Introduction

Definitive surgical management of extremity tumors has changed dramatically since the total femur reconstruction was first described by Buchanan in 1950.¹ Limb salvage methods during that period were controversial in contrast to the accepted standard of amputation.²,³ Earlier attempts at limb salvage had been reported; however, high rates of local recurrence limited its success.⁴ The development of adjuvant therapies during the latter half of the 20th century has allowed investigators to revisit...
limb salvage as a means of treating primary sarcomas and metastatic tumors in the extremities.¹⁵

With the advent of neoadjuvant chemotherapy and radiation therapy in combination with contemporary surgical techniques, several investigators in the 1970s successfully performed segmental endoprosthetic reconstructions for patients with tumors previously considered unresectable.⁶ In these early reports, significant diversity existed among the various devices utilized. In 1973, Parish⁷ reported his experience using homologous cadaveric allografts to reconstruct joint defects created by tumor excision, and in 1979, Salzer et al⁸ described the use of a modular ceramic endoprostheses for the replacement of the resected proximal humerus. In 1980, Katznelson and Nerubay⁹ performed a total femoral reconstruction in 5 patients using a device that extended from the hip to insert directly into the proximal tibia without an articulating knee joint. Also in 1980, Enneking et al⁹ described a reconstruction technique that utilized autogenous cortical bone grafting. Although early reconstruction methods differed, the principle of limb salvage and endoprosthetic reconstruction had become an acceptable treatment modality with local recurrence rates equivalent to amputation.¹⁰

Once limb salvage became an acceptable form of local tumor control, attention was focused on endoprostheses survival and function. Initial attempts at quantifying long-term clinical outcome and survivability was difficult due to multiple factors. Extremity sarcomas are rare and the number of cases included in most early studies was relatively small. Also, surgical techniques and device technology changed rapidly, often within the time frame of clinical studies, making the results difficult to interpret.¹¹¹⁶ In addition, studies combined data from oncology, trauma, and adult reconstruction and included data from multiple anatomic locations.²³⁹ These issues added to the complexity and inaccuracy of early outcome data, thereby making interpretation difficult.

Failure Classification: Mechanical and Nonmechanical

In the late 1990s, the use of metallic megaprotheses was becoming increasingly popular. Various investigators demonstrated improved limb survival and functional outcomes for modular, metallic endoprostheses.¹⁷¹⁹ Since experience with these devices has grown and patient survival has increased, investigators are now able to systematically assess some of the underlying causes for reconstruction failure. Wirganowicz et al¹⁰ addressed this issue by delineating reconstruction failure as mechanical vs nonmechanical. Henderson et al²¹ expanded on this idea and identified five types of failure. Under this classification scheme, failures are defined as follows: soft-tissue failure (type I), aseptic loosening (type II), structural failure (type III), infection (type IV), and tumor progression (type V) (Table). Subdividing these groups by their etiology of failure facilitates the detection of surgical, anatomic, biological, and biomechanical factors that may affect clinical outcome and survivorship. This review discusses the current literature using the five methods of failure as a framework to describe the contemporary practice and challenges of orthopaedic reconstruction in the treatment of bone and soft-tissue tumors of the extremities.

### Table. — Classification of Segmental Endoprosthesis Failures

<table>
<thead>
<tr>
<th>General Category</th>
<th>Classification</th>
<th>Mode of Failure</th>
<th>Description of Failure Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>Type I</td>
<td>Soft-tissue failure</td>
<td>Instability, tendon rupture, aseptic wound dehiscence</td>
</tr>
<tr>
<td></td>
<td>Type II</td>
<td>Aseptic loosening</td>
<td>Clinical and radiographic evidence of loosening</td>
</tr>
<tr>
<td></td>
<td>Type III</td>
<td>Structural failure</td>
<td>Periprosthetic or prosthetic fracture, deficient bony supporting structure</td>
</tr>
<tr>
<td>Nonmechanical</td>
<td>Type IV</td>
<td>Infection</td>
<td>Infected endoprosthesis not amenable to retention</td>
</tr>
<tr>
<td></td>
<td>Type V</td>
<td>Tumor progression</td>
<td>Recurrence or progression of tumor with endoprosthesis contamination</td>
</tr>
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Type I Failure: Soft-Tissue Failure

Soft-tissue failures are defined as functional deficiencies of the soft-tissue attachments about the implant that require reoperation. These failures may be due to disruption of or incompetence of periarticular ligamentous and tendinous restraints that lead to instability or failure of incorporation or ingrowth of host tendons to the endoprosthesis. In our retrospective review, soft-tissue failures accounted for 12% of all failures, with an absolute incidence of 2.9%. It was most common around the shoulder and hip, where soft tissue is critical for joint function and stability. In these joints, soft-tissue failures accounted for 28.7% of all failures. Alternatively, soft-tissue failures comprised only 5.7% of all failures in uniaxial, or hinged joints, which are used at the elbow and knee.

Several factors place patients undergoing limb preservation surgery for musculoskeletal tumors at risk for soft-tissue failures. Surgical exposures for tumor resection are generally expansile and may require resection of substantial portions of muscle, tendon, and ligamentous
connective structures. Resection of a muscle group results in local weakness and relative overpowering of its antagonist, causing unbalanced forces around the joint that can lead to instability.\textsuperscript{22} Also, reattachment of remaining muscle to a metal endoprosthesis has proven problematic since soft-tissue ingrowth to conventional prosthesis materials is insufficient.\textsuperscript{23} Similarly, reestablishing optimal muscle length-tension is difficult as small changes in this relationship result in substantial reductions in contractile force and excursion.\textsuperscript{24}

The most common manifestation of soft-tissue failure is joint instability. Patients who undergo proximal femoral replacement for the treatment of large structural deficiencies or tumors of the proximal femur often have insufficient abductor strength and walk with a Trendelenburg gait.\textsuperscript{16,25-31} The increased rate of hip dislocation seen in this patient population can be attributed to abductor insufficiency.

Many methods of hip abductor reconstruction following proximal femoral replacement have been described.\textsuperscript{16,32} These methods include abductor tendon attachment to allograft, tendon-to-prosthesis, and tendon-to-tendon reconstructions. Tendon-to-megaprosthesis appears to have great acceptance among publishing surgeons.\textsuperscript{16,25,29,31,33,34} However, facilitating soft-tissue ingrowth and attaining a lasting and functional tendon attachment to a metal prosthesis remain challenging.\textsuperscript{33}

Direct soft-tissue ingrowth into metal prostheses has been investigated.\textsuperscript{35,40} Current preparations of cobalt chromium have demonstrated limited soft-tissue ingrowth due to suboptimal pore geometry and limited interconnectivity. Titanium demonstrates superior soft-tissue interdigititation, with the limitation of reduced strength to withstand physiological stresses.\textsuperscript{34} Porous tantalum possesses adequate strength to allow processing of prostheses with porosities that facilitate soft-tissue and vascular ingrowth.\textsuperscript{35} Limited use of porous tantalum for these purposes is currently being tested; however, no studies have yet been published.

The soft-tissue ingrowth potential of several synthetic materials has been investigated.\textsuperscript{35-40} These materials include polyester (Dacron, Trevira, LARS, Mersilene), expanded polytetrafluoroethylene (ePTFE, GORE-TEX), polypropylene (Marlex, Prolene), and carbon fiber. Trevira (Trevira GmbH, Bobingen, Germany) has been used extensively in Europe for soft-tissue attachment to tumor prostheses,\textsuperscript{39} but it has limited tissue ingrowth due to an inflammatory response.\textsuperscript{41} Aortograft (InterGard Knitted Vascular Graft, Datascope, Montvale, NJ) is an ePTFE material that has been chosen for its durability in vivo and known soft-tissue ingrowth.\textsuperscript{38,42,43} The senior author (G.D.L.) has employed this device for reconstruction of the rotator cuff and abductor muscles with good results.\textsuperscript{44} Similar repairs have been described for the patellar tendon (Fig 1).\textsuperscript{19} Use of a purse-string hip capsule repair using Dacron demonstrated a reduction in the dislocation rate of proximal femur replacement compared to the literature.\textsuperscript{45}

![Fig 1. — Use of an Aortograft to facilitate patellar tendon reattachment after a segmental proximal tibial reconstruction (A) and attachment of the abductors and soft tissues after a proximal femur reconstruction (B).](image-url)
Type II Failure: Aseptic Loosening

Aseptic loosening of cemented segmental megaprostheses remains a major problem and accounted for 19% of device failures in our series of patients (Fig 2). Jeys et al reported on 661 patients with segmental endoprosthetic reconstructions of the upper and lower extremities. Aseptic loosening was the most common cause of mechanical failure in their series, accounting for 25% of revisions at 10 years. The incidence was highest for distal femoral and proximal tibial reconstructions, with 31% and 37% revision rates, respectively, in these subgroups. Unwin et al also observed similar rates of aseptic loosening in lower-extremity tumor endoprostheses and reported a higher incidence of this failure mechanism in younger patients and those with increased resection lengths of the tibia and femur. These results are consistent with our current understanding that increased physical demands put on these devices dispose them to greater mechanical strain and earlier failure. Additionally, aseptic loosening of humeral endoprostheses, a non-weightbearing joint, occurs less often due to decreased implant and interface stresses, further outlining the role that biomechanical forces have on long-term survivorship.

Polymethylmethacrylate (PMMA) cement has been a reliable means of early- and long-term fixation of segmental endoprosthetic devices. Benefits of cementation are its abilities to withstand immediate weight-bearing of the extremity and provide excellent stability against compressive loads. Importantly, this mode of fixation relies on interdigitation of the cement into osseous trabeculae surrounding the component stem to attain stability. Therefore, in the setting of sclerotic bone stock with inadequate osseous trabeculae, such as a revised femoral canal, cement interdigitation is diminished, subsequently affecting the long-term survivorship of the device.

Cementless, or press-fit, fixation of endoprostheses is increasingly popular in young patients who do not require local radiation treatment. Although initial fixation of these devices may not be as stable as cemented components, eventual osseous integration into the stem provides greater fixation and device stability in the long-term. Press-fit stems have been constructed of varied shapes (eg, fluted, fenestrated) and textures (eg, grit-blasted, porous-coated, beaded) in order to attain osteointegration into the surrounding bone. The introduction of hydroxyapatite (HA) and HA-tricalcium phosphate (HA-TCP) stem coatings has positively impacted tumor endoprosthesis fixation and survival. HA potentiates osteogenic adhesion to metallic surfaces and has applications in both adult joint and tumor reconstructive surgery. During device manufacturing, HA is applied via a plasma spray process onto a nonporous or porous surface (ie,
grit-blasted or fiber-mesh) of the titanium stem or the shoulder of the prosthesis. A benefit of applying HA to the stem is improved osteointegration with the inner cortical surface, thereby increasing long-term axial and rotational stability of the implant. Improved early stability of the endoprosthesis with HA coating was recently reported in a biomechanical study and is an important feature for immediate postoperative weightbearing.54 Blunn et al55 reported on the radiographic and finite element analysis (FEA) results of cementless, HA-coated fixation of 47 endoprosthetic implants. They observed no evidence of radiolucency surrounding the stems. However, specific patterns of osseous remodeling were noted to be potentially disadvantageous: bone resorption occurred at the periosteal surface while endosteal bone surrounding the stem was well-maintained. FEA suggested that reducing the amount of HA coating to one-third of the length of the device will result in less stress shielding of the outer cortex. Based on these and other reports of orthopaedic implants, long-term fixation of cementless devices is promising.

Application of HA onto the shoulder of the endoprosthesis (where the implant body buttresses cortical bone) has been performed to initiate bone growth from the outer cortex onto the device. This is supported by laboratory evidence showing that HA can conduct bone growth across gaps of up to 1 mm in length, even in the setting of 500 µm of motion.56 It has been hypothesized that HA shoulder coating and the subsequent formation of extracortical bone bridging provides a more efficient transfer of strain across the bone-prosthesis interface contributing to the implant’s long-term stability; however, this theory remains unproven.11 Nonetheless, the introduction of HA coating has been an integral advance in diminishing the incidence of aseptic loosening.11,57 Myers et al57 reported that in 192 patients with rotating-hinge, distal femoral reconstructions, the use of an HA collar decreased the incidence of revision at 10 years by 24%. Additionally, endoprostheses with HA-coated collars implanted after multiple failed cemented reconstructions have been reported to be effective despite the historically poor results in this subgroup of patients.58 The exact mechanism by which bone bridging at the HA collar inhibits aseptic loosening has not been elucidated, although some believe that circumferential sealing of the prosthesis from articular polyethylene wear debris may largely account for this phenomenon.59

Augmentation of arthroplasty devices with porous tantalum (PT) such as Trabecular Metal (Zimmer Inc, Warsaw, IN) has become popular in the field of adult reconstruction over the past decade. It is currently gaining acceptance as an alternative to the use of allograft and autograft in reconstructing bone deficits after tumor resection or in association with corticocancellous bone grafts. Biomechanical characteristics as well as its biocompatibility make it well suited for use in endoprosthetic devices and in various medical applications such as coronary stents and dental implants. Frequently, stress shielding of diaphyseal bone surrounding endoprosthetic stems occurs with stiffer metals such as cobalt-chromium. Conversely, the stiffness of PT more closely approximates that of trabecular bone, therefore decreasing stress shielding and subsequent osseous resorption. Vascular, soft-tissue, and osseous ingrowth occurs readily secondary to the porosity of PT, which is approximately 70% to 80% of its volume with pore sizes ranging from 400 to 500 µm (Fig 3). Its porosity is approximately three-fold greater than traditional porous metals, allowing for superior soft-tissue and osseous ingrowth.60 Augmentation of PT with osteoinductive agents as well as bisphosphonates has been promising, demonstrating up to an 800% increase in osseous ingrowth in laboratory studies.61 However, the available clinical data for the use of PT in segmental reconstruction are limited. Holt et al60 evaluated the results of 1 proximal tibia, 1 proximal femoral, and 4 distal femoral endoprostheses augmented with PT. At a mean follow-up of 81 months, they observed good functional results, no periprosthetic radiolucencies, and obvious radiographic evidence of osseous ingrowth into the PT in all cases. Despite the promising clinical and basic science data pertaining to the benefits of PT for use in segmental reconstructions, the theory of supplemental fixation by extracortical bone bridging and its effect on long-term stability remains hypothetical. Additional clinical studies are needed to better evaluate the role of PT in augmenting osseous fixation in segmental reconstructions.

Compressive osteointegration technology is a novel approach to combat the high rates of osteolysis after
proximal tibial and distal femoral reconstructions.\textsuperscript{10,17,36,57} The prototype for this technology is the Compress Pre-Stress Implant (Biomet Inc, Warsaw, IN). This implant utilizes spring tension to achieve high compressive forces at the bone-prosthesis interface, providing stabilization without the need for long-stem fixation. Benefits of its use are decreased stress shielding, diminished particle-induced osteolysis, and increased osteointegration at the bone-implant interface.\textsuperscript{58} A retrieval analysis of a similar device in a patient who died 10 months after implantation demonstrated bone formation along 79\% of the bone-implant interface.\textsuperscript{62} Although long-term clinical data supporting the longevity of this technology are not yet available, radiologic follow-up appears promising, and short-term survival of its use in distal femoral reconstructions was shown to be similar to traditional cemented endoprostheses.\textsuperscript{62}

**Type III Failure: Structural Failure**

While modular endoprosthetic designs have improved substantially since their inception, structural failure continues to occur commonly and has prompted further advances in metallurgy, design, and manufacturing techniques.\textsuperscript{20,38,46,57,63,64} In our series, fatigue failure occurred in 17\% of cases, accounting for the fourth most common etiology of failure (Fig 4). Given the young age of patients requiring limb preservation and the improved longevity in this patient population due to advances in systemic treatment, special considerations should be given to the increasing functional demands and loads put on these devices. Biological and biomechanical factors play key roles in their long-term success or failure and have guided the evolution of current designs.

Early tumor endoprostheses were monoblock devices, custom-made and manufactured from a variety of materials. In 1987, Bradish et al\textsuperscript{65} reported on an original total knee replacement constructed of an acrylic dental polymer that failed early in 1 patient due to seizure of the joint. Similarly, proximal humeral devices made of acrylic also failed prematurely.\textsuperscript{66} Later designs were constructed of cobalt-chrome-molybdenum and titanium alloys. The advent of acrylic cement in the 1960s permitted intramedullary fixation of the stem into the bone providing increased long-term stability. In the 1980s, modular designs emerged as a popular weapon in the armamentarium of limb salvage surgeons, providing increased options to re-establish limb length and soft-tissue mechanics during reconstruction.\textsuperscript{51}

With its advent, the need to produce a custom device was eliminated, decreasing the time interval between diagnosis and surgery.\textsuperscript{66} Improvements in manufacturing techniques have led to enhanced stem geometries such as curved and fluted stems, which better engage diaphyseal bone and provide stronger initial fixation and improved rotational stability.\textsuperscript{67} Broaching diaphyseal bone with hexagonal shapes or other geometries to accept a similarly shaped stem has been reported to improve the initial press-fit and enhance biological fixation.\textsuperscript{58}

Fig 4. — Structural failure of a distal femoral reconstruction (A), rotating hinge knee (B), and total elbow prosthesis (C).
The reported incidence of segmental stem fracture is variable, ranging between 1.6% to 16% of patients. In early Stanmore total knee designs, stems were constructed of pure titanium and were fraught with high fracture rates. Modern stems are made of titanium alloys containing aluminum and vanadium to provide additional stiffness and resistance against fatigue failure. Benefits of contemporary titanium alloys are resistance to corrosion, increased biocompatibility, and a low modulus of elasticity that decreases stress shielding and limits bone resorption. Despite improvements in metallurgy, however, fatigue failure of stems continues to occur. Griffin et al observed stem fractures in 6% of patients treated with cementless distal femoral and proximal tibial reconstructions. In this series, patients who had larger femoral resections and smaller diameter tibial stems were at greater risk of fatigue failure. Gosheger et al also reported a significant incidence of stem failure and noted that those with diameters less than 13 mm were at greater risk.

Ligamentous and tendinous structures that normally provide constraint to large joints such as the knee are often sacrificed during limb reconstruction. Historically, constrained devices such as hinges have been used to combat the loss of stability that occurs after articular resection. These designs increase stability but do so at the cost of amplifying constraint of the prosthesis and subsequently increasing the stress of the surrounding interface, thus potentiating osteolysis and failure. Rotating platform designs for distal femoral reconstructions were introduced in the 1980s to combat adverse shear forces at the bone-cement interface. Myers et al observed a significant increase in the survival of distal femoral reconstructions when comparing fixed vs rotating platform designs. Shih et al reviewed 61 cases of distal femoral reconstruction after resection of primary extremity tumors. Interestingly, they concluded that when compared to fixed designs, rotating platforms led to improved function and satisfaction, with good to excellent results achieved in 69% and 53%, respectively. Radiographic evidence of component loosening was observed in 88% in the fixed hinged group and in only 13% in those treated with rotating platform constructs. In addition, the Myers study observed a decrease of 11% in the incidence of revision at 10 years in patients who had rotating platforms compared to those with fixed hinges. Conversely, catastrophic implant failure occurred more commonly in the rotating platform group likely due to its more complex components. In all 6 cases of device failure, the tibial yoke that inserts into the tibial tray fractured, causing knee instability and subsequent revision in those cases.

Type IV Failure: Infection
Infection was the most common mode of endoprosthesis failure in our series, accounting for 34% of all failures. Many factors contribute to the high incidence of infection in this patient population. Extensive dissections and longer operative times are common with these surgeries and are known risk factors for infection. Chemotherapy and radiation exposure also contribute to the risk of infection.

Several promising technologies are aimed at decreasing the risk of infection following limb preservation. Elemental silver is an antimicrobial agent and has been used previously in medical devices as diverse as surgical dressings, external fixator pins, and endotracheal tubes to reduce infection. However, reports of efficacy have been mixed. The application of silver coatings to large tumor endoprostheses has been tested in animal models with promising results.

More recently, the use of silver nanoparticles has been shown to have more reliable antimicrobial properties as well as beneficial effects on wound healing. This technology has been successfully mated with titanium, which is commonly used in orthopaedic implants due to its low elastic modulus. Silver nanoparticles have also been successfully incorporated into hydroxyapatite compounds that are commonly applied to orthopaedic implants. These compounds have demonstrated no reduction in the bone ingrowth potential of standard hydroxyapatite. Furthermore, nanotechnology has facilitated the manufacturing of more osteoconductive surface preparations that encourage more robust osseous ingrowth after implantation.

Similar to the proposed modifications to tumor endoprostheses already mentioned, porous prostheses with the capability to leach high local concentrations of antibiotics are also in design phase.

Type V Failure: Tumor Progression
Limb preservation surgery is performed for both primary bone tumors and metastases to bone. Tumor progression remains a threat to the survival of the patient and the operative limb for the duration of the patient’s life and accounted for 17% of all limb salvage failures in our series.Attempts to minimize these failures include the use of pharmaceutical agents and advances in prosthesis technology.

Limb preservation for sarcoma is possible due to the advent of effective chemotherapeutic agents that improve the survival of patients receiving these procedures to levels similar to treatment with amputation. Further advances to improve survival in primary bone tumors have been slow to materialize. A recent multicenter trial of muramyl tripeptide demonstrated improved survival in patients with osteosarcoma. However, financial obstacles have prevented its widespread use. Other chemotherapeutic agents are currently in trial, but efficacy has not been demonstrated.

Bisphosphonates, most commonly used for the treatment of osteoporosis, have been shown in multiple trials to limit the incidence and extent of bone metastas-
Discussion

Limb-conserving surgeries for treating musculoskeletal sarcomas have achieved satisfactory results for local control. Most of these procedures require extremity reconstruction that is frequently accomplished with metallic, modular endoprostheses. These systems have improved substantially over the past three decades, allowing for accommodation of various reconstructive needs. However, major problems, including both mechanical and nonmechanical issues (eg, tumor relapse, infection), continue to affect treatment outcome. Such difficulties often lead to failure, requiring revision surgery and subsequent ramifications for patient function. Several methods and techniques to prevent primary device failure and improve revision outcomes continue to be investigated. The discussion below focuses specifically on recent advances and controversies of segmental endoprosthetic tumor reconstruction.

Interestingly, our review of the current literature demonstrated only a 2.9% rate of soft-tissue failure (type I). This issue may be minimized or underreported in the literature, likely due to the usual focus on the other three categories of failures: aseptic loosening, mechanical failure, and infection. We believe the problem of soft-tissue reattachment is important and should not be overlooked since it not only influences the risk of failure, but also is closely related to functional outcome.

The early lack of satisfactory techniques for reattaching soft tissues to prostheses led to utilizing different types of reconstructions. The use of massive allografts and allograft prosthesis composites (APCs) allowed reattachment of tendons and ligaments to the graft itself. This was especially useful for some sites of reconstructions, including the hip, proximal tibia, and proximal humerus. However, recent experience has demonstrated that careful reconstructive technique and the use of flaps in association with metallic endoprostheses (such as the medial gastrocnemius flap for the proximal tibia) may offer better function and more durable results than allograft techniques. Moreover, the use of massive allografts is fraught with high rates of complications in the long term, including early degenerative changes seen with osteoarticular allografts and a high incidence of infection for APCs, especially in patients receiving high-dose chemotherapy or radiation.

Soft-tissue reattachment is especially critical in the setting of proximal femur and proximal humeral reconstructions. Increased rates of soft-tissue failure have been reported for endoprosthetic reconstruction of these joints due to their high degree of polyaxial mobility. In our experience, devices with fenestrations in place for reattachment of tendons and ligaments have been crucial in decreasing the occurrence of this type of failure. In our opinion, modular megaprosthetic systems without this feature offer a major challenge to long-term, soft-tissue integration and consequently are at higher risk of type I failure.

In rare cases, proximal humeral resection with extensive excision of periartricular muscles and the axillary nerve is sometimes necessary. With loss of both the static and dynamic stabilizers of the shoulder, instability is a frequent sequela. Endoprosthetic reconstruction may be performed in order to preserve some level of function of the shoulder in these circumstances. In these cases, soft-tissue reattachment is especially important to prevent future dislocations.

Other materials and techniques are currently being investigated to improve soft-tissue integration. In the proximal tibia, the gastrocnemius flap can be reinforced using various materials such as artificial acrylic meshes (eg, Lars, Trevira) or other biologically derived devices. In the proximal humerus, the use of an Aortograft mesh has been suggested and reported by Marulanda et al to decrease the risk of dislocation and subluxation of the reconstructed shoulder. Similar techniques, with appropriate modifications, could be applied during proximal femur and proximal tibia reconstructions. Similarly, coverage of the prostheses with a premolded sleeve consisting of different materials, including HA and trabecular metal, is currently under investigation. We anticipate that these new techniques and materials will be useful in improving soft-tissue integration.

Aseptic loosening (type II failure) is a frequent mechanical complication in megaprosthetic reconstructions of long bones after tumor resection. Aseptic loosening of the stem is the most prominent and variably reported complication in the literature, with an incidence ranging from 3% to 27%. The mode of stem fixation, cemented vs uncemented, is of remarkable importance, and currently there is no clear distinction in...
outcomes between the two. The evidence for press-fit fixation in young patients has been discussed previously in this report. A fair amount of evidence is available that demonstrates a low incidence of aseptic loosening in uncemented femoral stems of megaprostheses. However, careful statistical evaluation, including multivariate analysis, is needed when considering cemented vs uncemented fixation. Different demographic factors and consequent risks in the pediatric population as well as whether the tumor is a primary or a secondary lesion are important independent features. Modifications of the periprosthetic bony cortex and stress-shielding phenomena are more frequent and intense in children and adolescents with non-cemented megaprostheses. In the case of secondary lesions, cemented stems are usually preferred, since radiotherapy to the whole bone is often recommended. Due to these and other considerations, careful deliberation of the treatment population as well as independent patient variables should be considered when reviewing the literature on this topic.

When utilizing uncemented stems, provisional rotational stability needs to be addressed in order to provide initial constraint and allow for osseous ingrowth. Current systems utilize various methods to reduce rotational stresses, including anti-rotational fins, hexagonally shaped stems, fixation plates, and spring tension to achieve high compressive forces. Most of these anti-rotation designs appear to be effective, although an assessment beyond mere comparison of rates of aseptic loosening has yet to be reported. Uncemented stems that do not provide a method for rotational stability should be considered unsatisfactory on this premise. The technique of preparation of the medullary canal also impacts the incidence of aseptic loosening of press-fit stems. Overreaming the canal or reaming line-to-line leads to early postoperative radiolucencies that may potentiate aseptic loosening in the long-term. Although underreaming, as recommended in some techniques, implies a greater risk of periprosthetic fracture, this outcome is less adverse to the long-term fixation of the stem.

In reconstructions of the knee, the type of prosthetic joint (fixed or rotating hinge) has certain implications. Rotating hinges can diminish torsional stresses applied to the stem and consequently reduce the risk of loosening. This factor is crucial when analyzing literature reports of major series of knee megaprostheses. In fact, the use of a fixed-hinge knee joint increases the risk of aseptic loosening to a rate equivalent to that of polyaxial joints.

Structural failure (type III) has progressively decreased in most authors’ experiences. This decrease is due to the technical development stem designs as well as utilization of modern materials. Avoidance of stems with diameters less than 13 mm is well documented in the literature and has been crucial to the decrease in device fracture rates. The introduction of the rotating hinge for knee reconstructions has dramatically reduced the risk of stem breakage in the absence of a major trauma since these hinges absorb the torsional moment that would otherwise be applied to the stem. Structural failures of components other than stems are of less clinical relevance and are rarely observed or reported in the absence of trauma.

Infection (type IV) is a crucial problem for reconstruction durability since it may compromise the result of the treatment in the long-term. Infection is less associated with the type of endoprosthetic reconstruction and more interrelated to perisurgical antibiotic prophylaxis, the surgeon’s skill and experience, the time and surgical exposure that the procedure requires, and the adequacy of prosthetic soft-tissue coverage. Longer surgical times due to complex reconstructions as well as the surgeon’s familiarity with a prosthetic system may indirectly associate reconstruction types with higher infection rates. In recent years, the use of silver-coated endoprostheses in the primary setting or for revision of infected implants has been studied, with reports of decreased infection rates. Papers evaluating the possible collateral toxicologic effects of such coatings have not demonstrated adverse clinical outcomes to date. In order to reduce the incidence of periprosthetic infections, all potentiating factors should be addressed. Utilizing adequate antibiotic prophylaxis, increasing the surgeons’ experience and training, and providing adequate muscle coverage of the prosthesis are all recommended, and silver coating can be considered.

Tumor progression (type V) is intimately related to the biology of the resected tumors, the adequacy of surgical margins, and the efficacy of chemotherapy and/or radiotherapy rather than to the type of endoprosthetic reconstruction. The relationship of tumor progression and endoprostheses survival is difficult to analyze in most series due to the heterogeneous nature and variable biologic aggressiveness of the different tumors. Nonetheless, tumor recurrence affects function (in the case of further soft-tissue and muscle excision) and may potentiate failure of endoprosthetic reconstructions. More appropriate medical treatment of the tumor, radiotherapy, and surgical strategy are key in reducing the incidence of type V failures.

Conclusions

Endoprosthetic reconstruction and its durability in the treatment of bone and soft-tissue tumors of the extremi-
ticiess a challenging and promising field. Advances have been accomplished with remarkable consequent improvements of function and reduction of complications. However, much work remains before completely solving the problems affecting long-term survivorship of tumor megaprostheses.

References


