CASE REPORT

Treatment of a Segmental Defect in the Humerus With Induced Membrane Technique

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SUMMARY

Treatment of large long bone segmental defects is typically performed by bone transport or induced membrane technique. Although both methods are more frequently described in the lower extremity, descriptions and outcomes of upper extremity defects are less well described. The purpose of this case report is to describe the management of a segmental bone defect in the humerus using induced membrane technique with bone graft harvest from the ipsilateral femoral medullary canal.

Key Words: segmental bone defect, induced membrane technique, reamer irrigator aspirator

INTRODUCTION

Segmental bone defects are challenging clinical problems with a limited number of solutions. Bone transport or induced membrane techniques are the most commonly used options to manage large bone defects, but most literature focuses on the lower extremity. Bone transport can be performed with an external fixator (with or without cable assistance) or a specialty intramedullary nail (with plate assistance). Each of these options has pros and cons, and the size and location of the defect influences the decision-making process.

Success rates of >80% have been demonstrated with the use of induced membrane technique for segmental defects, but some authors have reported the use of this method in the tibia may lead to higher recurrent infection rates than in the femur. Although the use of intramedullary nails with induced membrane technique has been associated with lower rates of reoperation in comparison with plates in the lower extremity, no large studies have addressed the upper extremity.

The use of induced membrane technique requires a staged approach and the need for a large volume of bone graft to be inserted at the second stage. Graft harvest site options include the iliac crest (ICBG), metaphyseal distal femur/proximal tibia, or the medullary canal of the femur or tibia. Each site has its benefits and unique risks, but the reamer irrigator aspirator (RIA; DePuy Synthes, West Chester, PA) has been shown to yield similar volume to posterior iliac crest while allowing for faster harvest times and less donor site pain.

Unfortunately, there is minimal evidence to guide the treatment of segmental defects in the upper extremity. The neurovascular anatomy of the upper extremity makes the use of a multiplanar external fixator challenging, and the common metaphyseal bone defect locations preclude the use of an intramedullary nail. This leaves using the induced membrane technique with a plate construct as the only option in some cases. The purpose of this case report is to demonstrate the use of a plate construct with induced membrane bone grafting for the management of a segmental humeral defect.

CASE REPORT

A 41-year-old man was referred to the clinic 1 year after sustaining a left humeral shaft fracture because of a gunshot wound and was treated with open reduction and internal fixation. Over the past year, he reported intermittent drainage from his posterolateral arm ballistic wound but denied fever, chills, or night sweats. He had been treated periodically with oral antibiotics but was currently not on antibiotics.

On physical examination, he had a moderately swollen left arm with a healed surgical incision and mildly painful 2-mm sinus tract over the posterolateral arm.

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some pain and the sensation of instability at the fracture site with forward elevation of the shoulder and with resisted elbow motion. There was minimal motion with manual stress of the fracture site, but this generated significant pain. Aside from some nondermatomal paresthesias in the hand, the patient had intact motor and sensory function in all distributions including the radial nerve.

Plain radiographs demonstrate an atrophic nonunion of the left humerus with multiple broken screws and varus alignment (Fig. 1). Laboratory values, at the time of clinic visit, demonstrated white blood cell 6.14 with 64% PMNs, erythrocyte sedimentation rate 20 mm/h, and C reactive protein 19.6 mg/L.

Assessment and Surgical Planning

Based on physical examination, radiographs, and laboratory findings, the diagnosis of septic atrophic nonunion was made. Both single and 2-stage reconstruction options were presented, and the final treatment plan was to be made based on intraoperative findings. In formulating a preoperative plan, the discussion with the patient centered around 2 important aspects of surgical treatment. The first portion was comprised of the need for aggressive debridement of any infected, devitalized soft tissue and bone, and removal of all indwelling implants. With aggressive debridement, the possible creation of a segmental bone defect during debridement was discussed. The size of the bone defect created with debridement would affect the way the defect would be handled. The acceptance of 2 cm of humeral shortening was discussed as an option that would allow for single stage reconstruction. In the interest of maintaining appropriate soft-tissue tension and avoidance of potential neurovascular compromise, shortening further than 2 cm would not be accepted, and induced membrane technique with plate fixation would be used after debridement. The patient expressed understanding of the surgical plan, and informed consent was obtained.

Surgical Treatment

The operation was performed with the patient in the lateral decubitus position. After the timeout, an extensile posterior approach\(^4\) was made using the previous surgical scar and elevating the triceps off the lateral intermuscular septum. Purulence was noted on dissection to the humerus. The posterolateral ballistic wound sinus tract communicated with this portion of the humerus, and the sinus tract was elliptically excised. The radial nerve was carefully identified and protected throughout the case. All of the indwelling implants were removed. Multiple tissue samples were obtained for the culture from all levels of the infection including the sinus tract, soft tissue, and devitalized bone. The bone ends of both proximal and distal segments were then aggressively debrided of the nonviable bone, and phlegmon from both proximal and distal segments was removed. All nonbleeding bone was excisionally debrided with a high-speed burr, and a 6-cm defect was present after debridement. At this point, the decision was made to proceed with staged management with induced membrane technique.

After thorough irrigation, 2 cm of shortening was performed through the nonunion site to decrease the volume of bone graft needed in the future. The residual defect was approximately 4 cm. A dual plating construct was selected because of the relatively short distal segment and the anticipated long duration of load bearing before union. An anatomically precontoured distal humerus plate was placed posterolaterally, and a 3.5 mm locking compression plate was placed on the lateral surface of the humerus (Figs. 2 and 3). Two packages of polymethylmethacrylate cement were mixed

FIGURE 1. Preoperative image of the left humerus demonstrating an atrophic nonunion of the humerus with broken implants.

FIGURE 2. Intraoperative anteroposterior (AP) and lateral of the left humerus after radial debridement and internal fixation.
with 4 g of vancomycin and 4.8 g of tobramycin, and when the cement was of appropriate consistency, the cement was placed in the bone defect of the humerus with cement overlapping the bone ends (Figs. 4 and 5). The cement was cooled with saline during curing to minimize risk of thermal injury to the radial nerve. The wounds were irrigated, and the posterior surgical exposure and the posterolateral sinus tract excision site were primarily closed. The patient was placed in a soft dressing and a sling. On the second postoperative day, cultures demonstrated *Enterobacter cloacae* growth sensitive to ciprofloxacin. He was discharged with oral ciprofloxacin 500 mg twice daily. He was encouraged to perform range of motion exercises as tolerated. At his 3-week follow-up, his incisions were healed, and his sutures were removed. His radial nerve function was intact after surgery, and he had regained nearly full motion of the shoulder and elbow by the 3-week follow-up visit. His C reactive protein normalized over 12 weeks, and the second stage of the surgery was planned.

The second stage was performed 96 days after the initial debridement and antibiotic spacer placement. He was placed in the lateral decubitus position with the entire left arm and the left hip and leg drapped simultaneously. A medial paratricipital approach was undertaken using the previous posterior midline incision to limit the amount of injury to the induced membrane and interference of the lateral column plate. The ulnar nerve was identified and protected throughout the case. The medial aspect of the induced membrane was encountered and preserved by incising and elevating it off of the antibiotic cement. The cement was removed piecemeal after carefully breaking it with an osteotome. No gross purulence or any questionable tissue was noted within the wound. Cultures were obtained from the medullary canals of both proximal and distal segments as well as a small portion of the soft tissue of the membrane. Next, a greater trochanteric starting point was obtained in the ipsilateral proximal femur through a percutaneous incision. An entry reamer was used to breach the cortex of the proximal femur, and a ball tip guidewire was placed into the center of the distal femur. The isthmus of the medullary canal was sized with fluoroscopic guidance and a radiographic ruler, measuring 13.5 mm. A size 14-mm RIA-2 (reamer irrigator aspirator) reamer head (DePuy Synthes) was used to harvest the bone graft. Two

FIGURE 3. Intraoperative anteroposterior (AP) and lateral of the left humerus after radial debridement and internal fixation.

FIGURE 4. Intraoperative anteroposterior (AP) and lateral of the left humerus after placement of antibiotic cement.

FIGURE 5. Intraoperative anteroposterior (AP) and lateral of the left humerus after placement of antibiotic cement.
intramedullary passes were performed using the RIA-2 device with the 14-mm head with the guidewire 2 different locations in the distal femur. This yielded a harvest of 40 mL of bone while avoiding eccentric medial reaming. Eccentric reaming can be prevented by using a medial trochanteric starting point and ensuring the reamer is centered in the medullary canal (Fig. 6) using fluoroscopic imaging. The autograft was expanded with 25 mL of cancellous allograft. The entire 65 mL of bone graft was used to fill the humeral bone defect (Figs. 7 and 8). The induced membrane was closed with absorbable suture, and the remaining incision was closed without complication.

Postoperatively, the patient had a normal neurologic examination, and his cultures resulted in no growth. He was discharged home on the second postoperative day and continued his oral ciprofloxacin until bone healing. He again quickly regained function in the arm with full motion of the left shoulder and elbow motion of 10–135 degrees, and his incision healed nicely. He resumed the use of the arm for activities of daily living after suture removal. Five-month follow-up radiographs (Figs. 9 and 10) demonstrate early consolidation of the graft in the segmental defect without change in alignment or implant loosening. At 5-month follow-up, the patient had resumed his daily activities and reported no pain at the RIA harvest site, and images showed some consolidation with no significant resorption of the graft.

**DISCUSSION**

The treatment of segmental bone defects remains a challenging problem for both patient and surgeon. Induced membrane technique had a few distinct advantages in this case of atrophic septic humeral nonunion with a segmental bone defect. It allowed for potentially more effective infection control after radical debridement by combining local antibiotic therapy in the antibiotic laden cement and culture-directed systemic antibiotics. Induced membrane technique also allowed the patient to avoid a ringed fixator which would have presented a challenge in obtaining adequate purchase in the short distal metaphyseal segment while avoiding the complex cross-sectional neurovascular anatomy of the distal humerus. The avoidance of pin

**FIGURE 6.** Intraoperative anteroposterior (AP) of the left femur during intramedullary bone harvest using reamer irrigator aspirator (RIA-2).

**FIGURE 7.** Intraoperative anteroposterior (AP) and lateral of the left humerus after removal of antibiotic cement and insertion of the bone graft material.

**FIGURE 8.** Intraoperative anteroposterior (AP) and lateral of the left humerus after removal of antibiotic cement and insertion of the bone graft material.
tract infection and an internal fixation construct that allowed early full range of motion also proved an advantage over a ringed external fixator/distraction osteogenesis in this case.

Other options exist for the treatment of segmental bone defects in the upper limb. Acute shortening is a unique option in the upper extremity, but there are concerns about neurovascular compromise with excessive shortening. Although the cosmetic change of minor shortening is well tolerated in the upper extremity, significant shortening of the lever arm of the biceps and triceps could also potentially render elbow function significantly impaired. For these reasons (albeit with limited evidence available), shortening more than 2–3 cm should be avoided. Free vascularized fibular transfer is also an option in large defects that can help maintain length and promote union of a segmental defect, but fixation options are limited; the technique requires micro-vascular support and has donor site morbidity up to 60%, so its application is also limited.

The ideal bone graft is osteoinductive, osteoconductive, and osteogenic. Even as technology continues to increase the number of available of bone graft substitutes, autograft remains the only graft option that meets all 3 of these criteria. When large volumes of autograft are needed, the options for harvest sites are limited to (ICBG) and long bone RIA harvest with the option to increase the graft volume with multiple autograft harvest sites or expanding its volume with allograft/bone graft substitutes. In comparison with ICBG, the graft harvested from RIA has been shown to contain higher levels of stem cells and growth factors important in the osteogenic cascade. Although the RIA system requires careful attention to detail to prevent eccentric reaming and excessive bleeding, the ease of use, low harvest site morbidity, and compelling basic science leaves RIA as the bone graft of choice for many surgeons.

FIGURE 9. Radiographs of the left humerus from 5 months after bone grafting demonstrating some early incorporation without significant resorption.

FIGURE 10. Radiographs of the left humerus from 5 months after bone grafting demonstrating some early incorporation without significant resorption.
CONCLUSION

Induced membrane technique offers some unique advantages compared with other bone defect treatment options in the upper extremity. In this case, the RIA-2 offered minimal morbidity and provided a large volume of autograft used in the second stage.

REFERENCES


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