Reconstruction of bone defects with impacted allograft in femoral stem revision surgery

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Abstract A retrospective clinical review was done on 54 revision hip patients. Radiological analysis examined the Gross and AAOS classifications, stem position, cement mantles, allograft and evolution (subsidence, resorption and remodelling). The Harris Hip score was used for clinical assessment. We used bone bank allograft and a polished non-collared stem LD. The follow-up period was 60.5 months (19.4–152.4), and the average age 68.5 (range: 22–85). There were 21 females and 33 males. The surgical approach was: lateral (5.56%) posterior (91.4%); trochanteric osteotomy: 25.9%; associated acetabular revision: 59.3%; previous operations: 1.9. The preoperative Harris score was 35 (28–40) and rose to 81 (50–99) postoperatively. The stem alignment was neutral (44.44%), varus (38.89%) and valgus (16.67%). The femur/stem diameter relationship was 1.8 (1.2–2.7). There were no changes in stem alignment in 94.4%. An adequate cement mantle was: proximal zone (61.1%), medium zone (27.8%) and distal zone (16.7%). The rate of any subsidence was 38.9% (progressive: 12.96%). The rate of complications was 40.7% and included periprosthetic fracture: 14.8%; superficial infection: 1.9%; deep late infection: 1.9%; dislocation: 3.7%; heterotopic ossification: 13%. The rate of new stem revision was 16.6%. The clinical and radiological success rate was 77.78%. A greater incidence of

revisions has been found in stem malalignment, progressive subsidence, a Harris increase of <20 points, allograft resorption, small diameter stems and inadequate cement mantle. We recommend hard impaction and a cement mantle of at least 2 mm. Non-progressive subsidence does not increase stem loosening. The technique has been useful in recovering bone stock in a severely defective femur and achieves a stable reconstruction. The level of evidence was therapeutic study level III-2 (retrospective cohort study; see the instructions to the authors for a complete description of the levels of evidence).

Résumé Une étude rétrospective a été réalisée chez 54 patients avec une analyse radiographie, selon la classification de Gross et de l'AAOS avec analyse de la position de la pièce fémorale, de l'aspect du manteau de ciment et de l'évolution de l'allogreffe (migration, résorption, remodelage). Les évaluations cliniques ont été réalisées selon le score de Harris. Nous avons utilisé une allogreffe de banque et une pièce fémorale polie sans appui sur le Merckel (LD). Le suivi a été de 60.5 mois (19.4 à 152.4), l'âge moyen de 68.5 (22 à 85). Vingt et un patients étaient de sexe féminin et 33 de sexe masculin. La voie d'abord a été latérale (5.56%), postérieure dans 91.4%. L'ostéotomie du grand trochanter a été réalisée dans 25.9%. Une révision de la cupule acétabulaire a eu lieu dans 59.3%. Tous ces patients présentaient en moyenne 1.9 intervention, le score préopératoire de Harris était de 35 (28 à 40) et postopératoire de 81 (50 à 99). La pièce fémorale était en position neutre dans 44.44%, en varus dans 38.89% et en valgus dans 16.67%. La relation entre le diamètre du fémur et la pièce fémorale était de 1.8 (1.2–2.7). Aucune modification de la pièce fémorale n'a été observée dans 94.4% des cas avec un bon aspect du manteau du ciment proximal dans 61.1%, médial (27.8%), distal (16.7%).

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Aucune migration n'a été observée dans 38.9% (progressive: 12.96%). Les complications sont au nombre de 40.7%: fracture périprothétique 14.8%, infection superficielle 1.9%, infection profonde 1.9%, luxation 3.7%, ossifications hétérotopiques 13%, nouvelle révision 16.6%. Nous avons observé un succès dans ré-intervention dans 77.78%. En conclusion, les critères de révision ont été la mauvaise position de la pièce fémorale et une migration progressive de celle-ci, un score de Harris inférieur à 20 points, une résorption de l'allogreffe, une petite diamètre de la pièce fémorale et un aspect inadéquat du manteau de ciment. Nous recommandons l'impaction à frottement dur avec un manteau de ciment d'au moins 2 mm. Aucune migration progressive ne doit survenir. Cette technique est utile pour retrouver un bon stock osseux.

Introduction

The challenge of revision hip arthroplasty is related to osteolysis and bone loss preventing immediate stability of the implant. There are many variations: cemented revision stems with mechanical failure due to a lack of bone-cement interdigitation, proximally coated long stems with poor ingrowth and high rates of femoral fractures, extensively porously coated stems with proximal stress shielding, megaprotheses with high rates of dislocation and modular stems. The Sloof-Ling technique tries to create a new endosteal surface-to-host cemented stem with reconstruction of cavitory defects using impacted cancellous allograft to achieve primary stability and restore bone stock. The Exeter [10, 15, 23] and the Nijmegen groups have pioneered the technique with good results.

Mechanical tests show that freeze-dried allograft is weaker under compression than fresh deep-frozen allograft. Allograft incorporation exhibits primary union followed by remodelling. Unlike cortical grafts allografts do not suffer osteoclastic invasion, and osteoblasts deposit osteoid, mixing with the dead graft and increasing the mechanical resistance [4, 21]. This occurs throughout the graft [11] as indicated by the increased radiological density. Impacted cancellous allografts behave in a manner in between those of cortical and cancellous grafts, being nearly as resistant as cortical grafts, but with the biological properties of cancellous grafts. The greater the size of the graft, the lower the incidence of subsidence and the degree of impaction correlates with stability. In vitro specimens behave partially as a cemented stem and a partially a non-cemented stem [1] to achieve stability. In vivo analysis shows an increasing stability in a few weeks [3, 21] with remodelling related to weight bearing [25]. Histological samples show mixed graft and new bone formation with remodelling (new trabeculae) after 2 years [24].

The Ling technique shows good clinical results with an incorporation of 89% of the graft [10, 13, 14]. However, complications such as femoral fractures [19] appear. The subsidence of the stem was initially considered as a natural evolution (cold flow of the stem in the cement mantle), but cement fracture may be the cause and could lead to mid-term failure of the stem [7, 10, 17]. Other concerns are related to having an adequate cement mantle and include the degree of impaction, stem alignment, subsidence progression, allograft resorption and cement penetration in the grafts. All these questions have been partially answered in the literature. This study tries to clarify the relationship of all these parameters to the outcome, looking for clinical factors that affect the outcome beyond the demonstrated in vitro stability of this technique [1].

Materials and methods

A retrospective clinical cohort study was done between 1988–2001 (hip arthroplasty revision surgeries with aseptic femoral stem loosening associated with severe cavitory cortico-cancellous femoral bone defects treated by the Ling technique). Among 114 hip revisions, 60 met the criteria (60 hips). The mean follow-up was 60.46 months (19.4–152.4; SD: 26.18; 50th percentile: 56.48). Complete follow-up was done in 54 patients. The average age was 68.5 years (range, 22.5–85; SD: 12.5). The male to female ratio was 33 (61.1%) to 21 (38.9%). All were examined preoperatively and postoperatively (1st, 2nd, 3rd and 6th months and annually thereafter). It was considered successful when the Harris Hip Score improved more than 20 points, the stem did not loosen and the patient did not need any further revision.

Infection was ruled out (Tc99 and Ga67, radiographs, laboratory tests, intraoperative frozen section analysis and culture). The surgical approach was posterior (Kocher-Langenbeck) in 51/54 (91.44%) and lateral (Hardinge) in 3/54 (5.56%). For wider exposure, trochanteric osteotomy was done in 14/54 (25.9%) patients. All had severe cavitory defects (cancellous and cortical erosion). Cancellous allograft was prepared from our bone bank. The fragments used were 2 mm or less in size (manual milling machine). Fragments were washed out and immersed in saline without antibiotics. After placing a plastic plug 2 cm distal to the stem, allografting was begun. The allograft was impacted distally and laterally with soft surface broachers. No centralising tools were used. The hardness of impactation was medium-high. After defect reconstruction, pressurised cementation (Palacos® Hereaus Kulzer GmbH) was done. Then, implantation of a new polished non-collared double-tapered stem (LD Polished Stem®) was performed. In cases of a thin cortical shell, prophylactic cerclage wires were

Fig. 1 In cases of a thin cortical shell, prophylactic cerclage wires were used

used (Fig. 1). Revision of the acetabular component was required in 32/59 patients (59.3%), and 13/54 (24.1%) needed allograft for an acetabular defect. Patients underwent earlier revision procedures 1.9 times (0–4; SD: 1.03). Prophylactic cephazoline was administered for 48 h. After 3 weeks of bed rest, non-weight-bearing walking with crutches was encouraged, beginning partial bearing in 2 to 3 months, and increasing gradually to full weight after 1 month. Two radiographs were obtained (anteroposterior and axial). Gross and AAOS Hip Committee classifications [5] were used. All patients were graded as having *intraluminal defects* and *cavitary defects* with endosteal erosions, respectively. All defects were severe. We assessed stem alignment that was valgus ($>3^\circ$), varus ($<3^\circ$) and neutral. Loosening could be progressive or non-progressive subsidence (minor if less than 5 mm, moderate if between 5–10 mm and severe if more than 10 mm) or radiolucencies around the stem (all around the stem with 2 or more mm at any point). A simplified system zone radiograph analysis was used (proximal, intermediate and distal). We analysed the allograft according to quantity (relationship between the

canal and stem diameter) and distance of the tip of the stem to the plug. Cement mantle quality was assessed as unclear, adequate, deficient or absent [16]. Healing was cortical (cortical widening), trabecular (trabecular appearance of the graft with no orientation), trabecular remodelling (trabecular appearance of the graft with orientation) and resorption [10].

The qualitative variables were presented as frequency distribution; its association was shown with the maximum similarity test (there were not enough cases for the chi-square test). The qualitative variables were calculated as the average, standard deviation and range and were compared with theoretical models; its association was shown with the Student's t-test and/or ANOVA test. Error type I was admitted to reject the hypothesis (<0.05). The SPSS 11.0 version of Windows® was used. No Kaplan-Meier survival curves were calculated.

Results

We reviewed 54 cases in 54 patients that fulfilled the criteria of inclusion with complete follow-up over 60.40 months (19.4–152.4; SD: 26.18). Preoperative HHS was 35 points (28–40; SD: 12) and a postoperative HHS of 81 points (50–99; SD: 14.2). The mean improvement in HHS was 51 points (20–69; SD: 14.2). We found 43/54 (79.62%) patients with the greater than 20 points of improvement in the HHS necessary to be considered as a successful case.

Radiologically, the stem alignment was neutral (24/54; 44.44%), varus (21/54; 38.89%) and valgus (9/54; 16.67%). There was progression to varus in 3/54 (5.56%), to valgus in 0/54 (0%), and no changes in alignment in 51/54 (94.44%). The mean distance from the tip to the medullary plug was 35.82 mm (0–100 mm; SD: 24.8). The canal diameter/stem diameter was 1.8 (1.2–2.7; SD: 1.8). The proximal zone of the cement mantle was unclear in 9/54 (16.67%), adequate in 33/54 (61.11%), deficient in 6/54 (11.11%) and absent in 6/54 (11.11%). The medium zone was unclear in 14/54 (25.93%), adequate in 14/54 (27.78%), deficient in 8/54 (14.81%) and absent in 18/54 (33.33%). The distal zone was unclear in 13/54 (24.07%), adequate in 9/54 (16.67%), deficient in 6/54 (11.11%) and absent in 26/54 (48.15%). There was no stem subsidence in 33/54 (61.11%) (Fig. 2) and some form of subsidence in 21/54 (38.89%); it was self-limited in 14/54 (25.92%) (Fig. 3) and progressive in 7/54 (12.96%) (Fig. 4). In the non-progressive group, the mean subsidence was 4 mm (2–15). In 11/14 (78.57%) cases it was less than 5 mm, in 1/14 (7.14%) between 5–10 mm and only in two cases was it 10 mm. In the progressive group all stems subsided over 10 mm. The femoral stem subsided into the cement in 20/21 (95.24%)

Fig. 2 No stem subsidence

cases, and in 1/21 (4.76%) cases the stem with the cement subsided into the allograft. We found radiolucencies around the stem in 10/54 (18.52%) cases and no radiolucencies in 44/54 (81.48%) cases. Therefore, 10/54 (18.52%) were loosened at the final follow-up. Of these loosened stems, six were revised and four await revision because they were asymptomatic. Analysing the behaviour of the allograft in each of the three selected zones of the femur, 80% of the

cases had some type of graft incorporation as shown in Table 1.

The complication rate was 15/54 (27.78%) (Table 2). The most prevalent was periprosthetic fracture; all but one were intraoperative. All of these patients were treated by osteosynthesis at the same operative procedure (Fig. 5).

We had 13 failures (24.07%): 10 loosened stems (including the 4 cases that were loose but asymptomatic),

Fig. 3 Self-limited subsidence

Fig. 4 Progressive subsidence

1 deep infection (that also needed revision), 1 case of postoperative periprosthetic fracture and 1 patient with a bad clinical result who required further revision (HHS improvement less than 20 points). Thus, 41/54 (75.93%) were successful.

The statistical correlation between revision and each of the variables analysed was calculated looking for statistical significance ($P < 0.05$) (Table 3). Thinner stems were revised less than wider diameter stems. Progressive subsidence always led to loosening. There was no difference in terms of loosening or revision between non-progressive subsidence and no-subsidence stems. All the loosened stems showed allograft resorption. When the cement mantle was unclear or deficient in the intermediate zone, stems loosened more (less correlation in the proximal zone, and no correlation in the distal zone). Patients with an adequate cement mantle did not subside more than 2 mm; this tendency increased in the distal zone ($P > 0.05$). In the proximal zone of the patients with more than 2 mm subsidence, 50% had a deficient or absent cement mantle and in 50% the cement mantle was adequate; in the intermediate zone, 66.6% were deficient or absent and 0% adequate, and in the distal zone, 83.3% were absent and none had an adequate cement mantle.

Cases that subsided more than 2 mm showed resorption in the proximal zone graft in 80%, in the intermediate zone in 60%, and in the distal zone in 60%. Patients that subsided less than 2 mm showed some type of healing in the proximal zone in 86.7%, in the intermediate zone in 84.7%, and in the distal zone in 82% ($P < 0.05$).

Discussion

The Ling technique increased the femoral bone mass (allograft remodelling). We found the factors related to progressive subsidence were malalignment of the stem, less than 20% improvement of the HHS, wider diameter stems, resorption of the graft and a deficient or absent cement mantle. Good results were achieved with small graft fragments (2 mm). Impaction should be hard, keeping in mind the risk of intraoperative fractures. Subsidence was frequent but acceptable, if not progressive (less than 5 mm).

Our group of patients is larger than many others [13, 21], but still below the number in the Gie articles [10]. Nevertheless, Gie's follow-up was less than ours (18 and 49 months). Our 60.45 (19–152) months are sufficient to evaluate results and reach solid conclusions. We have not found differences based on the ages of patients [22]. Patients with more revision procedures showed increased rates of repeat revision (20%) compared to 0% in patients with the Ling technique as the first revision procedure. The approach or trochanteric osteotomy did not correlate with an increased rate of revisions. Our technique differed in some details to Gie's [11] (using neither cannulated impactors nor a distal centraliser) which may be the reason for stem malalignment (39.6% for varus and 17% for valgus). The methods of processing the allograft are similar to others [12]. Most authors recommend fragments no less than 5 mm. The elastic recoil of these fragments after impaction is less than in the smaller fragments [24]. We think that big fragments are difficult to work with in a narrow diameter femoral cavity. Washing the fat out of the graft seems to improve healing [25]. Our impaction was medium-high depending on the surgeon (no quantitative measurements were made). Hard impaction should be the goal [13], although a diminished osteoconduction has been shown. The impactor used was 1 mm wider than the definitive stem, leaving little room for the cement mantle (although it can intrude into the superficial layer of the

Table 1 Allograft results

	Proximal zone	Medial zone	Distal zone
<i>Cortical healing</i>	2/54 (3.7%)	2/54 (3.7%)	1/54 (1.85%)
<i>Trabecular healing</i>	30/54 (55.56%)	30/54 (55.56%)	34/54 (62.96%)
<i>Trabecular remodeling</i>	11/54 (20.37%)	11/54 (20.37%)	9/54 (16.67%)
<i>No graft</i>	11/54 (20.37%)	11/54 (20.37%)	10/54 (18.52%)

Table 2 Complication rate

Type of complication	Rate of complication
Periprosthetic fractures (intraoperative)	8/54 (14.8%)
Vascular injury (intraoperative)	0/54 (0%)
Neurological injury (intraoperative)	0/54 (0%)
Cortical defect with cement extrusion	3/54 (5.56%)
Superficial infection	1/54 (1.85%)
Deep infection (early)	0/54 (0%)
Deep infection (haematogenous)	1/54 (1.85%)
Dislocation (early)	2/54 (3.7%)
Deep venous thrombosis	0/54 (0%)
Pulmonary embolism	0/54 (0%)

graft). The published data show differences between the impactor and stem diameter of 0.75 to 2 mm. Most authors used an Exeter stem (Howmedica, Rutherford, NJ, and Howmedica International, Staines, Middlesex, England) and a collarless polished tapered stem (Zimmer, Warsaw, IN). Our stem was a polished collarless double-tapered stem (LD stem). A few authors used porously coated stems [13]. When the femur/stem relation was less than 2, the revision rate was 22.2%, and when more than 2, the revision rate was 30% ($P>0.05$).

There is controversy about subsidence. Radiosterometric measurements are the most accurate way to measure subsidence [9]. Polished stems are supposed to subside into the cement mantle during the initial phases without clinical relevance (cold flow phenomenon) [14]. Some demonstrated fractures in the cement mantle in these cases

Fig. 5 Osteosynthesis treatment**Table 3** Statistical analysis

Variable	<i>P</i> (correlation with loosening)	<i>P</i> (correlation with revision)
Age (<69/>69)	0.4	0.5
No. previous revisions	0.69	0.1
Acetabular revision (yes/no)	0.59	0.2
Side (right/left)	0.83	0.8
Gender (male/female)	0.5	0.6
Approach (post/lateral)	0.2	0.4
Stem diameter (10 to 15 mm)	0.16	0.03
Trochanter osteotomy (yes/no)	0.5	0.3
Trochanter healing (yes/no)	0.47	0.6
HHS improvement (>20 or <20)	0.0	0.0
Stem alignment (varus/valgus/neutral)	0.96	0.4
Change alignment (no/varization)	0.56	0.18
Subsidence (no/non-progressive/progressive)	0.0	0.002
Subsidence (<2 mm/>2 mm)	0.0	0.01
Proximal radiolucencies (yes/no)	0.15	0.8
Intermediate radiolucencies (yes/no)	0.46	0.7
Distal radiolucencies (yes/no)	0.01	0.5
Distal distance	0.5	0.4
Ossifications (yes/no)	0.7	0.8
Proximal allograft incorporation (resorption, cortical healing, trabecular incorporation, trabecular remodeling, no graft)	0.06	0.2
Intermediate allograft incorporation	0.0	0.02
Distal allograft incorporation	0.0	0.05
Proximal cement mantle (nuclear, adequate, deficient, absent)	0.59	0.5
Intermediate cement mantle	0.05	0.2
Distal cement mantle	0.9	0.8

contradict the initial theoretical interpretation [16]. Compaction or resorption of the graft could lead to subsidence. Gie [10] had subsidence in 79% of the cases, with 98% into the cement (<5 mm). Elting [8] had 20% (2.8 mm), with 50% into the cement. Meding [18] had 38% with more than 10 mm, with 9% into the cement. Ornstein [19] had 100% (2.5 mm), and these were progressive in 33%. Franzen [9] had subsidence in 100% with no revisions. Biezen [2] had 80% (60% <5 mm and 20% >10 mm), with no revisions. In our study, we had subsidence in 38.89%: 25.92% (14/54) were non-progressive (averaging 4 mm and in 95% in the cement), and 12.96% (7/54) were progressive (averaging more than 10.3 mm). Subsidence occurred in most of the cases, and if not progressive, did not lead to loosening. When progression was related ($P<0.05$) to revision, the more the subsidence the greater incidence of revision ($P<0.05$). Others describe this phenomenon with polished

and proximal porous stems, although subsidence is six times less than in the former. The cement mantle is badly described in most of articles. The cement mantle is important, acting as a force-spreader between the stem and graft and a seal around the stem. Its quality influences the primary stability. Biezen [2] and Masterson [16] analysed it. In Masterson's series, the mantle was absent in 15–40%, mostly in the distal zones (Gruen 3 and 5). Kärrholm et al. [13] had 50% with two or more areas with insufficient cementation. In our study, the mantle in the proximal zone was unclear, insufficient or absent in 38% of the cases, 72% in the intermediate zone and 82% in the distal. The more distal, the more deficient the mantle was. Most authors found that the cement mantle was insufficient in many areas, but nevertheless obtained good outcomes, although it is assumed there was a risk of aseptic loosening [16]. We also found a relation ($P<0.05$) between bad cementation and a need for revision. This controversy still exists in primary hip arthroplasty. Because press-fit is not possible in impacted grafts, we think that the goal is a cement mantle of at least 2 mm.

Increasing bone stock with allograft healing increases the survival of the stem. For Biezen [2], 6% of the zones had resorption, 34% with cortical healing, and 50% with trabecular remodelling. For Kärrholm [13], 83% of the cases had trabecular remodelling or cortical healing in at least one zone of Gruen. Meding et al. [18] had some form of graft healing in 94% of the cases. In our patients, we found some form of graft healing in 80% of the patients, with no differences among the three zones. We found a relation ($P<0.05$) between graft resorption and revision.

Complications

We found complications in 15/54 of the cases (27.78%). We did not find any postoperative deep infection, but one (1.9%) haematogenous deep infection. Periprosthetic fracture is the most relevant complication [9, 10], rating from 50 to 4.4% intraoperatively and from 1.8 to 20% postoperatively. We had 14.8% intraoperative fractures. We, along with others, advise the use of prophylactic wiring of the femur before impacting the graft [6].

We had successful results in 75.93% (41/54), but if we only include patients that did not need further revisions, the rate would increase to 83.3% (45/54) (this includes four cases that were loosened but asymptomatic). All cases that were loosened had errors in alignment of the stem, and we only had one case that was loosened and well aligned. Kaplan-Meier survival curves were not calculated because the group of patients was homogeneous and stable during the period studied. Knowing this, we can say that the accumulated probability of not having a loosened stem is similar to having a successful outcome.

Future considerations

We have demonstrated the possibility of using non-cemented stems as a variation to the Ling technique. Although little has been published [20], we have begun a prospective trial group using this variation. A theoretical problem we anticipate will be the difficulty to assess primary stability.

References

- Berzins A, Summer DR, Wasieleski RC, Galante JO (1996) Impacted particulate allograft for femoral revision total hip arthroplasty: in vitro mechanical stability and effects of cement pressurization. *J Arthroplast* 11:500–506
- Biezen FC, Have LEF, Verhaar JAN (2000) Impaction bone-grafting of severely defective femora in revision total hip surgery. Twenty-one hips followed for 41–85 months. *Acta Orthop Scand* 71(2):135–142
- Blackley H, Davis A, Hutchinson CR, Gross AE (2001) Proximal femoral allografts for reconstruction of bone stock in revision arthroplasty of the hip: a 9 to 15-year follow-up. *J Bone Jt Surg* 83A:346–354
- Burchardt H (1983) The biology of bone graft repair. *Clin Orthop* 174:28–42
- D'antonio J, McCarthy JC, Bargar WL, Borden LS, Cappelo WN, Collis DK et al (1993) Classification of femoral abnormalities in total hip arthroplasty. *Clin Orthop* 296:133–139
- Duncan CP, Masterson EL, Masri BA (1998) Impaction allografting with cement for the management of femoral bone loss. *Orthop Clin North Am* 29(2):297–305
- Eldridge JD, Smith EJ, Hubble MJ, Whitehouse SL, Learmonth ID (1997) Massive early subsidence following femoral impaction grafting. *J Arthroplast* 12:535–540
- Elting JJ, Mikhail WEM, Zicat BA (1995) Preliminary report on impaction grafting for exchange femoral arthroplasty. *Clin Orthop* 319:159–167
- Franzén H, Toksvig-Larson S, Lidgren L, Önnertfalt R (1995) Early migration of femoral components revised with impacted cancellous allografts and cement: a preliminary report of five patients. *J Bone Jt Surg* 77B:862–864
- Gie GA, Linder L, Ling RS, Simon JP, Sloof TJ, Timperley AJ (1993) Impacted cancellous allografts and cement for revision total hip arthroplasty. *J Bone Jt Surg* 75B:14–21
- Gie GA, Linder LL, Simo JP, Sloof TJ, Timperley AJ (1993) Contained morselized allograft in revision total hip arthroplasty. Surgical technique. *Orthop Clin North Am* 24(4):717–725
- Gross AE, Allan GD, Lavoie GJ, Oakeshott RD (1993) Revision arthroplasty of the proximal femur using allograft bone. *Orthop Clin North Am* 24(4):705–715
- Kärrholm J, Hultmark P, Carlsson L, Malchau H (1999) Subsidence of a non-polish stem in revisions of the hip using impaction allograft. Evaluation with radiostereometry and dual-energy X-ray absorptiometry. *J Bone Jt Surg* 81B:135–142
- Leopold SS, Berger RA, Rosenberg AG, Jacobs JJ, Quigley LR, Galante J et al (1999) Impaction allografting with cement for revision of the femoral component: a minimum 4-year follow-up study with use of a precoated femoral stem. *J Bone Jt Surg* 81A:1092
- Ling RS (1997) Femoral component revision using impacted morsellised cancellous graft. *J Bone Jt Surg* 79B:874
- Masterson EL, Busch CA, Duncan CP, Drabu K (1999) Impaction allografting of the proximal femur using a Charnley-Type stem. A cement mantle analysis. *J Arthroplast* 14:59–63

17. Masterson EL, Duncan CP (1997) Subsidence and the cement mantle in femoral impaction allografting. *Orthopedics* 20(9):821–822
18. Meding JB, Ritter MA, Keating E, Faris P (1997) Impaction bone-grafting before insertion of a femoral stem with cement in revision total hip arthroplasty. A minimum 2-year follow-up study. *J Bone Jt Surg* 79A(12):1834
19. Ornstein E, Atrshi I, Franz N, Herbert MD, Johnson R, Sandquist P, Sundberg M (2001) Results of hip revision using the Exeter stem, impacted allograft bone and cement. *Clin Orthop Relat Res* 1(389):126–133
20. Pekkariinen J, Alho A, Lepist J, Ylikoski M, Yline P, Paavilainen T (2000) Impaction bone grafting in revision hip surgery: a high incidence of complications. *J Bone Jt Surg* 82B(1):103–107
21. Schreurs BW, Sloof TJ, Buma P, Verdonchot N (2001) Basic science of bone impactation grafting. In: Price C (ed) *Instructional course lectures*, vol 41. pp 211–220
22. Scott G (1997) Impaction allografting in proximal femoral reconstruction in the absence of cement using a hidroxiapatite coated prosthesis. *J Bone Jt Surg* 79Br(2S):266
23. Simon JP, Fowler JL, Gie GA (1991) Impaction cancellous grafting of the femur in cemented total hip revision arthroplasty. *J Bone Jt Surg* 73B(suppl)
24. Ullmark G, Obrant KJ (2002) Histology of impacted bone-graft incorporation. *J Arthroplast* 17:150–157
25. Wang JS, Aspenberg P (2000) Load-bearing increases new bone formation in impacted and morsellized allografts. *Clin Orthop Relat Res* 378:274–281