Feature Article

Reconstruction Using Expandable Endoprostheses for Skeletally Immature Patients With Sarcoma

ALEXANDER P. DECILVEO, BA; BARTLOMIEJ W. SZCZECH, MD; JACOB TOPFER, BS; JAMES C. WITTI,G MD

Abstract

Expandable endoprostheses have become an acceptable modality to address the issue of limb-length inequality in limb-sparing procedures for skeletally immature patients afflicted with lower extremity bone sarcomas. This study retrospectively analyzed postoperative outcomes and complications for 7 patients (8 limbs) who underwent minimally invasive or noninvasive reconstruction during a 12-year period. Musculoskeletal Tumor Society (MSTS) scores and complication rates were reported. Mean functional outcome (MSTS scores) at final follow-up was 93.3%. Functional outcomes for the noninvasive and minimally invasive expandable prostheses were 97% and 85%, respectively. Complications included temporary peroneal nerve palsy (2 limbs), infection (2 limbs), prosthesis revision (3 limbs), stiffness (3 limbs), and wound healing problems (3 limbs). None of the patients required amputation. Both minimally and noninvasive expandable prostheses appear to be safe and reliable means of reconstruction that permit limb salvage in skeletally immature patients and provide good functional results considering the alternative is above-knee amputation or hip disarticulation. Although complications are frequent (range, 13%-38%), they often can be managed successfully without amputation, thus providing a good quality of life and functional limb. The noninvasive prosthesis may prove to be a more attractive option by potentially negating additional surgeries and reducing infection rates; however, the short-term experience with this prosthesis warrants further investigations with more patients and longer follow-up. [Orthopedics. 2017; 40(1):e157-e163.]

Osteosarcoma and Ewing sarcoma are the 2 most common primary malignant bone tumors in childhood and adolescence. Forty-five percent of patients are younger than 16 years, and 17% are younger than 12 years. These tumors commonly affect the metaphysis of the distal femur (35%) and proximal tibia (20%). Because these tumors have a predilection for the metaphyseal region, resection often requires sacrificing the growth plate. In the past 3 decades, advancements in radiology, neoadjuvant chemotherapy, and technology have enabled limb-sparing surgery for approximately 90% of extremity bone sarcoma patients.1

Until the early 1990s, the recommended surgical treatment for most skeletally immature patients with a bone sarcoma was amputation or rotationplasty.1 Patients’ limbs were amputated if the calculated leg-length discrepancy was greater than 3 cm. Since then, advancements in limb-sparing surgery have allowed a more conservative approach. Advances in technology have led to more versatile and flexible options for limb-reconstruction. Expandable endoprostheses have become an acceptable modality to address the issue of limb-length inequality in limb-sparing procedures for skeletally immature patients afflicted with lower extremity bone sarcomas. This study retrospectively analyzed postoperative outcomes and complications for 7 patients (8 limbs) who underwent minimally invasive or noninvasive reconstruction during a 12-year period. Musculoskeletal Tumor Society (MSTS) scores and complication rates were reported. Mean functional outcome (MSTS scores) at final follow-up was 93.3%. Functional outcomes for the noninvasive and minimally invasive expandable prostheses were 97% and 85%, respectively. Complications included temporary peroneal nerve palsy (2 limbs), infection (2 limbs), prosthesis revision (3 limbs), stiffness (3 limbs), and wound healing problems (3 limbs). None of the patients required amputation. Both minimally and noninvasive expandable prostheses appear to be safe and reliable means of reconstruction that permit limb salvage in skeletally immature patients and provide good functional results considering the alternative is above-knee amputation or hip disarticulation. Although complications are frequent (range, 13%-38%), they often can be managed successfully without amputation, thus providing a good quality of life and functional limb. The noninvasive prosthesis may prove to be a more attractive option by potentially negating additional surgeries and reducing infection rates; however, the short-term experience with this prosthesis warrants further investigations with more patients and longer follow-up. [Orthopedics. 2017; 40(1):e157-e163.]

The authors are from Robert Wood Johnson Medical School (APD), Piscataway; St Joseph’s Regional Medical Center (BWS), Paterson; and the Department of Orthopedic Oncology (JT, JCW), Hackensack University Medical Center, Hackensack, New Jersey.

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Correspondence should be addressed to: James C. Wittig, MD, Department of Orthopedic Oncology, Hackensack University Medical Center, 20 Prospect Ave, Ste 501, Hackensack, NJ 07601 (jwittig@hackensackumc.org).

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During the past 20 years, expandable endoprostheses have become a popular option for limb-sparing surgery. In the United States, approximately 50 to 100 skeletally immature patients are affected annually by sarcomas of their distal femur and proximal tibia who may benefit from the use of an expandable endoprosthesis, thus making this type of operation rare and large prospective studies difficult.1,4 Most surgeons agree that the main indication for the use of an expandable endoprosthesis is an estimated leg-length discrepancy greater than 3 cm at maturity. Patients whose leg-length discrepancy is projected to be less than 3 cm can be treated with a normal “adult-type” prosthesis that is either made longer or shorter. However, it is controversial whether patients with leg-length discrepancy greater than 3 cm at maturity who require an expandable prosthesis because the remaining growth results in less than a 3-cm difference.1 Currently, the 2 types of expandable endoprostheses commonly used are minimally invasive and noninvasive varieties.

The original minimally invasive expandable prosthesis, Lewis Expandable Adjustable Prosthesis (LEAP), required additional surgeries for lengthening with a screwdriver.3 Although this endoprosthesis is less expensive than the noninvasive variety, it requires repeated open surgical procedures, which may result in infection (range, 0%-50%).6,7 There also were problems with mechanical failure and aseptic loosening (as high as 47%).6,7 In recent years, several companies, including Stryker and Biomet, have designed a modular minimally invasive expandable prosthesis with a durable lengthening mechanism to reduce complications such as hardware failure, yet these prostheses still required a surgical lengthening predisposing to infection (Figure 1).2

In the 1990s, the Phenix (aka Repiphysis; Wright Medical, Arlington, Tennessee) noninvasive expandable prosthesis was designed. This prosthesis did not require surgical lengthening; instead, a coiled spring within the prosthesis covered by a polymer could be melted by an external power source, thereby allowing expansion.8 In more recent years, Stanmore has developed a second-generation noninvasive expandable prosthesis that lengthens via an internal magnetic gearbox activated by an external magnetic field.9,10 In a 16-minute session, the Stanmore noninvasive “extendible” prosthesis can be lengthened by approximately 4 mm in an office setting (Figure 2).11 Although this prosthesis may decrease the number of surgical procedures and theoretically reduce the risk for infection, it is expensive, and there is little literature reporting the long-term outcomes.5,11,12

This study reports the use of noninvasive and minimally invasive expandable endoprostheses in skeletally immature patients with sarcoma. Early and late results as well as complications and their management are presented.

**MATERIALS AND METHODS**

Between 2002 and 2014, a total of 7 skeletally immature patients (8 limbs) underwent surgery performed by a single surgeon (J.C.W.) for high-grade osteosarcoma or Ewing sarcoma of the distal femur (n=4) or proximal tibia (n=4). Depending on patient characteristics and year of surgery, either a noninvasive or minimally invasive expandable endoprosthesis...
was used. Indications for an expandable endoprosthesis implant were estimated limb-length discrepancies greater than 3 cm at skeletal maturity and candidacy for limb-sparing surgery. Prior to 2010, either a minimally invasive Stryker Howmedica or a Biomet custom segmental expandable prosthesis was implanted in 3 patients (4 limbs); 1 of these patients developed bilateral proximal tibia osteosarcomas within 2 years, and the Biomet expandable prosthesis was used in the contralateral limb because the Stryker version was unavailable at the time of the second surgery. From 2011 to 2014, a Stanmore noninvasive extendible prosthesis was implanted in 4 patients (4 limbs).

Estimated limb-length discrepancy at skeletal maturity was calculated with both the multiplier method and charts devised by Andersen and Green using standard or computed tomography scanograms. All of the prostheses were custom and modular.

The resection portion of the procedure was standardized for each patient. The 3 main steps for surgery were tumor resection with appropriate margins, reconstruction of the involved bone and joints, and restoration of the soft tissue envelope for prosthetic coverage and function. Resection length was based on tumor extent and prosthesis length necessary to achieve expansion. For all of the prostheses (except for patient 6 who required a total femur replacement), a cemented stem was used to fix the component to the native bone and a smooth uncemented stem was used to transgress the opposing growth plate across the joint, which was maintained intact (Figure 3). All knee mechanisms consisted of a rotating hinge. If a revision was necessary, either for infection or if maximum expansion was reached, the prosthesis was either replaced or collapsed, an interbody segment was implanted, and the prosthesis was re-expanded over time.

All patients were treated with preoperative and postoperative chemotherapy protocols according to standard regimens, except for 1 patient who was treated at another institution by a different surgeon a year earlier and had a failed and infected allograft. Postoperatively, the physical therapy regimen varied according to the site of surgery.

To reduce postoperative complications, lengthenings were initiated only after patients had completed chemotherapy and leg-length discrepancy began to develop. Patients with a noninvasive expandable prosthesis underwent several 16-minute expansions of 4 mm every 4 to 8 weeks (Figure 4). Patients with a minimally in-
An expandable prosthesis underwent surgical expansion through a 3- to 4-cm incision. The prosthesis was unlocked and a screwdriver was then inserted and twisted. The prosthesis was lengthened by 1 to 2 cm during each procedure under fluoroscopic guidance while the knee was kept in 30° to 45° of flexion. All patients received postoperative antibiotics for 10 days. Surgical lengthenings were spaced at least 4 months apart to reduce the risk of infection and to allow patients to regain range of motion.

After each lengthening, radiographs were obtained. Patients were examined in the office after 10 to 14 days and then after 8 to 12 weeks to assess range of motion, gait, and any complications. At final follow-up, remaining limb-length discrepancy was recorded using scanograms, and the Musculoskeletal Tumor Society (MSTS) score was used to evaluate function. The MSTS score assesses patients’ physical and emotional status following limb-sparing surgery. For lower extremity reconstructive procedures, the MSTS score uses a scale ranging from 0 to 5 to assess 6 categories: pain (0=extreme pain, 5=no pain), function, emotional acceptance, walking ability, gait, and use of supports. A score of 5 in each category results in a final score of 30, which is the best possible MSTS outcome.

**RESULTS**

Between 2002 and 2014, a total of 7 skeletally immature patients (8 limbs) underwent treatment for sarcomas of the distal femur or proximal tibia with either a minimally or noninvasive expandable prosthesis (Table 1). Five patients were girls and 2 patients were boys; average age at the time of surgery was 10 years (range, 8-12 years).

Mean follow-up was 64 months (range, 12-164 months). Mean MSTS score at final follow-up was 93.3% (range, 83%-100%) (Table 2). The average number of expansions was 5.7 (range, 0-13). One patient (patient 4) died of disease approximately 1 year postoperatively and did not require a lengthening. Another patient (patient 7) died of metastatic disease at 86 months. The average amount of lengthening was 5.1 cm (range, 0-12 cm). Average resection length was 188.5 mm (range, 171-265 mm).

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**Table 1**

<table>
<thead>
<tr>
<th>Patient No./Sex/Age, y</th>
<th>Tumor Location, Type</th>
<th>Prosthesis Type</th>
<th>Follow-up, mo</th>
<th>No. of Lengthenings</th>
<th>Amount Lengthened, cm</th>
<th>Limb Discrepancy, cm</th>
<th>Length of Resection, mm</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/F/12</td>
<td>Proximal tibia osteosarcoma</td>
<td>Noninvasive Stanmore</td>
<td>36</td>
<td>11</td>
<td>4.4</td>
<td>&lt;1</td>
<td>171</td>
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<td>Proximal tibia osteosarcoma</td>
<td>Noninvasive Stanmore</td>
<td>18</td>
<td>2</td>
<td>.8</td>
<td>&lt;1</td>
<td>171</td>
<td>3</td>
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<td>3/M/10</td>
<td>Distal femur osteosarcoma</td>
<td>Noninvasive Stanmore</td>
<td>42</td>
<td>13</td>
<td>5.2</td>
<td>&lt;2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>165</td>
<td>None</td>
</tr>
<tr>
<td>4/M/8</td>
<td>Distal femur Ewing sarcoma</td>
<td>Noninvasive Stanmore</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>189</td>
<td>Metastases&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>5/F/11</td>
<td>Distal femur osteosarcoma</td>
<td>Minimally invasive Stryker</td>
<td>96</td>
<td>5</td>
<td>9</td>
<td>&lt;2</td>
<td>265</td>
<td>1,2,3,4,5; Type 4 revision&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>6/F/8</td>
<td>Distal femur osteosarcoma</td>
<td>Minimally invasive Stryker</td>
<td>164</td>
<td>6</td>
<td>12</td>
<td>2</td>
<td>177</td>
<td>2,4,5; Type 3 revision&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>7/F/11&lt;sup&gt;e&lt;/sup&gt;</td>
<td>Proximal tibia osteosarcoma</td>
<td>Minimally invasive Stryker</td>
<td>86</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>175 (L); 195 (R)</td>
<td>1,2,4; metastases&lt;sup&gt;c&lt;/sup&gt;; Type 4 revision&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Abbreviations: F, female; L, left; M, male; R, right.
<sup>a</sup>1=infection; 2=prosthesis revision/replacement; 3=paresthesia; 4=decreased range of motion; 5=wound healing problems.
<sup>b</sup>Patient had not reached skeletal maturity.
<sup>c</sup>Patient died from metastatic disease.
<sup>d</sup>Revision Type 3, structural failure; revision Type 4, infection.<sup>23</sup>
<sup>e</sup>Bilateral expandable prostheses.
Complications

Complications (Table 1) included temporary foot drop (2 limbs) that resolved within 6 months, infection (2 limbs), prosthesis revision (3 limbs), stiffness (3 limbs), and wound healing problems (3 limbs). Complications unrelated to the implant included a femoral neck fracture 2 years postoperatively due to a fall (patient 7). Patient 5 developed a prosthetic infection during her last lengthening and required staged revision to an adult modular total femur. Approximately 1 year later, a trochanteric claw that was used to repair the greater trochanter to the prosthesis failed. This patient, who has not yet undergone revision, has hip pain and poor range of motion in her knee and hip. Amputation was avoided in all patients.

Discussion

In the past 20 years, limb-sparing surgery has become the preferred treatment for most patients with primary bone sarcomas. Amputation is considered for patients who wish to participate in vigorous and full-contact activities. When amputation is not desired or can be avoided, the defect can be reconstructed using various prosthetic replacements. For children ages 5 to 14 years with lower extremity sarcomas, limb-length discrepancy is a major concern. Special expandable prostheses have been developed to address this issue. Early versions of expandable prostheses used mechanisms that required open surgery to lengthen the prosthesis. More recent versions of expandable prostheses have been developed that are lengthened without invasive surgery. This has been appealing for multiple reasons including ease of lengthening, less pain, less anesthesia-related risks, and theoretically lower infection rates.

This study included 7 patients (8 limbs) with primary sarcomas of the distal femur or proximal tibia. The overall functional outcomes (MSTS score of 93.3%) appear promising compared with previous reports of expandable prostheses. There are few reports describing a single surgeon’s experience with both minimally and noninvasive expandable prostheses. Ruggieri et al examined the use of both types of expandable prostheses and reported an average MSTS score of 79% at final follow-up; there was no statistically significant difference in functional outcomes among the different groups of prostheses. For studies that solely examined the use of minimally invasive expandable prostheses, MSTS scores varied from fair to excellent. Schindler et al reported an average MSTS score of 77% at final mean follow-up of 8.7 years for their minimally invasive cohort. In the literature, noninvasive prostheses are less studied and tend to have a shorter mean follow-up. Investigators using the Stanmore noninvasive extendible prosthesis reported MSTS scores ranging from 68% to 85%. The functional outcomes reported in the literature have been consistent across both types of prostheses.

In the current study, complications included temporary peroneal nerve palsy (25%), infection (25%), prosthesis revision (38%), stiffness (38%), and wound healing problems (38%). The peroneal nerve palsies, which resolved in 3 to 6 months, were unrelated to the type of prosthesis and more likely were related to the mobilization of the peroneal nerve. Stiffness was treated with an extensive regimen of physical therapy. Chemotherapy was initiated 4 to 6 weeks postoperatively to allow wound healing and avoid infection. None of the patients required an amputation.

Studies examining treatment with both types of prostheses reported major complications including infection (8%-47%.

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Table 2

<table>
<thead>
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<th>Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5a</th>
<th>5b</th>
<th>6</th>
<th>7c</th>
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<tr>
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<td>5</td>
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<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Function</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>3</td>
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<tr>
<td>Emotional acceptance</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Walking ability</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Gait</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
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<tr>
<td>Supports</td>
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<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>5</td>
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<td>Total</td>
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<td>25</td>
</tr>
<tr>
<td>Percent</td>
<td>100</td>
<td>87</td>
<td>100</td>
<td>100</td>
<td>83</td>
<td>57</td>
<td>100</td>
<td>83</td>
</tr>
</tbody>
</table>

*Prior to hardware failure.
*After hardware failure.
*Bilateral expandable prostheses.
of patients), amputation (0%-9%), aseptic loosening or mechanical failure (10%-28%), and periprosthetic fracture (5%-26%). Revision surgery was required in 23% to 50% of these patients, usually due to infection or aseptic loosening, and this may be attributed to surgical technique or progression of disease.

Patients in the current study demonstrated similar rates of infection and prosthesis revision; however, no cases of loosening or amputation occurred. This may be due to the small size of the patient population and length of follow-up (range, 12-164 months). In patients who were treated with a minimally invasive prosthesis, open surgery required for lengthening was most likely the cause of infection. One patient (patient 6) required a Type 3 revision for acetabular degeneration, and 2 patients (patients 5 and 7) required a Type 4 revision for deep infection. Patient 6, with an expandable total femur replacement, underwent successful revision to a total hip replacement with the remaining prosthesis left intact. Patient 5 underwent revision to an adult prosthesis, and patient 7 underwent revision to a minimally invasive expandable prosthesis replacement.

Studies investigating minimally invasive prostheses have reported high rates of infection (up to 68%) as well as loosening (up to 50%). The most common complications reported by Schindler et al were mechanical failure (100%), aseptic loosening (50%), and amputation (16%). Prosthesis revision was required in 83% of patients mainly due to loosening and infection. Studies investigating the Stanmore noninvasive extendible prosthesis reported major complications including infection (0%-18%), amputation (0%-20%), and revision (0%-18%). In their review, Hwang et al noted that half of the infections occurred within 3 months and that all were unrelated to the type of prosthesis; two-thirds of these infections required amputation.

In a medium-term study of the Stanmore device, Picardo et al reported 3 gearbox failures in 55 patients, with no cases of loosening. Two of the 3 gearbox failures were attributed to noncompliance with physical activity. In the current study, no cases of gearbox failure occurred in patients with a noninvasive prosthesis. Theoretically, the risk of infection should be reduced in the noninvasive prosthesis due to the ability to lengthen the prosthesis without an open surgical procedure. Revision surgeries were dramatically reduced in reports using the Stanmore device, and as hypothesized, lower rates of infection have been reported in the literature for noninvasive prostheses compared with minimally invasive prostheses.

Technically, the current study included 2 different groups of patients—noninvasive and minimally invasive. It is difficult to compare the results between these 2 groups because variables such as the length of follow-up, location of the tumor, length of resection, number of lengthening procedures, and amount of lengthening differed across the groups. Prior to 2010, the Stanmore noninvasive extendible prosthesis was unavailable in the United States, hence the authors choice of treatment from 2002 to 2010. Since its release, the Stanmore noninvasive prosthesis has become the senior author’s preference (J.C.W.) for reconstruction because it theoretically decreases the number of lengthening operations as well as the risk for infection and improves function. The Stanmore noninvasive prosthesis also seems easier to expand and more durable with less potential for mechanical failure compared with earlier types of noninvasive prostheses such as the Phenix/Reipiphysis.

There are several limitations to this study including its retrospective nature, small population size, short-term follow-up, consistency of device use, differences in diagnoses, socioeconomic factors, and different lengths of resection. Both the minimally invasive and Stanmore noninvasive prostheses appear to be safe and reliable means of reconstruction that permit limb salvage in skeletally immature patients and provide good functional results considering that the alternative is an above-knee amputation or hip disarticula-
References