Article published online: 2023-12-26

Distal Femoral Non-Union in Gunshot Wounds; Masquelet Technique Management and Literature Review

No unión de fémur distal secundario a lesiones por armas de fuego; Manejo con técnica de masquelet y revisión de la literatura

Andres Schmidt-Hebbel Niehaus[1,2] Robert Etienne Partarrieu Stegmeier[2,3] Matías Javier Croxatto[3] Sergio Arellano Garrido[1,2] Diego Edwards Silva[1] Alex Vaisman Burucker[1]

[1] Department of Traumatology and Orthopedics, Clínica Alemana, Santiago, Chile
[2] Department of Traumatology and Orthopedics, Hospital Padre Hurtado, Santiago, Chile
[3] Medical School, Clínica Alemana, Universidad del Desarrollo, Santiago, Chile

Address for correspondence Andrés Schmidt-Hebbel, MD, Department of Traumatology and Orthopedics, Clínica Alemana, Santiago, Chile (email: aschmidthebbel@gmail.com).

Rev Chil Ortop Traumatol 2023;64(3):e136–e142.

Abstract

Introduction Gunshot-related open fractures are at risk for significant bone loss. Consolidation is unlikely in defects larger than 2 cm. The induced membrane technique (IMT) results in the formation of a membrane to facilitate consolidation. We present two cases of gunshot-related open fracture progressing with infected non-union and bone defects and their subsequent management with IMT.

Cases We present two cases of open fracture of the distal femur secondary to a gunshot wound. Initially, the two cases underwent external fixation followed by an intramedullary nail (IMN) placement. Both progressed with infected non-union and a 4-cm bone defect. IMT resulted in infection control and fracture consolidation.

Discussion IMT was a successful salvage surgery for bone defects secondary to an infected femoral non-union. Managing bone defects is challenging due to infection, soft tissue loss, bone gap, and fracture healing potential. IMT is an attractive alternative for treating bone defects bigger than 2 cm since the repair is independent of the defect size and allows infection control.

Conclusion IMT is an effective salvage technique for the management of bone defects caused by gunshots. It allows limb salvage and comprehensively manages the several aspects requiring consideration in these cases.

Keywords
- induced membrane technique
- bone defect
- infected non-union

received July 10, 2023
accepted October 5, 2023

DOI https://doi.org/10.1055/s-0043-1777992.
ISSN 0716-4548.

Thieme Revinter Publicações Ltda., Rua do Matoso 170, Rio de Janeiro, RJ, CEP 20270-135, Brazil

Abstract

Introducción Las fracturas expuestas por arma de fuego están en riesgo de presentar una pérdida de tejido óseo significativa. En defectos mayores de 2 cm es poco probable la consolidación. La técnica de membrana inducida (TMI) induce la formación de una membrana que facilita la consolidación. Se presentan dos casos de fractura expuestas por arma de fuego que evolucionaron con no uniones infectadas, defectos óseos y posterior manejo con la TMI.

Presentación de los casos Se presentan dos casos de fractura expuesta de fémur distal, secundarias a herida por arma de fuego. Ambos inicialmente manejados con fijación externa seguida de un clavo endomedular (CEM), que evolucionaron con no unión infectada y defecto óseo de 4 cm. Ambos se manejaron con la TMI, logrando control de la infección y consolidación.

Discusión La TMI fue utilizada de forma exitosa como cirugía de salvataje para defectos óseos secundarios a no unión infectada de fémur. El manejo de defectos óseos es un desafío ya que influye la infección, la pérdida de tejidos blandos, el gap óseo y el potencial de curación de la fractura. La TMI es una alternativa atractiva en el tratamiento de defectos óseos mayores de 2 cm, siendo la reparación independiente del tamaño del defecto y permitiendo controlar infecciones asociadas.

Conclusión La TMI es una técnica de salvataje efectiva para el manejo de defectos óseos por arma de fuego, la cual permite salvar la extremidad, con un manejo integral de los diversos aspectos necesarios a considerar en estos casos.

Palabras Claves
- ► técnica de membrana inducida
- ► defecto óseo
- ► no unión infectada

Introduction

The bone is one of the few organs that, even in adults, retains its regenerative potential. It preserves its original pre-fracture properties before fracture and can consolidate primarily or secondarily. In secondary consolidation, intramembranous and endochondral ossification forms a bone callus due to osteoprogenitor periosteal cells and undifferentiated mesenchymal cells stimulation. This stimulation activates a cascade of cell proliferation and differentiation that, with adequate vasculature, culminates in bone callus formation.[1] Bone defect management is complex in traumatology. It has been reported that significant bone loss occurs in 0.4% of fractures, and this percentage is higher in open fractures. Even with adequate fixation, defects larger than 2 centimeters are unlikely to heal spontaneously. In selected cases, debridement to remove necrotic or infected edges increases the initial defect, creating a more difficult scenario for the reconstruction of the affected bone.[2]

Bone defect repair techniques include the distraction osteosynthesis (DO) and the induced membrane technique (IMT) described by Masquelet.[1]

DO consists of bone formation between two vascularized fragments separated by slow, gradual traction. Under the right conditions, bone neoformation occurs through intramembranous ossification.[3]

Another alternative for bone defect reconstruction, particularly larger ones, is the membrane ossification technique or MOT. In their original work, Masquelet et al. reported 100% union in segmental bone defects ranging from 4 to 25 cm. This technique combines the formation of a biological membrane with characteristics similar to the periosteum and an avascular bone graft.[4] The Masquelet technique consists of two stages. The first stage is the debridement of the infected, necrotic, or tumorous bone tissue, followed by the implantation of a cemented polymethylmethacrylate (PMMA) spacer, which may or may not be soaked in antibiotics, and bone defect fixation using internal or external immobilizers. The second stage consists of spacer removal, preserving the formed membrane, bone edge debridement, and placement of a bone graft in the defect.[5]

This paper reviews two cases of gunshot open fractures progressing with infected non-unions and bone defects and the subsequent bone reconstruction with IMT.

Case 1

A 43-year-old female patient suffered an open fracture of the distal femur due to a gunshot. The radiograph showed a comminuted fracture of the left distal femur (►**Figure 1**), and a computed tomography (CT) scan ruled out vascular damage. The patient was admitted and received an external fixation. She was admitted again four days later for definitive surgical management, i.e., placement of a retrograde intramedullary nail (rIMN) in the femur. Serial imaging follow-up occurred while the patient underwent motor kinesitherapy with progressive loading starting six weeks after definitive surgery with rIMN. However, in the outpatient follow-up 8 months after surgery, she reported pain with a visual analog scale of 5/10 at rest and 7/10 under load. Physical examination revealed surgical wounds with no signs of infection but a slight increase in volume. Inflammatory

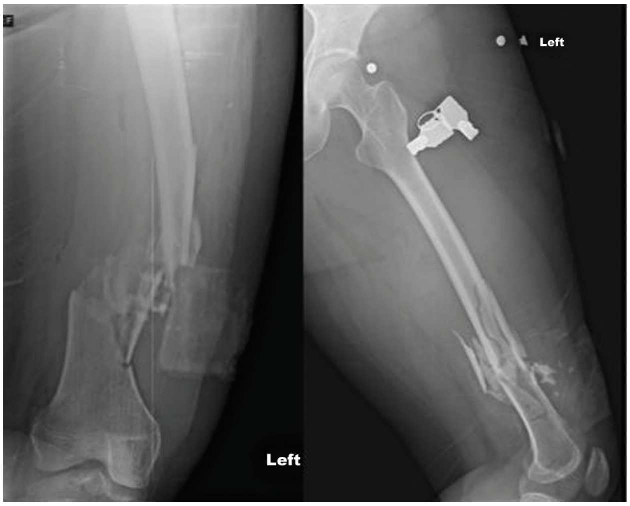

Figure 1 Comminuted fracture in the left distal femur.

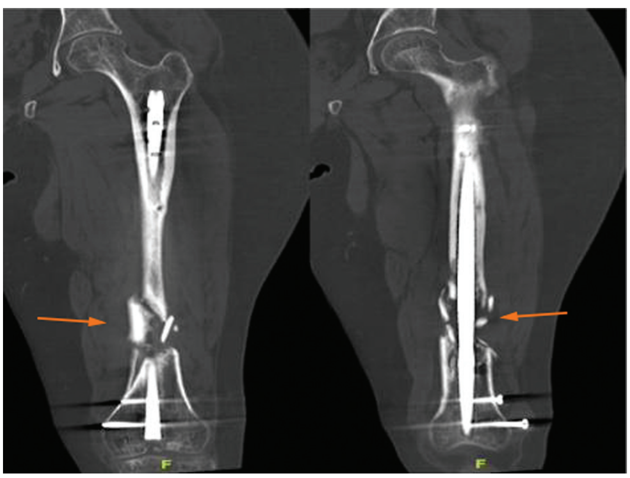

Figure 2 Computed tomography scan 8 months after surgery. Note the atrophic non-union (orange arrow) with no bone callus but presenting edge resorption.

parameters were within the normal range. A CT scan of the left femur (►**Figure 2**) showed atrophic non-union of the distal femur.

The patient was admitted again due to a suspected atrophic non-union with abundant necrotic tissue. We performed aggressive debridement of all devitalized tissue, leaving a bone defect measuring 4 × 4 × 3 cm. We decided on IMT and collected culture and biopsy samples. Subsequently, we filled the defect with bone cement with 1 g of vancomycin surrounding the previously placed nail (►**Figure 3**). As cultures revealed *Staphylococcus epidermidis*, we evaluated the patient after surgery for infectious disease to define antibiotic therapy. Antibiotic therapy continued for 8 weeks, before the second stage of the Masquelet technique. Upon completing the antibiotic therapy and evaluating the inflammatory parameters, we decided to perform the second stage. In this surgery, we removed the cemented spacer, replaced the rIMN, and filled the defect with a mixture of femoral head autograft and allograft (►**Figures 4** and **5**), preserving the Masquelet membrane. Postoperative follow-ups revealed a good clinical evolution, with clinical and radiographic bone consolidation at 6 months (►**Figure 6**). At the 27-month follow-up, the patient had bone remodeling and excellent clinical outcomes, with normal gait and full range of motion.

Case 2

A 21-year-old male patient went to the emergency room due to an open distal femur fracture caused by a gunshot (►**Figure 7**). After admission, the patient underwent surgical cleansing and received an external device.

The placement of a retrograde femur nail occurred 3 weeks later. The patient was discharged the next day (►**Figure 8**).

Two weeks after discharge, he returned to the emergency room due to persistent bleeding from the surgical wound and a 10-point drop in the packed cell volume. As an angioCT revealed femoral artery pseudoaneurysm, the patient was hospitalized for aneurysm repair. During this procedure, we

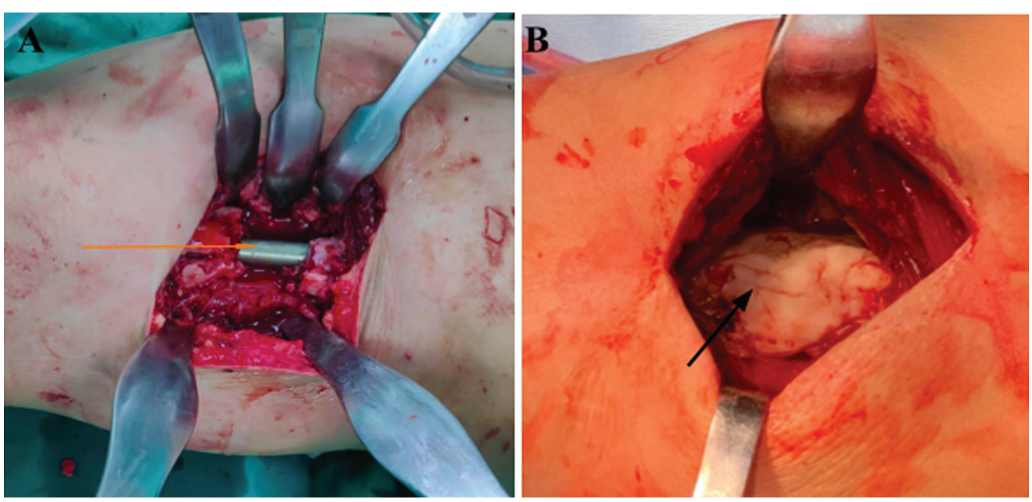

Figure 3 Intraoperative image from the first stage of the Masquelet technique. A) Bone defect after necrotic, devitalized tissue debridement of an infected non-union 8 months after the initial surgery. Stabilization with an intramedullary nail. B) Bone defect filling with cement (polymethylmethacrylate) and vancomycin (arrow) covering the whole defect.

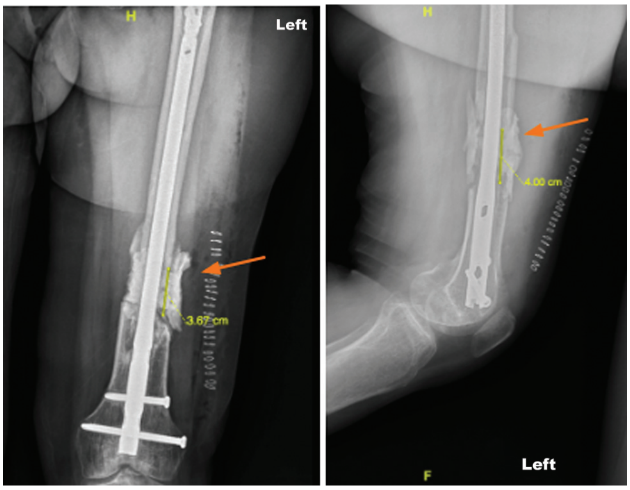

Figure 4 Anteroposterior and lateral radiographs after necrotic, devitalized tissue debridement. Note the polymethylmethacrylate cement (orange arrow) with vancomycin around the intramedullary nail covering the 4 x 4 x 3 cm bone defect.

noted a purulent secretion from the wound next to the fracture focus. We collected culture samples from the surgical bed, which were positive for multidrug-resistant, carbapenem-sensitive Serratia marcenscens. After the osteomyelitis diagnosis, antibiotic therapy started.

Since then, the patient underwent multiple surgical cleanings, with pre-cleaning cultures positive for the same infectious agent with equal sensitivity. At one cleansing, a bone tissue culture was positive for *Enterococcus faecalis*, so we adjusted the antibiotic therapy. We removed the intramedullary nail and placed external devices (►**Figure 9**). In the last cleaning, 3 months after readmission, we performed bone sequestration resection, leaving a 4 cm defect. We filled this defect with tobramycin and cement, maintaining fixation with external devices (►**Figure 10**). Six weeks later, we proceeded to the second IMT stage, removed the external devices, and placed an intramedullary nail and an iliac crest autograft (►**Figure 11**). Serial radiographs during hospitalization showed bone callus formation and fracture consolidation (►**Figures 12**).

Discussion

IMT was a successful salvage surgery for two patients with medium-sized bone defects after a femur non-union caused by a gunshot wound. The outcomes were satisfactory, with bone defect repair, adequate infection control, and subsequent good functionality. IMT is an attractive alternative for managing infected non-unions and bone defects, particularly those $\geq$ 4 cm.

Treating long bone defects in the lower extremities remains complex, with no consensus on its management, which is frequently salvaged, particularly in infectious non-unions or tumor lesions. Treatment of small defects, up to 2 cm in length, may use an autologous cancellous bone graft,[6] while larger segmental bone defects, especially those exceeding 4 to 5 cm, typically require bone transport by DO or bone graft through the induced membrane.[7,8] The Masquelet technique is an attractive alternative for treating these defects. This technique has been proven effective in treating bone defects caused by trauma or surgical debridement due to infections and non-unions.[5] Since its publication in 2003, IMT has been widely accepted, with a percentage of 67 to 100% union in well-indicated surgeries and a success rate higher than 90%.[9] In infected post-traumatic segmental bone defects in the tibia and femur, the Masquelet technique has also achieved a consolidation rate of over 95%.[10] In addition, it is widely used and the preferred technique for traumatic bone defects and those caused by gunshots in the military.[11]

The main alternative to the Masquelet technique is DO, which induces bone formation between two vascularized

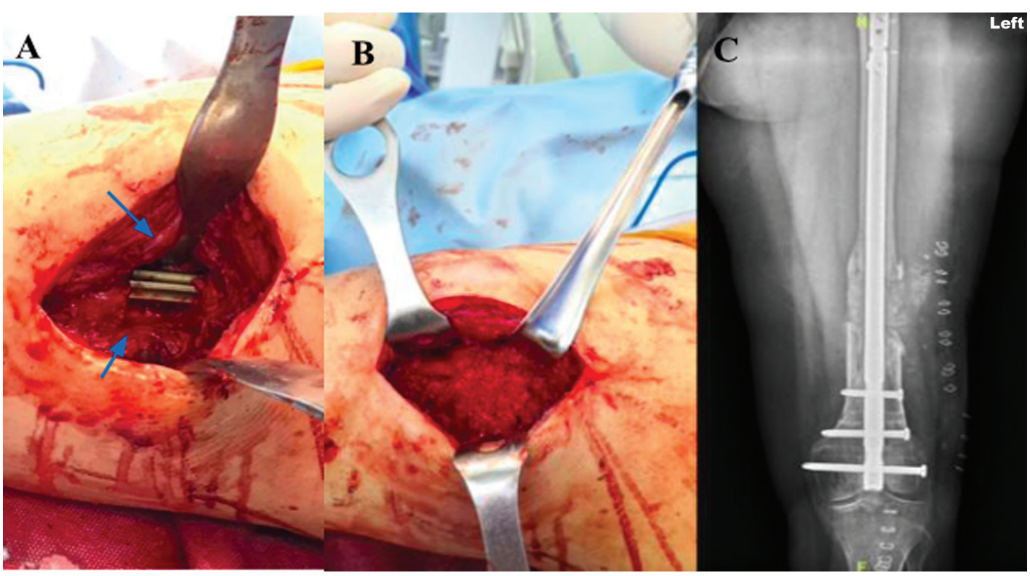

Figure 5 Intraoperative view of the femur at the second stage of the Masquelet technique. A) Note the femoral bone defect with intramedullary nail in situ and preserved membrane (arrow). B) Filled bone defect using autograft and allograft, achieving full coverage. C) Postoperative anteroposterior radiograph showing the complete bone defect coverage with the graft.

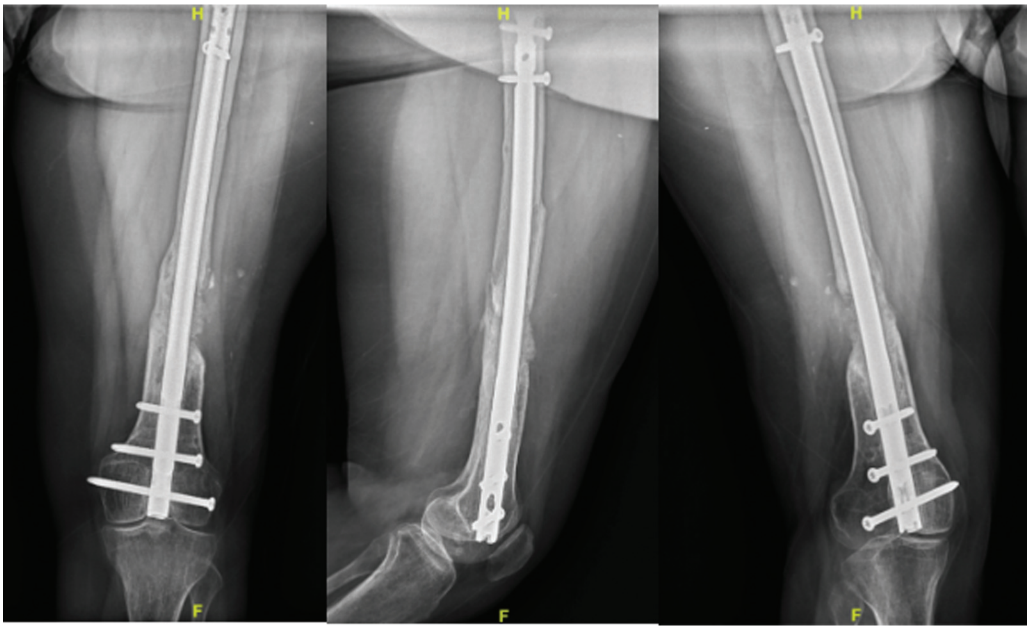

Figure 6 Anteroposterior, lateral, and oblique 9 months after surgery. Note the radiographic bone consolidation in at least three cortices.

bone fragments that slowly and gradually separate, forming new bone through intramembranous ossification.[12,13]

Few studies have compared DO and IMT. Animal studies have suggested their therapeutic effects on segmental bone defects depend on the lesion size. Zhen et al. studied bone repair in mice using radiographic, CT, histological, and immunohistochemical follow-up for bone defects of different sizes treated with IMT or DO. For small segmental bone defects, DO proved to be more appropriate and efficient than IMT, while the opposite occurred in larger defects, with a clear advantage of IMT over DO.[14] To our knowledge, no studies to date directly compared the Masquelet technique with DO. Multiple guidelines showed both techniques are effective but recommend the IMT or DO for large bone defects, particularly those over 15 cm.[15–17] DO provides a 95% success rate, early loading (when performed with an external Ilizarov device), angiogenesis stimulation, and production of good quality bone.[15] Important disadvantages include the technical difficulty in its implementation, the need for considerable and prolonged patient compliance, long treatment times, the need for unloading during treatment (with exceptions, such as Ilizarov external fixation), risk of nail and path infection, non-union, chronic pain, and joint contractures.[15] For DO, the elongation rate ranges

Figure 7 Anteroposterior radiograph of the left distal femur. Displaced comminuted fracture at the left distal femur.

Figure 8 Anteroposterior radiograph of the left distal femur after intramedullary nail placement.

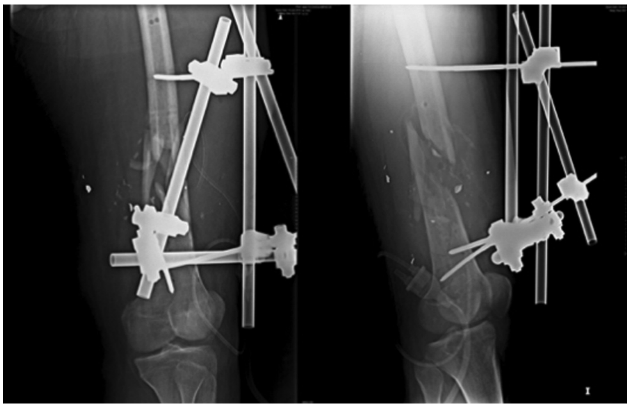

Figure 9 Anteroposterior and lateral radiograph of the left femur after intramedullary nail removal and external device placement.

from 0.5 to 1 mm per day, which is a significant issue when dealing with large bone defects, sometimes requiring 18 months or more for correct treatment.[3,14] In contrast, IMT offers a clear advantage in medium and large bone defects ($\geq$ 4 cm) since the repair usually does not depend on the defect size, and most defects heal in 8 to 12 months. The complete consolidation of a 25-cm bone defect occurred in 12 months.[16–19] Moreover, it uses standard surgical techniques and implants as a less technically demanding surgery; it allows early loading with intramedullary nails, and the need for high patient compliance and frequent clinical follow-up is lower, especially with internal fixation.[16] A significant part of these advantages comes from the membrane, which is essential to provide vascularization and growth factors to the bone autograft filling the defect, ensuring that this graft acts as a guide for bone callus formation and defect repair. Reviewing IMT, Taylor et al.

Figure 10 Anteroposterior radiograph of the distal femur. Note the bone defect filled with cement (polymethylmethacrylate) and tobramycin (orange arrow).

Figure 11 Anteroposterior radiograph of the distal femur after external device and cement spacer removal and intramedullary nail and cement placement at the bone defect with iliac crest autograft (orange arrow).

reported that the membrane is well vascularized and consists of type I collagen with fibroblasts, an inner layer of epithelial cells, and high vascular endothelial growth factor (VEGF), runt-related transcription factor 2 (RUNX2, also known as core-binding factor subunit alpha-1 [CBFA1]), transforming growth factor (TGF)-ß1, and bone morphogenetic protein 2 (BMP2) levels. These authors also noted a second internal membrane around the nail, potentially increasing local vascularization and osteoinductive factor levels.[15,20] There were two cases of infected non-union with post-surgical cleaning defects of at least 4 cm treated with the Masquelet technique. Both cases achieved excellent

Figure 12 Anteroposterior radiographs of the distal femur. Note the bone callus formation and fracture consolidation 2 (left) and 6 months (right) after the second stage of the Masquelet technique, respectively.

outcomes, with infection management, clinical and radiological consolidation, and favorable functional results.

Today, there is no evidence comparing IMT and DO, and no solid literature supports one technique over the other. In our experience, for bone defects greater than 4 cm, particularly in infectious non-unions, the Masquelet technique offers clear advantages compared to DO, leading to good outcomes when used correctly.

Conclusion

Based on our experience with these cases and the literature analyzed, we consider IMT a good alternative in patients with bone defects greater than 4 cm, particularly in infected non-unions, with excellent outcomes. The advantage offered by IMT regarding infection management and bone defect repair makes it a highly attractive alternative for these cases. This technique allows limb salvage, is less dependent on the patient's compliance, and allows consolidation in limited times.

Conflict of Interest
None declared.

Bibliography

1 Giannoudis PV, Einhorn TA, Marsh D. Fracture healing: the diamond concept. Injury 2007;38(Suppl 4):S3–S6. Doi: 10.1016/s0020-1383(08)70003-2
2 Keating JF, Simpson AH, Robinson CM. The management of fractures with bone loss. J Bone Joint Surg Br 2005;87(02):142–150. Doi: 10.1302/0301-620x.87b2.15874
3 Giannoudis PV. Treatment of bone defects: Bone transport or the induced membrane technique? Injury 2016;47(02):291–292. Doi: 10.1016/j.injury.2016.01.023
4 Klein C, Monet M, Barbier V, et al. The Masquelet technique: Current concepts, animal models, and perspectives. J Tissue Eng Regen Med 2020;14(09):1349–1359. Doi: 10.1002/term.3097
5 Masquelet A, Kanakaris NK, Obert L, Stafford P, Giannoudis PV. Bone Repair Using the Masquelet Technique. J Bone Joint Surg Am 2019;101(11):1024–1036. Doi: 10.2106/JBJS.18.00842
6 Rao N, Ziran BH, Lipsky BA. Treating osteomyelitis: antibiotics and surgery. Plast Reconstr Surg 2011;127(Suppl 1):177S–187S. Doi: 10.1097/PRS.0b013e3182001f0f
7 Lasanianos NG, Kanakaris NK, Giannoudis PV. Current management of long bone large segmental defects. Orthop Trauma 2010;24(02):149–163. Doi: 10.1016/j.mporth.2009.10.003
8 Marais LC, Ferreira N. Bone transport through an induced membrane in the management of tibial bone defects resulting from chronic osteomyelitis. Strateg Trauma Limb Reconstr 2015;10(01):27–33. Doi: 10.1007/s11751-015-0221-7
9 De los Santos MFA, Ceballos SJA, Hernández FE, Sierra PM, Herrera CZV. Técnica de Masquelet en no unión atrófica de tibia con osteomielitis crónica, su descripción. Acta Med Grupo Ángeles 2021;19(02):280–284. Doi: 10.35366/100456
10 Papakostidis C, Bhandari M, Giannoudis PV. Distraction osteogenesis in the treatment of long bone defects of the lower limbs: effectiveness, complications and clinical results; a systematic review and meta-analysis. Bone Joint J 2013;95-B(12):1673–1680. Doi: 10.1302/0301-620X.95B12.32385
11 Aronson J, Harrison BH, Stewart CL, Harp JH Jr. The histology of distraction osteogenesis using different external fixators. Clin Orthop Relat Res 1989;(241):106–116
12 Pesciallo CA, Garabano G, Dainotto T, Ernst G. Masquelet technique in post-traumatic infected femoral and tibial segmental bone defects. Union and reoperation rates with high proportions (up to 64%) of allograft in the second stage. Injury 2021;52(11):3471–3477. Doi: 10.1016/j.injury.2021.08.031
13 Ilizarov GA. Clinical application of the tension-stress effect for limb lengthening. Clin Orthop Relat Res 1990;(250):8–26
14 Shen Z, Lin H, Chen G, et al. Comparison between the induced membrane technique and distraction osteogenesis in treating segmental bone defects: An experimental study in a rat model. PLoS One 2019;14(12):e0226839. Doi: 10.1371/journal.pone.0226839
15 Ashman O, Phillips AM. Treatment of non-unions with bone defects: which option and why? Injury 2013;44(Suppl 1):S43–S45. Doi: 10.1016/S0020-1383(13)70010-X
16 Alford AI, Nicolaou D, Hake M, McBride-Gagyi S. Masquelet's induced membrane technique: Review of current concepts and future directions. J Orthop Res 2021;39(04):707–718. Doi: 10.1002/jor.24978
17 Bafor A. Distraction osteogenesis: A review of the literature. Nigerian Journal of Orthopaedics and Trauma 2020;19(01):1https://link.gale.com/apps/doc/A631007781/HRCA?u=anon~80fd8424&sid=googleScholar&xid=cd9bf3a
18 Klaue K. Knothe, et al. Biological implementation of autologous foreign body membranes in corticalization of massive cancellous bone grafts. Trans Orthopaedic Trauma Assoc, 1998
19 Morelli I, Drago L, George DA, Gallazzi E, Scarponi S, Romanò CL. Masquelet technique: myth or reality? A systematic review and meta-analysis. Injury 2016;47(Suppl 6):S68–S76
20 Taylor BC, French BG, Fowler TT, Russell J, Poka A. Induced membrane technique for reconstruction to manage bone loss. J Am Acad Orthop Surg 2012;20(03):142–150. Doi: 10.5435/JAAOS-20-03-142

