SURGICAL TECHNIQUE

Surgical Technique

Extraarticular Knee Resection with Prosthesis–Proximal Tibia-extensor Apparatus Allograft for Tumors Invading the Knee

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Received: 8 September 2010/Accepted: 18 March 2011/Published online: 12 April 2011 © The Association of Bone and Joint Surgeons® 2011

Abstract

Background Intraarticular extension of a tumor requires a conventional extraarticular resection with en bloc removal of the entire knee, including extensor apparatus. Knee arthrodesis usually has been performed as a reconstruction. To avoid the functional loss derived from the resection of the extensor apparatus, a modified technique, saving the continuity of the extensor apparatus, has been proposed, but at the expense of achieving wide margins. In tumors involving the joint cavity, the entire joint complex including the distal femur, proximal tibia, the full extensor apparatus, and the whole inviolated joint capsule must be excised. We propose a novel reconstructive technique to restore knee function after a true extrarticular resection.

Description of Technique The approach involves a true en bloc extraarticular resection of the whole knee, including the entire extensor apparatus. We performed the reconstruction with a femoral megaprosthesis combined with a tibial allograft-prosthetic composite with its whole extensor apparatus (quadriceps tendon, patella, patellar tendon, and proximal tibia below the anterior tuberosity). *Patients and Methods* We retrospectively reviewed 14 patients (seven with bone and seven with soft tissue tumors) who underwent this procedure from 1996 to 2009. Clinical and radiographic evaluations were performed using the MSTS-ISOLS functional evaluation system. The minimum followup was 1 year (average, 4.5 years; range, 1–12 years).

Results We achieved wide margins in 13 patients (two contaminated), and marginal in one. There were three local recurrences, all in the patients with marginal or contaminated resections. Active knee extension was obtained in all patients, with an extensor lag of 0° to 15° in primary procedures. MSTS-ISOLS scores ranged from 67% to 90%. No patients had neurovascular complications; two patients had deep infections.

Conclusions Combining a true knee extraarticular resection with an allograft-prosthetic composite including the whole extensor apparatus generally allows wide resection margins while providing a mobile knee with good extension in patients traditionally needing a knee arthrodesis.

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

Introduction

Wide excision is the standard treatment for primary bone or soft tissue tumors of the limbs. Advances in surgical techniques, prosthetic design, and bone allograft banking has made it possible to perform reconstruction procedures in most instances after wide excision of bone and soft tissues. This allows the surgeon to achieve adequate margins while salvaging the limb and its function. Nonetheless, extension of a tumor into a joint still poses a challenge

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Each author certifies that his or her institution 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.

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because possible contamination of the synovial fluid by tumor cells makes it necessary to perform a whole joint resection with the consequent difficulties of restoring a functional limb.

Reconstruction after extraarticular knee resection can be accomplished with an arthrodesis [4, 7, 17, 18] or with jointfunction-preserving procedures [2,12-15, 20]. Two techniques have been proposed for the latter option. The first technique consists of a limited extraarticular resection with preservation of the extensor mechanism. This approach requires vertical splitting of the patella in the frontal plane and detaching the suprapatellar synovial pouch and infrapatellar fat pad from the quadriceps and patellar tendon [12–15, 20]. Achieving wide surgical margins may be difficult or in some cases even impossible with this approach. The second technique is a classic extraarticular resection including en bloc removal of the extensor apparatus and its reconstruction with a pedicled medial gastrocnemius muscle flap [2, 12]. The literature suggests active extension is quite variable with this approach and extensor lags reportedly range from 0° to 70° [2, 12, 15, 20].

In 1996 we therefore introduced a more extensive surgical approach with a true en bloc extraarticular resection of the whole knee, including the entire extensor apparatus. We performed the reconstruction with a femoral megaprosthesis combined with a tibial allograft-prosthetic composite with its whole extensor apparatus. Our intent was to allow wide margins while retaining function and affording a low complication rate.

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We usually used a straight midline incision. A slightly anteromedial or anterolateral incision was used if needed to excise previous surgical scars or biopsy sites. We created two subcutaneous flaps, medial and lateral, exposing the entire anterior surface of the knee. The vastus medialis and vastus lateralis muscles were sectioned at their musculotendinous junctions, retaining a small portion of the tendinous structure to facilitate the subsequent repair. We then sectioned the quadriceps tendon proximally, at least 2 cm above the top of the suprapatellar synovial pouch to avoid inadvertent joint violation. The suprapatellar pouch, covered by the quadriceps tendon, the anterior capsule, the patella, and the patellar retinaculum were left intact to be removed en bloc with the tumor.

We then detached the muscles of the anterior compartment of the leg from the proximal tibia. The peroneal nerve was isolated and preserved. We next disarticulated the proximal tibiofibular joint or excised the proximal fibula together with the en bloc resected tumor, depending on the location of the tumor. The hamstring tendons were detached from the tibia. The medial and lateral collateral ligament and all the expansions of the extensor apparatus were left intact, together with the resection specimen. The medial and lateral gastrocnemius were isolated, sectioned 1 to 2 cm from the femur and detached from the posterior capsule. The semimembranosus was sectioned distally, leaving 1 cm attached to the tibia. On the medial side the popliteal vessels were identified and isolated, ligating and sectioning the branches entering the joint. Posteriorly, we left the capsule intact and we excised the entire popliteus muscle en bloc with the knee.

Femoral and tibial osteotomies were performed at least 2 cm from the tumor, after confirming the intended level of the osteotomy with an intraoperative radiograph. When not directly involved by the tumor, we performed an osteotomy of the tibia just below the tibial tuberosity and the femur was osteotomized above the suprapatellar pouch at the metadiaphysis transition level. A specimen from the medullary canal was collected from the proximal part of the femoral osteotomy and the distal part of the tibial osteotomy and sent for frozen-section analysis.

We used an allograft-prosthetic composite for reconstruction (Fig. 1). Since 2001 we have been using the Megasystem C (Waldemar Link, Hamburg, Germany), a modular system that allows coupling of a megaprosthesis with an allograft-prosthetic composite. However, the same procedure can be accomplished with other prosthetic revision systems: in this case an allograft-prosthesis composite is required on the femoral and tibial sides.

We prepared a size-matched proximal tibia allograft with its entire extensor apparatus to receive a tibial prosthetic component. We then reamed the graft and host tibial canal. A long-stem prosthesis was cemented into the allograft and at the same time implanted (with or without cement) in the host tibial diaphysis. The distal femur was replaced by a modular prosthesis because at this level there is no need for tendon reattachment.

The quadriceps tendon of the allograft was sutured to the remaining quadriceps tendon and to the muscular flaps composed of the vastus medialis and vastus lateralis using nonresorbable sutures (Fig. 1E). The quadriceps tendon of the allograft was reattached in slight tension with the knee in full extension, restoring the original quadriceps length and patellar position.

In three patients, a free or rotational flap was necessary for soft tissue coverage: a rotational medial gastrocnemius flap was performed in one patient (Patient10) and a free fasciocutaneous flap (anterolateral thigh flap from the contralateral limb) in two (Patients 11 and 12) (Table 1).

Postoperatively the knee was maintained in a plaster splint for 5 weeks, and the patient walked with two crutches without weightbearing. After removal of the



Fig. 1A–H (A) The T-2 MR image of a 64-year-old man shows a synovial sarcoma of the left knee involving the intraarticular and extraarticular spaces. (B) A photograph shows the clinical status before surgery. (C) An intraoperative view after en bloc extraarticular knee resection is shown. (D) The resected specimen is composed of the knee complex en bloc, including the distal femur covered by the vastus intermedius with the unviolated suprapatellar pouch, the intact capsule, the entire extensor apparatus (quadriceps tendon, patella, patellar tendon, patellar retinaculum), the popliteus muscle and the insertions of the gastrocnemius muscles, the insertion of hamstrings

splint, patients began passive and active mobilization, assisted by a physiotherapist. Partial weightbearing with two crutches was allowed with the use of a knee brace in extension for 4 additional weeks. Complete weightbearing usually was allowed after 3 months from surgery, depending on the patient's compliance and symptoms.

Antibiotic prophylaxis was provided using vancomycin (or teicoplanin) combined with tobramycin preoperatively and for 5 days after surgery by intravenous infusion, followed by amoxicillin plus clavulanic acid for 25 more days.

Patients and Methods

From 1996 to 2009 we performed an extraarticular knee resection and reconstruction with an allograft-prosthetic composite including the extensor apparatus in 14 patients. The patients' ages at surgery ranged from 17 to 68 years (average, 34.9 years). The indications for the procedure were: (1) primary bone tumors (distal femur, patella, proximal tibia) with massive involvement of the knee;

and semimembranosus muscles, the collateral ligaments, the medial part of the fibular head, and the proximal tibia cut below the tibial tuberosity. (E) Knee reconstruction is accomplished by an allograft-prosthetic composite. The quadriceps tendon of the allograft is sutured to the host quadriceps, as shown in the intraoperative photograph. (F) As a result of the excision of a wide skin area together with the tumor, a free anterolateral thigh flap was used for coverage. (G) The allograft-prosthetic composite reconstruction is seen on the lateral postoperative radiograph. (H) Function at 27 months from surgery is shown. Complete active extension is restored.

(2) intraarticular soft tissue malignant tumors; (3) extraarticular bone or soft tissue tumors of the knee area previously treated with inadequate and joint-contaminating surgery; and (4) the presence of a pathologic fracture widely contaminating the joint space. Contraindications for this surgery were: (1) a tumor involving the popliteal neurovascular structures, (2) wide involvement of superficial soft tissues not eligible for repair with local or free flaps, and (3) the presence of a septic complication. Seven of the 14 patients had primary bone tumors (five malignant, two aggressive benign tumors) and seven had primary soft tissue sarcomas. Details regarding histotype, tumor location, stage, previous surgical procedures, and adjuvant therapies performed are provided (Table 1). Nine of the 14 patients (64%) had previous inadequate surgery, including arthroscopic procedures. Resected specimens were examined according to the recommendations of the Association of Directors of Anatomic and Surgical Pathology [1].

The patients were followed with serial clinical and radiographic examinations of the limb, combined with radiographic or CT examination of the chest. For the first 3 months, clinical and radiographic followups were

Table 1.	Data and ch	naracteristics of the	14 patients					
Patient number	Age (years), gender	Tumor location	Diagnosis	Intraarticular/ extraarticular	Previous surgery	Chemotherapy/ radiotherapy	Margins, percent necrosis	Length of resected tibia (cm)
-	19, M	Proximal tibia	Osteosarcoma	I + E	Arthroscopic biopsy	CHT preoperatively/ postoperatively	Wide 99	10
7	17, M	Patella	Ewing's sarcoma	I + E	Arthroscopy, inadequate excisions	CHT preoperatively/ postoperatively, RT after recurrence	Wide but not all scars removed, focal necrosis	Ś
ю	23, F	Distal femur	Giant cell tumor	$\mathbf{I} + \mathbf{E}$	Curettage + cement	CHT postoperatively (lung metastasis)	Wide —	ε
4	29, F	Proximal tibia	Ewing's sarcoma	$\mathbf{I} + \mathbf{E}$	No	CHT preoperatively/ postoperatively	Wide 40	6
5	21, M	Distal femur	Osteosarcoma	$\mathbf{I} + \mathbf{E}$	No	CHT preoperatively/ postoperatively	Wide 30	9
6	39, F	Distal femur	Osteosarcoma	$\mathbf{I} + \mathbf{E}$	No	CHT preoperatively/ postoperatively	Wide 95	9
7	19, M	Distal femur	Chondroblastoma	I + E	Two curettages	Ι	Wide —	6.5
8	35, F	Soft tissues	Synovial sarcoma (recurrent)	I + E	Arthroscopic biopsy, inadequate excision, excision	CHT preoperatively/ postoperatively	Wide, focal necrosis	7
6	27, F	Soft tissues	Synovial sarcoma (recurrent)	I +	Inadequate excision, wide reexcision	CHT preoperatively/ postoperatively, RT postoperatively after recurrences	Wide but contaminated, focal necrosis	9
10	53, M	Soft tissues	Synovial sarcoma	$\mathbf{I} + \mathbf{E}$	Inadequate excision	CHT preoperatively/ postoperatively	Wide 40	12
11	64, M	Soft tissues	Synovial sarcoma	$\mathbf{I} + \mathbf{E}$	No	I	Wide —	6.5
12	68, F	Soft tissues	Pleomorphic sarcoma	I + E	Inadequate excision	I	Wide —	6.5
13	30, M	Soft tissues	Liposarcoma	Ι	Inadequate excision		Wide —	5.5
14	45, F	Soft tissues	Clear cell sarcoma	$\mathbf{I} + \mathbf{E}$	No	RT after recurrences, CHT after metastases	Marginal —	5

Table 1. (continued						
Patient number	Age (years), gender	Length of resected femur (cm)	Flap	Followup (months)	Status at followup	Complications, recurrences	ROM (lag extension), walking aids (living patients)
1	19, M	5	No	146	CDF	Prosthetic failure; rupture of patellar tendon allograft	0°–80° (15°), No aids
2	17, M	7.5	No	24	DOD	Local recurrence; lung metastasis	
б	23, F	11	No	102	AWD	Lung metastasis at presentation; rupture of patellar tendon at 95 months	0° 90° (0°) at 83 months, latest followup: revision surgery
4	29, F	9	No	65	CDF	Infection	$0^{\circ}-90^{\circ}$ (30°), no aids
5	21, M	17	No	25	DOD	Lung metastasis	
6	39, F	12	No	54	CDF	Infection	Arthrodesis
7	19, M	12.5	No	53	CDF		$0^{\circ}-100^{\circ}$ (0°), no aids
8	35, F	8	No	22	DOD	Lung metastasis	
6	27, F	6.5	No	48	NED	Two local recurrences	$0^{\circ}-90^{\circ}$ (10°), no aids
10	53, M	7	Medial gastrocnemius	18	DOD	Lung metastasis at presentation	
11	64, M	7.5	AL thigh free flap	27	CDF		$0^{\circ}-100^{\circ}$ (0°), no aids
12	68, F	8	AL thigh free flap	26	CDF		$0^{\circ}-100^{\circ}$ (15°), cane
13	30, M	6.5	No	24	CDF		$0^{\circ}-105^{\circ}$ (0°), no aids
14	45, F	٢	No	12	AWD	Local recurrence; subcutaneous metastasis (abdomen, thigh)	0°–90° (15°), no aids
M = male	: F = female;	I = intraarticular;	E = extraarticular; CHT =	chemotherapy;	RT = radiation	therapy: $AL =$ anterolateral; $CDF =$	continuously disease free; DOD = dead of

. 2 2 M = male; F = temale; I = intraarticular; E = extraarticular; CH1 disease; AWD = alive with disease; NED = no evidence of disease. obtained every month. Afterward, the patients were monitored according to our protocols for the different tumors (Appendix 1).

Four of the 14 patients died of disease (two with synovial sarcoma; one with osteosarcoma; one with Ewing's sarcoma). The time from surgery to death was, respectively, 18, 22, 24, and 25 months (average, 22.2 months). The minimum followup for the 10 surviving patients was 12 months (average, 55.7 months; range, 12–146 months). For the patients who died of disease, the most recent available data were used to ascertain the result of the procedure. For patients who were available for functional evaluation at the time of our study (living patients with a knee reconstruction not converted to arthrodesis), function of the knee was evaluated using the MSTS-ISOLS score [6]. One of the 10 living patients underwent a subsequent arthrodesis. Therefore, there were nine patients remaining for direct evaluation of functional outcome. For one patient (Patient 3) living abroad, a functional followup was available at 7 years postoperative showing good functional status. After 1 more year, sudden failure of active extension occurred, but the patient came to our unit only 6 months later. Rupture of the patellar tendon was diagnosed, and a revision procedure has been performed. Followup after this second procedure is limited; to evaluate the functional results of the primary procedure, we used the data available from the patient's 7-year followup.

Results

Histologic examination of the resected specimens showed wide surgical margins in 13 patients and marginal margins in one. The marginal excision was attributable to contact of the tumor with the popliteal vessels. For two patients, despite a wide excision, we considered the surgical resection contaminated. A less-extensive surgery had been planned (hemiarticular resection) for one patient but the intraoperative discovery of foci of tumor on the synovial lining required a shift to extraarticular resection. For the second patient, at the beginning of our experience, multiple scars from previous surgeries were present and some were not excised to avoid an adjunctive procedure for coverage. Subsequently, similar cases were treated more radically with free flaps. No local recurrences were observed in the 11 patients who had adequate surgery. All recurrences were in the three patients who had marginal or contaminated excisions. The overall local recurrence rate was 21%. Distant metastases occurred in six patients (already detected at onset in two).

Flexion ranged from 80° to 105° (average, 94°) (Table 1). Passive extension was complete in all patients. The active extensor lag was 0° in four patients, 10° in one patient, 15° in three patients, and 30° in one patient. The six patients who did not have subsequent revision procedures had an extensor lag ranging from 0° to 15° (average, 7°). The MSTS-ISOLS scores ranged from 67% to 90% (average, 83%). Nine of the surviving 10 patients used no walking aid at last followup, while one used a cane. No patient had more than modest nondisabling pain and three reported no pain. Among the four patients who died, one had an extensive deep vein thrombosis while receiving chemotherapy for lung metastases and early death precluded adequate evaluation of the functional result at the knee. The remaining three patients all had regained effective active extension with an extensor lag ranging from 0° to 10°. No evident additional functional impairment was observed in patients who underwent free flaps or radiation therapy.

Deep infection occurred in two patients. Both patients were treated with two-stage revision. Final reconstruction was accomplished in one patient with an intercalary arthrodesing prosthesis (Megasystem C, Waldemar Link), and in the other patient with a mobile prosthesis, saving the allogenic extensor apparatus implanted at first surgery. This latter patient recovered active extension with a residual extensor lag of 30°. Failure of the grafted patellar tendon occurred in two patients at 8 and 9 years after surgery, respectively. A revision procedure was performed with a new extensor apparatus allograft (Patient 3) or using an Achilles tendon allograft (Patient 1). Breakage of the femoral component of the prosthesis occurred in one patient. No patient had a vascular or neurologic complication.

Discussion

After en bloc resection of the knee with complete loss of the extensor apparatus, arthrodesis usually has been the preferred procedure [4, 7, 17, 18]. To maintain active knee extension, some authors have advocated a resection that spares part of the extensor apparatus by splitting the patella, and preservation of the patellar and quadriceps tendons [12–15, 20]. Reconstruction then can be performed with an osteoarticular whole knee allograft [13], a megaprosthesis [12, 15, 20], or an allograft-prosthetic composite [14]. Four of these studies reported the results in small series of cases (Table 2). We asked whether a more extensive surgical approach with a real en bloc extraarticular resection of the entire knee combined with a tibial allograft-prosthetic composite with its whole extensor apparatus would (1) provide adequate surgical margins; (2) allow restoration of a mobile knee; and (3) be associated with acceptable surgical morbidity after such an extensive procedure.

Table 2. Resul	ts in reported	l series for extraarticu	ular knee resection with	functional r	econstruction					
Study	Number of patients	Resection of the extensor apparatus	Reconstruction of extensor apparatus if completely excised	Average followup (months)	Extension lag (in patients evaluable at followup)	Local recurrence	Distant metastases (not already present at onset)	Deep infection	Walking aids	Mean MSTS Score (range)
Kendall et al. [12] 2000	6	Coronal splitting - 7 patients Complete excision - 2 patients	One medial gastrocnemius transfer, 1 semitendinosus transfer	30 (range, 6–56)	$20^{\circ} = 2$ patients, $10^{\circ}-20^{\circ} = 2$ patients. $< 10^{\circ} = 2$ patients, $0^{\circ} = 1$ patient	_	e	7	Not specified	56
Anract et al. [2] 2001	6	Complete excision	Medial gastrocnemius transfer (in 4 patients, a semitendinosus transfer was added)	23 (range, 6–30)	12° (range, 0°-40°)	0	ς	2	Three of 9 requiring a crutch	61 (36–100)
Nakamura et al. [15] 2001	. 13	Coronal splitting	I	61 (range, 17-45)	20° (range, 5°-70°)	Not specified, at least 1 (at followup 6 patients DOD, 1 NED, 6 CDF)	9	Not specified, at least 1	Most patients requiring a brace	69 (50–93)
Zwolak et al. [20] 2011	11	Coronal splitting	I	37.5 (range, 14 –80)	0°	1	ε	0	Not specified	Not specified
Current series	14	Complete excision	Allograft- prosthesic composite	56 (range, 12–146)	5° (range, 0°–30°)	œ	4	7	None	83 (67–90)
DOD = dead o	f disease, NE	D = no evidence of	disease, $CDF = continue$	tously diseas	e free.					

Volume 469, Number 10, October 2011

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Our study does have some limitations. First, as with the other series, we had a small number of patients, although relatively large compared with numbers in the other studies. The indication for extraarticular resection of the knee is rare and studies describing this kind of surgery combined with a functional reconstruction include between nine and 13 patients [2, 12–15, 20]. Second, our series of tumors was heterogeneous for type, stage, and adjuvant treatment. These variables certainly would affect rates of survival, but not whether we achieved adequate margins and restored function. Third, different procedures for soft tissue reconstructions were used, according to the case-specific situation. Fourth, followup is too short in some patients to determine local recurrence rates or to draw long-term conclusions regarding function and survival of the reconstructions.

The strategy we used for these rare, challenging cases generally allowed wide margins. An adequate excision was achieved in all but three patients, in whom specific situations led to marginal or contaminated surgery. The only local recurrences in our series occurred in these three patients. This underlines the importance of accurate planning of surgery, including the use of free flaps if wider soft tissue excisions need to be performed. In our opinion, the alternative technique of limited extraarticular resection with sparing of the extensor apparatus [12–15, 20] cannot be considered a true extraarticular procedure (Fig. 2). Opening of the joint and contamination of the surgical field with synovial fluid from effusions may occur when dissecting the quadriceps tendon from the thin synovial layer of the suprapatellar pouch or when performing the coronal Clinical Orthopaedics and Related Research®

osteotomy of the patella if only a small amount of bone is removed; however, a fracture may occur if too much bone is removed. Furthermore, dissection on the deep surface of the patellar tendon may be inadequate in the case of tumors arising from the infrapatellar fat pad. Finally, when cutting the tibia above the tibial tuberosity, the popliteal hiatus and the insertional area of the posterior cruciate ligament may be opened causing contamination of the surgical field by intraarticular fluid (a cut below the tibial tuberosity, removing the entire metaphysis and popliteal muscle, is safer). For these reasons, we now use the technique of coronal splitting of the patella for distal femur tumors with very limited bulging inside the joint covered by the synovial lining, and only when the extensor apparatus is not involved.

Other techniques for reconstruction of the extensor mechanism after en bloc resection of the knee have been described. Anract et al. [2] and Kendall et al. [12] reported their experience with extraarticular resection and reconstruction of the extensor apparatus by a medial gastrocnemius rotational flap, augmented in some cases with pes anserinus tendons [2] (Table 2). While the local recurrence rates have been low, the mean MSTS scores have ranged from 56 to 69; with our technique the mean MSTS score was 82.

Our concerns with this technique are: (1) inadvertent joint violation can occur when the medial gastrocnemius is separated from the capsule; (2) transposition of the medial gastrocnemius may determine a reduction in plantar flexion strength; (3) the vascular pedicle can be stretched during rotation and anterior transfer of the flap; and (4) reconstruction of the extensor mechanism is weak proximally

Fig. 2A–B (A) The surgical dissection line of a classic extraarticular resection is shown (continuous line) on the lateral MRI of the knee of a patient with a liposarcoma of the infrapatellar fat pad after inadequate surgery contaminating the joint. (B) The surgical dissection line according to the technique of patellar splitting and extensor mechanism preservation (dotted line) is shown. Surgical margins (B) are more likely to be inadequate.



where a muscle-to-muscle suture is performed (quadriceps to gastrocnemius) and distally, where the gastrocnemius tendon is sutured to a metal prosthesis. Difficulties in achieving solid reattachment of a tendon or muscle directly to a metal prosthesis are well known [5, 9]. Function may improve by using an allograft-prosthetic composite, as shown in intraarticular resections when the patellar tendon is reattached to the tendon of the graft [5, 9, 10]. We used a novel technique of allograft-prosthetic composite in which the proximal tibia allograft is used with its own full extensor apparatus. Proximally the quadriceps tendon of the donor is attached to the patient's quadriceps tendon stump. The efficacy of extensor apparatus reconstruction using an allograft has been reported in several studies concerning revision procedures after conventional knee prosthesis failure [3, 16, 19]. Our experience confirms the ability of this procedure to restore function when combined with an allograft-prosthetic composite after extraarticular resection of the knee. This allows us to maintain the continuity of the extensor apparatus at its distal attachment, which is the most critical issue in extensor apparatus reconstruction. Our patients appeared to have greater mean active knee extension than that reported for other extraarticular resection techniques (Table 2).

We believed the short- and long-term morbidity rates of this procedure were acceptable for treating tumors that widely involved the knee. Deep infection occurred in 14% of our patients, similar to rates in other reports of megaprostheses or allograft-prosthetic composites involving the proximal tibia, with incidences ranging from 16% to 24% [5, 8, 11]. Two patients experienced late rupture of the patellar tendon at 8 and 9 years after surgery and required surgical revision with a new extensor apparatus allograft. After excision of the whole knee with its extensor mechanism, an allograft-prosthetic composite is a reasonable option for reconstruction, allowing restoration of active extension in most patients. Larger series of patients and longer-term followup are needed to confirm our findings and establish the durability of this reconstructive technique.

Appendix 1. Followup protocols

Followup protocols for clinical and radiographic checks of the patients after treatment are as follows:

Osteosarcoma and Ewing's sarcoma = every 3 months in the first year after end of chemotherapy, every 4 months in the 2nd and 3rd years, every 6 months afterward until the 10th year.

High-grade soft tissue sarcomas = every 3 months in the first 2 years after surgery, every 4 months in the 3rd year, every 6 months in the 4th, 5th, and 6th years, once a year until the 10th year.

Aggressive benign bone tumors = every 4 months in the first year after surgery, every 6 months for the 2nd, 3rd, and 4th years, once a year until the 10th year.

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