Periprosthetic Fractures in Megaprostheses: Algorithmic Approach to Treatment

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abstract

With increases in both life expectancy and the number of patients with endoprosthetic replacements, more periprosthetic fractures are expected to occur. Periprosthetic fractures related to megaprostheses present a treatment challenge, with a high incidence (one-third of affected patients) of secondary revision as a result of prosthetic loosening, infection, nonunion, refracture, or even amputation. Efforts to improve endoprosthetic reconstruction should focus on preventing postoperative complications. Understanding the causes of complications and strategies to avoid them could lead to significant improvements in implant survival, limb function, and patient outcomes. This article presents a concise review of the current literature and an algorithmic approach to reconstruction of these complex injuries. [Orthopedics. 2017; 40(3):e387-e394.]

Significant advances have been made in musculoskeletal oncology in recent decades. Since the introduction of effective neoadjuvant chemotherapy in the 1980s, more than 80% of patients with osteosarcoma of an extremity have been considered candidates for limb salvage surgery.1,2

For many years, surgeons performed limb salvage surgery with massive allografts and allograft prosthesis composites. This type of reconstruction is considered a viable option, especially for young patients, because bulk structural allografts offer bone stock for future procedures and tendon and soft tissue reattachment is achieved more anatomically. Moreover, allograft reconstruction costs much less than a modular endoprosthesis. However, early infection, nonunion, bone resorption, and spontaneous fractures have limited the use of allografts.3

In the mid-1980s, modular megaprostheses were introduced for limb salvage surgery, offering intraoperative versatility and off-the-shelf availability. The associated improvements in medical oncology and advances in implant design and surgical techniques led to increased use of modular megaprostheses. Limb salvage surgery has comparable survival to amputation; however, patients with limb salvage ambulate normally, and surgical outcomes are better, both psychologically and cosmetically.4-7

A trend toward the use of massive prosthetic devices instead of allografts is a recent change in the treatment of lower extremity sarcoma.3 Megaprostheses provide consistently more predictable outcomes compared with allograft reconstruction. Advantages include early stability, mobilization, and weight bearing; good functional results; and early introduction of postoperative adjuvant therapy.8,9 In a comparison of limb salvage
Table 1

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Mode of Failure</th>
<th>Description of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>I</td>
<td>Soft tissue failure</td>
<td>Instability, tendon rupture, aseptic wound dehiscence</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>Aseptic loosening</td>
<td>Clinical or radiographic evidence of loosening</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>Structural failure</td>
<td>Periprosthetic or prosthetic fracture</td>
</tr>
<tr>
<td>Nonmechanical</td>
<td>IV</td>
<td>Infection</td>
<td>Infected megaprostheses</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>Tumor progression</td>
<td>Progression or recurrence of tumor</td>
</tr>
</tbody>
</table>


with endoprostheses and other reconstruction techniques and amputation, Grimer et al. showed that the use of megaprosthesis is clearly more cost-effective than amputation.

Many studies have investigated survival rates for modular endoprostheses after tumor resection. However, a systematic review of these outcomes is limited by the small number of patients and the different designs and principles of fixation of tumor megaprosthesis. Survival rates with megaprosthesis are 60% to 80% at 5 years and 40% to 70% at 10 years postoperatively.

Implementation of more effective protocols for adjuvant and neoadjuvant therapy led to improved survivorship; however, this also caused an inevitable increase in prosthesis-related complications. The reported complication rate is 5 to 10 times higher than that for routine total joint arthroplasty. This difference may be the result of longer survival rates for patients with sarcoma in addition to differences in the functional demands of young patients with primary bone sarcoma compared with elderly patients undergoing total joint arthroplasty for osteoarthritis. In the future, more patients are expected to require revision surgery and additional surgical interventions.

The current article reviews the types of periprosthetic fractures in patients with tumor prostheses and presents the options for treatment of these difficult cases. The current authors reviewed previously published data on periprosthetic fractures in the setting of a megaprostheses to show a rational approach to these complex cases.

### Modes of Failure

Failure of megaprosthesis has not been studied or classified adequately. Henderson et al. retrospectively reviewed the operative databases of 5 institutions in Europe and North America and identified 2174 skeletally mature patients who had a megaprosthesis after tumor resection. They classified failure modes into 5 types (Table 1). Type I (12%) is soft tissue failure that includes aseptic wound dehiscence and tendon rupture that may or may not cause instability of the endoprostheses. Type II failures (19%) show clinical or radiographic evidence of loosening. Type III failures (17%) are all structural failures that include periprosthetic and prosthetic fractures. Type IV failures (34%) are caused by deep periprosthetic infection and are not amenable to implant retention. Finally, Type V failures (17%) involve recurrence or progression of tumor and contamination of the megaprostheses.

### Incidence

Structural failures occur more often in the lower extremity than in the upper extremity. Fractures of the distal humerus and distal femur are more common than those of the proximal part of the humerus or those involving total femoral replacement. The rate of structural failures is higher with uniaxial endoprostheses than with polyaxial endoprostheses. Use of this classification system for reporting segmental outcomes could facilitate clearer communication of failure modes and a better understanding of the causes of failure.

Palumbo et al. showed that the incidence of type III structural failures has progressively decreased, in accordance with the findings of other investigators. The incidence of periprosthetic fractures and fractures of megaprosthesis has decreased as a result of technical improvements in stem design and the use of modern materials and metal alloys. Palumbo et al. also found that structural failure of components other than the stem is of lower clinical significance and is rarely observed or reported other than with traumatic events.

Given the relatively low frequency of this complication and the wide variety of implants, few studies have reported the incidence of periprosthetic fractures around tumor megaprosthesis. Most recent studies reported an incidence of periprosthetic fractures of 0.3% to 6.1% with megaprosthesis using rotating hinge devices.

### Etiology

The main causes of periprosthetic fractures include poor bone quality, stress shielding, osteolysis, and loosening of endoprostheses. The toxicity of chemotherapeutic agents or postoperative irradiation may be responsible for bone weakening. These factors are responsible for the increased risk of fracture in the setting of relatively minor trauma or repetitive cyclic loading during normal daily activities. Conditional risk of periprosthetic fracture may be the result of altered biomechanics as a result of tumor resection and altered
motor strength as a result of muscle loss. This is especially seen with extensive tumor resection of the proximal tibia and distal femur, where the remaining soft tissue envelope is limited.\textsuperscript{34,35} Moreover, with proximal tibia resection, the patellar tendon is detached from the tibial tuberosity and the extensor mechanism is reattached to the gastrocnemius.\textsuperscript{36,37} causing extension lag and weakness of the extensor mechanism.

**Classification**

Established classification systems can facilitate preoperative planning. Until now, no such classification had been proposed for periprosthetic fractures around massive segmental joint prostheses for tumors. The Vancouver classification for periprosthetic fractures, which considers the configuration of the fracture, the stability of the implant, and the quality of the bone stock, is used to establish fracture type and treatment options, whether fracture occurs proximally or more distally to the prosthesis or on a well-anchored or loose prosthesis.\textsuperscript{38} An analogous classification could be used, based on the location of the fracture and the status of the interface between the host bone and the stem of the megaprostheses.\textsuperscript{39}

**TREATMENT OPTIONS**

Therapeutic options include nonoperative treatment, fracture stabilization, and replacement of the endoprosthesis. Stable nondisplaced fractures may require only protected weight bearing or cast or brace immobilization.

Surgical treatment should be considered whenever there is significant displacement of the bone fragments. When loosening of the prosthesis is ruled out, osteosynthesis can be attempted; however, it is often unsuccessful because of poor bone quality, reduced potential for consolidation, and the presence of a stem.

Figure 1 shows an algorithmic approach to decision making in patients with periprosthetic fractures around megaprostheses. The stability of the endoprosthesis, the available bone stock, the proximity of the fracture to adjacent joints, and the possibility of tumor recurrence are factors in the choice between fracture repair and endoprosthetic revision.

**Open Reduction and Internal Fixation**

Fixation with conventional plates and screws or intramedullary fixation may be difficult because of the massive stem or cement in the medullary canal. Unicortical screws have been used to obtain fracture stability, but loosening of the plate often occurred. Locking plate fixation provides a feasible option (Figure 2). More recently, a variety of plates were designed to avoid the use of screws. However, the Dall-Miles plate with cables has been considered insufficient when used alone for periprosthetic fractures,\textsuperscript{40} and the Mennen plate with clips derived from the Jung strut does not offer sufficient stability to achieve fracture consolidation.\textsuperscript{41} More recently, the AO group proposed a cable plate that uses monocortical screws with a transverse tunnel that allows passage of a cerclage wire (Figure 3). Cables are very resistant to hoop stresses, and fixation becomes effective, whereas bicortical screws may be used for bone segments without a prosthetic stem.\textsuperscript{42}

**Revision**

Whenever anchorage of the prosthesis seems to be at risk, a change of the modular system that requires full revision of the implant may be indicated.\textsuperscript{43} In other cases, the segment of comminuted bone may be resected and the endoprosthesis may be lengthened to fill the gap with a new intercalary femoral or tibial body component. Sometimes additional joint replacement is required (Figure 4).\textsuperscript{44,45}

**OUTCOMES**

Reports of the management of periprosthetic fractures around tumor prostheses are limited. Most current studies include retrospective reviews of a small number of cases or case series without control groups. Therefore, the outcomes should be considered cautiously. The number of cases, type of periprosthetic fractures, treatment method, and reported outcomes of these studies are summarized in Table 2.

In 2006, Orlic et al\textsuperscript{31} retrospectively analyzed a cohort of 90 patients (median age at diagnosis, 30 years; range, 7-66 years) who underwent en bloc resection and modular endoprosthetic reconstruction of the lower limbs (hip and knee joints). Mean follow-up was 9 years (range, 3-19 years). Periprosthetic fractures occurred in 2 patients (2.2%). These fractures occurred after a car accident for 1 patient and during a sports activity for 1 patient. The first patient, who had osteosarcoma, underwent elongation of the endoprosthesis, and the second patient, who had a giant cell tumor, was treated with osteosynthesis of the fracture. Both patients were free of disease on final examination. The authors noted that reconstruction of the periprosthetic fracture should not be considered a limb-threatening problem in patients without primary disease.

In 2006, Ahlmann et al\textsuperscript{4} retrospectively reviewed the outcomes for 211 consecutive patients (mean age, 50 years; range, 11-86 years) who had undergone limb salvage for bone neoplasia with endoprosthetic reconstruction of the proximal femur (96 patients), distal femur (78 patients), proximal tibia (30 patients), and total femur (7 patients). Mean follow-up was 37.3 months (range, 1-204 months). Periprosthetic fracture occurred in 1 patient (0.5%), a 17-year-old boy who was involved in a motor vehicle accident and had a femoral fracture just proximal to the stem of a distal femoral endoprosthesis. 46.7 months after initial reconstruction. The implant was revised to a longer stem.

In 2007, Sim et al\textsuperscript{17} reviewed 50 consecutive patients with endoprosthetic reconstruction around the knee after tumor...
Median follow-up was 24.5 months (range, 2-124 months), and median age was 41 years (range, 13-79 years). Documented complications occurred among 17 patients, and 1 patient had a periprosthetic fracture of the tibia 3 years after tumor resection and underwent internal fixation.

In 2008, Jeys et al studied 661 patients who underwent endoprosthetic reconstruction after resection of a bone tumor a minimum of 10 years before the current study. Mean age at presentation was 34 years (range, 7-80 years). Mean duration of follow-up was 15 years for patients who survived the original disease. A total of 116 patients had revision surgery because of mechanical failure of the initial prosthesis as a result of aseptic loosening, implant fracture, instability, periprosthetic fracture, pain, or stiffness. Implant survival at 10 years was 75%, with mechanical failure as the end point. Two patients (0.9%) had periprosthetic fracture of the distal end of the femur, 3 patients (2%) had fracture of the tibia, and 1 patient (14%) had fracture after total femur endoprosthesis. All patients had revision surgery, with removal or exchange of the endoprosthetic metallic implant.

In 2009, Tyler et al retrospectively reviewed the charts of 221 patients who were treated with the Compress (Biomet Inc, Warsaw, Indiana) endoprosthetic device. Compressive osseointegration technology offers the option of relative easy fixation of the prosthetic implant because fixation is achieved with a short intramedullary device. Mean follow-up was 50 months (range, 1-123 months). Minimum follow-up for patients with periprosthetic fracture after fracture treatment was 14

Figure 1: Algorithm showing treatment options for management of a periprosthetic fracture around a megaprosthesis. Abbreviations: ORIF, open reduction and internal fixation; Rx, radiotherapy.
months (median, 62 months; range, 14-94 months). Anatomic locations were the distal femur (154), proximal tibia (38 patients), proximal femur (23 patients), distal humerus (4), and proximal humerus (2). Six patients (2.7%) had periprosthetic fractures, and 8 (3.6%) had nonperiprosthetic ipsilateral limb fractures 4 to 79 months postoperatively. All periprosthetic fractures occurred among patients with distal femoral implants (6 of 154). Surgery was performed for all 6 patients who had periprosthetic femur fractures and 1 who had a nonperiprosthetic patellar fracture. Five patients had prosthetic revision, and 1 patient who had internal fixation of the fracture ultimately underwent amputation for persistent infection. The other 7 patients with nonperiprosthetic ipsilateral limb fracture were treated with a cast or brace. The authors noted that periprosthetic fractures involving the Compress prosthesis occur infrequently, and most of them can be treated successfully with further surgery. When implant revision is needed, the bone that is preserved with the use of a shorter intramedullary Compress device compared with a conventional stem allows for less complex surgery and limb preservation.

In 2010, Kinkel et al. reviewed a cohort of 77 patients who had a cementless or cemented Modular Universal Tumor And Revision System (MUTARS; ImplantCast GmbH–Medizintechnik, Munster, Germany) endoprosthesis for a mean of 46 months (range, 3-128 months). Average age at the time of implantation was 38 years (range, 11-78 years). The distal femur (n=49) or proximal tibia (n=28) was reconstructed predominantly with cementless implants (femur, 69%; tibia, 92%). Resection of the tumor was intra-articular for 46 patients and extra-articular for 31 patients. Complications were frequent, with locking mechanism failure (n=15) and aseptic loosening (n=13) the most common modes of failure. Three patients had periprosthetic fracture that was treated with open reduction and internal fixation.

In 2010, Shehadeh et al. retrospectively reviewed 232 patients (241 implants, including 50 custom and 191 modular), ranging in age from 8 to 99 years (mean, 34 years; median, 30 years), who underwent endoprosthetic reconstruction for malignant and aggressive bone tumors in different
anatomic locations (distal femur, proximal femur, proximal humerus, proximal tibia, total femur, scapula). Minimum follow-up was 5 years (mean, 10 years; range, 5-27 years). Mechanical complications were the most common cause of implant failure. A total of 163 patients had a complication other than infection, and 8 (3.44%) had a periprosthetic fracture. Periprosthetic fracture was the third most common complication after aseptic loosening and tibial bearing. All patients underwent partial or complete prosthetic component revision.

In 2012, Gebhart and Shumelinsky studied 56 massive prostheses that were implanted for reconstruction of major bone defects for bone sarcoma around the knee. Two patients had traumatic periprosthetic fractures. Surgical treatment with open reduction and internal fixation with a cable-plate system preserved the prosthesis and provided stable fracture fixation and excellent fracture healing. No weight bearing was allowed for 6 weeks. Rehabilitation of the knee and hip was conducted for 3 months. The fracture healed without postoperative or late complications, with excellent clinical outcomes. Radiographic consolidation and gait function were identical to the preoperative situation.

### Table 2

Summary of Peer-Reviewed Literature on Periprosthetic Fractures in Megaprosthesis

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>No. of Patients</th>
<th>Site</th>
<th>Prosthesis</th>
<th>No. of Fractures (%)</th>
<th>Follow-up (Range)</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orlic et al31</td>
<td>2006</td>
<td>90</td>
<td>Mixed</td>
<td>Kotz Femoral and/or Tibial Replacement (designed by Kotz)</td>
<td>2 (2.2)</td>
<td>Mean, 9 y (3-19 y)</td>
<td>First patient, revision endoprosthesis; second patient, open reduction and internal fixation</td>
</tr>
<tr>
<td>Ahlmann et al4</td>
<td>2006</td>
<td>221</td>
<td>Mixed</td>
<td>Modular Segmental Replacement System (MSRS)7</td>
<td>1 (0.5)</td>
<td>Mean, 37.3 mo (1-204 mo)</td>
<td>Revision of endoprosthesis</td>
</tr>
<tr>
<td>Sim et al17</td>
<td>2007</td>
<td>50</td>
<td>Knee</td>
<td>Global Modular Replacement System (GMRS) rotating hinge knee endoprosthesis4</td>
<td>1 (2)</td>
<td>Median, 24.5 mo (2-124 mo)</td>
<td>Open reduction and internal fixation</td>
</tr>
<tr>
<td>Jeys et alb</td>
<td>2008</td>
<td>661</td>
<td>Mixed</td>
<td>Custom</td>
<td>6 (0.9)</td>
<td>Mean, 15 y</td>
<td>Removal or exchange of endoprosthesis</td>
</tr>
<tr>
<td>Tyler et al46</td>
<td>2009</td>
<td>221</td>
<td>Mixed</td>
<td>Compressc</td>
<td>6 (2.71)</td>
<td>Mean, 50 mo (1-123 mo)</td>
<td>5 revisions of endoprosthesis; 1 open reduction and internal fixation (after infection and amputation)</td>
</tr>
<tr>
<td>Shehadeh et al48</td>
<td>2010</td>
<td>232</td>
<td>Mixed</td>
<td>Customized on a case-by-case basis7 Modular (Segmental) Reconstruction System (MSRS/MRS)</td>
<td>8 (3.44)</td>
<td>Mean, 10 y (5-27 y)</td>
<td>Revision endoprosthesis</td>
</tr>
<tr>
<td>Kinkel et al17</td>
<td>2010</td>
<td>77</td>
<td>Knee</td>
<td>Cementless or cemented Modular Universal Tumor And Revision System (MUTARS)d</td>
<td>3 (3.89)</td>
<td>Mean, 46 mo (3-128 mo)</td>
<td>Open reduction and internal fixation</td>
</tr>
<tr>
<td>Gebhart and Shumelinsky39</td>
<td>2012</td>
<td>56</td>
<td>Knee</td>
<td>Custom-made Growing Megaprosthesis7 Orthopaedic Salvage System7</td>
<td>2 (3.57)</td>
<td>Median, 43 mo (6-131 mo)</td>
<td>Open reduction and internal fixation (cable-plate)</td>
</tr>
<tr>
<td>Healey et al49</td>
<td>2013</td>
<td>82</td>
<td>Knee</td>
<td>Compressc</td>
<td>10 (1.21)</td>
<td></td>
<td>2 patients, conservative; 3 patients, open reduction and internal fixation; 5 patients, revision of endoprosthesis</td>
</tr>
</tbody>
</table>

3Stryker Howmedica, Kalamazoo, Michigan.
7Lima Corporate, Villanova di San Daniele del Friuli (UD), Italy.
4Biomet Inc, Warsaw, Indiana.
5ImplantCast GmbH–Medizintechnik, Munster, Germany.
6Phenix Medical, Paris, France.
In 2013, Healey et al. retrospectively reviewed the clinical and radiographic records of 82 patients (median age, 20.4 years; range, 14-63 years) who underwent reconstruction with the Compress knee arthroplasty prosthesis. Follow-up was for a minimum of 12 months or until implant removal occurred (median, 43 months; range, 6-131 months); 13 patients had bone or device failure after Compress prosthesis implantation. Eight patients required prosthetic revision after fracture healing as a result of aseptic loosening alone (n=3) or aseptic loosening with periprosthetic fractures (n=5). All 5 fractures were revised with a new Compress prosthesis. Additionally, 5 periprosthetic bone failures or fractures occurred and did not require revision. Of these, 3 patients had periprosthetic bone failure without fixation compromise, and 2 had irregular prosthetic osteointegration patterns with concomitant fracture as a result of mechanical insufficiency. Three fractures proximal to the implant that did not disrupt the fixation were treated with internal fixation and healed without disruption of the prosthetic-bone interface. One patient had healing of the fracture but underwent amputation for resultant osteomyelitis. Two patients had fractures that healed uneventfully and retained the prosthesis with its original Compress fixation after further follow-up of 5 and 9 years, respectively. The first patient underwent open bone grafting, at which time the fracture had already healed spontaneously. Because the second patient showed the same pattern, the fracture was allowed to heal without surgery, with the use of only a functional fracture cast brace.

**Conclusion**

Periprosthetic fractures around tumor megaprostheses are uncommon. However, as both life expectancy and the number of patients with endoprosthetic replacements increase, more of these fractures are expected to occur. Periprosthetic fracture related to megaprostheses presents a treatment challenge, with a high incidence (one-third of affected patients) of secondary revision as a result of prosthetic loosening, infection, nonunion, refracture, or even amputation.

The decision as to whether to perform periprosthetic fracture repair or reconstruction should be based on the stability of the endoprostheses, available bone stock, proximity of the fracture to an adjacent joint, and possibility of tumor recurrence. Endoprosthetic reconstruction should focus on preventing postoperative complications. Understanding the causes of complications and strategies to avoid them can lead to significant improvements in implant survival, limb function, and patient outcomes.

**References**


