal head necrosis occur when the osteotomy is performed too distally and/or in an angle lower than 45° [7,12]. That is why we consider radiological control is always needed to perform minimal invasive osteotomies.

While the use of the ultrasound is widely accepted in soft tissue diagnosis, monitoring and interventionism, its role in bone tissue procedures is still limited, despite being useful in diagnostic and therapeutic procedures (exostosis, subperiosteal collections, fractures) [13-15]. Two events have delayed the development of ultrasound in the purely bone field. On the one hand, the assumption that ultrasound is a poor imaging method to observe bone tissue due to its high impedance and posterior acoustic shadow; on the other hand, conventional radiology is a widely used imaging exam that provides excellent bone information. The first assumption seems false to us since the high acoustic impedance of the bone is, in fact, one of the best qualities from the ultrasound point of view because it is easily identifiable [16,17]. Sometimes the bone surface is the only information that we need as an orientation to know the point where we must perform the surgical procedure. Regarding conventional radiology, although is an excellent and well-known visualization method, it has some drawbacks that can be avoided with the use of ultrasound.

The pernicious effects of radiation on the health of orthopedic surgeons and other personnel subjected to ionizing radiation are well known. Tumor conditions

[18], cataracts and skin lesions, especially in the hands, stand out especially. Despite this, ignorance and risk banalization are common among orthopedic surgeons. In an inquiry based on 91 active orthopedic surgeons, Saroki et al. [19] reported that 92.3% of them were unaware that real-time fluoroscopy exposes more ionizing radiation than static modalities and that 91.2% of surgeons believed that most of the surgeons needed additional education about radiation exposure and protection.

Although the radiation doses received by the surgeon have been estimated according to the procedure performed [20], it is difficult to predict exactly due to a large number of variables: the exposure time, the distance, the orientation of the fluoroscopic concerning the patient, the surgeon's position within the operative field, the use of plumb protections or the radiation unit design [21]. There is a consensus that the most exposed body areas are the surgeon's hands [22-25], and this is especially worrying in the case of percutaneous foot surgery, because the surgical instruments must be placed simultaneously with the radiological control, impeding to move the hands away from the radiated field. The popularization of mini-image intensifiers (mini c-arm), which deliver 10 to 100 radiation doses lower than those delivered by conventional image amplifiers has reduced the radiation dose received [26-28]. However, some articles have questioned the initial safety that was attributed to the mini c-arms, demonstrating exposures on the surgeon's hands up to 187 times greater than those predicted by the manufacturer [24]. It seems sensible to consider that the only safe radiation dose is one that is not received and therefore, alternative methods to conventional radiology should be welcomed if their safety and efficacy are demonstrated.

We have described the possibility of performing DMMO without using radiological control and with the help of ultrasound. We can identify the proximal phalanx base, the articular cartilage, the extensor tendons, the dorsal joint capsule, and the metatarsal head with the ultrasound, even the characteristic dorsal relief of the metatarsal head that we have called "the dorsal hump". Likewise, without substantial modifications in the usual surgical technique, we can identify the location of the osteotomy burr and its angulation concerning the metatarsal diaphysis, ensuring a good location and angulation of the resulting osteotomy. We have defined this dorsal hump as a specific point of osteotomy because this is a constant and extra-articular structure and is easily identifiable both by ultrasound and radiologically. We do not yet have clinical studies comparing the ultrasound-guided technique with the radiology-guided technique, but we believe that it should not make clinical differences because ultrasound-guided DMMO does not modify its biomechanical principles.

In our experience, we have not found cases of infection, malunion, or nonunion after US-DMMO, although the sample is still small for extrapolating conclusions.

Our cadaver studies, with a sample of 36 DMMOs performed on 9 cadaver pieces, demonstrated an average angulation of  $47.67^\circ (\pm 4.49, 40-59^\circ)$  and an average distance from the articular cartilage to the osteotomy point of 3.22 mm ( $\pm 1.27, 1-7$  mm), with a single joint capsule injury (without cartilage damage) in a fifth ray. It is in the fifth metatarsal where we have found the extreme values both in angulation and in distance to the articular cartilage, as well as the unique injury in neighboring structures. We did not find any iatrogenic tendon, neurovascular or cartilage damage. Unfortunately, there are no cadaveric studies that analyze the quality of the osteotomies performed by usual radiological-guided DMMO. Dhukaram et al. [29] just report greater verticalization of osteotomies with respect to planned, but do not provide objective data. Subjectively we believe that ultrasound may lead to a better location of the osteotomy point. Ultrasound dynamism allows us to obtain information in a large number of planes improving the three-dimensional orientation and does not superimpose different planes. Traditional radiographic plane is so sensitive to variations and reliable information about the exact location of the burr is only obtained from the pure tangential projection. Our study in cadaver shows an optimal location and angulation of osteotomies, so we think that the rate of nonunions could be reduced.

We know that the main limitation of the use of ultrasound is the learning curve. We believe that for an orthopedic surgeon with extensive anatomical knowledge and experience in open surgery, topographic interpretation of anatomical ultrasound images is straightforward. We have analyzed the ultrasound visualization capacity of the structures previously described by an orthopedic surgeon, and the intra and inter-observer variability respect to a radiologist expert in musculoskeletal ultrasound in a sample of 160 metatarsophalangeal joints in 20 healthy volunteers. The bony structures (proximal phalanx base, metatarsal head, and dorsal hump) were identified in 100% of the cases and the inter and intra-observer agreement percentage was 100%. Non-bony structures (extensor tendons, dorsal joint capsule, joint cartilage, and neurovascular bundle) were all identified above 88%, with an inter and intra-observer Cohen's kappa index above 0.65 in all cases. Several studies have already shown a good correlation when identifying bone lesions by ultrasound. [30-32]. Likewise, the visualization of the anatomical structures of the fifth metatarsal showed greater variability than the rest of the rays, which also explains the greater difficulty when performing osteotomies in this metatarsal, assuming the

only limitation that we found in the technique.

We believe that with this surgical modification, we open a new paradigm on the use of ultrasound in interventional procedures on bone tissue. Beyond the diagnostic ultrasound procedures on bone tissue, we have only found a previous publication on ultrasound-guided bone surgical procedures: the placement of supra-acetabular pelvic external fixators in pelvic fractures [33]. Ultrasonography not only avoids exposure to ionizing radiation but also allows the visualization of soft tissues, provides greater portability, and seem to be less expensive. We believe that the use of ultrasound as a guide in percutaneous processes can increase economic savings. Beyond the economic savings of dispensing with the X-ray technician, incorporating ultrasound as a valid tool in the guide of percutaneous and ambulatory processes increases the possibility of performing them even outside large hospitals [34], so we assume that percutaneous and ambulatory foot surgery under ultrasound control can be performed in a greater number of centers than that performed under radiological control. The promotion of ambulatory surgery and percutaneous foot surgery is associated with significant economic savings. We are exploring the possibility of performing other surgical procedures also under ultrasound control, such as percutaneous treatment of hallux valgus.

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