Segmental Bone Defects: Use of Custom-Designed Trabecular Titanium Implants

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ABSTRACT

Introduction: There is a wide variety of therapeutic options for the reconstruction of segmental bone defects caused by fractures, tumors, or infections, but it continues to be a challenge in orthopedic surgery. **Materials and Methods:** The present work presents six (6) cases of patients with massive bone loss treated by means of what we call a "synergistic combination" of an induced membrane, to provide biological benefits, plus a trabecular titanium scaffold designed for each patient to provide stability and structure. **Results:** Five men and one woman with an average age of 30 years were operated on by this technique. The average follow-up was 24 months. In the immediate postoperative period, the axis, length, and sufficient mechanical stability to initiate partial weight-bearing were reestablished. Full weight-bearing according to the patients' conditions (pain, muscle strength) required an average of 25 to 30 days. **Conclusion:** We propose a rare treatment option in our field with sufficient biomechanical stability to tolerate early weight-bearing, recovering the entire length of the defect in a single stage with excellent functional outcomes, understanding these as an advantage over traditional therapeutic options such as bone transport or the Masquelet technique.

Keywords: Trabecular titanium; scaffold; segmental bone defect.
Level of Evidence: IV

Defectos óseos segmentarios: uso de implantes de titanio trabecular diseñados a medida

RESUMEN

Introducción: Se dispone de una amplia variedad de opciones terapéuticas para la reconstrucción de defectos óseos segmentarios causados por fracturas, tumores o infecciones, pero aún es un desafío en la cirugía ortopédica. **Materiales y Métodos:** Se presentan seis casos de pacientes con pérdida ósea masiva tratados mediante lo que denominamos "combinación sinérgica" de una membrana inducida para aportar beneficios biológicos, más un andamiaje (*scaffold*) de titanio trabecular desarrollado especialmente, según cada paciente, para el aporte de estabilidad y estructura. **Resultados:** Cinco hombres y una mujer (edad promedio 30 años) fueron operados con esta técnica. El seguimiento promedio fue de 24 meses. En el posoperatorio inmediato, se logró el restablecimiento del eje, la longitud y la estabilidad mecánica suficiente para iniciar la carga parcial. La carga total, según las condiciones del paciente (dolor, fuerza muscular), demandó un promedio de 25 a 30 días. **Conclusiones:** Proponemos una opción de tratamiento poco frecuente en nuestro medio que brinda estabilidad biomecánica suficiente para tolerar la carga precoz recuperando la longitud total del defecto en un solo acto, con excelentes resultados funcionales, entendiendo estas como ventajas frente a las opciones terapéuticas de uso tradicional, como transporte o técnica de Masquelet.

Palabras clave: Titanio trabecular; andamiaje; defecto óseo segmentario.
Nivel de Evidencia: IV

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INTRODUCTION

In our daily practice, it is increasingly common to see patients suffering from serious injuries with extensive bone defects that require long treatments with multiple reconstructive surgeries and a high incidence of complications. There is a wide variety of therapeutic options for the reconstruction of segmental bone defects caused by fractures, tumors, or infections, but they remain a challenge in orthopedic surgery. Among the most widely used treatments in our field are bone grafting (whether autologous or heterologous),[1,2] vascularized grafts, bone transport,[3] the induced membrane technique,[4-9] and the growing use of calcium sulfate and phosphate bone substitutes (hydroxyapatite matrix), stem cells, and biological stimulators, such as growth factors, especially morphogenetic protein (BMP 2 and 7).

The advent of new materials and technologies based on tomographic reconstructions and three-dimensional printing allows us to develop 'customized' interlayer trabecular titanium implants[10-13] for each patient.

The biocompatibility of titanium and its intrinsic characteristics of osteoinduction, conduction, and integration,[12] as well as its mechanical[11] and infection[14,15] resistance, allow its safe implantation in previously infected patients, achieving full length recovery of the defect, early weight-bearing, and excellent functional outcomes.

The skeletal reconstruction principle we report is based on the "synergistic combination" concept proposed by our team. It involves the use of an induced membrane with its well-known biological benefits, generated under Masquelet's precepts, plus the implantation of a custom-made trabecular titanium scaffold to provide stability and structure.

In this article, we report the first description of this novel technique and present a series of cases with segmental bone defects of traumatic and infectious etiology in which the scaffolding technique was applied on trabecular titanium molds made with three-dimensional technology. We propose the following hypothesis: open fractures with segmental bone loss treated by this technique have a faster clinical-functional evolution than those treated by other methods, and patients resume their previous activities in less time.

MATERIALS AND METHODS

We carried out a retrospective and observational case series study. The series comprised six cases of patients with open fractures with massive lower limb bone loss between 2016 and 2019. Four were defects of the femoral shaft, one of the distal tibia, and one of the tibial midshaft. All patients were operated using what we call "synergistic combination". Each implant was developed in a particular way for each type of defect, taking the healthy limb as a reference. To do this, it is necessary to perform 1-mm thin-slice tomography scans in the three planes of the healthy and affected limb. By superimposing images of both bones, using a specific program, the length and diameter of the defect to be corrected are calculated. The RAOMED company was in charge of printing the final design developed jointly by our team in trabecular titanium.

We carried out a clinical evaluation before and after surgery, and requested radiographs and a CT scan. All patients were operated on with the same technique described by our team. According to the classification of long bone defects proposed by Solomin and Slongo, the fractures were grade C.

The inclusion criteria were: patients with a mature skeleton, segmental bone defects >4 cm, a history of bacterial infection confirmed by bacterial culture and with a specific treatment, open fractures.

The exclusion criteria were: patients with active bacterial infection, bone defects secondary to tumor.

CASE DESCRIPTION

Case 1

A 54-year-old woman with a Gustilo 3B open fracture of the left distal tibia and massive bone loss as a result of a traffic accident (Figure 1).

Initially, she was treated with debridement and an external fixator. She underwent serial debridement (3 times in total), placement of a cement spacer with antibiotics (vancomycin-imipenem) (Figure 2) and a vacuum aspiration system.

Figure 1. Gustilo 3B open fracture in the distal third of the left leg, extensive soft tissue injury.

Figure 2. Anteroposterior leg radiograph after antibiotic spacer placement and external fixation.

The culture of a bone sample was positive for *Enterococcus faecalis* and the patient received antibiotic treatment with ampicillin. After 22 days, the wound had improved, the antibiotic spacer was replaced, and a new bone puncture, definitive soft tissue coverage, and fibular osteosynthesis were performed. A positive culture for *Acinetobacter* was obtained from said surgery, so intravenous imipenem was indicated, which was later changed to meropenem to comply with a 90-day antibiotic treatment plan at home. After 45 days, the patient was readmitted due to a surgical site infection. She underwent a new cleaning, spacer replacement, Schanz repositioning, and sample collection for culture, the result of which was positive for *Staphylococcus aureus*. We administered outpatient treatment with cephalexin due to the good evolution of soft tissues. Once treatment with meropenem ended, a puncture was performed and the culture was positive for cephalexin-resistant *S. aureus*, so trimethoprim/sulfamethoxazole plus rifampin were indicated. After 90 days, six samples were taken for culture, all of which were negative. After 10 months, the patient underwent reconstructive surgery with the placement of a trabecular titanium implant.

Implant development

We developed cutting guides to regularize the fracture edges and determine the length of the resection, and designed a trabecular titanium implant for the placement of interfragmentary compression screws both proximally and distally. At the implant-bone interface, spikes were also used to interdigitate the bone-implant surface to increase contact surface and stability. An oval hole design was chosen to accommodate screws from an anterolateral LCP regional tibial plate (Depuy, Synthes) (Figure 3) placed to neutralize and avoid loss of reduction and eventual displacement of the implant (Figure 4).

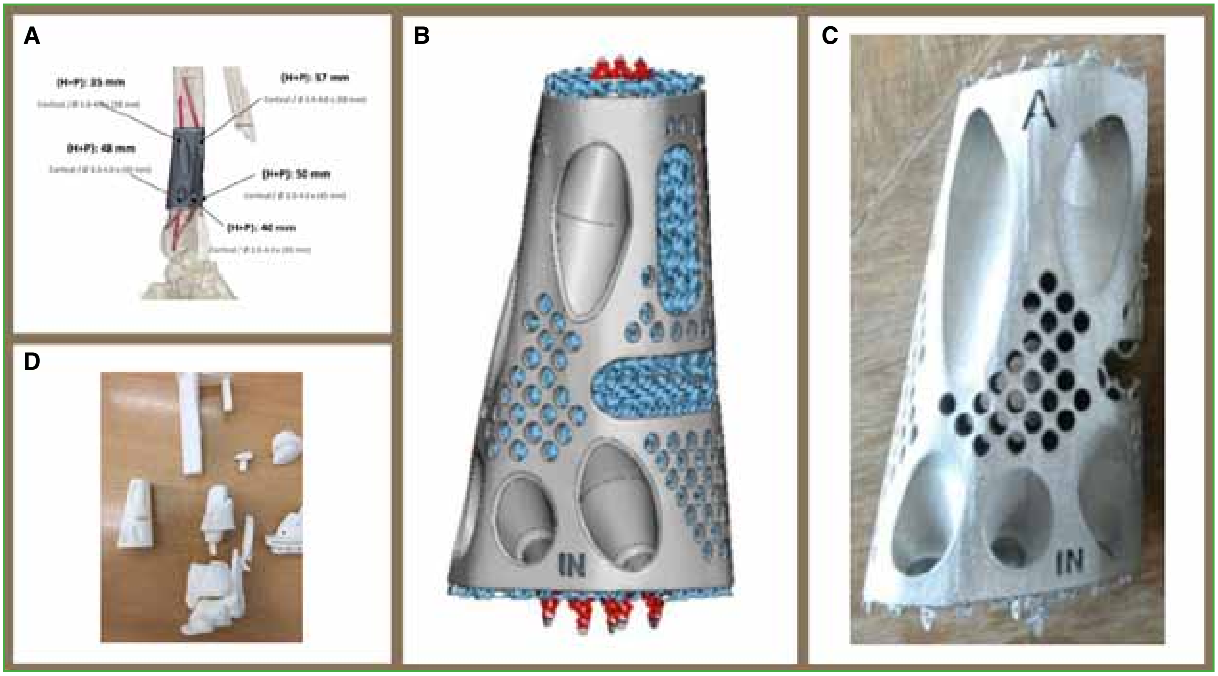

Figure 3. A. Scaffolding development: cutting guides and a trabecular titanium implant designed for the placement of interfragmentary compression screws were created. **B and C.** Final design of the virtual and real scaffolding. **D.** Scale polypropylene biomodelling of the bone defect and scaffolding for preoperative planning.

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Figure 4. Anteroposterior and lateral radiographs of the left leg two years after surgery.

Case 2

A 40-year-old man with an open fracture of the left tibia, an open fracture of the right patella, and a mid-shaft fracture of the right radius, with bone loss in the tibia, as a result of a traffic accident. The initial treatment consisted of debridement and resection of the third devitalized and contaminated fragment plus placement of an external fixator (Figure 5). The patient was hospitalized in the Intensive Care Unit for a splenic hematoma. At 48 h, he was evaluated again and *Streptococcus viridans* was isolated, so ampicillin was prescribed for 45 days.

Two weeks later, osteosynthesis of the right forearm and antibiotic nailing of the left tibia were performed. At the end of antibiotic treatment, a needle biopsy was performed, all samples were negative, and skeletal reconstruction was performed (Figure 6).

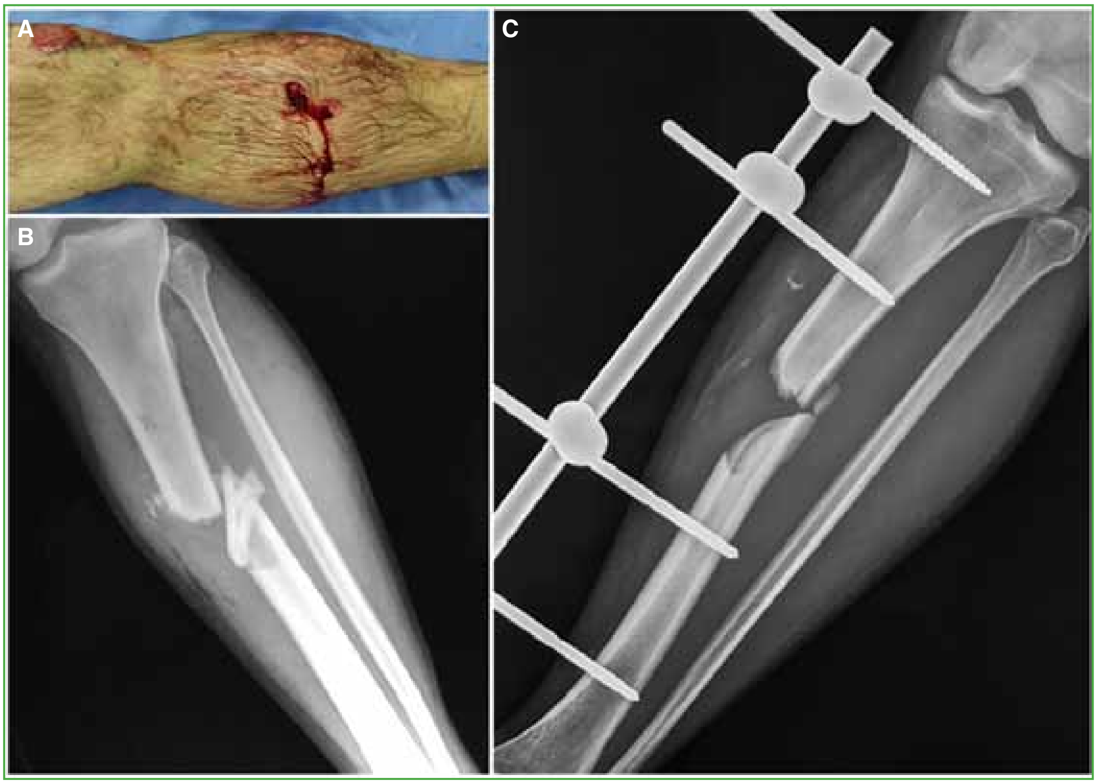

Figure 5. A. Gustilo 2 open fracture, soft tissue injury. **B.** Anteroposterior radiograph of the leg. The fracture line with segmental bone loss at the distal diaphyseal level of the left tibia is observed. **C.** Anteroposterior radiograph of the left leg after the first debridement and external fixation.

Figure 6. Anteroposterior and lateral radiographs of the left leg, two years after surgery.

Implant development

Cutting guides were developed to regularize the fracture edges. We chose stabilization with an intramedullary nail and designed a channel to house it; in this case, we added tabs at both ends to place fixation screws and prevent rotation and improve the stability of the scaffolding (Figure 7). We chose a smooth external surface to reduce soft tissue abrasion and avoid adherence of the ankle extensor tendons due to the particular anatomy of this region, and the implant was placed under the subcutaneous and submuscular tissue.

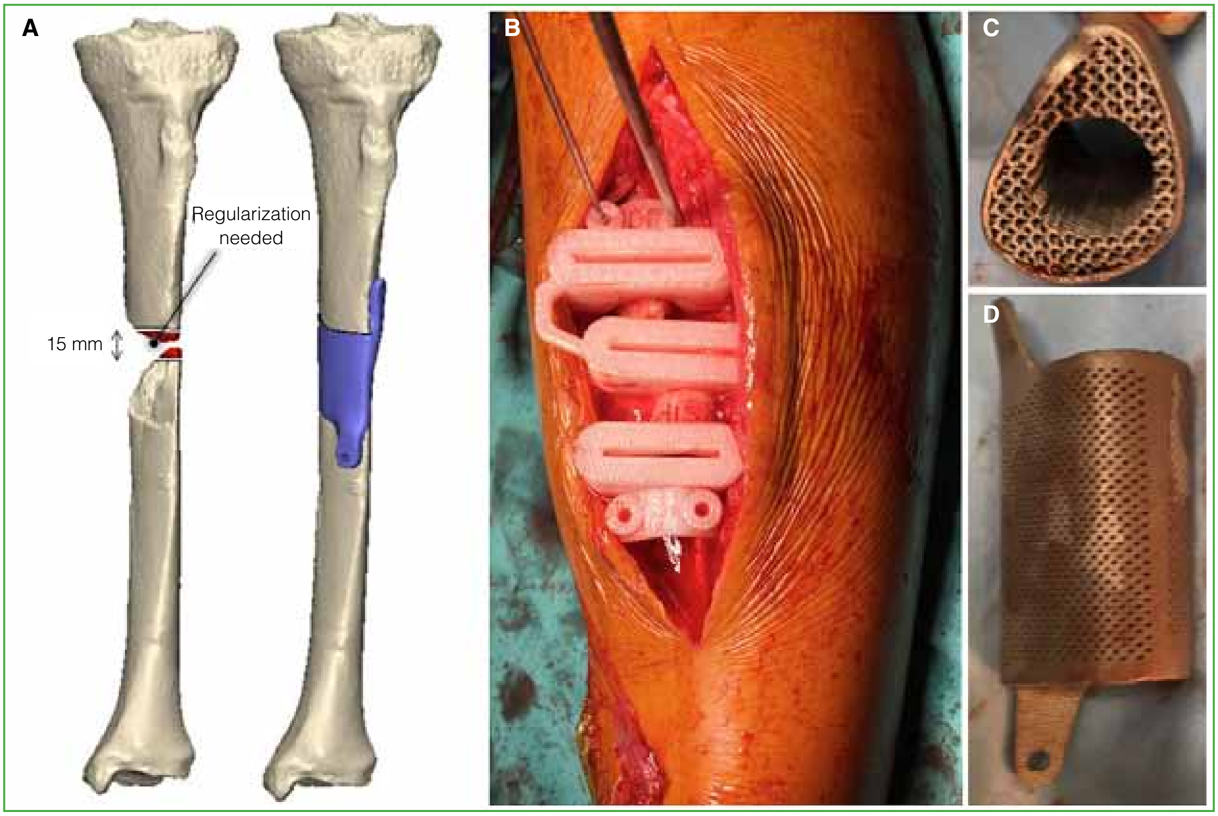

Figure 7. A. Bone regularizations necessary for the development of the scaffolding. **B.** Intraoperative image with cutting guides. **C.** Trabecular titanium implant with channel for intramedullary nail placement. **D.** Tabs were added at both ends to place fixation screws and prevent rotation.

Case 3

A 19-year-old man was referred from the province of Misiones due to a surgical site infection after osteosynthesis of the left femur with one month of evolution. He was treated empirically with cephalexin. Upon admission, he had a phlogotic wound with purulent secretion on the distal femur osteosynthesis plus a comminuted patella fracture without surgical treatment. He underwent debridement and the local placement of antibiotic beads. The samples taken were positive for extended-spectrum beta-lactamase-producing *Klebsiella*. Ten days after admission, the patient underwent a scheduled surgery to remove the beads and the osteosynthesis plate, we performed an oncological-type massive bone resection and placed the LFN nail and cement spacer with gentamicin (Figure 8). Due to the poor evolution of the wound, it was necessary to carry out four more cleanings, and to replace the nail and the cement spacer with antibiotics.

Figure 8. **A.** Radiograph of the left femur taken immediately after the first surgical stage (performed in another institution). **B.** Wound with spontaneous purulent discharge from a fistula. **C.** Radiograph of the left femur after the first debridement with exeresis of the devitalized fragments and placement of antibiotic beads. **D.** Oncological bone resection, placement of antibiotic spacer/beads, and stabilization with an intramedullary nail.

After the sixth debridement since admission, the wound began to improve. Antibiotic treatment was completed and puncture samples were taken, which were negative. Skeletal reconstruction was carried out, with good clinical-functional evolution.

Implant development

We developed a truncated cone interlayer segment with a larger diameter at both ends for better implant-bone coaptation (Figure 9). We chose stabilization with an intramedullary nail and designed a channel to house it. Given its length (13.5 cm), it was necessary to place a graft, so we decided to use a rough surface for embedding cancellous bone.

Figure 9. A and B. Final design of the scaffold. C and D. Anteroposterior and lateral radiographs of the complete femur two years after surgery. Bone formation encircling of the scaffold is observed.

Case 4

A 21-year-old man with a open femoral shaft fracture exposed on the posterior aspect of the thigh was referred four days after suffering a car accident. As background, drug addiction stood out. Initially, a mechanical-surgical debridement was performed with the placement of a tutor and reassessment at 48 h. Seven days later, intramedullary nailing was performed. Three days later, he was discharged with no complications (Figure 10).

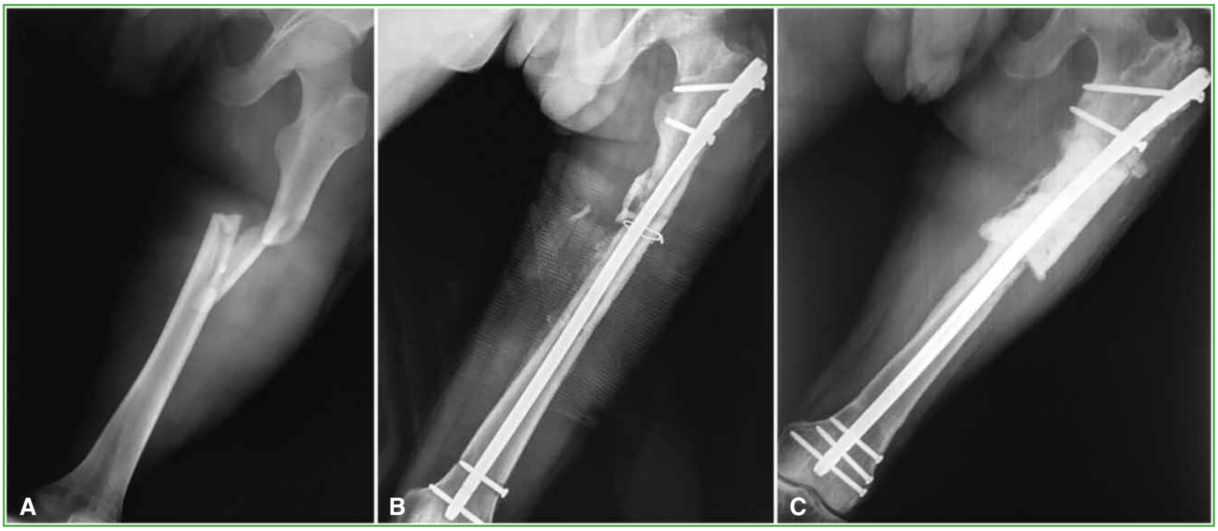

Figure 10. **A.** Anteroposterior radiographs of the left femur upon admission. **B.** Anteroposterior radiograph of the left femur after intramedullary nailing with cerclage wire. **C.** Postoperative anteroposterior radiograph of the left femur. The antibiotic spacer/beads and intramedullary nailing can be seen.

Three months after surgery, the patient presented with a purulent discharge and a fistula that coincided with the initial exposure site on the posterior thigh. Debridement with bacteriological isolation of methicillin-resistant *S. aureus* was performed twice, and targeted antibiotic treatment was indicated. Given the poor evolution, it was decided to remove the material and place a new nail with antibiotic coating. The patient escaped from the hospital and was readmitted a few days later due to discharge from the wound. A new debridement was carried out with *Staphylococcus haemolyticus* isolation. Psychological treatment was indicated. Due to the possibility of oral antibiotic treatment, he was discharged with regular check-ups in an outpatient clinic. At the third month, he reported that he had abandoned the antibiotic treatment without medical indication and that he had not attended physiotherapy sessions, he had stiffness in the ipsilateral knee. The patient did not comply with the traumatological and infectious guidelines and did not appear for subsequent controls. A year after the accident, he was admitted again with a thigh abscess under tension. Rarefaction of the fracture focus was observed on the radiograph. Debridement with positive isolation of methicillin-sensitive *S. aureus* was performed twice. Due to the poor evolution, we chose a radical approach which consisted of removal of the implant, resection of bad-looking bone fragments, and placement of a cement spacer with antibiotics. Given the good response, he was discharged to finish antibiotic treatment on an outpatient basis. A CT scan was requested for the preparation of the custom scaffolding.

Once the antibiotic treatment was finished, a puncture biopsy was performed, which was negative. Reconstructive surgery was performed (Figure 11).

Figure 11. Anteroposterior and lateral radiograph of the complete left femur, nine months after surgery. Bone formation encircling of the scaffolding is observed.

Implant development

We developed a conical interlayer titanium segment with a larger proximal diameter to allow the development of an internal oval-shaped canal, in order to facilitate the entry of the intramedullary nail without secondary displacement of the scaffold. To achieve greater coaptation of the bone segments, two divergent channels were designed in the direction of the lesser trochanter to place 3.5 mm cortical screws in compression. At the level of the medial aspect, we made a slot that extended connecting the proximal and distal segments, intended for the placement of bone graft in order to achieve an internal column of bone. Due to its length (11 cm), it required the placement of a graft, so it was decided to use a rough surface for embedding cancellous bone (Figure 12).

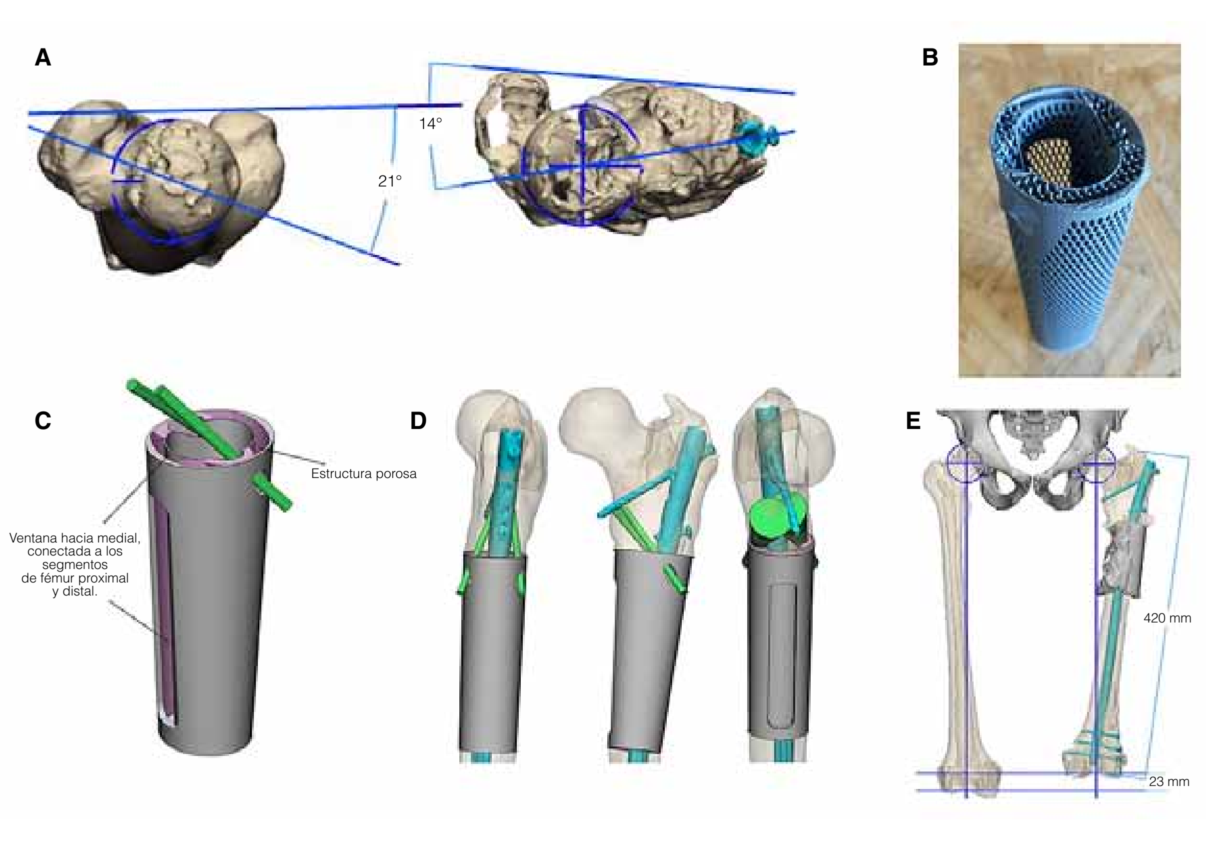

Figure 12. A. Comparative image with the healthy femur to carry out the design of the scaffolding taking into account the correction of axes, length, and rotation. B. Scaffold development. C. Development of an internal oval-shaped channel in order to facilitate the entry of the intramedullary nail. D. On the medial aspect, a slot that extends connecting the proximal and distal segments is created for bone graft placement. E. Final design of the scaffold to be implanted.

Case 5

A 22-year-old man was referred to our hospital with a plaster cast 5 weeks after a car accident. He had an open femoral shaft fracture, exposed on the anterior side with a segmental defect of approximately 10 cm, a comminuted fracture of the ipsilateral patella (Figure 13), and injury to the brachial plexus.

Upon admission, the open fracture wound was reviewed and it was decided to place skeletal traction for five days due to the marked shortening of the limb.

Figure 13. Anteroposterior and lateral radiographs of the femur. The fracture line with segmental bone loss of approximately 11cm is observed.

Before definitive surgery, an intramedullary nail was placed to equalize limb length together with a vancomycin-gentamicin cement spacer; oral antibiotic treatment was administered (Figure 14). Four months later, the spacer was replaced and samples were taken, which were negative. At two weeks, reconstructive surgery was performed (Figure 15).

Figure 14. **A.** Postoperative radiograph of the entire right femur. Intramedullary nailing with length recovery without focus opening. **B.** Anteroposterior radiograph of the entire right femur after the second surgery to place a cement spacer for Masquelet membrane formation.

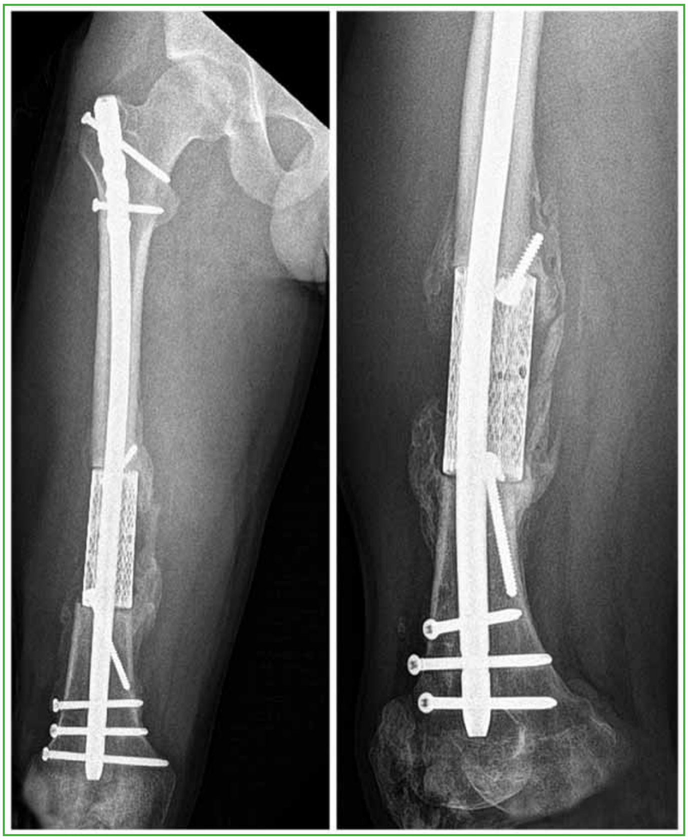

Figure 15. Anteroposterior and oblique radiographs of the entire right femur, two years after surgery. Bone formation encircling the scaffold is observed.

Implant development

We developed cutting guides. It was a cylindrical interlayer titanium segment with the same diameter as the patient's femoral diaphysis. Cutting guides were designed to regularize the fracture edges. We decided to perform stabilization with an intramedullary nail; therefore, a channel was designed to house it. In order to achieve greater coaptation to the bone segments, it was designed with a 45° channel, both proximal and distal, for the placement of 4.5 mm cortical screws in compression. Due to its length (12.5 cm), it required grafting, so it was decided to use a rough surface for embedding cancellous bone (Figure 16).

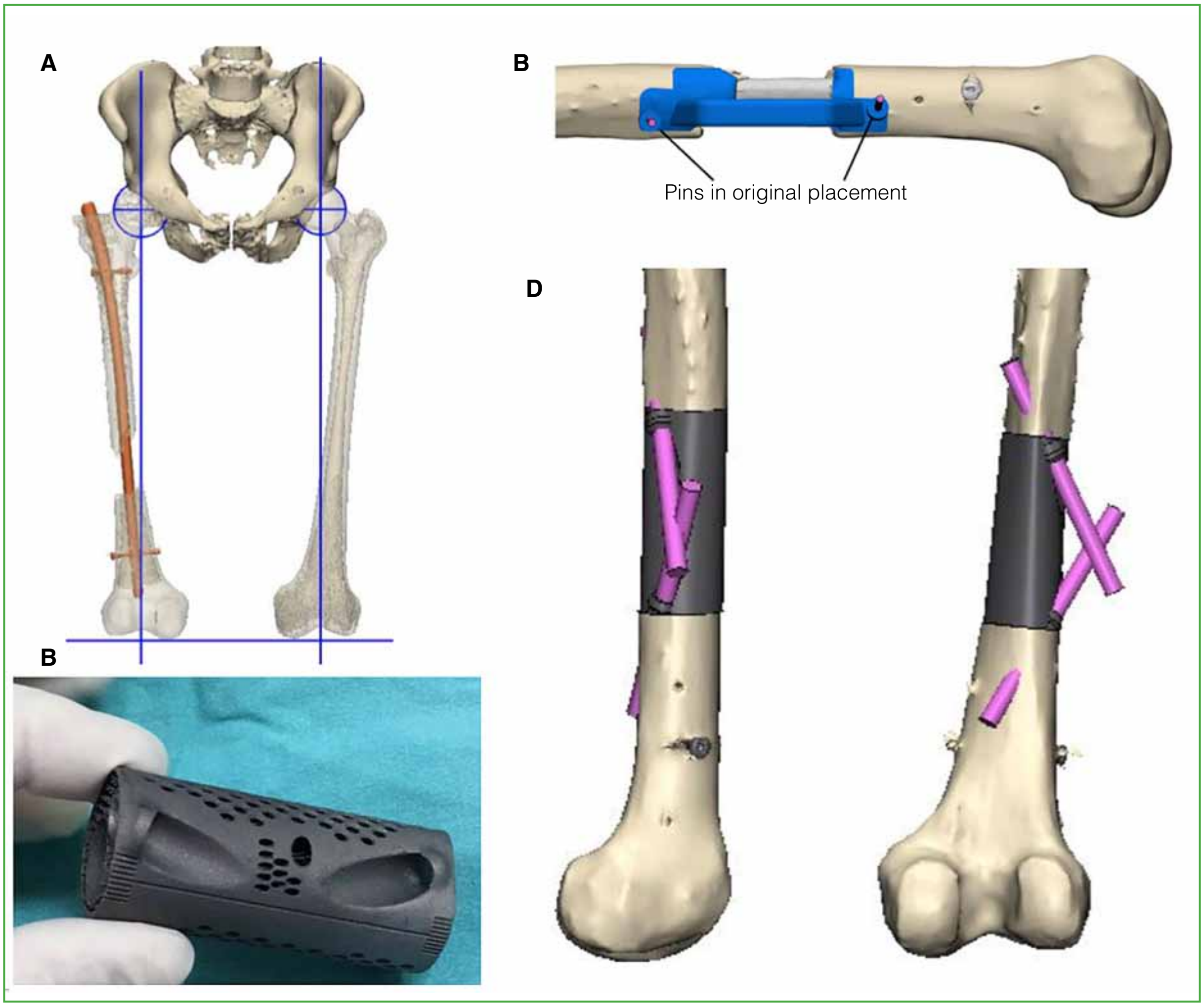

Figure 16. A. Comparative image with the healthy femur to carry out the scaffold design. B. Scaffold development. C. To achieve greater coaptation to the bone segments, it was designed with a 45° channel, both proximal and distal, for the placement of 4.5 mm cortical screws in compression. D. Final design of the scaffold to be implanted.

Case 6

A 24-year-old man was referred to our hospital 24 hours after a car accident. He had a multifragmentary open femoral shaft fracture, a fracture of the scapula, a fracture of the left 5th metatarsal, and multiple excoriations. Upon admission, mechanical-surgical debridement and external fixation were performed. After 10 days, intramedullary nailing of the femur and osteosynthesis of the 5th metatarsal were performed. He was discharged on the third day after surgery. After 10 days, he consulted again fo secretion from the wound and mechanical-surgical debridement was performed again. It was decided to remove the devitalized bone fragments and place antibiotic beads. The patient began empirical treatment with vancomycin, meropenem, and rifampicin. At 48 h, debridement was carried out again and the beads were replaced. Methicillin-resistant *S. aureus* was isolated from culture and, based on the antibiogram, the treatment switched to cephalothin plus rifampin. Given the poor evolution, we proceeded to remove the nail and all the bone fragments, and place a spacer with cement and antibiotics, which eradicated the infection and provided clinical improvement. After 20 days, he was discharged to complete 90 days of outpatient antibiotic treatment. The interlayer scaffolding design began. Once the antibiotic treatment was finished, a puncture was performed with a negative result and skeletal reconstruction was carried out after 10 days.

Implant development

We developed cutting guides. It was a cylindrical interlayer titanium segment with the same diameter as the patient's femoral diaphysis. We chose stabilization with an intramedullary nail; therefore, a channel was designed to house it. In order to achieve greater coaptation to the bone segments, it was designed with a 45° channel, both proximal and distal, for the placement of 4.5 mm compression cortical screws. Due to its length (13.5 cm), graft placement was required, so it was decided to use a rough surface for embedding cancellous bone (Figure 17).

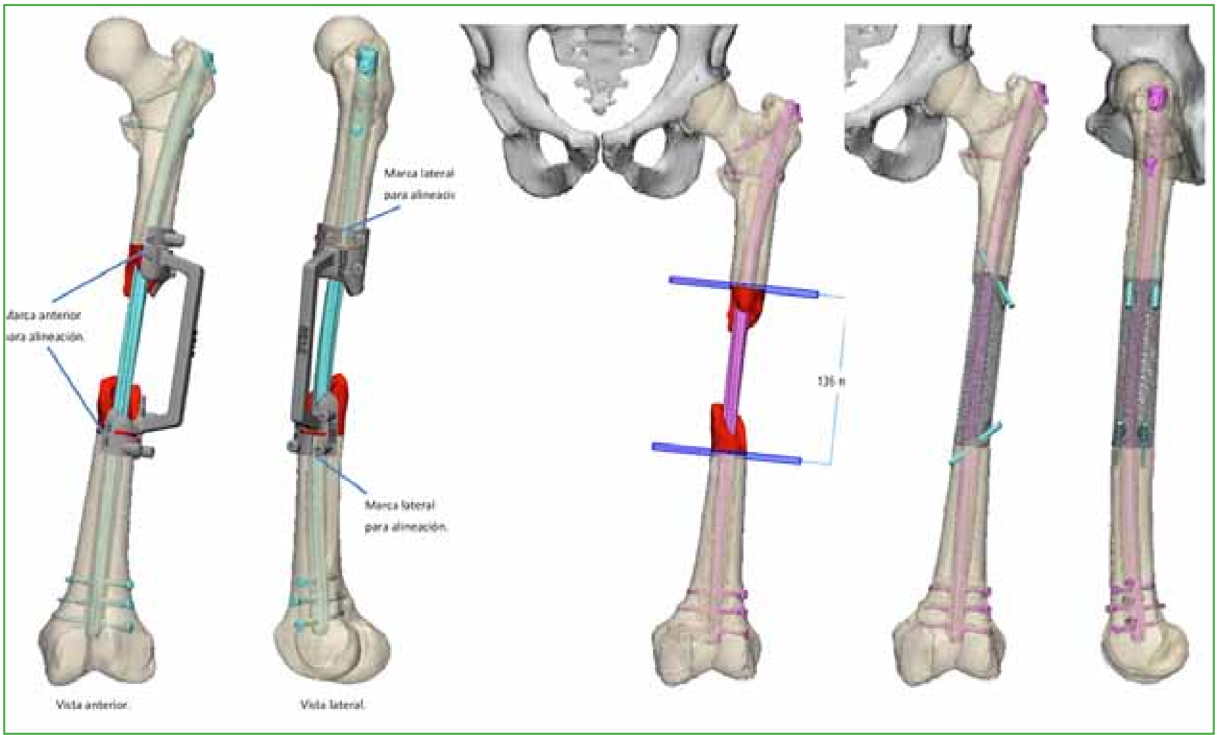

Figure 17. Development of the cutting guide that also contemplates the necessary rotation correction. In order to achieve it, the previous marks that indicate where the pins should be placed are observed and then they must be aligned in the same plane to achieve the axis correction.

Reconstruction

Once infection was ruled out by taking samples and puncture biopsy for culture and pathological anatomy, reconstruction surgery was scheduled.

Surgical technique

Preoperative period: We carry out a workshop preoperative planning with biomodelling of the anatomical segments to be treated and of the definitive implant developed in full-scale plastic. The surgical technique to be executed is reproduced with the entire surgical team, and the resections are practiced according to each caseIntraoperative period: The decision on the appropriate time to perform the reintervention is based on the infectious disease discharge of each patient, it is not possible to determine a fixed time. The antibiotic spacer/beads placed in the previous stage are removed according to bacterial isolation, adapting the approach according to the anatomical region, the need to extend it, and the possibility of using previous surgical incisions. Due to what has already been stated, the times usually exceed the ideal ones to make full use of the advantages of the induced membrane described by Masquelet. The opening of the membrane must be done in the axis of the limb in a meticulous way in order to preserve it. The correct preparation for the placement of the implant, by means of fibrosis exeresis and osteotomies for the regulation of fracture edges as necessary, is fundamental. The use of a femoral distractor or manual traction will be decided, as necessary.

The implant is placed in the place of the defect and the distractor traction is removed, leaving the cylinder as an interlayer, controlling the axis, rotation, and length of the limb and corroborating under fluoroscopy. Stabilization is performed according to the design (intramedullary nailing or regional plates). The maximum limit of effective osteoinduction of titanium is considered to be 8 cm in length. When longer implants are required to treat the defect, grafting becomes necessary. If the graft obtained by traditional means is not sufficient, special systems can be used, such as the RIA system (Synthes). In Case 3, it was used to harvest the intracanal graft from the contralateral femur and prepare the implant by seeding it.

RESULTS

The postoperative protocol consisted of physical kinesiotherapy rehabilitation seven days after the definitive surgery, which included joint mobility, magnetotherapy, and ultrasound.

This technique was used in five men and one woman (mean age 30 years, range 19-54). The median follow-up was 24 months (range 12-36).

All fractures were type C according to the Solomin and Slongo classification.[16]

In the immediate postoperative period, axis, length, and sufficient mechanical stability to initiate partial weight bearing were restored. Full weight-bearing according to the patient's conditions (pain, muscular strength) demanded an average of 25 to 30 days.

At 45 or 50 days, all patients were in rehabilitation and fully weight-bearing without using a cane or crutches.

At 60 days, we observed radiographic signs of incipient integration without signs of loosening. The patients had no pain or claudication.

At 90 days, they returned to their usual daily activities; the average score on the visual analog scale was 1.16.

After 120 days, all of them had range of motion in the physiological range of the joint adjacent to the operated limb, except for the patient in Case 3, due to joint stiffness secondary to a patella fracture.

At 150 days, complete bone incorporation was confirmed by computed tomography in all patients. Likewise, in simple radiographs, the bone 'engulfment' of the implant was observed, which was considered secondary to the inducing quality and the partial calcification of the membrane.

All patients resumed their previous activities in an average of 227 days. None presented shortening, angulation, or rotation of the affected limb.

Complications in the immediate postoperative period comprised a serous secretion from the wound (Cases 3 and 4). In both cases, exploration and surgical debridement with sample taking were carried out, the cultures of which were negative. This secretion occurred in patients who received a greater amount of cancellous bone graft.

There were no cases of infectious reactivation, intolerance to the material, or signs of loosening or fatigue requiring removal.

Two patients had an associated comminuted patella fracture. One (Case 5) has painless range of motion in the physiological range (extension 180º, flexion 95º), the other has full extension with limitation in flexion of 40º that limits him in his activities of daily living, but he preferred not to undergo another intervention.

DISCUSSION

In 2005, Attias et al. described the use of cylindrical metal mesh cages for the reconstruction of segmental bone defects in the humerus, with excellent outcomes.[17]

In 2011, Sewell et al. presented a retrospective study between 1998 and 2008 of 19 patients with a diaphyseal tibial tumor who had undergone oncological resection of the tumor and skeletal reconstruction with a titanium endoprosthesis. These were two-part implants that were joined with screws during surgery and contained stems at their ends that were fixed with cement and osteosynthesis plates if they were >4 cm long.[18]

In 2012, Van der Stok et al. described the use of trabecular titanium implants in rats and discussed the best structure and pore sizes.[19]

In 2015, Wieding et al. analyzed the advantages over other treatments in sheep.[20]

We used the benefits provided by the induced membrane by promoting groups of

vascular and ontogenetic inducing factors, and we added a trabecular titanium scaffolding that gave us the mechanical resistance that the graft alone cannot provide.

In 1991, Perren argued that the ideal metal should have good biocompatibility, optimal adhesion to reduce capsule formation and physical irritation of tissues, contain no allergenic components, and have a minimal rate of corrosion. The intrinsic characteristics of titanium to promote osteoinduction, osteoconduction, and osseointegration,[12] as well as its mechanical strength,[11] its minimal corrosive rate, and its resistance to infection[19,20] make it the material of choice.

Titanium implants are biologically superior, their good results in infected patients are clinically proven. Unlike surgical stainless steel, tissue adherence to titanium due to its biocompatibility and surface structure prevents the formation of dead space and biofilms[15] that promote harmful bacterial propagation.[14]

The choice to develop the implants in Ti-6Al-4V alloy was made respecting Perren's concepts. The 1-4 mm pore used is considered optimal to promote osteoconduction, osteoinduction, and osseointegration, so bone grafting is only necessary when the implant measures >8 cm.[13]

The properties of titanium in resistance to infection are evident, which allows its use in a previously infected segment.[14,15]

The recovery of the entire length of the defect in one stage, added to the biomechanical stability to tolerate early weight-bearing, has a positive effect on the reduction of rehabilitation times, with excellent functional outcomes. We observed a clear shortening of rehabilitation times compared to conventional techniques, such as grafting, Masquelet, and bone transport. In the different literature reports on the Masquelet technique, partial weight-bearing began between the 4th and 5th months and full weight-bearing, only after 6-8 months. The length of hospitalization is notably shorter when compared to elongation using tutors or another method.[5-7]

The use of the induced membrane concept and its advantages for callus formation is reflected in the presence of calcification encompassing the implant. Although we know that, around the third week, when the biological conditions are ideal for graft seeding and the highest levels of growth factors and adult stem cells (stem cells) are recorded in the membrane,[4,5] we are sometimes forced to exceed these times due to reasons related to infectious diseases.

The weaknesses of this study are its non-comparative retrospective design between different techniques for the treatment of segmental bone defects and the small size of the sample. Its strengths are the contribution of a new therapeutic option, the promising postoperative outcomes, and the low rate of complications.

CONCLUSIONS

We proposed a rare treatment option in our field, which provided sufficient biomechanical stability to tolerate early weight-bearing and recovered the full length of the defect in a single stage, with excellent functional outcomes. These results are considered advantages over the usual therapeutic options, such as bone transport or the induced membrane technique.

The cost of the implant and its development does not imply a higher expense than other therapeutic alternatives, since it shortens treatment and length of hospitalization and rehabilitation, especially in active working patients. This statement is currently under study.

Although this technique is promising to treat this type of injury, we understand that the number of cases to date is still scarce, but that it has a high potential for development. One difficulty is the long and detailed planning, as well as a demanding execution for the surgeon. It is necessary to have a greater number of cases and a control time to be able to define if this could be a method of choice for large bone defects.

FINAL COMMENT

A history of infection is not a contraindication to perform this type of treatment.

It is considered a highly demanding technique not only because of the surgical level, but also because of the development of the implant. The development of the interlayer implant requires extensive experience, knowledge, and permanent study of human biomechanics, and it is not only carried out by the medical team, but also by bio-engineers and designers.

Conflict of interest: The authors declare no conflicts of interest.

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