Telescope Allograft Method to Reconstitute the Diaphysis in Limb Salvage Surgery

John H. Healey MD, Ayesha Abdeen MD,
Carol D. Morris MD, Edward A. Athanasian MD,
Patrick J. Boland MD

Received: 22 May 2008 / Accepted: 15 September 2008 / Published online: 3 October 2008
© The Association of Bone and Joint Surgeons 2008

Abstract We propose a surgical technique for structural allograft reconstitution of the diaphysis of long bones, maximizing surface contact between host and allograft bone. This method, analogous to a telescope, overlaps the graft and host bone, theoretically increasing bone surface contact substantially. We report the outcome of 22 telescoped allograft junction sites in 19 patients who lacked sufficient host bone to accommodate a regular-length stemmed implant. This joint-sparing reconstruction preserved 15 of 16 adjacent joints at risk for replacement. Five patients needed additional surgery, but none for nonunion. The diaphyseal length could be reconstructed enough so that a short prosthesis (less than the critical 40% of total bone length) could be used. This biologic method to reconstruct major segments of the diaphysis is best suited for patients with quantitatively or qualitatively deficient residual bone stock after tumor resection or prosthetic revision. We believe it is an excellent technique for revision knee megaprotheses when there is a short remnant of proximal femur.

Level of Evidence: Level IV, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

Introduction

We propose the technique of modular diaphyseal allograft reconstruction to maximize the contact between host and structural allograft bone. The objectives of this technique are to preserve the adjacent joint, increase bone apposition surface area compared with conventional end-to-end techniques, reduce the frequency of early operations for nonunion, and reestablish bone length, minimizing the size of endoprostheses needed for reconstruction. This geometry theoretically increases bone surface contact threefold to tenfold. If the end-to-end apposition is suboptimal, merely achieving two-point contact, as is often the case, the increase in surface area is even more dramatic. This technique is distinct from the reported use of structural allograft to treat contained or uncontained metaepiphyseal defects around the knee or hip [2].

This method has several theoretical advantages and is designed to work in conjunction with a cemented long-stemmed endoprosthesis. Rather than end-to-end or step-cut apposition, a long allograft-host interface is created. This is analogous to the overlapping tube configuration of a telescope; thus, we have named this overlapping method the telescope technique of allograft reconstruction. This also has been referred to as intussusception of the host into the allograft. The allograft is placed either over the cortex of the host bone or, alternatively, impaled into the medullary canal of the host bone. This improves the intrinsic stability of the construct and greatly increases the apposed bone surface area commensurate with the allograft bone's inner diameter (ID) and the host bone's outer diameter

One or more of the authors (JHH) have received funding from the Sullivan Fellowship in Musculoskeletal Oncology and the Biomet Fellowship in Orthopedic Oncology Research. Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

J. H. Healey (✉), A. Abdeen, C. D. Morris,
E. A. Athanasian, P. J. Boland
Orthopaedic Surgery Service, Department of Surgery, Memorial
Sloan-Kettering Cancer Center, affiliated with Weill Medical
College of Cornell University, 1275 York Avenue, New York,
NY 10065, USA
e-mail: healeyj@mskcc.org

(OD). It is especially suitable in situations in which there is a deficiency of structurally competent bone after resection of a bone tumor or removal of a failed prosthesis. When the remaining bone fragment is very short, this method can obviate the need for total replacement of the bone and adjacent joint (eg, total femur arthroplasty).

We hypothesized the telescope method could (1) spare vulnerable adjacent joints, (2) substantially increase the bone apposition between allograft and host, (3) eliminate reoperations for delayed union or nonunion, and (4) reconstitute the diaphysis such that the resultant prosthetic segmental replacement would be less than 40% of the overall bone length.

Materials and Methods

We retrospectively reviewed the records and radiographs of all 19 patients (22 surgeries) who underwent telescoped allografts between September 1999 and June 2006. All patients had been evaluated prospectively at the weekly surgical indications conference and judged unsuitable for prosthetic reconstruction alone. In all patients but one with an intercalary tibial graft of the femur, the alternatives were total femur arthroplasty or bone augmentation with allograft in conjunction with replacement of the previously resected joint (knee, hip, or shoulder). This included 16 patients with allograft-prosthetic composites (APCs) with one junction site each and three patients with intercalary grafts that had two junction sites each. The mean age of the patients at the time of allograft reconstruction was 28 years (range, 4–56 years). Five patients (seven junction sites) were skeletally immature at the time of surgery. Followup was a minimum of 2 years or until the allograft failed or the patient died (mean, 4.0 years; range, 0.5–7.8 years). We obtained prior Institutional Review Board approval.

The primary bone tumor was osteogenic sarcoma in nine patients, chondrosarcoma in two, Ewing's sarcoma in two, malignant fibrous histiocytoma in one, and giant cell tumor of bone in one. One patient had rheumatoid arthritis, periprosthetic fracture, and an ipsilateral double-telescoped allograft over a proximal femoral hip stem and over a distal femoral knee replacement stem. Nineteen junction sites were in the femur (11 proximal, five distal, three middiaphysis) and three were in the humerus. Fifteen osteosynthesis sites used the technique whereby the allograft medullary canal is prepared and then placed over the host bone. In seven sites, the allograft was impaled into the medullary canal of the existing host bone. One patient had a hybrid with an intercalary allograft whereby the allograft was placed outside the host canal proximally and inside the host canal distally. Femoral allograft was used in 20 of the

junction sites. In one pediatric patient, a tibial allograft was placed as an intercalary graft in a telescopic fashion over the host femur. In this case, a vascularized fibular autograft was placed within the construct spanning the allograft and the host bone. At 16 sites, we used an APC; in six, an intercalary allograft was performed. In seven sites, the interference fit of the allograft-host junction was augmented with plate fixation (four sites) or an interlocking screw through the implant stem and cortical bone (three sites) to supplement rotational control. One patient had circumferential cables around the allograft to prevent it from splitting. The use of the supplemental hardware was at the discretion of the operating surgeon.

The telescope technique of allograft reconstruction was indicated for each patient owing to severe bone loss after primary resection of tumor or in the revision of a prosthesis. In these cases, the remaining bone was suboptimal quantitatively (eg, a very short diaphyseal segment), qualitatively (eg, attributable to osteolysis, component loosening, or perforations existing as a consequence of cement or implant removal), or both.

In this technique, the diaphysis of one bone is inserted into the medullary canal of the other. The resultant interference fit provides structural stability and possibly enhances biologic potential for osteosynthesis by increasing the surface area of bone contact. Reconstruction of the diaphyseal tube allows the femur to be cut to the length that matches available prosthetic reconstructions and minimizes the amount of femoral and humeral bone replaced. The best appositional area that can be achieved by the end-to-end osteosynthesis technique is mathematically expressed as apposing ellipsoidal rings: smallest of $\pi \times (OD_1 \times OD_2 - ID_1 \times ID_2)$, compared with the planned telescoped appositional surface area of $(\pm) 5 \times \text{circumference of an ellipse}$: $2\pi \times \text{square root } [(OD_1^2 + OD_2^2)/2]$ (Fig. 1).

Fig. 1 This figure depicts the difference in surface area between the telescope and the traditional end-to-end techniques. For simplicity of the illustration, the ellipsoidal cross section is assumed to have equal lengths of the x and y axis (ie, a circle.).

Preoperative planning is important. Allografts must be selected carefully with attention to the following steps so that the proposed graft will fit and create a stable construct. In general, when selecting a graft, larger diameter is better. Adequate stem lengths must be available to span the graft and the junction site. Proper sizing prevents the occasional problems reported here.

The steps listed subsequently describe the procedure for the most common indication, distal femoral arthroplasty. An upside-down, large distal femoral allograft is ideal for this indication (Fig. 2). (1) Measure the periosteal OD of the remaining host bone at the level of the proposed resection. (2) Find an allograft that has an endosteal ID equal to that of the host OD for a sufficient overlap distance, ideally 5 cm. (3) Select the proposed site on the allograft and make a provisional cut, removing the epiphysis of the allograft bone. This is typically at the superior cartilaginous edge of the distal femoral condyles. (4) Align the grafts to avoid creating varus-valgus or flexion-extension malalignment. (5) Mark out the OD circumference in the exposed cancellous medullary bone of the inverted allograft. (6) Carefully hollow out the cancellous bone to the exact diameter of the host OD over the planned 5-cm depth. Use of straight reamers and a high-speed burr helps to do this accurately. (7) Only if necessary, thin and/or taper the host OD so that it will match the allograft ID. Plane off a prominent linea aspera if necessary. (8) Impact the allograft over the host for a distance of two cortical diameters, usually 5 cm or until the graft stabilizes or bottoms out. The overlap you create establishes apposition of the allograft endosteum with the host periosteum, the so-called telescope. Consider using a temporary circumferential wire or bone-holding clamps around the allograft during the impaction process to prevent the thin allograft

cortical shell from cracking. (9) Cut the allograft to the length that restores the desired amount of distal femur. Because the allograft diaphyseal tube and the junction segment should be spanned by a long intramedullary stem, the modular length added by the allograft is limited by the available stem lengths. For example, if there is 5 cm of stem cemented into the host and 5 cm into the overlapping telescoped graft-host bone, a 12-cm segment of bone could be added if a 220-cm stem were to be used.

The variant technique uses the allograft as a dowel placed into the medullary canal of the remaining host bone. We typically used this approach when there was an extremely short metaphyseal segment remaining on the host (Figs. 3, 4). An important technical problem that must be avoided in this situation is a mismatch in the anteroposterior (AP) diameter of the bones. For example, a prominent linea aspera on the inverted allograft can make a large diaphyseal allograft segment too thick to fit into the narrow AP diameter in a supracondylar area of the host distal femur. This mismatch can be resolved easily by shaving off the linea aspera and selectively enlarging the reciprocal “kissing” area of the distal femur ID with a high-speed burr. Sometimes this thins the host excessively, so cerclage wiring is prudent to prevent fracture. Cancellous autograft should be impacted in any residual space at the osteosynthesis surface to promote additional biologic healing and prevent intrusion of pressurized cement into the interface.

A long-stemmed endoprosthesis then is cemented into this construct so that the stem spans the allograft, the overlapped bone, and as much of the allograft extension as is reasonable. A modular system of stems and segmental resection lengths is desirable. Antibiotic-impregnated cement was used in this series, and no infections occurred in revisions for nonseptic causes.

Fig. 2 The telescope technique is shown. The allograft is inverted and condyles cut off. The medullary canal is contoured to accept the graft. The graft is impacted onto the host, creating 5 cm of overlap. A long-stemmed prosthesis is cemented into position.

Fig. 3A–B (A) An AP radiograph shows a distal humeral telescoped allograft replacing the distal 10 cm of the humerus, secured with the long stem of an elbow replacement. (B) A lateral radiograph shows the distal humeral telescoped APC.

The technique can be tailored to other clinical situations. For example, additional rotational control can be achieved by adding a neutralization plate or an interlocking screw.

We determined by chart review if the vulnerable adjacent joints were spared. The operative reports and AP radiographs were used to assess the amount of overlap at the interface. The bone ODs and IDs at the junctional sites were measured on digitized radiographs. The appositional surface area was calculated by standard geometry assuming an ellipsoidal shape to the diaphyseal bone. The outer circumference was multiplied by the length of overlap in the telescoped cases, giving the resultant appositional surface area.

We reviewed charts and serial radiographs to determine when there was no pain or tenderness and bridging callus was present at the junction site. This defined allograft healing. The percentage of bone replaced in the 16 patients who had APCs was measured on AP radiographs. Allograft success was graded prospectively as part of routine clinic visits by the orthopaedic oncology fellow using the ISOLS radiographic evaluation system [13] and confirmed for this study by one of the investigators (AA).

Results

The at-risk joint was preserved in 15 of 16 patients with APCs. All four adjacent joints were preserved in

Fig. 4A–D (A) Anteroposterior and (B) lateral radiographs show an uncemented expandable prosthesis with a side plate that underwent painful septic loosening. After the infection was treated by prosthetic removal and antibiotics systemically and locally, a telescoped allograft was used to reconstitute the proximal femur using the inverted technique. This impacted the shaft of a femoral allograft

inside the medullary canal of the remaining proximal femur and secured it with a long-stemmed prosthesis. In postoperative (C) AP and (D) lateral radiographs, the allograft outline is highlighted by the dotted line. Cement was pressurized into the canal. Some extruded around the allograft and entered a short distance into the allograft-host interface (arrows).

Table 1. Comparison of the bone contact areas for alternative osteosynthesis methods

Osteosynthesis method	Inner diameter (cm)	Outer diameter (cm)	Contact area (π cm ²)	Multiple of conventional surface area
End-to-end	1.2	2.4	1.08	X6
Telescope	1.2	2.4	6.0	
End-to-end	1.2	2.8	1.6	X3.7
Telescope	1.2	2.8	6.0	
End-to-end	1.6	2.4	0.8	X10
Telescope	1.6	2.4	8.0	

intercalary grafts where there were intact adjacent joints. The patient with rheumatoid arthritis and fracture between hip and knee arthroplasties was able to retain her two intact prostheses, and their muscle and soft tissue attachments, which allowed full restoration of her function. Twenty-one of 22 adjacent joints were retained. The need for total femur or humerus arthroplasty was avoided in 18 of 19 patients, including all three of the patients with intercalary grafts. The failure was in a patient who had a recurrent infection 1.1 years postoperatively. He required two-stage resection of his entire prosthesis and allograft before undergoing a definitive total femur arthroplasty. Because his graft had united, this was considered a success from the standpoint of prosthetic structural reconstruction but a failure because the infection recurred. From a joint preservation vantage alone, the operation was successful.

In all patients, the bone apposition surface area was dramatically larger than what could have been obtained from conventional end-to-end techniques (Table 1). This was true even in the one patient who had a mechanical failure resulting from insufficient bone overlap (2 cm)

compounded by use of a stem that was of insufficient length to stabilize the junction site. The telescope method increased the calculated healing surface area by a mean of 8.5-fold (range, 2.7- to 15.3-fold).

Five reoperations were needed among 19 patients, none of which were for nonunion. There was one recurrent infection (described previously). The second patient sustained an allograft fracture and failure as noted previously. Only 2 cm of overlap was achieved because of a poorly matched allograft. The available stems did not span the junction site, so the fixation was augmented with a neutralization plate. The plate was difficult to contour because of acute stepoff at the junction of the wide allograft metaphyseal bone and the narrow host diaphyseal bone. After 4 months, there was radiographic evidence of incorporation of the allograft; however, the fixation failed and the graft fractured. She underwent conversion to a longer megaprosthesis. This case was considered a successful bony union and a prosthetic APC failure. The third patient had a fully incorporated allograft. Nevertheless, she required revision of the femoral component 1 year later owing to failure of the bearing surface and aseptic loosening at the bone-cement interface. The fourth reoperation was for fracture and infection of an intercalary graft. The final reoperation was for a fractured prosthetic stem 18 months after implantation, although the allograft had united.

The method reconstituted bone length effectively. The average amount of bone deficiency restored measured as a percentage of the overall preoperative length of the bone was 47% (range, 22%–76%) for a mean of 212 cm of bone reconstruction. In 11 of 17 femoral reconstructions, the bone deficiency was greater than 40% of the bone length. In all 11 cases, it could be reduced to less than 40% of the

Fig. 5A–D (A) A preoperative radiograph shows circumferential radiolucency of a long-stemmed megaprosthesis. (B) An intraoperative film shows the allograft overlapping the host bone over a 5-cm segment. (C) A radiograph taken 1 month postoperatively shows the profound periosteal new bone formation and healing. (D) A film taken 5 years postoperatively shows full healing and remodeling of the allograft and the host.

overall length of the femur, the threshold associated with distal femoral prosthetic failure. This method minimized the length of endoprosthetic reconstruction.

Secondary outcome measures were good or excellent by the ISOLS scale, showing no major graft resorption or failure. Tapering and remodeling of the allograft-host junction were universal (Fig. 5). The median time to full weightbearing was 6.1 months (range, 1.2–12.6 months). At final followup, of the 16 patients who underwent lower extremity reconstructions, seven were fully weightbearing with the use of two crutches, three with a cane, and six without any assistive device.

Discussion

We propose a surgical technique for structural allograft reconstitution of the diaphysis of long bones, maximizing the surface contact between host and allograft bone. This method, analogous to a telescope, overlaps the graft and host bone, theoretically increasing bone surface contact substantially. We report the outcome of 22 telescoped allograft junction sites in 19 patients who lacked sufficient host bone to accommodate a regular-length stemmed implant. We hypothesized the telescope method could (1) spare vulnerable adjacent joints, (2) substantially increase the bone apposition between allograft and host, (3) eliminate reoperations for delayed union or nonunion, and (4) reconstitute the diaphysis such that the resultant prosthetic segmental replacement would be less than 40% of the overall bone length.

The study has certain limitations. Surgical indications are difficult to characterize retrospectively. However, each case was presented as part of our weekly service surgical indications conference, and a consensus was reached that the telescope allograft method was the best strategy for each of the cases included here. Furthermore, there were no cases where the approach was abandoned, so this constitutes an intention-to-treat analysis. Thus, the analysis is powerful. There is some variation in the technique and surgical site, so all cases were not directly comparable. Although true, it merely serves to show how versatile this technique is for salvage of femoral and humeral reconstructions. The appositional surface area calculations are theoretical and not proven *in vivo*. Since it is impossible to make the measurements empirically, mathematical modeling will have to suffice. Furthermore, the theory and clinical success emphatically support use of the method. Finally, the analysis was not intended to assess the durability of these reconstructions. Long-term followup obviously is needed.

The surgical objectives were met. First, the technique saved 15 of 16 adjacent joints at risk in the patients with

APCs, three of four joints at risk in the patients with intercalary grafts, and the two intact prosthetic joints in the patient with an intercalary graft used to treat periprosthetic fracture. This method effectively conserved the adjacent unaffected joints. Maintenance of the adjacent joint considerably improves functional outcome and avoids sacrificing innocent normal tissue. In the current study, a total femoral arthroplasty would have been the alternative choice in 11 of the 16 patients and a total humerus arthroplasty in three. Use of the telescope allograft technique obviated the need for a total femur/humerus arthroplasty and preserved the adjacent, unviolated joints in 15 of those patients. No published data are available to allow a comparison of this outcome measure.

Second, this technique increases bone apposition, an important factor contributing to bone union. The theoretical calculation showed, in typical femora, surface area increased threefold to tenfold compared with the end-to-end technique used in other studies of alloprosthetic reconstructions [1, 3]. Because there is no direct observation of the interface between the two grafts and no imaging technique that could evaluate it, we cannot know how much of that surface area actually participated in the allograft-host healing. The interface appeared to unite successfully by clinical and radiographic criteria, supporting the assumption that much of the surface area was functional.

Third, the telescope method optimizes healing potential, improves the allograft-host junction from mechanical and biologic perspectives, and has a low nonunion rate. Delayed union and nonunion are persistent problems with APC reconstructions (15%–30%), often necessitating supplemental bone graft procedures or revision of the entire alloprosthetic construct [2, 4, 5, 7, 8]. Because nonunion or delayed union is one of the main disadvantages of large structural allografts, reportedly 17% and 56%, respectively [1, 10], avoiding this common problem is desirable. All 19 of our patients who underwent revision surgery with this method had their allografts unite without the need for additional bone grafting procedures. The rate of union seems to have been rapid, but there was no satisfactory method to have measured this in our study. Our patients achieved full weightbearing at a mean of 6.1 months after surgery. This was faster than the time to full weightbearing in our patients with traditional end-to-end reconstructions with internal fixation (data not shown). Because it is difficult to judge full union over the full 5 cm of overlap in the grafts, we are unable to directly compare the time to union with that of other techniques. Complications in this series consisted of infection, fracture, stem breakage, and articular failure, but not nonunion. The case of short 2-cm overlap in which the bone and plate failed was instructive. We now strive to achieve at least 5 cm of overlap between

the host and allograft bone to optimize stability and promote healing of the construct. Some situations, particularly in the humerus, may only allow shorter overlap. Supplemental plate fixation would be beneficial for such cases.

Finally, this method restored functional bone length during revision surgery in all 11 patients with a short bone remnant. This enabled us to reduce the length of prosthetic replacement to less than 40% of the overall length of the femur. The relative length of prosthetic replacement has been associated with distal femoral prosthetic failure, particularly when the femoral resection exceeds 40% of the overall length of the femur. Reduction of the femoral deficiency to less than 40% of the overall bone length may mitigate this effect [9, 11]. There is a tradeoff, however. Expenditures increase if an allograft and a prosthesis are used. Furthermore, longer allografts require corresponding increases in the length of the intramedullary stem to span the allograft and junction site. Longer stems are not always available and may require custom manufacture depending on the system being used. This limitation directly contributed to one of the failures we encountered, and accurate planning is needed to ensure the availability of a suitable implant. Alternatives such as using a short or cut stem to secure a long segmental replacement have particularly poor durability. When properly planned, it is possible to restore the diaphyseal tube and minimize the length of the prosthetic replacement.

There is no standard effective approach to solve the increasingly difficult problem of revising failed megaprotheses. The options include replacement alone or APC reconstruction. Both salvage strategies have inherent potential complications. Revision endoprotheses have a high failure rate, reportedly 19% to 56% at 5 years [6, 9, 12, 14]. A massive structural allograft may beneficially reestablish bone stock for subsequent revision megaprosthesis replacement. The benefits of APC reconstruction include restoration of bone stock, limb length equalization, and the potential for anatomic soft tissue reconstruction of relevant capsular and ligamentous attachments.

The telescope method achieved the surgical goals. It is particularly useful to lengthen a short bony remnant after a primary tumor resection or revision of a failed endoprosthesis with poor bone stock. In the absence of a randomized trial, it is impossible to prove this method is superior to traditional end-to-end allograft or APC reconstruction; however, the theoretical advantages and good early clinical performance of this method make it worth considering

when confronted with these difficult clinical situations. The telescope allograft technique has particular value as an alternative to total femur arthroplasty.

Acknowledgments This material was presented in part at the Musculoskeletal Tumor Society, St Louis, MO, 2007, and the International Society of Limb Salvage, Hamburg, Germany, September 2007.

References

1. Donati D, Colangeli M, Colangeli S, Di Bella C, Mercuri M. Allograft-prosthetic composite in the proximal tibia after bone tumor resection. *Clin Orthop Relat Res*. 2008;466:459–465.
2. Ghazavi MT, Stockley I, Yee G, Davis A, Gross AE. Reconstruction of massive bone defects with allograft in revision total knee arthroplasty. *J Bone Joint Surg Am*. 1997;79:17–25.
3. Gitelis S, Heligman D, Quill G, Piasecki P. The use of large allografts for tumor reconstruction and salvage of the failed total hip arthroplasty. *Clin Orthop Relat Res*. 1988;231:62–70.
4. Gitelis S, Piasecki P. Allograft prosthetic composite arthroplasty for osteosarcoma and other aggressive bone tumors. *Clin Orthop Relat Res*. 1991;270:197–201.
5. Gross AE. Revision total knee arthroplasty of bone grafts versus implant supplementation. *Orthopedics*. 1997;20:843–844.
6. Gross AE, Allen G, Lavoie G. Revision arthroplasty using allograft bone. *Instr Course Lect*. 1993;42:363–380.
7. Harris AI, Poddar S, Gitelis S, Sheinkop MB, Rosenberg AG. Arthroplasty with a composite of an allograft and a prosthesis for knees with severe deficiency of bone. *J Bone Joint Surg Am*. 1995;77:373–386.
8. Jeon DG, Kim MS, Cho WH, Song WS, Lee SY. Pasteurized autograft-prosthesis composite for reconstruction of proximal tibia in 13 sarcoma patients. *J Surg Oncol*. 2007;96:590–597.
9. Kawai A, Muschler GF, Lane JM, Otis JC, Healey JH. Prosthetic knee replacement after resection of a malignant tumor of the distal part of the femur: medium to long-term results. *J Bone Joint Surg Am*. 1998;80:636–647.
10. Mankin HJ, Gebhardt MC, Jennings LC, Springfield DS, Tomford WW. Long-term results of allograft replacement in the management of bone tumors. *Clin Orthop Relat Res*. 1996;324:86–97.
11. Unwin PS, Cannon SR, Grimer RJ, Kemp HB, Sneath RS, Walker PS. Aseptic loosening in cemented custom-made prosthetic replacements for bone tumours of the lower limb. *J Bone Joint Surg Br*. 1996;78:5–13.
12. Unwin PS, Cobb JP, Walker PS. Distal femoral arthroplasty using custom-made prostheses: the first 218 cases. *J Arthroplasty*. 1993;8:259–268.
13. Validation Committee ISO/LS. Protocols and Guidelines. Available at: <http://www.isols.org/files/protocols.cfm>. Accessed September 1, 2008.
14. Wirganowicz PZ, Eckardt JJ, Dorey FJ, Eilber FR, Kabo JM. Etiology and results of tumor endoprosthesis revision surgery in 64 patients. *Clin Orthop Relat Res*. 1999;358:64–74.