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CURRENT CONCEPTS REVIEW

# Revision of the femoral prosthesis with impaction allografting

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**Impaction allografting is the only technique, to date, that has been shown to reverse the loss of bone stock encountered during revision hip arthroplasty. However, early stem subsidence, dislocations and a high occurrence of periprosthetic fractures are well documented with this method. This article reviews the biomechanical and biological characteristics of compacted morsellised graft, on the femoral side, and examines the clinical results of this technique and its future development.**

**Keywords** : impaction allografting ; revision hip surgery ; osteolysis ; aseptic loosening.

## INTRODUCTION

Over the last two decades, complications associated with total hip replacement (THR) have declined significantly (*9*). However, periprosthetic osteolysis or aseptic loosening remains the most significant long-term complication with THR (*24*). It has been reported with all materials and prosthetic devices in use or that have been used to date. The majority of patients with aseptic loosening will need to undergo revision surgery. Furthermore, joint replacements of limited useful duration are being performed on ever younger patients at a time when average life-expectancy is continuing to rise (*14*). It can therefore be expected that the need for revision hip arthroplasty will continue to rise for the foreseeable future. The principal aims of revision hip surgery are to achieve immediate fixation and long-term stability and to reconstitute bone loss. However, reduction of bone stock available for subsequent implant fixation probably accounts for inferior results attained in revision surgery compared with the primary procedure (*33, 49,57*).

One method that has been employed to treat cavitary defects in the proximal femur, has been the use of impaction grafting, whereby morsellised cancellous allograft is impacted into the proximal femur and the revision prosthesis usually cemented into the canal. Whilst in structural grafts, bone ingrowth does not usually exceed 2 to 3 mm (*18,27*), in impacted morsellised allografts the bone growth distance has been shown to be greater (*38*), suggesting that impacted graft may be superior in terms of bone growth distance. Furthermore, this is the only technique, to date, that has been shown to reverse the loss of bone stock caused by osteolysis (*45*). This article will review the literature regarding the biomechanical and biological characteristics of compacted morsellised graft, on the femoral side,

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and examine the clinical results of this technique and its future development.

## HISTORY OF FEMORAL IMPACTION ALLOGRAFTING

Impaction grafting using either autograft or allograft was initially introduced on the acetabular side in the treatment of protrusio acetabuli (*25,41*). It was subsequently used in the treatment of acetabular osteolysis during revision hip (*53,55*). The first clinical reports of impaction allografting on the femoral side were in relation to revision with cementless stems (*47*). Although, the cementless method is used by some surgeons (*30*), the use of morsellised bone with cement has attracted more enthusiasm over the last decade. This was first described by the Exeter group (*22*) and later by other groups (*17*).

## TECHNIQUE OF IMPACTION ALLOGRAFTING

The technique of impaction allografting as described by the originators has evolved since that reported in the original series from Exeter (*21*). Most techniques now try to optimise the impaction of the allograft, reduce the possibility for periprosthetic fractures, and allow the use of femoral implants with variable stem geometry (*58*). On the femoral side, the surgery involves removing the old prosthesis, cement and fibrous membrane, and where necessary this is followed by placing cerclage wires or stainless steel mesh around the proximal femur and onlay struts over the proximal cortical defects. The femoral canal is blocked using a special revision polyethylene plug positioned at least 20 mm distal from the anticipated position of the stem tip and a 4 mm diameter guide wire is screwed into the revision plug, which ensures central compaction of the graft. A series of increasing diameter distal impactors that slide are used to impact the graft distally. To create space for the new stem a proximal impactor is driven into the graft. The former is of similar shape but marginally larger then the stem to allow for a cement mantle. During proximal impaction, graft is added in stages and it is advised that the proximal impactor should be driven into the graft until it is "so tight that it is impossible to withdraw it without using the slap hammer". Once the femur is fully impacted, more chips can be impacted using small hand taps around the top of the stem shaped impactor.

For revision acetabular reconstruction, the old implant, cement and fibrous interface are removed. Where necessary defects are closed using wire meshes, which are screwed into place. The bone chips are packed into the small cavities, and then layer by layer the entire socket is filled with the graft using different sized, hand held, domed impactors that can be struck with a hammer. The last impactor should be 2-4 mm larger than the cup diameter to accommodate the cement used for fixing the cup into position. At least two femoral heads are recommended for acetabular or femoral reconstruction.

## ALLOGRAFT PREPARATION

Impaction grafting is most commonly performed using fresh frozen femoral head allograft which is thawed at the time of surgery and milled to the required size. On the femoral side, the use of a bone mill to produce 2-4 mm chips is suggested, however larger particles, of approximately 10 mm, are recommended for the acetabulum (*36*). The most commonly used alternative to frozen allograft is processed bone (freeze dried or irradiated bone). Rarely, xenografts and autografts are utilised but as they are so infrequently used they will not be discussed in this review. The surgical technique is the same regardless of the type of graft used.

The use of fresh frozen allograft has been associated with the best long term results (*51*). However, the major disadvantage with its use is the possibility of transmission of pathogens to the patient such as hepatitis B, hepatitis C or HIV (*2,10,54,65*). Although processed bone has less potential for disease transmission, there have been concerns that it may have inferior mechanical properties compared with fresh frozen bone (*48,64*). However, recently in vitro studies have shown freeze-dried graft may provide a more stable fixation of the stem than fresh-frozen morsellised graft (*11*). Furthermore, the compaction of freeze-dried bone is faster than that of fresh-frozen bone with freeze-dried grafts requiring three to four times fewer impactions to achieve the same stiffness (*12*). As it is easier to impact freeze-dried bone it may be mechanically more efficient than the fresh-frozen bone in surgical conditions (*12*). Clinical studies using processed bone have shown inconsistent results (*7,13,50,63,64*) and it is not clear if the type of bone graft used or minor variations in technique are responsible for the differences in outcome. Currently, a review to compare the clinical effectiveness of processed bone versus fresh frozen bone is being conducted (*3*).

## CLINICAL RESULTS

Like many advances in orthopaedics, the clinical use of impaction allografting has preceded the basic biomechanical and biological knowledge. However, over the last ten years, the science behind impaction grafting is gradually becoming clearer. The assessment of published data on impaction allografting is restricted by three important factors which limit comparisons among clinical series. Firstly, the inclusion criteria in some cases have either not been defined at all (*16*) or there have been major inconsistencies between different series. For example, in some studies, only patients with severe bone loss have been included (*35,40,43*) whilst in other series such cases have specifically been omitted (*22*). Secondly, series have varied with respect to stem geometry, cementing technique, type of allograft used, surgical approach and postoperative protocol (*36*). Finally, the duration of patient follow-up have differed considerably among published reports (*36*).

Most studies on femoral impaction allografting have concentrated on the cemented method and to date there are no published series on the cementless technique. The cemented method has revealed promising results and shows reconstitution in bone stock in a majority of cases (*17,22,35,43,44*). In addition, radiological and histological graft incorporation have been confirmed (*22,67*). However, early stem subsidence, dislocations and a high occurrence of periprosthetic fractures are well documented (*16,19,39*).

There have been numerous reports on the short-tem follow-up using cemented cancellous impaction grafting using polished, tapered, collarless stems (*16,17,22,43*). Proponents of this technique claim that subsidence does not necessarily result in loosening as the stem's wedge-shaped geometry could allow restabilisation within the cement mantle as subsidence occurs (*17,22*). Cold flow of the cement mantle may allow the stem to subside without resulting in clinical loosening (*36*). Furthermore, subsidence of the wedge shaped stem may also offer a favourable compressive load to the bone graft (*46*). However, many surgeons have warned that subsidence is a major complication and results in postoperative thigh pain, cement mantle fracture and hip dislocations (*16,19,39,43*).

## EVIDENCE FOR GRAFT INCORPORATION

### Radiographic Analysis

Following impaction allografting, bone graft incorporation is said to be complete when the graft has been replaced by living bone in a trabecular pattern with an alignment pattern determined by the transmission forces from the stem of the femoral component of the distal femur (*15*). The precise pattern will depend on the geometry of the femoral stem used. However, radiographic evaluation of preoperative defects and assessment of postoperative radiographs in the presence of overlapping heterotopic bone, wire mesh, cortical bone, cortical allograft, bone cement and the femoral prosthesis is difficult (*15,22*). Furthermore, there is no universally agreed, reliable and valid radiographic classification system for describing graft incorporation. A radiographic grading system was proposed by the Exeter group (*22*) but remains unvalidated. However, radiographic reconstitution of living femoral bone stock with this technique has been noted by some authors (*15*). Where cortical and trabecular remodelling is clearly seen, this has been shown to correspond to new bone histologically.

### Histology

In a goat model, histological evaluation of impacted allografts surrounding the femoral prosthesis *(52)* has shown revascularisation and remodelling of the graft and new bone formation from the cortex towards the cement mantle at six and twelve weeks post surgery. In humans, most of the evidence for allograft incorporation during femoral impaction allografting comes indirectly from histological analysis of revised acetabuli. Histological studies on the revised acetabulum have shown graft incorporation with subsequent replacement by host bone to varying degrees *(8,26, 34,69)*. However, incorporation of the morsellised graft is often incomplete and frequently unpredictable *(61)* and in some cases incorporated allograft is present up to 8 years post surgery *(31)*. There have been only a limited number of direct histological studies evaluating femoral impaction allografting *(37,46,67,68)*. Of these, only three stem designs have been reported upon : the polished tapered CPT stem *(31)*, the Lubinus stem *(55)*, and two versions of the Charnley prosthesis *(66)*.

Histological evaluation of retrieved femurs following impaction allografting have shown three distinct zones *(46)* : an inner zone comprising mainly of dead bone trabeculae buried in cement ; an interface zone between cement and living tissue ; and an outer zone consisting mainly of well vascularised regenerated cortical bone with occasional islands of dead bone. The authors concluded that the bone cement forced into the graft immobilises the bone trabeculae at the interface and that the regenerating bone makes contact with these protruding dead trabeculae. Another study evaluated the histological findings of a retrieved femur 6 months after a cemented cancellous impaction grafting using a Charnley prosthesis *(67)*. This showed that most transplanted areas were revascularised and in the proximal femur there was new bone formation peripherally, but a substantial amount of fibrous stroma embedded graft pieces closer to the cement.

**Positron emission tomography (PET)**

Sorensen *et al* *(56)* used positron emission tomography (PET) to evaluate vascularisation and new bone formation in impacted morsellised allograft in 5 patients revised with femoral impaction allografting. They showed increased bone formation and blood flow close to the allograft as early as eight days post surgery. Four months post-surgery, bone formation and blood flow were about the same, but activity was highest in the graft material. At one year, blood flow within the graft bed reduced to levels of the un-operated femoral diaphysis.

**Animal studies**

Studies in the titanium chamber model in the rat *(59)* resemble those on the histological findings on human femurs in that the fibrovascular tissue penetrates the graft almost completely whilst new bone formation is more limited. The fibrous tissue was shown to be mechanically stronger than the freshly impacted graft *(60)*. Some authors have therefore concluded that remodelling is not always needed for a favourable clinical outcome and a combination of necrotic bone and fibrous tissue may constitute an excellent biomaterial for revision surgery *(1)*.

Load bearing has been shown to favour bone formation in a rat tibial prosthesis model *(72)*. The addition of OP-1 to impacted graft promotes bony ingrowth *(60)* and bone graft incorporation *(42)*, in an animal femoral impaction grafting model, proving that biological factors are important in impaction grafting. However, mixing allograft with OP-1 did not improve cup or stem fixation in revision hip surgery in humans *(29)*.

**Mechanical studies**

Any form of allografting should ideally restore bone stock and provide mechanical stability to prevent subsidence and failure of the construct. Most studies have shown that particle size of broad distribution exhibit superior mechanical properties compared with a graft of uniform size distribution *(5,62)*. It is worth mentioning that bone mills widely used in the U.K. produce particle sizes of more uniform distribution than is desirable for optimising resistance to shear stresses *(5)*.

Mechanical properties of impacted allografts have also been shown to improve with increasing normal load, shear strains and compaction energy (5). The impacted graft also exhibits visco-elastic properties (23) which are affected by several factors. Reducing the water and fat content improves both the static and dynamic behaviour of the bone graft (71). Removing the bone marrow from the bone graft appears to increase stability by reducing stem migration under loading (28). In contrast, lower graft porosity and stiffer bone graft decreases the visco-elastic behaviour of bone grafts (70). Biomechanical studies have shown significantly less stem subsidence in the impacted cortical morsellised graft compared with impacted cancellous graft (31,32).

## THE PROCESS OF GRAFT INCORPORATION

The process of cancellous graft incorporation is comparable to that of fracture healing and is divided into three stages (60). In Stage I, a haematoma forms at the graft site followed by an acute inflammatory reaction ; the clot attracts platelets, which release inflammatory mediators, which in turn recruit leucocytes and macrophages. In stage II, consolidation occurs whereby fibrovascular tissue invades the graft with subsequent recruitment of mesenchymal stem cells which differentiate into osteoblasts and osteocytes. Osteoclasts begin to resorb the graft whilst the osteoblasts begin to lay down the osteoid. Remodelling (Stage III) is mineralisation and further maturing of bone.

Incorporation of cortical grafts differs from that of cancellous grafts. Cortical grafts remodel slowly and seldom completely due to their dense structure compared with cancellous bone. This process is initiated by an osteoclast-mediated resorption (creating cutting cones through bone) followed by fibrovascular stromal invasion and an osteoblast mediated formation of new bone. Some reports indicate only 2-3 mm of ingrowth in massive cortical allografts (18). Conversely, cancellous bone graft is completely resorbed because its natural porosity and open architecture can be more easely penetrated by ingrowing vessels, bringing differentiating osteoblast precursor cells into place and depositing osteoid directly onto the graft trabeculae.

## TECHNIQUE VERSUS SYSTEM

Some surgeons have indicated that impaction allografting is a system requiring both an exact surgical method and a particular implant, the polished double-tapered stem (16,17,43,46). Others consider it a surgical technique and have varied the femoral stem geometry (28,35) and the method of graft delivery (40). The paucity of randomised, controlled clinical trials using impaction allografting makes it impossible to address this question. However, investigators have shown similarly good short-term to medium-term results with various femoral stems at numerous centres (45).

## THE FUTURE : BONE GRAFT SUBSTITUTES AND IMPACTION GRAFTING

In vitro studies evaluating the mechanical properties of HA/TCP particles in relation to morsellised bone graft for use in impaction grafting have shown that the biomaterial particles do not crunch or damage after impaction (70). Furthermore, the elastic and viscoelastic deformation of the biomaterials is minimal (70). The initial stability of acetabular cups has also been shown to be augmented with the addition of TCP/HA particles in bone impaction grafting (4). In addition, rigid fixation of the femoral component has been shown to be achieved with reasonable reliability when impaction bone grafting is performed with HA or a mixture of HA and allograft (20). This has important clinical implications as hydroxyapatite is readily available, easy to use in surgery and is not associated with the adverse effects encountered with allografts. Furthermore, compared with allograft alone a graft comprising of a mixture of allograft and HA may have greater mechanical stability, reduced subsidence rates and a significant reduction in the variability of the mechanical properties of the graft material (6).

## CONCLUSION

In summary, the number of patients requiring revision hip surgery can be expected to rise for the foreseeable future. The use of compacted, morsellised bone graft is one option for these procedures. The objective is to achieve stability of the graft construct and subsequently, by means of bone ingrowth, to allow the restoration of the living bone stock. The clinical results of this technique appear to be promising. However, the numerous complications associated with the use of bone grafts combined with the fact that demand for cancellous allografts may outstrip the supply in the future has prompted research investigating the use of this technique with bone graft substitutes such as hydroxyapatite. This has important clinical implications as hydroxyapatite is readily available, easy to use in surgery and is not associated with the adverse effects encountered with allografts.

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