

Chapter 5

Acetabular Revision with Impaction Bone Grafting



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Introduction

Impaction bone grafting was started at end of the 1970s by Tom Slooff at the Radboud University Medical Centre in Nijmegen [1]. He started this technique by modifying bone reconstruction methods that were introduced by Hastings and Parker [2] and McCollum et al. [3] (1980) in acetabular protrusion. He started to use the technique in primary total hips with acetabular protrusion and in revision hip surgery in patients with contained bone defects [1]. The difference with the previous described techniques was that he used larger bone chips produced by hand with a rongeur and that he impacted the bone grafts using a metal hammer and the trial cup as impactor. He used the technique only in combination with a cemented cup, at that time the Mueller 32 mm cup. Initially, all patients had a long time recovery period with 6 weeks bed rest. After the initial favourable results, the technique was extended to more complex primaries like reconstructions in developmental dysplasia of the hip (DDH) and more demanding revisions. For medial wall defects he used metal titanium perforated meshes to strengthen the medial wall to prevent a blowout during impaction. At that time there was a lot of concerns about this new technique and suggestions were made that too much contact between the reconstructed bone layer and bone cement would harm the incorporation of the bone graft [4]. By using the same metal meshes as he used for reconstructing of the medial wall mesh directly on top of these reconstruction, he was able to limit the bone cement contact. However, in retrospect the suggestion that bone cement would hamper bone incorporation was wrong, as was shown in many experiments. About 10 years after the start of this technique at our institution, we quit stopping these meshes on top of the

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bone graft. Also during the years we learned that early mobilisation of the patients was possible after these reconstructions, and we followed the trend to start early mobilisation after revision.

After our initial experience we started many experiments to underpin the science around this technique. We performed mechanical experiments *in vitro* using human cadaveric pelvic bone as well as an artificial developed acetabular model to study the mechanical effects of bone impaction grafting [5]. We found that after a technically proper impaction using a metal hammer and a metal impactor, and after pressurizing of the cement on top of these reconstructions a very nice cement bone graft interface was obtained, and that the cement did only slightly protrude into the impacted bone reconstruction. We also found out that it is important to use larger bone chips to obtain a better stability. For acetabular impaction bone grafting bone chips with a diameter of 8–12 mm seems to be the most attractive [5]. There have been studies from other centres suggesting that mixes of larger and smaller bone chips are also attractive [6]. However, there is certainly agreement that small sized bone chips (2–4 mm) are not attractive, as they will lead to more migration and less cup stability. We also learned that washing of the bone grafts may be attractive and hence reducing the fat in the bone chips is also attractive to improve cup stability [7], as was earlier confirmed by Dunlop et al. [6]. However, all our long-term clinical data are based on non-washed bone chips. We also performed animal experiments in goats use bone chambers to investigate the incorporation process of the bone graft [8]. In other animal experiments in goats, we did realistic hip surgery implanting cemented total hips in combination with acetabular bone impaction grafting [9]. These experiments showed that the impacted bone grafts do effectively incorporate. This was confirmed in human biopsy data and retrievals [10]. In our center we published two papers studying bone biopsies taken during re-operations after previous reconstructions with bone impaction grafting [10]. Overall, the bone chips were nicely incorporated with few remnants of the original bone chips. There was also a retrieval study by Heekin [11] that showed that these bone chips really incorporate into normal bone.

Indications and Guidelines for Use

Acetabular bone impaction grafting can be considered in all cases with acetabular bone stock loss in revision hip surgery. However, infection should be ruled out before the reconstruction is performed. In septic loosening, we advise two stage surgery if acetabular bone impaction grafting is considered. There is some information about using this technique also in one stage revisions in infective cases, however this is scientifically not sufficiently underpinned yet. There is a tendency to start using bone impaction grafting in the more extensive defects, when the surgeons primary choice of revision technique is not suitable anymore. This is a potential drawback for the technique of impaction bone grafting. Like in all techniques, it is important to start the experience with a technique in the less demanding and

hence forgiving cases. Once familiar with a technique one can start to use it in the more demanding cases. This is of course the same with impaction bone grafting. And as with all other techniques, the outcome in the more extensive defects is less favourable. However, this bone reconstruction technique is one of the few techniques that can make a future revision, despite a failure, less demanding as more bone can be present at the re-revision.

Technique

The posterolateral approach is our favourable exposure, because of the excellent view on the acetabulum. This exposure also facilitates the insertion of a superolateral mesh. Especially the fixation of these meshes on the posterior wall is difficult when using other approaches. If only a medial wall mesh is needed, other surgical approaches can certainly be considered. Identifying the major landmarks is helpful for orientation purposes because in many cases the anatomy is disturbed extensively by the loosening process itself or by methods to remove the cup. The important landmarks guiding the reconstruction are the tip of the greater trochanter, the tendinous part of the gluteus maximus, the lower border of the gluteus medius and minimus, the transverse ligament and the tuber ischiadicum, if needed. Be aware of the position of the sciatic nerve, although exposure of this structure is not advised. After exposure of the joint, three biopsies of the capsule are taken for cultures. Three other biopsies are taken of the interface behind the cup or of the femur.

Releasing the gluteus maximus tendon on the femoral side can be helpful to mobilize the femur anteriorly. A circumferential exposure of the entire acetabulum is achieved by removing all scar tissue anterior, superior and posterior at the acetabular rim, and perform a circumferential capsulotomy and or even capsulectomy. Sometimes a release of the tendinous part of the iliopsoas attachment is helpful for exposure, however one should consider that this will hamper the future activity level of the patient. In case of a noncemented cup in most cases a modern device that facilitates explantation is helpful using curved chisel mounted on a head that is central in the inner diameter of the cup. In cases of a still well fixed cemented cup the technique of reaming out the polyethylene cup using acetabulum reamers and subsequently splitting the cement with osteotomes is a technique that will prevent unnecessary bone stock loss. After removing the component, and is applicable the cement, the fibrous interface is removed completely from the irregular acetabular wall using sharp spoons and curettes. Care is taken to locate and trim the transverse ligament at the inferior part of the acetabulum. The acetabular walls are reconstructed from this level upwards. After taking of the biopsy samples, systemic antibiotic therapy is started although some evidence suggests that a shot of antibiotics at the beginning of the procedure will not hamper the outcome of the cultures and may prevent superimposed infections from the revision procedure itself.

The acetabular floor and walls are examined meticulously for any segmental defects. Often these defects can only be detected by manual examination of the

walls. Check carefully if there is a dissociation of the pelvis, in these cases additional plating is necessary to prevent failure of the revised reconstruction. Meshes are not strong enough to stabilize these defects. The plates can be used on the outside of the acetabulum but also inserted on the inner side of the acetabulum, depending on the case and the preference of the surgeon. Special care is given to the transverse ligament, this is still often available at revision surgery. This ligament can be used for especially estimating the extent of the superolateral wall defect. By placing a suitable sized trial prosthesis on this ligament in the correct position, the extent of the superolateral defect can be visualized. The defects are now reconstructed using wire meshes being able to contain the bone grafts. If one wants to use a reamer to optimize the bone bed for bone impacting grafting and to remove more debris, this has to be done before fixation of the meshes. If there is a medial wall defect or a weak medial wall that maybe will not resist the forces during bone impaction grafting, a medial wall mesh should be used. There are several options available that can be performed, we prefer titanium meshes. Often, these do not need any screw fixation and will snap in nicely, however screw fixation is an option. For segmental defects, using scissors and pliers, a flexible stainless steel or titanium preformed wire mesh is trimmed and adapted to fit the acetabular rim defects. The superolateral pelvic bone can be exposed by lifting up the abductors, there are no major structures that will be damaged by this exposure. The wire mesh is fixed to the remaining acetabular wall with at least three small fragment screws to ensure rigid fixation. In most cases 6 screws are used, one can use standard 3.5 mm small fragment screws or selftapping screws. Screws are placed on the most anterior and posterior positions in the mesh and on the superolateral position in the pelvis. If the posterior wall is weak or there is a significant bone defect of the posterior wall, bony support can be found by exposing the tuber ischiadicum. In these cases one can choose to support the often quite extensive mesh by a plate that is bowed flat over the mesh and extends from the tuber area to the anterior side of the acetabulum. Both pelvic reconstruction plates as well as one-third tubular plates can be used.

After closing of the defects on the rim and medial wall the acetabulum is now contained and transformed into a cavitary defect. If a sclerotic acetabular wall exists despite previous reaming, many small holes must be drilled into the sclerotic host bone to enhance surface contact and promote vascular invasion into the graft. Allograft bone chips are then ordered, some bone banks offer washed deep frozen trabecular bone chips of 8–12 mm. If not, deep-fresh-frozen femoral heads from the a bone bank are first cleaned after thawing in saline. These heads can then be divided in four parts and using rongeurs with a large beak bone chip of the suitable size can be produced by hand. Alternatively, one can use a bone mill in the operation theatre. All fibrous tissues and cartilage is removed. An option is to use a specially designed head reamer to remove the cartilage. Next, the remaining bone is divided into four equal parts. Substantial chips of at least 8–12 mm are by a specially designed Noviomagus Bone Mill (A One Medical, Oss, The Netherlands). Most commercial bone mill produce bone chips that are small (2–5 mm).

After cleaning and washing the acetabulum, any small cavity is packed tightly with chips and subsequently impacted using the small round, half moon and large

round impactors. Next, the entire socket is filled, layer-by-layer with cancellous chips. Acetabular shaped large metal impactors hammer the chips in situ, starting with the smallest-possible-size impactor and ending with the largest-size-impactor suitable for a new acetabular wall of preferable at least 5 mm thick. Consequently, the whole acetabular hemisphere is covered with an impacted and stable layer of allograft chips. It is evident that after impaction this bone layer is not circumferentially equal in thickness. The thickness of the bone graft layer depends of course on the variety of depth of the acetabular defect. After impaction, the pre-existing enlarged acetabular diameter has been reduced to a normal size. Next the size of the suitable cup is planned, this planning should allow a cement mantle of 2–4 mm around the cup. While the antibiotic-loaded cement is being prepared, pressure on the graft is maintained using the last impactor. After inserting and pressurizing the cement, the cup is placed and held in position with the pusher until the cement has been polymerized. The advantage of impaction bone grafting is clearly that within certain limits the surgeon decides during surgery the size and shape of the new acetabulum and subsequently the size and position of the new implant. It is important to reconstruct the anatomy of the hip in such a way that the cup is placed at the level of the transverse ligament, the anatomical centre of rotation that guarantees the best mechanical properties.

Postoperative management includes anticoagulation therapy for 4–6 weeks using subcutaneous low molecular weight heparins, and if one prefers systemic antibiotics for 24 h. Indomethacin is administered for 7 days to prevent the development of heterotopic ossification. Mobilization of the patient is nowadays like in the primary total hip replacement, out of bed the day of surgery or the next day and walking with two crutches and but only touch weight bearing for the first 6 weeks. In the second period of 6 weeks 50% weight bearing is allowed. In smaller defects we start loading with 50% in the first 6 weeks and after 6 weeks full weight bearing. In cases of pelvic discontinuity the protocol is individualized according to the different circumstances of the revision arthroplasty. A period of two to maximum of 6 weeks bed rest is not used anymore, only after rare cases with very extensive acetabular reconstructions.

Results

Two recent reviews of the literature on outcomes of bone impaction grafting on the acetabular side were published in 2013 and 2018 [12].

The first paper on the outcome of bone impaction grating from our institution was a mixed series of both primary and revision case and was published by Slooff et al. [1]. This was only short to medium follow-up. However, we published our long term experience in several subsequential publications focussing on a group of 62 consecutive revisions all done at our center [13, 14]. Between 1979 and 1986, four surgeons performed 62 acetabular reconstructions in 58 consecutive patients (13 men, 43 women) for the management of failed hip arthroplasty.

The indication for the revision surgery was aseptic or septic loosening in 58 hip and 4 hips respectively. The mean age of the patients at the time of the procedure was 59 years. Defects were cavitory in 39 hips and in 23 hips the defects were combined segmental cavitory according to the AAOS classification. All patients could be followed and no hip was lost to follow-up during this long term review. At the last publication in 2015 the follow-up was between 25 and 30 years, the Kaplan-Meier survivorship of the cup with the end point of revision for any reason was 52% at 25 years postoperatively (95% CI, 45–99%). Excluding two revisions that were performed for the management of septic loosening at 3 and 6 years postoperatively, survivorship with the end point of aseptic loosening was 58% at 25 years postoperatively (95% CI, 38–73%). Most hips had a stable radiologic appearance. In this last study we evaluated also the outcome of the re-revisions performed for the management of the acetabular reconstruction to prove that reconstructions with bone impaction grafting facilitates future revisions. In this part of the study we evaluated the clinical and radiographic outcomes of 11 consecutive repeat acetabular revisions in 10 patients with all repeat bone impaction grafting again and a cemented polyethylene cup. The mean follow-up was 10 years after repeat revision and 28 years after the primary revision. Data of all re-revisions were available. Using again a Kaplan-Meier survival analysis the survival with further revision of the cup for any reason as the end point was 91% (95% CI, 51–99%) at 10 years postoperatively. On the basis of the results of this study long-term follow-up, including the data of the re-revisions bone impaction grafting was considered to be a safe and adequate biological reconstruction technique of acetabular bone defects in revision surgery.

In patients with revision of the cup and diagnosis rheumatoid arthritis, the best results in the literature have been achieved using simple repeat cementation or bone impaction grafting with a cemented cup. In one of our studies, 35 consecutive acetabular revisions were performed in 28 patients with rheumatoid arthritis using acetabular bone impaction grafting and a cemented cup. At 8–19 years postoperatively, no patient was lost to follow-up, but outcomes were included for eight patients (ten hips) who died during the follow-up period. Acetabular bone stock defects were cavitory (11 hips) or combined segmental and cavitory (24 hips). At minimum 8-year follow-up, eight hips had a re-revision. With septic loosening excluded, Kaplan-Meier analysis demonstrated a survival rate with aseptic loosening as the end point of 85% (95% CI, 71–99%) at 11-year follow-up [15]. The literature on revisions with a noncemented cup in rheumatoid arthritis has been very disappointing [16]. In a recent study we showed that the bone impaction grafting techniques also works in revisions in young patients [17]. We studied the outcome of 34 hips (33 patients) who had a revision by performing both a femoral and acetabular bone impaction grafting in one revision procedure. All patients were under 55 years, the average age at surgery was 46 years. At a mean follow-up of more than 11 years, survival rate with the endpoint of re-revision for any component for any reason was 87% (95% confidence interval [CI], 67%–95%) and with the endpoint of re-revision for aseptic loosening, the survival rate was 97% (95% CI, 80%–100%). This is in striking contrast with the only study on the outcome on unce-

mented revisions in young patients by Gross and Lee [18] who reported only a survival of less than 70% with also a lot of patients lost to follow-up.

Several studies from other centres have confirmed the data from our original studies. Certainly in the less extensive defects results outcomes overall are very satisfying. Comba et al. [19] stated that the survival rate for the reconstruction was 95.8% (95% confidence interval 92.3–99.1) overall, and 98%, excluding revision due to sepsis. They concluded that their study from an independent center has reproduced the results of the originators of the method. Garcia-Cimbrelo and Cordero [20] concluded that the mid-term results with impacted allograft and cemented all-polyethylene cups were favourable in acetabular revision surgery. Other studies had the same conclusion, bone impaction grafting works well and most patients are satisfied, however in some cases there is radiological loosening of the cup with radiolucent lines, but patients have few complaints [21, 22].

However, the outcome in the larger defects type Paproski 3A and 3B the outcomes are less favourable and as in all techniques, the more extensive the defect the less favourable the long term outcomes. Buttaro et al. [23] stated that metal mesh, impaction grafting, and a cemented cup should be considered for reconstruction of medium uncontained acetabular defects, but not for severe combined deficiencies. Garcia-Rey et al. [24] reported in their paper the outcome of 226 of these cases with a lateral rim reconstruction with a metal mesh. In the more extensive defects at 15 years follow-up, the outcome for endpoint aseptic loosening was 80% versus an outcome of 89% in the cases with a smaller defect. However, especially the patients who had a medial wall mesh and a lateral rim mesh in their study were unsatisfying, with only a survival of just over 50% at 15 years. This was also stated in the paper of Gilbody et al. [22] that was already cited before, although the overall outcome in this large study with over 300 acetabular reconstructions was satisfying, the outcome of the Paprosky type 3 defects were less satisfying. The same experience was reported before by van Haaren et al. [25], Iwase et al. [26] and Kostensalo et al. [27] who all reported a survival in the larger IIIA en IIIB defects of around 73% at 7 years follow-up. It is important to compare these less satisfying outcome with other techniques, who also have problems in these more extensive defects. Recently, a group from the Unites States started using this technique especially in these larger defects, as this is the only option to have a biological reconstruction and they showed satisfying results, although these are short term data [28].

Certainly, it has been suggested that Paprosky grade 3 defects may be better managed with other techniques. A solution could be to combine in these defects the technique of bone impaction grafting with tantalum or titanium metal augments [29, 30]. Short term results are promising, but the effect after long term has to be studied. Also stronger or better fitting meshes could be a solution to improve the outcome in these demanding cases as was shown by Stigbrand et al. [31].

Although the technique was started in combination with cemented cups, there are now data that this technique will also work with noncemented cup implants. This is important as in revisions with noncemented cups, and especially in the younger patients, bone reconstruction is also essential. Although one of the concerns was that not using cement would lead to higher migrations and more

instability a recent RSA study proved that this assumption is not correct [32]. However, a caveat can be that in this study they used smaller sized bone chips. As stated before, cup stability is better when larger chips are used from 8 to 12 mm. Palm et al. [33] already reported about the use of bone impaction grafting with a noncemented cup. The extent of the graft was not extensive in all, but even in the case with a more extensive reconstruction the outcome at 7–11 years was satisfying. There are some other reports, but more information about the combination of impaction bone grafting is needed and this can also be a potent future reconstruction option leading to reconstruction of bone.

Conclusions and Recommendations

Bone impaction grafting is one of the few biological methods to really reconstruct the bone loss as is often seen in revision surgery. This is important, and especially in the younger patients facing a future revision. Unfortunately, we will be confronted with more revisions in younger patients [34]. The process of incorporation of impacted bone grafts has been studied both in animal experiments and in human biopsies, with nearly complete incorporation of these grafts demonstrated. Satisfactorily outcomes of acetabular bone impaction grafting for the management of cavitary and simple segmental defects in revision procedures have been reported in many studies. However, in the Paprosky type IIIA and IIIB defects there certainly is a need for improvement of the outcomes. There are some guidelines to improve the outcome. First, one should start to get familiar with bone impaction grafting in the smaller and less demanding defects before starting to reconstruct extensive defects. It is important, especially in the larger defects to use larger chips from 8 to 12 mm. There is a need to improve the quality of the meshes, certainly in the situation larger superolateral defects. The limitations of the technique are unclear about how extensive the reconstruction can be. A thickness to a maximum of 3 cm seems to be safe. However, even in the case of a failed bone impaction grafting, even in a large defect, often the next revision is more easy as there will be more bone then at the first revision.

References

1. Slooff TJ, Huiskes R, van Horn J, Lemmens AJ. Bone grafting in total hip replacement for acetabular protrusion. *Acta Orthop Scand*. 1984;55(6):593–6.
2. Hastings DE, Parker SM. Protrusio acetabuli in rheumatoid arthritis. *Clin Orthop Relat Res*. 1975;108:76–83.
3. McCollum DE, Nunley JA, Harrelson JM. Bone-grafting in total hip replacement for acetabular protrusion. *J Bone Joint Surg Am*. 1980;62(7):1065–73.
4. Jones LC, Hungerford DS. Cement disease. *Clin Orthop Relat Res*. 1987;225:192–206.
5. Bolder SB, Schreurs BW, Verdonschot N, van Unen JM, Gardeniers JW, Slooff TJ. Particle size of bone graft and method of impaction affect initial stability of cemented cups: human cadaveric and synthetic pelvic specimen studies. *Acta Orthop Scand*. 2003;74(6):652–7. <https://doi.org/10.1080/00016470310018144>.

6. Dunlop DG, Brewster NT, Madabhushi SP, Usmani AS, Pankaj P, Howie CR. Techniques to improve the shear strength of impacted bone graft: the effect of particle size and washing of the graft. *J Bone Joint Surg Am.* 2003;85-A(4):639–46.
7. Arts JJ, Verdonshot N, Buma P, Schreurs BW. Larger bone graft size and washing of bone grafts prior to impaction enhances the initial stability of cemented cups: experiments using a synthetic acetabular model. *Acta Orthop.* 2006;77(2):227–33. <https://doi.org/10.1080/17453670610045957>.
8. van der Donk S, Weernink T, Buma P, Aspenberg P, Slooff TJ, Schreurs BW. Rinsing morselized allografts improves bone and tissue ingrowth. *Clin Orthop Relat Res.* 2003;408:302–10.
9. Schimmel JW, Buma P, Versleyen D, Huiskes R, Slooff TJ. Acetabular reconstruction with impacted morselized cancellous allografts in cemented hip arthroplasty: a histological and biomechanical study on the goat. *J Arthroplast.* 1998;13(4):438–48.
10. van der Donk S, Buma P, Slooff TJ, Gardeniers JW, Schreurs BW. Incorporation of morselized bone grafts: a study of 24 acetabular biopsy specimens. *Clin Orthop Relat Res.* 2002;396:131–41.
11. Heekin RD, Engh CA, Vinh T. Morselized allograft in acetabular reconstruction. A postmortem retrieval analysis. *Clin Orthop Relat Res.* 1995;319:184–90.
12. Ibrahim MS, Raja S, Haddad FS. Acetabular impaction bone grafting in total hip replacement. *Bone Joint J.* 2013;95-B(11 Suppl A):98–102. <https://doi.org/10.1302/0301-620X.95B11.32834>.
13. Schreurs BW, Slooff TJ, Buma P, Gardeniers JW, Huiskes R. Acetabular reconstruction with impacted morselized cancellous bone graft and cement. A 10- to 15-year follow-up of 60 revision arthroplasties. *J Bone Joint Surg (Br).* 1998;80(3):391–5.
14. Te Stroet MA, Keurentjes JC, Rijnen WH, Gardeniers JW, Verdonshot N, Slooff TJ, Schreurs BW. Acetabular revision with impaction bone grafting and a cemented polyethylene acetabular component: comparison of the Kaplan-Meier analysis to the competing risk analysis in 62 revisions with 25 to 30 years follow-up. *Bone Joint J.* 2015;97-B(10):1338–44. <https://doi.org/10.1302/0301-620X.97B10.34984>.
15. Schreurs BW, Luttjeboer J, Thien TM, de Waal Malefijt MC, Buma P, Veth RP, Slooff TJ. Acetabular revision with impacted morselized cancellous bone graft and a cemented cup in patients with rheumatoid arthritis. A concise follow-up, at eight to nineteen years, of a previous report. *J Bone Joint Surg Am.* 2009;91(3):646–51. <https://doi.org/10.2106/JBJS.G.01701>.
16. Mont MA, Domb B, Rajadhyaksha AD, Padden DA, Jones LC, Hungerford DS. The fate of revised uncemented acetabular components in patients with rheumatoid arthritis. *Clin Orthop Relat Res.* 2002;400:140–8.
17. Te Stroet MA, Rijnen WH, Gardeniers JW, van Kampen A, Schreurs BW. Satisfying outcomes scores and survivorship achieved with impaction grafting for revision THA in young patients. *Clin Orthop Relat Res.* 2015;473(12):3867–75. <https://doi.org/10.1007/s11999-015-4293-y>.
18. Lee PT, Lakstein DL, Lozano B, Safir O, Backstein J, Gross AE. Mid-to long-term results of revision total hip replacement in patients aged 50 years or younger. *Bone Joint J.* 2014;96-B(8):1047–51. <https://doi.org/10.1302/0301-620X.96B8.31587>.
19. Comba F, Buttaro M, Pusso R, Piccaluga F. Acetabular reconstruction with impacted bone allografts and cemented acetabular components: a 2- to 13-year follow-up study of 142 aseptic revisions. *J Bone Joint Surg (Br).* 2006;88(7):865–9. <https://doi.org/10.1302/0301-620X.88B7.17227>.
20. Cimbrello G, et al. The survival and fate of acetabular reconstruction with impaction grafting for large defect. *CORR.* 2010;468:3304–3–13.
21. Fadulelmola A, Drampalos E, Hodgkinson J, Hemmady M. Survivorship analysis of eighty revised hip arthroplasties with the impaction grafting technique using whole femoral head allografts with the articular cartilage. *J Arthroplast.* 2017;32(6):1970–5. <https://doi.org/10.1016/j.arth.2017.01.021>.
22. Gilbody J, Taylor C, Bartlett GE, Whitehouse SL, Hubble MJ, Timperley AJ, Howell JR, Wilson MJ. Clinical and radiographic outcomes of acetabular impaction grafting without cage reinforcement for revision hip replacement: a minimum ten-year follow-up study. *Bone Joint J.* 2014;96-B(2):188–94. <https://doi.org/10.1302/0301-620X.96B2.32121>.

23. Buttaro MA, Comba F, Pusso R, Piccaluga F. Acetabular revision with metal mesh, impaction bone grafting, and a cemented cup. *Clin Orthop Relat Res.* 2008;466(10):2482–90. <https://doi.org/10.1007/s11999-008-0442-x>.
24. Garcia-Rey E, Madero R, Garcia-Cimbreno E. THA revisions using impaction allografting with mesh is durable for medial but not lateral acetabular defects. *Clin Orthop Relat Res.* 2015;473(12):3882–91. <https://doi.org/10.1007/s11999-015-4483-7>.
25. van Haaren EH, Heyligers IC, Alexander FG, Wuisman PI. High rate of failure of impaction grafting in large acetabular defects. *J Bone Joint Surg (Br).* 2007;89(3):296–300. <https://doi.org/10.1302/0301-620X.89B3.18080>.
26. Iwase T, Ito T, Morita D. Massive bone defect compromises postoperative cup survivorship of acetabular revision hip arthroplasty with impaction bone grafting. *J Arthroplast.* 2014;29(12):2424–9. <https://doi.org/10.1016/j.arth.2014.04.001>.
27. Kostensalo I, Seppanen M, Virolainen P, Mokka J, Koivisto M, Makela KT. Acetabular reconstruction with impaction bone grafting and cemented polyethylene socket in total hip revision arthroplasty. *Scand J Surg.* 2015;104(4):267–72. <https://doi.org/10.1177/1457496914568408>.
28. Waddell BS, Boettner F, Gonzalez Della Valle A. Favorable early results of impaction bone grafting with reinforcement mesh for the treatment of paprosky 3B acetabular defects. *J Arthroplast.* 2017;32(3):919–23. <https://doi.org/10.1016/j.arth.2016.09.037>.
29. Borland WS, Bhattacharya R, Holland JP, Brewster NT. Use of porous trabecular metal augments with impaction bone grafting in management of acetabular bone loss. *Acta Orthop.* 2012;83(4):347–52. <https://doi.org/10.3109/17453674.2012.718518>.
30. Gill K, Wilson MJ, Whitehouse SL, Timperley AJ. Results using Trabecular Metal augments in combination with acetabular impaction bone grafting in deficient acetabula. *Hip Int.* 2013;23(6):522–8. <https://doi.org/10.5301/hipint.5000053>.
31. Stigbrand H, Gustafsson O, Ullmark G. A 2- to 16-year clinical follow-up of revision total hip arthroplasty using a new acetabular implant combined with impacted bone allografts and a cemented cup. *J Arthroplast.* 2018;33(3):815–22. <https://doi.org/10.1016/j.arth.2017.10.006>.
32. Mohaddes M, Herberts P, Malchau H, Johanson PE, Karrholm J. High proximal migration in cemented acetabular revisions operated with bone impaction grafting; 47 revision cups followed with RSA for 17 years. *Hip Int.* 2017;27(3):251–8. <https://doi.org/10.5301/hipint.5000452>.
33. Palm L, Jacobsson SA, Kvist J, Lindholm A, Ojersjo A, Ivarsson I. Acetabular revision with extensive allograft impaction and uncemented hydroxyapatite-coated implants. Results after 9 (7-11) years follow-up. *J Arthroplast.* 2007;22(8):1083–91. <https://doi.org/10.1016/j.arth.2006.11.021>.
34. Schreurs BW, Hannink G. Total joint arthroplasty in younger patients: heading for trouble? *Lancet.* 2017;389(10077):1374–5. [https://doi.org/10.1016/S0140-6736\(17\)30190-3](https://doi.org/10.1016/S0140-6736(17)30190-3).