Overview of Endoprosthetic Reconstruction

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BACKGROUND
- Limb salvage—reconstruction following resection of malignant tumors of the extremities—has seen dramatic advances in a relatively brief period of time. The traditional surgical approach to the treatment of sarcoma, namely immediate amputation of the extremity, was advocated in the early 1960s and 1970s to ensure local control of disease.
- Early pioneers in orthopaedic oncology worked diligently to define the optimal level of amputation and developed techniques to manage wounds of the pelvis and shoulder girdle following hind- or forequarter amputation. However, such aggressive surgical management failed to impact overall patient survival, with most patients dying of metastatic disease.
- Only after the introduction of effective doxorubicin- and methotrexate-based chemotherapy protocols in the early 1970s could alternatives to amputation be considered. A handful of surgeons began to challenge the orthodoxy of amputation in children and adults with bone sarcomas. Marcove, Francis, and Enneking were among the pioneers who developed the rationale and basic techniques used in limb-sparing surgery. The former two surgeons were the first in the United States to develop endoprosthetic replacements for tumor patients.
- Starting with a very few highly selected patients with extremity osteosarcoma, limb-sparing surgery now is a treatment option for most bone and soft tissue sarcomas, not only of the extremities, but of the pelvis and shoulder girdles as well.
- Today, over 90% to 95% of tumor patients may be expected to undergo successful limb-sparing procedures when treated at a major center specializing in musculoskeletal oncology. This dramatic alteration in patient care required significant advances along many fronts, including the following:
  - Better understanding of tumor growth and metastasis
  - Determination of appropriate surgical margins
  - Use of effective induction (neoadjuvant or preoperative) chemotherapy
  - Development of improved approaches, preserving soft tissue vascularity
  - Deeper understanding of skeletal biomechanics
  - Advanced engineering and manufacturing techniques
  - Development of inherently stable modular prostheses.
- The chapters in this section outline in specific detail many of the surgical approaches and techniques of oncologic resection and reconstruction currently used by leaders in the field of orthopaedic oncology. The importance of meticulous surgical technique cannot be overstated, because this is vital to ensure an optimal oncologic and functional outcome for the patient. A successful limb-sparing surgery consists of three interdependent stages performed in sequence:
  1. Tumor resection with appropriate oncologic margins
  2. Reconstruction and stabilization of the involved bone and joints
  3. Restoration of the soft tissue envelope for prosthetic coverage and function.

History of Endoprosthetic Reconstruction
- Austin Moore and Harold Bohlman, in 1940, were the first to publish an example of endoprosthetic reconstruction for a bone tumor, consisting of a custom-designed Vitallium proximal femur used for a patient with a giant cell tumor of bone.
- In the early 1970s, Francis and Marcove ushered in the current age of endoprosthetic reconstruction by developing prostheses to replace the distal femur and the entire femur for resection following radical resection of osteosarcomas (Fig. 1).
- A major drawback for these custom implants quickly became evident: each implant would take 6 to 12 weeks to manufacture, during which time the patient’s tumor could progress significantly. This led to the development of the concept of induction (initially called preoperative or neoadjuvant) chemotherapy, in which the newly proven drugs doxorubicin and methotrexate were administered during the interval between diagnosis and delivery of the manufactured custom implant. Both of these drugs had just been shown to have activity against bone sarcomas. Induction chemotherapy has since been adopted in the management of an increasingly large variety of other cancers.
- As the demand for endoprosthetic reconstruction grew, a wide variety of custom implants became available from a number of orthopaedic manufacturers. Many of these early implants, however, suffered from design flaws and errors in manufacturing, resulting in significant problems with implant failures (Fig. 2A).
- However, improved material and manufacturing techniques developed for the profitable and ever-expanding market for total joint replacements eventually were applied to these “mega” prostheses. The adoption of the rotating hinge for implants around the knee and bipolar heads for the hip followed successful use of these designs for total joint replacement. While these advances significantly improved the performance of custom implants, problems with the time required for manufacturing and the lack of flexibility at the time of implantation hampered the widespread acceptance of custom endoprosthetic reconstruction.
- Manufacturers responded to this problem by incorporating the concept of modularity, adapting concepts and designs from modular total hip and knee prostheses to develop interchangeable and easily assembled endoprosthetic systems (Fig. 2B, C). Although modularity increased the complexity of the mechanical construct and carried a risk of failure associated with the sum of all of the components, these potential problems were easily outweighed by significant benefits.
- The primary advantage of a modular endoprosthesis is the system’s flexibility: the surgeon can concentrate on performing the best possible oncologic resection knowing that any
changes in the preoperative plan can be accommodated by selecting those components that fit the patient’s anatomy and actual skeletal defect optimally.

Modular trial components allow the surgeon to mix and match pieces and test the reconstruction prior to selection and assembly of the actual final prosthesis.

Standardization of components permits the implant manufacturer to increase the level of quality control greatly, while reducing the overall cost of manufacturing through economies of scale.

Modular systems reduce overall inventory and time to delivery while providing a large choice of prosthetic shapes and sizes.

Modular systems permit hospitals to maintain an on-site inventory that has allowed these systems to be available immediately as a backup option for selected non-oncologic patients, such as those undergoing difficult joint revision surgery or patients with significant periarticular fractures.

A first-generation modular endoprosthetic system was the Howmedica Modular Replacement System (HMRS, Howmedica International, Limerick, Ireland), designed and manufactured in Europe. This system featured intramedullary cementless press-fit stems supported by external flanges and cortical transfixation screws, while the knee mechanism consisted of a simple hinge design. Although the system truly was modular, in clinical practice the long-term outcomes were disappointing. Significant problems encountered with this device included aseptic stem loosening (osteolysis), substantial stress shielding with bone resorption, screw fracture and migration, and a polyethylene failure rate higher than 40% for the knee mechanism. Consequently, this system rarely was used in the United States.

An example of a second-generation modular system is the saddle endoprosthesis (Waldemar-Link, Germany; FIG 3A,B). This prosthesis, originally designed for the treatment of infected failed total hip replacements, was modified to allow for reconstruction of the hip following resection of the pelvis.

The unique feature of this system is the saddle itself, which is a U-shaped component that straddles the ilium, allowing motion in flexion–extension, and abduction–adduction in the anteroposterior and lateral planes against the bone.

The saddle is attached with a rotating polyethylene lined ring, increasing the degree of freedom and allowing for hip rotation. These are attached to a series of interchangeable modular bodies that, in turn, connect to a standard cemented femoral stem.
FIG 2 • A. Examples of failed, retrieved, custom endoprosthetic implants used during the 1980s. The most common mode of mechanical failure was stem breakage or bending, typically due to small stem diameter or from stress risers caused by the sharp transition from the prosthetic body to the stem. B. Modular implant design featuring a Kinematic rotating-hinge knee. Interchangeable components permit easy off-the-shelf flexibility in the operating room, allowing the implant to match the patient's anatomy. C. Intraoperative assembly of the prosthesis requires impaction of locking Morse tapers to connect the stem, body segments, and joint modules. (Courtesy of Martin M. Malawer.)
This device preserves limb length following resection of the periacetabulum (eg, type 2 pelvic resection, modified internal hemipelvectomy) while functioning like a total hip prosthesis. The clinical and functional results following saddle reconstruction of the pelvis with this system have been promising.1

The first successful universal modular system was introduced in 1988 as the Modular Segmental Replacement System (MSRS, Howmedica Inc, Rutherford, NJ), renamed the Modular Replacement System (MRS) and now available as the updated Global Modular Replacement System (GMRS; Stryker/Howmedica Inc., Mahwah, NJ; FIG 3C–E). This system was designed to provide modular replacements for the proximal humerus, proximal femur, total femur, distal femur, and proximal tibia and has been instrumental in the widespread adoption of endoprosthetic reconstruction following segmental bone resection.

The growing popularity of endoprosthetic reconstruction has led to the introduction of similar modular systems from several orthopaedic manufacturers (eg, Orthopaedic Salvage System [Biomet, Warsaw, IN], Guardian Limb Salvage System [Wright Medical Technology [Arlington, TN]]. Current implant manufacturers still offer customized solutions for challenging anatomic issues. However, these custom implants often consist of a custom module mated to an existing modular system to ensure maximal flexibility.

**TYPES OF ENDOProSTHETIC RECONSTRUCTION**

Specific anatomic examples of endoprosthetic reconstruction are discussed in the following paragraphs.

**Hip**

- Tumors involving the proximal femur are extremely common, and include both primary sarcomas and metastatic carcinomas. Replacement of the proximal femur (FIG 4) is readily accomplished following resection of a primary tumor or fracture through a subtrochanteric metastatic lesion. A bipolar hemiarthroplasty is used for the hip joint, with soft tissue reconstruction of the hip capsule to minimize the risk of dislocation.2 Reconstruction of the hip abductors is accomplished directly via laterally placed holes or loops, or, if a portion of the trochanter was saved, by use of a trochanteric claw with cerclage cables. Less common are resections of the entire hip joint (ie, type II pelvic resection and its modifications). This defect can be reconstructed with a saddle prosthesis or with the recently designed partial pelvic implants that attach to the remaining ilium. Stability is achieved by balancing the muscle tension between the medial iliopsoas and the lateral hip abductors.

**Distal Femur**

- The distal femur is the single most common site for primary bone sarcomas. Endoprosthetic reconstruction (FIG 5) requires a unique combination of flexibility combined with overall stability, because the knee capsule and the cruciate and collateral ligaments are removed during the resection. The Kinematic rotating hinge knee (GMRS, Stryker/Howmedica, Mahwah, NJ) and similar partially constrained hinged designs permit substantial flexion-extension as well as rotation at the anatomic axis of the knee, while providing inherent stability in the varus–valgus and anterior–posterior planes. Reconstruction of the extensor mechanism rarely is necessary, because the patella often can be saved during the resection. Resurfacing of the patella is possible, but often unnecessary.

**Total Femur**

- Patients presenting with extensive intramedullary tumors (eg, Ewing sarcoma or the rare diaphyseal osteosarcoma), as
well as patients with multiply failed total joints and little remaining bone stock, can be treated with a total femoral replacement (FIG 6). Modular systems provide a readily available solution by combining distal femoral and proximal femoral components by means of interbody segments. This type of reconstruction has proven to be extremely durable because of the combination of the high degree of freedom associated with the two separate but related joints.

Proximal Tibia
- The tibia is anatomically unique in its anterior subcutaneous border and patellar tendon insertion. Routine use of a gastrocnemius rotation flap has dramatically reduced the incidence of postoperative complications, and compound reconstruction of the tendon insertion and careful attention to postoperative rehabilitation can result in minimal extensor lag. Joint stability at the knee is ensured by using the same rotating hinge design used for distal femoral replacements (FIG 7). Meticulous soft tissue reconstruction of the extensor mechanism is crucial for the postoperative function of this prosthesis.

Proximal Humerus
- High-grade sarcomas of the proximal humerus require extra-articular resection, including the entire rotator cuff and deltoid muscles, to minimize the risk of local recurrence (FIG 8). Accordingly, ultimate functional outcome may be greatly restricted. A combination of static and dynamic suspension, including transfer of the pectoralis muscle, stabilizes the proximal humerus to the scapula, permitting painless and functional use of the elbow, wrist, and hand. Low-grade tumors can be treated with intra-articular resections; preservation of the rotator cuff and deltoid can lead to function comparable to that provided by total shoulder replacements.
FIG 5 • Distal femoral replacement. **A, B.** Kinematic rotating hinge mechanism featuring an all-polyethylene tibial component permits a full range of flexion, rotation, and axial motion while restraining the knee in the AP and medial-lateral planes, respectively. **C.** Intraoperative view of distal femoral replacement after final assembly of the components. **D–E.** Distal femoral and proximal tibia modular replacement system. This system permits reconstruction of several segments of various bones simultaneously if required. (**A, B:** Courtesy of Martin M. Malawer.)

FIG 6 • Total femoral replacement for osteosarcoma of the femur. **A.** Implant and trial components consist of a modular proximal femoral replacement connected to a modular distal femoral replacement of means of a male-to-male interbody segment. **B.** Postoperative radiograph demonstrating bipolar hip and rotating hinge joints.
Scapula

- Following scapulectomy, endoprosthetic replacement of the scapula and glenohumeral joint lateralizes the humerus and improves stability and function of the shoulder (FIG 9). New scapular designs feature a locking articulation to improve stability, while use of a large-diameter Gore-Tex (W. L. Gore Ltd., Flagstaff, AZ) vascular graft to restore a joint capsule helps to ensure optimal stability. As with proximal humeral replacement, ultimate functional outcome depends on the amount of muscle that can be preserved during the resection. Multiple muscle transfers are necessary to stabilize and power the prosthesis as well as to provide adequate coverage.

Elbow

- The elbow joint is not often affected by sarcomas or metastatic disease. Customized, hinged implants with small-caliber stems to fit the ulna can be used provided sufficient soft tissue remains to cover the prosthesis. Function depends on preservation of the biceps insertion.

Total Humerus

- As with the total femur, the total humerus implant is a combination of a proximal humeral implant and an elbow replacement. Indications for this procedure are rare, but preservation of a sensate, functional hand remains superior to any amputation prosthesis.

Calcaneus

- One case has been reported of a total calcaneal prosthesis implanted for osteosarcoma in lieu of a below-knee amputation. Ten years after surgery, the patient remained fully ambulatory without assistive devices.
Intercalary Endoprostheses

- Replacement of the central portion of a long bone following diaphyseal resection for tumor has the significant advantage of preserving the patient’s native adjacent joints in the humerus, femur, and tibia. Traditional implants limited the indication for this type of reconstruction due to the amount of remaining bone required to fix the prosthetic stems securely. Customized stems using crosspin fixation and the newer Compress fixation method (Biomet) have greatly expanded the indications for this procedure (FIG 10).

Expandable Implants for Skeletally Immature Patients

- Reconstruction of the axial skeleton in immature patients remains challenging (FIG 11). Children over 10 to 12 years of age often can be treated similarly to adults, using smaller versions of the modular prostheses, occasionally in combination with contralateral epiphysaldisis to equalize leg lengths at skeletal maturity. For children younger than 5 years, primary amputation remains the preferred solution, given the difficulty in obtaining a proper oncologic margin around the critical neurovascular bundles. Between these two age groups, reconstruction is feasible, but limb-length inequality becomes functionally disabling as the child grows. Use of implants that can be expanded multiple times during growth permits prosthetic reconstruction for these children. These custom-created implants have been used in both the upper and lower extremity with mixed results, as mechanical failures of the expansion mechanism is not uncommon. Whereas traditional expandable implants would require multiple invasive procedures to achieve expansion (with some patients undergoing 10 or more surgeries), the recently introduced custom Rephyisis noninvasive expandable implant (Wright Medical Technology, Arlington, TN) features a unique method of expansion that does not require surgery.

PATIENT SELECTION FOR ENDOPROSTHETIC RECONSTRUCTION

- Appropriate patient selection for limb-sparing surgery is essential to ensure optimal outcomes. While the introduction of effective chemotherapy for osteosarcoma was a major impetus in the development of limb-sparing techniques, increasing patient survival has placed greater emphasis on functional outcome and durability of reconstruction. Patients expect solutions that address their functional, cosmetic, and psychological needs and demands, and often reject the option of amputation.

- Although tumor size and location often are the determining factors in selecting patients for limb salvage, neoadjuvant (preoperative) chemotherapy may convert formerly unsalvageable
patients to candidates for limb-sparing procedures by inducing significant tumor response. Consequently, a complete reevaluation of the patient following neoadjuvant treatment is necessary before an appropriate surgical plan is selected. For appropriate patients, endoprosthetic reconstruction offers a durable and functional option for skeletal reconstruction.

- Limb-sparing procedures should not be limited to patients with favorable response to treatment. Patients with poor prognostic factors, such as metastatic disease at time of initial presentation or tumor growth during chemotherapy, often require surgery for local control of disease and palliation of symptoms such as pain. Although amputation may be necessary for some, limb-sparing surgery can avoid the significant psychological impact associated with mutilative procedures. Endoprosthetic reconstruction offers immediate stability and rapid mobilization while avoiding the need for prolonged bracing, crutches, or inpatient rehabilitation.

- The proven success and durability of endoprosthetic reconstruction has led to its adoption for other challenging, nontumorous conditions in which restoration of a segmental skeletal...
tal defect is required. For example, patients with multiple failed total joint replacements around the hip and knee may develop significant bone loss that cannot be corrected readily with traditional revision total joint components. In this subset of patients, resection of the failed prosthetic joint and removal of all devascularized bone followed by reconstruction with a “tumor” endoprosthesis can lead to significant functional recovery.

- Similarly, severely comminuted periarticular fractures not amenable to internal fixation can be addressed by removal of the fragmented bone and replacement with a segmental endoprosthesis. This procedure is extremely valuable for the obese, elderly patient with osteoporotic bone (often with significant medical comorbidities) who trips and falls on the knee, resulting in a type C distal femur (or, if a total knee replacement is in place, periarticular) fracture. Endoprosthetic reconstruction can be performed in a fraction of the time necessary for meticulous internal fixation, and since the prosthesis is inherently stable, the patient can begin immediate weight bearing without functional bracing.

GUIDELINES FOR ENDOPROSTHETIC RECONSTRUCTION

- Regardless of the anatomic location, certain basic principles apply to all endoprosthetic reconstructions. Restoration of the normal axis of motion and extremity length depends on component selection. Careful attention to implant size and soft tissue reconstruction also can optimize functional outcomes. Proper stem selection, bone preparation, cementation technique, and use of extracortical fixation can reduce the risk of aseptic loosening and maximize implant longevity.

- Following resection of a bone tumor, careful measurement of the specimen is necessary to select the desired implant length. Trial components, available with all modular systems, permit easy comparison with the specimen and permit multiple trial reductions to determine optimal length and positioning for the final implant.

- Meticulous preparation of the intramedullary canal is done for stem insertion. Selection of the stem diameter depends on the anatomy of the canal, which should be sequentially reamed so that it can accommodate the largest diameter stem possible.

- Tendon and soft tissue reconstruction is determined by the anatomic site and the amount of residual tissue following tumor resection. Again, functional outcome can be enhanced with meticulous attention to details and restoration of proper biomechanics.

- Rotational muscle flaps often are necessary to ensure adequate soft tissue coverage and also may serve to reinforce tendon attachments or capsular tissue.

- Frequently performed transfers include the following:
  - **Shoulder.** Transfer of the pectoralis major and latissimus dorsi muscles covers and dynamically stabilizes a proximal humeral prosthesis. Dacron tapes are used to suspend the prosthesis statically from the scapula.
  - **Hip.** Transfer of the psos and external rotators is performed to create a pseudocapsule around the prosthetic head. This capsule then is reinforced with circumferential Dacron tapes to prevent dislocation. Reattachment of the abductor muscles is necessary to minimize the Trendelenburg lurch in the postoperative phase. This limp improves over time with strengthening of the abductors.
  - **Knee.** Twenty-five percent of distal femoral replacements and all proximal tibial replacements require rotation of a gastrocnemius muscle (typically the medial head) to repair the soft tissue defect following resection of a tumor around the knee. In addition, this local flap is incorporated into the reconstruction of the patellar tendon for proximal tibial replacements.
  - **Final closure of the wound may be jeopardized by skin loss following resection of a biopsy tract. In general, patients with very large tumors often have redundant skin because the tumor has acted as an internal skin stretcher. This extra skin may be rotated or trimmed as needed to facilitate wound closure. Excess skin along the incision should be excised to avoid marginal wound necrosis related to disruption of the microvasculature from elevation of large subcutaneous flaps. Patients with tight skin closures are best served by leaving the skin open to avoid pressure-induced ischemia, and performing a primary or secondary split-thickness skin graft.
  - **Limbs should be elevated maximally in the postoperative phase to reduce swelling that can jeopardize the wound closure.**
  - **Use of large-bore closed suction drains and correction of any postoperative coagulopathies help prevent hemato talking tissue defects following endoprosthetic reconstructions are not uncommon.**

CLINICAL RESULTS FOLLOWING ENDOPROSTHETIC REPLACEMENT

- Prosthetic survival has improved dramatically as improved surgical techniques, advanced prosthetic designs, and modern manufacturing techniques have been adopted. Results of early custom prostheses were disappointing, leading many surgeons to use allografts or other methods of reconstruction.

- More recently, there has been increased interest in endoprosthetic reconstruction as multiple centers have reported improved outcomes. Informal polling of members of the Musculoskeletal Tumor Society has shown a significant swing from a majority of members using primarily allograft reconstructions to a majority of members using endoprosthetic reconstruction.

- Recently published results looking at long-term survival of 242 cemented endoprosthetic replacements demonstrated an overall survival of 88% at 5 years and 85% at 10 years (Table 1). Prosthetic survival varied by type and location, with the poorest survival seen in patients with early custom-designed implants and in patients with proximal tibial replacements. Infection was the single most common cause of implant failure, with infected patients having an 83% risk of implant failure (FIG 12).

- Functional results vary by implant location. Outcomes following reconstruction of the distal femur in 110 patients were judged as good to excellent in 85% of patients.

COMPLICATIONS

- Complications following any type of limb-sparing reconstruction are not uncommon. Most patients have depressed immune systems from chronic disease, chemotherapy, and malnutrition. Patients often are anemic and have clotting abnormalities, including thrombocytopenia. The presence of long-term indwelling catheters for the administration of
Chemotherapy may lead to unrecognized bacteremia and potential hematogenous seeding of the operative site.

- The anatomic location of a tumor and necessary resection may result in significant disruption of the venous and lymphatic drainage of the extremity during resection, leading to venous stasis, swelling, and lymphedema. This can lead quickly to flap necrosis during the postoperative period, secondary infection, and eventual amputation.

- Finally, oncologic complications, including local recurrence of tumor or tissue necrosis from radiation, may result in failure of a limb-sparing procedure.

- Complications specific to endoprosthetic reconstruction may be related to mechanical or biologic factors. Prosthetic fracture, disassociation of modular components, fatigue failure, and polyethylene wear have been described. Improved implant designs, metallurgy, and manufacturing techniques can reduce the incidence of these problems significantly.

- Our institutional experience with more than 200 MRS (Materials Research Society, Warrendale, PA) implants over the past 18 years have revealed no stem fractures, body fractures, or taper disassociations to date. Polyethylene bushing failure occurs in fewer than 5% of patients with the Kinematic rotating hinge mechanism (Howmedica, Rutherford, NJ).

Biologic failure of an endoprosthesis may occur as a result of joint instability, aseptic loosening, or periprosthetic fracture of bone around the prosthesis. Meticulous attention to soft tissue reconstruction has virtually eliminated joint instability as a problem. The use of circumferential porous coating, properly sized large-diameter stems, and third-generation cementation techniques has helped to prevent aseptic loosening in our patients. Surgical technique and the use of polished cemented stems have prevented periprosthetic fractures during surgery. Several patients with secondary, late fractures as a result of blunt trauma (eg, falls, auto accidents) have been treated successfully with casting and protected weight bearing.

**FUTURE TRENDS FOR ENDOPROSTHETIC RECONSTRUCTION**

- Current modular endoprosthetic reconstruction has greatly facilitated limb-sparing surgery following resection of bone sarcomas. Its success also has expanded the indications to include bone defects for non-oncologic problems. Increasing experience in the salvage of failed total joint replacements, chronic nonunions of fractures, and reconstruction following radical resection of osteomyelitis has shown that the proven

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**Table 1**

<table>
<thead>
<tr>
<th>Prosthesis Type</th>
<th>No. patients</th>
<th>No. failures</th>
<th>Median F/U (mos)</th>
<th>Survival at median F/U</th>
<th>5-yr survival (95% CI)</th>
<th>10-yr survival (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRS PH</td>
<td>36</td>
<td>4</td>
<td>30</td>
<td>0.89</td>
<td>0.89 (0.70–1.00)</td>
<td>0.76 (0.30–1.00)</td>
</tr>
<tr>
<td>MRS PF</td>
<td>22</td>
<td>0</td>
<td>25</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>MRS DF</td>
<td>78</td>
<td>11</td>
<td>29</td>
<td>0.94</td>
<td>0.86 (0.78–0.94)</td>
<td>0.76 (0.56–0.94)</td>
</tr>
<tr>
<td>MRS PT</td>
<td>31</td>
<td>7</td>
<td>33</td>
<td>0.94</td>
<td>0.86 (0.83–1.00)</td>
<td>0.65</td>
</tr>
<tr>
<td>All MRS</td>
<td>173</td>
<td>22</td>
<td>30</td>
<td>0.93</td>
<td>0.86 (0.82–0.91)</td>
<td>0.76 (0.64–0.88)</td>
</tr>
<tr>
<td>All custom implants</td>
<td>50</td>
<td>23</td>
<td>85</td>
<td>0.71</td>
<td>0.81 (0.77–0.87)</td>
<td>0.55 (0.47–0.62)</td>
</tr>
<tr>
<td>All limbs</td>
<td>242</td>
<td>55</td>
<td>37</td>
<td>0.92</td>
<td>0.88 (0.85–0.90)</td>
<td>0.85 (0.81–0.90)</td>
</tr>
</tbody>
</table>

*Failure was defined as implant removal for any reason; patients were censored at time of last follow-up or at time of death.

DF, distal femur; MRS, Modular Replacement System; PF, proximal femur; PH, proximal humerus; PT, proximal tibia.

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**FIG 12**

A. Kaplan-Meier survival curve comparing all Modular Replacement Systems by anatomic site. Proximal femur and proximal humerus replacements have the most superior survival results, followed by distal femur, and then proximal tibia. B. Kaplan-Meier survival curve showing superior results of modular replacement system when compared to custom prostheses over all anatomic sites.
concepts of limb-sparing surgery can be applied to many different clinical situations. Today, more endoprosthetic reconstructions are performed for non-oncologic reconstructions than for osteosarcomas.

- Ongoing research continually strives to improve the outcome following endoprosthetic reconstruction. Continued work on improved metallurgy and polymers, particularly with the introduction of cross-linked polyethylene, promises improved long-term durability. Routine use of premixed antibiotic cement and experimentation with antimicrobial implant surfaces may help to reduce the risk of periprosthetic infection. New techniques for tendon attachment to the prosthesis include novel clamps and ingrowth surfaces to promote improved junctional strength.

- New implant technologies such as the Rephysis noninvasive expandable prosthesis offer hope to younger children with few alternative options. New fixation methods, including hydroxyapatite stems with porous coated surfaces, may be of great value in non-oncologic patients.

- The recently introduced Compress system represents the first new method of prosthetic fixation in decades. We have already adapted this system to expand the applicability of intercalary endoprosthetic reconstruction. Although future advances in tissue engineering hold the promise of artificially engineered living bone, we expect that endoprosthetic reconstruction will remain the preferred choice of orthopaedists for many years to come.

REFERENCES