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The role of osteosynthesis in upper limb transplantation in Mexico: a case report

Abstract

Stable bone fixation maintains alignment between the donor and recipient bones during upper limb transplantation and subsequent union. The choice of implant depends on the level of amputation, the quality of the residual bone, the dimensions of the medullary canal in cases of internal fixation, and the time elapsed before graft reperfusion. We describe the osteosynthesis of the left humerus in a 51-year-old man who underwent bilateral arm transplantation following a high-voltage electrical injury. The transplant was performed in October 2015 at the right glenohumeral and left transhumeral levels. Fixation of the left humerus was achieved using an 8.5 × 260 mm expandable intramedullary nail, without locking screws. Cortical contact and initial stability were verified under direct visualization; follow-up revealed adequate union. This report examines the orthopedic fixation criteria of a previously described case from anatomical, microsurgical, and functional perspectives. The expandable nail allowed for rapid fixation and subsequent union in this patient. Implant selection requires an assessment of immediate stability, placement time, and the mechanical demands of union and rehabilitation.

Keywords: upper limb transplantation, osteosynthesis, humerus, expandable intramedullary nail, bone union, vascularized composite allograft, case report

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Abbreviations: VCA, vascularized composite allograft; INCMNSZ, Salvador Zubirán National Institute of Medical Sciences and Nutrition; DASH, Disabilities of the Arm, Shoulder, and Hand

Introduction

Amputation of the upper extremities limits self-care, work, and social participation, particularly when both limbs are affected. Vascularized composite allograft (VCA) transplantation restores the bony, muscular, vascular, nervous, and cutaneous components of the missing limb. Functional recovery varies depending on the level of the transplant and reinnervation; a systematic review of 96 recipients found lower postoperative disability scores in distal transplants than in proximal ones.[1]

Osteosynthesis maintains alignment and contact between the donor and recipient bones and provides a stable structure for vascular, muscular, tendinous, and nervous repair. Bone union depends on the

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mechanical conditions of the osteotomy and the preservation of the local blood supply. Absolute stability may allow for direct union, while relative stability allows for union through callus formation.[2,3]

Internal fixation options include plates and intramedullary nails. The design of the nail determines the control of axial and rotational movement: locking screws provide fixation through the cortex, while expandable nails increase contact with the medullary canal without the need for locking screws.[4] Ischemia-reperfusion injury and the preservation of graft viability require coordination among multidisciplinary teams.[5,6]

This report describes the selection, placement, and radiographic outcome of an expandable nail used for left humeral osteosynthesis during an arm transplant in Mexico. The anatomical and microsurgical procedures and the functional follow-up for this patient have been previously published.[7,8] This report focuses on bone fixation.

Materials and methods

Patient and Preoperative Evaluation

A 51-year-old man sustained a high-voltage electrical injury in January 2012 that required bilateral upper limb amputation. The right stump retained the proximal epiphysis of the humerus; the left amputation was transhumeral. Bilateral arm transplantation was performed at the Salvador Zubirán National Institute of Medical Sciences and Nutrition (INCMNSZ) in Mexico City on October 16, 2015. The donor was a 33-year-old man who was brain dead. The right limb was transplanted at the glenohumeral joint level, and the left at the level of the humeral diaphysis.[7,8]

Preoperative evaluation included examination of the stumps and X-rays to assess humeral length, residual bone, and the planned osteotomy level (Figures 1 & 2). On the right side, marked osteopenia of the residual humeral head necessitated transplantation of the entire humerus with glenohumeral reconstruction. On the left side, the residual humeral shaft allowed for intramedullary fixation. The dimensions of the donor and recipient canals were compatible with the selected nail.[7]

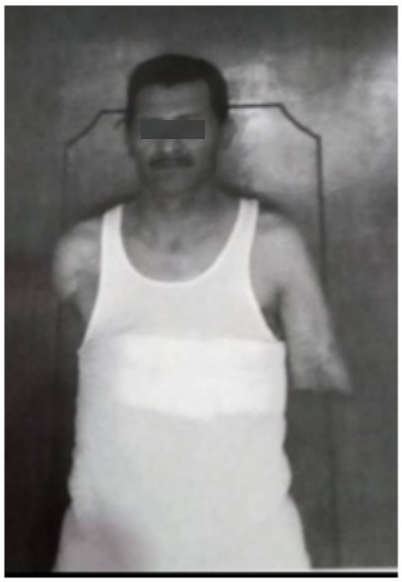


Figure 1 Preoperative clinical appearance following bilateral upper limb amputation due to a high-voltage electrical injury.



Figure 2 Preoperative X-ray showing the different residual humeral levels on the right and left sides.

Surgical technique and osteosynthesis

Teams from orthopedics, plastic and reconstructive surgery, vascular surgery, transplantation, and anesthesiology participated in the procedure. The medial and lateral incisions of the left stump were joined transversely, and anterior and posterior skin flaps were elevated toward the deltoid insertion. The brachial vessels, the median, ulnar, and radial nerves, and the residual biceps and triceps muscles were identified. The osteotomy of the recipient humerus was performed distal to the insertion of the deltoid muscle. The donor osteotomy was prepared at the corresponding level, preserving the muscle units necessary for reconstruction.[7]

The left humerus was fixed with an 8.5 × 260 mm. Fixation expandable intramedullary nail, without locking screws.[7] This implant was chosen to achieve fixation without the need for locking screws and to minimize the time required prior to vascular repair. Expansion within the medullary canal ensured contact between the implant and the bone of both the donor and the recipient. Exposure of the osteotomy allowed for direct verification of alignment, cortical contact, and initial stability.

Following osteosynthesis, a terminal-to-terminal anastomosis of a brachial vein and the brachial artery restored perfusion to the left graft. The tendons of the long heads of the biceps and triceps were repaired, and the short head of the biceps and the coracobrachialis were reinserted into the coracoid process. The donor muscles were attached to the corresponding recipient remnants using the piggyback technique. The median, ulnar, and radial nerves were repaired using end-to-end neuroraphies. The donor's musculocutaneous nerve was repaired using a terminolateral anastomosis to the recipient's radial nerve. The wounds were then closed.[7]

Postoperative X-rays were used to evaluate implant position, maintenance of alignment, and humeral union. The published follow-up report provided radiographic assessment of union at six months and subsequent functional outcomes.[8]

Ethical considerations

The transplant was performed in accordance with the INCMNSZ upper limb transplant protocol, approved by the Human Research Committee under reference number 84.[8]

Results

Placement of the expandable nail took less than 10 minutes. Direct inspection after fixation revealed contact between the donor and

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recipient humeral segments, as well as sufficient initial stability to proceed with vascular and soft-tissue reconstruction. The left graft had a total ischemia time of 6 hours and 35 minutes, consisting of 5 hours and 57 minutes of cold ischemia and 38 minutes of warm ischemia. The entire bilateral transplant procedure lasted 17 hours.[7]

Radiographic follow-up documented union of the left humeral diaphysis at six months.8 The postoperative anteroposterior radiograph shows the intramedullary implant in position and union at the osteotomy site, with no radiographic signs of loosening (Figure 3 & Figure 4).



Figure 3 Postoperative anteroposterior radiograph of the left humerus showing the expandable intramedullary nail and union at the osteotomy site between the donor and recipient segments.



Figure 4 Anatomical and functional outcome after 18 months of postoperative follow-up.

The published 18-month follow-up described left elbow flexion and extension with M4 strength and a DASH score of 67.5, compared with 75.83 before the transplant.[8] Elbow reconstruction included a secondary transfer of the pectoralis major muscle. These functional results were achieved following bone, vascular, nerve, and soft-tissue reconstruction, along with prolonged rehabilitation.

Discussion

The left humeral osteotomy healed following fixation with an expandable intramedullary nail. The brief placement time without the need for fluoroscopically guided locking screws, direct access to the osteotomy site, and the compatibility of the donor and recipient canals were the main criteria for selecting this implant. The fixation maintained the bone relationship necessary for subsequent vascular and soft-tissue repairs. The callus formation documented during follow-up was consistent with secondary bone union.[2,8]

Expandable nails have reduced operative time in studies of diaphyseal humeral fractures. Ozan et al. reported a mean time to union of 4.5 months in 14 diaphyseal humeral fractures, with loss of fixation and nonunion in one patient.[10] Papadakis et al. reported a mean operative time of 20 minutes for humeral fractures treated with an expandable nail. Their systematic review included 790 fractures of the femur, tibia, and humerus, with 33 cases of nonunion.[11]

Mechanical stability requires controlling displacement and rotation during union. In this case, direct cortical contact and the compatibility of the channels favored the use of the expandable implant. Residual bone quality, the length of each humeral segment, and the osteotomy level determine the possibilities for fixation. Excessive motion or insufficient vascularization can hinder union, while the stability of the fixation determines whether union occurs directly or through callus formation.[2–4]

Plate fixation and locked nails are alternatives with different complications. Beeres et al. found shorter operative times and fewer postoperative radial nerve infections and paralysis with nails than with open plating, although reoperation for shoulder impingement was more frequent after nail fixation.[11] The choice between these fixation methods requires consideration of the available bone, surgical access, and the location of vascular and nerve repairs.

Pre-revascularization fixation contributes to warm ischemia time. Prolonged ischemia can damage skeletal muscle and trigger inflammatory responses after reperfusion, whereas cold preservation limits metabolic demand during transport and preparation.[5,6] The left graft in this patient had 38 minutes of warm ischemia, which included the steps necessary for bone fixation and vascular repair.[7] Coordinating these procedures was particularly important because the bilateral transplant took 17 hours.

Both sides of this transplant required different bone reconstructions. The right side included the entire humerus and glenohumeral reconstruction due to marked osteopenia of the residual humeral head. The left side allowed for humeral osteosynthesis.[7] Lahlali et al.[12] subsequently described a bilateral proximal arm transplant in which a short humeral stump was reconstructed with donor fibula reinforcement on one side and the entire humerus was transplanted on the other; bone union was achieved.[12] The level and quality of the residual bone determined the reconstruction in both reports.

Radiographic union provides the structural continuity necessary for rehabilitation, while functional recovery also depends on nerve regeneration, muscle reconstruction, secondary procedures, and continuity of treatment and rehabilitation. The 18-month findings in this patient were obtained following a pectoralis major transfer and prolonged rehabilitation.[8] The literature on transplants describes functional improvements alongside rejection, infection, and other complications that affect long-term follow-up.[1]

This report describes a patient and a humeral osteosynthesis procedure. Implant selection was individualized, without simultaneous comparison to plates or locked nails. The placement time refers to fixation, whereas the cited studies on fractures reported the operative time of the procedure. The nail's contribution to total ischemia time, union, and functional recovery cannot be estimated independently of other surgical and rehabilitation procedures.

Conclusion

The expandable intramedullary nail allowed for rapid initial fixation and subsequent union of the left humeral osteotomy in this bilateral arm transplant. The choice of implant must take into account the dimensions of the donor and recipient canals, residual bone quality, the level of osteotomy, and the stability required during union, rehabilitation, and, above all, the placement time when tissue viability

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is at stake.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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