What are Estimated Reimbursements for Lower Extremity Prostheses Capable of Surgical and Nonsurgical Lengthening?

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Abstract

Background Growing prostheses accommodate skeletally immature patients with bone tumors undergoing limb-preserving surgery. Early devices required surgical procedures for lengthening; recent devices lengthen without surgery. Expenses for newer expandable devices that lengthen without surgery are more than for their predecessors but overall reimbursement amounts are not known.

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Questions/purposes We sought to determine reimbursement amounts associated with lengthening of growing prostheses requiring surgical and nonsurgical lengthening.

Methods We retrospectively reviewed 17 patients with growing prostheses requiring surgical expansion and eight patients with prostheses capable of nonsurgical expansion. Insurance documents were reviewed to determine the reimbursement for implantation, lengthening, and complications. Growth data were obtained from the literature.

Results Mean reimbursement amounts of surgical and nonsurgical lengthenings were \$9950 and \$272, respectively. Estimated reimbursements associated with implantation of a growing prosthesis varied depending on age, sex, and location. The largest difference was found for 4-year-old boys with distal femoral replacement where reimbursement for expansion to maturity for surgical and nonsurgical lengthening prostheses would be \$379,000 and \$208,000, respectively. For children requiring more than one surgical expansion, net reimbursements were lower when a noninvasive lengthening device was used. Annual per-prosthesis maintenance reimbursements to address complications for surgical and nonsurgical lengthening prostheses were \$3386 and \$1856, respectively.

Conclusions This study showed that reimbursements for lengthening of growing endoprostheses capable of non-surgical expansion may be less expensive in younger patients, particularly male patients undergoing distal femur replacement, than endoprostheses requiring surgical lengthening. Longer outcomes studies are required to see if reimbursements for complications differ between devices.

Level of Evidence Level III, economic and decision analysis. See the Guidelines for Authors for a complete description of levels of evidence.

Introduction

Neoadjuvant and adjuvant treatment of bone sarcomas have allowed successful limb preservation surgery in pediatric patients [30, 34]. Median Musculoskeletal Tumor Society (MSTS) functional scores of 80 have been reported in this population [1, 13]. Mean patient satisfaction, measured with the Pediatric Outcomes Data Collection Instrument (PODCI), has been reported to range from 80 to 90 [11, 20].

Expandable endoprostheses accommodate growth of skeletally immature patients [24, 25, 28, 31]. Over four decades these devices evolved with changes in the lengthening mechanisms. Early devices required the addition of metallic spacers or exchange of modular components to facilitate expansion and required additional surgery for lengthening [8, 23]. Recent devices have used a worm drive actuated by a screw accessible by percutaneous dissection (Fig. 1) [18]; these devices allow fine adjustment and are associated with reduced hospital stay [5].

The most recent generation of expandable devices incorporates nonsurgical lengthening. One implant uses a

telescoping wheel powered by an internal motor driven by an external electrical coil (Fig. 2). Early reports suggest this technology provides reliable lengthening with minimal complications [16, 17].

The financial expense of all expandable devices is considerable. Manufacturer charges for newer extendible prostheses capable of nonsurgical lengthening are increased over those of their predecessors, however, overall reimbursements for longitudinal care are unclear.

We compared reimbursements of lengthening endoprostheses capable of surgical and nonsurgical lengthening to answer the following questions: (1) What are reimbursement amounts for a single surgical and nonsurgical lengthening of an expandable prosthesis? (2) What are predicted healthcare cost provider reimbursements for lengthening a child's limb from implantation to skeletal maturity? (3) How much lengthening is required to reach an equivalence point where the cost provider's reimbursements for the two devices are equivalent and at what age does this occur? (4) What additional reimbursements are required for device complications and failures?

Fig. 1 A second-generation expandable endoprosthesis requiring surgical lengthening is shown.

Fig. 2 A third-generation expandable endoprosthesis capable of nonsurgical lengthening is shown.

Patients and Methods

We queried our database for patients with adequate followup who had received an extendible endoprosthesis. From July 2001 to May, 2007, 18 patients (Group 1) received an extendible endoprosthesis requiring minimally invasive surgical lengthening (Stryker Orthopaedics, Mahwah, NJ, USA); one was excluded owing to insufficient data. From December 2004 to May 2009, eight patients (Group 2) received an endoprosthesis capable of nonsurgical lengthening (Stanmore Implants, Elstree, UK) at our institution (Table 1). Both implants have FDA approval. The mean age of patients in Group 1 was 10.9 years (range, 4–14 years) and in Group 2 was 10.6 years (range, 6–15 years); there was no significant difference in age between groups with the Student's *t*-test ($p = 0.84$). Although no attempt was made to assign prosthesis type by sex, there was a significant difference in sex ratios between groups with Fisher's exact test ($p = 0.03$). There was no

significant difference between Group 1, which had 14 patients with a diagnosis of osteosarcoma and three with Ewing sarcoma, and Group 2, which had four patients with a diagnosis of osteosarcoma and four with Ewing sarcoma by Fisher's exact test ($p = 0.16$). We had prior Institutional Review Board approval.

After discharge from the hospital, patients returned to clinic 1 to 2 weeks after surgery and then 6 weeks after implantation. Skeletally immature patients then were seen every 3 months and radiographs were obtained. Surgical lengthening was offered when the patient's operative leg had a discrepancy of 1 cm or greater compared with the nonoperative leg; all lengthening procedures were performed as outpatient procedures and the mean operative time was 17 minutes. Nonsurgical lengthening was offered when the operative leg had a discrepancy of 4 mm or greater.

Failures experienced by patients in this series included two Type 1 failures, two Type 2 failures, one Type 3 failure, one Type 4 failure, and no Type 5 failures (Table 2) [19]. One physeal arrest and two patients with maximal extension of their growing prosthesis who required additional growth had failures not accounted for by this classification system. Four patients with superficial wound infections and one patient with flexion contracture had Grade I complications and one patient with seroma and one with wound dehiscence had Grade III complications. One failure for deep infection (Patient 3) and one superficial infection (Patient 14) followed surgical lengthening

Table 1. Patient demographics

Prosthesis	Patient	Age at surgery (years)	Sex	Location	Diagnosis
Stryker	1	9	F	DFR	Osteosarcoma
	2	11	F	DFR	Osteosarcoma
	3	11	M	PFR	Ewing sarcoma
	4	12	M	DFR	Osteosarcoma
	5	11	F	DFR	Osteosarcoma
	6	12	M	DFR	Osteosarcoma
	7	13	F	DFR	Osteosarcoma
	8	13	F	DFR	Ewing sarcoma
	9	12	M	DFR	Osteosarcoma
	10	8	F	PFR	Osteosarcoma
	11	6	F	PTR	Osteosarcoma
	12	14	F	PTR	Osteosarcoma
	13	4	F	DFR	Ewing sarcoma
	14	12	F	DFR	Osteosarcoma
	15	12	M	PTR	Osteosarcoma
	16	12	F	DFR	Osteosarcoma
	17	13	M	DFR	Osteosarcoma
Stanmore	18	7	M	DFR	Ewing sarcoma
	19	9	M	DFR	Osteosarcoma
	20	11	M	DFR	Osteosarcoma
	21	6	F	PFR	Ewing sarcoma
	22	10	M	DFR	Ewing sarcoma
	23	15	M	PFR	Ewing sarcoma
	24	12	M	DFR	Osteosarcoma
	25	15	M	DFR	Osteosarcoma

PFR = proximal femur replacement; TFR = total femur replacement; DFR = distal femur replacement; PTR = proximal tibia replacement.

Table 2. Adverse events of subjects receiving expandable endoprostheses

Prosthesis	Patient	Adverse event(s)
Stryker	3	Type 4 failure (revision); Type 3 (revision)
	5	Superficial infection (oral antibiotics); Type 2 failure (revision); wound dehiscence (wound revision)
	11	Type 1 failure (wound revision, amputation)
	12	Type 1 failure (patellar tendon tensioning); Type 2 (revision)
	13	Physeal arrest (bar excision); flexion contracture (lysis of adhesions, temporary revision to fixed-extension implant); extension mechanism exceeded (revision 2)
Stanmore	14	Superficial infection (oral antibiotics); seroma (evacuation)
	18	Extension mechanism exceeded (revision)
	20	Superficial infection (oral antibiotics)
	23	Superficial infection (oral antibiotics)

Type 1 = soft tissue failure; Type 2 = aseptic loosening; Type 3 = structural failure; Type 4 = infection; Type 5 = tumor progression.

procedures. No patients receiving nonsurgical lengthenings had complications related to a lengthening or required admission to the hospital for any reason.

Insurance records for patients receiving lengthening procedures between January 1, 2006 and December 31, 2009 were used to determine the reimbursement amounts for initial implantation surgeries, lengthening procedures, and treatment of complications. Amounts of the expandable endoprostheses requiring surgical lengthening were \$20,000 (US dollars) for the proximal and distal femur replacement models and \$25,000 for the proximal tibia replacement model; amounts of comparable nonsurgical lengthening devices were \$34,200 per device. Reimbursement for a primary implantation surgery was \$30,155. Reimbursement for a single lengthening procedure for each device was determined.

Total reimbursement for lengthening a prosthesis from implantation to skeletal maturity was calculated using reimbursements for the implant, implantation surgery, total expansion procedures (determined by anticipated growth), and the maximum growth allowed by the individual prosthesis (dictating whether revision for lengthening mechanism completion was required). Revision surgery was deemed necessary if more than 2 cm of anticipated growth remained after maximal prosthesis expansion. In the event that a revision surgery was included in the calculation, the reimbursement of one lengthening procedure or 1 cm of lengthening, whichever was greater, was

subtracted because it is our practice to perform intraoperative lengthening during the revision process through implant length selection. The external power source for facilitating nonsurgical lengthenings is provided at no charge and no reimbursement for its use was sought.

Annual physal growth rates were obtained from the literature and a multiplier of 1.243 was used based on the finding of contralateral limb overgrowth in this population [2, 3, 7]. Based on our practice, surgical expansions were assumed to be 1 cm per lengthening procedure and non-invasive expansions were 0.40 cm each; 2-cm surgical lengthening procedures were included in the analysis for completeness although lengthening of this amount is not performed at our institution (Tables 3 and 4). The maximum lengthening potentials of the implants were obtained from the manufacturers and were 90 mm and 85 mm for the surgical and nonsurgical lengthening devices, respectively.

Results

What are reimbursements for a single surgical and non-surgical lengthening of an expandable prosthesis? Mean provider reimbursement for a surgical lengthening, adjusted to 2010 inflation, was \$9947.54 (range, \$4897.29–\$12,166.39). This amount included two fixed-amount expansions for which itemized reimbursements were

Table 3. Growth and expansion requirements by location in boys

Age at surgery (years)	Growth remaining (cm)			Number of expansions								
	Proximal femur	Distal femur	Proximal tibia	Proximal femur			Distal femur			Proximal tibia		
				1 cm	2 cm	Nonsurgical	1 cm	2 cm	Nonsurgical	1 cm	2 cm	Nonsurgical
4	9.4	23.1	14.5	9	5	21	23	12	58	15	7	36
5	8.5	20.8	13.2	8	4	21	21	10	52	13	7	33
6	7.7	18.8	11.9	8	4	19	19	9	47	12	6	30
7	6.9	16.9	10.7	7	3	17	17	8	42	11	5	27
8	6.1	15.0	9.6	6	3	15	15	7	37	10	5	24
9	5.4*	13.2	8.4	5*	3*	13*	13	7	33	8	4	21
10	4.6	11.4	7.3	5	2	12	11	6	28	7	4	18
11	3.9	9.7	6.2	4	2	10	10	5	24	6	3	16
12	3.3	8.0	5.1*	3	2	8	8	4	20	5*	3*	13*
13	2.6	6.3	3.9	3	1	6	6	3	16	4	2	10
14	1.8	4.5*	2.7	2	1	5	4*	2*	11*	3	1	7
15	1.1	2.7	1.5	1	1	3	3	1	7	1	1	4
16	0.6	1.4	0.6	1	0	1	1	1	3	1	0	2
17	0.2	0.5	0.2	0	0	1	1	0	1	0	0	0
18	0.1	0.1	0.0	0	0	0	0	0	0	0	0	0

Prosthesis type: 1 cm = invasive-type expansion (1 cm); 2 cm = invasive-type expansion (2 cm); nonsurgical = nonsurgical-type expansion;

* ages where approximately 5 cm of growth remains.

Table 4. Growth and expansion requirements by location in girls

Age at surgery (years)	Growth remaining (cm)			Number of expansions								
	Proximal femur	Distal femur	Proximal tibia	Proximal femur			Distal femur			Proximal tibia		
				1 cm	2 cm	Nonsurgical	1 cm	2 cm	Nonsurgical	1 cm	2 cm	Nonsurgical
4	8.0	19.7	12.7	8	4	18	20	10	49	13	6	32
5	7.1	17.4	11.2	7	4	18	17	9	43	11	6	28
6	6.2	15.3	9.8	6	3	16	15	8	38	10	5	25
7	5.4	13.3	8.6	5	3	14	13	7	33	9	4	21
8	4.7*	11.5	7.4	5*	2*	12*	11	6	29	7	4	18
9	3.9	9.6	6.2	4	2	10	10	5	24	6	3	16
10	3.2	7.9	5.0*	3	2	8	8	4	20	5*	3*	13*
11	2.5	6.1	3.8	2	1	6	6	3	15	4	2	10
12	1.7	4.3*	2.6	2	1	4	4*	2*	11*	3	1	6
13	1.0	2.6	1.4	1	1	3	3	1	6	1	1	4
14	0.5	1.2	0.6	0	0	1	1	1	3	1	0	1
15	0.2	0.4	0.2	0	0	0	0	0	1	0	0	0
16	0.1	0.1	0.0	0	0	0	0	0	0	0	0	0
17	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0
18	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0

Prosthesis type: 1 cm = invasive-type expansion (1 cm); 2 cm = invasive-type expansion (2 cm); nonsurgical = nonsurgical-type expansion; * ages where approximately 5 cm of growth remains.

Table 5. Hospital and operative costs associated with surgical expansion procedure

Surgical expense	Mean reimbursement (US dollars)
Operating room	\$2068.20
Pharmacy	\$1414.58
Laboratory medicine	\$377.89
Radiology	\$563.97
Intravenous fluids	\$85.09
Central supply	\$1035.12
Recovery	\$1637.46
Anesthesia	\$1184.20
Orthopaedic surgeon	\$2220.97
Total	\$10,587.49

unavailable. Exclusion of these procedures raised the mean reimbursement to \$10,587.49 (Table 5). Reimbursement for an in-clinic expansion of the Stanmore device, including clinic fees and radiographs, was \$272.44.

What are predicted total healthcare cost provider reimbursements for lengthening a child's limb from implantation to skeletal maturity? Substantial differences existed in the reimbursements associated with lengthening an expandable prosthesis to achieve equivalent leg lengths for boys (Table 6) and girls (Table 7) from age 4 years to skeletal maturity. Larger differences were seen in boys, who reach skeletal maturity later than girls. The distal

femoral physis has the greatest growth potential and therefore its replacement requires more lengthening procedures than the other locations; the proximal femoral physis showed the smallest reimbursement difference. The implants in consideration had expansion capabilities within 5 mm of each other, therefore the number of anticipated revisions did not differ between prostheses.

How much lengthening is required to reach an equivalence point where the cost provider reimbursements for the two devices are equivalent and at what age does this occur? The equivalence point for the proximal and distal femur prostheses was reached with 1.6 surgical lengthening procedures; the equivalence point for proximal tibial prostheses was reached with a single surgical lengthening. In boys when 1-cm surgical lengthenings were considered, equivalence for proximal femur replacement occurred at approximately 14 years. For distal femur replacement and proximal tibia replacement, equivalence occurred between ages 15 and 16 years (Fig. 3A). Use of 2-cm lengthenings lowered the equivalence age (Fig. 3B). For girls, when 1-cm surgical lengthenings were considered, equivalence for proximal femur replacement occurred at approximately 12 years and for proximal tibia and distal femur replacement between 13 and 14 years (Fig. 3C). Use of 2-cm lengthenings in girls also lowered the equivalence age (Fig. 3D).

What additional reimbursements occur from device complications and failures? Adverse events contributed to increased payments from healthcare cost providers

Table 6. Estimated reimbursements of expandable endoprosthesis use in boys

Age at surgery (years)	Estimated net reimbursements (US dollars)								
	Proximal femur			Distal femur			Proximal tibia		
	1 cm	2 cm	Nonsurgical	1 cm	2 cm	Nonsurgical	1 cm	2 cm	Nonsurgical
4	\$139,683	\$99,892	\$70,076	\$379,258	\$269,835	\$208,866	\$259,523	\$179,942	\$138,517
5	\$129,735	\$89,945	\$70,076	\$309,208	\$199,785	\$142,876	\$239,628	\$179,942	\$137,700
6	\$129,735	\$89,945	\$69,531	\$289,313	\$189,837	\$141,514	\$229,680	\$114,840	\$136,883
7	\$119,788	\$79,997	\$68,986	\$269,418	\$179,890	\$140,152	\$164,578	\$104,892	\$71,711
8	\$109,840	\$79,997	\$68,441	\$249,523	\$169,942	\$138,790	\$154,630	\$104,892	\$70,893
9	\$99,892*	\$79,997*	\$67,897*	\$229,628	\$119,788	\$137,700	\$134,735	\$94,945	\$70,076
10	\$99,892	\$70,050	\$67,624	\$209,733	\$109,840	\$136,338	\$124,788	\$94,945	\$69,259
11	\$89,945	\$70,050	\$67,079	\$149,630	\$99,892	\$70,893	\$114,840	\$84,997	\$68,714
12	\$79,997	\$70,050	\$66,534	\$129,735	\$89,945	\$69,804	\$104,892*	\$84,997*	\$67,897*
13	\$79,997	\$60,102	\$65,989	\$109,840	\$79,997	\$68,714	\$94,945	\$75,050	\$67,079
14	\$70,050	\$60,102	\$65,717	\$89,945*	\$70,050*	\$67,352*	\$84,997	\$65,102	\$66,262
15	\$60,102	\$60,102	\$65,172	\$79,997	\$60,102	\$66,262	\$65,102	\$65,102	\$65,445
16	\$60,102	\$50,155	\$64,627	\$60,102	\$60,102	\$65,172	\$65,102	\$55,155	\$64,900
17	\$50,155	\$50,155	\$64,627	\$60,102	\$50,155	\$64,627	\$55,155	\$55,155	\$64,355
18	\$50,155	\$50,155	\$64,355	\$50,155	\$50,155	\$64,355	\$55,155	\$55,155	\$64,355

Prosthesis type: 1 cm = invasive-type expansion (1 cm); 2 cm = invasive-type expansion (2 cm); nonsurgical = nonsurgical-type expansion; * ages where approximately 5 cm of growth remains.

Table 7. Estimated reimbursements of expandable endoprosthesis use in girls

Age at surgery (years)	Estimated net reimbursements (US dollars)								
	Proximal femur			Distal femur			Proximal tibia		
	1 cm	2 cm	Nonsurgical	1 cm	2 cm	Nonsurgical	1 cm	2 cm	Nonsurgical
4	\$129,735	\$89,945	\$69,259	\$299,260	\$199,785	\$142,059	\$239,628	\$169,995	\$137,428
5	\$119,788	\$89,945	\$69,259	\$269,418	\$189,837	\$140,424	\$164,578	\$114,840	\$71,983
6	\$109,840	\$79,997	\$68,714	\$249,523	\$179,890	\$139,062	\$154,630	\$104,892	\$71,166
7	\$99,892	\$79,997	\$68,169	\$229,628	\$169,942	\$137,700	\$144,683	\$94,945	\$70,076
8	\$99,892*	\$70,050*	\$67,624*	\$209,733	\$109,840	\$136,610	\$124,788	\$94,945	\$69,259
9	\$89,945	\$70,050	\$67,079	\$149,630	\$99,892	\$70,893	\$114,840	\$84,997	\$68,714
10	\$79,997	\$70,050	\$66,534	\$129,735	\$89,945	\$69,804	\$104,892*	\$84,997*	\$67,897*
11	\$70,050	\$60,102	\$65,989	\$109,840	\$79,997	\$68,441	\$94,945	\$75,050	\$67,079
12	\$70,050	\$60,102	\$65,445	\$89,945*	\$70,050*	\$67,352*	\$84,997	\$65,102	\$65,989
13	\$60,102	\$60,102	\$65,172	\$79,997	\$60,102	\$65,989	\$65,102	\$65,102	\$65,445
14	\$50,155	\$50,155	\$64,627	\$60,102	\$60,102	\$65,172	\$65,102	\$55,155	\$64,627
15	\$50,155	\$50,155	\$64,355	\$50,155	\$50,155	\$64,627	\$55,155	\$55,155	\$64,355
16	\$50,155	\$50,155	\$64,355	\$50,155	\$50,155	\$64,355	\$55,155	\$55,155	\$64,355
17	\$50,155	\$50,155	\$64,355	\$50,155	\$50,155	\$64,355	\$55,155	\$55,155	\$64,355
18	\$50,155	\$50,155	\$64,355	\$50,155	\$50,155	\$64,355	\$55,155	\$55,155	\$64,355

Prosthesis type: 1 cm = invasive-type expansion (1 cm); 2 cm = invasive-type expansion (2 cm); nonsurgical = nonsurgical-type expansion; * ages where approximately 5 cm of growth remains.

(Table 8). The least expensive complication we treated was a superficial wound infection, for which we prescribed enteral vancomycin and checked laboratory values. The most expensive complication was staged revision

attributable to deep infection, which required removal of the infected device, parenteral antibiotics, and revision surgery. When maintenance reimbursements by group were divided by total implant service years for all patients in the

Fig. 3A–D Estimated expansion costs for surgical and nonsurgical lengthenings of expandable endoprotheses for proximal femoral replacement (PFR), distal femoral replacement (DFR), and proximal tibial replacement (PTR) are shown for: (A) boys receiving 1-cm

surgical lengthenings; (B) boys receiving 2-cm surgical lengthenings; (C) girls receiving 1-cm surgical lengthenings; and (D) girls receiving 2-cm surgical lengthenings.

Table 8. Treatment costs for adverse events

Complication	Treatment protocol	Costs
Superficial wound infection	Vancomycin (oral) for 10 days, initial laboratory study (CBC, ESR, CRP)	\$1034
Joint contracture – initial	Physical therapy for 6 weeks, three sessions per week	\$3720
Joint contracture – refractory	Lysis of adhesions, placement of fixed-extension implant	\$24,969 + implant
Seroma	Surgical evacuation	\$9288
Wound dehiscence	Surgical wound revision	\$9790
Patellar tendon rupture	Patellar tendon tensioning	\$10,703
Refractory wound dehiscence	Surgical wound revision, amputation	\$27,607
Aseptic loosening	Prosthesis revision	\$26,266 + implant
Extension mechanism exceeded	Prosthesis revision	\$26,587 + implant
Prosthesis fracture	Prosthesis revision	\$26,828 + implant
Physeal arrest with deformity	Deformity correction, prosthesis revision	\$27,149 + implant
Deep infection, early	Surgical irrigation and debridement, outpatient vancomycin (intravenous) for 6 weeks, laboratory study every 3 weeks (CBC, ESR), x-rays at start and end of intravenous treatment	\$25,282
Deep infection, late	Implant removal surgery, vancomycin (intravenous) for 6 weeks, laboratory studies every 3 weeks (CBC, ESR), implant revision	\$70,383 + implant

CBC = complete blood count; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein.

group, mean reimbursements for Group 1 and Group 2 were \$3386 and \$1856, respectively.

Discussion

Advances in medical oncology have made limb preservation a viable option for many children with malignant extremity tumors [30, 34]. Substantial financial expenses associated with these procedures require that their use be coupled with justification of their functional and fiscal viability.

We acknowledge limitations to this study. We did not include costs to the patient's family, including travel and lost work productivity. Although these costs are relevant, they would vary substantially for patients treated at a tertiary center and would be influenced by the family's financial situation and lifestyle. Our intention was to address only the reimbursements associated with expansion of these devices from the cost provider's standpoint. Second, our analysis was based on mean surgical expansions of 1 cm or 2 cm and mean nonsurgical expansions of 0.40 cm. Altering these amounts would change the results of this analysis. Third, our analysis was based on average growth patterns at the remaining physes and contralateral limb with a compensatory multiplier because physeal growth has been shown, on average, to accelerate after limb preservation [7]. Physeal activity may be affected by factors specific to an individual patient's diagnosis and treatment and individual growth rates may vary considerably [7]. Fourth, reimbursements for oral analgesia after discharge from the hospital after surgical lengthenings were minimal and were not included in the analysis. Fifth, other endoprostheses are capable of noninvasive expansion and were not included in this study. Sixth, the reimbursements reported here were from private insurance and may not reflect the payments associated with a government-subsidized health plan.

Our review of financial records showed a mean reimbursement difference between surgical and nonsurgical lengthening procedures of almost 40-fold. This substantial difference is offset somewhat by a higher device reimbursement for the nonsurgical lengthening implants. Complete analysis of reimbursements associated with use of these devices, however, requires consideration of the number of anticipated lengthenings and reimbursement for the index surgery, planned revisions, and incidence of complications [14].

The results of our study showed that total expansion reimbursements for the youngest patients receiving extendible endoprostheses may approach \$400,000 even in the absence of complications, which are common. Endoprosthesis alternatives must be considered. Amputation and

rotationplasty are alternatives to limb-preservation surgery [4, 12, 22, 30]. These surgeries require the patient to use an external prosthesis for ambulation. Longitudinal reimbursements for these surgeries in children have not been studied. Grimer et al. [14] investigated long-term reimbursements of amputation with prosthetic limb use compared with nonexpandable limb preservation and reported substantially lower reimbursements with limb preservation. The reimbursement associated with amputation with private insurance was \$9442, with additional amounts for prosthesis fitting and maintenance of \$16,033 per year. Adjusted for 2010 inflation, these amounts would be \$12,778 and \$21,698, respectively. Their 20-year projections for amputation and prosthesis use showed an eightfold reimbursement increase over use of a non-expandable endoprosthesis [14]. When applied to a four-year-old male patient, their model shows total surgical and prosthetic reimbursement at skeletal maturity would be \$273,154. By contrast, our model yielded total expansion reimbursements for the same patient from \$70,076 to \$379,000, depending on the anatomic location and choice of prosthesis. The early, multifold cost-effectiveness of endoprostheses reported by the authors for nonexpandable devices is not seen with the more expensive expandable devices [14]. If a child achieves skeletal maturity with the endoprosthesis intact, even with a revision, continued external prosthesis maintenance reimbursement amounts associated with amputation would overtake net reimbursements for expandable device use within a decade even for distal femoral devices requiring surgical lengthening.

Results from our study suggest that the initial, increased reimbursements for an expandable endoprosthesis capable of nonsurgical lengthening compared with one requiring surgical lengthening are negated if more than one surgical procedure is performed. This indicates that reimbursements for prostheses requiring surgical expansion are less than for nonsurgical expanding devices only in patients who are approaching skeletal maturity. These findings also were reflected in the late ages at which equivalence was reached. Given that limb-length discrepancies of 1 to 2 cm are treated effectively with a shoe lift and discrepancies of 4 cm may be treated with contralateral epiphysiodesis [35], these treatments combined with a conventional endoprosthesis may be considered in lieu of a growing prosthesis. When future shoe lift use is planned, careful assessment of skeletal age and predicted growth should be performed given the substantial variability of contralateral physeal growth rates [7]. Even with strict attention to growth potential, unanticipated limb length discrepancies may result, leaving the surgeon without an uncomplicated solution [7].

Although our goal was to create a model for comparing the reimbursements for lengthening these devices,

complications will affect their ultimate financial impact. When reporting on tumor endoprosthesis reimbursements, Grimer et al. [14] reported an average of \$1419 per year for maintenance or replacement of nonexpandable implants (\$1920 in 2010 US dollars). Their analysis did not consider expandable implants and therefore the reported maintenance reimbursements reflected only the incidence of complications averaged over all implant recipients. Failure rates for extendible tumor endoprostheses are high and revision surgery is not uncommon for complications including infection, tumor recurrence, and prosthesis fracture [28, 31–33]. Higher reimbursements for growing prostheses are explained partially by the added complexity of their lengthening mechanisms and their use in children [8, 16, 31], therefore opening them to modes of failure in addition to those described [19]. A high rate of prosthesis fracture is attributed to reduced structural integrity owing to the lengthening mechanism [28]. In the current study, premature physal closure resulted in one patient. Flexion contractures may be more common in this population owing to repetitive lengthening without soft tissue stretching [16]. Maximum extension of the prostheses before skeletal maturity also may occur and require revision [28]. In addition, children tend to be more active than adults and may be less compliant with activity restrictions [26]. Overall we observed fewer complications with the nonsurgical lengthening prostheses, however, this limited series and those in the literature cannot provide statistical justification of one device over another [8, 9, 15, 16, 18, 20, 24, 25, 28, 31]. When considering inflation, the maintenance reimbursements for our noninvasive lengthening devices were similar to that reported by Grimer et al., albeit with less followup [14].

Expandable prostheses continue to evolve but their role remains ill-defined. Numerous small series have compared patient function, quality of life, and reconstruction longevity after expandable endoprosthesis and amputation or rotationplasty with external prosthesis; no one option has presented as a clear winner [4, 12, 21, 27, 29]. Lacking from these analyses has been any mention of the expense of these implants. Our findings showed that expandable prosthesis use requires continued financial investment on the part of the healthcare cost provider and the magnitude of that investment is correlated to the patient's age, sex, tumor location, and complication incidence. Prosthesis selection or, more appropriately, lengthening mechanism selection also appears to have a considerable effect on the net reimbursements associated with these implants. Additional study is needed, but given similar or perhaps higher complication rates for the surgical lengthening devices, the smallness of the lengthening required to exceed the equivalence point allowing these implants a financial edge calls into question whether these devices should be used. The prosthesis is not at fault, but rather it is the substantial

expense of taking a patient to the operating room. Unfortunately percutaneous lengthening procedures are performed more easily with fluoroscopy and to attempt surgical lengthening in the office setting precludes many techniques that decrease surgical site infection [10]. Our practice is to use nonsurgical lengthening endoprostheses when pediatric limb preservation is required.

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References

1. Aksnes LH, Bauer HC, Jebsen NL, Folleras G, Allert C, Haugen GS, Hall KS. Limb-sparing surgery preserves more function than amputation: a Scandinavian sarcoma group study of 118 patients. *J Bone Joint Surg Br.* 2008;90:786–794.
2. Anderson M, Green WT, Messner MB. Growth and predictions of growth in the lower extremities. *J Bone Joint Surg Am.* 1963; 45:1–14.
3. Anderson M, Messner MB, Green WT. Distribution of lengths of the normal femur and tibia in children from one to eighteen years of age. *J Bone Joint Surg Am.* 1964;46:1197–1202.
4. Cammisa FP Jr, Glasser DB, Otis JC, Kroll MA, Lane JM, Healey JH. The Van Nes tibial rotationplasty: a functionally viable reconstructive procedure in children who have a tumor of the distal end of the femur. *J Bone Joint Surg Am.* 1990;72: 1541–1547.
5. Delepine G, Delepine N, Desbois JC, Goutallier D. Expanding prostheses in conservative surgery for lower limb sarcoma. *Int Orthop.* 1998;22:27–31.
6. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg.* 2004;240: 205–213.
7. Dominkus M, Krepler P, Schwameis E, Windhager R, Kotz R. Growth prediction in extendable tumor prostheses in children. *Clin Orthop Relat Res.* 2001;390:212–220.
8. Eckardt JJ, Kabo JM, Kelley CM, Ward WG Sr, Asavamongkolkul A, Wirganowicz PZ, Yang RS, Eilber FR. Expandable endoprosthesis reconstruction in skeletally immature patients with tumors. *Clin Orthop Relat Res.* 2000;373:51–61.
9. Eckardt JJ, Safran MR, Eilber FR, Rosen G, Kabo JM. Expandable endoprosthetic reconstruction of the skeletally immature after malignant bone tumor resection. *Clin Orthop Relat Res.* 1993;297:188–202.
10. Fletcher N, Sofianos D, Berkes MB, Obrebsky WT. Prevention of perioperative infection. *J Bone Joint Surg Am.* 2007;89: 1605–1618.
11. Frances JM, Morris CD, Arkader A, Nikolic ZG, Healey JH. What is quality of life in children with bone sarcoma? *Clin Orthop Relat Res.* 2007;459:34–39.
12. Ginsberg JP, Rai SN, Carlson CA, Meadows AT, Hinds PS, Spearing EM, Zhang L, Callaway L, Neel MD, Rao BN, Marchese VG. A comparative analysis of functional outcomes in adolescents and young adults with lower-extremity bone sarcoma. *Pediatr Blood Cancer.* 2007;49:964–969.
13. Grimer RJ. Surgical options for children with osteosarcoma. *Lancet Oncol.* 2005;6:85–92.
14. Grimer RJ, Carter SR, Pynsent PB. The cost-effectiveness of limb salvage for bone tumours. *J Bone Joint Surg Br.* 1997;79: 558–561.

15. Gupta A, Meswania J, Blunn G, Cannon SR, Briggs TW. Stanmore non-invasive growing arthrodesis endoprosthesis in the reconstruction of complicated total knee arthroplasty: a case report. *Knee*. 2006;13:247–251.
16. Gupta A, Meswania J, Pollock R, Cannon SR, Briggs TW, Taylor S, Blunn G. Non-invasive distal femoral expandable endoprosthesis for limb-salvage surgery in paediatric tumours. *J Bone Joint Surg Br*. 2006;88:649–654.
17. Gupta A, Pollock R, Cannon SR, Briggs TW, Skinner J, Blunn G. A knee-sparing distal femoral endoprosthesis using hydroxyapatite-coated extracortical plates: preliminary results. *J Bone Joint Surg Br*. 2006;88:1367–1372.
18. Heck RK, Neel MD. Expandable prostheses for reconstruction after tumor resection in young patients. *Curr Opin Orthop*. 2006;17:532–537.
19. Henderson ER, Groundland JS, Pala E, Dennis JA, Wooten R, Cheong D, Windhager R, Kotz RI, Mercuri M, Funovics PT, Hornicek FJ, Temple HT, Ruggieri P, Letson GD. Failure mode classification for tumor endoprostheses: retrospective review of five institutions and a literature review. *J Bone Joint Surg Am*. 2011;93:418–429.
20. Henderson ER, Pepper AM, Marulanda GA, Millard JD, Letson GD. What is the emotional acceptance after limb salvage with an expandable prosthesis? *Clin Orthop Relat Res*. 2010;468:2933–2938.
21. Hillmann A, Hoffmann C, Gosheger G, Krakau H, Winkelmann W. Malignant tumor of the distal part of the femur or the proximal part of the tibia: endoprosthetic replacement or rotationplasty. Functional outcome and quality-of-life measurements. *J Bone Joint Surg Am*. 1999;81:462–468.
22. Hopyan S, Tan JW, Graham HK, Torode IP. Function and upright time following limb salvage, amputation, and rotationplasty for pediatric sarcoma of bone. *J Pediatr Orthop*. 2006;26:405–408.
23. Letson GD, D'Amato G, Windham T, Muro-Cacho C. Extendable prostheses for the treatment of malignant bone tumors in growing children. *Curr Opin Orthop*. 2003;14:413–418.
24. Lewis MM. The use of an expandable and adjustable prosthesis in the treatment of childhood malignant bone tumors of the extremity. *Cancer*. 1986;57:499–502.
25. Lewis MM, Bloom N, Esquieres EM, Kenan S, Ryniker DM. The expandable prosthesis: an alternative to amputation for children with malignant bone tumors. *AORN J*. 1987;46:457–470.
26. Marina N, Gebhardt M, Teot L, Gorlick R. Biology and therapeutic advances for pediatric osteosarcoma. *Oncologist*. 2004;9:422–441.
27. McClenaghan BA, Krajchich JJ, Pirone AM, Koheil R, Longmuir P. Comparative assessment of gait after limb-salvage procedures. *J Bone Joint Surg Am*. 1989;71:1178–1182.
28. Neel MD, Wilkins RM, Rao BN, Kelly CM. Early multicenter experience with a noninvasive expandable prosthesis. *Clin Orthop Relat Res*. 2003;415:72–81.
29. Otis JC, Lane JM, Kroll MA. Energy cost during gait in osteosarcoma patients after resection and knee replacement and after above-the-knee amputation. *J Bone Joint Surg Am*. 1985;67:606–611.
30. Rougraff BT, Simon MA, Kneisl JS, Greenberg DB, Mankin HJ. Limb salvage compared with amputation for osteosarcoma of the distal end of the femur: a long-term oncological, functional, and quality-of-life study. *J Bone Joint Surg Am*. 1994;76:649–656.
31. Scales JT, Sneath RS. The Extending Prosthesis. In: Coombs R, Friedlander G, eds. *Bone Tumour Management*. London, England: Butterworths; 1987:168–177.
32. Schiller C, Windhager R, Fellingner EJ, Salzer-Kuntschik M, Kaider A, Kotz R. Extendable tumour endoprostheses for the leg in children. *J Bone Joint Surg Br*. 1995;77:608–614.
33. Schindler OS, Cannon SR, Briggs TW, Blunn GW. Stanmore custom-made extendible distal femoral replacements: clinical experience in children with primary malignant bone tumours. *J Bone Joint Surg Br*. 1997;79:927–937.
34. Simon MA, Aschliman MA, Thomas N, Mankin HJ. Limb-salvage treatment versus amputation for osteosarcoma of the distal end of the femur. *J Bone Joint Surg Am*. 1986;68:1331–1337.
35. Stanitski DF. Limb-length inequality: assessment and treatment options. *J Am Acad Orthop Surg*. 1999;7:143–153.