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Case Report

Allograft Remodellation in a Pediatric Segmental Tibial Trauma Defect; Follow-Up Case

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Abstract

High-energy fractures with bone loss are a true challenge for orthopedic surgeons, requiring complex reconstruction techniques and the use of bone grafts. Despite basic science advances, knowledge about the process of human bone allograft integration is limited. The aim of this case report is to document the remodel and integration process of a cortical bone allograft, until indistinguishable from the bone host in a pediatric patient with case follow-up for 8 years.

Evidence level: IV.

Keywords: *Bone Loss; Fracture; Allograft; Integration; Remodel*

Abbreviations

MESS Scale: Mangled Extremity Severity Score; LC-DCP: Limited Contact Dynamic Compression Plate

Introduction

Tibial fractures are common in pediatric population, representing 10 - 15% of all pediatric fractures in the United States, being the age of 8 years the most representative, while exposed fractures occur in approximately 6 - 10% of cases [1]. These types of injuries tend to heal faster in pediatric population and have a lower rate of infection as well as lower incidence of non-union. The growth and mineralization of the skeleton are processes that begin during fetal development and continue at different rates during childhood and adolescence until the third decade of life, when the maximum peak of bone mass is reached, unlike adult bone, the periosteum of pediatric patients has a great capacity for bone formation, being subjected to a continuous process of neoformation [2,20].

The usual treatment for open tibial fractures is early surgical lavage, intravenous administration of antibiotics, and fixation; however, amputation is a latent possibility. In the case of segmental bone loss, treatment options include external fixation with autologous or heterologous bone graft placement, bone elongation or bone transport [1,3]. The use of allograft is widely implemented, with the advantage of availability in large quantities, different sizes and shapes, the possibility of choosing between cortical bone, cancellous bone or an osteochondral graft depending on the needs of the lesion, while avoiding donor site morbidity, reducing surgical time and blood loss [3]. Cortical bone allograft exhibits osteoconductive properties, providing a receptive scaffold for bone formation. The allograft integration process includes the host inflammatory response, bone cell proliferation, cell migration, differentiation and revascularization resulting in the process of bone formation and union between the graft and the host [4].

A case of an open fracture of the tibia and fibula with 5cm segmental bone loss is presented, treated using cortical bone allograft, supplemented with platelet-rich plasma and autologous bone marrow, emphasizing the potential for bone allograft integration and remodeling in a pediatric patient as well as the possible difficulties or complications that we can face when using this technique.

Clinical Case

7-year-old male patient, comes to the emergency room 30 minutes after being hit by a car, leaving both legs pressed against a concrete wall, resulting in an open fracture of the right tibia AO 42-D/5.1 Gustilo-Anderson IIIA and open fracture of the left tibia/fibula AO 42-D/5.2 Gustilo-Anderson IIIB with a 5 cm segmental defect in the distal region of the tibia in which the third fragment was not at the fracture site. 5 points in MESS scale (Mangled Extremity Severity Score). Initially patient is treated by surgical lavage and debridement, plus placement of external fixators in both pelvic limbs. A double antibiotic scheme (Cephalothin and Amikacin) was administered, after 3 days the external fixator was removed from the right tibia, wound closure and osteosynthesis of the tibia is performed with a 3.5 mm LC-DCP (limited contact dynamic compression plate). After seven days of admission and surgical lavage every two days, the patient underwent surgery, performing debridement of the necrotic skin on the left pelvic limb and osteosynthesis of the tibia with an LCP plate using a cortical bone allograft to fill the 5 cm bone defect; In addition, fixation of the fibula is performed with a Kirschner nail, and in the same surgical event, skin coverage is provided with a vascularized muscle flap and partial-thickness skin grafts (Figure 1).

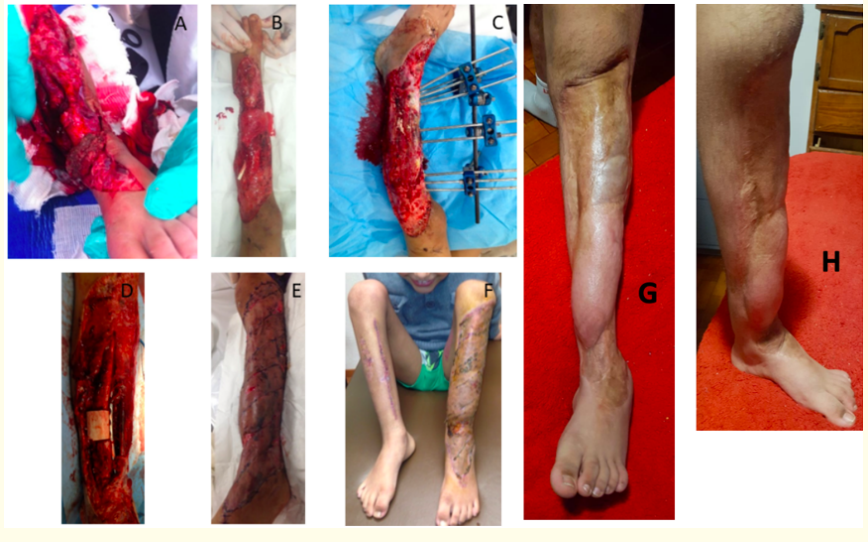

Figure 1: *State of soft and bone tissues. (A) Initial state of soft tissues and bone, observing the absence of the third fragment at the fracture site. (B) Lesion after debridement. (C) Fracture stabilization using external fixators. (D) Bone allograft placement. (E) Skin graft placement. (F) Evolution of skin graft 6 months after placement. (G)(H) Evolution of skin graft 8 years after placement.*

Results and Discussion

Clinical and radiographic follow-up until bone consolidation was documented. Ten months after the second surgery, the osteosynthesis material is removed from the left pelvic limb, during which a biopsy of the bone allograft site is performed, said sample is sent to pathology, reporting the integration of the allograft to the host bone, observing the invasion of trabeculae with Haversian canals (Figure 2). After removal of the osteosynthesis material, the follow-up radiographs show adequate bone integration with a valgus deformity. 12 months after the secondary fracture, the radiograph shows remodeling and complete integration of the allograft (Figure 3).

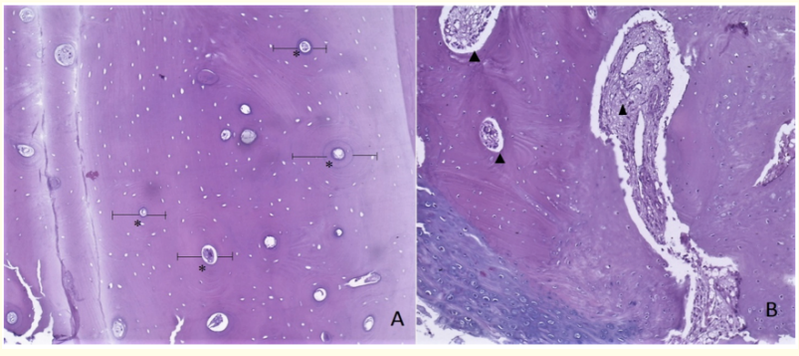

Figure 2: *State of soft and bone tissues. (A) Initial state of soft tissues and bone, observing the absence of the third fragment at the fracture site. (B) Lesion after debridement. (C) Fracture stabilization using external fixators. (D) Bone allograft placement. (E) Skin graft placement. (F) Evolution of skin graft 6 months after placement. (G)(H) Evolution of skin graft 8 years after placement.*

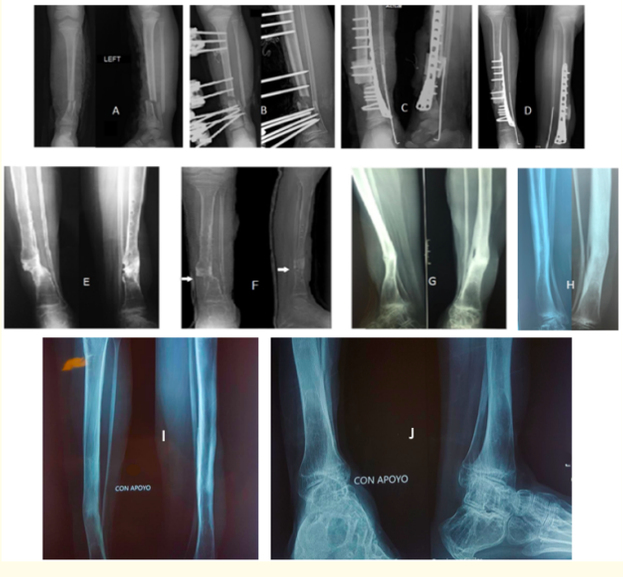

Figure 3: *Chronological sequence of bone integration until final remodeling. (A) Initial diagnostic radiograph of the left tibial fracture. (B) Surgical lavage and external fixation of the left tibia showing the bone defect (5 cm). (C) Immediate postoperative X-ray after removal of external fixation and plate osteosynthesis. (D) X-ray 6 months postoperatively showing bone integration. (E) Radiograph after plate and screw removal still showing residual valgus. (F) 12 months postoperatively, the arrow indicates the second fracture below the bone graft site. (G) 24 months postoperatively showing the remodeling of the graft site. (H) 7 years after allograft placement. (I) (J) 7 years after allograft placement.*

Among the options available for the treatment of bone defects, multiple techniques such as bone transport, the Masquelet membrane induction technique and placement of vascularized bone grafts have been documented; however, due to the complexity of these techniques, the orthopedic team considers that the treatment of this type of pathology with bone allograft is optimal for enriching its characteristics with autologous bone marrow and growth factors. In this patient the use a bone allograft is decided to to avoid donor site morbidity, reduce trans-operative bleeding and surgical time. Drilled holes through the allograft pose a significant risk of weakness due to cortical bone resorption, secondary to the generation of a stress point at a potential revascularization site [7,8] just as observed in the case. Patient age is an important factor for successful cortical allograft bone remodeling, as seen on the last follow-up radiograph showing an almost identical diameter of the allograft to that of the host tibia (Figure 3).

There is extensive literature on the management of complex open fractures in adults, while in pediatrics there is little on treatment guidelines. Keating reports that bone grafts can be used in diaphyseal defects of 6 cm or more. Ruta and Ozer describe the main benefits of the use of bone grafts which allow rigid osteosynthesis, recover bone length and muscle tension, and decreases the rate of infection and edema by eliminating dead space and restoring venous and lymphatic circulation. Finally, they refer to the reduction of soft tissue contracture as well as fibrous changes. Fakoor., *et al*. conducted a prospective study of 144 patients with open tibial fractures treated with bone graft, with the aim of observing the time of graft consolidation based on the time of its placement. They observed a mean consolidation time of 14.24 ± 4.4 weeks in the patients in whom the graft was placed at 3 weeks and a mean of 16.4 ± 5.4 weeks in those who were placed at 6 weeks. Tropet., *et al*. found that in cases with type IIIB open fractures, the mean graft consolidation was 24 weeks [13]. Blick., *et al*. observed a rate of deep graft infection in 79% of cases with grade III open fractures.

Bone is highly labile and dynamic, responding to a variety of metabolic, physical, and endocrine stimuli. It is in a constant cycle of resorption and renewal, it undergoes continual chemical exchange and structural remodeling due to both internal mediators and external mechanical demands. Despite these complex features, it has a relative simplicity in terms of structural elements, which allows it to restore its normal function and architecture after injury. It is capable of maintaining optimal shape and structure throughout its life through a continual renewal process through which it can respond to changes in its mechanical environment by "reshaping" to meet different load demands [21].

In orthopedic surgery one of the most complex challenges is the resolution of large bone losses, where the use of bone graft is ideal, which based on its biological effects, should have the following properties: osteoconduction, which allows the bone graft to be used as a scaffold to generate new bone tissue; osteoinduction, involves the stimulation of osteoprogenitor cells to differentiate into osteoblasts to induce new bone formation, favoring a rapid integration of bone graft, and the last property is osteogenesis, which occurs when living osteoblasts from the graft (only autologous) contribute to the formation of new bone [5,15,16].

The integration process of an allograft is based on the immune reaction and inflammatory response of the host around it, revascularization of the graft through the Haversian and Volkmann canals. It is now recognized that successful bone grafting depends on the host bed having adequate vascularization. Vascularization has been identified as a central component that influences bone healing and therefore plays a key role in achieving good graft repair. In cases of decreased blood supply, the choice of a vascularized bone graft seems unavoidable, as bone grafts with intrinsic blood supply lead to higher success rates and acceleration of the repair process in the reconstruction of skeletal defects and necrotic lesions [4,21]. Osteogenesis occurs through the progressive replacement of the graft and bone formation, which in the context of a cortical allograft is given through intramembranous ossification [7], as we can observe in the histological sample of the patient.

Rigid internal fixation of a long bone allograft is very important to ensure mechanical integrity and can be achieved through intramedullary implants, plates, and screws. Once the allograft is integrated with the host and sufficiently strong, bone structure remodeling occurs based on functional demand and mechanical loading.

The growth and mineralization of the bone skeleton are processes that begin during fetal development and continue at different rates during childhood and adolescence until the third decade of life, when the maximum peak of bone mass is reached. During childhood and adolescence until the acquisition of adult height, two phenomena concur: formation of new bone from the growth cartilage (endochondral ossification) and resorption-neoformation of the previously synthesized extracellular matrix (action of osteoblasts and osteoclasts). Both phenomena are combined and coupled, resulting in the acquisition of bone mass and advantage for remodeling and integration of an allograft, since in adulthood bone mass is maintained and during the last decades of life bone neoformation decreases, the balance becomes negative and leads to a progressive decrease in bone mass [20]. However, pediatric patients are not exempt from difficulties such as angular deformities and the possibility of presenting a peri-implant fracture due to the revascularization-resorption process of the cortical bone.

Conclusion

To conclude, emphasis is placed not only on the success and ease of use of the technique, but also on the ability the graft has to remodel, adapting to the contour and characteristics of the native bone, making the radiological image of the allograft indistinguishable from the host bone after 8 years. Histologically, it is demonstrated by the slow and progressive invasion of bone and marrow cells, and vascular sprouts inside (Figure 2). Graft revascularization allows osteoblastic, osteoclastic, and bone marrow cells to progressively invade the graft body and initiate graft remodeling, also known as Phemister's creeping substitution, which continues indefinitely [22]. In this case, the incorporation is a success since it was possible to revascularize the graft, stimulate the formation of new bone and obtain early structural strength.

Conflict of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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