Clin Orthop Relat Res (2009) 467:2325–2334
DOI 10.1007/s11999-009-0777-y

SYMPOSIUM: PAPERS PRESENTED AT THE ANNUAL CLOSED MEETING OF THE INTERNATIONAL HIP SOCIETY

Proximal Femoral Reconstructions with Bone Impaction Grafting and Metal Mesh

Martín A. Buttaro MD, Fernando Comba MD, Francisco Piccaluga MD

Published online: 18 March 2009

Abstract Extensive circumferential proximal cortical bone loss is considered by some a contraindication for impaction bone grafting in the femur. We asked whether reconstruction with a circumferential metal mesh, impacted bone allografts, and a cemented stem would lead to acceptable survival in these patients. We retrospectively reviewed 14 patients (15 hips) with severe proximal femoral bone defects (average, 12 cm long; 14 type IV and one type IIIB using the classification of Della Valle and Paprosky) reconstructed with this method. The minimum followup was 20 months (average, 43.2 months; range, 20–72 months). Preoperative Merle D'Aubigné and Postel score averaged 4.8 points. With revision of the stem as the end point, the survivorship of the implant was 100% at one year and 86.6% at 72 months. The mean functional score at last followup was 14.4 points. We observed two fractures of the metal mesh at 31 and 48 months in cases reconstructed with a stem that did not bypass the mesh. Dislocation (3 cases) and acute deep infection (3 cases) were the most frequent complications. Patients with complete absence of the proximal femur may be candidates for biological proximal femoral reconstructions using this salvage procedure. Bone impaction grafting must be a routine technique if this method is selected.

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

Each author certifies that he has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
Each author certifies that his institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

M. A. Buttaro (✉), F. Comba, F. Piccaluga
Hip Surgery Unit, Institute of Orthopaedics "Carlos E. Ottolenghi," Italian Hospital of Buenos Aires, Potosí 4215 (C1199ACK), Buenos Aires, Argentina
e-mail: martin.buttaro@hospitalitaliano.org.ar

Introduction

Revision total hip arthroplasty with extensive femoral bone deficiency poses a considerable challenge to the orthopaedic surgeon. When the proximal femur is deficient or absent there are few options for reconstruction, including long distal fixation uncemented implants [1], proximal femur replacement stems [24, 35, 36], and allograft-prosthesis composites [2, 28]. Success rate varies from 55 to 84% at 2 to 11 years followup.

Impaction bone grafting has become an accepted technique to treat severe femoral bone loss during complex revision total hip arthroplasty (THA) procedures [14, 23, 25, 34, 37, 40]. One of the essential requisites for this method is containment of the impacted cancellous bone within the medullary cavity. In patients with segmental bone loss, this procedure can be performed with metal mesh on the outside of the femur [39, 40]. We have been using metal meshes to reconstruct femoral deficiencies since 1990. Because of favorable outcomes in the literature [15, 20, 25, 39] as well as in our patients [4] and laboratory tests [18], we extended the indication of these devices to reconstruct complete circumferential proximal cortical bone loss. However, this circumferential bone loss has been considered a contraindication for the impaction bone grafting technique in the femur by one group [39].

We asked three questions: (1) What is the short-term survival with reconstruction using a circumferential metal

mesh, impacted bone allografts, and a cemented stem in patients with massive bone loss of the proximal femur due to non-neoplastic conditions? (2) Could this method improve functional scores in cases with complete absence of the proximal femur? (3) What would be the complication rate in these complex patients?

Materials and Methods

We prospectively followed 14 patients (15 hips) with severe proximal femoral bone defects reconstructed with a circumferential metal mesh, impacted bone allografts, and a cemented stem between March 2000 and December 2006. During this same period, we revised 356 patients with bone defects using impacted bone allografts and a cemented stem. The right hip was affected in 12 cases and the left hip in three cases in the study group. Initial diagnosis was osteoarthritis in nine cases, developmental dysplasia of the hip in five cases, and rheumatoid arthritis in one case. The indications for revision surgery were septic failures in five cases, aseptic loosenings in three, and Vancouver type B3 [10] periprosthetic fractures in seven cases (two of these fractures were infected) (Fig. 1A–B). Two of these 15 cases had been previously operated in our institution. The patients presented an average of 2.2 previous hip surgeries (range, 1–4 surgeries). None of the patients died or were lost to followup. We (MB) collected data prospectively. We used our information sheet in which individual data are collected for every patient. Patients' average age was 67 years (range, 43–82 years); there was one male and 14 females. The average preoperative Merle D'Aubigné and Postel score [8] was 4.8 points. The minimum followup was 20 months (average, 43.2 months; range, 20–72 months). We had prior approval of our local ethics review board.

We classified femoral deficiencies radiographically before surgery and confirmed the class after removal of components during the procedure using the system reported by Della Valle and Paprosky [9] and the Endoklinik (Engelbrecht and Heinert) classification [12] (Table 1). There were 14 cases presenting a Type IV and one case with a Type IIIB defect using the system of Della Valle and Paprosky. In a type III femoral defect, the metaphysis is damaged severely and nonsupportive. There is some intact cortical bone present distal to the isthmus. In a type IV defect, there is extensive metadiaphyseal damage in conjunction with a widened femoral canal, the isthmus is nonsupportive, and distal fixation cannot be achieved [9].

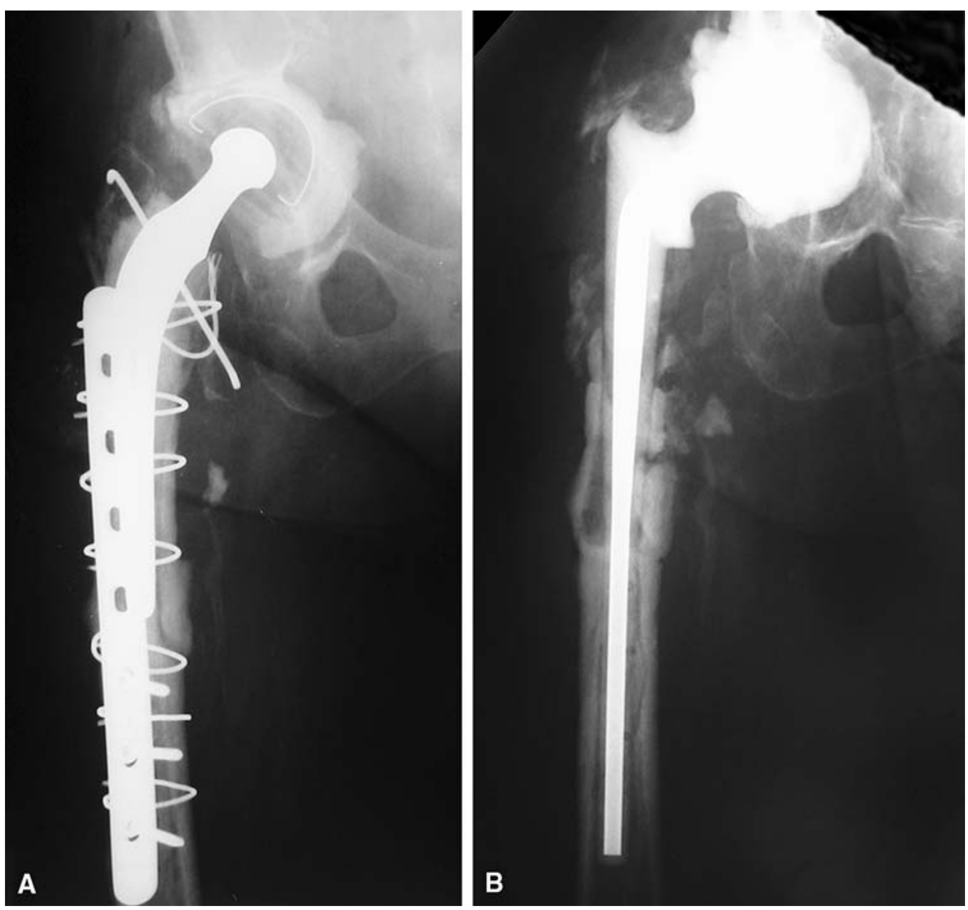

Fig. 1A–B Case 12. (**A**) Anteroposterior right hip radiograph of a septic failed Vancouver B3 (Duncan) periprosthetic fracture is shown. (**B**) Anteroposterior right hip radiograph after removal of components and implantation of a long antibiotic-loaded cement spacer with massive bone loss of the proximal femur is observed.

Table 1. Epidemiology

Case	Age	Diagnosis	Revision diagnosis	# Previous surgeries	MDA preop	Paprosky	Bone deficit (cm)
1	55	DDH	SL	4	6	4	12
2	61	DDH	AL	2	6	4	12
3	43	DDH	AL	2	7	**4**	15
4	75	OA	AL	1	7	4	10
5	69	OA	SL	3	6	4	15
6	73	OA	SL	3	5	**4**	11
7	82	OA	peripr. Fx	1	1	4	15
8	72	OA	SL	2	4	4	15
9	71	OA	SL	2	5	3B	9
10	64	DDH	SL	2	4	4	10
11	69	OA	peripr Fx + SL	3	4	4	13
12	80	OA	peripr. Fx	1	2	4	15
13	63	DDH	mesh Fx	3	6	4	10
14	64	RA	peripr. Fx	2	6	4	11
15	68	OA	peripr. Fx	2	4	4	12

DDH = developmental dysplasia of the hip; OA = osteoarthritis; AL = aseptic loosening; SL = septic loosening; peripr. Fx = periprosthetic fracture; mesh Fx = mesh fracture; MDA = functional Merle D'Aubigne and Postel score.

All the cases presented a Grade 4 Endoklinik deficiency, characterized by gross destruction of the proximal third of the femur with involvement of the middle third, precluding the insertion of even stemmed prosthesis [12]. The average height of the circumferential proximal femoral bone loss was 12 cm (range, 9–15 cm).

Five patients presented having had three previous transtrochanteric approaches, and one patient four previous transtrochanteric approaches. In four patients, severe major trochanteric osteolysis was present and in five the major trochanter was absent due to failed surgeries.

Surgeries were performed by the three authors (MB, FC, FP) following the general principles that have been described for the original impaction grafting technique [15]. Under epidural hypotensive anesthesia, a posterolateral approach was performed in 13 cases with an additional intrapelvic approach to remove an excessively protruded cup in one case and a transtrochanteric approach in two cases. The presence of active infection during one-stage surgeries or second-stage reimplantations was ruled out in all patients using intraoperative frozen section biopsy [33] and bacteriologic and pathologic analysis. All implants, polymethylmethacrylate, granulation tissue, and interface were completely removed and the remaining distal femur was identified. The removed failed femoral stems presented an average length of 14.4 cm (range, 12–26 cm) and they were all cemented except one uncemented implant.

The femoral metal mesh was 0.15 inches thick and had 2-mm^2 perforations. Fico® (Fico®, Buenos Aires, Argentina) metal mesh was implanted in 13 cases, and X-Change metal mesh (Stryker Howmedica, Newbury, UK) was used in two cases. To make reconstruction easier and to measure the length of the needed mesh, a proximal impactor is temporarily inserted as a form around which the meshes are bent. The meshes were fixed with three double cerclage metal circumferential monofilament wires (Ortron 90; diameter, 1 mm; DePuy Int., Leeds, UK, Warsaw, Ind.) (Fig. 2A). Approximately 10 cm of circumferential metal mesh was fixed to the remaining bone.

We obtained bone allografts from frozen femoral heads from our own bank following the protocol of the American Association of Tissue Banks for the harvesting and processing of grafts [13, 29]. We made the cancellous chips 7 to 10 mm with a grinder from the unwashed bone allografts and mixed for 15 minutes with 1 g dry powdered vancomycin (Lilly, Indianapolis, Ind.) per femoral head according to previous investigations [5]. Grafts were impacted according to the technique described by Gie et al. [15] using specific instruments (Primary Impaction Grafting Instruments; DePuy Int., Leeds, UK in 13 cases and Exchange Revision Instruments System; Stryker Howmedica Osteonics, Allendale, NJ in two cases). An additional three double cerclage wires were placed in the proximal mesh to contain the impaction force that was applied uniformly until rotational stability of the impactor was achieved. An average of 3.5 allograft femoral heads were needed per revision, including the acetabulum (range, 3–5). A cancellous bone thickness of 10 mm was intended to be obtained in the proximal part of the reconstructed femur (Fig. 2B).

We retrogradely injected bone cement CMW1 with gentamicin (DePuy, Warsaw, IN) in 13 cases and Simplex with tobramycin cement (Stryker Howmedica Osteonics,

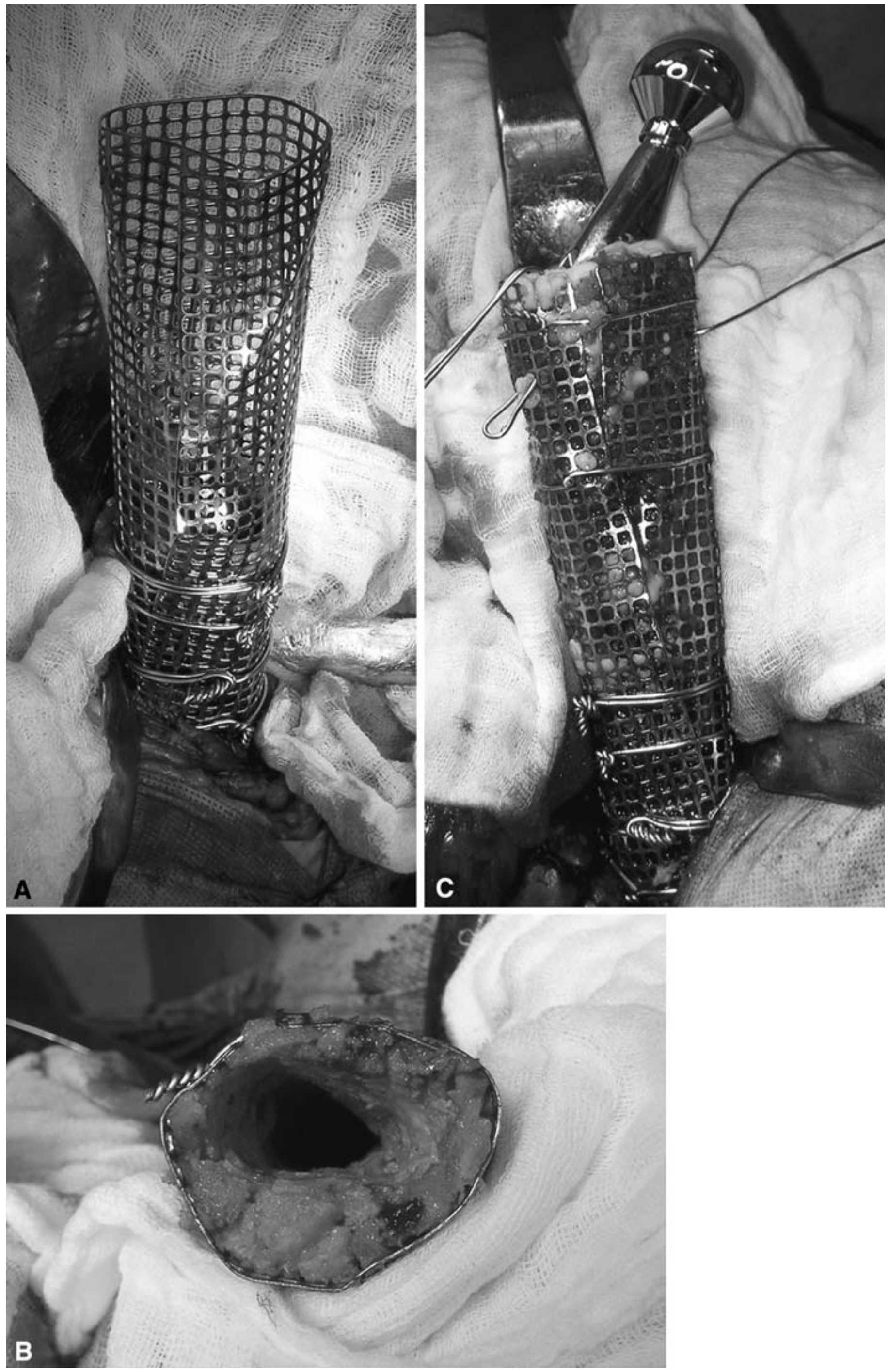

Fig. 2A–C Case 12. (**A**) This intraoperative photograph shows a distally fixed metal mesh wrapping the remaining femur. (**B**) Intraoperative aspect of the reconstructed femoral canal is observed prior to cementation. (**C**) This intraoperative photograph depicts the definitive cemented triple taper femoral stem before final reduction.

Rutherford, NJ) in two. A C-Stem (DePuy) (Ra 0.05 um) triple-taper polished femoral stem was implanted in 10 cases (Fig. 3), a Charnley stem (DePuy) (Ra 0.64 um) was cemented in three cases, and an Exeter stem (Stryker Howmedica Osteonics) (Ra 0.05 um) was used in two cases. The average length of the femoral stems was 222 mm (range, 130–260 mm). A 28-mm femoral head was implanted in 12 cases and a 22.225-mm in three cases. The femoral stems bypassed the circumferential mesh for an average of 5 cm (range, 1–9). The average operative time was 196 minutes (range, 150–240 minutes) (Fig. 3).

In aseptic cases we prescribed antibiotic prophylaxis with cefazolin 1 g every 8 hours for 48 hours. All patients with a previous infection received the same intravenous antibiotic treatment that had been used after the first stage; antibiotics were stopped when the infection was controlled. Routine prophylaxis for thromboembolic disease was continued for the first postoperative month. This consisted of intravenous

heparin during surgery, early postoperative mobilization, enoxaparin 0.4 mg in patients with a high clinical risk of thromboembolic disease (i.e., malignancy, particularly if associated with chemotherapy; antiphospholipid syndrome, immobility, or a history of venous thromboembolism; administration of tamoxifen, raloxifene, oral contraceptives, or estrogen; morbid obesity; stroke; atherosclerosis; and an American Society of Anesthesiologists physical status classification of 3 or greater), and aspirin 325 mg in patients with a low clinical risk [38]. We did not routinely prescribe prophylaxis against heterotopic calcification. The mean in-hospital transfusion requirements were 3.5 concentrated red blood cell units per case (range, 2–6).

The rehabilitation protocol included early mobilization 48 hours after surgery and ambulation with a walker and toe-touch weightbearing on the operated side for 90 days. After that, we encouraged patients to progressively weight bear as tolerated with the use of a cane for at least 1 month.

Two of us (MB, FC) evaluated patients clinically and radiographically at 15, 45, 90, and 180 days postoperatively and then yearly. We used the Merle D'Aubigné and Postel scoring system [8]. As a result of the presence of metal meshes and cerclage wires, we could not evaluate the incorporation of the graft. Femoral radiolucencies and periprosthetic osteolysis, defined as progressive bone loss in an area larger than 5 mm^2 were assessed in the distal part of the femoral stems, where metal mesh was not present. Femoral radiographic loosening of the Charnley stems was classified according to Harris and McGann in three categories: definitive, probable, and possible loosening [21]. Subsidence of the femoral stem was determined using the method described by Loudon and Charnley [26], which depends on measuring the distance from a selected (but variable) point in the femoral prosthesis to a fixed point in the bone.

One patient having repeat surgery agreed to have biopsy specimens from six of the seven zones described by Gruen et al. [17] through the fenestrations of the metal mesh using a 4-mm Jamshidi needle. These samples were evaluated by an independent orthopaedic pathologist.

We defined clinical failure as the need for further femoral revision irrespective of the reason. The radiographic definition of failure of the polished tapered stems was progressive migration by more than 5 mm in any direction on standard anteroposterior (AP) and lateral radiographs or mesh fracture. Success was defined as the presence of a functional hip prosthesis at the time of the latest followup. A functional hip was considered when pain was absent or slight during walking (with or without the use of a cane) without radiographic findings that indicated the possibility of a future operative intervention.

We determined survival using the Kaplan-Meier survival method using further femoral revision as the end point [22].

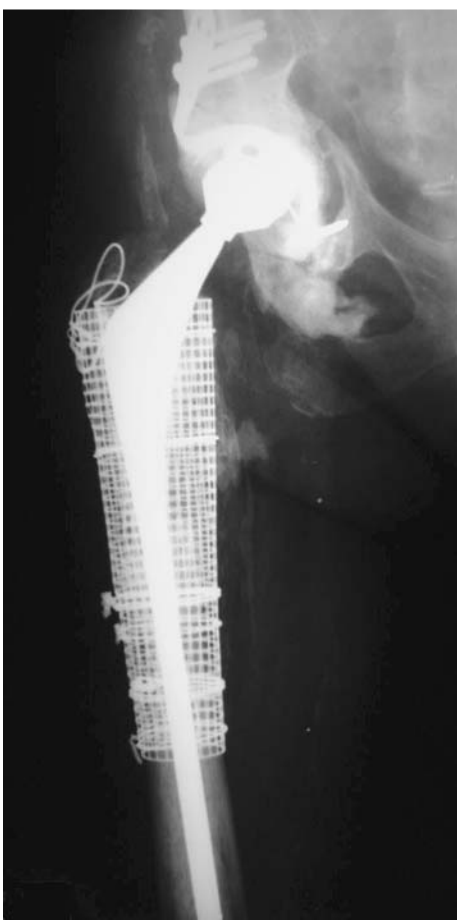

Fig. 3 Case 12. Anteroposterior radiograph of the right hip and proximal femur is observed at 5 years postoperatively.

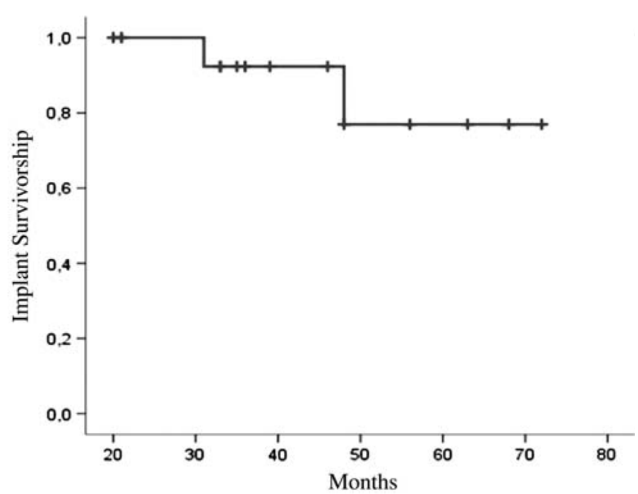

Fig. 4 Kaplan-Meier femoral survivorship analysis with revision of the stem as the end point is shown.

Table 2. Results

Case	Mesh length (cm)	Implanted stem	# Femoral heads	Followup (months)	MDA postop	CF	RF	Observations
1	15	Charnley	4	48	12	Yes	Yes	Mesh fracture at 48 months
2	15	Charnley	3	31	15	Yes	Yes	Mesh fracture at 31 months
3	18	Exeter	5	63	18	No	No	
4	11	Cstem	3	46	18	No	No	
5	15	Cstem	4	35	14	No	No	Infection, IDR + dislocation
6	18	Exeter	4	68	15	No	No	Infection, IDR + dislocation
7	18	Cstem	4	39	16	No	No	
8	13	Cstem	3	33	11	No	No	Dislocation
9	11	Cstem	3	56	18	No	No	
10	7	Cstem	3	33	16	No	No	
11	15	Cstem	4	48	15	No	No	
12	13	Cstem	3	36	14	No	No	
13	13	Charnley	3	72	15	No	No	
14	16	Cstem	3	21	12	No	No	Infection, IDR
15	17	Cstem	3	20	16	No	No	Dislocation

MDA postop = functional postoperative Merle D'Aubigne and Postel score; CF = clinical failure; RF = radiographic failure; IDR = irrigation, débridement, and retention of components.

Fig. 5 Case 2. Anteroposterior right hip radiograph with a fracture of the metal mesh at 31 months postoperatively is observed.

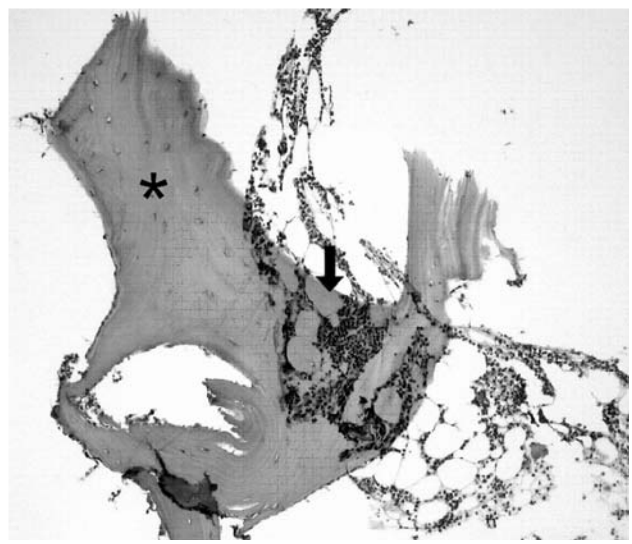

Fig. 6 Case 8. Histological sections from Gruen's [17] zone 5 with necrotic lamellar trabeculae are shown(*). Active bone marrow areas (black arrow) are observed (stain, hematoxylin-eosin; original magnification ×150).

Results

With revision of the stem as the end point, the survivorship of the implant was 100% at one year and 86.6% at 72 months (Fig. 4) (Table 2). Reoperation rate for any reason was 53%. Charnley stems showed no subsidence and none of the tapered femoral stems presented a more than 3 mm subsidence.

There was an improvement in the functional score from a mean of 4.8 to 14.4 points.

Radiographically five major trochanters were stable, there were four cases with a trochanteric pseudarthrosis, and

there were six cases with an absent trochanter. In 13 cases, we observed no femoral radiolucencies or periprosthetic osteolysis in the distal part of the femoral stems, where metal mesh was not present. None of these cases is awaiting femoral surgery and there were no radiographic signs of impending failure in any of these femurs at last followup. One patient presented a progressive acetabular migration that started with symptoms after 3 years postoperative and now is waiting for acetabular revision surgery. We observed two fractures of the metal mesh at 31 and 48 months in cases reconstructed with a short stem that did not bypass the mesh (Fig. 5). Both cases were the first two reconstructions and presented a Charnley stem that incompletely bypassed the metal mesh 1 cm in the first failure and 1.5 cm in the second one. The first failure was treated with an alloprosthesis, and fractured two osteosynthesis plates due to lack of the osteotomy consolidation. Three years after the mesh failure, a third surgery consisting of a distal osteotomy with a new alloprosthesis fixed with two plates showed the osteotomy consolidation. The second failure (Case 2) (Fig. 5) was treated with a new circumferential metal mesh, impacted bone allografts, and a long 200-mm cemented stem bypassing the mesh 6 cm (Case 13). One patient presented a single episode of dislocation that was treated nonoperatively with reduction and an abduction device for 6 weeks. No new episodes of dislocation were present at last followup in this patient. Three cases presented recurrent dislocations that needed open reduction. These dislocations were treated with trochanteric advancement and femoral head lengthening in one case, and femoral head lengthening in another case. Three acute deep infections were successfully treated with irrigation, débridement, antibiotics, and component retention.

Patient 8 presented with four episodes of recurrent dislocation and needed a constrained cup that was cemented into a stable acetabular reconstruction ring at 10 months postoperatively; the patient had agreed to biopsies of the grafted material. These showed the absence of lacunar nuclei, corresponding to necrosis of the lamellar trabeculae. Active bone marrow in some medullary spaces was present as well as reparative fibrous tissue with isolated reactive lymphocytes (Fig. 6).

Discussion

Revision total hip arthroplasty with extensive femoral bone deficiency is challenging to treat and when the proximal femur is deficient or absent there are few options for reconstruction. While extensive circumferential proximal cortical bone loss is considered by some a contraindication for impaction bone grafting technique, we have used this approach for some years. We therefore analyzed our data to see if the use of a circumferential metal mesh, impacted bone allografts, and a cemented stem in patients with massive bone loss of the proximal femur could provide an acceptable survival rate and improve functional scores with a similar complication rate as with other alternatives.

Limitations of this study include a small patient cohort with a short term followup and the lack of a control group of patients with similar age, weight, and femoral defects. Longer followup will determine whether any of these reconstructions will require more reoperations. We implanted three geometrically different stem designs, two with a polished surface finish and one with a matte finish.

Table 3. Results of non-neoplastic femoral revision surgery with massive bone loss using different methods

Author	Year	Reconstructive method	Cases	Success rate	Followup (years)	Complications
Malkani et al. [27]	1995	PFR prosthesis	50	64%	11	Dislocation 22%
Haentjens et al. [19]	1996	PFR prosthesis	16	ND	2–11	Dislocation 37%
						Infection 16%
						Intraoperative fractures 21%
Parvizi et al. [36]	2007	PFC prosthesis	43	73%	5	Reoperation rate 23%
						Fair or poor results 49%
Clarke et al. [7]	1998	APC	11	55%	5.5	Subsidence 18% Dislocation 27% Allograft fractures 18%
Blackley et al. [2]	2001	APC	48	77%	11	Infection 10% Loosening 6% Reoperation for allograft nonunion 6% Reoperation for dislocation 6%
Maury et al. [28]	2005	APC	25	84%	5	Unhealed osteotomies 16%
						Allograft resorption 24%
						Trochanteric migration 24%

PFR prosthesis = proximal femoral replacement prosthesis; ND = not determined; APC = allograft prosthesis composite.

One study suggested triple-tapered stems performed similar to double-tapered designs in primary THA [11]. In one study the Charnley stems in combination with impaction grafting achieved 93% survivorship at 54 months followup [37]. Other authors reported similar incidences of subsidence without clinical consequence [34, 39]. In a recently published single-surgeon experience on impaction grafting, no stems subsided more than 2.5 mm. Most of the stems (66%) demonstrated no measurable subsidence. The authors believed the vigorous impaction of bone graft with containment of the metaphysis of the stem with impacted bone graft was responsible for the minimal subsidence [25]. These patients presented different diagnoses, which included septic, aseptic, and traumatic situations. Different outcomes might have been obtained in one of these isolated situations. Although we had the opportunity to take bone biopsies and observe their histological appearance, the microscopic appearance of these sections seems inconclusive after 10 months postoperatively. Additional biopsies and autopsy retrievals of femurs reconstructed with this technique are needed to confirm our findings. However, the presence of active bone marrow may be interpreted as future areas of vascular invasion, remodeling bone graft, and new bone formation.

Reported treatment alternatives for these complex situations include modular fluted stems [1, 30], tumoral prostheses that replace the proximal femur [19, 27, 35, 36], and allograft-prostheses [2, 16, 28]. Revision arthroplasty with use of a modular fluted stem has been described as an option in these situations. However, stress due to the absence of proximal femoral bone support could be sufficiently high to put these implants at risk for fatigue fracture [6]. Furthermore, the long-term outcomes of such reconstructions are not yet available. Because of concerns about possible early failure, the use of modular prosthetic replacements (so-called megaprostheses) is typically reserved for elderly and sedentary patients as implantation can be performed in a more expeditious manner than other, more complex reconstructive procedures [19, 27, 35, 36]. The diaphyseal cement fixation predisposes the bone-cement-prosthesis to high torsional and compressive stresses leading to early loosening [35] (Table 3). Although allograft-prosthesis composite appears to provide better survival than proximal femoral replacement for the treatment of neoplastic conditions [41], complications including unhealed osteotomies, allograft resorption, trochanteric migration and dislocation are frequently described with this treatment method [2, 16, 28] (Table 3).

Although we could not find comparative data in the literature, we consider more than 15-cm segmental defects a contraindication for the use of circumferential metal mesh, impaction grafting, and a cemented stem. In these patients, we currently use an alloprosthesis composite. We also prefer this method in neoplastic conditions compromising the proximal femur [32]. However, it is essential to have a good bone quality in the distal femur in order to avoid unhealed osteotomies if an allograft-prosthesis composite is chosen [31]. Multiple failed previous surgeries, as well as a previous history of local infection (seven of our 15 cases) prompted us to avoid the use of a massive proximal femoral allograft. The fact that cancellous bone can act as an antibiotic carrier [5] and the 20 years' experience in our institution with the bone impaction grafting technique played a major role in the decision to use this surgical technique.

High survival and functional scores have been reported with the use of impaction bone grafting and metal meshes in segmental defects [14, 25, 39, 40]. We observed circumferential metal meshes, impaction bone grafts, and long cemented triple-tapered femoral stems presented a favorable initial resistance, reaching more than 600 kg to axial forces in bovine femurs [18].

Recent experimental reports recommend the use of open wire mesh instead of strut grafts for segmental femoral defect reconstruction in combination with impaction grafting to allow for optimal revascularization in an area with impaired vascularity [3]. Our histologic observations of biopsies obtained from impacted bone allografts contained by calcar femoralis metal mesh demonstrated morselized bone incorporation under these devices was not affected [4]. Although we observed signs of active hematopoietic bone marrow, osteoid and viable new bone apposition in the biopsied case, further investigations are needed to completely understand the biology of impacted bone allograft under circumferential meshes.

Dislocation was the most frequent complication in our series. Although it was observed in four of our 15 cases, this incidence is comparable to the ones reported with megaprosthesis [36] and allograft-prosthesis composites [7] (Table 3). Multiple failed previous surgeries through transtrochanteric approaches with an absent abductor mechanism and difficult proper leg length could explain this high incidence. This situation prompted us to consider constrained cups at first attempt in the last cases we performed this technique. We are also concerned about the high incidence of acute infections that might also be related to the number of previously failed surgeries and the prolonged operative time. Other authors have recently published up to 420 minutes of operative time with the use of megaprostheses [36]. Additional followup is essential to assess long-term outcomes of these reconstructions.

Although the incidence of complications in these patients was high, we believe this is related to the complexity of the cases. Failures of the system were not observed except in the two cases presenting technical defects. We recommend the use of long stems bypassing

the metal mesh in order to avoid fractures. We do not consider impaction grafting a contraindication in cases with as much as 15 cm absence of the proximal femur. However, we recommend the use of long stems bypassing the metal meshes. Patients with complete absence of the proximal femur due to non-neoplastic conditions for whom other available reconstructive procedures cannot be used may be candidates for biological proximal femoral reconstructions using circumferential metal mesh, impacted bone allografts and a cemented stem.

Acknowledgments We thank E. Santini Araujo, MD, Professor of Orthopaedic Pathology, and G. Santini Araujo, MD, for their collaboration on the histologic evaluation.

References

1. Berry DJ. Treatment of Vancouver B3 periprosthetic femur fractures with a fluted tapered stem. *Clin Orthop Relat Res.* 2003;417:224–231.
2. Blackley HR, Davis AM, Hutchison CR, Gross AE. Proximal femoral allografts for reconstruction of bone stock in revision arthroplasty of the hip. A nine to fifteen-year follow-up. *J Bone Joint Surg Am.* 2001;83:346–354.
3. Bolder SB, Schreurs BW, Verdonschot N, Veth RP, Buma P. Wire mesh allows more revascularization than a strut in impaction bone grafting: an animal study in goats. *Clin Orthop Relat Res.* 2004;423:280–286.
4. Buttaro M, Araujo GS, Araujo ES, Comba F, Piccaluga F. Viability of impacted bone allografts under metal mesh at the calcar in revision surgery of the hip. *J Bone Joint Surg Br.* 2008;90:228–231.
5. Buttaro M, Comba F, Piccaluga F. Vancomycin-supplemented cancellous bone allografts in hip revision surgery. *Clin Orthop Relat Res.* 2007;461:74–80.
6. Buttaro MA, Mayor MB, Van Citters D, Piccaluga F. Fatigue fracture of a proximally modular, distally tapered fluted implant with diaphyseal fixation. *J Arthroplasty.* 2007;22:780–783.
7. Clarke HD, Berry DJ, Sim FH. Salvage of failed femoral megaprostheses with allograft prosthesis composites. *Clin Orthop Relat Res.* 1998;356:222–229.
8. D'Aubigne RM, Postel M. Function al results of hip arthroplasty with acrylic prosthesis. *J Bone Joint Surg Am.* 1954;36:451–475.
9. Della Valle CJ, Paprosky WG. The femur in revision total hip arthroplasty evaluation and classification. *Clin Orthop Relat Res.* 2004;420:55–62.
10. Duncan CP, Masri BA. Fractures of the femur after hip replacement. *Instr Course Lect.* 1995;44:293–304.
11. Ek ET, Choong PF. Comparison between triple-tapered and double-tapered cemented femoral stems in total hip arthroplasty: a prospective study comparing the C-Stem versus the Exeter Universal early results after 5 years of clinical experience. *J Arthroplasty.* 2005;20:94–100.
12. Engelbrecht E, Heinert K. Klassifikation und Behandlungsrichtlinien von Knochensubsanzverlusten bei Revisionsoperationen am Huftgelenk mittelfrsige Ergebnisse. *Primare und Revisionsalloarthroplastik Hrsg-Endo-Klinik.* Hamburg, Germany: Springer-Verlag; 1987:189–201.
13. Fawcett K, Barr AR. *Tissue Banking* (American Association of Blood Banks). Basel, Switzerland: Karger; 1987:97–107.
14. Fetzer GB, Callaghan JJ, Templeton JE, Goetz DD, Sullivan PM, Johnston RC. Impaction allografting with cement for extensive femoral bone loss in revision hip surgery: a 4- to 8-year follow-up study. *J Arthroplasty.* 2001;16(8 Suppl 1):195–202.
15. Gie GA, Linder L, Ling RS, Simon JP, Slooff TJ, Timperley AJ. Impacted cancellous allografts and cement for revision total hip arthroplasty. *J Bone Joint Surg Br.* 1993;75:14–21.
16. Gross AE, Hutchison CR. Proximal femoral allografts for reconstruction of bone stock in revision arthroplasty of the hip. *Orthop Clin North Am.* 1998;29:313–317.
17. Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res.* 1979;141:17–27.
18. Guala AJ, Buttaro M, Piccaluga F. Initial stability of circumferential meshes with impacted bone allografts for massive femoral defects. *Int Orthop.* 2008;32:605–609.
19. Haentjens P, De Boeck H, Opdecam P. Proximal femoral replacement prosthesis for salvage of failed hip arthroplasty: complications in a 2–11 year follow-up study in 19 elderly patients. *Acta Orthop Scand.* 1996;67:37–42.
20. Halliday BR, English HW, Timperley AJ, Gie GA, Ling RS. Femoral impaction grafting with cement in revision total hip replacement. Evolution of the technique and results. *J Bone Joint Surg Br.* 2003;85:809–817.
21. Harris WH, McGann WA. Loosening of the femoral component after use of the medullary-plug cementing technique. Follow-up note with a minimum five-year follow-up. *J Bone Joint Surg Am.* 1986;68:1064–1066.
22. Kaplan E, Meier P. Nonparametric estimation from incomplete observations. *J Am Stat Assoc.* 1958;53:457–481.
23. Kim YH. Cemented revision hip arthroplasty using strut and impacted cancellous allografts. *J Arthroplasty.* 2004;19:726–732.
24. Klein GR, Parvizi J, Rapuri V, Wolf CF, Hozack WJ, Sharkey PF, Purtill JJ. Proximal femoral replacement for the treatment of periprosthetic fractures. *J Bone Joint Surg Am.* 2005;87:1777–1781.
25. Leone WA, Jr., Naughton M, Gratto-Cox G, Luland CM, Kilgore JE, Hill GE. The effect of preoperative planning and impaction grafting surgical technique on intraoperative and postoperative complication rate for femoral revision patients with moderate to severe bone loss mean 4.7-year results. *J Arthroplasty.* 2008; 23:383–394.
26. Loudon JR, Charnley J. Subsidence of the femoral prosthesis in total hip replacement in relation to the design of the stem. *J Bone Joint Surg Br.* 1980;62:450–453.
27. Malkani AL, Settecerri JJ, Sim FH, Chao EY, Wallrichs SL. Long-term results of proximal femoral replacement for non-neoplastic disorders. *J Bone Joint Surg Br.* 1995;77:351–356.
28. Maury AC, Pressman A, Cayen B, Zalzal P, Backstein D, Gross A. Proximal femoral allograft treatment of Vancouver type-B3 periprosthetic femoral fractures after total hip arthroplasty. *J Bone Joint Surg Am.* 2006;88:953–958.
29. Mowe JC, ed. *Standards for Tissue Banking*. Arlington, VA: American Association of Tissue Banks; 1988.
30. Murphy SB, Rodriguez J. Revision total hip arthroplasty with proximal bone loss. *J Arthroplasty.* 2004;19(4 Suppl 1):115–119.
31. Muscolo D, Ayerza M. Allografts. In: Callaghan JJ, Rubash HE, eds. *The Adult Hip*. Philadelphia, PA: Lippincott-Raven*;* 1998: 297–312.
32. Muscolo DL, Ayerza MA, Aponte-Tinao LA. Massive allograft use in orthopedic oncology. *Orthop Clin North Am.* 2006;37:65–74.
33. Nunez LV, Buttaro MA, Morandi A, Pusso R, Piccaluga F. Frozen sections of samples taken intraoperatively for diagnosis of infection in revision hip surgery. *Acta Orthop.* 2007;78:226–230.

34. Oakes DA, Cabanela ME. Impaction bone grafting for revision hip arthroplasty: biology and clinical applications. *J Am Acad Orthop Surg.* 2006;14:620–628.
35. Parvizi J, Sim FH. Proximal femoral replacements with megaprostheses. *Clin Orthop Relat Res.* 2004;420:169–175.
36. Parvizi J, Tarity TD, Slenker N, Wade F, Trappler R, Hozack WJ, Sim FH. Proximal femoral replacement in patients with non-neoplastic conditions. *J Bone Joint Surg Am.* 2007;89:1036–1043.
37. Piccaluga F, Gonzalez Della Valle A, Encinas Fernandez JC, Pusso R. Revision of the femoral prosthesis with impaction allografting and a Charnley stem. A 2- to 12-year follow-up. *J Bone Joint Surg Br.* 2002;84:544–549.
38. Salvati EA, Sharrock NE, Westrich G, Potter HG, Valle AG, Sculco TP. The 2007 ABJS Nicolas Andry Award: three decades of clinical, basic, and applied research on thromboembolic disease after THA: rationale and clinical results of a multimodal prophylaxis protocol. *Clin Orthop Relat Res.* 2007;459:246–254.
39. Schreurs BW, Arts JJ, Verdonschot N, Buma P, Slooff TJ, Gardeniers JW. Femoral component revision with use of impaction bone-grafting and a cemented polished stem. Surgical technique. *J Bone Joint Surg Am.* 2006;88(Suppl 1 Pt 2):259–274.
40. Sierra RJ, Charity J, Tsiridis E, Timperley JA, Gie GA. The use of long cemented stems for femoral impaction grafting in revision total hip arthroplasty. *J Bone Joint Surg Am.* 2008;90:1330–1336.
41. Zehr RJ, Enneking WF, Scarborough MT. Allograft-prosthesis composite versus megaprosthesis in proximal femoral reconstruction. *Clin Orthop Relat Res.* 1996;322:207–223.