The increasing need for total hip replacement (THR) in an ageing population will inevitably generate a larger number of revision procedures. The difficulties encountered in dealing with the bone deficient acetabulum are amongst the greatest challenges in hip surgery. The failed acetabular component requires reconstruction to restore the hip centre and improve joint biomechanics. Impaction bone grafting is successful in achieving acetabular reconstruction using both cemented and cementless techniques. Bone graft incorporation restores bone stock whilst providing good component stability. We provide a summary of the evidence and current literature regarding impaction bone grafting using both cemented and cementless techniques in revision THR.

In 2011, over 70 000 primary total hip replacements (THR) were performed in the United Kingdom with more than 8000 revisions, and this figure is set to rise in line with the ageing population.

One of the major challenges facing hip surgeons is how best to address the bone deficient acetabulum, restoring the hip centre and joint biomechanics. This can be achieved using impaction bone grafting (IBG) to create a stable acetabular bed facilitating sound implant fixation. IBG in THR was first described by Hastings and Parker in 1975 for rheumatoid patients with acetabular protrusion and was subsequently developed for revision THR by Slooff et al. The early reports described IBG in association with a cemented implantation technique, however its use in cementless revision THR is now well established. This article is an up-to-date summary of cemented and cementless IBG techniques in acetabular revision. Advances in this field will be discussed with a particular reference to synthetic bone substitutes.

**Impaction bone grafting with cemented cups**

In 1984, Slooff et al reported their initial experience with acetabular IBG in cemented primary and revision THR, complicated by acetabular protrusion and deficient bone stock. In a cohort of 43 hips, graft union was confirmed through radiographic observations at between two and four months after surgery with no signs of loosening between the bone and cement mantle.

The original technique described involved careful acetabular preparation including removal of previously implanted cement. Cortico-cancellous graft would then be pressed into the defect. The graft lined the native acetabulum with a layer of cancellous bone chips, which was impacted using a trial implant. Anchorage holes were created in the acetabular roof and in the graft, and the graft bed would then be covered with a metal mesh. Following irrigation with cooled ringer solution and drying, the acetabular component would be cemented in place laterally and distally relative to the original position. They used either autogenous femoral heads or allografts or a combination of allograft and autogenous bone chips from the posterior iliac crest. The use of a metal mesh to limit cement penetration was later discontinued as it was potentially harmful to bone incorporation and did not add to initial stability.

Slooff’s group reported their five year follow-up of 88 acetabular revisions and found complete union between graft and host-bone in all cases with improved mean Harris hip scores. However four patients required revision (two infections and two aseptic loosening), with one showing evidence of progressive radiological loosening. Radiographic failure was reported in a further five patients with migration of more than 5 mm in four and continuous lucency thicker than 2 mm in one; a combined clinical and radiographic failure rate of 11.4%. At a minimum 10-year follow-up (mean 11.8 years) the
survival rate was 94% using aseptic loosening as the end point. The three cases revised (at six, nine and 12 years) had radiolucent lines visible at two years post-operatively, which subsequently progressed. The long-term results in 2004 reported: 96% (95% CI 91 to 100) survivorship at 10 years for aseptic loosening, and 84% (95% CI 73 to 95) at 15 years follow-up. All revised cases for aseptic loosening had radiological signs of loosening in all DeLee and Charnley zones. The latest outcomes (20 to 25 years) of the same cohort had a survivorship of 87% (95% CI 76 to 97).

Other centres have reproduced these results, however an isolated report found a high failure rate with a survivorship of only 72% (95% CI 54.4 to 80.5) at mean follow-up of 7.2 years. The majority of failures were found in the American Academy of Orthopaedic Surgeons (AAOS) Type III defects (combined segmental and cavitary deficiency) and type IV defects (pelvic discontinuity) which were deemed contraindications to Slooff’s technique.

A major limitation at that time was the prolonged period of post-operative bed rest (three to six weeks), which is regarded as unacceptable in the current era of enhanced recovery. However even the originators now advocate earlier mobilisation. Other disadvantages include the requirement of three or more femoral head allografts for every revision, which is expensive and resource-intensive. It is a time consuming operation and the technique itself is demanding, and can be difficult to reproduce in less experienced hands. Van Haaren et al found that 11 out of the 20 failures observed were performed by surgeons who had experience of only three years using the technique, even when assisted by a visiting surgeon from the Slooff group. Overall this technique has been successful in technologically challenging patients with rheumatoid arthritis and patients younger than 55 years.

In relation to the Paprosky classification, Slooff’s technique has produced a survival rate of 84% for Grade 3A (bone loss from ten o’clock to the two o’clock position around the acetabular rim) and 82% for Grade 3B (the acetabular rim is absent from nine o’clock to the five o’clock position) at mid-term follow-up. A combination of trabecular bone augments with IBG and cemented acetabular components have satisfactory clinical and radiological results at short-term follow up.

Biomechanically, cemented morsellised allograft has a high capacity to incorporate in animal models dependent upon achieving initial adequate stability in the construct. However subsequent loss of stability despite initial incorporation has been reported.

**Impaction bone grafting with cementless cups**

Cementless acetabular components are becoming the norm in both primary and revision THR. Early failures were reported in cementless revision when using inadequately designed acetabular implants such as those with a smooth-threaded configuration. However, cementless THR has evolved, aided by improved metallurgy where the majority of present-day acetabular components are porous-coated with sintered-head technology, titanium mesh or plasma spraying in order to increase surface area and porosity.

Cementless implants permit in-growth of host-bone whilst remodelling occurs at the metal-bone interface; this leads to durable and stiff biological fixation. Cementless revision of the failed acetabular component yields excellent long-term results. In the authors’ experience, it is possible to achieve press fit stability on the rim of an acetabulum at the same time as impaction grafting. IBG allows bone restoration medially and into segmental defects, whilst the press fit is still achieved on the rim of the socket. This technique, combined with a cementless porous-coated component with supplementary screw fixation, is now a well-established method for acetabular revision in the context of restoring bone stock.

Cementless revision using IBG is indicated for defects that can be contained, rendered contained, or where rim fixation can be achieved. It is use is contraindicated where bony in-growth and initial stability is not possible, such as severe osteoporosis, osteonecrosis, irradiation, metabolic bone disorders, tumours and pelvic discontinuity. A cementless acetabular reconstruction in revision THR is recommended for Paprosky type 1 and some type 2 defects, however many studies have also used the cementless IBG technique successfully in type 3 defects.

The authors use IBG and cementless components predominantly for Paprosky Type 1 and the majority of type 2 defects. The technique for selected type 3 bone defects is also employed. Following adequate exposure, any granulomatous tissue or pseudo-membrane is excised and the acetabulum is prepared using hemispherical reamers. Drilling of the sclerotic bone can be used to encourage healthy bleeding. Isolated cavitary defects and other areas of bone stock deficiency are densely packed with morsellised cancellous bone (Fig. 1) (1 mm to 10 mm fresh-frozen non-irradiated femoral head allograft). In cases with insufficient bone graft, synthetic materials can also be used and have a good success rate with 50:50 mixtures. Impaction is achieved using the trial prosthesis and reverse reaming, initially using a smaller sized reamer, followed by the last reamer used when originally preparing the acetabulum.

In order to obtain a better press-fit, a porous-coated titanium cup 1 mm to 2mm larger than the last trial is routinely used. Regardless of how stable the prosthesis appears, fixation is supplemented using a minimum of two screws. Our seven year follow-up of 69 cementless acetabular revisions (Paprosky Type 2 defects) augmented with IBG display demonstrated 95% survivorship (95% CI 88.4 to 100.0) using aseptic loosening as the end point. There are several studies illustrating the successful use of cementless acetabular reconstruction with IBG. Amongst them, successful use with IBG alone, however there are studies which
provide evidence to the contrary. \cite{34,37} Lakstein et al.\cite{38} found the use of trabecular metal cups\cite{39,40} with IBG provided a reasonable treatment option where less than 50% host-bone contact was available. At a mean follow-up of 45 months (24 to 71), the revision rate was 4% for cup migration and failure.

**Advances in impaction bone grafting**

IBG ideally involves the use of bone autograft, however this is in limited supply, may be of poor quality and has associated morbidity at harvest sites.\cite{41,42} Allograft has been extensively used in IBG, yet there are concerns regarding transmission of infection and the risk of invoking an immune response. Both issues can be solved through gamma irradiation and freezing, which adversely affects the osteoinductive or osteoconductive potential and strength of the graft.\cite{43}

Synthetic bone substitutes address these issues. A combination of tricalcium phosphate (TCP) and hydroxyapatite (HA) has been the subject of \textit{in vitro} testing in the context of IBG.\cite{44-46} Bolder et al.\cite{45} assessed different mixtures of graft substitute (TCP/HA) and morsellised allograft in cemented acetabular revision using acetabular models under dynamic loading conditions. Increased stability is observed when TCP/HA is used independently because of cement penetration although this is not desirable when seeking bone graft incorporation; however, when combined with allograft, stability was achieved whilst reducing cement penetration.

The first human trial using TCP/HA mixed with allograft in IBG was reported in 2009.\cite{47} The combination of 80% TCP and 20% HA mixed with allograft (50:50) was used to augment 43 revision THRs (9 cemented and 34 cementless acetabular components). There were no cases of implant migration and no re-revisions at two years.

There is interest in the use of demineralised bone matrix and bone morphogenic proteins in IBG, but published evidence is scarce. Only one clinical study with short-term follow-up reports the use of this combination in association with morsellised allograft in acetabular revision.\cite{48} There was a significant improvement in Harris hip scores and full bone incorporation in 18 out of 20 hips. No evidence of loosening was subsequently found. Other areas of innovation include the use of an \textit{ex vivo} (on table and sterile) compaction device (to deliver reproducible grafts with consistent compression-stiffness and porosity).\cite{49} Antibiotic impregnated morsellised bone graft for use in single stage infected acetabular revision has also been reported.\cite{50}

![Fig. 1](image1.png)  
Photograph showing morselised bone graft with bone chips filling acetabular defects following acetabular preparation and prior to impaction.

![Fig. 2](image2.png)  
Photograph showing impaction using reverse reaming technique.

![Fig. 3](image3.png)  
Photograph showing a reflection 3 cup (Smith & Nephew, Memphis, Tennessee) fixed with four screws into the acetabulum on top of impaction bone grafting.
Conclusion
IBG is now a routine technique in revision THR. It has initially gained favour as an application using cemented implants, and now, with increasing confidence worldwide, in cementless acetabular reconstruction. Improving implant surface technology and fixation for acetabular components may extend the indications, as may the availability of improved synthetic bone graft materials.

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References

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Prosthesis</th>
<th>Defect</th>
<th>Mean follow-up (mths)</th>
<th>Failure rate (aseptic loosening)</th>
<th>Survival rate (aseptic loosening)</th>
<th>Overall survival rate (95% CI)</th>
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<tr>
<td>Tanzer et al30</td>
<td>1992</td>
<td>HG, Porous-Coated (PCA, Dureloc, Önmitt, HG)</td>
<td>AAOS I-IV</td>
<td>127</td>
<td>41</td>
<td>1.4%</td>
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<td>Jasty30</td>
<td>1998</td>
<td>Jumbo Cup</td>
<td>&gt; 4 cm medial wall defect &amp; loss of Anterior Column</td>
<td>19</td>
<td>120</td>
<td>5.2%</td>
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<tr>
<td>García-Cimbrelo32</td>
<td>1999</td>
<td>Porous Coated (PCA, Dureloc, Önmitt, HG)</td>
<td>Paprosky I-IIIB</td>
<td>42</td>
<td>89</td>
<td>-</td>
<td>89.5% (79.8 to 99.2)</td>
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<td>Etienne et al30</td>
<td>2004</td>
<td>Not recorded</td>
<td>Not recorded</td>
<td>108</td>
<td>85</td>
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<td>-</td>
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<td>Dorrairajen et al31</td>
<td>2005</td>
<td>Porous, HAC</td>
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<td>50</td>
<td>32</td>
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<td>Palm et al32</td>
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<td>Gustilo &amp; Pastermak I-IV</td>
<td>87</td>
<td>108</td>
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<td>-</td>
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<td>Lee and Nam33</td>
<td>2011</td>
<td>Trilogy or HG II, Porous-Coated (PCA, Dureloc, Önmitt, HG)</td>
<td>AAOS I-IV &amp; Paprosky I-IIIB</td>
<td>71</td>
<td>144</td>
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<td>Patel et al34</td>
<td>2013</td>
<td>Trilogy or Reflection Paprosky I-II, Porous-Coated</td>
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<td>62</td>
<td>84.5</td>
<td>4.8%</td>
<td>94.6% (88.4 to 100)</td>
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Table I. Examples of published studies investigating cementless acetabular reconstruction using impaction bone grafting (CI, confidence interval).
32. Dorairajan A, Reddy RM, Krikler S. Outcome of acetabular revision using an unce-
33. Lee JM, Nam HT. Acetabular revision total hip arthroplasty using an impacted morselized allograft and a cementless cup: minimum 10-year follow-up. J Arthro-
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