Impaction grafting and cemented acetabular revision

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Introduction

In the period 1968 to 1989, 2461 primary total hip replacements of the cemented Müller curved stem design were performed and 471 replacements of the Müller straight stem design. From this series, a total of 261 total hip arthroplasties (=10%) were revised. In addition, a total of 149 revision arthroplasties were performed at our Institute which had initially been operated on at other clinics using a variety of prosthetic designs. We therefore performed 410 cemented revision procedures. Loosening of the acetabular components was associated with severe bone destruction in 134 cases. Since the mid-1970s, impaction grafting has been used to restore bone stock on the pelvic side and since the 1980s also on the femoral side, combined with cement fixation of the prosthetic component.

This chapter presents the history of the use of bone grafts in cemented revision total hip arthroplasty, an overview of our experimental investigations: the initial stability of the components in the grafted acetabulum and femur, the histology of graft incorporation and our clinical results after 10 years of application to the acetabulum. The principles, preoperative planning and surgical technique are also discussed.

The history of the use of bone grafts in cemented revision total hip arthroplasty

Most of the graft incorporation data[1–18], obtained in the past, were related to animal experiments. This can be summarized as follows:

- The process of graft incorporation represents a sequence of events and reflects a partnership between graft and host-derived factors.
- The host contributes all the blood vessels and the cells required to incorporate the graft. The graft may serve as a scaffold to promote the host response, and the graft matrix stimulates cellular activity for bone formation from the host.
- Cortical grafts are incorporated slowly, unpredictably, irregularly, incompletely and with mechanical weakening. Compared to cortical grafts, cancellous grafts have a more open structure which, in theory, allows rapid vascular invasion and should therefore enable rapid, more complete and uniform incorporation.
- The incorporation mechanisms of solid and morsellized cancellous grafts are less clearly understood. The rigidity and size of a solid graft may stress-protect any new bone that is formed within it. It has been speculated that impaction of a chip graft leads to an increase in bone density and helps to prevent mechanical weakening.
- Irrespective of the type of graft, essential factors which influence the process of incorporation are the stability of fixation, the amount of contact, the vascularity of the host bone bed, the strain pattern and the degree of antigen-matching.

Based on this information, the clinical application of many types of graft should be considered for total hip arthroplasty revision. In the 1970s, Hastings and Parker[19] and Harris et al.[20] reported on acetabular reconstructions with bone chip wafers and solid corticocancellous bone grafts for primary and revision total hip arthroplasties, respectively. The grafts were combined with cement and metal reinforcement materials, such as meshes, screws and bolts. The indications for reconstruction were mainly pelvic protrusion and insufficiency of the acetabular roof and rim, caused by a primary idiopathic process or resulting from failed total hip arthroplasty. These initial reports were followed by clinical studies on patients with intrapelvic protrusion[21–23], using primary cemented arthroplasties combined with autogenous bone chips supported by a metal mesh.

In 1984 we published our experience with a modification of the techniques developed by Hastings[19] and McCollum[21], [24]. We used morsellized allografts and impacted the chips rigidly in the reconstructed acetabulum. In the case of segmental and cavitary defects, containment was made with metal meshes for the graft which resulted in direct stability of the reconstruction.

The technique of cement fixation and bone grafting has also been adopted by Hirst et al.[25], Olivier and Sanouiller[26], Berry and Mueller[27] and Rosson and Schatzker[28]. Depending on the severity of the acetabular defects, they combined this technique with the use of metal reinforcement materials, such as the Müller ring, the anti-protrusion cage and the Burch–Schneider cage.

The original technique described by Harris et al.[20] introduced the use of solid grafts but provided only a short-term solution. Recently Harris et al. have published arguments against the use of solid weight-bearing allografts[29–31].

In order to obtain more insight into the incorporation process of the graft and into the initial mechanical stability of acetabular and femoral reconstructions using impacted morsellized allografts, we performed two animal experiments.

Animal experiments

Both the acetabular and femoral reconstruction techniques using impaction grafting and cement were developed and tested on animal models[32–37]. The animal of choice was the goat.

The aims of these experiments were to make:

A. Histological evaluation of the different processes involved in the incorporation of (1) acetabular and (2) femoral grafts and,
B. Mechanical evaluation of the initial stability (*in vitro*) and stability of cemented (1) acetabular and (2) femoral components after incorporation of the graft.

Materials and method

All the trabecular bone grafts were harvested from the sternum of donor goats under sterile conditions. The grafts were freshly frozen and stored at –80°C ready for implantation. In adult goats, the right hip was operated on under general anaesthesia using standard aseptic techniques. A dorsolateral incision was used, followed by dislocation of the hip and resection of the femoral head. Acetabular and femoral reconstructions were performed in two separate animal experiments. After the operation all the goats were kept in a hammock for 2 days. AP and lateral radiographs were taken immediately after the operation. The goats were then kept in cages which allowed free walking or in a field.

Surgical technique

The acetabular cartilage was removed and a cavitary defect was made in the anterosuperior segment of the acetabulum using hand reamers. Impaction grafting of the resulting defect was performed in the same way as during clinical application to patients. The acetabular component was cemented. Three specimens were used to analyse the initial stability (*in vitro*). Six goats were sacrificed at intervals of 6, 12, 24 and 48 weeks. Three of the 6 cases from each interval were used for histology and three for biomechanical analysis.

The surgical approach to the femur consisted of preparing the medullary cavity with hand reamers. A concentric intramedullary graft could be impacted in a retrograde fashion (Figure 14.1) using a specially developed set of instruments. Cement was inserted into this construction, followed by the insertion of the femoral stem. The clinical application of this technique to patients has recently been published[38, 39]. To evaluate the femoral reconstruction we used 18 goats. The initial stability of the reconstruction was analysed in 4 specimens *in vitro*. To evaluate the postoperative changes, 7 goats were sacrificed after 6 and 12 weeks. Four specimens from each period were used for the biomechanical study, the other 3 were used for histological analysis.

Biomechanical method

For mechanical testing of the grafted acetabulum and femur, tantalum pellets were fixed to both components prior to insertion. The 3D displacement of the components relative to the bone

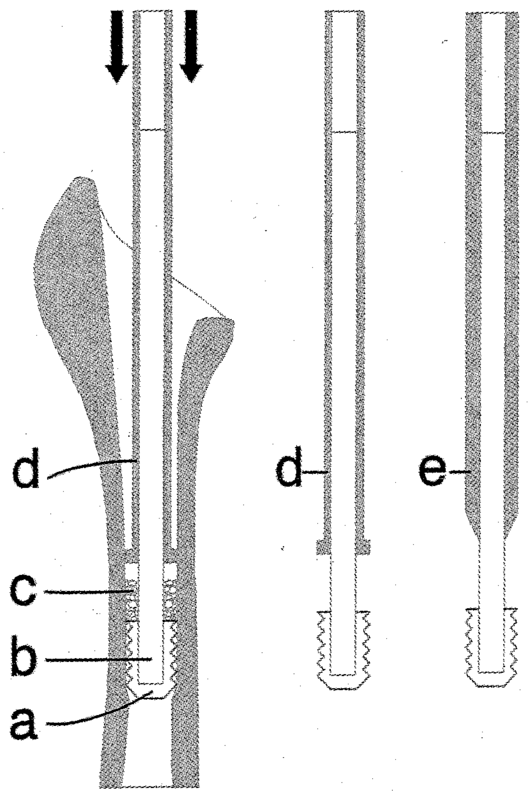


Figure 14.1 Schematic representation of the graft impaction technique by using a special set of instruments. A bone cement plug (a) is screwed on a metal rod (b) and introduced into the canal. The space between this metal rod and the cortical bone is filled with trabecular bone grafts (c). These grafts are impacted using metal tubes sliding over the central rod. Different types of tubes are used for axial (d) and radial impaction (e) of the grafts (from Schreurs et al.[36]).

(rotation and translation) was measured using Röntgen-Stereophotogrammatic Analysis (RSA), developed by Selvik[40].

The acetabula and femora for the mechanical study were freshly harvested and stored at –80°C ready for testing. After thawing, both bone specimens were embedded in polymethylmethacrylate (PMMA). Tantalum pellets were inserted into small holes drilled into the pelvic and femoral bones in standard positions. Furthermore, small PMMA rods containing tantalum pellets were glued to the proximal, medial and lateral parts of the femoral prosthesis and inserted into the acetabular component. The prostheses–bone structures were then loaded into a MTS-testing device in a physiological way (Figure 14.2). A pelvic load was applied stepwise from zero to 350 and to 700 N and again unloaded. Stereoröntgenograms were taken before loading, after each loading step and 10 minutes after the final unloading. A femoral load was also applied stepwise from zero to 200, 500, 800 N and again unloaded. Each loading period lasted 10 minutes.

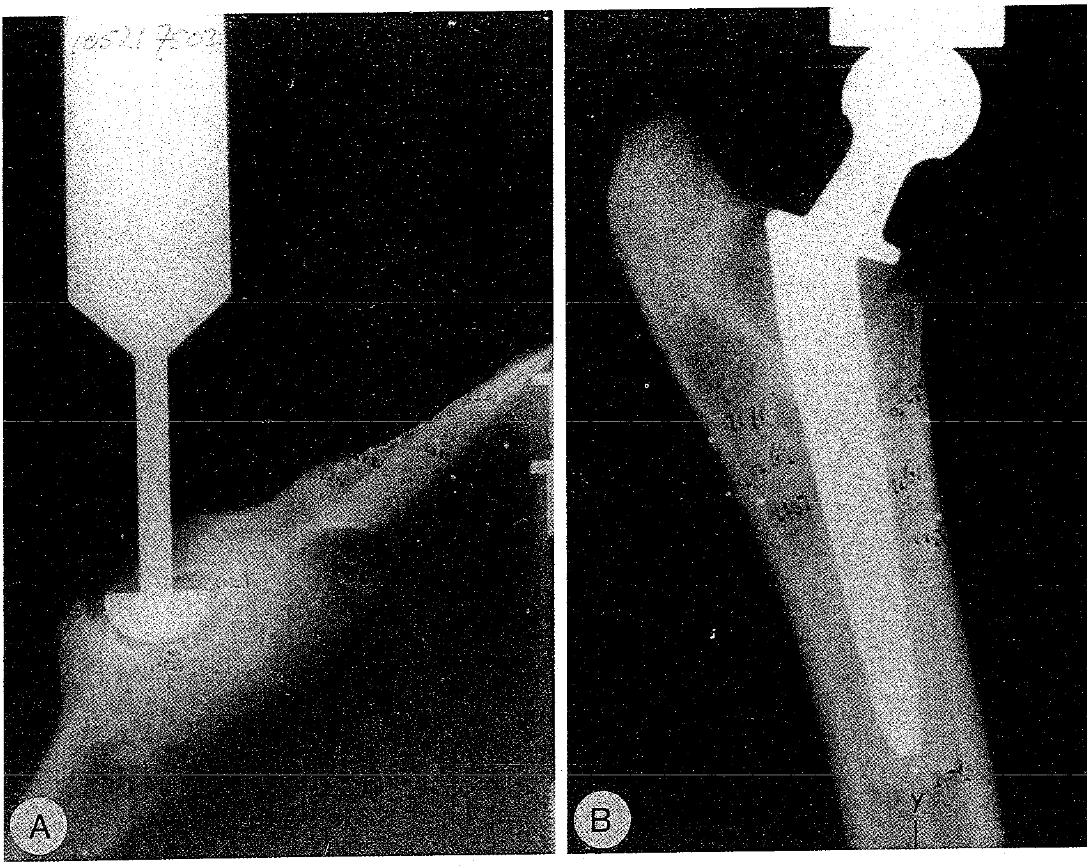
All stereoröntgenograms were evaluated on an Aristomat digitizer, and the 3D pellet positions were determined with the RSA computer programme. Relative rotations and translations around and along the coordinate axes were calculated. To increase the accuracy of the results, all the stereoröntgenograms were measured 5 times and the results were averaged.

Histological methods

The goats received different types of fluorochrome to enable the qualitative evaluation of bone ingrowth into the graft[41]. The acetabula and femora were harvested after perfusion of the lower extremity with Micropaque(R) as described by Rhineländer and Baragry[42]. After fixation in a buffered paraformaldehyde solution the acetabula and femora were contact-radiographed and sectioned with a water-cooled saw into slices of 2–3 mm. Radiographs were taken of the slices. Calcified and decalcified bone sections of various thickness were subsequently stained according to routine protocols.

Histological evaluation of the grafted acetabulum (Figure 14.3)

The impacted graft consisted of fairly large pieces of trabecular bone, which displayed small microfractures at all levels. Generally, the bone graft was devoid of any well-preserved osteocytes, the osteocytes had completely resolved, or if they were still present, they had a very pyknotic appearance. Most of the medullary fat in the pieces of graft had been squeezed out during the process of impaction and had been replaced by a fibrin clot. Owing to surgical trauma, a circumferential necrotic zone of about 1–4 mm was found in the host bone. After revascularization of the host bone, a front of vascular sprouts accompanied by loose connective tissue with many macrophages, penetrated into the graft at a speed of about 70 μm per day. A very high dynamic bone turnover was observed in the graft in association with this granulation reaction, comprising bone graft resorption by osteoclasts and bone apposition by osteoblasts. This resulted



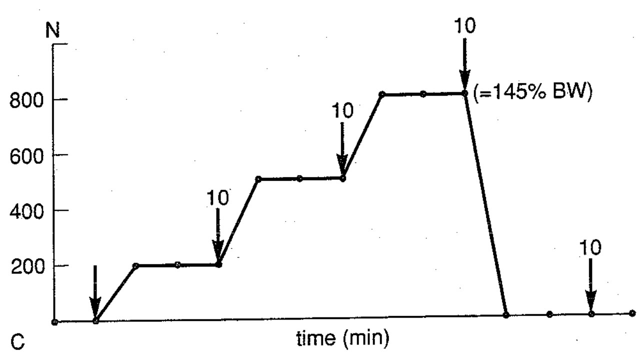


Figure 14.2a,b Loading position of the acetabulum and femur in the MTS-machine. c, The loading schedule of the femoral intramedullary grafts. Stereoröntgenograms were made 1 and 10 minutes after each step in load (arrows).

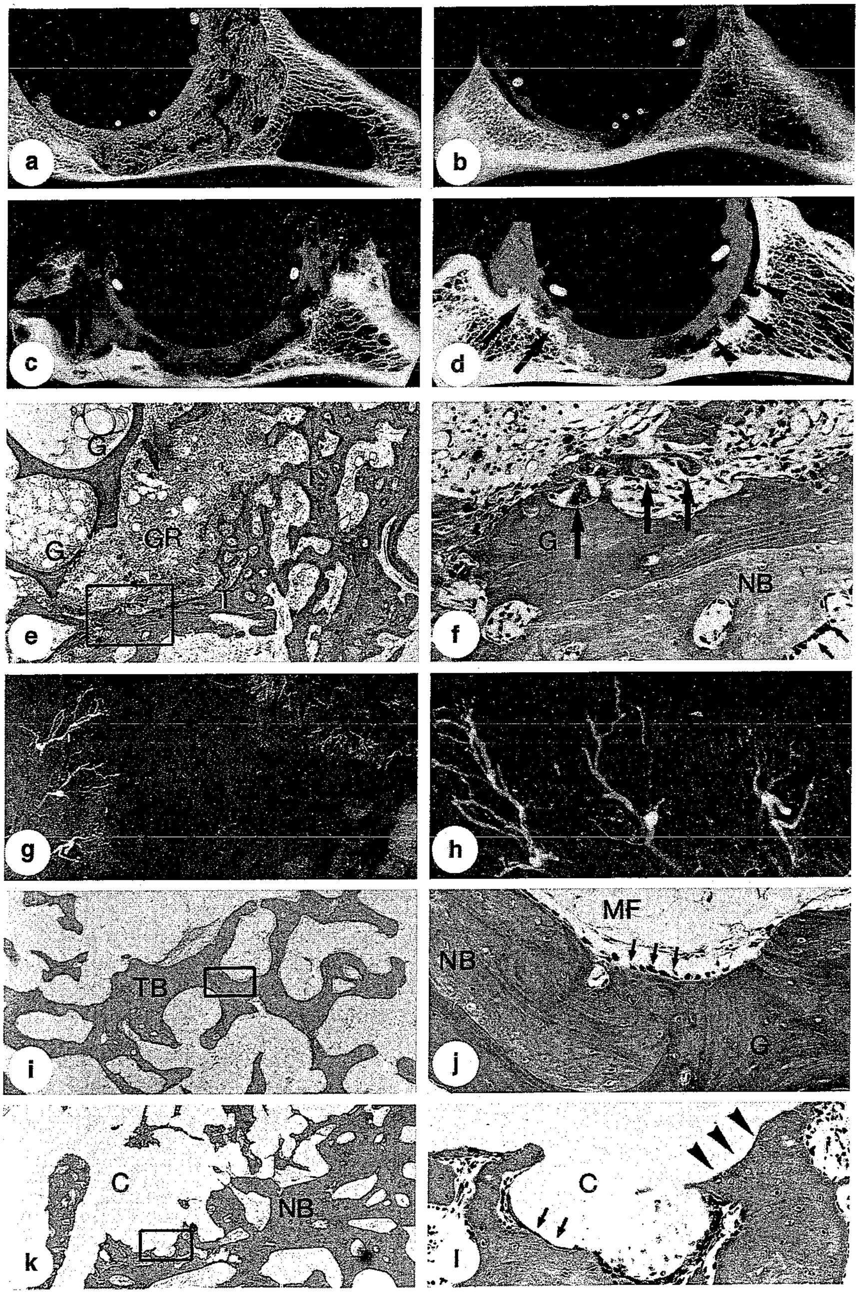


Figure 14.3 Röntgenograms of thick sections through the acetabulum of the goat taken at 0 (a), 12 (b), 24 (c) and 48 weeks (d) after surgery. a, Note large pieces of graft and the clear transition zone to the host bone bed. b, Complete consolidation of the graft with the host bone. The incorporation of the graft is almost completed. c, A radio-lucent zone is present between the cement layer and the bone, indicating that a soft-tissue interface has been formed. d, Note local contact areas between bone and cement (arrows) and a radio-lucent zone (arrow heads). Note also the dense bone adjacent the cement layer. e, Granulation tissue (GR) in the transition zone between avital graft (G) and newly-formed trabecular bone (T) three weeks after surgery. f, Enlargement of encircled area in e. Many osteoclastic bone cells (large arrows) resorb the graft (G) and osteoblasts (small arrows) synthesize new bone (NB). g, A vascularization front penetrates into the graft (G) 12 weeks after the surgery. Cement (C) had penetrated into the graft. h, Enlargement of left part of g.i, Structure of new trabecular bone after 12 weeks. j, Enlargement of encircled area in i showing active osteoblasts (arrows) and new bone (NB). Remnants of the graft (G) can be recognized by the empty osteocyte lacunae. k, Interface between new bone (NB) and the cement 48 weeks after surgery. Cement (C) that was removed during processing of the tissues, had penetrated deeply into the graft. l, Locally at higher magnification a very thin, one cell layer thick (arrows) soft-tissue interface is present, while at other locations the new bone is in direct contact with the cement layer (arrowheads). e, g, i, k ×12.5; f, h, j ×125 (from Slooff et al.[43]).

in a new trabecular structure which consisted of a mixture of the remnants of the graft and newly-formed, mainly woven bone. Subsequently the percentage of graft in the new trabecular structure decreased further by bone remodelling. Radiographic and histological evaluation demonstrated that the orientation of the newly-formed trabecular bone was such that load transfer was possible from the cement layer to the host bone bed. After 12 weeks, the amount of bone graft was minimal and lamellar bone was found in the new structure. A fibrous tissue membrane of varying thickness had developed at the cement–graft interface. However, all the animals showed local areas where vital bone was in intimate contact with the cement layer, without the interposition of such a soft-tissue interface. Between 24 and 48 weeks after surgery, the graft in the defect of the acetabulum and femur had become completely revascularized. The percentage of graft present in the new bony structure was very low. Direct bone–cement contact sites were still present.

Histological evaluation of the grafted femur (Figure 14.4)

In the femoral study the same observations were made. There was a clear difference in revascularization, consolidation, incorporation and remodelling of the graft between proximal levels where the graft was in direct contact with trabecular bone and more distal levels along the stem of the prosthesis where the graft was in contact with compact cortical bone. Cortical bone remodelling of the necrosis induced by disruption of the endosteal circulation, preceded the process of graft incorporation. Proximally, the process of revascularization took place much faster, which resulted in a difference of about 6 weeks in the incorporation process. Again bone resorption and new bone apposition on the graft resulted in a mixture of graft and new bone. As expected, there was more remodelling of the graft in the 12-week group and the remodelling process was not completed after 12 weeks, which was in accordance with the histological results of the acetabulum. Cement had penetrated into the graft to a depth of at least 1 mm. A soft-tissue interface (20–100 μm) was generally seen between the graft and cement, but again there was direct contact between the graft and cement at some sites with active bone formation in the direct vicinity of the cement mantle.

Mechanical evaluation of the acetabulum (Figure 14.5)

All the specimens seemed to be firmly fixed when tested manually. Co-ordinate axes were chosen as follows: X axis dorsoventral, Y axis craniocaudal, Z axis medial–lateral. In most of the specimens, elastic recovery was observed after unloading. Initial stability was considered by testing the specimens immediately after implantation. Maximum persistent translation in this group was found in a craniocaudal direction (0.6 mm). Maximum rotation was measured around the X-axis (–3.1°). In course of time a rather consistent pattern was observed showing increasing stability after 12 weeks of implantation. Persistent translation in all directions declined from the zero group to the 12-week group, as was the case for rotations. At 12 weeks maximum persistent translation was measured in a medial–lateral direction (0.2 mm) with maximum persistent rotation around the Z axis (–2.1°).

Mechanical evaluation of the femur (Figure 14.6)

In the *in vitro* study, which estimated the postoperative stability immediately after the operation, the most important motions were axial rotation and subsidence of the stem (max. 2.1°, and 0.500 mm, respectively). In the *in vivo* study, the maximum load on the femoral head (800N) was estimated to be at 145% of the body weight. The loading mode applied resulted in bending and rotational forces, which are important for testing the stability of hip prostheses. In agreement with Schreurs et al.[33], the stability after 6 and 12 weeks implantation had clearly increased relative to the initial stability of the stems immediately after insertion. In the 6 and 12 week specimens, most of the motion was axial rotation and subsidence and they both increased with increasing load. The maximum rotation was 0.24° under 800 N, but after unloading there was significant elastic recovery which resulted in a maximum permanent rotation of 0.14°. There were no differences between the 6 and 12 week groups. Maximum subsidence under a load of 800 N was 0.164 mm, while after unloading the maximum permanent subsidence was 0.078 mm. Although there were no significant differences between the results of the 6 and 12 week specimens, there was a trend towards greater permanent displacement in the 12-week group. The standard deviations for translations and rotations observed during biomechanical testing were estimated to be 0.036 mm and 0.07°, respectively.

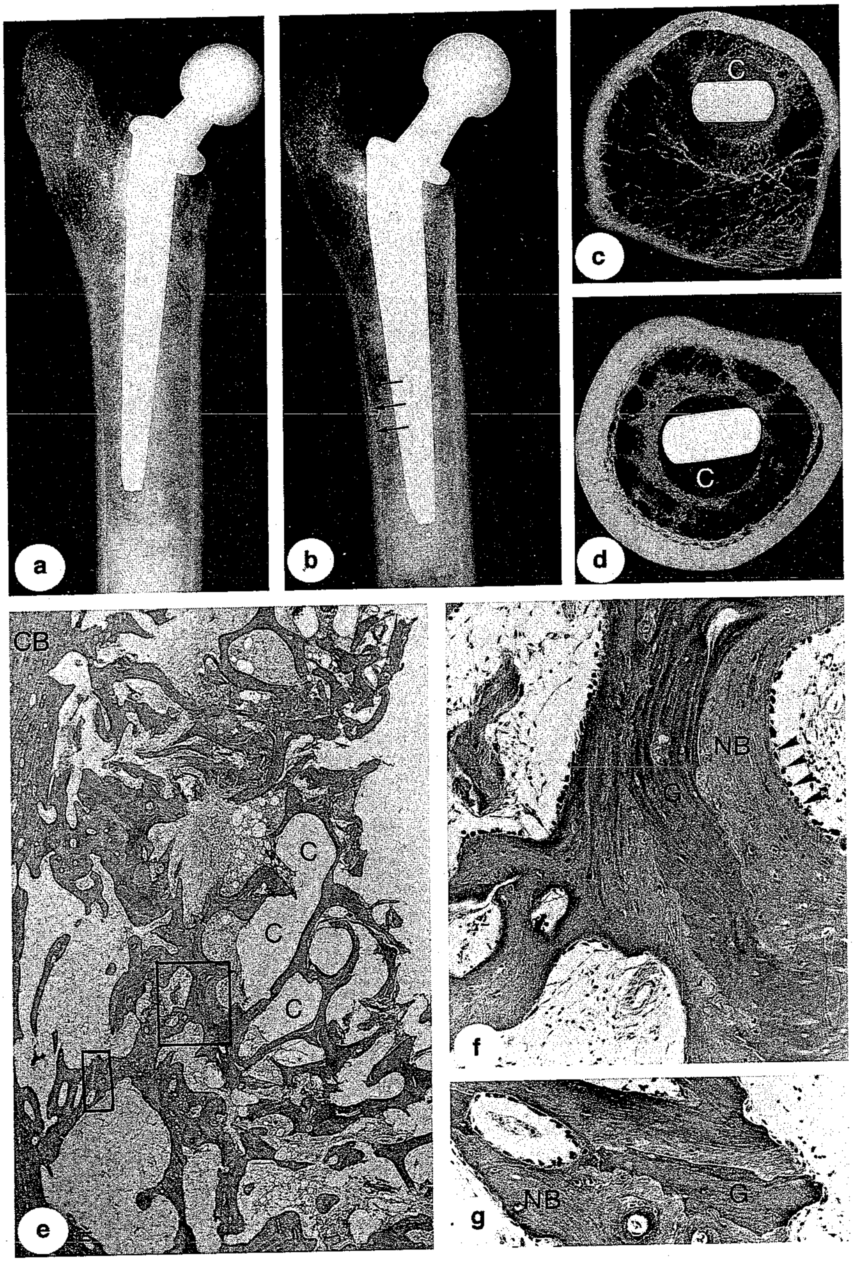


Figure 14.4 a and b, Röntgenograms of the prosthesis after 6 and 12 weeks, respectively. Note in a the change in trabecular appearance between the lateral proximal and more distal regions around the prothesis. b, Locally a radiolucent line is present in the cortical bone (arrows). c and d, Röntgenograms of thick sections of the proximal (c) and mid-shaft level (d) of the femur after 12 weeks. Note the orientation of the trabeculae from the cement layer (C) to the pre-existing cortical host bone. e, H & E stained section midshaft after 12 weeks. The graft is incorporated into a new bony structure that connects the cement layer (C) with the host cortical bone (CB). Note the penetration of the cement into the graft (×18). f and g, Enlargements of the boxed areas in e. Note that the trabeculae are a mixture of new bone (NB) and remnants of the graft (G). Osteoblasts (arrowheads) are present indicating bone formation, (×150) (from Schreurs et al.[36]).

Conclusions from the animal experiment

The reconstruction technique resulted in rapid union between the graft and the host bone. From 12 weeks onwards, very little of the impacted bone graft remained. Instead a new trabecular bony structure of lamellar bone had formed. Although a fibrous tissue membrane of modest thickness had formed in some areas at the bone–cement interface, direct contact was present at some sites between the cement and newly-formed bone.

Our histological and mechanical results showed that the reconstruction technique provides sufficient initial stability to enable the incorporation of the impacted acetabular and femoral grafts.

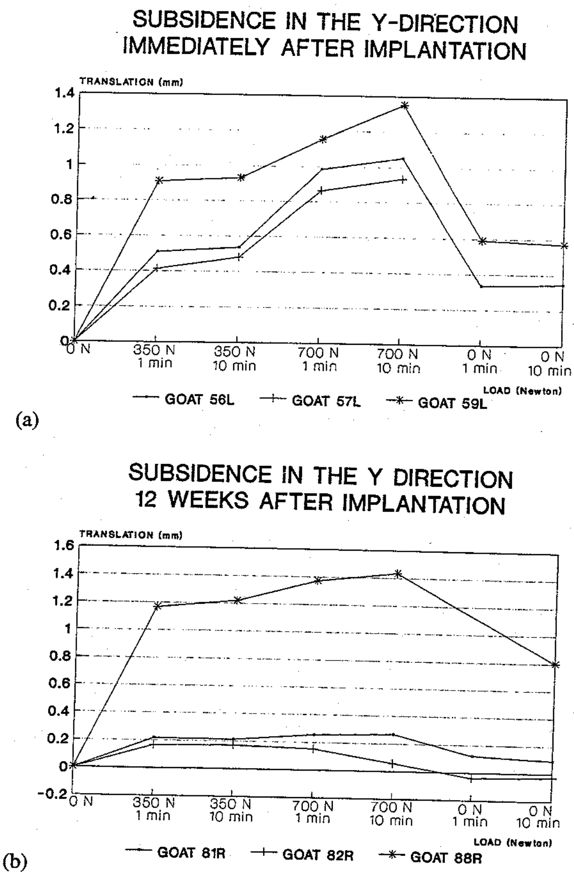


Figure 14.5 Translations found in craniocaudal direction (Y axis) immediately after implantation (a) and after 12 weeks after implantation (b). Implant in goat 88R showed excessive translations and rotations in all directions and was considered loose.

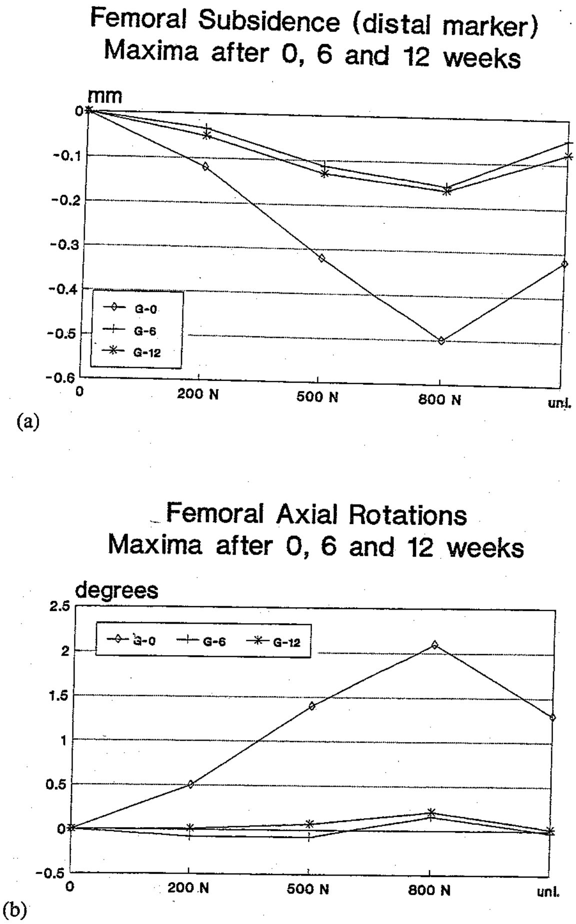


Figure 14.6 a, Maximal femoral subsidence after 0, 6 and 12 weeks. Note increasing stability after incorporation of the graft. b, Maximal rotations of the graft after 0, 6 and 12 weeks showing the same trend.

Principles for clinical application to the acetabulum

Although the follow-up period in the above-described animal experiments was limited to 48 weeks and the surgically prepared host bone bed was far less compromised than in human surgery, the results of the experimental study encouraged us to apply this biological reconstruction method to clinical acetabular[26, 44] and femoral deficiencies[38, 39]. The clinical instruments for the femoral technique were implemented and developed in close collaboration with Mr Ling and Mr Gie (from Exeter) and Howmedica International (Staines, England). Studies performed during the past few years have provided increasing support for choosing the most appropriate approach to acetabular reconstruction[20, 26, 27, 29, 31, 43–51]

The aims of acetabular reconstruction are:

- restoring the centre of rotation
- restoring acetabular integrity
- providing adequate containment of the graft and socket
- achieving direct stability of the reconstruction

These aims were achieved by employing the following surgical measures (Figures 14.7, 14.8):

- Segmental defects were repaired with a wire mesh. In this way acetabular integrity was obtained which resulted in adequate containment of the graft.

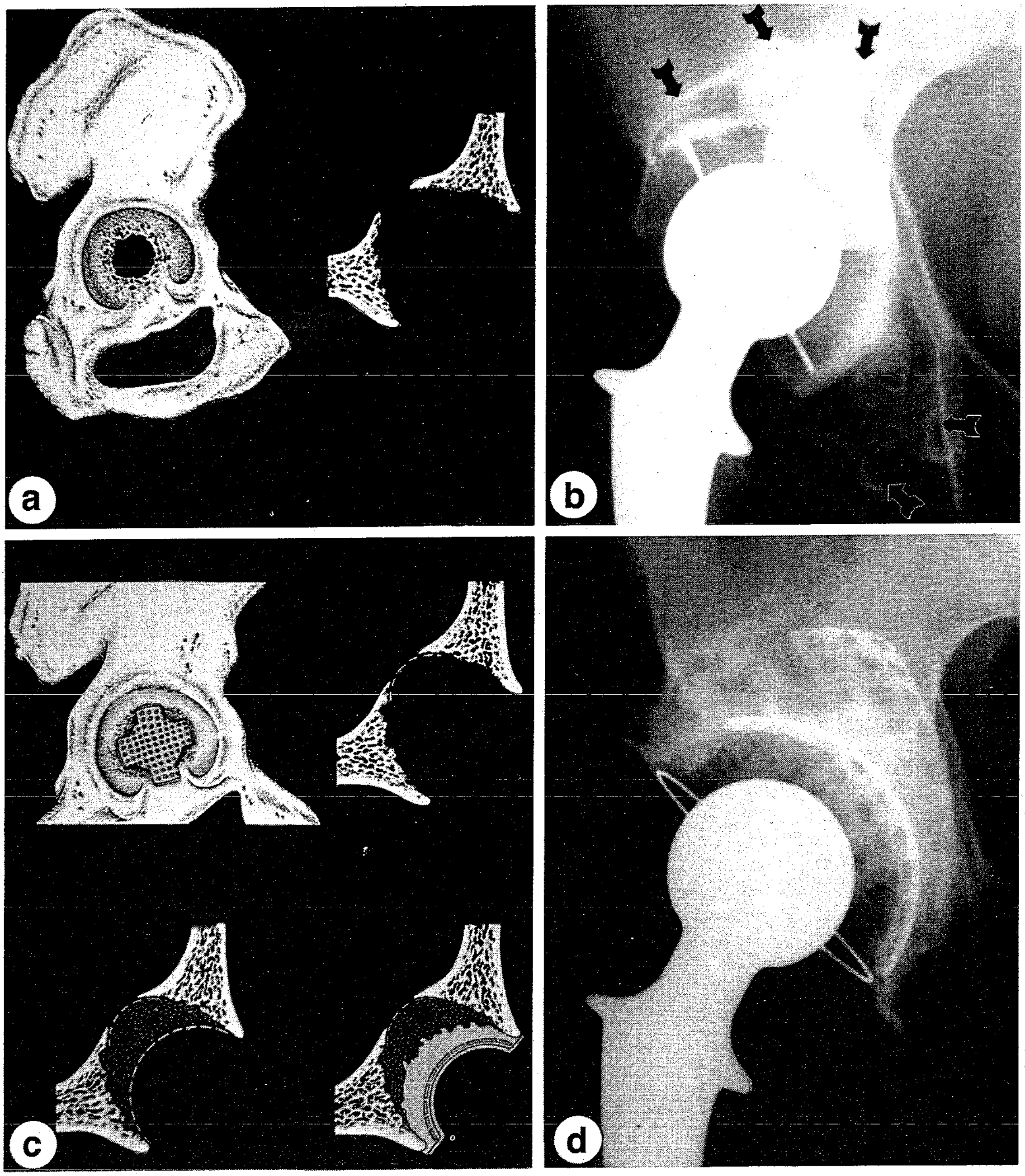


Figure 14.7 a, Schematic view of medial segmental defect. b, preoperative radiograph of medial segmental defect. c, Acetabular reconstruction of medial segmental defect. d, Radiograph 5 years after acetabular reconstruction with impaction grafting and cement (from Slooff et al.[43]).

- Cavitary defects were closed with wire mesh and augmented with tightly impacted morsellized cancellous allografts. As much graft material as necessary was packed until the trial socket was built up to the level of the transverse ligament, i.e. the anatomical location of the acetabulum. In this way, it was possible to use only conventional-size implants.
- After packing, the graft was covered with a flexible wire mesh to spread the load evenly over the graft.

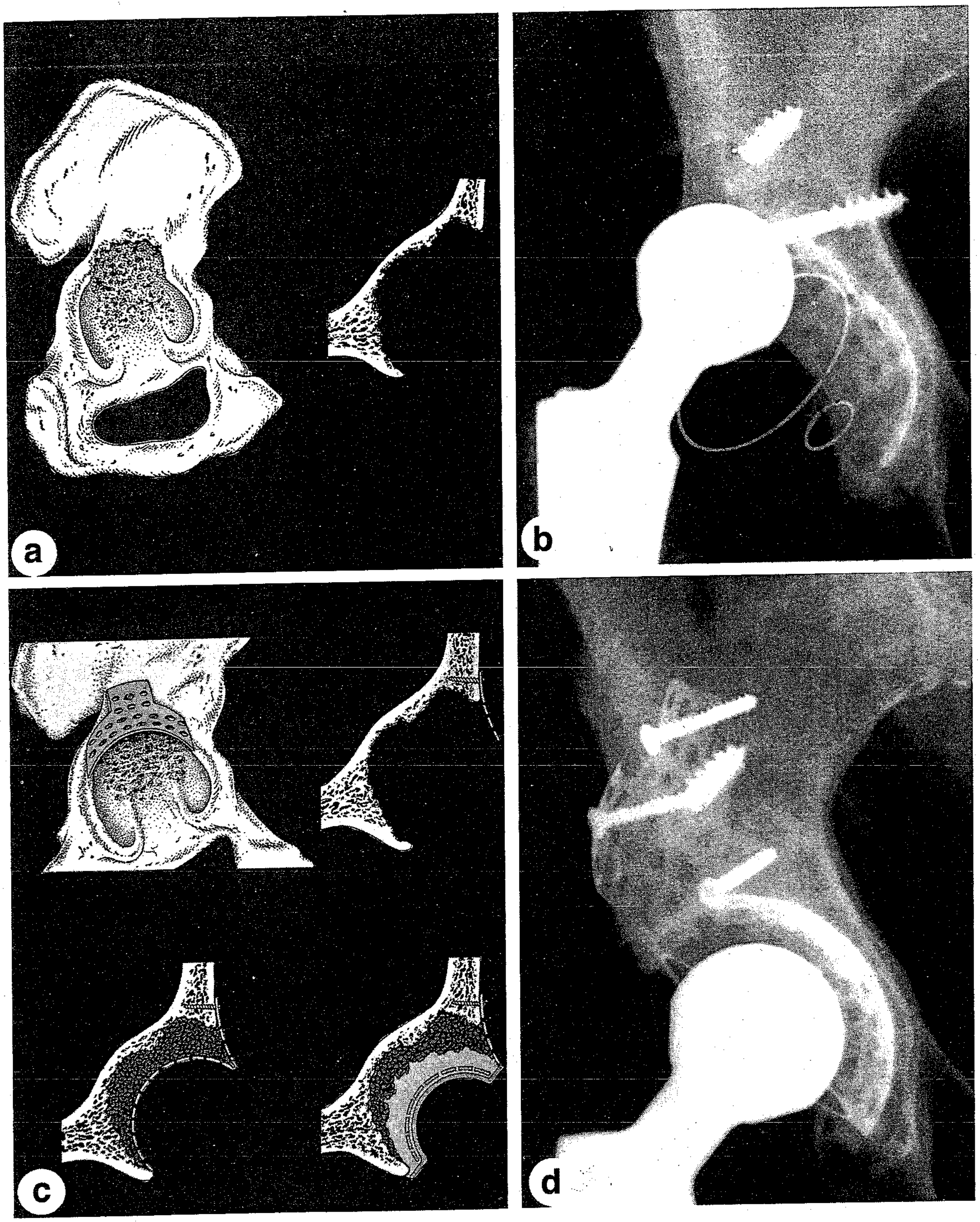


Figure 14.8 a, Schematic view of combined segmental cavitary defect. b, Preoperative radiograph of a patient with a combined defect. c, Schematic view of reconstruction. d, Postoperative radiograph after cemented acetabular reconstruction with impaction grafting (from Slooff et al.[43]).

- Bone cement was used to stabilize the reconstruction directly. The hemispherical surface of the graft provided an ideal rough surface to interlock the cement.

Since 1978, this surgical technique for acetabular reconstruction has been standardized and is still being used today.

Preoperative planning

Preoperatively, the patients were treated systematically according to a standard protocol. Our attention was chiefly directed at making the diagnosis of loosening and establishing the cause of failure. Once the diagnosis had been established, clinical treatment started with the direct or delayed exchange of components or resection arthroplasty. Our patient records showed that many of the patients with loosened components were functioning without any complaints of pain. The loosening process resulted in resorption of the bone bed and formed the major indication to revise the arthroplasty. It is therefore vital to evaluate all the patients with total hip arthroplasty periodically according to a standard protocol of routine investigations, to monitor postoperative complaints, problems with wound healing, function and to prevent extensive loss of bone stock in the case of loosening. At our clinic, follow-up was carried out after 3, 6, 12 weeks and after 6 months, and then periodically at yearly intervals. If any radiographic changes were observed, the follow-up interval was reduced as a means to prevent extensive bone loss.

Before revision of the loose component, the patients underwent a thorough physical examination, including hip mobility and gait. Weight-bearing on the affected side often resulted in a positive Trendelenburg sign. Reduction in the range of motion was rarely seen, but forced passive rotations were painful. A very reliable diagnosis of loosening could be made if the patient was unable to raise his/her leg while keeping it straight. Local examination of the hip and soft tissues was also important to locate previous incisions and areas of tenderness. Preoperatively, the neurovascular status and any discrepancies in leg length were assessed carefully. The thorough physical examination was followed by laboratory tests, including ESR, white blood cell counts and C-reactive protein. To assess loosening of the components, good quality plain radiographs were taken. These radiographs were used to evaluate the severity of the anatomical distortions, the location and extent of bone lysis, the distribution of cement, any deficiencies and bony defects. Serial radiographs were compared to monitor any progressive changes in the position of the component, the cement and the bone stock over the course of time. In this way, we were also able to detect very slowly progressing changes. The presence of a radiolucent line was not an indication of failure, but any radiolucency between the acrylic cement and bone which progressed in time, in extent and width, constituted a definite radiological and clinical diagnosis of loosening. Migration of the components and progressive bone destruction, which could be assessed easily on the serial radiographs if there was gross movement and abnormalities at the interface, reflected definite evidence of loosening. In cases of suspected loosening, preoperative management also included subtraction arthrography combined with an intra-articular needle biopsy and a bone scan to exclude septic loosening. Positive results and the exclusion of other causes of failure meant that the diagnosis of loosening was a distinct possibility.

The standard operative technique

A posterolateral approach was used in all the cases and was combined with trochanteric osteotomy in only 3 cases. The proximal part of the femur was carefully released and mobilized, followed by dislocation of the hip. After testing for loosening, both components were released from the cement mantle. The whole socket of the acetabulum was exposed from the transverse ligament to the superior margin, and from the posterior wall to the anterior wall. After removing the socket and the cement, the fibrous interface was separated from the thin irregular acetabular wall using sharp spoons. Removal of this layer led finally to abundant bleeding of the sclerotic bone. At least three specimens were taken of the interfacial fibrous membrane for frozen section and culture. After this procedure, a prophylactic antibiotic regimen was started. The wall and floor of the cavity were examined to establish their integrity, the bone quality and to detect any defects. Reconstruction aimed to achieve adequate containment of the graft by closing the cavitary and peripheral segmental defects with a metal mesh. The cavitary defects were then filled with impacted chip grafts. Finally, the graft was covered by a second metal mesh and a polyethylene cup was cemented to it with a diameter 4 mm smaller than the mould itself.

Postoperative treatment

Postoperative treatment comprised anticoagulation therapy for 3 months and systemic antibiotics for 24 hours. Indomethacin was administered for 7 days to prevent heterotopic ossification. Passive motion exercises were started after 24 hours, partial weight-bearing after 6 weeks, and full weight-bearing at 3 months p.o.

The series of patients

Between January 1979 and January 1988, 91 revision hip arthroplasties (83 patients) were performed at our Institute using the above-described acetabular reconstruction technique with impaction grafting and cement. The original reasons for performing primary hip arthroplasty were primary osteoarthritis in 35 cases, secondary osteoarthritis due to congenital dysplasia, femoral head necrosis or trauma in 42 cases and rheumatoid arthritis in 11 cases. The initial arthroplasties comprised 5 femoral head prostheses, 13 double cup prostheses and 70 total hip replacements. In 8 cases, the reason for revision was septic loosening; the procedure was performed in two or more stages after debridement and local and systemic antibiotic treatment. The remaining revisions were necessary because of aseptic loosening. Morsellized autografts were used in 15 reconstructions, morsellized cancellous allografts from the hospital bone bank were used in 70 cases and a combination of these grafts was used in 3 cases. Patients were excluded from the follow-up study if the revision procedure was performed without bone grafts or a metal acetabular reinforcement ring had been used.

In the first half of 1990, all the patients eligible to take part in the study were invited for a clinical and radiographic examination by two of the authors (T.S., J.W.S.). Seven patients (7 hips) had died of causes not related to the revision procedure. One patient (1 hip) was lost to follow-up. The majority of patients had been followed-up routinely at yearly intervals, so it was possible to study the records and radiographs of their last visit. Finally, 88 hips (80 patients) entered the study with an average follow-up of 70 months (range 24–132 months). The average age at revision was 62 years (range 33–89 years).

Classification of acetabular defects

It is important to define and classify acetabular defects in order to make a preoperative plan, to standardize terminology and to compare different reconstruction techniques. The American Academy of Orthopedic Surgeons (AAOS) Committee on the Hip, has proposed a practical classification system for acetabular deficiencies[52]. The system defines two basic categories: segmental and cavitary defects. A segmental defect is any complete loss of bone in the supporting hemisphere of the acetabulum, including the medial wall. Cavitary defects represent a volumetric loss of bony substance from the acetabular cavity, including the medial wall. Pelvic discontinuity is a defect across the anterior and posterior columns with total separation of the superior and inferior acetabulum. Using this AAOS classification, our group comprised 44 cavitary defects, 43 combined segmental/cavitary defects and 1 segmental defect.

Clinical results

At the time of the study, 4 acetabular components had been re-revised because of recurrent infection in 2 cases, and aseptic loosening with migration in the other 2 cases. Clinical evaluation of the remaining 84 hips was based on the Harris hip score. The clinical result was considered to be excellent with a score of (i) 9–100 points, good with (ii) 81–90 points, fair with 70–80 points and poor with less than 70 points. The average score of our study group was 78 points (range 23–100). In 90% of the hips, the score was 80 points or more.

Radiographic results

Radiographs were used to assess the following processes:

- incorporation which included consolidation
- migration and
- radiolucency

Consolidation

Consolidation of the graft, i.e. union of the graft to the host bed, was defined as the presence of clearly delineated trabeculae crossing the graft–host junction. Consolidation was complete in all 88 hips.

Graft incorporation was assessed according to the criteria of Conn et al.[53] and was defined as: identical radiodensity of the graft and host bone, with a continuous trabecular pattern throughout. Eight acetabula showed incomplete graft incorporation. Two cups had remained stable during the follow-up period, 5 cups had migrated with partial graft resorption but were clinically asymptomatic and 1 cup had been re-revised because of progressive loosening.

Migration

Migration of the cup was established after digitizing the serial radiographs. Reliable reproducible measurements could be performed on the monitor. The position of the socket was determined by the metal wire marker on the cup and was measured relative to Köhler's line and the tear drop line. The reliability of this method was estimated at 5 mm. The 5 cups with incomplete graft incorporation showed definite migration and were considered to be loose.

Radiolucency

Radiolucency at the graft–cement interface was assessed according to the criteria of DeLee and Charnley[54]. Cups with continuous lucent lines of greater than 2 mm in all the segments were considered to be loose. One cup showed progressive continuous lucency with incomplete graft incorporation but an absence of any migration.

We defined failure as:

re-revision	4 cases
migration > 5mm	5 cases
continuous lucency > 2mm	1 case
	10 cases (11.4%)

In our series of 88 cup revisions, we had 10 failures of which two were due to recurrent infection (2.3%).

The primary aetiology of the aseptic loosened cup comprised 4 loosenings (11.4%) in the primary osteoarthritis group, 3 loosenings (7.1%) in the secondary osteoarthritis group and 1 (9%) in the rheumatoid arthritis group. Excluding the septic failures, the failure rate in the cavitary-type defect group did not differ significantly from that in the combined cavitary/segmental defect group: 9.1% and 9.3% respectively. This indicates that there was no difference in structural stability between the contained and non-contained acetabular defects reconstructed with impaction grafting and cement.

Conclusions

The clinical use of bone grafts in cemented revision acetabular reconstruction is a well-accepted surgical procedure. We developed a surgical method for revision THA with impaction grafting and cement. The impacted graft was used to replace severe bone loss, to restore acetabular anatomical distortions to normal and to improve the cement interlock. This surgical method was based on an animal investigation in the goat in which the incorporation process and the initial stability of the reconstruction were measured and evaluated. The experimental results encouraged us to apply the surgical technique in clinical practice. The clinical and radiographic results of 10 years experience with this reconstruction technique justify its use.

Acknowledgements

The authors wish to thank Miss Diny Versleyen for generously performing and preparing the histological sections for the animal experiments and Mrs M.L. Beenen for help in manuscript preparation.

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