Impaction grafting and cement in acetabular revision arthroplasty

Impaction Grafting and Cement in Acetabular Revision Arthroplasty

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Summary

Animal experiments were performed to restore bony defects with morsellized allograft chips. Acetabular defects were created in the Dutch milk goat and impacted with fresh frozen allograft bone chips. The speed of consolidation with the host bone bed, the mechanism and completeness of incorporation and the processes at the graft cement interface were studied in detail with histological and biomechanical procedures.

Histology showed that the graft had consolidated with the trabecular host bone bed within three weeks. In the subsequent period a front of vascular sprouts infiltrated the graft. Graft resorption, new bone formation and bone remodelling resulted in a new trabecular structure with optimal trabecular orientation for load bearing. After twelve weeks only scarce remnants of the original dead graft material remained in the incorporated area of the graft. At revascularized areas of the graft-cement interface, graft resorption and new bone formation had resulted in direct vital bone-cement contact sites and in areas with a soft tissue interface. After longer follow-up periods progressive interface formation and loosening of the cup was found in most of the animals.

The histological results were confirmed by biomechanical stability tests. In the first postoperative weeks the stability of the reconstruction increased, but at later follow-up periods, interface formation at the new bone-cement layer compromised the stability of the reconstruction.

The results indicated that reconstruction with morsellized graft material leads to rapid consolidation, incorporation and remodelling of the graft. Problems at the graft-cement interface are probably not related to the use of the morsellized graft, but to the goat model used.

Introduction

Without doubt it can be stated that bone transplantation was already performed in the early centuries. However, it takes a deep and extensive study of all historical reviews to distinguish the truth from fairy-tales. From sporadic use of autogenous grafts and allografts in the past, bone grafting has gained in popularity during the last decades. As laboratory and clinical work on bone transplantation was introduced by Ollier [28] in

France, MacEwen [25] in Scotland, Barth [4] and Axhausen and Lexer [3, 24] in Germany and Curtis [13] in the USA. The development of preservation techniques by Bush and Wilson in 1947 [12] and in 1950 the foundation of the National Naval Tissue Bank in Bethesda (U.S.A.) made it possible to use allografts clinically on a larger scale.

In general it can be stated that with regard to graft incorporation most of the current data are related to animal experiments [1, 2, 3, 5, 10, 12, 15, 16, 18, 19, 22, 26, 29, 30, 40]. Heiple, Herndon and Chase [23], Burwell [9, 10] and Campbell [12] demonstrated an immune response in animals receiving allograft bone. In 1953, Urist and coworkers [41–43] developed the theory of osteoinduction. A substantial part of allograft studies was also activated by the development of modern surgical methods in orthopaedic oncology [7, 8, 14].

An important clinical application which started in the 70th's, was the repair of major acetabular bone deficiencies in association with primary and revision total hip arthroplasties. Initial reports by Hastings and Parker [21] and Harris and Crothers [20] about these acetabular reconstructions with morsellized and structural cortico-cancellous bone graft set a stage in this field. In the human situation this process has been usually evaluated on radiographs which are in our opinion only a crude parameter.

Summarizing the data in the literature about the reconstruction methods of failed total hip arthroplasties, it is essential to distinguish the use of different types of grafts. In all grafts there can be several processes occurring such as union, incorporation, rejection, infection and remodelling. With special regard to union and incorporation, these processes are different for the various grafts. In our clinical series we define successful graft incorporation as complete revascularization and concurrent substitution of the graft with new bone without significant loss of strength. The new bony structure can bear physiologic loads and remodel itself in response to changes in load and fatigue damage.

Compared to cortical grafts, cancellous grafts do have a more open structure, which in theory allows a more uniform, a more complete and a more rapid vascular invasion. Cortical grafts incorporate irregularly, incompletely, slowly and with mechanical weakening due to fatigue damage.

The difference between solid and morsellized cancellous grafts is less clearly understood. When using femoral head allograft, the stiffness, quality and size of the structural graft may lead to stress protection of any new bone that is formed within it. Finally, it must be mentioned that the incorporation process depends on the security of fixation (stability), the degree of contact, the vascularity of the host bone bed, the strain pattern and the degree of antigen matching.

In summary, the use of bone grafts for primary acetabular reconstruction and revision is nowadays a generally accepted procedure. Union of the graft to the host bone bed is nearly always achieved. However, the incorporation and remodelling processes of the various types of grafts are quite different and are not well understood. This distinction in behaviour is clearly demonstrated, particularly during longer follow-up, when cortical, solid or morsellized grafts are used. Clinical success does not necessarily reflect the fate of the grafts. Plain radiographic imaging does not unequivocally prove the solidity of the reconstructed acetabulum. Plain radiographs are, at best, difficult to interpret. Therefore, histologic evidence of the viability and incorporation of the graft is crucial.

In 1984 and subsequently in 1992 we published our acetabular method [38, 39] with a modification of the techniques of Hastings and Parker [21] and McCollum et al. [27]. We used morsellized chip allograft, impacted the graft firmly and pressurized the cement on the graft. With this technique it was possible to treat extensive and serious defects in primary and revision total hip arthroplasty.

Animal Experiments

To support scientifically our surgical reconstruction technique the acetabular method using impaction grafting and cement was developed and tested on an animal model [6, 31–35]. The animal of choice was the goat.

The aims of these experiments were:

A. To make a histological evaluation of the different processes involved in the incorporation of the graft.
B. To evaluate the initial mechanical stability (in vitro) of the graft and the stability of graft incorporation 12 weeks after implantation.

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 dorsal lateral incision was used, followed by dislocation of the hip and resection of the femoral head. The acetabular cartilage was removed and a cavitary defect was made in the anterior-superior 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 analyze the initial stability (in vitro). Six goats were sacrificed at intervals of 6, 12, 24 and 48 weeks. After the operation all the goats were kept in a hammock for 2 days. Antero-posterior and lateral radiographs were taken immediately after the operation. The goats were kept in cages which allowed free walking or in the open field. Three of the 6 cases from each interval were used for histology and three for biomechanical analysis.

Histological Procedures

The goats received different types of fluorochrome to enable the qualitative evaluation of bone ingrowth into the graft. The acetabula were harvested after perfusion of the lower extremity with Micropaque (R) as described by Rhinelander and Baragry. After fixation in a buffed paraformaldehyde solution the acetabula 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.

Biomechanical Procedures

For mechanical testing of the grafted acetabulum tantalum pellets were fixed to the component prior to insertion. The 3-D displacement of the component relative to the bone (rotation and translation) was measured using Rontgen-Stereophotogrammatic Analysis (RSA), developed by Selvik [36, 37].

The acetabula for the mechanical study were freshly harvested and stored at −80°C ready for testing. After thawing, the bone specimens were embedded in polymethylmethacrylate (PMMA). Tantalum pellets were inserted into small holes drilled into the pelvic bone in standard positions. Furthermore, small PMMA rods containing tantalum

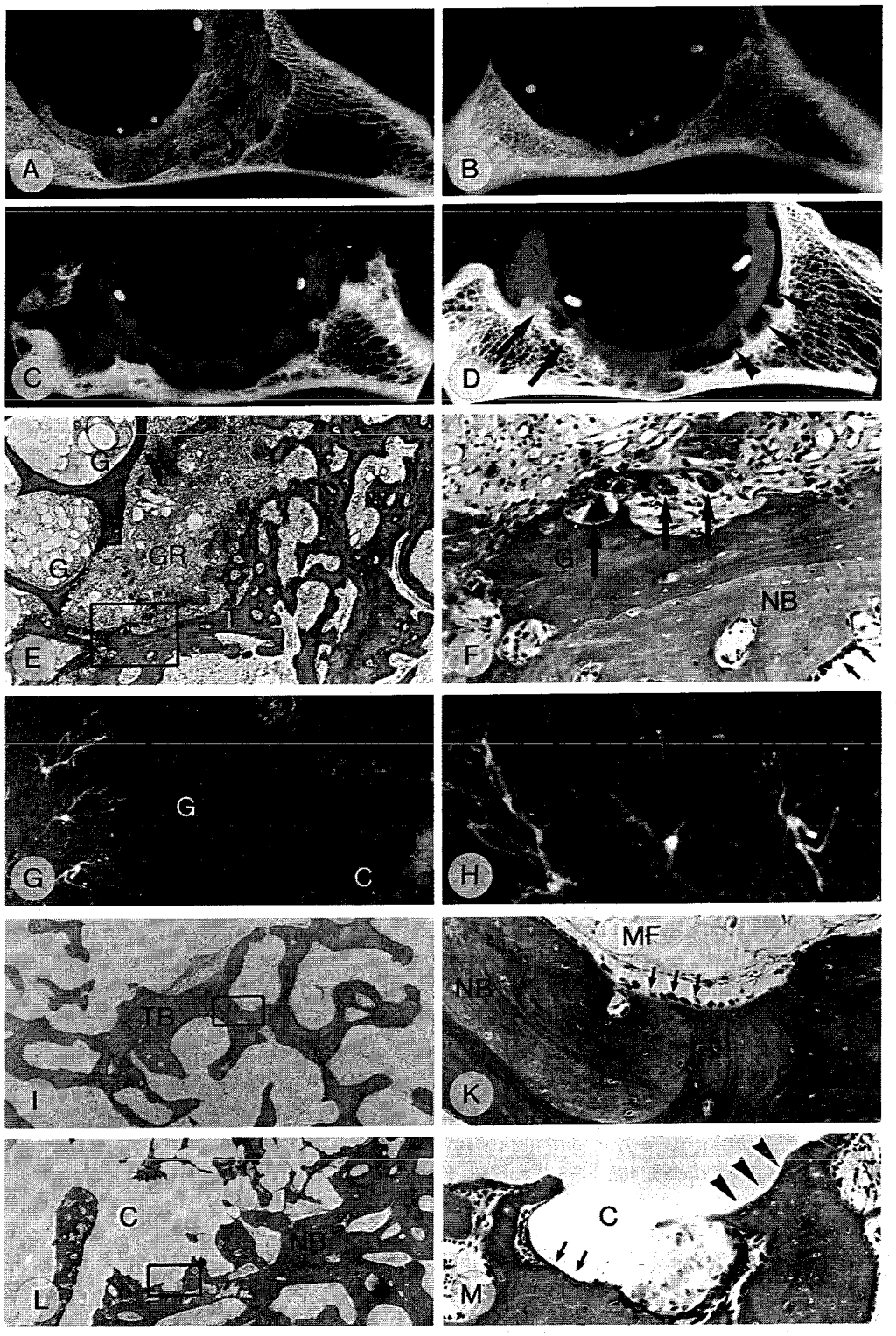

Fig. 1. A–D Roentgenograms of thick sections through the acetabulum of the goat taken at 0 (A), 12 (B), 24 (C) and 48 weeks (D) after surgery. **A.** Note large pieces of graft and the clear transition zone to the host bone-bed. **B.** Complete consolidation of the graft with the host bone. The incorporation of the

(*continued*)

pellets were inserted into the acetabular component. The prosthesis-bone structures were then loaded into a MTS-testing device in a physiological way. A pelvic load was applied stepwise from zero to 350 and to 700 N and again unloaded. Stereoroentgenograms were taken before loading, after each loading step and ten minutes after the final unloading. Each loading period lasted 10 minutes.

All stereoroentgenograms were evaluated on an Aristomat digitizer, and the 3-D 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 stereoroentgenograms were measured 5 times and the results were averaged.

Histological Evaluation or the Grafted Acetabulum

The impacted graft consisted of fairly large pieces of trabecular bone (Fig. 1A), which displayed small micro-fractures at all levels. Generally, the bone graft was devoid of any well-preserved osteocytes, the osteocytes had completely disappeared, or if they were still present, they had a pycnotic appearance (Fig. 1K). 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 circa 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 circa 70 μm per day (Fig. 1G, H). 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 (Fig. 1E, F). This is resulted in a new trabecular structure which consisted of a mixture of the remnants of the graft and newly formed, mainly woven bone (Fig. 1B, I, K). 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 (Fig. 1B, D). 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 (Fig. 1C, D). 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 (Fig. 1L, M). Between 24 and 48 weeks after surgery, the graft in the defect 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 to 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.** 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. **K.** 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. **L.** Transition 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. **M.** Enlargement of encircled area of K shows that locally 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). A–D × 1. E, G, I, L × 12.5; F, H, K, M × 125

acetabulum and femur had become completely revascularized. The percentage of the dead graft present in the new bony structure was very low. Direct bone-cement contact sites were still present, but particularly at later follow up periods the interface had thickened and showed signs of loosening.

Mechanical Evaluation of the Acetabulum

All the specimens seemed to be firmly fixed when tested manually. Coordinate axes were chosen as follows: X-axis dorso-ventral, Y-axis cranio-caudal, 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 craniocaudal direction (0.6 mm) (Fig. 2H).

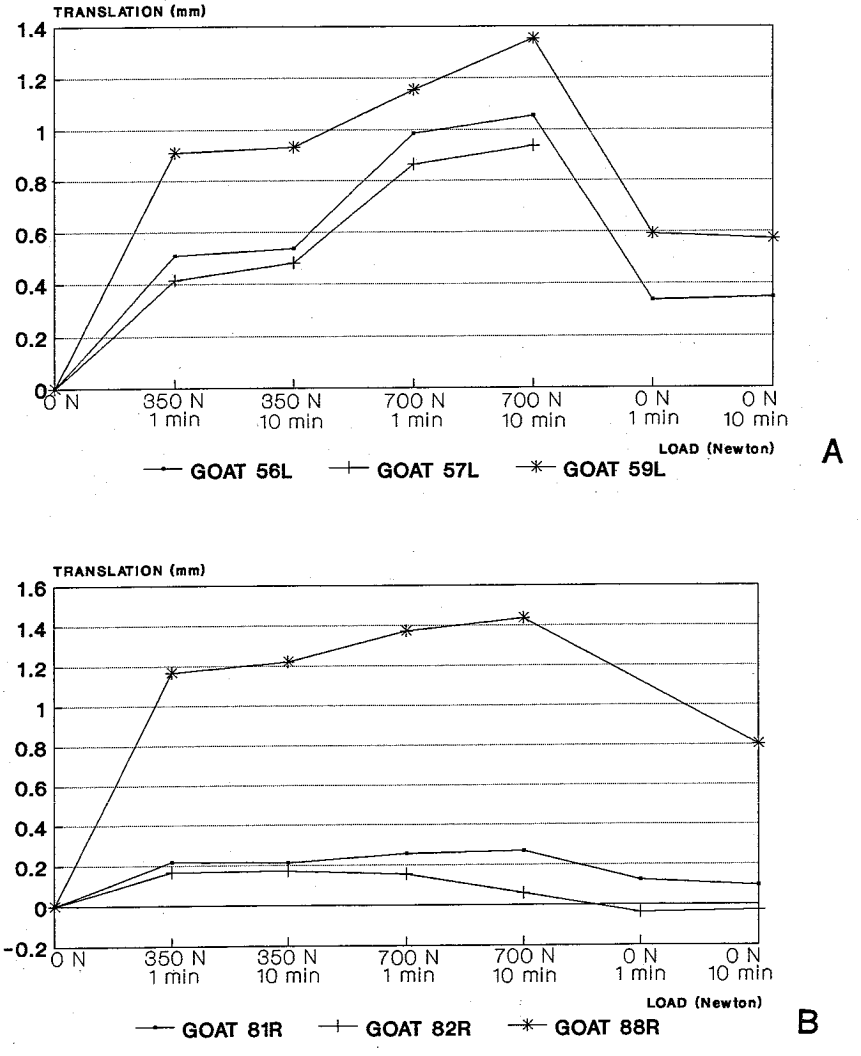

Fig. 2. Translations found in cranio-caudal direction (Y-axis) immediately after implantation (**A**) and 12 weeks after implantation (**B**). Implant in goat 88R showed excessive translations and rotations in all directions and was considered loose

Maximum rotation was measured around the X-axis (−3.1 degrees). In course of time a rather consistent pattern was observed showing increasing stability 12 weeks after implantation. Persistent translation in all directions declined from the zero group to the 12 weeks group, as was the case for rotations. At 12 weeks maximum persistent translation was measured in a medial-lateral direction (0.2 mm) (Fig. 2) with maximum persistent rotation around the Z-axis (−2.1 degrees).

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 sites remained between the cement and newly formed bone.

Our histological and mechanical results showed that the reconstruction technique provided sufficient initial stability to enable the incorporation of the impacted acetabular grafts. Although the follow-up period in these animal experiments was limited to 48 weeks and the surgically prepared host bone was far less compromised than in the real clinical situation of humans with failed total hip arthroplasties, the results of this study encouraged us to continue to apply this biological reconstruction in small and large acetabular deficiencies.

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