Due to improvements in imaging and treatment of musculoskeletal tumors, joint-sparing segmental resection of diaphyseal tumors has become more common. Benefits of reconstruction following segmental resection include preservation of joint function and preservation of the physis in skeletally immature patients. Options for reconstruction include the use of autografts, allografts, distraction osteogenesis, custom implants, and modular intercalary endoprostheses. Although some data exist showing successful outcomes for patients treated with autograft or allograft following limb-salvage surgery, restriction in weight-bearing activity to allow for bone union and hypertrophy of graft may be a significant drawback, especially for patients with cancer, who are at greater risk for complications and increased time to union because of radiation and immunosuppressive chemotherapy. Reconstruction with a metallic prosthesis provides advantages including immediate postoperative stability, early weight bearing, and low rates of infection.

The objective of this study was to report on the functional outcomes of 3 consecutive patients who underwent wide resection of the radial diaphysis followed by reconstruction with a custom intercalary prosthesis. Three consecutive patients underwent wide resection of the radial diaphysis followed by reconstruction with a custom intercalary prosthesis. A custom intercalary prosthesis with lap joint design was used in all 3 cases. Mean follow-up was 18 months (range, 9-25 months). All patients were weight bearing as tolerated 1 week postoperatively. At the most recent follow-up, patients’ mean elbow flexion and extension arc was 137° (range, 130°-140°). At the forearm, mean supination was 60° (range, 30°-90°) and mean pronation was 70° (range, 60°-90°). At the wrist, mean palmar flexion was 80° (range, 70°-90°) and mean dorsiflexion was 80° (range, 70°-90°). All patients reported minimal to no pain and no significant functional limitations. Mean Musculoskeletal Tumor Society score was 26/30 (87%). Reconstruction with an intercalary prosthesis is a viable option for patients with metastatic disease of the radial shaft. All patients had satisfactory results and early return to function; none required return to the operating room.

Possible advantages of reconstruction with an intercalary prosthesis compared with reconstruction with a bone graft or polymethylmethacrylate osteosynthesis include early return to function and minimal weight-bearing restrictions postoperatively.

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**Abstract**

Improvements in imaging and treatment of musculoskeletal tumors have increased the variety of options for reconstruction following joint-sparing diaphyseal resection. The purpose of this case series was to show that reconstruction of malignant tumors of the radial shaft with an intercalary prosthesis may be an option for patients with segmental bone loss. Three consecutive patients underwent wide resection of the radial diaphysis followed by reconstruction with a custom intercalary prosthesis. A custom intercalary prosthesis with lap joint design was used in all 3 cases. Mean follow-up was 18 months (range, 9-25 months). All patients were weight bearing as tolerated 1 week postoperatively. At the most recent follow-up, patients’ mean elbow flexion and extension arc was 137° (range, 130°-140°). At the forearm, mean supination was 60° (range, 30°-90°) and mean pronation was 70° (range, 60°-90°). At the wrist, mean palmar flexion was 80° (range, 70°-90°) and mean dorsiflexion was 80° (range, 70°-90°). All patients reported minimal to no pain and no significant functional limitations. Mean Musculoskeletal Tumor Society score was 26/30 (87%). Reconstruction with an intercalary prosthesis is a viable option for patients with metastatic disease of the radial shaft. All patients had satisfactory results and early return to function; none required return to the operating room.

Possible advantages of reconstruction with an intercalary prosthesis compared with reconstruction with a bone graft or polymethylmethacrylate osteosynthesis include early return to function and minimal weight-bearing restrictions postoperatively. [Orthopedics. 2017; 40(2):e242-e247.]

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tive patients treated at the authors’ institution with a custom intercalary prosthesis following diaphyseal resection of metastatic lesions of the radial shaft.

**Materials and Methods**

After institutional review board approval was obtained, 3 consecutive patients with metastatic disease who underwent wide resection of the radial diaphysis followed by reconstruction with a custom intercalary prosthesis between January 2010 and January 2015 were retrospectively identified. Postoperatively, range of motion, weightbearing status, and Musculoskeletal Tumor Society (MSTS) functional outcome scores were reviewed.

Custom intercalary prostheses (OrthoTin, Whippany, New Jersey) with lap joint design (Figure 1) were used in all 3 cases. Food and Drug Administration custom device exemption is required for custom implants. To make the custom implant, the manufacturer used details regarding the size of the intramedullary space and the lesion and the estimated size of resection as per correspondence with the senior surgeon (J.B.).

Both the traditional volar and dorsal approaches to the forearm were used for exposure prior to implantation. A volar or dorsal approach can be used, depending on surgeon preference for wide resection and the possible involvement of neurovascular structures. After the radius was exposed, circumferential dissection was performed, extending 2 to 3 cm proximally and distally of the pathologic segment of bone. Marking the location of planned osseous cuts, retractors were placed beneath the radius to protect deep structures during the resection. A sagittal saw was then used to make parallel cuts for en bloc resection with wide margins. Resection with wide margins was obtained in all cases. Subsequently, the resected specimen was removed with the biopsy tract left in continuity. Surgical margins were then obtained and found to have negative results intraoperatively via frozen sections prior to reconstruction.

Reconstruction (Figure 2) began by inspecting the osseous cuts to the radius, verifying they were perpendicular to the radial shaft and parallel to one another, as uneven cuts can introduce deformity after implantation. Next, using bone-holding clamps to stabilize the resected bone, reaming was performed. Each fragment of the bone was reamed to a depth 1 cm longer than stem depth. Regarding diameter, overreaming was performed 1.5 mm to allow for adequate cement mantle. After reaming, the implant was trialed to verify that the prosthesis was seated appropriately within the canal and that adequate length could be obtained after the lap joint was secured with screw fixation. If length was found to be inadequate or lap screw holes did not correspond when appropriate length was set, an additional bone resection could be made either proximally or distally until screw holes corresponded at appropriate length.

After the implant was trialed, the surgical site was then irrigated while polymethylmethacrylate cement was mixed on the back table. Cement was injected into the proximal and distal intramedullary space after reaming. Stems were then cemented into the proximal and distal medullary canal and held in place until hardening of the cement. The lap joint was assembled and reduced, with 2 to 3 set screws placed to lock in the joint. Following soft tissue coverage of the implant, all wounds were closed, with 1 drain left in place.
Postoperatively, patients were placed in a volar resting splint for 5 to 7 days to assist with pain control and soft tissue healing. Drains were discontinued when output was minimized to less than 50 mL during a 24-hour period (1 to 2 days postoperatively). Patients were seen 1 week postoperatively to assess wound healing, remove the splint, and encourage range of motion without restrictions regarding weight bearing. Subsequently, patients were seen for clinical and radiographic examination at 3 weeks, 3 months, 6 months, 1 year, and annually thereafter.

**RESULTS**

Mean age at diagnosis was 71 years (range, 59-81 years). Two patients were male and 1 patient was female. Diagnoses were metastatic multiple myeloma, melanoma, and renal cell carcinoma, respectively. All patients presented with painful lesions, with 2 patients presenting with solitary metastases and 1 patient (patient 3) presenting with metastases to both the radial and humeral shafts. Wide margins were obtained in all cases. Mean resection of the radial shaft was 5.2 cm (range, 5.5-5.5 cm) and mean operating room time, including intraoperative biopsy and pathologic confirmation, was 3.7 hours. However, 1 patient (patient 1) had a second lesion at the contralateral humerus, which was treated with resection and osteosynthesis, increasing mean operating room time considerably. A tourniquet was used for 60 minutes in the case (patient 3) with renal cell carcinoma, in addition to preoperative embolization. Patient 1 was initially treated conservatively with a brace for 2 months after presenting with a pathologic fracture, but ultimately decided to undergo resection to relieve pain. The mean follow-up was 18 months (range, 9-25 months). Pre- and postoperative imaging for each patient is shown in Figure 3, Figure 4, and Figure 5.

One patient (patient 2) receiving long-term prednisone for Addison’s disease presented with a partially healed periprosthetic fracture at 17 months postoperatively. It had healed both clinically and radiographically at the most recent follow-up, 19 months postoperatively, following conservative treatment with a brace.

At the most recent follow-up, all patients were pain free and weight bearing as tolerated. At the elbow, patients had a mean flexion and extension arc of 137° (range, 130°-140°). At the forearm, patients had mean supination of 60° (range, 30°-90°) and mean pronation of 70° (range, 60°-90°). At the wrist, patients had mean palmar flexion of 80° (range, 70°-90°) and mean dorsiflexion of 80° (range, 70°-90°). Mean MSTS score was 26/30 (87%) (Table).

**DISCUSSION**

Advancements in imaging, chemotherapy, and radiation have contributed to improved lifespan for patients with malignant bone tumors. As a result, a growing emphasis on limb salvage in favor of increasing postoperative function...
has led to an advancement of prosthetic designs and techniques. Although in this patient population an optimal method of reconstruction following a diaphyseal defect is uncertain, reconstruction with an intercalary prosthesis may provide numerous advantages over other methods of reconstruction. Goals of limb salvage for patients with metastatic disease must include reduction of pain and improvement of quality of life with return to function quickly with minimal restriction.

Reconstruction of segmental defects using large allografts has been successful in numerous studies for patients with tumors, with a 10-year survival rate between 75% and 89%. Several of these studies have shown nonunion rates greater than 30%. Further, the detrimental impact of chemotherapy on bone healing contributes to high fracture rates (range, 15%-51%) and high nonunion rates (range, 18%-64%), as well as risk of infection (range, 6%-30%). In the context of survival time of patients with metastatic bone tumors, morbidity associated with allograft may contribute to poorer quality of life in the perioperative period. Because these patients generally have a lifespan of only a few years, this is an important consideration.

As a way to reduce infections in patients who are immunocompromised, autoclaved or irradiated autografts have been investigated but have high rates of nonunion, fracture, and infection comparable with those of allograft. The use of vascularized fibula transfer is more traditionally pursued for patients with primary tumors. Chang and Weber used vascularized fibula transfer both as a primary method of diaphyseal reconstruction and for patients with allograft nonunion, finding a mean union time of 6 and 10 months, respectively. Further, results of several studies suggest that this method of reconstruction may not be ideal for large defects.

Cemented intercalary prostheses have the benefit of not relying on bone healing, thus allowing early weight bearing and improved range of motion. This benefit is particularly advantageous to

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**Table**

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Diagnosis</th>
<th>Age, y</th>
<th>Follow-up, mo</th>
<th>Resected Segment, cm</th>
<th>Approach</th>
<th>Complications</th>
<th>Elbow Flexion and Extension</th>
<th>Forearm Supination/Pronation</th>
<th>Wrist Dorsiflexion/ Palmar Flexion</th>
<th>MSTS Score,a</th>
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<tr>
<td>1</td>
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<td>25</td>
<td>5.5</td>
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<td>140°</td>
<td>90°/90°</td>
<td>90°/90°</td>
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</tr>
<tr>
<td>2</td>
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<td>81</td>
<td>19</td>
<td>5</td>
<td>Volar</td>
<td>Periprosthetic fracture</td>
<td>130°</td>
<td>30°/60°</td>
<td>70°/70°</td>
<td>26</td>
</tr>
<tr>
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<td>59</td>
<td>9</td>
<td>5</td>
<td>Volar</td>
<td>None</td>
<td>140°</td>
<td>60°/60°</td>
<td>80°/80°</td>
<td>26</td>
</tr>
</tbody>
</table>

*Abbreviation: MSTS, Musculoskeletal Tumor Society.

*aOut of a possible total of 30.*
patients with metastatic disease, for whom restoring maximal function earlier can lead to large improvements in quality of life. To the authors’ knowledge, no studies have investigated functional outcomes for patients treated with an intercalary endoprosthesi at the radius. However, numerous other studies have shown satisfactory results with both custom and modular endoprosthetic reconstruction for diaphyseal defects. In a study of patients with reconstruction of the humerus,ibia, and femur, Abudu et al10 found that although 22% of patients experienced loosening, no patients developed wear or breakage of implants at a mean follow-up of 65 months. Additionally, the majority (77%) of patients were able to achieve 80% or more of their presurgical functional capabilities. A study by Damron et al9 investigating outcomes of patients treated with a modular intercalary humerus spacer showed that most patients were able to use the operative extremity with activities of daily living on the first postoperative day. Further, all but 1 of these patients had an improvement in MSTS scores postoperatively, and the study showed 100% implant survival at a median 20-month follow-up. In a multi-institutional study on functional outcomes for patients treated with an intercalary prosthesis at the humerus,ibia, and femur, the authors found 100% implant survival at a mean follow-up of 14 months and MSTS scores of 82% at the upper extremity.25

Individuals with metastatic disease to the bones are a diverse group with varying functional demands and expected lifespans. This small case series reveals a possible surgical option when dealing with diaphyseal lesions in the radius, yet is not without its inherit weaknesses. Only 3 cases were reported and all implants were used in an older patient population. It is difficult to predict whether similar results would be expected in a more demanding population with this endoprosthetic reconstruction.

CONCLUSION

Reconstruction with an intercalary prosthesis following diaphyseal resection of the radius is a viable option for patients with metastatic disease. In comparison with other limb-salvage options such as allograft or autograft, reconstruction with an intercalary prosthesis allows for earlier weight bearing and more rapid return to function. In this case series, all patients were able to return to function with minimal weight-bearing restriction within 2 weeks postoperatively.

REFERENCES


