Revision of Broken Knee Megaprotheses

New Solution to Old Problems

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Abstract

Background Low-cost indigenous megaprotheses used in the developing world are prone to mechanical failure but the frequency and causes are not well established.

Questions/purposes We retrospectively analyzed the causes of failure, particularly design, and suggest changes to reduce the breakage. We also report our experience with revision surgery.

Methods We identified 28 breakages in 266 megaprosthesis knee arthroplasties performed between January 2000 and December 2006. Twenty-six breakages were revised to another prosthesis. The complications were studied and the function was evaluated. Prostheses were studied for failure

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Each author certifies that all investigations were conducted in conformity with ethical principles of research.

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by the computer-aided design program SolidWorks® and Hyperworks® for finite element analysis (FEA). Design improvements were performed based on these results.

Results In 21 cases, the failure occurred at the stem-collar junction, the point of maximum stress predicted by FEA. Stainless steel implants were prone to failure. There was one early and one late infection. Three patients died of metastatic disease. The most difficult surgical step involved the removal of the well-cemented broken stem from the intramedullary canal. Musculoskeletal Tumor Society scores varied from 27 to 29 after revision. FEA revealed stress could be reduced by filleting the stem-collar junction and by two-piece stems.

Conclusions Revisions of broken total knee megaprotheses, though technically difficult, have allowed patients reasonable function. We recommend design analysis for custom prostheses to point to areas of weakness. Breakages can be reduced by using titanium stems and filleting the junction or by having two-piece inserted stems. Incorporating these changes has reduced the failures in our experience.

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

Introduction

Megaprotheses have been the backbone of limb salvage surgery. A large majority of tumors occur in the metaphyseal area in the bones around the knee and the principles of wide resection necessitate resection of the knee. Modern tumor endoprotheses have evolved in the last four decades and today have a reported survival rate of 75% to 90% at 5 years and 59% to 86% at 10 years

[2, 3, 5, 9, 14, 16, 18, 19]. Most failures are due to aseptic loosening in the modern era. Unlike in the past, modern prostheses reportedly have a very low breakage rate from 0% to 6% [7–9, 13, 16]. Limb salvage surgery has been expensive mainly due to the high cost of the prosthesis. High costs have been a major deterrent in development of limb salvage programs in the developing world.

Some surgeons, along with local implant manufacturers, have attempted to make some local affordable implants, but in most cases these were likely manufactured without proper knowledge of design and biomechanics, leading in our experience to catastrophic failures. In the year 2000, with the help of a local implant manufacturer, we began fabricating a very low-cost megaprosthesis to kick-start our limb salvage program [1]. The initial design was primitive and simplistic, but it gradually evolved as we learned from our failures; we had many breakages of the implant.

We asked the following questions: (1) What was the incidence of failure along with the common sites and causes? (2) What changes were required in the prosthesis to reduce the failures? (3) What were the technique and outcomes of revision surgery?

Patients and Methods

We implanted knee megaprotheses in 266 patients between January 2000 and December 2006. Of these implants, 210 (79%) were of Indian manufacture and 56 (21%) were imported. The Indian implant was initially a fixed stainless steel hinge (Fig. 1) custom made indigenously by machining from a block of stainless steel 316L (Electronic Supplementary Material). All implants were

cemented (Simplex, Stryker, NJ) with the second generation cementing technique using a gun after plugging the canal with a Hardinge cement restrictor. The imported implants were Howmedica Modular Resection System until 2005 and Global Modular Resection System thereafter (Stryker Orthopaedics, Mahwah, NJ). Of the 266 patients, 32 were lost to followup, leaving 234 available for evaluation. The minimum followup was 24 months except where the patient died of disease or implant was removed for infection, breakage or local recurrence (mean, 40 months; range, 3 to 108 months).

The 28 broken prostheses we encountered form the study group. Twenty-five of these occurred from implantations between January 2000–December 2006. Three were implanted prior to January 2000 (Table 1). The sites of breakage were analyzed. Computer-aided design (CAD) and finite element analysis (FEA) software were used to analyze failures (Electronic Supplementary Material). Different types of transitions in stem diameter were collected for comparative study of the strains involved (Fig. 2). This included a normal stem with sharp transition (Fig. 2A), chamfer or taper (Fig. 2B), filleted transition (Fig. 2C), and two-piece (separate pieces connected by Morse taper) (Fig. 2D). The goal was to find out which of these produced the least strain, which is indicative of the potential for failure. A normal stem geometry with a small diameter (10 mm), a large diameter (25 mm), and a length of 100 mm was modeled in the SolidWorks® CAD program (Dassault Systèmes SolidWorks Corp, Concord, MA). The three variations mentioned above were also modeled. They were imported in the preprocessing module Hyperworks® (Altair Engineering Inc, Troy, MI) of the finite element method program. Here a virtual load ranging of 360 N was

Fig. 1A–E Photographs illustrate the evolution of the indigenous prosthesis. (A) In the year 2000, a simple stainless steel fixed-hinge customized implant was made to start our limb salvage program. Note the sharp edges and the “squarish” condyle. The dimensions of the condyle portion and tibial tray were standardized and kept constant, with only the resection length and intramedullary stem diameter variable. The condyle size was kept small to fit all ages of patients and to facilitate easy closure. (B) In 2001, the condyle was made more rounded. Note the transverse grooves on the intramedullary stem. The

grooves were the site of breakage and were eliminated in (C) 2002. The intramedullary stem was now smooth and curved to match the anatomy. This resulted in very early loosening and we reverted to matt-finished stems with a longitudinal groove in (D) 2003. Bushings and bumpers were added to prevent metallosis. The central locking hinge pin failed in a few cases and it was a problem to access the notch in revisions due to the tight quadriceps. (E) The locking mechanism was changed to a circlip in 2005.

Table 1. Details of the patients experiencing breakages

Patient	Age (years)	Gender	Date of previous surgery	Date of revision	Time to failure (months)	Histology	Bone	Stem extraction method	Broken implant	Site of breakage	Revision implant	Disease status	Complication	MSTS before breakage	MSTS after revision
1	17	Female	Feb 1994	Dec 2000	81	OGS	F	C	Custom of unknown make	Stem-collar junction	TMH-NICE	DF	Breakage again	30	29
1	17	Female	Dec 2000	Jun 2008	90	OGS	F	W	TMH-NICE	Tibial base plate stem	GMRS	DF	Nil	29	27
2	20	Male	Aug 2000	Jan 2002	16	OGS	F	W	TMH-NICE	Transverse groove on stem	TMH-NICE	DF	Nil	30	27
3	15	Female	Oct 2000	Sep 2004	44	OGS	F	W	TMH-NICE	Transverse groove on stem	TMH-NICE	DF	Breakage again	30	28
3	15	Female	Sep 2004	Aug 2008	46	OGS	F	V	TMH-NICE	Stem-collar junction	GMRS	DF	Nil	28	27
4	35	Female	May 1993	July 2000	85	GCT	F	W	Custom of unknown make	Stem-collar junction	TMH-NICE	DF	Nil	Not recorded	28
5	17	Male	Aug 2001	Nov 2004	38	GCT	F	C	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Nil	30	28
6	14	Male	Jan 2000	Nov 2004	57	OGS		W	HMRS	Stem-collar junction	HMRS	DF	Infection; rotationplasty done	30	NA
7	16	Female	May 2001	Dec 2004	42	GCT	F	W	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Nil	30	27
8	13	Male	Oct 2001	May 2004	30	OGS	T	W	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Nil	30	27
9	25	Male	Oct 1997	Jan 2001	39	OGS	F	W	Custom of unknown make	Stem-collar junction	TMH-NICE	DF	Delayed infection; revised to arthrodesis	Not recorded	Not recorded
10	13	Male	Mar 2002	Jun 2004	26	OGS	F	W	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Nil	30	28
11	23	Male	June 2002	Dec 2005	41	OGS	T	W	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Nil	30	29
12	52	Male	Apr 2002	Nov 2003	18	OGS	F	C	TMH-NICE	Body	TMH-NICE	PM	Dead from disease	28	Not recorded
13	15	Male	Oct 2003	Jan 2005	14	OGS	T	W	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Breakage again	29	28
13	15	Male	Jan 2005	Apr 2009	50	OGS	T	V	TMH-NICE	Stem-collar junction	GMRS	DF	Nil	28	27
14	16	Male	Nov 2003	Mar 2006	27	OGS	T	W	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Nil	29	28

Table 1. continued

Patient	Age (years)	Gender	Date of previous surgery	Date of revision	Time to failure (months)	Histology	Bone	Stem extraction method	Broken implant	Site of breakage	Revision implant	Disease status	Complication	MSTS before breakage	MSTS after revision
15	19	Female	Sep 2003	Mar 2005	17	Parosteal OGS	T	W	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Breakage again at hinge at 54 months	29	28
16	19	Female	Sep 2003	Jun 2008	56	GCT	T	V	TMH-NICE	Body	GMRS	DF	Nil	30	28
17	15	Male	Mar 2003	Oct 2004	18	OGS	T	C	TMH-NICE	Stem-collar junction	TMH-NICE	PM	Dead from disease	29	28
18	26	Female	Jun 2004	Oct 2004	3	OGS	F	W	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Nil	Not recorded	28
19	20	Male	Sep 2004	Oct 2005	12	OGS	F	W	TMH-NICE	Stem-collar junction	TMH-NICE	DF	Breakage again at 24 months; revised to rotationplasty	30	28
20	17	Female	Dec 2004	Apr 2006	15	OGS	T	V	TMH-NICE	Stem-collar junction	ISQU	PM	Dead from disease	30	28
21	25	Male	May 2005	Jun 2008	36	OGS	F	V	TMH-NICE	Stem-collar junction	GMRS	DF	Nil	29	27
22	26	Male	June 2004	Jan 2007	30	OGS	T	W	TMH-NICE	Stem-collar junction	RESTOR	DF	Nil	30	28
23	24	Female	May 2003	Jul 2007	50	OGS	F	V	TMH-NICE	Stem-collar junction	RESTOR	DF	Nil	30	27

MSTS = Musculoskeletal Tumor Society score; OGS = osteosarcoma; GCT = giant cell tumor; F = femur; T = tibia; C = corticotomy alone; W = window made in bone; V = vise grip and hammering alone; TMH-NICE = Tata Memorial Hospital new indigenous customized prosthesis; HMRS = Howmedica modular resection system; GMRS = global modular resection system; ISQU = custom-manufactured implant (ISQU Orthopaedics, Capetown, South Africa); RESTOR = the indigenous modular prosthesis (Adler Mediequip, Ratnagiri, India) used in replacement of TMH-NICE by us since December 2006; DF = disease free; PM = pulmonary metastases; NA = not applicable.

Fig. 2A–D Various stem designs modeled using SolidWorks® software are shown: (A) stem with sharp transition from body; (B) stem with a fillet; (C) stem with a chamfer; and (D) a two-piece stem connected with a taper. The body is 25 mm and stem is 10 mm.

Fig. 3 Actual physical testing was performed on stems fabricated in stainless steel 316L using the geometry and shapes shown in Figure 2. The strain gauges on the stems measure the strain.

applied at a point 40 mm from the end of stem. Static structural analysis was performed using OptiStruct® (Altair Engineering Inc, Troy, MI). Strains and stresses were calculated at a distance of 90 mm from the end (10 mm from the large diameter). The four stems were also manufactured in stainless steel 316L. The large-diameter portion was gripped in two V-blocks in a fixture, and the loads ranging from 75 N to 360 N were applied 40 mm from the end of the small diameter. The strains were measured by mounting 5-mm, 120-Ω uniaxial strain gauges 90 mm from the end of stem (Fig. 3). The two sets of strains were compared.

The revision surgery to another megaprosthesis was performed in 26 of the 28 patients with broken implants.

One was converted to a rotationplasty and another patient refused any treatment. The revision surgery was performed through the same skin incision. After the exposure of the broken prosthesis, the prosthesis body was disarticulated from the hinge and removed. Before April 2006, the method of extracting the broken stem consisted of making a corticotomy and attempting to hammer the stem out (Fig. 4). If this was unsuccessful, the corticotomy was converted into a rectangular window to expose the stem and cement and the broken stem was removed. The window was then wired back with cerclage wires (Fig 4G). After April 2006, we initially removed a 2-cm ring of bone from the distal end to expose the stem (Fig. 4A–C). Cement was burred out from around the stem (Fig. 4D). The stem was then held with a vise grip and an attempt was made to hammer it out (Fig. 4E). If unsuccessful, then an anterior corticotomy was performed over a length of 5 to 7 cm and again an attempt was made to hammer the stem out with a vise grip and mallet. If this failed, the corticotomy was converted to a window (Fig. 4F). The 2 cm ring was discarded and the length compensated by a longer prosthesis. The new implant was then cemented in the usual way, ensuring the tip was above the proximal extent of the window. The corresponding mating component was changed if necessary. Extensive soft tissue release was often required, especially if the indigenous implant was replaced with an imported one, which was generally bigger. Before April 2006, a rectangular bone window was required in 13 of the 17 revisions (76%). The other four stems were extracted after a linear corticotomy. After April 2006, when we started using the ring corticotomy and vise grip to extract the stem, only three of the nine cases (33%) required a window in the bone. The other six were extracted with a vise grip alone (Table 1).

Postoperatively, patients were started on quadriceps-strengthening exercises and then allowed weightbearing ambulation unless a cortical window was used. In these cases, the patient was kept nonweightbearing for 3 months, giving adequate time for the window to heal.

We followed patients at 3 months then every 3 months or 6 months based on time since diagnosis of disease. Those within the first 3 years were followed up every 3 months until they completed 3 years from first surgery, then every 6 months until 5 years from first surgery, and then yearly. We used the Musculoskeletal Tumor Society (MSTS) score [6] for functional assessment.

Results

There were 25 breakages with the 183 indigenous prostheses (14.2%) implanted between January 2000 and December 2006. Three of the breakages occurred in custom

Fig. 4A–G Photographs illustrate the steps in extraction of a broken stem. (A) A ring osteotomy is performed about 2 cm above the bone end to expose (B) the embedded stem. (C) The stem is now exposed. (D) A high-speed burr is used to remove the cement at the mouth around the stem. (E) The stem is now held with a vise grip and

hammered out. (F) If unsuccessful, then a corticotomy is performed, and if the stem is still stuck, a window is made to clear the cement. (G) A postoperative radiograph shows the window put back and held with cerclage wires.

Fig. 5A–E Sites of stem failure are shown. (A) Breakage through the transverse groove was seen in two cases. This groove was eliminated after 2001. (B) The stem-collar junction is the highest stress area, which failed in 22 cases. This figure shows the failure at the base of the fillet. (C) Failure through the body is illustrated here. The thick threaded stem has transferred load to the thin wall of the body, which

has failed. This is a manufacturing flaw that has now been eliminated. (D) Failure through the tibial stem is seen in this rare instance. (E) Failure through the hinge wall in a proximal tibia is seen here. This happened in a patient who was revised 4 years earlier for failure at the stem-collar junction.

indigenous prostheses of unknown make implanted before January 2000. Only one of the 51 (2%) imported implants broke, at 57 months from surgery. The commonest site of breakage was the stem collar junction, which occurred in 22/28 breakages (Fig. 5A). Two breakages occurred through a transverse groove on the stem present in the first generation of the implant (Fig. 5B). Two breakages occurred through the body of the implant (Fig. 5C) and one

failure occurred in the tibial base plate at the junction of the stem with the base plate (Fig. 5D). One recent failure was seen through the hinge of proximal tibia prosthesis (Fig. 5E). Thirteen of 183 (7%) distal femur implants broke compared to 13 of the 73 (15%) proximal tibia prostheses. The breakages occurred during a period of 3 to 90 months with an average of 38 months. Most breakages occurred between 1 to 5 years. One broke at 3 months in

the body from a manufacturing defect and three broke after 6 years. The mean stem diameter in cases with breakage was 10.5 mm. Mean resection length was 135 mm. The failures were not related to either the weight or size of the patient or to the resection length. Manual labor was not a factor in any of the failures.

The trend of results from FEA and physical testing matched (Table 2). A gradual transition in diameter (chamfer or a fillet) decreased stress concentration and reduced strain equally (Fig. 6). Though the two-piece stem has the same strain as single piece-sharp transition at the measured location, it has better stress distribution, specifically, lower stress at the critical location (transition of diameters), making it superior to single piece-sharp transition stems.

Twenty-six of the 28 failures were revised to a new prosthesis (Table 2). The ring corticotomy technique described allowed easy extraction of the broken stem without the need for a window in two-thirds of the cases. There were two deep infections (7.6%). One patient with an early infection underwent a two-stage revision to a rotationplasty. Another patient presenting with late infection after seven

years underwent an arthrodesis. We had one intraoperative femoral fracture through the window made for stem removal. This was fixed with cerclage wires. Three patients died of metastatic disease. Three patients have asymptomatic radiographic loosening. The MSTS scores after revision were slightly lower than the prefracture status (Table 1) ranging from 27–29 in the 23 patients where an assessment was performed. In 20 breakages, the revision was performed to another indigenous implant and five of these broke again (20%) at periods ranging from 18 to 90 months. Three were revised to a new imported prosthesis. One is awaiting revision and one was converted to a rotationplasty after the second breakage at the patient's request. None of the six patients revised to an imported implant have failed.

Discussion

The use of titanium and chrome-cobalt alloy have reduced fatigue failure in megaprotheses [19]. A rotating hinge design combined with an HA coated or porous coated collar for extracortical bridging have improved longevity by reducing aseptic loosening [16, 19]. Internationally available megaprotheses incorporating these features are expensive and thus out of reach for a large majority of patients in a developing country like India. Since the implants are commercially profitable, the manufacturers are unwilling to share the technology. This forced us into making an effort to fabricate our own prosthesis. We had several challenges as it was difficult to find an industrial partner willing to invest in a technology that would be used in a small number of patients. We were successful in persuading a large local manufacturer of standard orthopaedic implants to make 15 fixed-hinge stainless steel megaprotheses annually in the downtime of their machines. We chose stainless steel as the material since it was easy to work with and would keep the implant cost low. Our early experience with these prostheses in limb salvage for osteosarcoma was reported in 2007 [1]. A low-cost but technically compromised implant is a reality in many developing countries and not well reported.

Fig. 6 A graph shows physical strain variation against applied loads. Fillet and chamfer designs show resistance to deformation than stems with sharp transition. Though the Two-piece stem shows more strain, it is distributed over a wider area improving the safety.

Table 2. Variance between predicted and experimental strain

Load (N)	Strain values (µε)							
	Normal stem		Chamfer		Fillet		Taper lock	
	Physical	Virtual	Physical	Virtual	Physical	Virtual	Physical	Virtual
115	568	521	475	519	467	500	495	487
135	734	612	568	610	575	587	591	579
155	909	703	661	701	670	673	681	661
175	1108	793	754	791	768	760	773	757

Guo et al. reported a 6.7% fracture rate from the indigenous stain steel implant fabricated in Beijing [10]. The lower breakage rate may be due to the rotating hinge design as well as a minimum stem diameter of 12 mm. Implant breakage has been a major problem in our series. The goal of this study was to analyze the failures and to find solutions. We believe this experience will help others facing a similar situation avoid the problems we encountered. Since revisions are necessary for the broken implants, we also report the technique and results of revision.

We note several limitations. First, the study is limited by the small number of cases and the relatively short followup. Second, the implant design has evolved over time and so has the technique of revision surgery, making it difficult to analyze subcohorts. However, there are very few studies on broken megaprotheses in the literature. Breakages have been reduced by using superalloys and a rotating hinge [9, 14, 16, 19]. These problems are restricted to the developing world and not typically faced by the surgeons of the developed world as the internationally available implants have already addressed these issues. This study also discusses the steps taken to improve the design to reduce the breakage. We believe this will be useful to surgeons from the developing world attempting to make a indigenous prosthesis. The surgical procedure of revising a broken stem is also discussed along with the functional outcome after such complicated surgery. Very little information is available in literature on both these points.

The intramedullary stem-collar junction is an area of high stress concentration and shows the highest incidence of failure. Stainless steel coupled with the smaller diameter of our intramedullary stem is probably the root cause of failure. The most common stem diameter used in our cases is 10 mm compared to 12–13 mm from other series [10, 19]. Capanna et al. [4] reported six fractures from 95 uncemented chrome-cobalt femoral stems: four in 10-mm stems and two in 13-mm stems with none in 16-mm stems. They concluded fractures occurred more frequently with small stem diameters and with greater quadriceps excisions. Gosheger et al. [9] reported a low rate of stem fracture in their series, but these failures occurred in stems with diameters less than 12 mm. After the initial few failures, we recruited the engineers from our engineering university to study the design and suggest improvements. Filleting was performed to reduce the stress concentration, but failures still occurred in the stainless steel stems. In sharp contrast, we saw only one failure from the 56 imported implants used in the same time period. In December 2006, our prosthesis system underwent a major transformation (ResTOR, Sushrut-Adler, Devrukh, India). The metal of the intramedullary stem was changed to titanium. The articulating portions of the femoral and tibial prostheses were now casted from chrome-cobalt alloy. The

Fig. 7 The modular prosthesis used from year 2006. The condyles and tibial base plate are from chrome-cobalt alloy and the intramedullary stems are made from titanium.

entire prosthetic system was now modular (Fig. 7). The stems in addition were either one piece filleted or two-piece taper-locked (Fig. 2C–D). The two-piece stem has an added advantage of ease of manufacture, modularity, and lower cost. No failures were seen from the 150 implants performed in the 36 months since then. This is notable considering, from our earlier experience, 12 of the 28 failures (43%) occurred within the first 30 months. Several approaches have been used by implant manufacturers to improve durability and performance since the first-generation hinged knee designs: (1) rotational freedom; (2) a deepened patella-femoral articulation to improve tracking; (3) metal-backed tibial base plates to improve polyethylene wear and prevent catastrophic failure of the hinge post; (4) an improved stem design to allow portions of press fit in the femoral diaphysis; (5) a porous-coated modular section to allow osseous ingrowth into the implant; and (6) better instrumentation for more accurate implantation [11]. We have taken a similar route in an attempt to “reinvent the wheel.” Biau et al. [3] also reported a high incidence of stem fractures and hinge failures with their first-generation Guepar 1 chrome-cobalt prosthesis. Design changes in Guepar 2 eliminated these, but the authors have not described the design change or the rationale for the change. Our observations demonstrate a proper analysis by engineers improves the design and therefore longevity of the implant. Our studies have shown FEA results match the trend of actual physical testing results. Encouraged by the early success, we have now undertaken the ambitious government-aided project of making a low-cost but technically high-quality knee prosthesis. Some of the best engineering brains in our country have worked alongside doctors to evolve a rotating-hinge prosthesis with hydroxyapatite-coated collars. Knee simulators have been

Table 3. Comparison with existing literature

Study	Year	Number of prostheses revised	Number of broken implants	No of failed revisions	Functional score after revision	Remarks
Inglis and Walker [12]	1991	40	0	16	Not done	4 needed third revision after 3 years High incidence of femur fracture around the stem High incidence of infection
Renard et al. [17]	1998	26	2	8	Worse in 3 Better in 2 Unchanged in 9	9 revisions were for polyethylene wear and these did not compromise function.
Shin et al. [20]	1999	52, 25 knees	9	12/35 prosthesis (7 aseptic loosening, 3 infection, 2 breakage)	Comparable to the scores after primary revision	The failure rate (33%) of revised prostheses was higher than that of the initial operation (25%).
Wirganowicz [21]	1999	64	10	2 (both loosening)	Slightly less or equal unless infection	9/48 revised to prosthesis failed again with 4 needing amputation Risk of revision failing no greater than risk of primary surgery
Mittermayer et al. [15]	2002	21	0	5 (all for aseptic loosening)	No deterioration after revision	No difference in the incidence of complications between primary procedure and revision
Agarwal et al. [current study]	2010	28	28	5/20 revised to prosthesis broke again	Same or slightly lower than primary	Only series dealing exclusively with broken implants

made to test these implants and benchmark them against the imported implants as a part of preclinical testing.

It may be argued we should not have begun with a compromised implant. However, many patients benefited from even these compromised implants. We did not judge the failure rate of 15% as catastrophic and we thought it acceptable in a situation where the imported implant was not an option (and where amputation or a rotationplasty would have been the alternative). The limb salvage surgery allowed many children to continue with education and adults to remain employed. The revisions have also been successful, with a low chance of amputation and a functional score the same or slightly lower than after primary surgery, with a risk of failure similar to that after primary surgery. Our observations match those of others (Table 3), with only a minor or no loss of function [15, 17, 20, 21]. In 1991 Inglis and Walker [12] reported poor outcomes with a revision for hinged prostheses. However, since then, there has been tremendous improvement in design and quality, and evolution to a rotating hinge and extracortical bridging has lowered the failure rates [16, 19].

There are several constraints when performing revision surgery. The quadriceps is often tight and it is difficult to get exposure into the notch. Besides releasing the

quadriceps, it is often necessary to get a lateral release, especially if the indigenous implant was revised to a bigger imported implant. The most difficult part of the surgery is the removal of the well-cemented broken stem from the bone. Initially, we had to use a window in $\frac{3}{4}$ of our cases. Now, with a ring osteotomy and extraction with a vise grip, a window is needed in only $\frac{1}{3}$ of the cases. This made the surgery easier and incurred less bone damage. There is no obvious difference in the functional outcome between a window and a ring osteotomy. The followup period in this study is likely not long enough to show the long-term impact on function and aseptic loosening.

We believe it important to analyze the failures and incorporate the design changes to reduce these failures. It is important to work as a team with engineers to evolve the implant. Though revision surgeries are complex, the functional scores have been equal to or slightly lower than those after primary surgery.

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