Impaction bone-grafting of severely defective femora in revision total hip surgery

21 hips followed for 41–85 months

Frans C van Biezen, Bas L E F ten Have and Jan A N Verhaar

Department of Orthopaedic Surgery, University Hospital, PO Box 2040, NL-3000 CA Rotterdam, The Netherlands.
Tel +31 10–4634686. Fax –4634611
Submitted 99-02-10. Accepted 99-12-02

ABSTRACT – We performed a prospective study to evaluate the application of impacted allograft bone particles at revision surgery of severely defective femora. According to the Endo-Klinik classification, 21 hips had grade III or IV femoral defects, of which 4 had a preoperative fracture. No femoral re-revisions had been necessary after a mean follow-up of 60 (41–85) months. The mean Harris Hip Score improved by 39 points to 78 points. 2 fractures occurred postoperatively, 1 of which needed reoperation with osteosynthesis. 1 patient needed a closed reduction after dislocation. 4 stems showed significant subsidence (> 10 mm) in the follow-up radiographs. In total hip revision surgery, even severely damaged femora can be successfully treated by impaction allografting.

■

The introduction of impacted cancellous allografting of the deficient acetabulum combined with a cemented acetabular cup has created new opportunities in revision total hip surgery (Slooff et al. 1984). Gie and Ling used this technique to implant the polished, double-tapered Exeter prosthesis in the femur (Gie et al. 1993a). The first two published clinical studies showed promising short-term results (Gie et al. 1993b, Elting et al. 1995). However, recent studies have reported high rates of unpredictable early subsidence of the stem requiring re-revision (Eldridge et al. 1997, Meding et al. 1997).

To evaluate whether impaction bone-grafting is an adequate revision technique in severely defective femora, we present the results of a consecutive series of 21 stem revisions in femora with grade III or IV femoral defects, according to the Endo-Klinik classification.

Patients and methods

Patients

From September 1992 to September 1995, 18 women and 3 men (21 hips) were operated on and followed by one surgeon (FCB) (Table 1). The average age of the patients at the time of operation was 65 (33–82) years. In 9, this was the first revision procedure, in 9, the second, in 2, the third, and in 1 case, the fourth. The indication for revision surgery was aseptic loosening of the prosthesis in 19 hips, 4 of which were accompanied by a fracture of the femur due to severe bone loss. 1 painful porous-coated prosthesis was revised in 2 stages because removal of the primary hip prosthesis required splitting the femur. 1 patient had a Girdlestone situation for 10 years. All patients had grade III or IV femoral defects, according to the Endo-Klinik classification; they also had combined segmental and cavitary defects (Table 1).

Surgical procedure

We used the technique described by Gie (1993a), except for a lateral approach with an osteotomy of the greater trochanter. A cement plug was placed at least 2 cm distal to the new stem or the most distal cortical defect. The femoral canal was reconstructed by impacting allograft bone chips into

Table 1. Study population

No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	85	F	36	61	21	0	G	B	McKee Arden	IV	III+VI	C	y	C	A	A	10+54	0+30	C	A	y	I	I	30	1,4b-7
2	80	F	76	75	28	2	A	A	Müller	IV	III+V	C	y	C	B	D	12+26	0+20	D	A	y	I	I	4	–
3	79	F	69	58	20	1	A	A	Minneapolis	III	III	C	y	C	A	C	32+35	10+34	C	A	n	I	II	4	1
4	68	F	65	70	27	0	B	B	Charnley	IV	III+VI	B	y	C	A	B	16+51	0+44	D	C	n	I	II	30[b]	2-4a
5	62	F	79	68	23	1	A	A	Müller	IV	III	B	y	C	A	A	32+42	15+25	C	A	y	I	I	15	1-4a
6	71	F	33	76	24	1	C	D	Judet	IV	III+VI	B	y	B	A	A	39+9	10+20	B	A	n	II	II	3	1
7	60	F	43	57	21	3	D	C	Charnley	IV	III	B	n	D	F	A	32+40	10+34	D	C	y	II	III	3	–
8	64	F	72	52	20	0	D	A	Charnley	IV	III	B	n	D[a]	A	A	48+32	20+24	C	A	y	II	II	0	1
9	50	F	65	77	25	1	A	A	Osteonics	IV	III	C	n	B	A	A	36+35	10+20	C	A	n	I	II	32	2-4a
10	58	M	70	71	22	1	A	A	Charnley	III	III	B	y	D	A	A	65+20	30+10	C	B	y	II	II	6	–
11	62	F	58	58	23	0	B	A	McKee Arden	III	III	C	n	C	A	A	33+64	10+34	A	A	n	I	I	0	1
12	60	F	74	74	26	1	A	A	Charnley	III	III	A	y	A[a]	A	A	61+12	20+20	C	B	y	II	II	1	–
13	55	F	82	63	24	1	A	A	Minneapolis	III	III	B	n	C	A	B	42+44	10+34	A	A	n	II	III	5	1
14	62	F	66	63	28	0	F	A	Lord	III	III	A	n	D	A	B	58+30	30+10	A	A	y	I	II	0	1
15	53	M	41	70	24	2	E	A	Minneapolis	III	III	A	y	D	A	A	58+28	10+30	C	A	y	IV	IV	4	–
16	56	F	75	67	25	1	A	A	Stanmore	III	III	A	y	C	C	A	40+56	20+20	C	A	y	I	I	0	1
17	55	F	66	58	23	0	C	A	McKee Arden	III	III	B	n	C	A	A	41+56	20+24	C	B	y	I	I	6	–
18	46	F	75	60	22	1	A	B	Müller	IV	III+VI	C	n	C	A	A	4+74	0+44	C	A	y	I	I	1	–
19	42	F	73	93	34	0	E	A	McKee Arden	IV	III	B	n	C	B	A	61+26	30+10	C	A	y	I	I	1	–
20	41	M	56	61	21	0	B	A	Charnley	IV	III	C	y	D	A	A	70+8	30+0	A	B	n	I	I	4	1
21	45	F	78	50	23	0	F	B	Charnley	IV	III+VI	C	n	C	A	A	13+86	10+34	C	B	y	I	III	3	–

A Follow-up, months
B Gender
C Age
D Weight
E Quetelet index
F Number of previous revisions
G Primary disease
- A arthrosis
- B rheumatoid arthrosis
- C dysplasia
- D osteonecrosis
- E posttraumatic arthrosis
- F congenital dislocation
- G ankylosing spondylitis

H Revision indication
- A aseptic loosening
- B femoral fracture + loosened prosthesis
- C Girdlestone
- D mid-thigh pain

I Prosthesis removed
J Endo-Klinik defect classification I–IV
K AAOS defect classification I–VI
L Femoral reinforcement
- A none
- B Partridge cerclages + wire meshes + AO-acetabular plate
- C Partridge cerclages + wire meshes
- D Partridge cerclages
- E wire meshes + AO-acetabular plate

M Centralizer
- y yes
- n no

N Cup revision; [a] head diameter 22 mm
- A no
- B cemented Elite cup
- C cemented Elite cup + impacted bone graft
- D cemented Elite cup + impacted bone graft + massive bone graft

O Orthopedic complications
- A none
- B femoral fracture
- C dislocation
- D delayed wound healing
- E acetabular graft resorption
- F delayed wound healing + acetabular graft resorption

P Other complications
- A none
- B urinary tract infection
- C cardiac problem
- D urinary tract infection + cardiac problem

Q Preoperative HHS ± postoperative
R Preoperative pain score ± the postoperative increase
S Trendelenburg sign
- A pre- and postoperative negative
- B preoperative negative and postoperative positive
- C preoperative positive and postoperative negative
- D pre- and postoperative positive

T Preoperative trochanter
- A not osteotomized
- B osseous consolidated osteotomy
- C not osseous consolidated osteotomy

U Postoperative osseous consolidated trochanter
- y yes
- n no

V Brooker directly postoperative I–IV
W Brooker at latest follow-up I–IV
X Stem subsidence in millimeters; [b] varization of the stem
Y Radiolucent line between stem and cement in Gruen's zones

Legends to Table 1 continued

Endo-Klinik defect classification:
- I radiolucent lines confined to the upper half of the cement mantle; clinical signs of loosening
- II generalized radiolucent zones and endosteal erosion of the upper femur leading to widening of the medullary cavity
- III widening of the medullary cavity by expansion of the upper femur
- IV gross destruction of the upper third of the femur, with involvement of the middle third, precluding the insertion of even a long-stemmed prosthesis

AAOS defect classification:
- I segmental
- II cavitary
- III combined segmental and cavitary
- IV malalignment
- V femoral stenosis
- VI femoral discontinuity

the excavated femoral tube. The chips were obtained from fresh-frozen femoral heads, which were crushed to an average of 5 mm particles. Reinforcement of the vulnerable proximal femur with meshes, AO acetabulum plates and/or cerclage wires was often necessary to withstand the applied forces when allograft chips were impacted. Finally, a standard Exeter stem was cemented into the neomedullary canal with erythromycin and colistin-soaked Simplex cement. Reattachment of the greater trochanter was performed with a double cross-over wire and a compression spring, according to Wroblewski and Shelley (1985).

During the operation and the first 2 postoperative days, the patients received antibiotics (cefamandol nafate). Patients were confined to bed for the first 6 weeks. After 6 weeks of mobilization without weight bearing, patients were allowed to walk with crutches and gradually increase weight bearing. Most patients were fully weight bearing 6 months postoperatively.

Clinical evaluation

All patients were examined 1 day prior to the operation and postoperatively 3, 6 and 12 months, and annually thereafter. The mean follow-up was 60 (41–85) months, and all patients are still being followed. The Harris Hip Score (HHS) (Harris 1969) was used to evaluate pain and function. Because all patients were operated on with a transtrochanteric approach, we noted the presence of the Trendelenburg sign in relation to (non)consolidation of the greater trochanter.

Radiographic evaluation

The loss of bone stock was estimated with the preoperative radiographs and peroperatively-found defects. The classification systems of the Endo-Klinik (Engelbrecht and Heinert 1987) and the American Academy of Orthopaedic Surgeons (D'Antonio et al. 1993) were used.

Radiolucent lines between stem and cement, and between cement and bone, were noted in each of the 7 zones of Gruen et al. (1979). The amount of subsidence of the stem was determined by the methods of Loudon (Loudon and Charnley 1980) and Fowler et al. (1988) who subsequently used the trochanteric wires and space between the cement mantle and the proximolateral stem surface as a reference point. The most distinct distal point of osteosynthetic material was used as a reference point, if the trochanteric osteotomy was not consolidated.

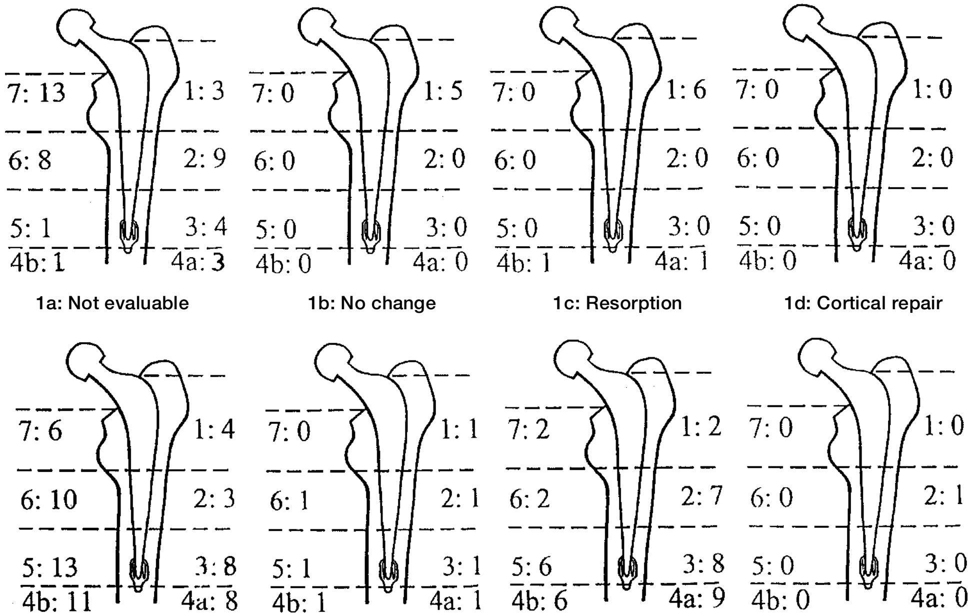
The radiographic pattern of the bone transplant was evaluated using the guidelines of Gie et al. (1993b), while distinguishing between cortical healing, trabecular incorporation and trabecular remodeling. Cortical healing is the postoperative thickening of the cortex compared to a preoperatively defective cortex, either through thinning of the cortex or endosteal scalloping. Trabecular incorporation is the trabecularization of the graft without any distinctive orientation. The distinctive trabecular network going from the endosteal cortex into the cement in the lines of the predominant stresses is called trabecular remodeling. Every zone of Gruen was evaluated and zone 4 was divided into two: zone 4a being the lateral part and zone 4b the medial part.

The extent of heterotopic ossification was graded using the classification of Brooker et al. (1973).

Results

Clinical results

To date, none of the stems has been re-revised. The mean HHS improved from 39 points to 78 points. The average pain-score improved by 25



1a: Not evaluable **1b: No change** **1c: Resorption** **1d: Cortical repair**

1e: Trabecular remodeling **1f: Trabecular incorporation** **1g: Cortical repair + remodeling** **1h: Cortical repair + incorporation**

Figure 1. Radiographic evaluation of graft in each Gruen zone in the study population. Of 168 zones, 126 were evaluable. Figures 1b–1h concern these 126 zones.

points to 39 points, postoperatively. 4 of the patients showed a positive Trendelenburg sign at the latest follow-up.

Radiography

The radiographic evaluation of the graft remodeling was difficult, for several reasons. The use of wires, meshes and plates disturbed the radiographic detail, especially in zone 7, where judgment of the graft was possible in only 8 of the 21 patients. We were able to evaluate 75% (126/168) of all zones (Figure 1). In 4% (5/126) of the zones, the graft showed no change at all, in 6% (8/126) of the zones, we noticed resorption, in 50% (63/126), trabecular remodeling, in 6% (7/126), trabecular incorporation, in 33% (42/126) cortical repair combined with trabecular remodeling and in 1% (1/126), cortical repair, combined with incorporation of the graft. All 21 patients had endocortical defects in, or more distal from, zone 4a or zone 4b. 10 patients had ectasial defects and 7 had segmental defects in, or more distal from, zone 4a or zone 4b. Table 2 shows the apparent cortical repair in zone 4a or zone 4b. 18 patients had at least cortical defects in zone 4a, of which 9 showed cortical repair (Figure 2), 5 cases showed no change in cortex, 1 case showed resorption and 3 zones were not evaluable. 15 patients had at least cortical defects in zone 4b, of which 6 showed cortical repair, 7 cases showed no change in cortex, 1 case showed resorption and 1 zone was not evaluable.

4 stems showed no signs of subsidence, 13 subsided 1–6 mm, and 4 stems subsided 15–32 mm (Table 1).

Table 2. Cortical repair in zones 4a and 4b

Defect localization	Patients	Cortical repair	Zone 4a	Zone 4b
All around	11	cortical repair	6	4
		no change	3	6
		resorption	1	1
		not evaluable	1	1
Anterolateral	6	cortical repair	3	
		no change	2	
		not evaluable	1	
Posteromedial	2	cortical repair		1
		no change		1
Anteromedial	1	cortical repair		1
Posterolateral	1	not evaluable	1	

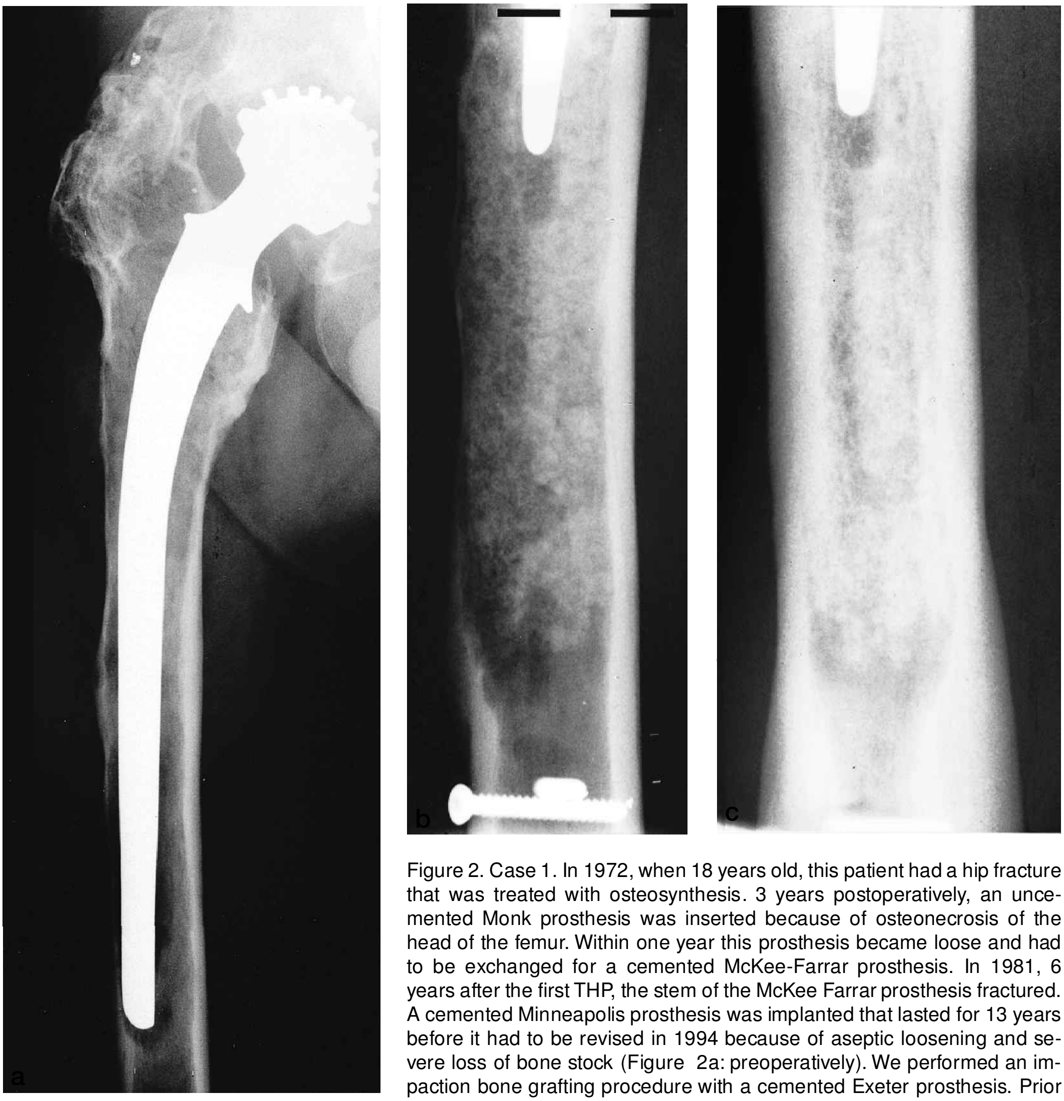


Figure 2. Case 1. In 1972, when 18 years old, this patient had a hip fracture that was treated with osteosynthesis. 3 years postoperatively, an uncemented Monk prosthesis was inserted because of osteonecrosis of the head of the femur. Within one year this prosthesis became loose and had to be exchanged for a cemented McKee-Farrar prosthesis. In 1981, 6 years after the first THP, the stem of the McKee Farrar prosthesis fractured. A cemented Minneapolis prosthesis was implanted that lasted for 13 years before it had to be revised in 1994 because of aseptic loosening and severe loss of bone stock (Figure 2a: preoperatively). We performed an impaction bone grafting procedure with a cemented Exeter prosthesis. Prior to the impaction of the bone particles, a screw was placed distal in the diaphysial region to prevent the cement plug from migrating more distally. At the latest follow-up, the patient had a Harris Hip Score of 86 points (pain score 40 points). He had returned to full-time work as a warehouse operator. Although the stem subsided 4 mm, there were no radiographic signs of loosening. Figures 2b (3 days postoperatively) and 2c (35 months postoperatively) show the graft remodeling in zone 4: the cortex has thickened, and the trabecular pattern shows a fully remodeled graft.

1 of the stems that subsided 30 mm was the only prosthesis that migrated into a varus position. No femora showed a radiolucency at the cement-graft interface, 17 patients had radiolucent lines at the stem-cement interface in zone 1 due to subsidence of the stem. All 4 severely subsided stems showed continuing radiolucent lines at the stem-cement interface from zone 1 into zone 4a, or from zone 7 into zone 4b. 3 of these stems subsided over 10 mm within the first postoperative year.

In 7 hips, the greater trochanter showed no osseous consolidation. 2 of the patients with a non-consolidated trochanter, and 2 with a consolidated trochanter had a positive Trendelenburg sign.

The 4 extensively subsided stems all had grade IV femoral defects with the Endo-Klinik classification. 2 of them also had a preoperative shaft fracture. They all had at least 1 segmental defect and a complete cortical defective and hollowed proximal femur 8 cm or more below the lesser trochanter.

Complications

3 months postoperatively, 1 patient (Table 1, No. 19) had a postoperative fracture, just distal to the prosthesis, which was operated on and fixed with a plate. This patient had a segmental defect in zone 5, and the proximal femur was completely excavated down to 10 cm distal to the lesser trochanter. At the latest follow-up the fracture had consolidated with a fully remodeled graft with no change of the cortex in zone 4a, cortex repair in zone 4b and no signs of loosening of the stem.

1 patient (No. 2) had a fissure of the femur just beneath the tip of the prosthesis following a fall at 4 1/2 months postoperatively. This patient had a segmental defect in zone 4a and in zone 4b, and the proximal femur was ectatic as far down as 13 centimeters distal to the lesser trochanter. The fissure was successfully treated conservatively with bed rest and mobilization without weight bearing. At the latest follow-up, we saw a fully remodeled graft with cortical repair in zones 4a and 4b.

Patient No. 16 underwent closed reduction of a prosthesis dislocated 3 years postoperatively.

1 patient (No. 7) had delayed wound healing. 9 months postoperatively, this patient was operated on again, because severe resorption of a massive acetabular allograft required a cup revision with another allograft augmentation.

Other types of complications included urinary tract infections in 4 patients and cardiac problems in 2.

Discussion

The introduction of impacted allograft bone particles in revision surgery of total hip prostheses is a good way to ensure a relatively stable fixation of the revision prosthesis. The few retrieval and biopsy studies of human femora (Ling et al. 1993, Nelissen et al. 1995), and the histological studies in goats (Schreurs et al. 1994) indicate that the impacted graft consolidates and becomes incorporated into the patient's femur. In this way, the repaired femoral bone stock can again withstand long-term usage of the prosthesis. Cadaveric studies have shown good mechanical properties of impacted allograft with little translational and rotational displacement of the cemented prosthesis after repeated cycles (Berzins et al. 1996, Malkani et al. 1996). Radiographic evaluation of the remodeling process of the graft remains difficult. There is no consensus about the assumption that radiographic signs of trabecular remodeling, incorporation, and cortical repair in fact occur in vivo.

Besides a considerably longer follow-up, our patients had more severe defective femora than in other studies. We had no stem re-revisions and very low complication rates for femoral fractures and dislocations. After a mean follow-up of 30 months (minimum 18 months), Gie (1993b) reported 2 revisions in 56 hips. Elting (1995) had 2 of 56 stems revised after a mean follow-up of 31 months (minimum 24 months), and Meding et al. (1997) 2 of 34 stems after a mean follow-up of 30 months (minimum 24 months). According to the Endo-Klinik classification, the studies by Gie and Elting showed that 13/56 and 15/56, respectively, of the patients had femoral defects grade III or IV. In the studies by Elting and Meding, 25/56 and 8/34 of the patients, respectively, had segmental defects, possibly combined with cavitary defects. Gie reported 1 postoperative fracture treated with reduction and plating, Elting and Meding reoperated on 2 postoperative femoral fractures. Dislocations occurred in 1 patient in Meding's group, in 3 in Gie's group, and in 6 in Elting's material, of whom 2 needed reoperation.

According to the Exeter group, the polished and double-tapered shape of the Exeter stem enables it to subside into the cement mantle giving optimal radial force transmission from the stem onto the surrounding cement, graft and host bone, thereby providing essential mechanical stimulation for the bone to remodel (Fowler et al. 1988, Gie et al. 1993b). Provided there is a sufficiently thick cement mantle, the creep ability of acrylic cement will allow the stem to subside (to some degree), without fracturing the cement mantle (Verdonschot and Huiskes 1997). However, it has been asked whether it is possible to acquire a sufficiently thick cement mantle with the Exeter system impactors (Masterson et al. 1997). We could not always see whether the stem subsided into the cement, or the cement mantle or the graft subsided into the femur.

Eldridge et al. (1997) studied 79 patients with a mean follow-up of 13 months and found 9 stems with subsidence of more than 10 mm. All 9 patients had initial thigh pain postoperatively, whereas our patients with extensively subsided stems did not. Meding et al. (1997) expressed their concerns about the high rate (13/34) and unpredictable nature of early subsidence that they found in their group of operated patients. Other investigators suggested inadequate impacting of the bone chips as a possible reason for early massive subsidence (Eldridge et al. 1997, McLaren et al. 1998), thereby compromising the initial and long-lasting stable conditions of the graft that are necessary to allow the process of osteoconduction and osteoinduction (Goldberg and Stevenson 1987, Stevenson et al. 1996). Kuiper et al. (1998) performed a mechanical study and found that the extent of subsidence during impaction was a logarithmic function of the number of impaction blows. The subsidence measured after cycled loading of a cemented tapered stem into the impacted graft also appeared to be a logarithmic function of the load cycle. To obtain an initially stable fixed stem, with a relatively predictable early postoperative subsidence pattern, this study indicates that impaction should be continued until there is little, if any, sinkage of the impactor with each impaction blow.

In our series, the 4 stems with more than 10 mm subsidence showed continuing radiolucent lines between the stem and the cement layer, indicating that a fracture of the cement mantle had occurred. These femora had extensive cancellous and cortical defects, which needed a substantial amount of bone graft, that may have not been impacted firmly enough. They were not re-revised because of a lack of clinical deterioration, and the radiographs suggested that consolidation of the graft had occurred at the graft-host interface.

Questions remain about the osteoconductive limits of a deficient femoral endosteum. Moreover, there is a limit to the amount of graft needed to ensure the necessary stable conditions for the graft to become remodeled into viable bone. Per- and postoperative care are essential for patients with a vulnerable cortex around the tip of the prosthesis. The remodeling process of the graft, especially cortical repair, will, in most cases, make for a strong and healthy proximal femur that can again withstand the forces from the pelvis onto the femur. The good clinical results and the appearance of graft incorporation with good initial and long-lasting stem fixation for most of the prostheses in our series indicate that impaction grafting is a reliable procedure for even severely damaged femora. The extent of subsidence for the long-term prognosis remains to be established.

Berzins A, Sumner D R, Wasielewski R C ,Galante J O. Impacted particulate qllograft for femoral revision total hip arthroplasty. J Arthroplasty 1996; 11: 500-6.

Brooker A F, Bowerman J W, Robinson R A, Riley L, Jr. Ectopic ossification following total hip replacement. Incidence and a method of classification. J Bone Joint Surg (Am) 1973; 55: 1629-32.

D'Antonio J, McCarthy J C, Bargar W L, Borden L S, Cappelo W N, Collis D K, Steinberg M E, Wedge J H. Classification of femoral abnormalities in total hip arthroplasty. Clin Orthop 1993; 296: 133-9.

Eldridge J D, Smith E J, Hubble M J, Whitehouse S L, Learmonth I D. Massive early subsidence following femoral impaction grafting. J Arthroplasty 1997; 12: 535-40.

Elting J J, Mikhail W E, Zicat B A, Hubbell J C, Lane L E, House B. Preliminary report of impaction grafting for exchange femoral arthroplasty. Clin Orthop 1995; 319: 159-67.

Engelbrecht E, Heinert K.. Klassifikation und Behandlungsrichtlienen von Knochensubstanzverlusten bei Revisionsoperationen am Huftgelenk — mittelfristige Ergebnisse. In: Primär- und Revisions-Alloarthroplastik, Hüft- und Kniegelenk: 10 Jahre Endo-Klinik Hamburg. Springer Verlag Berlin 1987: 189 - 201.

Fowler J L, Gie G A, Lee A J, Ling R S. Experience with the Exeter total hip replacement since 1970. Orthop Clin North Am 1988; 19: 477-89.

Gie G A, Linder L, Ling R S, Simon J P, Slooff T J, Timperley A J. Contained morselized allograft in revision total hip arthroplasty. Surgical technique. Orthop Clin North Am 1993a; 24: 717-25.

Gie G A, Linder L, Ling R S, Simon J P, Slooff T J, Timperley A J. Impacted cancellous allografts and cement for revision total hip arthroplasty. J Bone Joint Surg (Br) 1993b; 75: 14-21.

Goldberg V M, Stevenson S. Natural history of autografts and allografts. Clin Orthop 1987; 225: 7-16.

Gruen T A, McNeice G M, Amstutz H C. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop 1979; 141: 17-27.

Harris W H. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J Bone Joint Surg (Am) 1969; 51: 737-55.

Kuiper J H, Netzet B, Pollitine P, Mohommed A, Northmore-Ball M D, Richardson J B. Bone density and particle size distribution influence early mechanical stability and cement penetration in impaction grafting, Eighth Annual Meeting of the European Orthopaedic Research Society, Amsterdam, The Netherlands 1998.

Ling R S, Timperley A J, Linder L. Histology of cancellous impaction grafting in the femur. A case report. J Bone Joint Surg (Br) 1993; 75: 693-6.

Loudon J R, 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: 450-3.

Malkani A L, Voor M J, Fee K A, Bates C S. Femoral component revision using impacted morsellised cancellous graft. A biomechanical study of implant stability. J Bone Joint Surg (Br) 1996; 78: 973-8.

Masterson E L, Masri B A, Duncan C P, Rosenberg A, Cabanela M, Gross M. The cement mantle in femoral impaction allografting. A comparison of three systems from four centres. J Bone Joint Surg (Br) 1997; 79: 908-13.

McLaren A C, Brown S G, Lucero E M. Early failure of impaction bone grafting for revision total hip replacement, Scientific Program of the 1998 Annual Meeting of the American Academy of Orthopaedic Surgeons, San Francisco, United States of America 1998.

Meding J B, Ritter M A, Keating E M, Faris P M. Impaction bone-grafting before insertion of a femoral stem with cement in revision total hip arthroplasty. A minimum two-year follow-up study. J Bone Joint Surg (Am) 1997; 79: 1834-41.

Nelissen R G, Bauer T W, Weidenhielm L R, LeGolvan D P, Mikhail W E. Revision hip arthroplasty with the use of cement and impaction grafting. Histological analysis of four cases. J Bone Joint Surg (Am) 1995; 77: 412-22.

Schreurs B W, Buma P, Huiskes R, Slagter J L, Slooff T J. Morsellized allografts for fixation of the hip prosthesis femoral component. A mechanical and histological study in the goat. Acta Orthop Scand 1994; 65: 267-75.

Slooff T J, Huiskes R, van Horn J, Lemmens A J. Bone grafting in total hip replacement for acetabular protrusion. Acta Orthop Scand 1984; 55: 593-6.

Stevenson S, Emery S E, Goldberg V M. Factors affecting bone graft incorporation. Clin Orthop 1996; 324: 66-74.

Verdonschot N, Huiskes R. Acrylic cement creeps but does not allow much subsidence of femoral stems. J Bone Joint Surg (Br) 1997; 79: 665-9.

Wroblewski B M, Shelley P. Reattachment of the greater trochanter after hip replacement. J Bone Joint Surg (Br) 1985; 67: 736-40.