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# Revision Hip Arthroplasty: Management of Bone Loss

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Additional information is available at the end of the chapter

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## 1. Introduction

Total hip arthroplasty (THA) is one of the most successful surgical procedures with well documented survivorship at up to 25 years. With ageing of the population and higher arthritis prevalence in older adults, the demand for the procedure increases worldwide [89]. In addition, over the last two decades the age range has been broadened to include younger patients. Over 270 000 hip replacements are performed annually in the US alone, and the annual volume of hip joint replacement is projected to double by the year 2030 [89]. Although very successful procedure, significant percentage of patients undergoing total hip arthroplasty require revision within 10 to 15 years after the surgery. Aseptic loosening and the associated osteolysis have been recognized as the main reason for implant failure in 71% of cases [66]. Other indications for revision include periprosthetic fracture, dislocation, and infection. New technologies in implant design and advances in surgical technique have improved the outcomes after primary total hip arthroplasty and decreased the rate of complications. However, as a consequence of increased rate of primary THA's the prevalence of revision hip surgery is increasing proportionally. The increased rate and costs of revision procedures impose high demands on both surgeon and healthcare system. Moreover, the cost of hip replacement is exponentially increasing [82].

Bone loss is the major challenge in revision setting. In 2009, Bozic et al. reviewed the most common causes for revision hip arthroplasty [8]. Aseptic loosening, instability, and infection were reported as the main reasons for revision surgery. This study underlined the need for a complex approach to evaluation and management of patients with implant failure after hip replacement. Such approach will guarantee precise diagnosis, proper selection of revision implant and surgical approach, uncomplicated surgery, and optimal clinical result.

This chapter provides an overview of aseptic loosening of revision hip arthroplasty and outlines the management strategies in the clinical scenario of a failed hip prosthesis.

## 2. Patient evaluation

Various signs and symptoms can occur in the clinical setting of a failed hip prosthesis. Painful hip arthroplasty is the most common complication after total hip arthroplasty reaching 18% of patients in some series [6]. Most of these painful hips will require revision. Groin pain can be referred to implant failure easily whereas occasional hip pain, pain in the buttock, knee pain or migrating pain can have different etiology. Other diseases and conditions such as disk disease, radiculopathy, inguinal or femoral hernia, pelvic infections, tumors, and trauma may have manifestations similar to that of a failed prosthesis.

The differential diagnosis of hip pain requires a careful history and examination. In simple cases, the reason could be identified with clinical examinations and standard radiographs only. Thorough examination elicits the underlying cause of hip complaints such as infection, neurological injury, referred pain, wear, aseptic loosening or instability. In many cases, the diagnosis is a challenge to the surgeon. In addition to clinical history and physical examination, radiographic examination and advanced imaging techniques could help establish exact localization of pain, and its possible connection with the implant. Additional radiographic examinations as well as an algorithmic approach with special diagnostic imaging and tests help establishing precise diagnosis. Computed tomography and 3-D computed tomography is often helpful in establishing periprosthetic osteolysis and its severity. In addition to plain radiographs arthrography with contrast medium could be considered in certain cases.

Once extrinsic and periarticular diseases have been excluded as a reason for the hip pain, septic loosening should be excluded. Laboratory investigations are the initial tests that help differentiate septic from aseptic loosening. A standard set includes WBC, Erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), complete chemistries and urinalysis. In addition to plain radiographs and laboratory tests joint aspiration is considered the most important diagnostic tool in ruling out periprosthetic infection. The aspirate should be sent for cell count and anaerobic and aerobic cultures. Recently, local markers such as interleukin-6 (IL-6) and other cytokines [34], synovial CRP, and leukocyte esterase (LE) [118] from joint aspirate have been proposed. All of these local markers have shown accuracy of more than 90% in predicting periprosthetic infection. Nuclear medicine scans with technetium-99m-HDP, gallium citrate, and labeled WBC have been used to diagnose the presence of infection. However, because of poor sensitivity, specificity, and accuracy, it is cost-prohibitive and remains a tertiary tool. Nuclear medicine is used only if infection could not be proven otherwise. Intraoperatively, diagnostic evaluations such as Gram stains and frozen sections have been proposed.

Guidelines and algorithms for evaluation of painful hip arthroplasty have been published in the literature and implemented in practice [119]. Such approach helps eliminate infection of the failed hip that would change treatment approach and could exclude one-stage revision.

### 3. Classification systems for bone defects

It is important to have a practical, relatively simple classification system for assessment of bone defects associated with loose hip implants. The use of a radiographic classification system helps to establish the severity and localization of bone defects, and to guide treatment decisions. It should allow the surgeon to be prepared for the possible intraoperative findings and to plan adequate treatment approach. Numerous classification systems have been described in the literature [17,23,25,32,40,58,60,99,116,137,158].

#### 3.1. AAOS classification

The American Academy of Orthopedic Surgeons (AAOS) classification system of bone defects, described by D'Antonio et al. identifies the pattern and localization of osteolysis but does not quantify the bone loss [23-25]. It is one of the most widely used classification system in the literature.

#### 3.2. Paprosky classification

Perhaps the most widely used classification system, the Paprosky Classification [32,116,158] (Tables 1, 2) was developed to establish bone defect type, size, and localization in order to allow selection of appropriate cementless reconstructive option for a given bone loss pattern. We base our clinical decisions on this classification system.

The key advantage of this classification is the assessment of the host bone ability to provide initial stability of a cementless implant until bone ingrowth occurs. The bone defects are usually classified on the basis of plain radiographs. However, final assessment is made intraoperatively, after removal of the failed implant and thorough debridement of the host bone. Intraoperative assessment of implant stability is made with help of trial components. The remaining host bone determines the stability of the implant and the type of the defect.

Type	Radiographic and intraoperative findings
1	Minimal metaphyseal bone loss
2	Extensive metaphyseal bone loss and an intact diaphysis
3A	Extensive metadiaphyseal bone loss and a minimum of 4 cm of intact cortical bone in the diaphysis
3B	Extensive metadiaphyseal bone loss and <4 cm of intact cortical bone in the diaphysis
4	Extensive metadiaphyseal bone loss and a nonsupportive diaphysis

**Table 1.** Paprosky classification systems for femoral defects.

Type	Radiographic and intraoperative findings
1	Acetabular rim, anterior-posterior column intact
2	Less than 3 cm superior migration Distorted acetabular rim. Intact anterior and posterior columns Adequate stability with Trial. Greater than 50% contact surface
2A	Superior and medial cavitation defect. Intact rim
2B	Segmental supero-lateral defect (less than 1/3 of circumference)
2C	Medial defect with cup medial to Kohler's line (Protrusio)
3	Greater than 3 cm superior migration Non-supportive acetabular rim for biological fixation
3A	Lateral to Kohler's line. Intact medial support Moderate ischial lysis (<15 mm below superior obturator line) Medial limb of teardrop is intact Superior and lateral migration "up and out" Contact of trial with bone over 40-60%
3B	Broken Kohler's line. No medial or superior support Extensive ischial osteolysis (>15 mm below superior obturator line) Complete destruction of tear drop Superior and medial migration "up and in" Under 40% contact surface. High risk of occult pelvic discontinuity

**Table 2.** Paprosky classification system for acetabular defects.

#### 4. Preoperative planning

Careful preoperative planning is a prerequisite for successful revision surgery. The principle aims in revision hip arthroplasty are to achieve supportive host bone, secure implant fixation and to restore hip center and joint kinematics. The type and severity of host bone loss determine the method of reconstruction. Careful preoperative planning improves effectiveness during surgery, and helps distinguish more complex alternatives for reconstruction if needed.

Thorough clinical and radiographic examination is essential for determining the extent and severity of bone loss, quality of the host bone, exclusion of infection, additional deformities, and potentially confounding factors. Computed tomography may be needed in the presence of massive bone loss. In case of medial migration of the failed components angiography with contrast medium should be considered. Manual or digital templating helps for ade-

quate selection (size, diameter, length) of revision implant and reduce the operative room inventory. Templating also helps determine whether stable initial fixation could be obtained and the need for additional procedures. Preoperative planning is critical for the assessment of the need of graft, tools for implant removal, and selection of proper components available at the time of surgery. Appropriate surgical exposure should be planned with an extensile approach often necessary. Classification system of bone defects based on radiographs that assesses the severity of bone loss according to the type of fixation for a given bone loss pattern is beneficial. In our practice, we find the Paprosky classification system a useful tool for guidance of clinical decisions. Any attempt should be made to identify the failed implant. The implant manufacturer should be contacted for implant-specific extraction devices if available. In case of isolated partial revision, it is advisable to have an option for partial (liner or head) exchange.

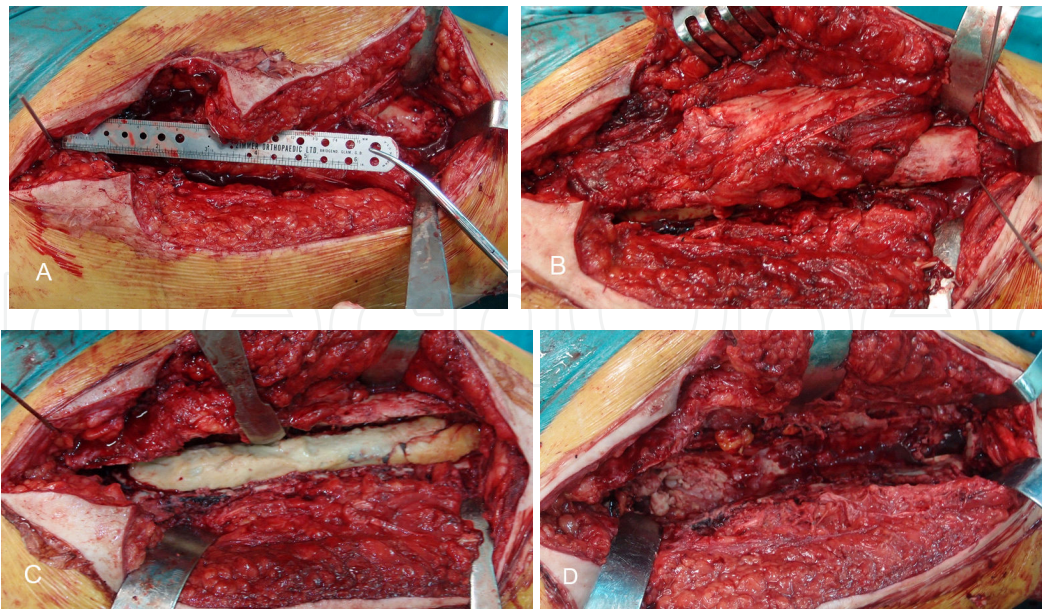
## 5. Surgical approaches in revision arthroplasty

The aims of revision surgery are to extract the failed prosthesis with minimal soft tissue and bone damage, to restore bone loss, and to implant prosthesis with stable and durable fixation. Ultimate goals are long-lasting and painless joint function. To obtain these goals arthroplasty surgeons may require a variety of approaches for adequate exposure of the femur and acetabulum in different revision settings. Usually arthroplasty surgeons are familiar and most comfortable with a certain approach and use it in most surgeries. However, in order to obtain reproducible results after revision of most difficult cases, surgeons should be familiar with all approaches to the hip joint. Next to standard approaches used in primary total hip arthroplasty, extensile approaches were developed in order to minimize damage to the host bone, safely remove the loose implant and provide good visualization for correct insertion of the revision components. Contained defects can be reconstructed through any conventional approach. For uncontained defects, we prefer to have wide access and, therefore, we use transtrochanteric approach or trochanteric slide osteotomy with preserved insertion of vastus lateralis. If greater exposure is needed extended trochanteric osteotomy is advisable.

### 5.1. Extended trochanteric osteotomy

The extended trochanteric osteotomy (ETO) is one of the significant achievements in revision surgery [9] (Figure 1).

It is safe and straightforward, saving time and minimizing risk of fracture during cement and failed implant removal. However, it limits femoral component options to those that rely on distal fixation. Advantages of the technique are: predictable healing of the osteotomy, decrease in intraoperative fractures and femoral perforations, direct access to the distal canal for cement removal and neutral reaming, and decreased surgical time [9,104]. Favorable clinical results after use of ETO have been published in the literature [9,104].



**Figure 1.** (A) The Extended trochanteric osteotomy is performed by cutting from the greater trochanter distally along the long axis of the femur. (B) The bone is cut with a saw. (C) The flap with the attached muscles is elevated. (D) Exposed femoral bone bed.

## 6. Surgical revision options

Majority of hip revisions could be performed using cementing technique. However, patients with severe bone loss and poor bone quality require complex alternatives for revision.

### 6.1. Options for Femoral revision

#### 6.1.1. Cemented fixation of the femoral component

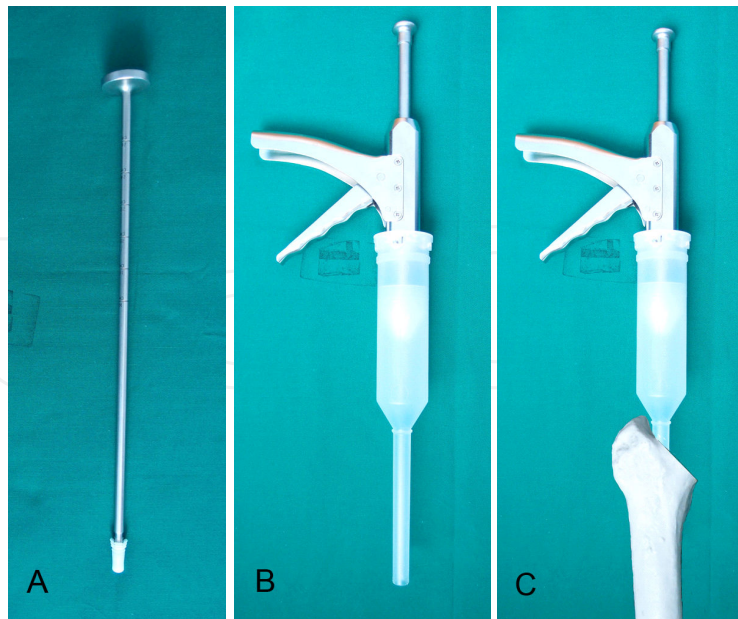
Various studies publish the outcomes after cemented femoral revision [2,13,122]. Use of the early cementing technique produced disappointing results [2,69]. Gaining more extensive experience resulted in acceptable short- to mid-term results [13,81,122]. Re-revision rates ranging from 4.3% to 6.0% and radiographic loosening ranging from 12% to 44% after mid-term follow-up of 3.4 to 4.5 years were reported (Table 3). However, long-term studies showed suboptimal outcomes after revision with an early cementing technique. At 8.1-year follow-up of the initial group of cemented revisions, Pellicci et al. found more than doubled incidence of re-revision and radiographic loosening ranging from 5.4% to 19% and from 13.6% to 29%, respectively [121]. Similar results were published by Kavanagh et al. in a 10-year follow-up study [79]. Sixty-four per cent of the stems had been revised or were radiographically loose. The incidence of revision had more than doubled from 18% at 3 years to 39% at final follow-up.

Authors	Year	Hips (No)	Follow-up (yrs)	Re-revision rate (%)	Radiographic loosening (%)
<b>Early technique</b>					
Amstutz et al. [2]	1982	66	2.1	9.0	29.9
Pellicci et al. [122]	1982	110	3.4	5.4	13.6
Pellicci et al. [121]	1985	99	8.1	19.0	29.0
Kavanagh et al. [81]	1985	166	4.5	6.0	44.0
Engelbrecht et al. [39]	1990	138	7.4	8.8	38.0
<b>Improved technique</b>					
Rubash and Harris [134]	1988	43	6.2	2.0	11.0
Katz et al. [78]	1997	79	11.9	5.4	16.0
Callaghan et al. [13]	1985	139	3.6	4.3	12.0
Estok and Harris [43]	1994	38	11.7	10.5	10.5
Mulroy and Harris [109]	1996	43	15.1	20.0	6.0

**Table 3.** Results of cemented femoral revision.

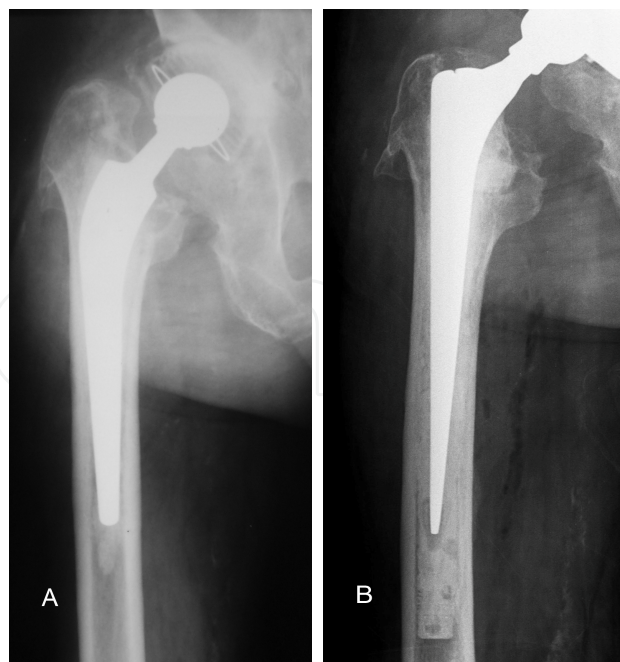
The main reason for suboptimal results with early cemented revisions was difficulty in obtaining stable and long-lasting fixation in compromised host bone stock where the rate of re-revision was very high [83]. In early studies, the reactive sclerotic bone between the fibrous membrane and the native cancellous bone was not removed [12]. Poor fixation of the revision femoral component compared to that in the primary setting may be due to inadequate excision of residual fibrous membrane, incomplete drying of bone, suboptimal cement filling technique, or insufficient cement-bone interlock on the smooth sclerotic bone surface. In such setting, even long cemented stems, are generally difficult to be inserted with adequate primary and long lasting stability. Femoral revision using so-called modern cementing techniques may yield promising results (Figure 2).





**Figure 2.** Modern cementing technique. (A) Distal cement plug. (B) Cement injector. (C) Delivery and pressurization of cement using cement injector.

Different studies have demonstrated that modern cementing techniques have improved implant survival and clinical outcome compared with the mid-term results after revision with use of so-called first-generation technique [71,85,109,128,134] (Figure 3).



**Figure 3.** (A) Preoperative radiograph of a failed cemented prosthesis. (B) Grade A cemented fixation achieved with modern cementing technique.

Cemented femoral revision has several advantages in elderly patients. It allows early mobilization, a shorter operating time, and possibly less risk of a peroperative fracture. Use of modern cementing techniques seems to improve fixation of the femoral components and clinical outcomes and justifies its use. Whenever possible the failed arthroplasty should be revised before occurrence of severe bone loss and femoral enlargement.

#### *6.1.1.1. Cement-within-cement fixation of the femoral component*

Removal of the well-fixed cement mantle around the stem can be extremely difficult, time consuming, and risky procedure. A solution to the problem, cement-within-cement revision was first proposed by Eftekhar who advised on preserving the existing well cemented mantle and re-cementing the new stem into it [36]. In a biomechanical study, Greenwald et al. demonstrated that the separation strength was 94% that of a single block when the existing cement mantle was adequately prepared [56]. The technique requires that the old cement surface be dried and roughened in order to provide contact area for fixation of the new cement. The cement should be injected in the early liquid phase in order to prevent lamination and to promote polymerization within the existing cement mantle.

This technique has been questioned by other authors [96], but subsequent biomechanical and clinical studies have favored its use in properly selected cases [35,67,97]. In a cadaver study, Rosenstein et al. demonstrated that cut strength at the cement-cement interface was greater than the strength at the cement bone interface [133]. However, the cut strength of the cement bone interface was 30% weaker when cement was placed against a revised bone surface.

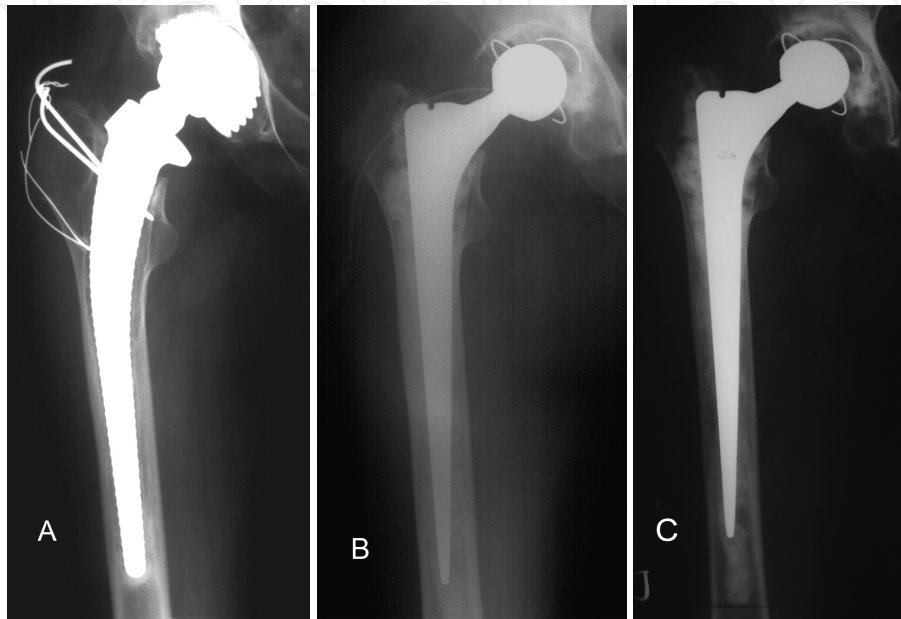
#### *6.1.2. Impaction grafting technique for femoral revision*

Femoral impaction grafting with a cemented stem was first performed in Exeter in 1987 [67] (Figure 4). The rationale behind this simple concept is to rebuild femoral bone stock and to provide secure fixation to the femoral stem. The biologic approach of bone restoration during revision hip arthroplasty is a highly appealing solution for restoring host bone stock a difficult procedure with usually deficient femurs.

Following the initial report of Gie and coworkers of highly successful results after 56 revisions with follow-up of 18-49 months [53] the technique received wide attention and spread rapidly [64,114,141,161]. Further studies confirmed the favorable outcomes, and it became evident that the technique resulted in restoration of femoral bone loss as the impacted allograft was incorporated and remodeled [67,161].

The technique of impaction grafting appeared to be reliable, reproducible, can be learned rapidly, and produced predictably favorable outcomes. In a series of 226 revisions, Halliday et al. reported the Exeter initial experience with femoral impaction grafting [64]. The overall rate of mechanical failure was 7% (16/221) at a minimum follow-up of five years. Ten to 11-year survivorship with removal of the stem for any reason as the end point was 90.5% and survivorship with revision for aseptic loosening as the end point was 99.1% [64]. In 2006, Schreurs et al. published their results with the technique using a cemented

polished tapered stem at an average 10.4-year follow-up [140]. The average subsidence of the stem within the cement mantle was 3 mm, and seven stems migrated 5 mm. [140]. No stem was revised for aseptic loosening. Three periprosthetic fractures at the results of 1305 femoral revisions with impaction grafting from the Swedish arthroplasty registry [114]. Survivorship at 15 years for aseptic loosening was 99.1%, for infection 98.6%, for subsidence 99.0%, and for fracture 98.7%.



**Figure 4.** Femoral impaction grafting. (A) Preoperative radiograph. B) Immediate postoperative and, (C) at 8 years after revision.

However, other authors reported higher percentage of intraoperative complications, mainly femoral fractures and suboptimal cementing technique [84,86,101,123]. A high incidence of up to 12% intraoperative femoral fractures have been reported [64,140,103]. Stem subsidence of greater than 5 mm is a typical complication with this technique with a prevalence of up to 38% in some series [38,49,86,101]. Impaction grafting has certain disadvantages: it is prone to femoral fractures [103]; has a steep learning curve; and shows highly variable outcomes, probably related to the surgical technique. The causes of early subsidence of the stem might be insufficient impaction of the allograft, suboptimal cement penetration and interdigitation, use of synthetic graft substitutes, or other graft additives, loss of primary fixation of the allograft-cement composite due to soft-tissue infiltration and substitution of the allograft in the process of remodeling and revascularization, unrecognized femoral fracture, or fracture of the cement-allograft composite. However, in a study on saw femurs, Flannery et al. and Cummins et al. were unable to find a correlation between threshold force needed to achieve stable construct in impaction bone grafting without fracture and bone mineral density, canal-cortex ratio, or cortical thickness [22,48]. According to Gokhale et al. four variables (age, intramedullary canal diameter, stem design, and density of the graft at the tip of the stem) affected the subsidence of the stem [54].

The original technique of impaction grafting utilized the Exeter stem [53]. The impacted graft is subjected to continuous loading and deformation. Thus, the use of double-tapered polished stem appears suitable option as the stem could achieve secondary stability after subsidence. Arguing that the technique is more important than the type of prosthesis other authors have used different implant designs from those of Exeter wedge shaped prosthesis [49,77, 124]. Uncemented technique was also used with an equally good outcome at mid-term follow-up [100].

Femoral impaction bone grafting is a suitable indication for cases with severe bone deficiency. The technique is expensive, prone to complications, has steep learning curve, and results depend on surgical skills. It may be a viable revision option for young patients with severe bone loss.

### *6.1.3. Proximal femoral allografts in revision surgery*

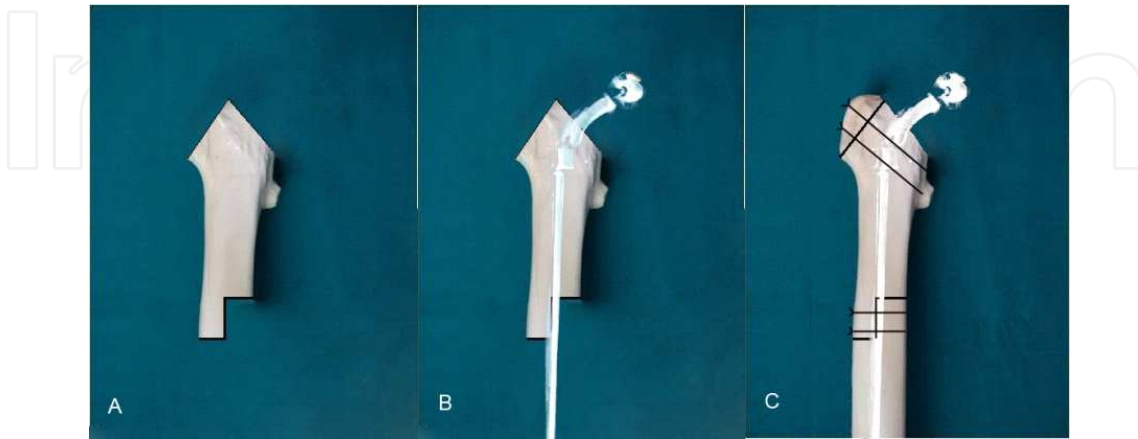
Severe bone loss in femoral revision is increasing problem as the number of patients with multiple previous revision increases. These complex cases are further increasing as the age of patients undergoing hip replacement is diminishing.

A stable initial fixation is hardly obtainable in complex cases with circumferential proximal bone loss >5 cm in length. Severe bone loss makes femoral revision using conventional techniques difficult. Alternatives include distal fixation of the stem or use of a proximal femoral allograft. Distal fixation requires the use of a proximally femoral replacement prosthesis or megaprosthesis. This has some disadvantages such as: instability due to poor soft-tissue attachment [62,120], early loosening of the distally fixed stem [47], stress shielding [10,46,110], intraoperative fractures [110] or difficulty with fixation in an ectatic femur. Various studies of revisions using megaprosthesis reported survival rate within the range 58% to 84% at five to ten year follow-up [98,120,164].

The viable revision technique using proximal femoral allograft consists of a long-stem prosthesis cemented to the allograft but not to the host bone [59] (Figure 5). Uncemented fixation of the allograft prosthesis construct would not result in long lasting stability of the prosthesis as neither in-growth nor on-growth could be expected at the allograft-implant interface. The importance of the allograft-host bone contact is a key factor for achieving stability of the construct and ensuring long-term stability of the implant [136].

Individual studies published encouraging results after use of proximal femoral allograft-prosthesis construct in large segmental defects of the proximal femur. In a series of 44 revisions with a mean follow-up of 7.2 years Vastel et al. observed two deep infections, two aseptic loosening and two fractures below the tip of the prosthesis [155]. The final prosthesis survivorship rate with revision as the end point was 82.4% at 14 years of follow-up. The nonunion of the greater trochanter was considered major complication and was observed in 25 cases. In another series of 30 hips who underwent revision total hip replacement with an allograft prosthetic composite Sternheim et al. observed favorable long-term outcome [149]. The survivorship at 10, 15 and 20 years was 93%, 75.5% and 75.5%, respectively. Encouraging results were published by Blackley et al. with 78% successful results for an average of

eleven-year follow-up [7]. The allograft-prosthesis construct survivorship at five years was 90% and at 10 years was 86%. A recent systematic review of 498 hips with a mean follow-up of 8.1 years reported survival rate of 82% [131]. The major complications were aseptic loosening observed in 13.7% of patients followed by dislocation in 12.8%.



**Figure 5.** The technique of bone reconstruction with use of a proximal femoral allograft-prosthesis construct as described by Gross et al. [59]. (A) The proximal allograft is shaped from a proximal femoral allograft according to the preoperative planning. It should accommodate the selected stem and the step cut of approximately 2 by 2 cm of the host bone. (B) The stem is cemented in the femoral allograft. The contact surface of the allograft to the host bone should be free of cement. (C) The proximal femur-allograft construct is stabilized to the host bone by the stem of the implant. The step cut is reinforced by cerclage wires. Usually, the construct is reinforced with cortical struts prepared from the remnants of the allograft or from bone-bank allografts.

The use of a proximal femoral allograft-prosthesis construct has some inherited disadvantages characteristic for complex surgery. Allograft resorption eventually leading to failure of the revision is of major concern with longer follow-up [61]. Usually, it was observed after several years of follow-up but did not progress [7,155]. Authors that utilize uncemented distal fixation support the concept of direct loading of the host-allograft junction and argue that it minimizes allograft resorption [7,59]. On the other hand, cementing the prosthesis to the distal femur and thus stress shielding the allograft may explain the high rate of allograft resorption [61]. Nonunion of the allograft-host junction [7] or the greater trochanter [61,155] are of major concern with this technique. A step-cut osteotomy may provide rotational stability while an oblique osteotomy may provide greater surface area for bone healing compared to a transverse osteotomy. Dislocation is a frequent complication after revision with proximal femoral allograft with incidence ranging from 7.3% to 16.7% [15, 61,131,155]. As with other cases, the high risk of dislocation may be lowered by optimal reconstruction of length, adequate version and high offset of the prosthesis-allograft construct and by maintaining the soft tissue tension and its attachment to the host femur [131]. The infection rates after revision with allograft-prosthesis construct are higher than that reported after primary hip arthroplasty. Rates of infection ranging from 0 to 10.9% were reported [15,94,132,136,155]. However, considering the high complexity of the technique these levels of infection are not unacceptable.

Femoral revision using proximal femoral allograft cemented to a long-stem prosthesis is appealing option for revision. The current data from the literature support the use of the technique as a durable solution, with available evidence reporting a long-term survivorship up to 86%. It is of a particular interest in the young patients because of its potential to improve bone stock and provide a substrate for subsequent revision. The development and refinement of this technique should be encouraged.

#### *6.1.4. Cementless fixation of the femoral component*

Obtaining stable and long lasting fixation in femoral revision in patients with severe bone deficiency is a difficult task. Long-term results after cemented revision have not been optimal [81,83,121]. High failure rates ranging between 12% to 44% at mid-term follow-up have been reported [2,81,83,121]. The main reason was difficulty in obtaining stable and long-lasting fixation in severe bone loss. Cementless fixation proved a promising alternative and was soon introduced in practice. However, for fears of stress shielding the ingrowth surface of first-generation designs was confined to the proximal part of the stem. Although highly successful in primary arthroplasty, the limited amount of porous coating with proximal fixation led to less favorable results in revision surgery (Table 4). Failure rates of 4% to 10% were reported at short- to mid-term follow-up. These results were slightly better than those obtained with an early cementing technique. The technique yielded acceptable results in less severe deformities [71]. Retrieval studies have demonstrated that less bone ingrowth occurs in revision stems compared to primary stems [21]. Porous surface extending to the diaphysis is needed to ensure stable primary fixation. In support of this, various authors have reported promising long-term results after revision with use of extensively coated uncemented stems [1,41,88,115].

Proximal femoral deficiency results from osteolysis, infection, fracture or bone damage during implant extraction. In such cases with severe bone loss, distal fixation with cylindrical, tapered or fluted stem designs is a viable option [4,14,41]. The technique requires accurate preparation of 4 cm to 7 cm of diaphyseal bone [41,92,102]. It is adaptable and can be used in situations with different severity of bone loss. Moreover, it can be used in periprosthetic fractures and is adjustable with extended trochanteric osteotomy. Distal stem fixation is the most successful strategy in terms of primary and secondary mechanical stability, bone osteointegration, and most importantly clinical results [4]. The main reason for its success is the fact that the implant is in contact with viable bone. Success rates of 90% to 95% have been reported with extensively coated monoblock stems over 10-year follow-up [105,115,158]. However, issues, such as thigh pain and proximal stress shielding, were reported frequently.

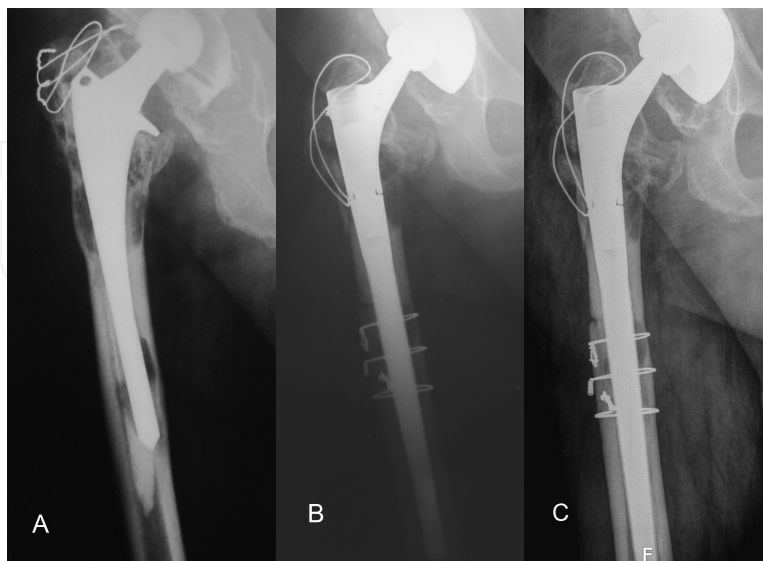
The principles of the Wagner stem are utilized in the tapered stems [156]. The cone prosthesis achieves good contact between the supportive distal diaphysis and the middle or distal third of the stem (Figure 6). The conical shape and the longitudinal splines promotes primary axial and rotational stability, which are prerequisites for osteointegration and long-lasting endurance of the cementless implant. The concept of modularity was introduced in the tapered stems with the advantages of versatile proximal fill and distal fit [76]. By modu-

larity the sizes and shapes of the prosthesis can be increased by varying the diameter and shape of the proximal and distal part of the stem and locking them in different way. Modularity offers certain advantages such as correction and restoration of leg length, correction of offset and version, selection of optimal proximal fill, as well as compatibility with extended trochanteric osteotomy [4,92]. The potential problem of thigh pain was not associated with tapered stem design [156]. Disadvantages of modular taper stem designs include complexity, risk of stem fracture, fretting and corrosion of the junction, increased inventory, and higher cost.

Authors	Year	Hips (No)	Follow-up (yrs)	Re-revision rate (%)	Radiographic loosening (%)
Lawrence et al. [95]	1993	174	7.4	5.7	1.1
Engh et al. [42]	1988	127	4.4	1.6	2.4
Kang et al. [76]	2008	39	2 (minimum)	2.6	0
Krishnamurthy et al. [88]	1997	297	8.3	1.7	0.7
Harris et al. [65]	1988	23	2 (minimum)	0	4.3
Moreland and Bernstein [106]	1995	175	5.0	1.1	4.2*
Moreland and Moreno [105]	2001	137	9.3	4	-

\* Mechanical failure

**Table 4.** Results of cementless femoral revision.



**Figure 6.** Cementless revision of Paprosky type 3A defect with a modular tapered stem (A) resulting in good initial (B) and mid-term stability at 2 years (C).

Various studies have reported favorable outcomes of various uncemented tapered distal fixation stems with high survival of more than 95% at 5 to 10-year follow-up [41,88,102]. The technique of cementless revision with distal fixation of the stem has been shown to be a reliable and straightforward. It adds no additional risks or complications. It can be used in all but the most severe segmental defects [4,14,41,102]. When the simple principles of the method are followed it provides stable and durable fixation of the revision implant. However, distal fixation does not restore host bone, thus making further revision surgery more difficult.

## 6.2. Options for acetabular revision

The goals of revision arthroplasty are to relieve pain and to improve function. In order to obtain these goals stable and durable fixation of the revision components must be achieved with restoration of hip center. Acetabular revision is the most difficult part of hip revision. Unfortunately, there is no single surgical technique to solve the problem of fixation. The achievement of stable initial and long-lasting fixation is challenged by the severity of different acetabular defects and soft tissue damage. The main acetabular reconstruction option is cementless press-fit fixation of the cup with or without allograft [19,73]. When severe combined segmental and cavitary bone deficiencies, poor bone quality and viability or pelvic discontinuity are identified, other more complex options for acetabular reconstruction are required. These include trabecular metal (TM) cups, modular metallic augments, reconstruction cages, reinforcement rings, cup-cages, and structural or morsellized allografts that can be used to support the reconstruction.

### 6.2.1. Cemented fixation of the acetabular component

In cases with no or moderate bone loss revision could be performed with simple cemented exchange of the implant. Historically, early revisions were performed with the same technique that had been used for primary arthroplasty. However, difficulties in achieving consistent long-term results had prevented use of this technique. Failure to achieve adequate cement interdigitation explained poor results reported with early cementing techniques. Key factors for good cementing technique are optimal exposure of cancellous bone, adequate containment of the cup, and a clean and dry socket [130]. Sutherland and colleagues demonstrated that preservation of the subchondral bone can increase stiffness and stress concentration at the bone-cement junction [150]. Callaghan et al [13] reported 4.3% revisions and 34% radiographic loosening at 3.6-year follow-up of cemented revisions. Similar high rates of loosening were reported by Pellicci et al at 3.4-year follow-up [122]. The long-term results after cemented revision were considerably worse [121]. Even with improvement of the cementing technology, the cemented acetabular fixation has not improved (Table 5).

At longer follow-up, using modern cementing techniques failure rates ranging from 35% to 65% were reported [78,112]. Ten-year survivorship of the acetabular component with radiographical loosening as the endpoint event was 72% [78]. Consequently, cement fixation of the acetabular component has become less popular among orthopedic surgeons. In contrast, hemispherical porous-coated cups with bone ingrowth potential were developed and demonstrated consistently better results.



Authors	Year	Hips (No)	Follow-up (yrs)	Re-revision rate (%)	Radiographic loosening (%)
Raut et al. [127]	1995	387	5.5	6.2	18.8
Estok and Harris [43]	1994	32	11.7	22.0	19.0
Mulroy and Harris [109]	1996	29	15.1	38.0	44.0
Katz et al. [78]	1997	79	11.9	16.0	23.5
Eisler et al. [38]*	2000	83	3.6	8.0	22.0
Huo and Salvati [70]	1993	113	4.1	1.0	5.0

\* Third generation cementing technique

**Table 5.** Results of acetabular revision using modern cementing technique.

### 6.2.2. Cementless fixation of the acetabular component

The approach to each individual case depends upon the severity and localization of host bone loss. Results after cementless revision of the acetabular component have outperformed cemented fixation [30,31,44]. With supportive and viable host bone and a reliable ingrowth surface a hemispherical metal shell supported with screws is a straightforward solution for acetabular reconstruction (Table 6). The success of the technique has been so dramatic that it is currently considered the gold standard by most arthroplasty surgeons in the USA.

Authors	Hips (No)	Follow-up (yrs)	Re-revision rate (%)	Radiographic loosening (%)
Della Valle CJ et al. [30]	138	15.0 (minimum)	4.5*	1.5
Park et al. [117]	138	20.0 (minimum)	8.0*	5.0
Wysocki et al. [162]	187	5.0 (minimum)	2.0	5.0
Lachiewicz and Hussamy [91]	60	5.0	0	0
Tanzer et al. [152]	140	3.4	0.7	4.3
Silverton et al. [145]	109	8.3	0	5.0
Templeton et al. [153]	61	12.9	0	3.0

\*Combined wear and loosening

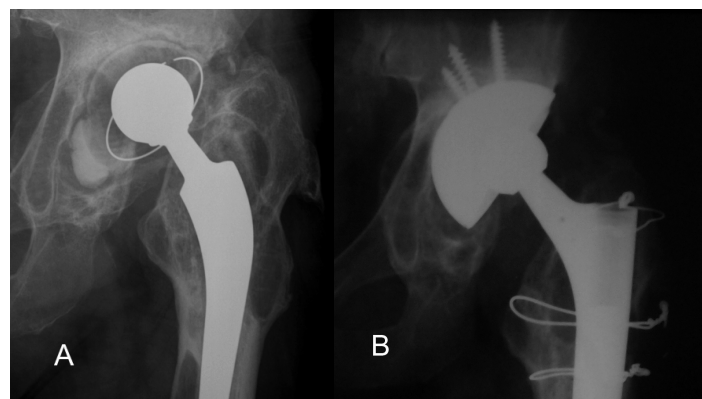
**Table 6.** Results of cementless cup revision.

In minor or contained defects, hemispherical cup with/without grafting produced excellent results [30,31,44]. Cementless fixation is suitable for patients with Paprosky types 1, 2A and 2B defects: without hip center migration or pelvic discontinuity. As a general rule, at least 50% of the host bone is needed to be in contact with the implant in order to sup-

port a hemispherical cup. Transfixational screws are usually used to support ingrowth of the press-fit cup. Morcellized allografts could be used to fill the cavitory defects. In a deficient acetabulum with major bone loss such as Paprosky type 3 defects a hemispherical cup could be placed against the intact supportive roof ("high hip center"). Sometimes extra large (jumbo cup) or oblong cups can bypass severe bone defects and provide stable initial fixation for bone ingrowth. Cementless fixation results in an anatomical hip center or in a high hip center [26].

#### 6.2.2.1. High hip center

The failed acetabular components migrate in the direction of joint reaction forces creating a deficient acetabular bed with greater superoinferior dimension compared to the antero-posterior dimension. In such revision setting implantation of the cementless hemispheric press-fit cup in the anatomical hip center is not possible. A straightforward decision for treatment of such defects is to place a small hemispherical press-fit cup against the supportive bone at the roof of the acetabular defect - the so-called high hip center (Figure 7). Most authors consider arbitrary the hip center high if it is proximally greater than 35 mm to the inter-teardrop line [27].



**Figure 7.** Type 3A defect of the acetabulum (A) resulting in high placement of the cup (B).

Results after cementless press-fit fixation of the acetabular component inserted with screws outperformed cemented revision. With use of this approach, despite extensive acetabular bone loss excellent implant fixation was consistently reported. The durability of cementless acetabular fixation was proven in long-term studies, too. In the study of Templeton et al., none of the cementless cups have been revised for aseptic loosening at 12.9-year follow-up and only 3 cups have migrated [153]. In a study with minimum follow-up of 20 years, Park et al. demonstrated 95% survivorship with revision of the cup for aseptic loosening or radiographic signs for loosening as the end point [117]. However, with longer follow-up, the problem of polyethylene wear and osteolysis emerged. In their series, re-revisions for wear and osteolysis were first performed at approximately twelve years postoperatively [117]. At last follow-up 20 years after revision, the incidence of reoperations for polyethylene wear and/or osteolysis continued to increase.

The technique saves costs, time, and eliminates the use of structural allografts or cement. However, high rate of complications was reported [27,74]. This might reflect the complexity of the procedure. Certain disadvantage of the technique is restoration of limb-length discrepancy on the femoral side whereas the defect is on the acetabular side. This would result in abnormal hip biomechanics. Increased hip joint reactive forces with high hip center and impingement might partially explain the relatively higher rate of dislocation with this technique [117,162].

Considering the excellent results reported with porous coated press-fit acetabular components in terms of implant fixation, we believe that the use of press-fit cups should be considered in every revision setting if there is sufficient host bone stock to support the cup.

#### 6.2.2.2. *Jumbo cups*

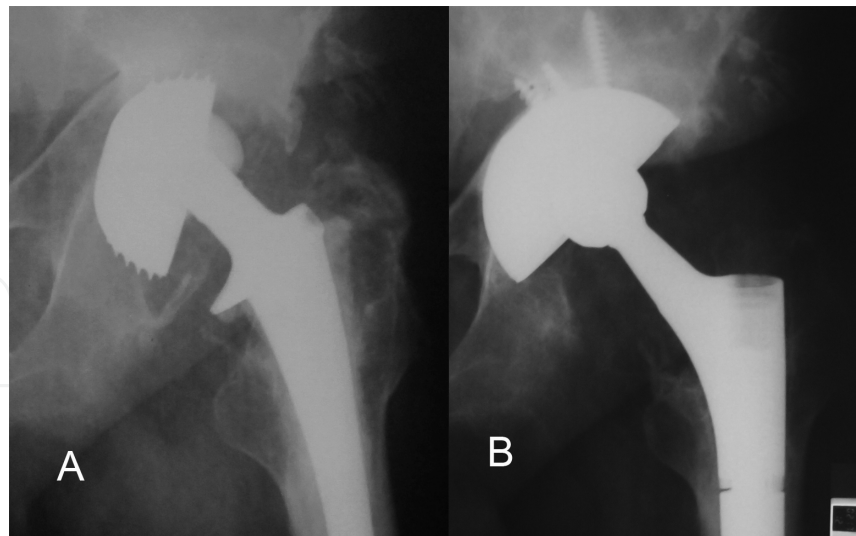
Extra-large cups offer certain advantages in maximizing the contact area between the cup and host bone when revising deficient acetabulum. There is no universally-accepted definition of the jumbo cup. Extra-large cups are arbitrarily defined compared to the size of the pelvis, the hip joint, and the previous implant. Whaley and coworkers defined jumbo cups as having a minimum outside diameter of 66 mm (men) or 62 mm (women) [159]. This was based upon the fact that the revision cups used at their institution were 10 mm larger than the mean implant diameters used for primary hip arthroplasty.

The method has certain advantages [126]: the acetabulum is prepared straightforward by reaming to a large hemisphere; the large implant fills in the deficiencies and bone grafting is usually unnecessary; the center of rotation is transferred inferiorly and to some extent laterally restoring hip biomechanics (Figure 8); the large implant provides greater contact area and greater lever arm. Disadvantage of the technique are the limitations in restoring bone stock. Moreover, most of the defects are oblong with a greater superoinferior dimension than anteroposterior dimension. Converting an oblong defect to a hemispherical with extensive reaming may disrupt posterior wall or column which is critical for cup stability [159]. This risk of host bone compromise may result in high implantation of the socket.

Whaley et al. reported on 89 acetabular revisions using extra-large hemispherical components from the Mayo clinic [159]. The probability of survivorship of the cup at eight years was 93% with removal for any reason as the end point, and 95% with radiographical loosening or revision for aseptic loosening as the end point [159]. Wedemeyer et al., Obenaus et al., and Dearborn and Harris published similar results with cup survivorship with an end point aseptic loosening higher than 94% at mid-term follow-up [26,113,157].

The technique saves costs, time, and eliminates the use of structural allografts or cement. However, the rate of complications reported was rather high. In the series of Park et al., the most common reason for revision in 11.6% of 138 hips was infection and dislocation [117]. Similar high rates of revision were reported by Dearborn and Harris [26] and Della Valle et al. [30]. This might reflect the complexity of the procedures.

Extra large cups are a reasonable alternative in patients with moderate defects (Paprosky type 2).



**Figure 8.** Correction of the center of rotation with a large oversized cup.

#### 6.2.2.3. Oblong cups

As described earlier, large oval contained defects cannot be filled-in superiorinferiorly without excessive reaming of the anterior or posterior column of the acetabulum to produce hemisphere. Another option is high placement of the cup. Attractive alternative in such cases is oblong cup. Oblong cup has smaller anteroposterior and mediolateral dimensions compared to the superiorinferior dimension. By accommodating the implant to the defect oblong cups can restore hip center and increase implant contact with host bone. Advantages of the technique are: lack of increased reaming of the anterior or posterior columns or metalization of the cup; increased contact between the device and the host bone; restoration of hip center [19,73]; and avoidance of structural allografts [5]. Disadvantages include higher cost, difficulties in cases with insufficient contact [16], possible component malpositioning, failure to restore bone [5], and excessive bone removal in order to achieve press-fit [126].

In a multicenter study on 38 hips revised with oblong press-fit cups, Berry et al. published good results at mean 3 years after surgery [5]. There was only one failure for acetabular loosening that required re-revision. Mean Harris Hip Score (HHS) increased from 50 points preoperatively to 90 points after revision. The hip center was 37 mm above the inter-teardrop line before the operation and was corrected to 25 mm above the inter-teardrop line. Civinini et al. published good mid-term results after revising with oblong cup Paprosky type 2 and 3 acetabular defects [19]. In a series of 55 hips followed-up for an average of 7.2 years only one cup was revised for loosening. Similar good results were reported by DeBoer and Christie on 18 hips revised with oblong press-fit cups [28]. At the latest follow-up, 4.5 years after revision no component was loose and the mean HHS increased from 41 points preoperatively to 91 points after revision. The authors reported near anatomic restoration of the hip center to 17 mm above the inter-teardrop line after revision. Chen and Engh reported less favorable results in 37 revisions (29 with massive type 3 defects) followed-up for an

average of 41 months [16]. Eight percent of the hips were probably loose and 16% were unstable. Eight of the 14 hips that had more than two centimeters of superior migration of the component and disruption of Koehler's line on preoperative radiographs failed [16]. The authors found a correlation between loosening and average distance from the inferior edge of the cup and the interteardrop line. Five of the six unstable components initially had not reached to the level of the radiographic teardrop or distal to it [16]. In their early series, Sutherland [151] reported a 50% failure rate (3 of 6) after revision with an oblong cup of type 3 defects. Discouraging mid-term results were published by Babis et al. using a cementless oblong cup for revision of Paprosky 3A defects [3]. After a mean follow-up of 60.5 months 18 hips (29.0%) were revised and a further four hips (6.4%) were loose and awaited revision. Further analyses proved that careful patient selection is critical for the success of this revision technique.

Acetabular revision with an oblong cup is an attractive alternative, especially when the surgeon plans correction of an elevated hip center [16,108]. The technique is suitable for Paprosky type 2A, 2B and 3A defects where the acetabular defect is oval. Obtaining initial stability and supplementary fixation by screws are mandatory for the stability of the implant and are key factors for long-term success of the reconstruction. However, the medial wall should be intact and the failed component should not have migrated more than two centimeters. Pelvic discontinuity is also a contraindication for this technique. Alternative techniques such as structural allograft or cage should be considered in such revision settings.

### *6.2.3. Impaction grafting technique for acetabular revision*

Cemented acetabular revision yielded unacceptably high rate of loosening [13,80,81]. Possible reason is the deficient, weakened and sclerotic acetabular bone frequently found at revision. An attractive alternative for cup fixation in massive contained defects is impaction grafting where the cup is cemented on a premoulded bed of impacted morsellized cancellous bone. In such revision setting the contact with host bone is very limited if not absent. The morsellized bone has osteoinductive and osteoconductive properties and is used as a filler scaffold of contained defects. The technique of impaction bone grafting and cemented fixation of the cup was first described in 1984 by Slooff and coworkers [146], and later standardized by the same authors with minor modifications and technique-specific instrumentation [11,142]. Morsellized graft could be used with a cementless hemispherical cup if more than 50% of the cup is in contact with viable host bone [57]. Transfixing screws should be used for additional stabilization of the cup. In cases with less than 50% contact between the cup and viable host bone the cemented cup into impacted cancellous bone should be used [146].

The technique can provide stable and durable reconstruction of the hip joint. However, initial mechanical stability of the morsellized allograft-cemented cup composite is a prerequisite for a successful biological reconstruction. Subsequent remodeling and incorporation of grafts, provides long-term stability. In contrast to cementless revision, this technique could restore bone loss. The modern evolved technique consists of reconstruction of segmental and rim defects with use of a metal mesh or a solid graft. The sclerotic areas are perforated

with multiple 2-mm drill-holes, and fresh-frozen morsellized bone chips are impacted layer by layer into the acetabulum. The clinical success of the of impaction grafting depends on the surgical technique and on the biological and mechanical properties of the morsellized bone graft. Various factors connected with the graft such as graft type (cancellous, cortical-cancellous, chemical composites, synthetic additives), graft processing (fresh frozen, freeze-dried, irradiated), graft particle size and grade influence the clinical result. The originators of the technique use fresh frozen allografts [11,142,143].

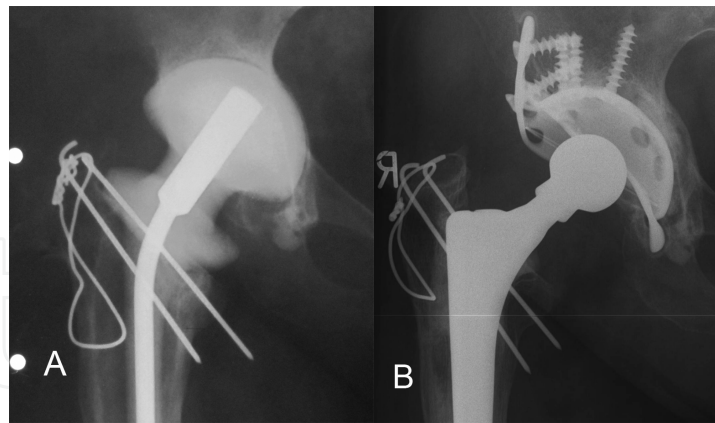
The technique of acetabular impaction grafting is well-established and various authors demonstrated reproducible results [20,51,143,154]. Schreurs et al. reported good results after acetabular revision with impaction allografting at 15 to 20-year follow-up [142]. With revision for aseptic loosening as the endpoint, cup survivorship was 84% at 15 years [142]. In a 20 to 28-year follow-up study, Busch et al. from the same study group evaluated 42 patients with impaction grafting younger than 50 years [11]. With revision for aseptic loosening as the end point, survivorship was 85% after twenty years and 77% after twenty-five years [11]. With end point event signs of loosening on radiographs, survival was 71% at twenty years and 62% at twenty-five years. Results declined over time, but the authors concluded that the technique is useful in younger patients with major bone defects [11].

Acetabular revision using impaction grafting is a reliable alternative for biologic restoration of hip joint mechanics. The procedure is technically demanding and exacting. Results comparable to those after revision with cementless hemispheric cups were obtained after use of correct surgical technique.

#### 6.2.4. Reconstruction cages

Reconstruction cages and antiprotrusion rings are an established method of treatment for severe acetabular bone loss if contact with 50% host bone could not be established [57]. They have the advantage of fixation into viable host bone of the ilium and ischium with flanges while protecting allograft (Figure 9). Failure rates higher than 60% at an average of 2.9 years have been reported in cases with massive allografts not supported by cages [116]. Because of the poor results following use of unsupported structural allograft use of reconstruction cages has been advised [148]. Reinforcement rings or reconstruction cages can provide adequate support for the reconstruction with massive allografts in Paprosky type 2C and type 3 defects. Favorable results were reported after use of reconstruction cages by different authors [50,68,107,125]. Recently, this treatment approach has been questioned as TM implants provide more favorable conditions for graft incorporation and bone ingrowth [148].

The reconstruction cages and antiprotrusion rings have definite advantages: the cage and ring allow for restoration of hip center; they provide uniform load to the allograft stimulating bone remodeling and incorporation into host bone [72]; cementing allows use of local antibiotic protection; allow correct placement of the cemented cup independent of the cage or ring. The cage protects either the morsellized or structural allograft while it remodels, and if the cage fails cementless revision can be done [55,57].



**Figure 9.** Reconstruction of a Paprosky type 2C defect (A) with a cage (B). Remodeling of the allograft at 2 years.

Disadvantages include higher cost, need for wide surgical exposure of the superolateral part of the ileum. The latter may risk injury of the superior gluteal nerve and limping. The major concern with standard nonporous cages and rings is that they do not allow bone ingrowth. Finally, they loosen and break. However, this inability of bone ingrowth is compensated by the mechanical stability and incorporation of the graft reducing the risk of fatigue fracture of the cage. Close fit between the cage and the allograft as well as adequate fixation of the cage are a prerequisite for successful reconstruction. Cement augmentation of screws is recommended in cases with severe osteolysis or osteoporosis.

The limits of using antiprotrusion rings were demonstrated by Haentjens and coworkers and Zehntner and Ganz [63,163]. High rate of migration up to 44% (12/27) at mid-term follow-up of 7.2 years was reported [163]. Previous designs of reconstruction cages did not allow bone ingrowth and a failure rate of 16.4% due to loosening was reported on average 4.6 years after surgery [55]. Sporer et al. reported a 2- to 8-year follow-up of 45 hips where a cage was used for a type 3 defects [148]. Nine hips were revised for aseptic loosening, and an additional nine hips were radiographically loose.

In contrast, Winter et reported no loosening or revision in 38 hips followed-up at mean 7.3 years after revision with cage [160]. In a long-term study, 18 acetabular revisions for pelvic discontinuity have been reported on average 13.5 years after surgery [129]. Two cages were revised for aseptic loosening, and another two allografts showed signs of severe osteolysis. Survivorship of the acetabular component at 16.6 years with end points revision for any reason, loosening or nonunion of the allograft was 72%. The increased rate of loosening and revision is probably multifactorial and reflexes the increased case load. Frequent indication for use of reconstruction cages is pelvic discontinuity. However, designs without bone ingrowth do not have potential for biologic fixation and rely solely on mechanical fixation.

Antiprotrusion cages and rings are an effective technique for treatment of severe bone defects. However, in recent years, newer implant designs have gained popularity. In cases with more than 50% host bone support cementless cup transfixed with screws is the treatment method of choice. Trabecular metal implants, porous augments, and triflanged acetabular components are an attractive alternative for complex acetabular reconstructions,

[33,57,148]. TM cups have been proposed if contact with viable host bone is 30% to 50%. If contact with viable host bone is less than 30% a cup-cage construct was suggested [57]. Longer follow-up studies are needed to support the clinical use of these new implants.

#### 6.2.5. Structural acetabular allografts

One of the most difficult scenarios in revision surgery is a reconstruction of a massive acetabular bone loss. Structural acetabular allografts are a suitable revision option for uncontained bone defects (Paprosky type 2B, 3A and 3B). The size of the allograft may range from a femoral head in superolateral uncontained defects to total acetabular allograft when severe uncontained defects or pelvic discontinuity are present.

Advantages of the technique include restoration of hip center and restoration of bone stock for future revisions [50,68,90,125]. However, actual restoration of viable and mechanically competent bone is questionable. Moreover, results are unpredictable. The technique is demanding and associated with various complications.

Results after revision with structural allografts have been largely controversial. Harris initially reported successful results after reconstruction of severe acetabular defects with structural allografts [135]. However, the encouraging period of initial good functioning for 5 to 10 years was followed by later failures. In 1993, Kwong et al. reported 47% failures in 30 hips with a mean follow-up period of 10 years [90]. In 1997, the senior author reported total rate of revision or loosening 60% at an average of 16.5 years [144]. High hip center for placement of the cup was suggested in cases with severe acetabular bone loss [135].

In a series of 33 hips followed-up on average 7 years after revision with a structural allograft, Garbuz et al. reported 55% success rate [50]. Fifteen hips were revised: seven hips because of failure of the prosthesis and eight hips because of failure of both the allograft and the prosthesis. Gross et al. reported on 107 hips reconstructed with bulk allograft [58]. Thirty hips (28%) were revised and in 15.9% of cases (17 hips) the indication was aseptic loosening. The authors reported 76% successful results in the 33 hips with minimum duration of follow-up of 5 years (average, 7.1 years) after the revision. However, eight hips needed additional reoperation because of failure of the graft and another six hips were revised for loosening. Hooten et al. reported on a series of 31 revisions with structural allograft and cementless cup followed-up on average 46 months after surgery [68]. Twelve (44%) cups were radiographically loose and five of these hips were revised. In contrast, Paprosky et al. reported a failure rate of 19 per cent (6/31) at an average follow-up of 5.7 years after revision with use of a structural allograft [116]. The only failures in that series were in hips in which the allograft supported more than 50 per cent of the cup. In another study, Morsi et al. found a success rate of 86% (25/29) at mean follow-up of 7.1 years [107]. They used a minor bulk allograft that supported less than 50% of the cup.

Although results after revision with structural allograft are controversial, most authors agree that the rate of success increases if more than 50% of the cup is in contact with viable host bone [50,68,116]. According to Morsi et al. [107] and Pollock and Whiteside [125] a re-



peat revision does not mean failure of the reconstruction. This complex reconstruction can be considered successful if bone stock is restored for future revisions.

Revision with structural allograft is a suitable option for restoration of hip center. The role of the allograft is to support the cementless cup with partial stability until adequate ingrowth occurs. The success after the procedure is technically-related. In order to optimize result after revision with structural allograft a number of principles should be followed. Structural allografts combined with antiprotrusio cages, and a cemented cup should be considered only in cases with insufficient host bone to provide a stable fixation for a press-fit cup [26].

For an optimal result, an appropriate allograft must be selected to match the mechanical requirements of the desired reconstruction. The method of processing of the bone allografts is important for the clinical result. Greater success rate with fresh frozen bone allografts was obtained compared to freeze-dried allografts [58]. The trabeculae of the allograft should be in the direction of load for optimal stress transfer. After trimming of the allograft in order to obtain maximal contact with the host bone the allograft is fixed with 6.5 mm parallel screws in the direction of load. In case of pelvic discontinuity, the column should be fixed with a plate before fixating the allograft. Use of reinforcement cages improves results after reconstruction with structural allograft [50,138].

#### 6.2.6. Custom triflanged implants

Custom triflanged prostheses have been proposed for treatment of massive acetabular defects and pelvic discontinuity, but the experience is limited and the rate of complications is high [75]. The implant is manufactured from 3-D CT data reconstruction of the degree and localization of bone loss as well as its spatial orientation.

In 2007, DeBoer et al. evaluated the outcome of revision with a custom-designed porous-coated triflanged acetabular implant in 20 hips at an average 10-year follow-up [28]. A definite healing of the pelvic discontinuity was found in 18 hips (90%). The remaining two implants were radiographically stable and did not migrate even when discontinuity persisted. However, the overall dislocation rate in the series was 25%. Christie et al. followed-up retrospectively 67 complex revisions with custom-made triflanged implant [18]. Two discontinuities persisted, but both were asymptomatic and no implant was revised. Six (7.8%) hips were revised for recurrent dislocation. Using custom triflanged acetabular components Dennis reported three failures in 24 revisions with mid-term follow-up of 4 years [33]. He questions the value of the technique in pelvic discontinuity unless supplemented with additional column plating.

The technique has high cost, it is time consuming, requires extensile exposure, and lacks modularity. It could not be used in urgent clinical situation where it is not possible to wait for manufacturing the product. With complex implant and technically challenging surgery custom-designed triflanged prosthesis should be reserved for cases where less costly and less technically demanding options could not be used. Many surgeons consider it a salvage procedure for cases where the bone loss is catastrophic.

### 6.2.7. Trabecular metal cups

Trabecular metal cups can be used in massive contained or uncontained defects. As tantalum provides favorable environment for biological fixation, TM cups have been suggested for revision of Paprosky type 3 defects [57,148] instead of an allograft-cage construct.

Early results with use of TM implants have been encouraging [111]. TM has decreased the need for at least 50% contact of the implant with viable host bone. In Paprosky 3A an 3B defects, because cages do not provide biologic fixation, Gross suggested use of a cup and cage construct (the so-called cup-cage technique) when less than 30% contact can be made with viable host bone [57]. The rationale behind the technique is that load will be taken off the cage, once bone ingrowth occurs into the trabecular metal cup. So early and mid-term failures of the cages will be prevented.

Sporer et al. reported on 13 hips with pelvic discontinuity revised with tantalum cups with or without augments [147]. At mean 2.6 years after revision 12 of the 13 cups were radiographically stable. Lakstein et al. reported on 53 revisions of contained defects with 50% or less contact with host bone using TM cups [93]. Two cups (4%) were revised, and two additional cups (4%) had radiographical evidence of probable loosening at a mean 45-month follow-up. The fact that some of the TM cups lacked contact with a viable host bone is impressive. Four hips (8%) dislocated and one (2%) sciatic nerve palsy was observed. In a large multicenter study, 263 revisions with tantalum TM cups were followed-up at an average 7 years after surgery. At the most recent follow-up, all cups were radiographically stable and no revision for loosening was reported. Eight dislocations (3%) in the series were successfully treated with closed reduction, and one sciatic palsy partially resolved at last follow-up. Kosashvili et al. reported on 26 revisions of pelvic discontinuities using cages combined with trabecular metal components and morsellized bone (cup-cage technique) [87]. At mean follow-up of 45 months 23 hips (88.5%) were radiographically stable.

Promising midterm results have been demonstrated after revision with use of these new techniques. Currently, the preference is to biological fixation whenever possible, and to alternative options when initial stability could not be obtained.

### 6.2.8. Modular components (metal augments)

Modular metal augments of various sizes and shape are used to decrease defect size and to restore bone defect to contained one capable of supporting a revision cup (Figure 10).

The size and placement of augments is highly dependable on the bone loss pattern. Augments are secured with multiple screws to host bone and remaining defects are filled in with morsellized bone. The hemispherical cup is impacted into the defect with the interface between the shell and the metal augment cemented.



**Figure 10.** TM modular augments (courtesy of Zimmer, Warsaw, IN, USA).

## 7. Conclusion

During the last two decades, revision hip arthroplasty is constantly in the focus of orthopedic surgeons as the numbers of these difficult and risky surgeries are increasing. Up to date, the paradigms of revision surgery has been evolving constantly. From polyethylene wear, osteolysis and loosening, to complexities such as pelvic discontinuity, there is a wide range of surgical options for successful reconstruction. Analysis of clinical results from various studies outlines the preference for biological fixation of the revision implant whenever possible. It is vital for the surgeon to be familiar with different treatment approaches and to anticipate various intraoperative scenarios. Systematic approach with considerable preoperative evaluation and planning will achieve a good result. Prerequisite for a successful and durable revision include viable host bone, adequate surgical technique, and stable and endurable implant. Current improvements in surgical techniques, implant designs, as well as biomaterials and bearing surfaces are a significant contribution for obtaining favorable outcome after revision hip arthroplasty. However, we do not have complex solution. The optimal surgical approach for revision THA varies considerably among different settings. On the other hand, the economic burden of total joint replacement is increasing at a steep rate. This necessitates improved methods for evaluation of existing technology and particularly patient-derived outcomes assessment instruments. Further research and well-designed clinical studies are needed in order to provide optimal treatment to the increasing number of patients requiring revision surgery in the future.

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