Management of segmental bone defects resulting from trauma can present the surgeon with an uncommon challenge because of the potential complications and poor prognosis associated with this type of injury. The impact on the patient is often significant and may result in permanent disability or loss of limb. Treatment recommendations for long-bone defects have included autogenous bone grafting, bone transport, acute bone shortening, and amputation.\(^1\)\(^-\)\(^5\) The disadvantages of using autograft bone include the blood loss associated with harvest and the morbidity at the iliac crest donor site.\(^6\)\(^-\)\(^8\)

For bone defects larger than 5 cm, historical options have included amputation, bone transport, and vascularized fibular transfers.\(^9\)\(^-\)\(^12\) All these options have potentially significant morbidity associated with treatment. Donor-site morbidity of fibular graft site was reported in 19% of cases,\(^13\) and secondary fracture through fibular graft was reported in 23% of cases.\(^14\)

Use of recombinant human bone morphogenetic proteins (rhBMPs) may be a viable alternative to autogenous bone grafting. With its significant osteoinductive effects,\(^15\)\(^,\)\(^16\) rhBMP-2 has already been found effective in bone formation in critical-size bone defects in multiple animal models.\(^17\)\(^-\)\(^20\) Johnson and colleagues\(^21\) reported on use of human BMP extracts combined with autograft to treat 6 tibial segmental defects; all patients developed solid union, and mean time to union was 4.7 months.

Here we describe the off-label use of rhBMP-2 on a posttraumatic 8-cm bone defect in an ulna successfully treated with rhBMP-2/absorbable collagen sponge (ACS) along with calcium phosphate ceramic granules (Infuse\(^0\)/MasterGraft, Medtronic Sofamor Danek, Memphis, Tenn).

**Case Report**

A left-hand–dominant 16-year-old boy initially presented with grade II open radial and ulnar midshaft fractures, in addition to other injuries, including pulmonary contusion, facial lacerations, and right hand extensor tendon injury, all sustained in a motor vehicle collision. Left forearm injuries were treated with IV antibiotics as well as multiple surgeries for irrigation and débridement and for compression plating. The other injuries were addressed.

The patient subsequently developed osteomyelitis of the left ulna and underwent multiple irrigations and débridements, sequester removal, and placement of tobramycin and vancomycin antibiotic beads. He was left with an 8-cm bone defect in the midshaft of the left ulna (Figure 1). Cultures had grown *Serratia marcescens* and *Enterobacter aerogenes*. For 8 weeks, an infectious disease physician treated the patient with piperacillin/tazobactam and gentamicin antibiotics through a peripherally inserted central catheter.

We have obtained the patient’s informed, written consent to publish his case report.

**Surgical Procedure**

After informed consent for the procedure and for rhBMP use was obtained, surgery was begun. A longitudinal incision was made over the left ulna using the previous incision. The antibiotic beads were removed, and the wound was thoroughly irrigated. A burr was used to recanalize the proximal and distal ends of the defect, obtaining good bleeding bone. The bed was clinically clean.

To fill the 8-cm longitudinal deficiency, a macropore sheath (Interpore multiple polylactic absorbable scaffold; Interpore Cross International, Irvine, Calif) was cut to 10 cm and contoured into a half-tube longitudinally. The

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**Figure 1.** Intraoperative photograph shows 8-cm defect in ulna.
rhBMP-2 solution was prepared and soaked onto the ACS carrier per manufacturer instructions. Next, 30 cm$^3$ of MasterGraft granules were folded up into 5.6 cm$^3$ of rhBMP-2/ACS, and this combined graft was placed into the defect (Figure 2). The MasterGraft granules were used for their osteoconductive properties. After the defect was completely filled, another macropore sheath was placed over the top of the graft to form a temporary cage to prevent collapse of soft tissues onto the ACSs. Although a possible risk for infection, the macropore sheath was thought necessary to preserve proper space for subsequent bone formation in this particular case. We now perform this type of bone grafting without a macropore sheath, as it seems unnecessary. This sheath was then stabilized into the ulna both proximally and distally with 4 bioabsorbable 3.5-mm bicortical screws. The wound was then closed in the usual fashion, and the extremity was placed in a bulky dressing with long-arm posterior splint immobilization.

The postoperative course was uncomplicated. The patient was initially immobilized in the long-arm splint for 2 weeks. Then, gentle range of motion of the elbow and long-finger splint was initiated with no other activity of the extremity for the next 4 weeks. Gradual return to activities was then allowed over several months. The patient achieved full active elbow and wrist motion and was playing sports 15 weeks after the grafting procedure (against the surgeon’s wishes). Sequential radiographs continued to show consolidation of the defect graft over time, with a 12-month radiograph showing consolidation (Figure 3). At the last follow-up, 22 months after the grafting procedure, there were no reported symptoms from the injury (Figure 4), according to radiographs and a clinical report from elsewhere.

**DISCUSSION**

We report here on the use of rhBMP-2/ACS combined with calcium phosphate ceramic in an 8-cm posttraumatic, postinfectious ulnar defect with excellent clinical results. Treatment of posttraumatic, postinfectious segmental bone defects continues to be difficult. Clinicians continue to search for new treatments given the frequent complications associated with current treatment regimens. Bone morphogenetic protein grafting has the potential to become a valuable new option for segmental defects, as it has already been shown useful in other types of orthopedic procedures, such as spinal fusion and tibial nonunion.22,23

Bone morphogenetic protein has been studied extensively in segmental defects in animals. Bostrom and colleagues17 used a 2-cm ulnar defect model in rabbits to show dose-dependent bone formation, including union in all defects given the highest dosage. Moreover, histologic analysis demonstrated normal bone formation with use of rhBMP-2/ACS. Yasko and colleagues19 also found dose-related healing in a rat model. Sciadini and Johnson20 found comparable healing with autograft and rhBMP-2/ACS in the same canine defect model.

Recently, Jones and colleagues24 presented results from a small clinical trial involving rhBMP-2/ACS used as part of a staged bone grafting procedure. Their study involved treatment of 30 tibial fractures with traumatic bone loss of 1 to 5 cm in length. Patients were randomized to receive iliac crest autograft or allograft plus rhBMP-2/ACS. The authors concluded that rhBMP-2/ACS combined with allograft yielded healing similar to that occurring with autogenous bone graft.

The rhBMP-2/ACS implant has been found to be safe in humans and to have excellent osteoinductive effects. Bone morphogenetic protein grafting has the potential to become a valuable new option for the treatment of segmental defects, and we will continue to evaluate patients critically for possible use of this technique.
AUTHORS’ DISCLOSURE STATEMENT

Dr. Schwartz reports no actual or potential conflict of interest in relation to this article.

Dr. Hicks wishes to note that he is a paid consultant and speaker for Medtronic Sofamor Danek.

REFERENCES