Treatment options for large acetabular defects in hip revision surgery

Current options and a custom-made solution

Marieke Scharff-Baauw

Treatment options for large acetabular defects in hip revision surgery

Current options and a custom-made solution

Marieke Scharff-Baauw

The work in this thesis was supported by the Sint Maartenskliniek Nijmegen, The University Medical Centre Groningen and Materialise NV.

Financial support for the publication of this thesis was provided by:
Universitaire Medisch Centrum Groningen
Rijksuniversiteit Groningen
Research Institute SHARE
Nederlands Orthopaedische vereniging
Materialise NV

ISBN
978-94-6473-079-1 (printed book)

Cover & Lay-out design
Ramon Scharff

Print
IPSKamp printing

rijksuniversiteit
groningen

Treatment options for large acetabular defects in hip revision surgery

Current options and a custom-made solution

Proefschrift

ter verkrijging van de graad van doctor aan de
Rijksuniversiteit Groningen
op gezag van de
rector magnificus prof. dr. C. Wijmenga
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op

maandag 15 mei 2023 om 12.45 uur

door

Marieke Scharff-Baauw

geboren op 26 februari 1987
te Nieuwegein

Promotores
Prof. dr. S.K. Bulstra
Prof. dr. P.C. Jutte

Copromotor
Dr. M. Spruit

Beoordelingscommissie
Prof. dr. R.L. Diercks
Prof. dr. R.G.H.H. Nelissen
Prof. dr. B.W. Schreurs

Contents

I

Introduction, aims and outlines

In 2007 an article in The Lancet referred to total hip arthroplasty (THA) as 'the operation of the century'.[1] The evolution of this successful orthopedic operation has been a long journey from (un)successful inventions to the current developments in hip arthroplasty including custom-made implants. To gain better insight in the development of THA and ultimately custom-made acetabular implants, this thesis will start with a short historical background on THA including epidemiology and pitfalls using the semantics of 'total hip arthroplasty', although in a different sequence. Thereafter it will focus on the increasing burden of acetabular revision THA demonstrating the increasing need for effective acetabular implants for acetabular defects.

Hip

The definition of the noun hip according to the Cambridge dictionary is: 'the area below the waist and above the legs at either side of the body, or the joint that connects the leg to the upper part of the body'.[2]

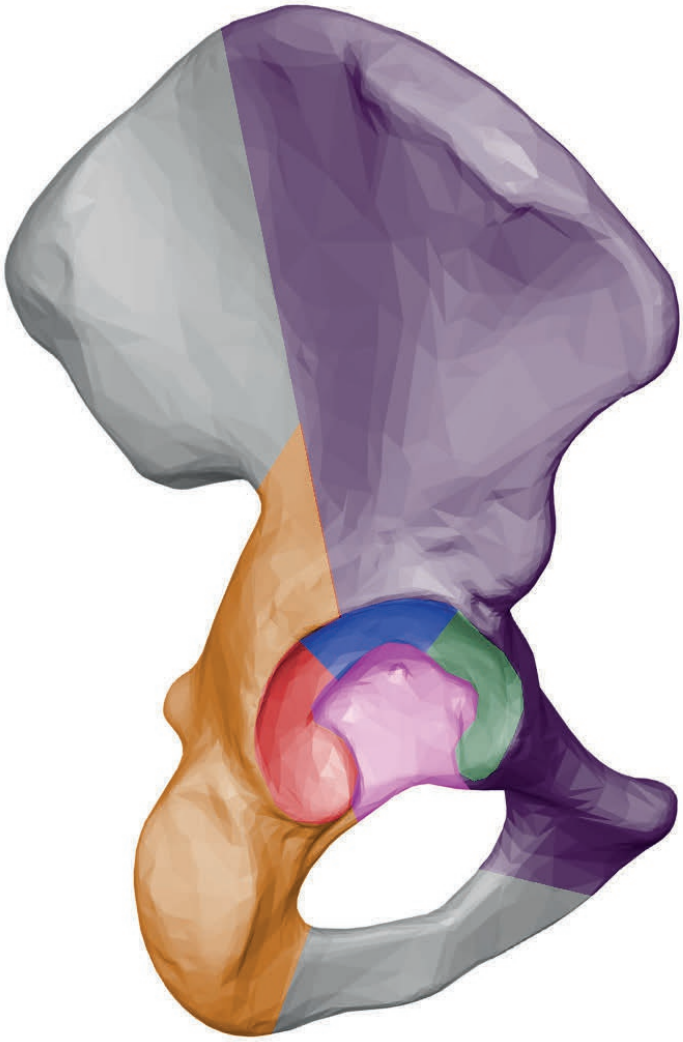
Anatomy of the hip

The hip joint is the primary link between the trunk and the lower limb. It consists of the spherical head of the femur and the concave socket of the pelvis, called the acetabulum. The articulation, scientifically called the acetabulofemoral joint, consists of bones, articular cartilage, muscles, ligaments and tendons, and synovial membrane and fluids. It is a ball and socket joint with a center of rotation allowing for a wide range of motion: flexion and extension, abduction and adduction, internal and external rotation, and circumduction. It plays an important role in the generation and transmission of forces during routine daily activities. As the entire weight of the upper body is transmitted to this joint during standing, the acetabulofemoral joint sacrifices some mobility in favor of stability and it is the most stable joint in the human body.

The acetabulum is located at the union of the ilium, ischium, and pubis bones of the pelvis. Initially these three bones are separated by a Y-shaped triradiate cartilage that fuses in puberty. The acetabulum socket is three quarters of a circle with a deficiency anteroinferior which is called the acetabular notch. The circle consists of the anterior wall, the posterior wall, the medial wall and the roof wall or so-called weight bearing dome. When talking about pelvic anatomy the pelvis is often divided in two additional parts: the anterior and the posterior column. The anterior column is composed of the anterior border of the ilium, the anterior wall and dome of the acetabulum, and the superior pubic pubis. The posterior column consists of the greater and lesser sciatic notches, the posterior wall of the acetabulum, and the ischial tuberosity. Inferiorly the columns are bridged by the ischiopubic ramus, which is composed of the inferior pubic ramus and the inferior ischial ramus (Figure 1).[3]

With the hip being such an important joint in daily functioning one can imagine that any disease affecting the hip joint is very incapacitating. That is why already early on many doctors tried to treat disabling hip diseases. These diseases include many that are still indications for total hip arthroplasty nowadays such as osteoarthritis; developmental dysplasia of the hip; inflammatory arthritis, including rheumatoid arthritis; post-traumatic arthritis following fractures and/ or dislocations of the acetabulum and proximal femur; primary or metastatic tumors of the hip joint; and post-infectious or post-perthes arthritis.[4]

Figure 1.
Acetabular Anatomy



Orange: posterior column; Bleu: superior wall; Purple: anterior column; Green: anterior wall; Red: posterior wall; Pink: medial wall.

Hip Arthroplasty

The word arthroplasty arises from ancient Greek and consists of three parts: ***arthros*** meaning joint, ***plastos*** which is something molded and ***y*** referring to a place for an activity.[5] This molding of the hip joint came in many varieties throughout the last few centuries.

Excision arthroplasty

The first molding concept of the hip joint was the idea of an osteotomy of the proximal femur. In 1827 the American John Rea Barton was the first to report on an intertrochanteric osteotomy performed in 1826 on a sailor named John Coyle who had a spontaneous joint fusion. Barton manipulated the extremity 20 days after the surgery to provoke a fibrous reaction and create a mobile yet stable pseudoarthrosis.[6] Barton was not the first to perform an excision arthroplasty, this is credited to Anthony White in 1821 in London. But Barton was the first to prove that motion would prevent fusion of bone, or at least temporarily because many hips ankylosed again after an osteotomy, making for unpredictable results.[7,8] In the 1940s the British Gathorne Robert Girdlestone revived excision arthroplasty, mostly in patients with tuberculosis and infection. He described a radical subtrochanteric excision of bone and muscle, open packing, and secondary healing.[9] This operation, although much less radical, still bears his name nowadays and is used as a last resort in failed total hip arthroplasty.

Interpositional arthroplasty

The next step in the development of hip arthroplasty was the notion that material could be placed between the femur and the acetabulum. Around the mid to late 19th century several surgeons worldwide performed interpositional arthroplasty on the hip joint, experimenting with many interpositional materials. These materials varied from human (autograft) tissues, including skin, fascia, and muscle, to autografts of both the animal variety, for example pig's bladder, and several metals including gold foil and silver plate. However, most of these attempts failed.[7,8]

In the early 20th century interpositional arthroplasty entered a new era with Norwegian-born American surgeon Marius Smith-Petersen. In 1923 he provided synthetic interpositional arthroplasty with a mold prosthesis, loosely placed between the re-shaped head femoral head and acetabulum, intending to facilitate bone-implant movement at both sides of the implant. He started using glass molds, which unfortunately quite often broke, and subsequently experimented with Celluloid, Bakelite, and Pyrex. After a suggestion by his dentist, he tried Vitallium® in 1937. In the following 10 years he implanted 500 Vitallium® moulds with good clinical results, providing the first predictable results in interpositional hip arthroplasty.[10]

Hemi arthroplasty

The following development in hip arthroplasty was a combination of the resection of the femoral head and interposition of material which was fixated in the femur. Different materials were used to create a femoral prosthesis including rubber, ivory, and acrylic. The French Judet brothers garnered a lot of attention with their acrylic femoral prosthesis, but unfortunately the acrylic was very susceptible to wear. The concept of hemi arthroplasty was further developed by the American Frederick Röeck Thompson who, in 1950, developed a femoral prothesis of Vitallium® with a distinctive flared collar below the head and a vertical intramedullary stem. Around the same time, Americans Harold R. Böhlman and Austin Moore developed a Vitallium® femoral prosthesis with a fenestrated stem that allowed bone ingrowth. Both implants were the first to be widely distributed and are still used nowadays in the elderly following femoral neck fractures.[7,11] But in diseases also affecting the acetabulum, it only replaces the femoral head and leaves the acetabulum untreated.

Total Hip Arthroplasty

By the Cambridge dictionary the word 'total' is defined as: 'the amount you get when several smaller amounts are added together.'[12] In hemi arthroplasty only the femur is replaced, and it leaves the acetabulum untreated. In total hip arthroplasty both the femur and the acetabulum are treated.

Development

Perhaps the first total hip arthroplasty (THA) was performed by the German Themistocles Glück, already in the 1880s. He replaced several tuberculous joints, including hips, with artificial joints made of ivory. At first, he fixated these with nickel plated screws, later he experimented with bone cements. Unfortunately, he chose the wrong patients, with tuberculosis, and the wrong material. And even though short-term results were spectacular, all the prosthesis failed in the long-term due to chronic infection. However, he led the way in the development of hip implant fixation, he was the first to recognize that prior infection could be a contra-indication for arthroplasty, and he was the first to develop the idea of biocompatibility.[7,8,13]

In 1938, the British Philip Wiles was the first to develop a more advanced THA, using precisely fitted stainless steel components, implanted in each other, that were attached to the bone with screws and bolts. This implant is regarded as the precedent of the modern genre. However, the results were not satisfactory.[1,7,11] To improve outcomes, the next few decennia the development of THA was mainly based on the fixation of the implant, cemented or uncemented, and on the tribology of the articulation between femoral head and acetabular socket. Tribology being the study of friction, lubrication, and wear between moving subjects. In the 1950s and 1960s several surgeons, including McKee, Watson-Farrar, Ring, Huggler and Müller, developed metal-on-metal arthroplasties some of them cemented and some of them uncemented.[7] The most famous orthopedic surgeon of THA in recent history is perhaps John Charnley, who in the early 1960s performed a revolutionary THA with low-friction implants using a high-density polyethylene between the metal components and fixating the implants with acrylic cement.[14] Cemented hip arthroplasties like those of Charnley and those of Ling and Lee in Exeter were the golden standard in THA in the 1960s and 1970s and are still used, with small implant modifications, nowadays.[11]

Cementless implants started to get back in fashion after the discovery of the so called 'cement disease' which referred to the premature loosening and localized areas of bone resorption (osteolysis) found in the cemented arthroplasties. Different cementless components were designed aiming to provide adequate initial stability and fixation but also long-term stability and fixation by encouragement of osteointegration of bone into the implant surface.[1] Later it was found that not cement particles, but polyethylene wear particles were to blame for osteolysis and the ensuing aseptic loosening.[15] Metal-on-metal implants were used once again and ceramic -on-ceramic implants were developed to limit the effect of wear. And after the new understanding of the mechanisms of lyses from polyethylene, polyethylene itself has been innovated to reduce wear.[16]

Acetabular implants

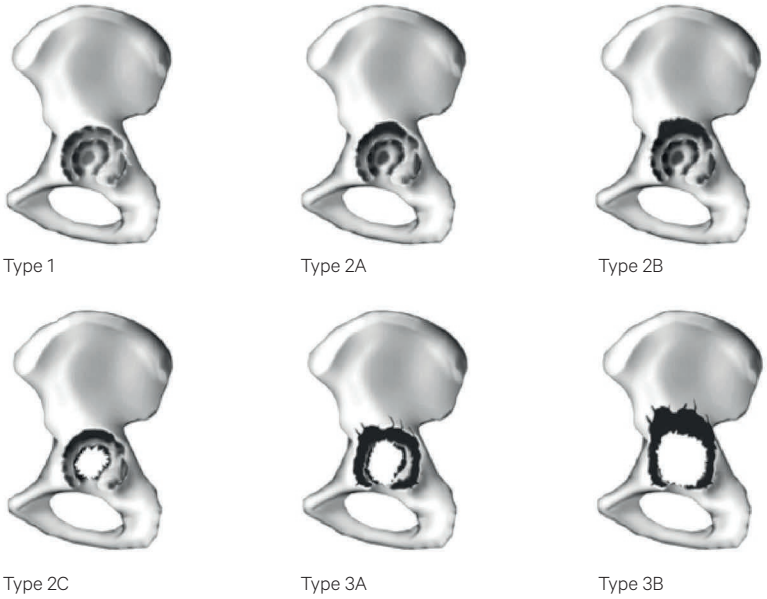
Acetabular implants are considered the weakest link in THA. The high failure rate of the cemented Charnley cups, especially in younger patients, contributed to the evolution of cementless cups. Cementless fixation was first achieved with metal screws in cups with poor results. Later different kinds of porous coating of the implant, which allows for bone ingrowth, were tried for long term stability and fixation. Porous coated implants were combined with spikes, threats, screws, press-fit or a combination of these to achieve both initial and long-term stability and fixation.[1,17] Nowadays several orthopedic manufacturers have introduced their own products of highly porous metals and show promising results.[17] Survival rate of cemented cups has also improved, mostly by the advancement in cementing techniques. Cement is not a glue but achieves fixation by mechanical interlock. Cleaning of the reamed acetabulum using pulse lavage, subsequently drying the acetabulum and sustained pressurization of the cement have all enhanced the fixation of the cemented cups.[1]

But despite all these innovations the last few years the acetabular component was revised almost twice as often as the femoral component. [4,18–20] Indications for revision include aseptic loosening, fixation failure, malposition, progressive osteolysis, infection and instability.[17] Implant loosening because of aseptic loosening (AL) due to aseptic osteolysis accounts for most THA revisions. Osteolysis is the long-term consequence of the biological response to wear debris and products derived from corrosion of implants and associated with both cemented and cementless cups. AL of the acetabular component is characterized by osteolysis at the bone-implant surface, destroying the anterior and posterior acetabular walls while the cup migrates medially and affects the acetabular roof and the medial wall. Osteolysis is associated with pain if the bone loss results in decreased mechanical support for the acetabular and extensive bone loss can occur without affecting implant stability. Therefore, patients can be clinically asymptomatic despite significant destruction of the pelvic bone. When patients become symptomatic and the need for acetabular component revision arises, these large acetabular defects compromise the revision surgery making it more technically challenging than primary arthroplasty.[21] The extent of the acetabular defect determines the type of acetabular revision surgery. Therefore, preoperative planning, to identify the anatomy and the extent of the acetabular bone defect, is essential. Plain radiographs are an easy and readily available source to evaluate bone loss. However, the bone loss is almost always more extensive then seen on radiographs alone.

CT scans can provide cross-sectional images of osteolytic lesions and metal artifact reduction protocols permit acceptable visualization even with the metal artifacts from the adjacent prosthetic components. Multislice CT scanning with metal artifact minimization can show the actual extent and location of osteolysis and is more sensitive than plain radiographs for identifying and quantifying osteolysis around acetabular components.[21]

In the 80s and 90s two classification systems for acetabular bone loss were developed which are still widely used (Figure 2).[22,23] At the same time acetabular implants and techniques for these large defects were developed. Some techniques were targeted on reconstruction of the acetabular bone defects using autologous or heterologous bone grafts, like techniques using bone impaction grafts and structural allografts. With these techniques the aim is not only to fill the defect but also to replenish the bone defects which may make revisions down the line easier. Other techniques were aimed at filling the defects with large metal constructs ranging from large ‘acetabular cups called jumbo cups to more elaborate constructs with cups and cages including antiprotrusio cages, cup cage constructs and triflange components. The latter is named for the three stabilizing flanges it has on the three bones the acetabulum: ilium, ischium, and pubis.[24]

Figure 2.
Illustrations of the Paprosky classification of acetabular bone loss adaption from Seth et al.[24]



Factors that affect long-term survivorship include not only wear properties and patient-related factors, such as medical comorbidities and activity levels, but also component positioning.[25] Malpositioning of the acetabular component is associated with instability, increased wear, and early failure after THA.[26,27] Improving acetabular component positioning will improve outcomes and reduce health-care costs. [27] Numerous factors, both within and beyond the surgeon's control, can affect acetabular component orientation and include poor visualization, greater patient size, inaccuracy of mechanical guides, and changes in patients' position.[27] The optimal position of the acetabular component is still controversial. Methods for determining the optimal acetabular position using patient specific morphology include preoperative imaging (e.g., templating on conventional radiographs, CT scans), intraoperative imaging (e.g., radiographs and fluoroscopy), intraoperative tests, and intraoperative landmarks.[27] However, not only determining the ideal acetabular component orientation is a challenge, placing the component within this determined zone might even be more challenging. The accuracy of freehand acetabular component positioning in primary THP was found to be only 70.5% within 10° degrees of their intended position for both INCL and AV.[28] In hip revision surgery these results were found to be even worse.[29]

In the last couple of decades computer-assisted surgery systems were developed, with the aim of increasing the accuracy and reliability in which hip implants are positioned. These techniques include passive computer navigation, active robotic-assisted surgery, and patient-specific instruments. The accuracy of cup positioning might increase and complications like dislocation might reduce but further study is required to see if these techniques lead to long time clinical benefit and implant survival. Furthermore, concerns have been raised about the costs and the increased operative time. Patient specific instrumentation, in which three-dimensional templates printed from preoperative images are used, might be the least expensive and certainly the technique with the least time burden of the computer-assisted surgery techniques.[1,25,30] The newest development in acetabular cups that combines computer-assisted surgery techniques and a solution for large acetabular defects are the custom-made acetabular triflange implants.

The burden

A burden can be defined as 'a duty or responsibility that is hard to bear'.[31] The burden of THA and revision THA is expected to rise further in the future.

Osteoarthritis

There are many indications for Total hip arthroplasty (THA) including trauma, osteonecrosis, dysplasia, rheumatoid arthritis, and tumors. However, the most common indication is osteoarthritis (OA), accounting for 86.1% of THAs in the Netherlands in 20.[4] OA is the most common form of arthritis worldwide.[32] OA involves the whole joint and leads to alterations in the hyaline articular cartilage, subchondral bone, ligaments, capsule, synovium, and periarticular muscles. The pathogenesis is complex and involves mechanical, inflammatory, and metabolic factors. It is an active and dynamic disease arising from an imbalance between the repair and destruction of joint tissue, ultimately leading to structural destruction and failure of the synovial joint.[33] Subsequently it causes swelling and stiffness, and most importantly pain which is experienced as the most disabling symptom leading to a loss of mobility and function. OA can involve any joint, but the most frequently affected joints are the hip, knee, hand, foot, and spine.[32,33] The strongest predictor of the development and progression of OA is age, and it is more common in women. The burden of OA is high, it being one of the ten most disabling diseases in developed countries. A total of 18% of women and 10% of men over the age of 60 have symptomatic OA worldwide. Over the last few years, the incidence and prevalence of OA has risen and is expected to keep on rising, caused by ageing populations and growing obesity rates.[34] Between 2011 and 2020 the prevalence of OA increased with 55% for men and 40% for women in the Netherlands and in 2020 over 1.5 million people had symptomatic OA. The prevalence of OA in the Netherlands is expected to increase even further with 36% in the period between 2018-2040.[35]

Primary total hip arthroplasty

Several treatment options exist for symptomatic OA. Conservative options include pain medication, physiotherapy, knee braces, and intra-articular injections with either corticosteroids or hyaluronans. In OA in the hip conservative treatment mostly consists of pain medication. For end stage OA, joint replacement is a clinically relevant and cost-effective treatment for end-stage OA.[33] Worldwide, over 1 million THA are performed each year. The number of primary THA has increased rapidly in the last decade with an average increase of THA by 22% between 2009 and 2019.[34] In the Netherlands the number of primary THA has risen from 23913 in 2010 to 33076 in 2019,[4] in Austria the number of THA increased by 14% between 2009 and 2015,[36] and in Australia an increase of 73% was found for primary THA over a 10-year period (2003-2013)[37]. The burden of primary THA is expected to increase even further over the next few decades. For example, in Australia the expected rise of THAs is by 208% from 2013 to 2030.[37]

Revision total hip arthroplasty

Not only the number of primary THAs has risen in the last couple of decades but also the amount of revision THAs. Reasons for revision include loosening of one or both components, infection, dislocation, inlay wear and periprosthetic fracture.[4] In Austria between 2009 and 2015 the number of primary THAs increased by 14% while the amount of THA revisions over the same period increased by 34.7%. In this period 7.1 % of primary THAs needed revision.[36] In the Netherlands the number of THA revisions also increased from 2010 to 2019 and the acetabular component was revised almost twice as often as the femoral component.[4,18–20] Increase in revision THAs may not only be explained by the increased number of primary THA but also by the increased number of younger patients receiving a THA. In the USA the number of younger patients receiving a THA has increased and patients younger than 65 are predicted to represent 52% of all patients by 2030.[38] In the UK and Australia, the proportion of younger patients has remained stable[30] but with increasing numbers of primary THA overall still a higher absolute number of

younger patients will receive a primary THA. Primary THAs are expected to last for 25 years in around 58% of patients.[39] However, the age at surgery had a significant effect on revision risk. The lifetime revision risk is about 5% for patients who received their primary THA at an age of 70 or higher. But this risk increases for younger patients up to a lifetime revision risk of 29.6% in male patients that received surgery between the ages of 50-54.[40] With an increasing number of THA revisions and subsequently acetabular revisions the burden of the problems encountered with acetabular revision such as acetabular bone loss is also expected to increase.

Aims and outline of this thesis

Acetabular component revision is especially challenging when facing large acetabular bone deficiencies. The burden of this orthopedic procedure is expected to rise due to an increase of the number of total hip arthroplasty revisions. The general aim of this thesis is to evaluate the current treatment options for large acetabular defects and to introduce and evaluate a new acetabular implant to treat large acetabular defects. One of the unique features of this implant is the ability to plan the precise position of the implant, using patient specific instruments, which is important for implant survival.

The following objectives are established:

1. To determine and evaluate the current treatment options for large acetabular defects.
2. To describe a new patient specific technique to treat large acetabular defects with a 3D printed custom-made acetabular implant.
3. To effectively evaluate the placement accuracy of this new custom-made acetabular implant.
4. To evaluate the short-term survival and clinical and radiological outcomes of this new custom-made acetabular implant.

Outline of the thesis

Chapter two presents a review of the literature on the current treatment options for large acetabular defects. Using the most used classification systems for acetabular defects the term 'large acetabular defects' is defined. The different treatment options found in the literature are shortly explained and most importantly their outcomes are discussed. It aims to highlight the difficulty of the treatment of these acetabular defects, especially when the defects are extremely large. In **chapter three** a new custom-made acetabular implant for large acetabular defects is introduced including its surgical technique. A case series of the first 12 patients who received this implant in the Sint Maartenskliniek, Nijmegen, the Netherlands, is presented with clinical outcomes after a minimum follow-up of 18 months. The accuracy of the placement of the implant is evaluated in **chapter four.** In a total of 16 patients who received the custom-made acetabular implant the planned position of the components was compared to the postoperative position using CT-scans. Furthermore, intra-operative and early complications were reported. In the next chapter **(chapter five)** this analysis is repeated for another 16 patients and the first and second group are compared. The aim of this chapter is to re-evaluate our previous results in a more difficult case load. **Chapter six** is a prospective case series of 50 hips that received the custom-made acetabular implant and describes the clinical and radiological follow-up at two years. The final chapter, **chapter seven,** presents a general discussion on the main findings in the previous chapters and provides future perspectives including propositions for further research.

References

1. Learmonth ID, Young C, Rorabeck C. The operation of the century: total hip replacement. Lancet. 2007;370(9597):1508-1519. doi:10.1016/S0140-6736(07)60457-7
2. Hip | meaning, definition in Cambridge English Dictionary. Last accessed September 25, 2022. https://dictionary.cambridge.org/dictionary/english/hip
3. Scheinfeld MH, Dym AA, Spektor M, Avery LL, Joshua Dym R, Amanatullah DF. Acetabular fractures: what radiologists should know and how 3D CT can aid classification. Radiographics. 2015;35(2):555-577. doi:10.1148/RG.352140098
4. LROI, 2022. Annual report 2022. Last accessed September 25, 2022. Retrieved from https://www.lroi-report.nl/
5. Elias JS. Science terms made easy: a lexicon of scientific words and their root language origins. Published online 2007. Last accessed September 25, 2022. https://books.google.com/books/about/Science_Terms_Made_Easy.html?hl=nl&id=OeWtzgEACAAJ
6. Barton JR. On the Treatment of Anchylosis, by the Formation of Artificial Joints. Lond Med Phys J. 1827;3(14):138. doi:10.1056/nejm182707010160307
7. Gomez PF, Morcuende JA. Early Attempts at Hip Arthroplasty: 1700s to 1950s. Iowa Orthop J. 2005;25:25. Accessed September 25, 2022. /pmc/articles/PMC1888777/
8. Hernigou P. Earliest times before hip arthroplasty: from John Rhea Barton to Themistocles Glück. Int Orthop. 2013;37(11):2313. doi:10.1007/S00264-013-2004-4
9. Brand RA. Acute Pyogenic Arthritis of the Hip: An Operation Giving Free Access and Effective Drainage: G. R. Girdlestone B M OXFD, F R C S. Clin Orthop Relat Res. 2008;466(2):258. doi:10.1007/S11999-007-0082-6
10. Smith-Petersen MN. Evolution of mould arthroplasty of the hip joint. 1948. Clin Orthop Relat Res. 2006;453:17-21. doi:10.1097/01.BLO.0000246557.19973.43
11. Markatos K, Savvidou OD, Foteinou A, et al. Hallmarks in the History and Development of Total Hip Arthroplasty. Surg Innov. 2020;27(6):691-694. doi:10.1177/1553350620947209
12. Total | meaning, definition in Cambridge English Dictionary. Last accessed September 25, 2022. https://dictionary.cambridge.org/dictionary/learner-english/total
13. Brand RA, Mont MA, Manring MM. Biographical Sketch: Themistocles Gluck (1853–1942). Clin Orthop Relat Res. 2011;469(6):1525. doi:10.1007/S11999-011-1836-8
14. Charnley J. Arthroplasty of the hip. A new operation. Lancet. 1961;1(7187):1129-1132. doi:10.1016/S0140-6736(61)92063-3
15. Purdue PE, Koulouvaris P, Nestor BJ, Sculco TP. The central role of wear debris in periprosthetic osteolysis. HSS J. 2006;2(2):102-113. doi:10.1007/S11420-006-9003-6
16. Harris WH. The first 50 years of total hip arthroplasty: lessons learned. Clin Orthop Relat Res. 2009;467(1):28-31. doi:10.1007/S11999-008-0467-1
17. Pulido L, Rachala SR, Cabanela ME. Cementless acetabular revision: past, present, and future. Revision total hip arthroplasty: the acetabular side using cementless implants. Int Orthop. 2011;35(2):289-298. doi:10.1007/S00264-010-1198-Y
18. LROI, 2019. Annual report 2019. Last accessed September 25, 2022. Retrieved from https://www.lroi-report.nl/
19. LROI, 2020. Annual report 2020. Last accessed September 25, 2022. Retrieved from https://www.lroi-report.nl/
20. LROI, 2021. Annual report 2021. Last accessed September 25, 2022. Retrieved from https://www.lroi-report.nl/
21. García-Rey E, García-Cimbrelo E. Acetabular revision surgery in major bone defects. Acetabular Revision Surgery in Major Bone Defects. Published online October 24, 2018:1-223. doi:10.1007/978-3-319-98596-1/COVER
22. D'Antonio JA, Capello WN, Borden LS, et al. Classification and management of acetabular abnormalities in total hip arthroplasty. Clin Orthop Relat Res. 1989;(243):126-137.
23. Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplasty. 1994;9(1):33-44. doi:10.1016/0883-5403(94)90135-X
24. Sheth NP, Nelson CL, Springer BD, Fehring TK, Paprosky WG. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. J Am Acad Orthop Surg. 2013;21(3):128-139. doi:10.5435/JAAOS-21-03-128

25. Pivec R, Johnson AJ, Mears SC, Mont MA. Hip arthroplasty. Lancet. 2012;380(9855):1768-1777. doi:10.1016/S0140-6736(12)60607-2
26. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am. 1978;60(2):217-220.
27. Moskal JT, Capps SG. Improving the accuracy of acetabular component orientation: avoiding malposition. J Am Acad Orthop Surg. 2010;18(5):286-296. doi:10.5435/00124635-201005000-00005
28. Bosker BH, Verheyen CCPM, Horstmann WG, Tulp NJA. Poor accuracy of freehand cup positioning during total hip arthroplasty. Arch Orthop Trauma Surg. 2007;127(5):375-379. doi:10.1007/S00402-007-0294-Y
29. Choi HR, Anderson D, Foster S, et al. Acetabular cup positioning in revision total hip arthroplasty with Paprosky type III acetabular defects: Martell radiographic analysis. Int Orthop. 2013;37(10):1905-1910. doi:10.1007/S00264-013-2008-0
30. Ferguson RJ, Palmer AJ, Taylor A, Porter ML, Malchau H, Glyn-Jones S. Hip replacement. Lancet. 2018;392(10158):1662-1671. doi:10.1016/S0140-6736(18)31777-X
31. Burden | meaning, definition in Cambridge English Dictionary. Last accessed September 25, 2022. https://dictionary.cambridge.org/dictionary/learner-english/burden
32. O'Neill TW, McCabe PS, McBeth J. Update on the epidemiology, risk factors and disease outcomes of osteoarthritis. Best Pract Res Clin Rheumatol. 2018;32(2):312-326. doi:10.1016/J.BERH.2018.10.007
33. Hunter DJ, Bierma-Zeinstra S. Osteoarthritis. Lancet. 2019;393(10182):1745-1759. doi:10.1016/S0140-6736(19)30417-9
34. OECD, 2021. Hip and knee surgery. Health at a Glance 2021: OECD Indicators. OECD Publishing, Paris.
35. VZinfo.nl 2022. Artrose | Leeftijd en geslacht | Volksgezondheid en Zorg. RIVM: Bilthoven, 27 januari 2022. Last accessed September 25, 2022. https://www.vzinfo.nl/artrose/leeftijd-en-geslacht
36. Leitner L, Türk S, Heidinger M, et al. Trends and Economic Impact of Hip and Knee Arthroplasty in Central Europe: Findings from the Austrian National Database. Sci Rep. 2018;8(1). doi:10.1038/S41598-018-23266-W
37. Ackerman IN, Bohensky MA, Zomer E, et al. The projected burden of primary total knee and hip replacement for osteoarthritis in Australia to the year 2030. BMC Musculoskelet Disord. 2019;20(1). doi:10.1186/S12891-019-2411-9
38. Kurtz SM, Lau E, Ong K, Zhao K, Kelly M, Bozic KJ. Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030. Clin Orthop Relat Res. 2009;467(10):2606-2612. doi:10.1007/S11999-009-0834-6
39. Evans JT, Evans JP, Walker RW, Blom AW, Whitehouse MR, Sayers A. How long does a hip replacement last? A systematic review and meta-analysis of case series and national registry reports with more than 15 years of follow-up. Lancet. 2019;393(10172):647-654. doi:10.1016/S0140-6736(18)31665-9
40. Bayliss LE, Culliford D, Monk AP, et al. The effect of patient age at intervention on risk of implant revision after total replacement of the hip or knee: a population-based cohort study. Lancet. 2017;389(10077):1424-1430. doi:10.1016/S0140-6736(17)30059-4

II

Current construct options for revision of large acetabular defects
A Systematic Review

Marieke Baauw
Miranda L. Van Hooff
Maarten Spruit

JBJS Reviews 2016 Nov 8;4(11):e2

Abstract

Background
Many treatment options are available for the revision of large acetabular defects. Debate continues as to which technique is most effective.

Methods
A systematic review was performed according to the Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines to evaluate the effectiveness of interventions for large acetabular defects. Quality assessment was performed next with use of 8 items of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist for reports of observational studies. Large acetabular defects were defined as American Academy of Orthopaedic Surgeons (AAOS) type III or IV or Paprosky type 3A or 3B. Outcomes included re-revision, radiographic loosening, complications, and clinical outcomes.

Results
We found 7 different treatment options for large acetabular defects in 20 included studies: antiprotrusio cage (8 studies), Trabecular Metal (Zimmer) augment and shell (4 studies), bone impaction grafting with a metal mesh (2 studies), hemispherical implant with hook and flanges (2 studies), Trabecular Metal augment or structural allograft with cup (2 studies), cup-cage reconstruction (1 study), and custom-made triflange component (1 study).

Conclusions
Trabecular Metal augments and shells gave the most promising results in terms of the re-revision rate and radiographic loosening. Reconstruction with an antiprotrusio cage was the most frequently reported technique, with good results in a physically low demand elderly population. Bone impaction grafting seems not appropriate for pelvic discontinuity and prone to failure in patients with Paprosky type-3B defects. In those cases, a custom-made triflange implant or a cup-cage reconstruction might be the best alternative, but few reports of sufficient quality are available yet.

Level of Evidence
Therapeutic Level IV.

Introduction

Many different treatment options are available for acetabular revision, including (jumbo) non-cemented hemispherical cups, structural allografts, bone impaction grafting, antiprotrusio cages, Trabecular Metal (Zimmer) augments and shells, cup-cage constructs, oblong cups, and custom-made triflange components.[1-6] Preoperative planning is essential to choose the appropriate implant, and therefore one needs to objectively define the nature of the defect to assess remaining acetabular bone stock and bone quality. Two widely used classification systems that provide detailed anatomical information for defect-specific preoperative planning are the American Academy of Orthopaedic Surgeons (AAOS) system[7] and the system of Paprosky et al.[8]. In general, the larger the defect, the more challenging the acetabular revision. It is important to choose the appropriate strategy to treat these acetabular defects. Many studies evaluating different treatment options are available. However, most are small case series evaluating treatment methods that have been used for the treatment of various types of acetabular defects.

The objective of the present systematic review is to assess the effectiveness of revision options for the treatment of objectively classified large acetabular defects on the basis of re-revision rates, radiographic loosening, complications, and clinical outcomes.

Materials and Methods

A literature search was performed according to the Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines[9]. Studies were identified in PubMed, MEDLINE, and Embase from 2000 to March 2014. The search strategy is shown in Table I. Two investigators independently screened the titles, abstracts, and full texts according to predetermined inclusion and exclusion criteria (Table II). Discrepancies were settled by consensus.

Table I.
Search Strategy

Database	PubMed, MEDLINE, and Embase
Date	March 2014
Strategy	#1 AND #2 AND #3
Limi	Human AND English
#1	Extensive OR large OR massive OR major OR substantial OR big OR considerable OR extended OR expanded OR voluminous OR wide OR broad OR capacious OR bulky OR hefty OR huge OR immense OR colossal OR gigantic OR ample OR great OR sizable OR spacious OR vast OR enormous OR tremendous OR severe OR complex OR tough OR complicated OR elaborate OR intricate OR Paprosky 3 OR Paprosky 3 OR Paprosky 3 a OR Paprosky 3 b OR Paprosky 3a OR Paprosky 3b OR Paprosky III OR Paprosky IIIa OR Paprosky IIIb OR Paprosky type 3 OR Paprosky type 3 a OR Paprosky type 3 b OR Paprosky type 3a OR Paprosky type 3b OR Paprosky type III OR Paprosky type IIIa OR Paprosky type IIIb OR AAOS type III OR AAOS type 4 OR AAOS type IV OR AAOS 3 OR AAOS III OR AAOS4 OR AAOS IV
#2	Acetabular OR acetabulum OR pelvis OR pelvic
#3	Revision OR revisions

Table II.
Search Strategy

Inclusion criteria	
	Human observational studies
	.90% of patients with either Paprosky type-3A or 3B defects or AAOS type-III or IV defects
	Sample size .10 patients
	Average follow-up .2 years
	Written in English
Exclusion criteria	
	Case report, review, or conference abstract
	Patients with primary total hip replacement included Publication before 2000
	Oncology
	No full text available

Studies in which the AAOS system[7] or the Paprosky system[8] was used to objectively define the acetabular defect were included. AAOS types III and IV and Paprosky types 3A and 3B were rated as large acetabular defects. These classification systems are widely used and accepted. AAOS type-III defects are characterized by a combination of segmental bone loss and cavitary deficiency. Type-IV defects are similar to pelvic discontinuity and are characterized by complete separation between the superior and inferior aspects of the acetabulum[7]. Paprosky type-3A acetabular defects are characterized by moderate-to-severe destruction of the acetabular walls and posterior column, rendering these structures nonsupportive, but the Kohler line remains intact, thus preventing substantial medial displacement of the component. If the acetabulum is considered as a circular structure represented by a clock face, then the bone loss involves the superior rim of the acetabulum from 10 o'clock to 2 o'clock. Paprosky type-3B defects are similar to type-3A defects, but the rim defect involves the region from 9 o'clock to 5 o'clock[8]. When both classification systems were used, we registered the Paprosky system as it is a more quantitative system.

Data extraction from the included full texts was performed by the primary investigator and was checked by the senior investigator. The data were collected on a prespecified data-extraction form and included authors, publication year, journal, study design, sample size, mean age, primary diagnosis, reason for revision, number of previous revisions, duration of follow-up, treatment method, co-interventions, classification, and the method that was used to determine the classification. Outcome measures were determined as the number of revisions for any reason, the number of implants with radiographic loosening based on the definition of radiographic loosening used in the article (including those that were revised because of loosening), the dislocation rate, complications, and clinical outcomes as determined with use of objective hip scores.

Two investigators independently evaluated the quality of the included full texts. Quality assessment was performed with use of 8 items of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE)[10] checklist for reports of observational studies that we deemed relevant for case series (Table III). Each item was scored as well described (+), partly described (+/-), or poorly/not described (-). If an item contained sub-items, the scores were added. The final score was rounded off downward (e.g., an item that consisted of 1 well-described [+] and 1 partly-described [+/-] sub-item was scored as partly-described [+/-]).

Table III.
STROBE Items Used[10]

Item*	Description
Setting (5)	Was the intervention clearly described in the study? Was the duration of follow-up reported?
Participant (6)	Were the eligibility criteria for entry into the study explicit and appropriate? Were participants recruited consecutively?
Variables (7)	Were additional interventions clearly reported in the study? Are the outcome measures clearly defined in the introduction or methods section?
Data sources / measurement (8)	Were relevant outcomes appropriately measured with objective and/or subjective methods?
Statical methods (12)	Were statistical tests used appropriately to assess the relevant outcomes?
Descriptive data (14)	Were the characteristics of the participants included in the study described? Did the participants enter the study at a similar point in the disease? Was the loss to follow-up reported?
Outcome data (15)	Were adverse events reported?
Main results (16)	Did the study provide estimates of the random variability in the data analysis of relevant outcomes?

*The item number from the STROBE checklist is shown in parentheses.

In cases of disagreement, consensus was sought between the 2 investigators. Articles were included if ≥75% of items were well described (+). Two partly-described items (+/-) counted as 1 well-described item (+). Finally, if studies (partially) used the same patient data, the studies with newer or more extensive patient data were included.

The results of the included studies are presented according to the available treatment option and in order of frequency. Data were pooled according to treatment option: the total number of hips that were operatively treated as well as total number of hips per outcome (re-revision rate, radiographic loosening, and reoperation for any reason). Percentages were calculated per treatment option by dividing the outcome data by the total number of hips that were treated.

Results

The detailed flow of the search and selection process is shown in Figure 1. A total of 38 articles reporting on 33 studies were eligible for the quality assessment (Table IV)[11-48]. The basic characteristics of the 20 included studies[11,15,19,22,23,25,27,29,30,32,33,37,39,43,45,46,48]
are summarized in Table V. All studies were case series with Level-IV evidence[49,50].
Seven studies were prospectively performed[11,13,15,23,43,46,48]. In most studies, the mean age of participating patients was between 60 and 70 years; in 1 study, a mean age of 82 years was reported[23]. The main indication for index revision surgery was aseptic loosening.

The outcome measures are summarized in Table VI. We found 7 different treatment options for large acetabular defects: antiprotrusio cage[14,23,27,29,33,37,46,48], Trabecular Metal augment and shell[19,22,32,45], bone impaction grafting with metal mesh[15,24], hemispherical implant with hook and flanges[12,30]. Trabecular Metal augment[13] or structural allograft with cup[39], cup-cage reconstruction[11], and a custom-made triflange component43. In all but 2 studies[14,33], only large acetabular defects (Paprosky types 3A and 3B and AAOS types III and IV) were operatively treated. We included all data from these 2 studies as they mainly (>90%) involved revisions for large acetabular defects. In 1 study, pelvic discontinuity (which coincides with AAOS type IV) was used as a classification[11]. In most studies the classification of the defect was based on intraoperative findings[11,13-15,23,24,27,29,32,33,36,45,46,48], in 3 studies it was based on preoperative radiographs[22,39,43], and in 3 studies the classification system was mentioned but the method was not reported[12,19,30]. All studies included postoperative hip scores. In the studies in which preoperative hip scores were reported[12,14,19,22-24,29,30,32,33,36,39,45,46], the scores improved postoperatively.

Antiprotrusio Cage[14,23,27,29,33,37,46,48]

The antiprotrusio cage was the most widely used method in the included studies (8 studies, 315 hips). The Burch-Schneider cage was used in 4 studies[23,27,37,48], the Kerboull reinforcement device was used in 3 studies[29,33,46], and the Richards contour cage was used in 1 study[14]. Remaining defects were filled with cement in study[23], whereas morselized bone allograft was used in other studies. In all studies, cemented cups or liners were used in the antiprotrusio device.

The device was revised in 11 (3.5%) of the pooled 315 hips. One more revision probably should be added as Okano et al.[33] excluded 1 hip because of infection and removal of the components 1 month postoperatively. Radiographic loosening was present in 22 hips (7.0%), and a total of 18 fractures of the device or screws were reported. Not all studies counted implant and/or screw breakage as radiographic loosening. The definition of radiographic loosening was well described in all but 2 studies. Bostrom et al.[14] did describe the kind of radiographic loosening that was present (i.e., breakage or migration) but did not quantify the migration. Jones et al.[27] did not quantify radiographic loosening but did report a mean vertical migration of 2.99 mm (range, 8.79 mm caudal to 4.05 mm cranial) and a mean horizontal migration of 3.43 mm (range, 7.98 mm medial to 4.19 mm lateral). As most studies quantified radiographic loosening as a migration of the implant of >3 to 5 mm, radiographic loosening was underreported in that study.

A total of 27 hips (8.6%) underwent reoperation for any reason, and 13 hips dislocated. Other complications included 9 infections, 9 hematomas, and 4 (partial) neurological deficits (2 neurapraxias of the sciatic nerve, 1 peroneal nerve palsy, and 1 transient sciatic nerve irritation).

Trabecular Metal Augment and Shell[19,22,32,45]

A Trabecular Metal augment and shell was used in 4 studies (125 hips). Morselized bone allograft was used in 3 of these studies[19,22,32], and the augment was cemented into the shell in 1 study[45]. Liners were cemented in some cases.

Two hips (1.6%) were revised, and 3 hips (2.4%) showed radiographic loosening. Flecher et al.[22] did not provide a definition of radiographic loosening; however, they reported that no mechanical failure, screw breakage, loosening, or migration was noticed during the time of the study. In 1 study[19], a patient with radiographic loosening was on the waiting list for revision with a custom-made implant; therefore, the number of hips undergoing revision is to be expected to increase to 3.

Dislocation occurred in 10 hips. Nineteen hips (15.2%) underwent reoperation for any reason, with 6 of them needing a liner revision. Lingaraj et al.[32] implanted a liner with an elevated rim or a constrained liner in most patients. A total of 11 other complications were reported, including 5 infections and 3 nerve palsies. Weeden and Schmidt[45] only reported the most common complication (dislocation), which may have led to underreporting of the complication rate.

Figure I.
Flow diagram of the literature search

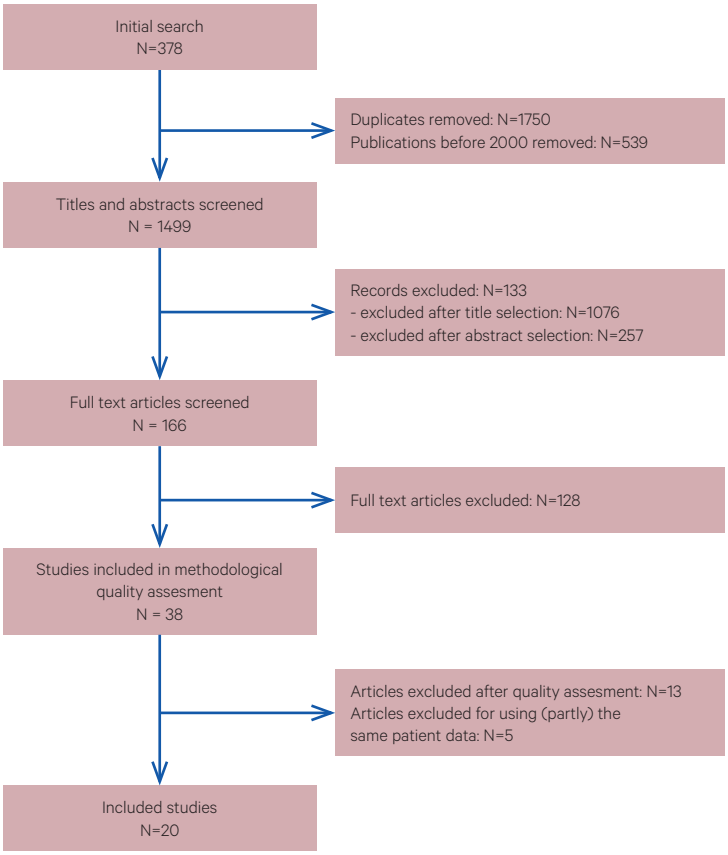


Table IV.
Quality Assessment*

Study	Case Series Design	Item on STROBE Checklist							
		Item 5	Item 6	Item 7	Item 8	Item 12	Item 14	Item 15	Item 16
Abolghasemian et al.[11] (2012)	Prospective	+	-	+	+	+	+/-	+	+
Babis et al.[12] (2011)	Retrospective	+	-	+	+	+	+/-	+	+
Borland et al.[13] (2012)	Prospective	+	+/-	+	+	+	+/-	+	+
Bostrom et al.[14] (2006)	Retrospective	+	+/-	+	+/-	+	+	+	+
Buttaro et al.[16] (2008)	Prospective	+	-	+	+	+	+/-	+	+/-
Buttaro et al.[16] (2012)	Prospective	+	-	+	+	+	+	+/-	-
Carroll et al.[17] (2008)	Prospective	+/-	+/-	-	-	+	+	+	+
DeBoer et al.[18] (2007)	Prospective	+	+/-	+	+/-	+	+	+	+
Del Gaizo et al.[19] (2012)	Retrospective	+	+/-	+	+	-	+/-	+	+
Dennis[20] (2003)	Retrospective	+/-	-	+/-	+/-	-	-	+	+
El-Kawy et al.[21] (2005)	Retrospective	+	+/-	+	+	-	-	+	+
Flecher et al.[22] (2008)	Retrospective	+	-	+	+	+	-	+	+
Gaiani et al.[23] (2009)	Prospective	+	+/-	+	+	-	+/-	+	+
Garcia-Cimbrelo and Cordero[24] (2002)	Retrospective	+	-	+	+	+	+/-	+/-	+
Garcia-Cimbrelo et al.[25] (2010)	Retrospective	+	+	+	+	+	+/-	+	+
Holt and Dennis[26] (2004)	Retrospective	+	-	+/-	+/-	-	-	+	+
Jones et al.[27] (2012)	Retrospective	+	+/-	+/-	+	+	+/-	+	+
Joshi et al.[28] (2002)	Retrospective	+	+/-	+	+/-	-	+/-	+	+
Kerboull et al.[29] (2000)	Retrospective	+	+	+	+	+	+	+	+
Kim et al.[30] (2012)	Retrospective	+	-	+	+	+/-	+	+	+
Kosashvili et al.[31] (2009)	Prospective	+	+/-	+	+	+	+/-	+	+
Lingaraj et al.[32] (2009)	Retrospective	+	+	+	+	+	+	+	+

Okano et al.[33] (2010)	Retrospective	+	+/-	+	+	+	-	+	+
Paprosky et al.[34] (2005)	Prospective	+	+/-	+	+	-	-	-	-
Piriou et al.[35] (2003)	Prospective	+	+/-	+/-	+	-	+	+	+/-
Regis et al.[36] (2008)	Retrospective	+	+/-	+	+	+/-	+	+	+
Regis et al.[37] (2012)	Retrospective	+	+	+	+	+	+/-	+	+
Schelfaut et al.[38] (2009)	Retrospective	+/-	+/-	+	+/-	+	+	-	-
Sporer et al.[39] (2005)	Retrospective	+	+/-	+	+	+	+/-	+	+/-
Sporer and Paprosky[40] (2006)	Retrospective	+	+/-	+	+	+/-	+/-	+/-	+/-
Sporer and Paprosky[41] (2006)	Retrospective	+/-	+	+/-	+	-	-	+/-	+
Stiehl et al.[42] (2000)	Retrospective	-	+/-	+/-	+/-	-	-	+	-
Taunton et al.[43] (2012)	Prospective	+	+/-	+	+	+	+/-	+	+
Traina et al.[44] (2005)	Retrospective	+	-	+	+	+	+/-	-	+
Weeden and Schmidt[45] (2007)	Retrospective	+	+	+	+/-	+	+/-	+/-	+/-
Wegrzyn et al.[46] (2015)	Prospective	+	+	+	+	+	+	+	+
Weise and Winter[47] (2003)	Retrospective	+	+/-	+	+	+	+/-	+	+
Winter et al.[48] (2001)	Prospective	+	+/-	+	+	+	+/-	+	+

*The method used to assess quality is described in the text.

Table V.
Study Characteristics

Study	Case Series Design	No. of Hips	Duration of Follow-Up* (mo)	Age† (yr)	No. of Previous Hip Operations*‡	Reason for Revision*§
Abolghasemian et al.[11] (2012)	Prospective	26	47 (24 to 68)	65 (44 to 84)	2.4 (1 to 5)	NR
Babis et al.[12] (2011)	Retrospective	62	61 (26 to 84)	62 (37 to 81)	1.6 (1 to 3)	Aseptic loosening (62)
Borland et al.[13] (2012)	Prospective	24	61 (32 to 81)	62 (24 to 87)	NR (1 to 4)	Aseptic loosening (24)
Bostrom et al.[14] (2006)	Retrospective	31	30 (24 to 58)	68 (48 to 90)	2 (1 to 4)	Aseptic loosening (29), infection (2)
Buttaro et al.[15] (2008)	Prospective	23	35 (24 to 56)	62 (23 to 88)	NR	Aseptic loosening (19), infection (4)
Del Gaizo et al.[19] (2012)	Retrospective	37	60 (26 to 106)	60 (36 to 80)	NR	Aseptic loosening (31), infection (5), instability of a hemiarthroplasty (1)
Flecher et al.[22] (2008)	Retrospective	23	35 (24 to 50)	58 (34 to 84)	2.3 (NR)	Aseptic loosening (17), others (NR)
Gaiani et al.[23] (2009)	Prospective	46	6 yr (2 to 10 yr)	82 (78 to 85)	At least 2 in 13 hips	Aseptic causes (46)
Garcia-Cimbrelo et al.[25] (2010)	Retrospective	181	7,5 yr (0,3 to 17.7 yr)	64 (28 to 89)	1.5 (1 to 6 hips)	Aseptic loosening (181)
Jones et al.[27] (2012)	Retrospective	30	85 (64 to 118)	68 (45 to 87)	2 in 10 hips	NR
Kerboull et al.[29] (2000)	Retrospective	60	124 (3 to 192)	58 (24 to 80)	1.2 (1 to 3)	Aseptic loosening (60)
Kim et al.[30] (2012)	Retrospective	17	6.8 yr (5.0 to 9.0 yr)	58.9 (31 to 72)	1.1 (1 to 2)	Aseptic loosening (17)
Lingaraj et al.[30] (2009)	Retrospective	22	41 (24 to 62)	67 (38 to 81)	2 (1 to 7)	Aseptic loosening (21), infection (1), periprosthetic femoral fracture (1)
Okano et al.[33] (2010)	Retrospective	31	6.3 yr (3.0 to 10.0 yr)	68 (35 to 84)	NR	Aseptic loosening (31)
Regis et al.[37] (2012)	Retrospective	18	13.5 yr (10.5 to 16.6 yr)	63 (33 to 77)	1.2 (1 to 3)	NR
Sporer et al.[39] (2005)	Retrospective	23	10.3 yr (7 to 15 yr)	61 (37 to 77)	3.2 (1 to 4)	Aseptic loosening (20), infection (3)
Taunton et al.[43] (2012)	Prospective	57	76 (24 to 215)	61 (35 to 81)	NR	NR
Weeden and Schmidt[45] (2007)	Retrospective	43	2.8 yr (2 to 4 yr)	65 (45 to 86)	NR	Aseptic loosening
Wegrzyn et al.[46] (2014)	Prospective	61	89 (60 to 138)	67 (10)	1.1 (1 to 2)	Aspetic loosening (37), infection (4), pain after hemiarthroplasty (2)
Winter et al.[48] (2001)	Prospective	38	7.3 yr (4.2 to 9.4 yr)	76 (49 to 83)	NR	Aseptic loosening (38)

*The values are given as the mean, with the range in parentheses. †Results are shown as presented in the articles: mean (standard deviation) or mean (range). ‡NR= not reported. §The number of hips is given in parentheses.

Bone Impaction Grafting with Metal Mesh[15,25]

The use of bone impaction grafting with mesh and a cemented cup was reported in 2 studies15,25 butwas in fact the second most common technique (204 hips). No patients with pelvic discontinuity were managed with this technique. Garcia-Cimbrelo et al.[25] found that hips with Paprosky type-3B defects had a higher risk of failure compared with those with Paprosky type-3A defects.

Fifteen hips (7.4%) underwent reoperation for any reason, and 14 hips (6.9%) had an acetabular revision. Eighteen hips (8.8%) had signs of radiographic loosening; 5 of these hips were not revised because they were only mildly symptomatic. Dislocation occurred in 5 hips. Two other complications, both deep infections, were reported.

Hemispherical Implant with Hook and Flanges[12,30]

An oblong implant with hooks and flanges was used in 2 studies (79 hips). Babis et al.[12] only used this technique for Paprosky type-3A defects.

Nineteen hips (24%) were revised, and 4 patients were waiting for re-revision for radiographic loosening[12]. A total of 22 hips (27.8%) had radiographic loosening. Kim et al.[30] reported radiographic loosening in all 3 hips with pelvic discontinuity. Dislocation occurred in 2 hips. Other complications included 1 broken hook and side plate, 4 infections, and 1 nerve palsy.

Trabecular Metal Augment or Structural Allograft with Cup[13,39]

Two studies (47 hips) involved the use of either a structural allograft[39] or a trabecular augment[13] to provide stability for the acetabular component. The structural allografts were only used for Paprosky type-3A defects[39].

Six hips (12.8%) were revised. Eleven hips (23.4%) had radiographic loosening. One hip dislocated. Only 1 other complication, a nerve palsy, was reported.

The study involving a Trabecular Metal augment[13] demonstrated a lower revision rate but a similar rate of radiographic loosening and also had a shorter follow-up period (5 years compared with10 years).

Cup-Cage Reconstruction[11]

In 1 article (26 hips), a cup-cage construct was used for the treatment of pelvic discontinuity[11]. In that study, 2 hips (7.7%) needed revision and 5 (19.2%) had radiographic loosening. Other complications included 2 dislocations, 1 infection, and 1 nerve palsy.

Custom-Made Triflange Component[43]

Only 1 study (57 hips) evaluated the use of a custom-made component[43].

Three hips (5.3%) were revised, 2 because of deep infection. Nine hips (15.8%) had aseptic loosening, but only 1 of them was revised. Twelve hips dislocated.

Twenty-four hips (42.1%) underwent reoperation for any reason; of those, 10 had a liner revision because of instability. Other complications included 2 infections and 2 nerve palsies.

Table VI.
Outcome Data

Study	Treatment	Cointerventions	Classification (no. of hips)	Classification Determanination	Cup Revision for Any Reason (no. of hips)	Reoperation for Any Reason (no. of hips)
Bostrom et al.[14] (2006)	Richards contour cage	Morselized bonegraft. Cemented cups.	2 Paprosky type 2B, 7 type 3A, 22 type 3B	Intraoperative findings	2	4
Gaiani et al. [23] (2009)	Burch-Schneider antiprotrusio cage	Bony defects filled with cement.	46 AAOS type III or IV	Intraoperative findings	1	2
Jones et al. [27] (2012)	Burch-Schneider antiprotrusio cage	Morsellized bonegraft. Cemented cup.	21 Paprosky type 3A, 9 Paprosky type 3B	Intraoperative findings	2	6
Kerboull et al. [29] (2000)	Kerboull antiprotrusio cage	Bulk allograft, morselized bonegraft. Cemented cup.	48 AAOS type III and 12 type IV	Intraoperative findings	2	3
Okano et al. [33] (2010)	Kerboull antiprotrusio cage	Morselized boneallograft. Cemented cups	2 AAOS type II, 29 AAOS type III	Intraoperative findings	1	1
Regis et al. [36] (2012)	Burch-Schneider antiprotrusio cage	Pressfitted bulk allograft. Morselized bone allografts. Cemented liners.	18 AAOS type IV	Intraoperative findings	3	3
Wegryzn et al.[46] (2014)	Kerboull antiprotrusio cage	Structural allograft. Morselized bone allograft. Cemented dual mobility cup	54 AAOS type III, 7 type IV	Intraoperative findings	0	4
Winter et al.[48] (2001)	Burch-Schneider antiprotrusio cage	Morselized bone allograft. Cemented cup	34 AAOS type III, 4 type IV	Intraoperative findings	0	4
Del Gaizo et al.[19] (2011)	Trabecular metal augment and shell	Morselized bonegraft. Cementless.	37 Paprosky type 3A	NR	1	12
Flecher et al.[22] (2008)	Trabecular metal augment and shell	Morselized bonegraft. 19 cemented liners. 4 cementless liners.	17 Paprosky type 3A, 6 type 3B	Preoperative radiographs	0	1
Lingaraj et al.[32] (2009)	Trabecular metal augment and shell	Morselized boneallograft. Cemented liners.	16 Paprosky type 3A and 6 Paprosky type 3B	Intraoperative findings	0	5
Weeden and Schmidt[45] (2007)	Trabecular metal augment and shell	Cemented augment to shell connection. Uncemented liners. 2 cemented liners in cup-cage construct for pelvic discontuinity.	33 Paprosky type 3A, 10 type 3B	Intraoperative findings	1	1
Buttaro et al.[15] (2008)	Impaction bonegrafting with metal mesh	Cemented cups.	23 AAOS type III	Intraoperative findings	2	3
Garcia-Cimbrelo et al.[24] (2010)	Impaction bonegrafting with metal mesh	Cemented cup.	98 Paprosky type 3A, 83 paprosky type 3B	Intraoperative findings	12	12
Babis et al.[12] (2011)	Oblong implant with modular side plates and hook	Morselized bonegraft. Cementless.	62 Paprosky type 3A	NR	18	18
Kim et al.[30] (2012)30	Cementless porous-coated hemispherical cup with a hook and flanges	Morselized boneallograft. Cementless.	14 AAOS type III and 3 type IV	NR	1	1
Borland et al.[13] (2012)	Trabecular metal augments	Morselized bonegraft. Cemented cups.	15 Paprosky type 3A, 9 type 3B	Intraoperative findings	1	1
Sporer et al.[39] (2005)	Structural distal femoral allografts and cementless hemispherical cup	Cementless.	23 Paprosky type 3A	Preoperative radiographs	5	5
Abolghasemian et al.[11] (2012)	Cup-cage reconstruction.	Morselized bonegraft. Cemented liner.	26 Pelvic discontuinity	Intraoperative findings	2	2
Taunton et al.[43] (2012)	Custom-made triflange component	Morselized bone allograft. Cementless.	57 AAOS type IV	Preoperative radiographs	3	24

* NR= not reported. †HHS = HarrisHipScore, UCLA = University of California Los Angeles, and WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index. Scores are given as the mean and the standard deviation (if available) or as the mean and the range (if available).

Table VI.
(Continued)

Radiographic Loosening Definition	Radiographic Loosening (no. of hips)	Dislocations (no. of hips)	Other Complications (no. of hips)	Clinical Outcomes
NR	7	5	1 superior gluteal artery laceration, 2 infections, 1 periprosthetic fracture, 4 fractures of the contour cage.	Harris hip scores (HHS) improved from 45 ± 12 to 79 ± 13.
Migration of > 5mm, progressive radiolucencie or screw breakage	0	2	2 neuropraxia of the sciatic nerve, 1 pulmonary embolus, 2 deep-vein trombosis	HHS improved from 28.2 to 82.5 (62.2-94.8)
NR	0	1	3 superficial infections, 1 deep infection, 1 evacuation of haematoma	Average Oxford Hip Score of 34.5 (18-46) and UCLA activity score of 4.4 (3-7)postoperative
Cup migration of > 3mm or angular rotation of > 3degree	3	0	1 nonunion of greater trochantic, 1 deep vein trombosis, 1 deep hematoma, 1 peroneal nerve palsy, 2 fractures of the kerboull ring, 2 screw fractures	Merle D'Aubergne and Postel score improved from 11.7 (2.4) to 17.4 (0.6)
Migration of > 3mm, >3°change inclination and screw breakage.	7	2	1 transient sciatic nerve irritation, 1 deep thrombosis, 1 device fracture, 3 screw fractures, 2 device and screw fractures	Merle D'Aubergne and Postel score improved from 11.1 (9-14) to 14.0 (11-17)
Migration of > 5mm	4	2	2 iliac screw breakage	HHS improved from 31.9 (10-81) to 77.0 (46-95)
Cup migration or angular rotation of >3mm or screw or implant breakage	1	0	1 hematoma, 2 mechanical ruptures of a femoral modular revision stem, 1 periprosthetic fracture, 1 device and screw fracture	HHS improved from 53 ± 19 to 79 ± 13
Change in the acetabular index of > 3 degree or linear migration of > 3mm	0	1	2 DVT, 6 hematomas, 2 subcutaneous inflammatory reactions, 1 deep infection	HHS improved 82.6 (58.2-94.9)
Change in the abduction of > 10° or a change in the horizontal or vertical position of > 6 mm after correcting for magnification	1	5	2 periprosthetic femur fracture, 4 deep infections	HHS improved from 33.0 (12.6-58.7) to 81.5 (27.0-99.8)
NR	0	1		Merle D'Aubergne and Postel score improved from 6.8 (4-9) to 10.6 (8-12)
A change in the abduction of > 10° or migration of > 5 mm	1	2	3 sciatic nerve injuries, 1 superficial wound infection, 1 deep-vein thrombosis	Merle D'Aubergne and Postel score improved from 8.2 (3-15) to 13.7 (11-18). HHS increased from 43 (14-86) to 75.7 (53-100)
Any measurable cup migration 1 year after implantation	1	2		Merle D'Aubergne and Postel score increased from 4.3 to 9.2. HHS increased from 32 (10-60) to 84 (28-100)
Progression of radiolucent lines in the three acetabular areas or migration of > 5mm	6	1	1 hematogenous deep infection	Average Merle D'Aubergne and Postel score of 16.2 points postoperative
Change in the abduction of >5 degree or migration of > 5mm	12	4	1 deep infection	Merle D'Aubergne and Postel score improved from 7.8 to 16.5
Linear migration of > 3mm or a rotational change >5 degrees	19	0	3 deep infections, 1 femoral nerve palsy, 1 broken hook and side plate.	HHS improved from 45 (0-82) to 81 (35-98) after 12 months. But deteriotates after 3 years.
Migration of the implant of >2mm.	3	2	1 deep infection	Merle D'Aubergne and Postel score improved from 6.9 (5-12) to 14.5 (12-18) in the 13 stable hips. In the three migrated cups the scores were two of 12 and one of 15
Migration of > 5mm of the cup	5	0	1 partial sciatic nerve injury	WOMAC scores signifficantly improved after 2 years.
A change in the abduction of >10 degree or migration of > 6mm	6	1		Merle D'Aubergne and Postel score improved from 11.1 (9-14) to 14.0 (11-17)
Migraton of >5mm of the cup cage	5	2	1 deep infection and one partial sciatic nerve injury	Average HHS of 76.6 (55.5-92) postoperative
Migration of > 2 mm with implant rotation, screw breakage, or progressive bead shedding	9	12	3 periprosthetic fracture, 2 deep infections, 2 aseptic loosening of the femoral component, 12 limited head and liner exchanges for instability (10) or acute postoperative infection (2), 2 superficial seromas, 1 nerve exploration for sciatic palsy, 1 reoperation for removal of wire from around the proximal femur, 2 permanent peroneal nerve palsies	HHS of 74.8 at 5.4 years follow up

Discussion

The aim of this systematic review was to assess the effectiveness of available interventions for large acetabular defects. We found 7 treatment options for large acetabular defects as reported in 20 case series.

We are not the first to provide an overview of the different options for acetabular revision reconstruction[1,2,5], and others have also limited the search to large acetabular defects[3,4,6]. Only 1 of those studies[4] was a systematic review of the literature; that review, which included 50 studies, evaluated treatment options for large acetabular defects. However, the search in that study[4], which was based on different treatment options, was different from our search, which was based on large acetabular defects. Those authors reported on studies investigating treatment options for large but also smaller defect sizes, which may have introduced a bias. Moreover, the use of bone impaction grafting for large defects was not reported.

In the present study, we only included articles that mainly (>90%) reported on revisions for large acetabular defects (Paprosky types 3A and 3B and AAOS types III and IV) in order not to have the outcome data biased by the results of treatment of smaller defects.

The best results for large acetabular defect reconstruction in terms of the rates of re-revision and radiographic loosening were reported for procedures involving a Trabecular Metal augment and shell as described in 4 studies[19,22,32,45]. However, a high dislocation rate resulted in many liner revisions. In our opinion, the use of a constrained liner might reduce the dislocation rate, although it might also increase the risk of aseptic loosening.

The antiprotrusio cage was the most widely reported technique and was described in 8 studies[14,23,27,29,33,37,46,48]. The re-revision rate was only slightly higher and the duration of follow-up in the included studies was longer in comparison with those in the studies on the Trabecular Metal augment and shell (Table V). The rate of radiographic loosening was relatively high. However, many hips did not need revision, probably because of satisfactory clinical results in a physically low demand elderly population (mean age, 65 years). This finding suggests that this technique may be reliable for the treatment of large defects in elderly patients. In younger, more physically demanding patients, implant breakage resulting from a lack of stability and biological fixation may result in poor clinical outcomes.

In the present study, bone impaction grafting with mesh was found to be associated with acceptable results[15,24]. In cases of failure, the same technique might be used as bone impaction grafting results in at least partial restoration of bone stock. The effective restoration of bone stock is the main advantage of bone impaction grafting. However, this technique is not appropriate for pelvic discontinuity, and inferior results have been reported for Paprosky type-3B defects[15,24].

The present study included only 1 study involving a cup-cage solution[11] and 1 study involving a custom-made triflange component[43]. Both studies demonstrated acceptable revision rates, and both techniques were limited to defects with pelvic discontinuity. The higher rates of radiographic loosening associated with both techniques might be explained by the pelvic discontinuity.
Unsatisfactory results were reported when a hemispherical cup with hooks and flanges[12,30] was used and when an allograft[39] or a Trabecular Metal augment[13] with a cup was used. Trabecular Metal augments may be favorable compared with structural allografts, which are only used for Paprosky type-3A defects and may fail because of resorption.

The present study had a few limitations. First, we limited our search to the 2 most commonly used defect classification systems (Paprosky and AAOS) to provide uniformity, but studies investigating large acetabular defects classified with use of other qualification systems might have been missed as a result. Second, all of the included studies were case series. As far as we know, no instruments are available to sufficiently assess the risk of bias of case series. Therefore, we used the STROBE checklist[10], which we adjusted for case series to assess the methodological quality. Third, there was no uniform definition of radiographic loosening in the different studies. Therefore, we reported the definition of radiographic loosening used in each study. Also, demographic factors such as comorbidities and body mass index that may correlate with patient outcomes were inconsistently and poorly reported in the articles. As a consequence, we were not able to comment on the possible influence of these factors on implant choice. Finally, we did not analyze the effect of reconstruction options on clinical outcome scores as different outcome scores were used and some reports did not provide preoperative scores[11,13,15,27,43,48].

In conclusion, Trabecular Metal augments and shells to reconstruct large acetabular defects may be considered the technique with the most promising results, whereas the use of antiprotrusio cages is the most frequently reported technique. Antiprotrusio cages may be a valuable option for elderly, less physically demanding patients. Restoration of bone stock is the ultimate goal of bone impaction grafting, but this technique has inferior results for Paprosky type-3B defects, especially those associated with pelvic discontinuity. For large, type-3B defects, custom-made implants or cup-cage reconstructions might work, but few studies are available. In order to make recommendations with regard to the most effective intervention for large acetabular bone defects, prospective controlled studies would be most helpful.

Disclosure

The authors indicated that no external funding was received for any aspect of this work. On the Disclosure of Potential Conflicts of Interest forms, which are provided with the online version of the article, one or more of the authors checked “yes” to indicate that the author had a relevant financial relationship in the biomedical arena outside the submitted work.

References

1. Blumenfeld TJ Implant choices, technique, and results in revision acetabular surgery: a review. Hip Int. 2012;22(3):235-47.
2. Chen AF, Hozack WJ. Component selection in revision total hip arthroplasty. Orthop Clin North Am. 2014;45(3):275-86.
3. Issack PS, Nousiainen M, Beksac B. et al. Acetabular component revision in total hip arthroplasty. Part II: management of major bone loss and pelvic discontinuity. Am J Orthop (Belle Mead NJ). 2009;38(11):550-6.
4. Jain S, Grogan RJ, Giannoudis PV. Options for managing severe acetabular bone loss in revision hip arthroplasty. A systematic review. Hip Int. 2014;24(2):109-22.
5. Sheth NP, Nelson CL, Springer BD, Fehring TK, Paprosky WG. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. J Am Acad Orthop Surg 2013;21:128-139.
6. Villanueva M, Rios-Luna A, Pereiro De Lamo J, Fahandez-Saddi H, Böstrom MP. A review of the treatment of pelvic discontinuity. HSS J. 2008;4(2):128-37.
7. D'Antonio JA1, Capello WN, Borden LS et al. Classification and management of acetabular abnormalities in total hip arthroplasty. Clin Orthop Relat Res. 1989;(243):126-37.
8. Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplasty 1994;9:33-44.
9. Stroup DF, Berlin JA, Morton SC et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. JAMA. 2000;283(15):2008-12.
10. von Elm E, Altman DG, Egger M. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet. 2007 Oct 20;370(9596):1453-7.
11. Abolghasemian M, Tangsataporn S, Luzyk P.R.T. et al. Cup-cage solution for pelvic discontinuity. Semin Arthro 2012;23:171-175
12. Babis GC, Sakellariou VI, Chatziantoniou AN, Soucacos PN, Megas P. High complication rate in reconstruction of Paprosky type IIIa acetabular defects using an oblong implant with modular side plates and a hook. J Bone Joint Surg Br. 2011;93(12):1592-6.
13. 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 Aug;83(4):347-52.
14. Bostrom MP, Lehman AP, Buly RL, Lyman S, Nestor BJ. Acetabular revision with the Contour antiprotrusio cage: 2- to 5-year followup. Clin Orthop Relat Res. 2006;453:188-94.
15. 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.
16. Buttaro MA, de la Rosa DM, Comba F, Piccaluga F. High failure rate with the GAP II ring and impacted allograft bone in severe acetabular defects. Clin Orthop Relat Res. 2012;470(11):3148-55.
17. Carroll FA1, Hoad-Reddick DA, Kerry RM, Stockley I. The survival of support rings in complex acetabular revision surgery. J Bone Joint Surg Br. 2008;90(5):574-8.
18. DeBoer DK, Christie MJ, Brinson MF, Morrison JC. Revision total hip arthroplasty for pelvic discontinuity. J Bone Joint Surg Am. 2007;89(4):835-40.
19. Del Gaizo DJ, Kancherla V, Sporer SM, Paprosky WG. Tantalum augments for Paprosky IIIA defects remain stable at midterm followup. Clin Orthop Relat Res. 2012;470(2):395-401.
20. Dennis DA. Management of massive acetabular defects in revision total hip arthroplasty. J Arthroplasty. 2003;18(3 Suppl 1):121-5.
21. El-Kawy S, Hay D, Drabu K. Clinical and radiological results of impaction bone allograft technique in acetabular revisions associated with massive bone stock deficiencies: Four to ten years follow up study. Hip Int. 2005; 15(1):45-51.
22. Flecher X, Sporer S, Paprosky W. Management of severe bone loss in acetabular revision using a trabecular metal shell. J Arthroplasty. 2008;23(7):949-55.
23. Gaiani L, Bertelli R, Palmonari M, Vicenzi G. Total hip arthroplasty revision in elderly people with cement and Burch-Schneider anti-protrusio cage. Chir Organi Mov. 2009;93(1):15-9.
24. Garcia-Cimbrelo E, Cordero J. Impacted morsellised allograft and cemented cup in acetabular revision surgery. A five to nine year follow-up study. Hip Int 2002;12(3):281-288.
25. Garcia-Cimbrelo E, Cruz-Pardos A, Garcia-Rey E, Ortega-Chamarro J. The survival and fate of acetabular reconstruction with impaction grafting for large defects. Clin Orthop Relat Res. 2010;468(12):3304-13.
26. Holt GE, Dennis DA. Use of custom triflanged acetabular components in revision total hip arthroplasty. Clin Orthop Relat Res 2004;429:209-214.

27. Jones L, Grammatopoulos G, Singer G. The Burch-Schneider cage: 9-year survival in Paprosky type 3 acetabular defects. Clinical and radiological follow-up. Hip Int. 2012;22(1):28-34.
28. Joshi AB, Lee J, Christensen C. Results for a custom acetabular component for acetabular deficiency. J Arthroplasty. 2002;15(2): 643-648
29. Kerboull M, Hamadouche M, Kerboull L. The Kerboull acetabular reinforcement device in major acetabular reconstructions. Clin Orthop Relat Res. 2000;(378):155-68.
30. Kim KC, Ha YC, Kang BJ. Use of cementless acetabular component with a hook and iliac flanges in revision arthroplasty for massive acetabular defect. J Orthop Sci. 2012;17(1):18-24.
31. Kosashvili Y, Backstein D, Safir O, Lakstein D, Gross AE. Acetabular revision using an anti-protrusion (ilio-ischial) cage and trabecular metal acetabular component for severe acetabular bone loss associated with pelvic discontinuity. J Bone Joint Surg Br. 2009;91(7):870-6.
32. Lingaraj K, Teo YH, Bergman N. Acetabular revision using an anti-protrusion (ilio-ischial) cage and trabecular metal acetabular component for severe acetabular bone loss associated with pelvic discontinuity. J Bone Joint Surg Br. 2009;91(12):1555-60.
33. Okano K, Miyata N, Enomoto H, Osaki M, Shindo H. Revision with impacted bone allografts and the Kerboull cross plate for massive bone defect of the acetabulum. J Arthroplasty. 2010;25(4):594-9.
34. Paprosky WG, O'Rourke M, Sporer SM. The treatment of acetabular bone defects with an associated pelvic discontinuity. Clin Orthop Relat Res. 2005;441:216-20.
35. Piriou P, Sagnet F, Norton MR, de Loubresse CG, Judet T. Acetabular component revision with frozen massive structural pelvic allograft: average 5-year follow-up. J Arthroplasty. 2003;18(5):562-9.
36. Regis D, Magnan B, Sandri A, Bartolozzi P. Long-term results of anti-protrusion cage and massive allografts for the management of periprosthetic acetabular bone loss. J Arthroplasty. 2008;23(6):826-32.
37. Regis D, Sandri A, Bonetti I, Bortolami O, Bartolozzi P. A minimum of 10-year follow-up of the Burch-Schneider cage and bulk allografts for the revision of pelvic discontinuity. J Arthroplasty. 2012;27(6):1057-63.e1.
38. Schelfaut S, Cool S, Mulier M. The use of structural periacetabular allografts in acetabular revision surgery: 2.5-5 years follow-up. Arch Orthop Trauma Surg. 2009;129(4):455-61.
39. Sporer SM, O'Rourke M, Chong P, Paprosky WG. The use of structural distal femoral allografts for acetabular reconstruction. Average ten-year follow-up. J Bone Joint Surg Am. 2005;87(4):760-5.
40. Sporer SM, Paprosky WG. The use of a trabecular metal acetabular component and trabecular metal augment for severe acetabular defects. J Arthroplasty. 2006;21(6 Suppl 2):83-6.
41. Sporer SM, Paprosky WG. Acetabular revision using a trabecular metal acetabular component for severe acetabular bone loss associated with a pelvic discontinuity. J Arthroplasty. 2006;21(6 Suppl 2):87-90.
42. Stiehl JB, Saluja R, Diener T. Reconstruction of major column defects and pelvic discontinuity in revision total hip arthroplasty. J Arthroplasty. 2000;15(7):849-57.
43. Taunton MJ, Fehring TK, Edwards P, et al. Pelvic discontinuity treated with custom triflange component: a reliable option. Clin Orthop Relat Res 2012;470:428-434.
44. Traina F, Giardina F, De Clerico M, Toni A. Structural allograft and primary press-fit cup for severe acetabular deficiency. A minimum 6-year follow-up study. Int Orthop. 2005 Jun;29(3):135-9.
45. Weeden SH, Schmidt RH. The use of tantalum porous metal implants for Paprosky 3A and 3B defects. J Arthroplasty. 2007;22(6 Suppl 2):151-5.
46. Wegrzyn J, Pibarot V, Jacquel A et al. Acetabular reconstruction using a Kerboull cross-plate, structural allograft and cemented dual-mobility cup in revision THA at a minimum 5-year follow-up. J Arthroplasty. 2014;29(2):432-7.
47. Weise K, Winter E. Revision arthroplasty--acetabular aspect: cementless acetabular bone reconstruction. Int Orthop. 2003;27 Suppl 1:S29-36.
48. Winter E, Piert M, Volkmann R et al. Allogeneic cancellous bone graft and a Burch-Schneider ring for acetabular reconstruction in revision hip arthroplasty. J Bone Joint Surg Am. 2001;83-A(6):862-7.
49. Howick J, Chalmers I, Glasziou P et al. Explanation of the 2011 Oxford Centre for Evidence-Based Medicine (OCEBM) Levels of Evidence (Background Document). Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653 Available from: http://www.cebm.net/ocebm-levels-of-evidence/ Accessed on February 28, 2016
50. Robert G. Marx, MD; Sean M. et al. Updating the Assignment of Levels of Evidence. J Bone Joint Surg Am, 2015: 97(1):1-2

III

A custom-made acetabular implant for Paprosky type 3 defects

Marieke Baauw
Gijs G. van Hellemondt
Maarten Spruit

Orthopedics 2017 Jan 1;40(1):e195-e198

Abstract

Acetabular revision is a challenging operation, especially when dealing with major bone loss and poor bone quality. This article describes a detailed approach to defect analysis, including measurement of bone deficiency and bone quality. A custom-made titanium implant, with precisely outlined flanges to the host bones of the ilium, ischium, and pubis, taking into account the bone quality for optimal screw purchase, was used to reconstruct the acetabular defect. Preliminary results for 12 patients who were retrospectively reviewed after a minimum follow-up of 18 months were promising.

Introduction

Acetabular revision becomes more challenging with increasing bone loss and decreasing bone quality. Current solutions for acetabular reconstruction of large Paprosky type 3 defects[1] include the use of bone impaction grafting, structural allograft, tantalum augments, ring and cage reconstruction, oblong cup reconstruction, cup-cage reconstruction, and triflange reconstruction.[2]

The authors present a technique to analyze the defect in detail and to reconstruct the acetabulum using a custom-made trabecular titanium implant (aMace Acetabular Revision System; Mobelife, Leuven, Belgium) that matches the anatomy of the bone-deficient acetabulum, taking into account the patient's bone quality to achieve primary implant stability.

Materials and methods

In 2011 and 2012, the authors used this technique to treat 12 consecutive patients. The authors included patients with failed acetabular reconstructions and bone defects to such an extent that the use of regular techniques for reconstruction of large defects (ie, bone impaction grafting, solid bone graft, and anti-protrusio cages) was precluded. The authors were always able to introduce the custom device in the series of 12 and never had to resort to standard techniques as an escape.

Patients were retrospectively reviewed after a minimum follow-up of 18 months (range, 18-39 months). All patients were asked to answer a questionnaire, which included the 12-item Oxford Hip Score[3] translated in Dutch and completed with extra questions described by Gosens et al,[4] the Hip Disability and Osteoarthritis Outcome Score– Physical Function Short Form (HOOS-PS),[5] the visual analog scale, and 2 core questions. The core questions were: (1) Would you recommend this procedure to a family member or friend? (2) How did your daily functioning change after the procedure? Complications were reviewed in the complication registration system. One patient was not available to complete the questionnaire. Incomplete parts of the questionnaire were excluded for review.

Pre- and postoperative scans of 8 patients were available for comparison of the planned and the postoperative center of rotation. The study had institutional review board approval and all patients gave informed consent.

Surgical Technique

First, patients had a computed tomography scan with a slice thickness between 1 and 2 mm of the complete pelvis. Special software was used to subtract all parts of the existing reconstruction to assess the ultimate bone defect (Figure 1). A descriptive Paprosky classification[1] was used to assess the deficient acetabular rim and the anterior and posterior columns.

The next step was to calculate the total radial acetabular bone loss. The total radial acetabular bone loss classification is a quantitative, computerized method to assess the degree of acetabular bone deficiency in the acetabulum. It is based on advanced 3-dimensional computed tomography–based image processing and effective 3-dimensional anatomical reconstruction methodology.[6] The output data consist of a ratio and a graph. Both can be used for direct comparison between specimens or acetabular sides. The ratio is a measure for the amount of original acetabular bone that is missing. The graph represents the remaining bony support in the radial direction (Figure 2). The software also allows an assessment of the bone quality with a color gradient from red (inferior) to green (excellent).

On the basis of this information, one porous augment and a cage were designed, as either a monoblock (Figure 3) or a modular construct, to restore the center of rotation and to compensate for the missing bone volume. The implant was fixated with exactly planned (crossed) screw trajectories and screw lengths through the cup and the precisely outlined flanges to the host bones of the ilium, ischium, and pubis, taking into account the bone quality for optimal screw purchase (Figure 4). Screws also provide fixation of modular constructs in a similar manner. During the entire process, the surgeon gave feedback on the defect classification, the design, and the implant orientation in the defect to optimize inclination, anteversion, and center of rotation of the construct.

Figure 1.
The ultimate acetabular bone defect.

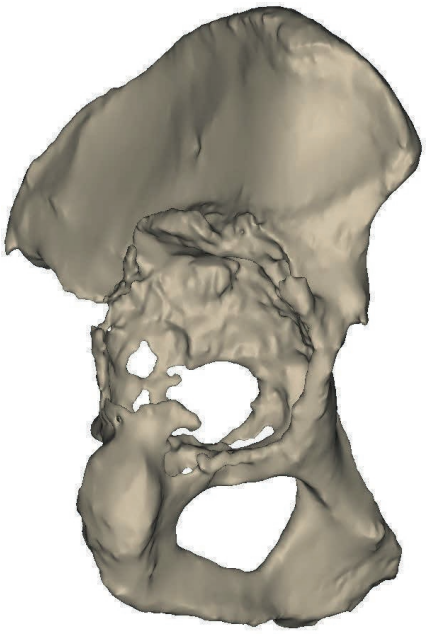


Figure 2.
Total radial acetabular bone loss graph and bone quality assessment with color gradient.

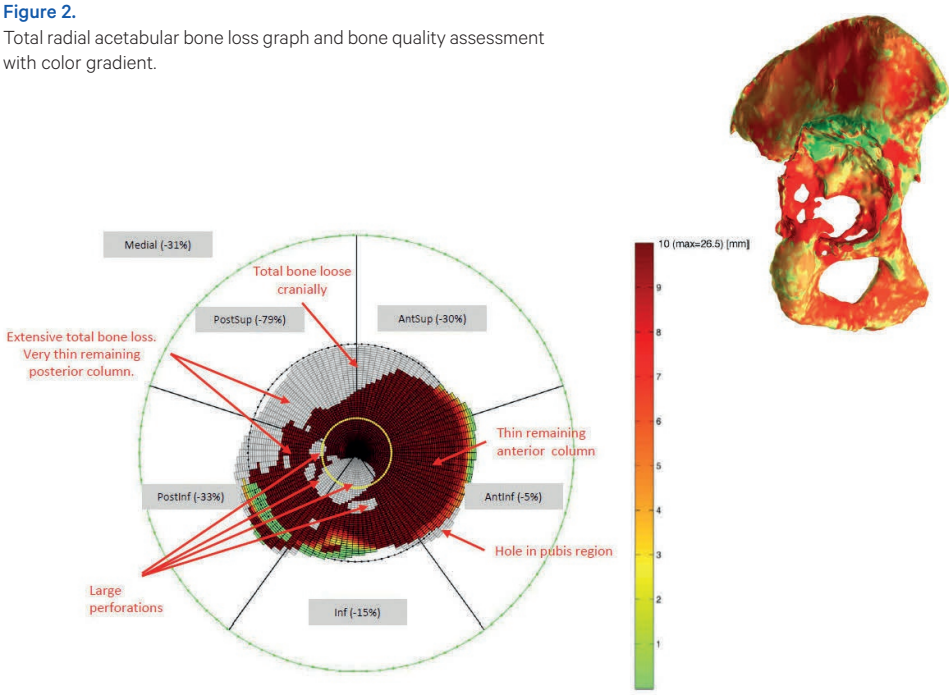
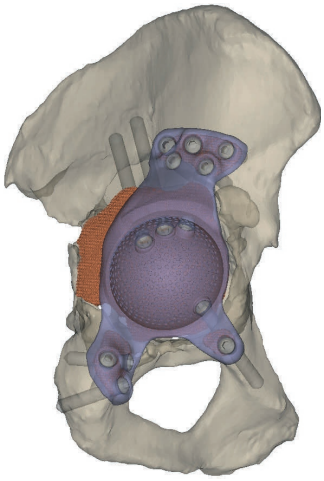


Figure 3.
Monoblock implant in an an anatomical plastic model of the hemipelvis.

Figure 4.
Complete monoblcok construct and planned screw trajectories.



During surgery, the surgeon was provided with an anatomical plastic model of the hemipelvis, trial implants in modular and monoblock fashion, and drill guides. The plastic model helps to identify the defect as assessed in the computed tomography scan analysis. Exposure was obtained using a posterolateral approach. Removal of a fixed femoral component is not mandatory. After release and careful tissue dissection, the entire acetabular defect was exposed, including the ilium, ischium, and pubic bone. Osteophytes may have to be removed according to preoperative planning. Morselized allograft bone may be used in cases of voids and cavitary defects between the host bone and the implant. It is used mostly in large medial defects to avoid filling these completely with titanium. Using the trial implants, the preplanned fit of the final implant to the acetabular defect was achieved (Figure 5).

Finally, the implant was introduced in the defect and fixed with the flange and cup screws using the drill guides. Intraoperatively, the length of all screws measured had to be compared with the planning. A dual mobility cup design was cemented into the custom-made implant to reduce dislocation risk (Figure 6).

Figure 5.
Total radial acetabular bone loss graph and bone quality assessment with color gradient.

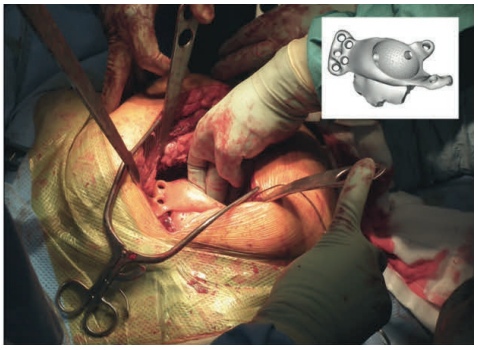
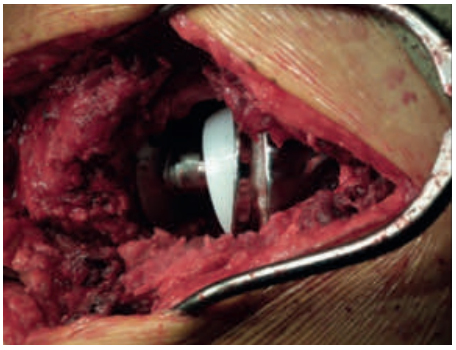


Figure 6.
Dual mobility cup cemented into the custom-made implant.



Results

The patients' data are provided in the Table. Four patients had complications. There were no infections and no additional surgery was needed.

All patients were satisfied with their custom-made implant. All patients, except for patient 4, would recommend the treatment to a family member or friend. Most patients thought their daily functioning was improved after the custom-made implant except for patients 2 and 4, who thought their functioning was slightly worsened. Additionally, those 2 patients did not have better mobility or less pain of the hip after the procedure. All of the other patients had better mobility and less pain except for patient 9, who had less pain but not better mobility of the hip.

Table.
Patient Data

Patient No./Sex/ Age, y	Follow-up, mo	Primariy Diagnosis	Revision Reason	Paprosky Type	No. of Revision	Stem Revision	Use of Bone Graft	Oxford Hip Score	HOOS-PS	VAS Score		Health[a]	Complications
										During Rest	During Activity		
1/M/66	39	OA	Aseptic loosening	3B	2nd	No	No	18	20.0	0	0	A[b]	
2/F/79	31	RA	Aseptic loosening	3B	3rf	No	Yes	46	82.4	3.3	8.0	C[c]	Stress fracture of the ramus inferior os pubis after 3 months, no additional treatment
3/F/33	30	RA	Aseptic loosening	3B	2nd	No	No	32	41.7	0	0.3	C	
4/F/51	29	CHD	Aseptic loosening	3A	1st	No	No	41	46.1	1.5	5.2	B[d]	Intraoperative anterior wall fracture, no additional fixation needed
5/F/65	25	RA	Aseptic loosening	3A	5th	Yes	No	31	41.7	0	2.6	C	
6/M/75	25	OA	Girdle stone	3A	4th	Yes	No	30	33.9	0	0	C	Hematoma after 4 weeks due to a high INR
7/F/75	21	CHD	Aseptic loosening	3B	1st	Yes	No	38	30.4	0	-	C	
8/F/65	21	AVN	Aseptic loosening	3B	2nd	No	Yes	15	4.6	0	0	A	
9/F/74	20	OA	Girdle stone	3B	2nd	Yes	Yes	28	-	0	0	A	
10/M/76	19	OA	Aseptic loosening	3B	2nd	Yes	No	27	-	0.2	3.1	C	
11/F/71	19	RA	Wear and osteolysis	3B	2nd	Ceclage	No	-	-	4.6	5.2	C	Discloation after 5 weeks treated with closed reduction and a brace. Partial femoral nerve palsy because of hematoma a few weeks postoperatively.
12/F/62	18	RA	Aseptic loosening	3A	1st	Yes	No	30	37.7	0	0	C	

Abbreviations: AVN, avascular necrosis of the femoral head; CHD, congenital hip dysplasia; F, female; HOOS-PS, Hip Disability and Osteoarthritis Outcome Score–Physical Function Short Form; INR, international normalized ratio; M, male; OA, osteoarthritis; RA, rheumatoid arthritis; VAS, visual analog scale.

[a] Patients were asked which situation suited them the best, [b] Unilateral hip problems, [c] Hip problems and health problems that influence daily functioning, [d] Bilateral hip problems.

[e] No stem revision but cerclage and tibia stut graft was used because of poor femoral bone.

Discussion

Custom-made implants for reconstruction of large acetabular defects are not new.[7-11] The current technique, however, has several features that can be considered unique compared with the custom designs reported in the literature. Detailed acetabular defect analysis is the gateway to a descriptive classification, measurement of total radial acetabular bone loss, and reconstruction options. Bone quality assessment predetermines crossed, not parallel, screw fixation options to obtain optimal fixation and primary implant stability. The final implant matches the patient's anatomy not only with the custom-made augment filling the acetabular defect perfectly but also with the precisely outlined flanges over the ilium, ischium, and pubic bone. Traditional augments and cages cannot accomplish this. Ultimately, the reconstruction restores the center of rotation. During the development process, the surgeon is providing feedback and the manufacturer can adapt to the surgeon's recommendations. Finally, several tools are available to assist the surgeon during the operation and to introduce the custom-made implant as accurately as possible according to planning.

Existing literature shows the difficulty of treating large defects with custom-made implants, with complication rates from 16% to 53%, re-revision rates from 11% to 35%, and component removal rates from 0% to 21.5%.[7-11] This case series showed satisfactory clinical results, especially considering that most patients were also inhibited in their daily functioning because of the contralateral hip or other health issues. There were no cases that needed revision surgery and all of the patients were satisfied with the results. The cases with the worst outcomes were understandably those that were complicated by fractures.

Conclusion

The authors have described an integral approach to treat large acetabular defects that require a revision strategy different from the more common options available. Preliminary results in this small series are promising. The authors will continue with this technique and its follow-up for large acetabular defects.

Disclosure

Dr Baauw has no relevant financial relationships to disclose. Dr van Hellemondt has received payment from Mobelife, Smith & Nephew, and Zimmer Biomet for presentations. Dr Spruit has received payment from Mobelife for presentations.

References

1. Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty: a 6-year follow-up evaluation. J Arthroplasty. 1994; 9(1):33-44.
2. Sheth NP, Nelson CL, Springer BD, Fehring TK, Paprosky WG. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. J Am Acad Orthop Surg. 2013; 21(3):128-139.
3. Dawson J, Fitzpatrick R, Carr A, Murray D. Questionnaire on the perceptions of patients about total hip replacement. J Bone Joint Surg Br. 1996; 78(2):185-190.
4. Gosens T, Hoefnagels NH, de Vet RC, et al. The "Oxford Heup Score": the translation and validation of a questionnaire into Dutch to evaluate the results of total hip arthroplasty. Acta Orthop. 2005; 76(2):204- 211.
5. Davis AM, Perruccio AV, Canizares M, et al. The development of a short measure of physical function for hip OA HOOS-Physical Function Shortform (HOOS-PS): an OARSI/OMERACT initiative. Osteoarthritis Cartilage. 2008; 16(5):551-559.
6. Gelaude F, Clijmans T, Delport J. Quantitative computerized assessment of the degree of acetabular bone deficiency: total radial acetabular bone loss (TrABL). Adv Orthop. 2011; 2011:494382.
7. DeBoer DK, Christie MJ, Brinson MF, Morrison JC. Revision total hip arthroplasty for pelvic discontinuity. J Bone Joint Surg Am. 2007; 89(4):835-840.
8. Holt GE, Dennis DA. Use of custom triflanged acetabular components in revision total hip arthroplasty. Clin Orthop Relat Res. 2004; 429:209-214.
9. Joshi AB, Lee J, Christensen C. Results for a custom acetabular component for acetabular deficiency. J Arthroplasty. 2002; 17(5):643-648.
10. Taunton MJ, Fehring TK, Edwards P, Bernasek T, Holt GE, Christie MJ. Pelvic discontinuity treated with custom triflange component: a reliable option. Clin Orthop Relat Res. 2012; 470(2):428-434.
11. Wind MA Jr, Swank ML, Sorger JI. Short-term results of a custom triflange acetabular component for massive acetabular bone loss in revision THA. Orthopedics. 2013; 36(3):e260- e265.

IV

The accuracy of positioning of a custom-made implant within a large acetabular defect at revision arthroplasty of the hip

Marieke Baauw
Gijs G. van Hellemondt
Miranda L. van Hooff
Maarten Spruit

The Bone and Joint Journal 2015 Jun;97-B(6):780-5

Abstract

We evaluated the accuracy with which a custom-made acetabular component could be positioned at revision arthroplasty of the hip in patients with a Paprosky type 3 acetabular defect.

A total of 16 patients with a Paprosky type 3 defect underwent revision surgery using a custom-made trabecular titanium implant. There were four men and 12 women with a median age of 67 years (48 to 79). The planned inclination (INCL), anteversion (AV), rotation and centre of rotation (COR) of the implant were compared with the post-operative position using CT scans.

A total of seven implants were malpositioned in one or more parameters: one with respect to INCL, three with respect to AV, four with respect to rotation and five with respect to the COR.

To the best of our knowledge, this is the first study in which CT data acquired for the preoperative planning of a custom-made revision acetabular implant have been compared with CT data on the post-operative position. The results are encouraging.

Introduction

With increasing numbers of total hip arthroplasties (THA)[1] being undertaken and a rate of revision after ten years of 12.9%,2 the burden of revision THA is expected to rise.

Revision of the acetabular component is especially challenging in patients with a large bony defect and poor quality bone. The Paprosky classification[3] is widely used to classify acetabular bone loss because of its comprehensive and practical nature. Type 3 defects are the most complex patterns of bone loss and are the most difficult to reconstruct. Several techniques are available and include the use of impaction grafting;[4] structural allograft; tantalum augments; anti-protrusio cages; oblong cups; cup-cage constructs and (custom-made) triflange rings.[5,6] Most of these techniques use implants of a specific size and shape and the patient's anatomy needs to be modified to achieve stable fixation.

In our clinic, we have used the aMace acetabular revision system (Mobelife, Leuven, Belgium), a custom-made trabecular titanium implant, in the treatment of these defects. This implant is designed from a detailed CT-based analysis of the defect with special reference to bone quality and the anatomy of the bone-deficient acetabulum. We describe a technique used to evaluate this implant at an early stage by comparing its final position with the position determined by pre-operative planning.

Materials and Methods

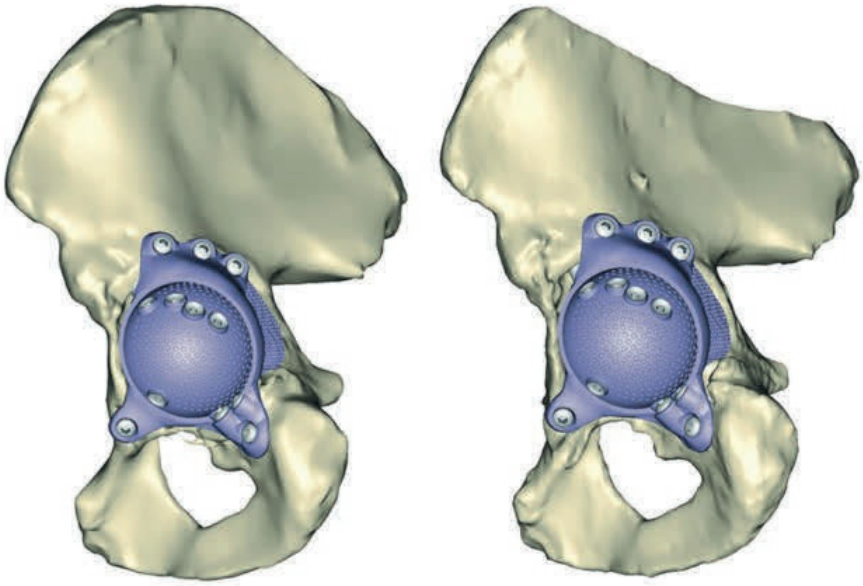
Between April 2011 and February 2014, the two senior authors (MS, GGH) used the custom-made aMace acetabular revision system to revise the acetabular component of 16 patients (16 hips) with a Paprosky type 3 defect, in whom other options, such as the use of impaction grafting or mesh, were not thought to be feasible. There were four men and 12 women with a median age of 67 years (48 to 79; interquartile range (IQR) first and third quartile, 60.75 to 73.75). Each patient had a routine post-operative CT scan while still an inpatient.

The study had ethical approval and all patients gave informed consent.

Each patient had a pre-operative CT scan of the whole pelvis to characterise their acetabular defect. The manufacturer of the implant (Mobelife, Leuven, Belgium) then used special software to subtract all parts of the existing reconstruction in order to assess the bone defect. The deficient acetabular rim, anterior column and posterior column were assessed from which the Paprosky type was determined. The total radial bone loss (TraBL) was then calculated. By using advanced threedimensional (3D) CT-based processing and 3D anatomical reconstruction, the degree of bone loss and the quality of the remaining acetabular bone could both be assessed.[7] This information was used to design a porous-coated augment and cage. These can either be made as a monobloc component or in two parts as a modular construct. The data can also be used to plan the length and trajectory of each screw, and the precise design of the flanges for the ilium, ischium and pubis, while taking into account the quality of the available bone so that the screws have optimal purchase. While planning the custom-made implant, the surgeon provides feedback on the classification of the defect and the design and orientation of the implant needed to achieve the optimal inclination (INCL) and anteversion (AV) of the component and to restore the centre of rotation (COR).

The posterolateral approach to the hip was used in each patient: the femoral component was not revised if well fixed and appropriately positioned. Patient-specific aids and instruments, such as a 3D plastic anatomical model of the hemipelvis, trial implants in modular and monobloc fashion and drill guides, were at the surgeons' disposal. The original implant, any broken hardware and, if necessary, osteophytes were removed as determined by the pre-operative planning. The planned fit of the implant was achieved using the trial implants. Allograft was used in patients with voids and for cavitary defects between host bone and implant. The implant was fixed with the cup and flange screws using the drill guides. Finally, an Avantage Dual Mobility cup (Biomet, Warsaw, Indiana) was cemented into the custom-made implant with the same anteversion and inclination as the implant itself. Post-operatively, patients were mobilised taking half their body weight on the operated leg for the first six weeks.

Figure 1.
Diagram showing A) the planned and B) the post-operative position of an accurately placed acetabular component (case 11).



A B

The post-operative position of the implant was compared with the pre-operative plan by Mobelife using the CT scans (Fig. 1). INCL, AV and COR were compared using a pelvic coordinate system (Fig. 2). The anterior superior iliac spines (ASIS) of the pre-operative 3D models of the pelvis were used to set the sagittal plane of the pelvic coordinate system in accordance with the standard laid down by the International Society of Biomechanics (ISB).[8] The z-axis of the scan and the ASIS line were used to determine the coronal plane. The transverse plane was a plane at right angles to the sagittal and coronal planes. In order to minimise the difference between the pre- and post-operative pelves, the post-operative models of the bones and implants were aligned to the coordinate system using the iterative closest point algorithm.[9] All other objects (implants, screws, femur) were aligned according to the same transformation. Rotation in the acetabular plane was determined clockwise, anticlockwise values being negative. The position of the COR was described in relation to the different orthogonal components: anteroposterior (AP), lateromedial (LM) and superoinferior (SI) (Fig. 3). Values were positive when deviating anteriorly, laterally or superiorly.

Figure 2.

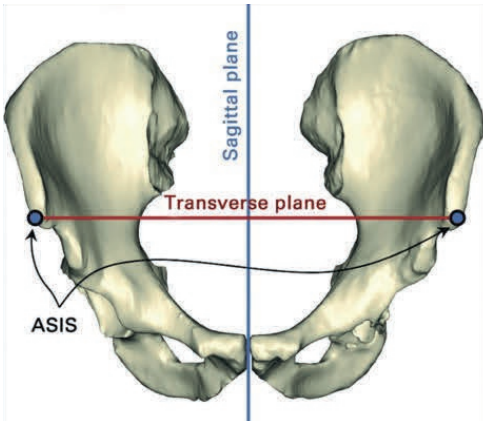


Diagram showing the pelvic coordinate used to compare the pre- and post-operative CT scans.

Figure 3.

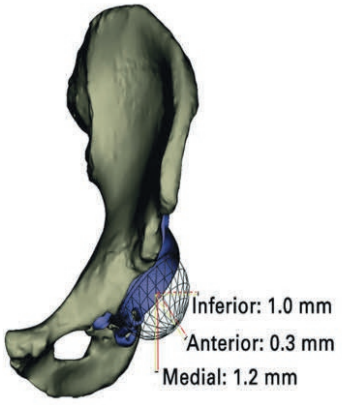


Diagram showing the position of the centre of rotation on the different orthogonal components: anteroposterior, lateromedial and superoinferior. Planned position (red) is compared with the post-operative position (yellow).

Lewinnek's safe zone[10] of 15° (standard deviation (SD) 10) of AV and 40° (SD 10) of INCL for orientation is often used for placement of the acetabular component.[11] This suggests that deviations > 10° in AV and/or INCL are clinically relevant. Consequently, this 10° value was considered the threshold for malpositioning of the implant. Rotational malpositioning was also set at > 10°, and a deviation of > 5 mm in the COR was seen as malpositioning. Due to a lack of consensus in the literature, these limits were determined on the basis of consensus between the authors.

The operation notes were reviewed for intra-operative complications, and complications within the first six weeks of surgery were recorded.

Statistical analysis

The data were determined as being non-parametric using the Kolmogorov–Smirnov test. Spearman's test was used to test for correlations between the CT measurement data (difference in INCL and AV, rotation and the COR deviation) and body mass index (BMI), modular or monobloc construct, number of revisions and the use of bone graft. Statistical analyses were performed using SPSS version 20 (IBM Corporation, Armonk, New York). We interpreted a correlation with r = 0.51 to 1.00 as strong.12 A p-value of < 0.05 was considered significant.

Table I.
Patient Characteristics

Case	Gender	Age (yrs)	BMI	Primary diagnosis	Reason for revision	P*	Rev†	Stem revision	Implant	Bone graft	T‡	Previous implant
1	Male	66	31	OA	Aseptic loosening	3B	2nd	No	Modular	No	55	Structural allograft + BIG with mesh + cemented cup
2	Female	79	26	RA	Aseptic loosening	3B	3rd	No	Modular	Yes	14	APC + bone graft + cemented dual mobility cup
3	Male	51	26	CHD	Aseptic loosening	3A	1st	No	Monobloc	No	71	Structural allograft+cemented cup
4	Female	75	30	CHD	Aseptic loosening	3B	1st	Yes	Monobloc	No	282	Cemented cup in neo acetabulum/ high hip centre
5	Female	65	29	AVN	Aseptic loosening	3B	2nd	No	Monobloc	Yes	13	BIG+cemented cup
6	Female	74	25	OA	Girdle stone	3B	2nd	Yes	Modular	Yes	192	BIG + cemented cup
7	Male	76	26	OA	Aseptic loosening	3B	2nd	Yes	Monobloc	No	180	Girdlestone
8	Female	71	27	RA	Wear and osteolysis	3B	2nd	No	Monobloc	No	8	APC + bone graft + cemented cup
9	Female	68	33	OA	Recurrent dislocation	3B	2nd	Yes	Monobloc	No	10	Uncemented cup
10	Female	48	29	AVN	Aseptic loosening	3B	2nd	No	Monobloc	No	13	Uncemented jumbo cup
11	Male	59	25	RA	Aseptic loosening	3B	2nd	Cerclage§	Monobloc	Yes	22	APC + bone graft + cemented dual mobility cup
12	Female	71	24	RA	Aseptic loosening	3B	2nd	No	Monobloc	Yes	75	BIG + mesh + cemented cup
13	Female	60	25	OA	Aseptic loosening	3B	2nd	No	Monobloc	No	13	BIG + mesh + cemented cup
14	Female	65	31	OA	Aseptic loosening	3B	3rd	No	Monobloc	No	14	BIG + mesh + cemented cup
15	Female	63	24	OA	Aseptic loosening	3B	3rd	No	Monobloc	Yes	79	BIG + mesh + APC + dual mobility cup
16	Female	73	22	OA	Aseptic loosening	3B	3rd	No	Monobloc	Yes	23	BIG + mesh + cemented cup

*P, Paprosky classification
†Rev, number of revisions
‡T, time from previous surgery in months
§No stem revision but cerclage and tibial strut graft was used because of poor femoral bone
BMI, body mass index; OA, osteoarthritis; BIG, bone impaction grafting; RA, rheumatoid arthritits; APC, anti-protrusio cage; CHD, congenital hip dysplasia; AVN, avascular necrosis of the femoral head

Results

The characteristics of the patients are shown in Table I. Their median age was 67 years (IQR 60.75 to 73.75) and their median BMI 26 kg/m2 (IQR 25 to 29.75).

The planned median INCL was 44° (IQR 40.5 to 45), INCL post-operative was 47° (IQR 45 to 48) with a median difference between planned and post-operative of 2° (IQR 1 to 3.75). The AV had a median of 16.5° (IQR 15 to 19) planned and of 11° (IQR 6.75 to 21) post-operative with a median difference of 5° (IQR 2.25 to 7.75). One patient (case 3) (Fig. 4) was malpositioned with respect to INCL, 3 patients (cases 7, 8 and 12) with respect to AV (Table II).

Table II.

Inclination (INCL) and anteversion (AV) differences. Differences ≥ 10° between planned and post-operative (Post-op) positions are marked in bold

Case number	INCL (°) Planned	Post-op	Δ*	AV (°) Planned	Post-op	Δ*	Δ* Screws
1	46	48	2	17	9	8	2
2	45	48	3	16	11	5	1
3	**40**	**57**	**17**	6	6	0	0
4	46	45	1	18	21	3	0
5	44	47	3	15	9	6	0
6	46	47	1	13	11	2	1
7	45	47	2	**16**	**0**	**16**	0
8	43	47	4	**16**	**5**	**11**	4
9	44	45	1	14	10	4	1
10	44	45	1	20	15	5	1
11	44	46	2	15	16	1	0
12	40	43	3	**18**	**3**	**15**	3
13	42	49	7	28	21	7	2
14	40	39	1	19	24	5	1
15	40	42	2	19	22	3	1
16	42	48	6	22	23	1	2

*Δ, delta: difference

The median number of screws planned was 14 (IQR 12 to 15), post-operative 12 (IQR 11.25 to 13.75) and the median difference was 1 (IQR 0 to 2). In four cases with a difference of two screws or more still at least 12 screws were placed (Table II).

The median deviation of rotation was 4° (IQR 1.975 to 9.9). In four patients there was a difference in rotation > 10°. The median deviation of the COR was 1.4 mm (IQR 0.325 to 1.8) in the AP plane, 1.3 mm (IQR 0.8 to 2.475) in the LM plane and 2.4 mm (IQR 0.775 to 4.475) in the SI plane. Six patients had a deviation in the COR > 5 mm in one of the three planes (Table III).

The main outliers were cases 3, 8 and 12. Case 3 was malpositioned for INCL, rotation and COR. Cases 8 and 12 were malpositioned for AV, rotation and COR.

No strong correlation was found between the CT measurement data and BMI, modular or monobloc construction, number of revisions and the use of bone graft (see supplementary material).

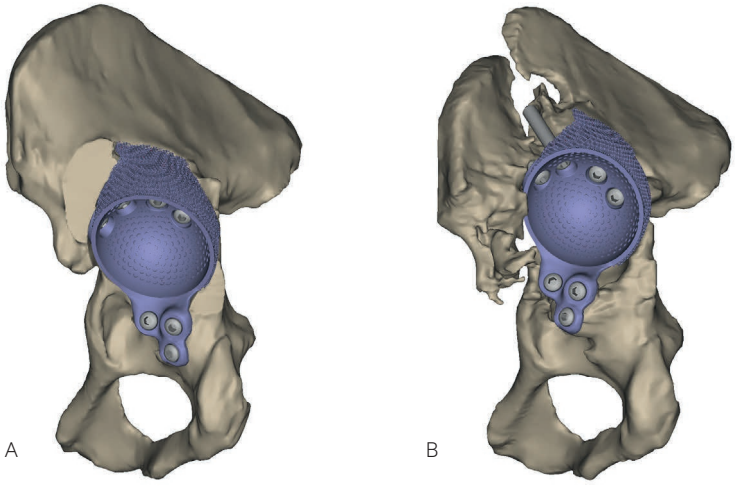
Table III.
Rotation and centre of rotation (COR) differences

			COR (mm)		
Case number	**Treatment side**	**Rotation Clockwise**	**AP**	**LM**	**SI**
1	Right	-4.0	–1.3	4.2	0.4
2	Left	2.8	1.1	1.2	0
3	Left	**13.6**	1.4	1.6	**17.9**
4	Left	4.0	1.3	–0.3	0.7
5	Left	3.0	–1.4	2.5	2.9
6	Right	-2.9	1.8	2.4	3.1
7	Left	8.2	**–7.5**	0.8	4.1
8	Left	**22.4**	1.8	**5.0**	4.6
9	Left	0.9	–1.4	–0.5	2.0
10	Right	-4.3	–2.0	–0.8	**5.1**
11	Left	1.7	0.3	–1.3	–1.0
12	Left	**11.4**	**–5.0**	0.3	2.8
13	Right	**-10.3**	0.0	1.3	1.6
14	Left	0.5	0.0	–0.8	0.1
15	Right	-0.5	–0.1	3.5	**5.5**
16	Right	-8.7	0.4	1.9	1.7

Rotation differences ≥ 10° and differences in the centre of rotation (COR) ≥ 5 mm between planned and post-operative positions are marked in bold
AP, anteroposterior; LM, lateromedial ; SI, superoinferior

One patient had an intra-operative complication, a fracture of the anterior wall of the acetabulum which did not require additional fixation (Fig. 4) (case 3). Within the first six weeks there were two dislocations; both were treated successfully by closed reduction and a brace (cases 8 and 11). One patient (case 14) required debridement of the wound one week post-operatively for persistent wound leakage; cultures were negative.

Figure 4.
Diagram showing a) the planned and b) the post-operative position of an implant (case 3) which is malpositioned with respect to inclination, rotation and centre of rotation. An acetabular fracture was induced intra-operatively.



Discussion

This study highlights the difficulty of positioning a custommade implant accurately in patients with a large acetabular defect. Despite the fact that most patients had already undergone a failed revision procedure which involved the use of other adjuncts such as an anti-protrusio cage, impaction grafting or mesh, we were usually able to implant the trabecular titanium cup accurately, but problems did occur despite extensive pre-operative planning. The difference between the planned and the post-operative INCL can be readily explained in the patient who had an intra-operative fracture, as poor bone quality and fragile osteolytic defects contribute to the risk of an acetabular fracture.[13]

There was no clear explanation for the two other malpositioned implants, and no doubts were expressed about their position in the operation notes. This is not surprising, as intra-operative assessment of the anteversion and abduction of an acetabular component is often inaccurate.[14] Only 64.5% of 200 components were placed within 5° of the estimated INCL, and 61% for AV. The same study showed that only 70.5% of acetabular components which were introduced freehand were within 10° of their intended position for INCL and AV.14 A study by Saxler et al[15] showed worse results, with only 27 of 105 components within the safe zone of Lewinnek for both INCL and AV. A study by Barrack et al[16] found 1363 (88%) of 1549 components within the planned INCL and AV, but this study used wider planned ranges of 30° to 55° for INCL and 5° to 25° for AV. Others have found satisfactory alignment of acetabular components at primary THA performed with the patient supine which is a difficult position for revision THA.[17]

Choi et al[18] reported that freehand positioning of the acetabular component can be inaccurate at revision THA in patients with Paprosky type 3 defects: in their series only 19 of 34 components (56%) were positioned within the safe zone of Lewinnek. However, they used different methods of reconstruction in their study.18 In our study, only three of 16 patients did not meet the parameters of Lewinnek's safe zone. The safe zone, as such, was not the main goal, because normal acetabular anatomy should not be expected, nor should it be assumed that the average position of the acetabular component is ideal for every patient[11] and Goudie et al[19] found natural acetabular orientation in arthritic hips outside of the safe zone of Lewinnek in up to 75% of hips. This is especially true in revision surgery for large acetabular defects. In four patients the target of staying within 10° of the planned INCL and AV was not met. Our results are at least comparable with those in the aforementioned studies.[14-18]

We used patient-specific instrumentation to introduce the implant as closely as possible to the position suggested by pre-operative planning. Few studies have measured the accuracy of placement of the acetabular component using such instruments. Two studies of primary THA showed mean differences between planned and post-operative INCLs of 1.96 ° and 2.8°, and of 0.22° and 3.7°for AV.20,21 These values seem slightly better than our median differences of 2°(1° to 17°) for INCL and 5° (0° to 16°) for AV but they are for patients who underwent primary, rather than revision, THA. Other studies using custom-made acetabular implants for large defects in revision THA did not study the INCL, AV, rotation and restoration of the COR of the implant.[22-26]

There are few reports about differences in the COR. Measurements of the COR are often performed in different planes on conventional radiographs. We used a CT pelvic coordinate system based on the ISB standard. In one study in which patient-specific instrumentation was used on a hemipelvis, the authors reported a mean difference of the COR in the AP plane of 1.9 mm (0.1 to 3.1), in the LM plane of 1.2 mm (0 to 4.3) and in the SI of 1.6 mm (0 to 3.9).[27] These results are similar to those in our study. However, ours was an in vivo study involving patients with large acetabular defects.

There is no clear evidence in the literature as to which differences in COR are clinically relevant. Some studies claim that small differences of 1 mm to 2 mm increase wear, the load on the hip, and the risk of aseptic loosening and subsequent revision.[28-30] Other studies have found no influence of the COR on wear[31] and good outcomes in patients with a high COR.[32] If the COR does influence these factors, it is mostly because of displacement in the LM plane.[29,30,33] This suggests that in our study only one outlier of 5 mm in the LM plane might be clinically relevant, which appears to have been confirmed as the hip dislocated.

Although we did not find any strong correlation between CT measurement data and specific patient characteristics, we do realise that interpretation is difficult because of the small number of patients. BMI has been found to be a risk factor for malpositioning of the acetabular component,[34] but we found no strong correlation between BMI and the CT measurement data. The use of bone graft was not strongly correlated with malpositioning. The use of bone graft is based on the intra-operative observation of remaining voids or cavitary defects and is not part of pre-operative planning. The type of construct, either monobloc or modular, did not correlate with malpositioning. However, once again interpretation of this finding is difficult, as a modular construct was only used in three patients. Finally, the number of previous revisions had no strong correlation with malpositioning, which might be explained by the fact that a large acetabular defect is not related to the number of revisions. Because of high variation in the primary diagnosis and small variations in the type of Paprosky defect, we did not calculate the correlation with those parameters.

There were few complications compared with most studies which address custom-made acetabular implants.[22-26] One of the two dislocations can probably be explained because it was malpositioned. The other implant that dislocated, however, was perfectly positioned. Further clinical and radiological follow-up is needed to assess the consequences of malpositioning and to further evaluate this new custom-made implant. We report encouraging early results with custom-made implants when used in the reconstruction of Paprosky type 3 acetabular defects.

Disclosure

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

Supplementary material

Correlations between CT measurement data and BMI, modular or monobloc construction, number of revisions and the use of bone graft

					Rotation	COR (mm)		
		INCL(°)	AV(°)	Screws	clockwise (°)	AP	LM	SI
BMI	Corr[§]	-0.6	0.1	-0.3	-0.3	0.3	-0.2	-0.2
	P-value	0.0	0.6	0.2	0.3	0.3	0.4	0.5
Rev[*]	Corr[§]	-0.2	-0.1	0.3	-0.4	-0.5	-0.1	-0.4
	P-value	0.5	0.7	0.2	0.1	0.0	0.8	0.1
Implant[†]	Corr[§]	-0.2	-0.4	-0.4	-0.1	0.0	-0.4	0.3
	P-value	0.4	0.2	0.1	0.6	0.9	0.1	0.3
Bonegraft[*]	Corr[§]	-0.3	0.2	-0.2	0.0	0.5	-0.2	0.2
	P-value	0.2	0.4	0.6	1.0	0.0	0.5	0.4

[*] Rev, number of revisions
[†] Type of implant used; monoblock or modular
[*] Bonegraft used; yes or no
[§] CORR, correlation: using Spearman's test
BMI, body mass index; AP, anteroposterior; LM, lateromedial; SI, superoinferio

References

1. No authors listed. Hip and knee replacement. In Health at a Glance 2013: OECD Indicators. Paris: OECD Publishing, 2013:96–97.
2. Labek G, Thaler M, Janda W, Agreiter M, Stöckl B. Revision rates after total joint replacement: cumulative results from worldwide joint register datasets. J Bone Joint Surg [Br] 2011;93-B:293–297.
3. Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplasty 1994;9:33–44.
4. Gilbody J, Taylor C, Bartlett GE, et al. 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:188–194.
5. Sheth NP, Nelson CL, Springer BD, Fehring TK, Paprosky WG. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. J Am Acad Orthop Surg 2013;21:128–139.
6. Abolghasemian M, Sadeghi Naini M, Tangsataporn S, et al. Reconstruction of massive uncontained acetabular defects using allograft with cage or ring reinforcement: an assessment of the graft's ability to restore bone stock and its impact on the outcome of re-revision. Bone Joint J 2014;96-B:319–324.
7. Gelaude F, Clijmans T, Delport J. Quantitative computerized assessment of the degree of acetabular bone loss (TrABL). Adv Orthop 2011494382.
8. Wu G, Siegler S, Allard P, et al. Standardization and Terminology Committee of the International Society of Biomechanics. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion--part I: ankle, hip, and spine: International Society of Biomechanics. J Biomech 2002;35:543– 548.
9. Besl JB, McKay ND. A method for registration of 3-D shapes. IEEE Trans Pattern Anal Mach Intell 1992;14:239–255.
10. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg [Am] 1978;60-A:217–220.
11. Moskal JT, Capps SG. Improving the accuracy of acetabular component orientation: avoiding malposition. J Am Acad Orthop Surg 2010;18:286–296.
12. Cohen J. A power primer. Psychol Bull 1992;112:155–159.
13. Davidson D, Pike J, Garbuz D, Duncan CP, Masri BA. Intraoperative periprosthetic fractures during total hip arthroplasty. Evaluation and management. J Bone Joint Surg [Am] 2008;90-A:2000–2012.
14. Bosker BH, Verheyen CC, Horstmann WG, Tulp NJ. Poor accuracy of freehand cup positioning during total hip arthroplasty. Arch Orthop Trauma Surg 2007;127:375– 379.
15. Saxler G, Marx A, Vandevelde D, et al. The accuracy of free-hand cup positioning--a CT based measurement of cup placement in 105 total hip arthroplasties. Int Orthop 2004;28:198–201.
16. Barrack RL, Krempec JA, Clohisy JC, et al. Accuracy of acetabular component position in hip arthroplasty. J Bone Joint Surg [Am] 2013;95-A:1760–1768.
17. Eilander W, Harris SJ, Henkus HE, Cobb JP, Hogervorst T. Functional acetabular component position with supine total hip replacement. Bone Joint J 2013;95- B:1326–1331.
18. Choi HR, Anderson D, Foster S, et al. Acetabular cup positioning in revision total hip arthroplasty with Paprosky type III acetabular defects: martell radiographic analysis. Int Orthop 2013;37:1905–1910.
19. Goudie ST, Deakin AH, Deep K. Natural acetabular orientation in arthritic hips. Bone Joint Res 2015;4:6–10.
20. Hananouchi T, Saito M, Koyama T, et al. Tailor-made surgical guide based on rapid prototyping technique for cup insertion in total hip arthroplasty. Int J Med Robot 2009;5:164–169.
21. Small T, Krebs V, Molloy R, et al. Comparison of acetabular shell position using patient specific instruments vs. standard surgical instruments: a randomized clinical trial. J Arthroplasty 2014;29:1030–1037.
22. Wind MA Jr, Swank ML, Sorger JI. Short-term results of a custom triflange acetabular component for massive acetabular bone loss in revision THA. Orthopedics 2013;36:260–265.
23. Taunton MJ, Fehring TK, Edwards P, et al. Pelvic discontinuity treated with custom triflange component: a reliable option. Clin Orthop Relat Res 2012;470:428–434.

24. DeBoer DK, Christie MJ, Brinson MF, Morrison JC. Revision total hip arthroplasty for pelvic discontinuity. J Bone Joint Surg [Am] 2007;89-A:835–840.

25. Holt GE, Dennis DA. Use of custom triflanged acetabular components in revision total hip arthroplasty. Clin Orthop Relat Res 2004;429:209–214.

26. Joshi AB, Lee J, Christensen C. Results for a custom acetabular component for acetabular deficiency. J Arthroplasty 2002;17:643–648.

27. Buller L, Smith T, Bryan J, et al. The use of patient-specific instrumentation improves the accuracy of acetabular component placement. J Arthroplasty 2013;28:631–636.

28. Karachalios T, Hartofilakidis G, Zacharakis N, Tsekoura M. A 12- to 18-year radiographic follow-up study of Charnley low-friction arthroplasty. The role of the center of rotation. Clin Orthop Relat Res 1993;296:140–147.

29. Bicanic G, Delimar D, Delimar M, Pecina M. Influence of the acetabular cup position on hip load during arthroplasty in hip dysplasia. Int Orthop 2009;33:397–402.

30. Baghdadi YM, Larson AN, Sierra RJ. Restoration of the hip center during THA performed for protrusio acetabuli is associated with better implant survival. Clin Orthop Relat Res 2013;471:3251–3259.

31. Wan Z, Boutary M, Dorr LD. The influence of acetabular component position on wear in total hip arthroplasty. J Arthroplasty 2008;23:51–56.

32. Hendricks KJ, Harris WH. High placement of noncemented acetabular components in revision total hip arthroplasty. A concise follow-up, at a minimum of fifteen years, of a previous report. J Bone Joint Surg [Am] 2006;88-A:2231–2236.

33. Doehring TC, Rubash HE, Shelley FJ, et al. Effect of superior and superolateral relocations of the hip center on hip joint forces. An experimental and analytical analysis. J Arthroplasty 1996;11:693–703.

34. Callanan MC, Jarrett B, Bragdon CR, et al. The John Charnley Award: risk factors for cup malpositioning: quality improvement through a joint registry at a tertiary hospital. Clin Orthop Relat Res 2011;469:319–329.

V

Patient matched implants in multiple revised large acetabular defects: good surgical reproducibility and low complication rate

Marieke Baauw
Miranda L. van Hooff
Gijs G. van Hellemondt
Paul C. Jutte
Sjoerd K. Bulstra
Maarten Spruit

Nederlands Tijdschrift voor Orthopaedie December 2020,
27e jaargang, nr. 4

Abstract

Background
The purpose of this study was to assess surgical accuracy and document complications in order to re-evaluate our previous results of a custom-made implant in multiple revised large acetabular defects.

Methods
A new, second, case series of 16 patients was compared to our previous series of 16 patients for surgical accuracy and complication rate. Surgical accuracy was evaluated by using computer tomography (CT)-scans to compare planned and postoperative inclination (INCL), anteversion (AV), rotation of the implant (RO) and the centre of rotation (COR). The medical records were reviewed for intra-operative complications, and complications within the first six weeks after surgery.

Results
The second series had a significant higher number of previous revisions and a higher planned and postoperative AV. Despite a more difficult caseload there was a trend to better surgical accuracy and less complications. In the second series no implants were malpositioned for AV and no dislocations occurred versus two dislocations in the first series.

Conclusion
Good surgical reproducibility and even a trend towards better surgical accuracy and less complications were found over time despite a higher complexity of cases. The improved surgical accuracy for AV in combination with a higher planned AV might be relevant to reduce dislocation, the most common complication in revision hip surgery.

Introduction

Generally multiple revised hips present with extensive acetabular bone loss, which is the main difficulty for the surgeon to address. Typically, it concerns Paprosky type 3 defects with severe bone loss and frequently a pelvic discontinuity.[1] Underestimation of the bone loss may lead to treatment with unsuitable implants and consequently to a high failure rate. With each revision not only the amount of bone loss may increase but also the quality of the remaining host bone stock may decrease.[2] Various reconstruction techniques for these large acetabular defects have been reported with inconsistent results. Most techniques use of the shelve products such as trabecular metal augments and buttress, jumbo cups and cup cage constructs for discontinuity cases. [3,4]

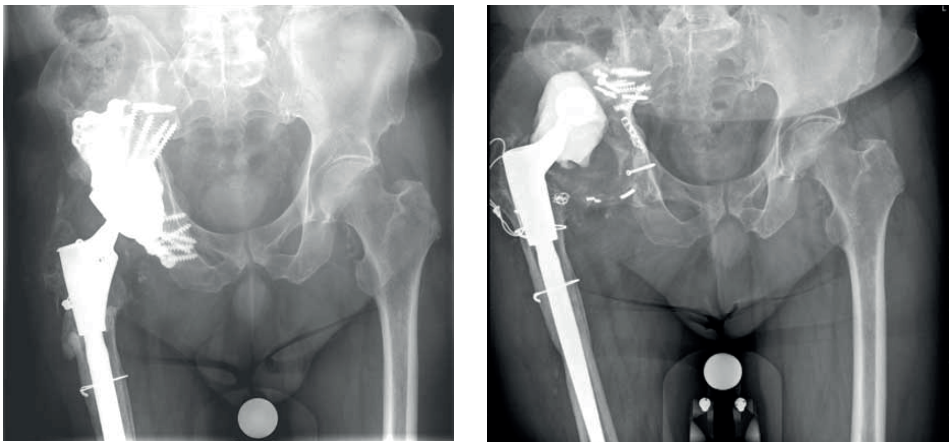
For large defects in multiple revised cases a custom-made 3-dimensional (3D) printed implant may be a viable alternative.[5] Dislocation is a complication that is often described for these devices in hip re-revision surgery, with rates ranging from 4% to 30%. [6-14] Although dislocation is a multi factorial problem it is also influenced by cup placement as in anteversion and inclination angle[15-17], which remains a challenge with custom-made designs.

Previously we have evaluated the surgical accuracy of placing a new custom-made implant (Materialise, Leuven, Belgium) in Paprosky type 3 defects, which takes into account the bone deficiency and bone quality of the defect. These results were encouraging especially considering the complexity of the acetabular defects treated and the lack of viable alternatives. [18] Over time the complexity of cases has been increasing in our practice. This, in combination with our previous encouraging results, led to the purpose of this study: to assess surgical accuracy and document complications to evaluate our results in a more difficult caseload.

Material and methods

Between April 2011 and March 2016 32 patients were included; a previously published case series of 16 patients[18] (first series) and a next case series of 16 patients (second series). These patients underwent acetabular revision surgery with the custom-made aMace acetabular revision system (Materialise, Leuven, Belgium). Indications for the use of this custom-made implant were Paprosky type 3 acetabular defects in which other surgical options were not considered feasible. (Fig. 1)

Figure 1.
AP pelvic X-rays demonstrating A) the preoperative situation of a failed acetabular component and B) the postoperative situation with the well-fixed custom-made implant at the follow-up after 2.5 years (case 21).



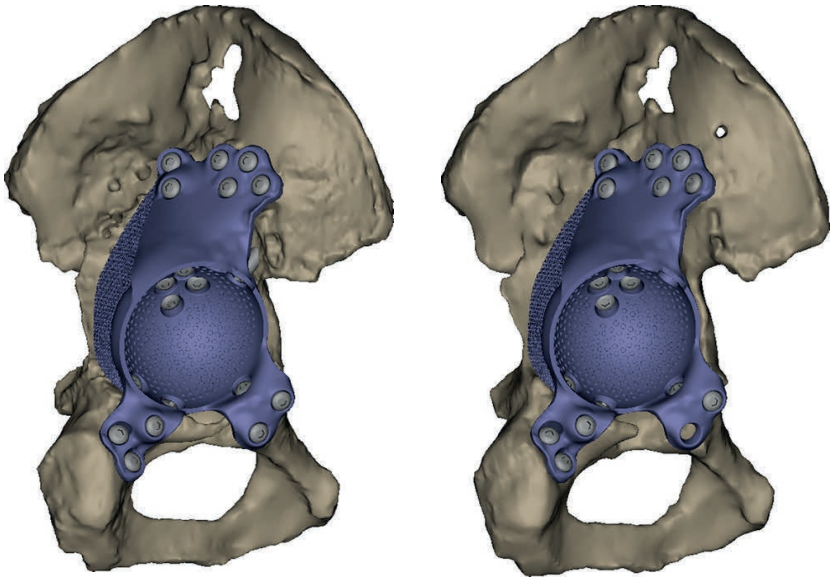
A B

Patients were included if they underwent surgery by two of the senior authors (MS, GGH) and if they had had a routine post-operative computer tomography (CT) scan while still admitted. The study had approval of the internal review board, all patients gave informed consent and to report the study we followed the CARE guidelines for case series.[19]

All patients received a pre-operative CT scan of the pelvis to evaluate the acetabular defect. Based on a complete defect analysis[20] a proposal for a 3D-printed custom reconstruction was presented by the manufacturer of the implant. The final implant geometry was determined with specific surgeon input enabling reconstruction of the acetabulum with optimal inclination (INCL), anteversion (AV) and centre of rotation (COR). In all patients the surgical approach was posterolateral and the surgeons had 3D printed patient-specific drill guides and a printed true scale hemipelvis at their disposal during the surgery. In the custom-made implant a dual mobility cup (Avantage Biomet, Warsaw, Indiana or Saturne, Ortotech, Denmark) was cemented with the same INCL and AV as the implant itself. In case of absent hip abductor muscles a constraint cup was available. Post-operatively, patients were allowed 50% weight bearing with two crutches for the first six weeks.

To determine the accuracy of the placement of the implant, the position of the implant after surgery was compared to the preoperative planning using the pre- and postoperative CT-scans. (Fig. 2) INCL, AV, rotation (RO) (in degrees) and the COR (in mm) were compared by an engineer in a similar fashion as previously described for the first 16 patients.[18] RO was determined clockwise, anticlockwise values being negative. The position of the COR was decomposed into three different orthogonal components: anteroposterior (AP), lateromedial (LM) and superoinferior (SI). Values were positive when deviating anteriorly, laterally or superiorly. The RO was corrected in all 32 patients due to the fact that in the previously published study a dependency of the RO with the INCL and AV was shown. Before measuring RO, the difference between the planned and the post-operative AV-INCL was neutralized by translating the postoperative COR to the planned COR and by rotating the post-operative acetabular plane to the planned acetabular plane.

Figure 2.
Diagram showing A) the planned and B) the post-operative position of an accurately placed acetabular component (case 21).



A B

The threshold for malpositioning of the implant in an individual CT measurement was a deviation of > 10° in AV, INCL and RO or as a deviation of > 5mm in one of the orthogonal components of the COR. Overall malpositioning of the implant was defined as a malpositioning in any one of these individual values. These thresholds were chosen in correspondence with our previous research[18], which were based on the Lewinnek's safe zone of 15°(standard deviation (SD) 10) of AV and 40° (SD 10) of INCL.[21] Medical records were reviewed for intra-operative complications and complications within the first six weeks after surgery.

The second series was compared to the first series. The primary outcome was overall malpositioning of the implant. Secondary outcomes were malpositioning in the individual CT measurement results (a deviation of > 10° in AV, INCL and RO or as a deviation of > 5mm in one of the orthogonal components of the COR), the number of complications (intra-operative and within the first six weeks postoperatively) and the differences in the CT measurement results (differences between planned and postoperative AV, INCL, RO and COR deviation).

The Shapiro-Wilk test was used to test the normality of the data. Descriptive statistics was used to evaluate patient characteristics and the position of the implant on a series level. As the data were not normally distributed, for continuous parameters median (interquartile ranges) were used and for categorical parameters, numbers. Differences between patient characteristics, assessed at the baseline, were determined with the two-sided non-parametric Mann-Whitney U test for continuous variables (age and BMI) and the Fisher's exact test for categorical variables (gender, number of revisions, primary diagnosis, stem revision and the use of allograft).

The comparison between both series for the number of malpositioned implants, the number of complications and the malpositioning in the individual CT measurement results was done using the two-sided Fisher's exact test. The Mann-Whitney U test was used to determine the differences of the CT measurement results (differences between planned and postoperative AV, INCL, RO and COR deviation) between both series. A p-value of <0.05 was considered statistically significant. Statistical analyses were performed using SPSS version 20 (IBM Corporation, Armonk, New York).

Results

The characteristics of the new second series of 16 patients are shown in Table 1. Except for the number of previous revisions (two versus three, $p<0.01$) all patient characteristics were similar in both series. The planned and postoperative AV was significantly different between both series. (Table 2)

When comparing both series, with respect to the number of implants that were malpositioned in one or more parameters (six versus five), this appeared not to be significantly different ($p=1.00$).

The differences in planned and postoperative CT measurement results (AV, INCL, RO and COR deviation) did not appear significantly different between both series. (Table 2)

A total of eight parameters were outside the threshold in the second series compared to 11 in the first series. With respect to INCL, two implants were malpositioned (one implant in the first series). None of the implants were malpositioned with respect to AV (Table 3) versus two implants in the first series. One implant had a difference in rotation of > 10° in this series, three in the first series. In total five measurements, in four patients, deviated > 5mm in one of the three planes of the COR compared to four measurements in four patients in the first series. (Table 4) All of these values appeared not significantly different between the two series.

No intraoperative complications occurred. One patient was found to have insufficient hip abductor muscles intraoperative, for which a constrained liner was cemented in the custom-made implant (case 24). Three postoperative complications in three patients were documented. All were delayed wound healing and did not need surgical debridement (cases 23, 25 and 27). The number of complications (four versus three) did not differ significantly between both series ($p=0.69$). In the first series two dislocations occurred, compared to none in the second series.

Table 1.
Patients characteristics

Case	Gender	Age (yrs)	BMI	Primary diagnosis	Reason for revision	P*	Rev*	Stem revision	Implant	Bone graft	T*	Previous implant
17	Female	60	33	CHD	Aseptic loosening	3B	5th	No	Monobloc	Yes	11	BIG + mesh + plate + cemented cup
18	Male	76	29	OA	Aseptic loosening	3B	3rd	No	Monobloc	Yes	26	BIG + cemented cup
19	Female	64	28	CHD	Aseptic loosening	3B	1st	No	Monobloc	Yes	392	Cemented cup
20	Female	69	27	OA	Aseptic loosening	3B	1st	No	Monobloc	No	179	RR + cemented cup
21	Male	68	30	PT OA	Aseptic loosening	3B	9th	Yes	Monobloc	Yes	15	Girdlestone
22	Male	59	26	OA	Aseptic loosening	3B	4th	No	Monobloc	Yes	11	TM augment + BIG + APC + cemented cup
23	Female	71	44	OA	Aseptic loosening + dislocation	3B	3rd	No	Monobloc	Yes	116	BIG + RR + cemented cup
24	Female	82	28	OA	Aseptic loosening + recurrent dislocation	3B	5th	No	Monobloc	Yes	6	APC + structural allograft + cemented cup
25	Female	71	28	RA	Aseptic loosening	3B	3rd	No	Monobloc	Yes	51	BIG + mesh + cemented cup
26	Female	89	24	OA	Aseptic loosening	3B	3rd	No	Monobloc	No	113	APC + cemented cup
27	Female	59	30	OA	Aseptic loosening	3B	3rd	No	Monobloc	No	29	BIG + mesh + cemented cup
28	Female	56	28	SED	PE wear/ osteolysis	3B	1st	Yes	Monobloc	Yes	221	Uncemented cup
29	Female	62	34	PT OA	Aseptic loosening	3B	3rd	Yes	Monobloc	Yes	125	BIG + mesh + RR + cemented cup
30	Female	77	30	OA	PE wear/ osteolysis	3B	3rd	Yes	Monobloc	Yes	5	Girdlestone
31	Female	48	24	SD	Aseptic loosening	3B	2nd	No	Monobloc	Yes	40	BIG + mesh + plate + cemented cup
32	Female	54	24	CHD	Aseptic loosening	3B	3rd	No	Monobloc	Yes	71	Uncemented cup

*P, Paprosky classification; †Rev, number of revisions; ‡T, time from previous surgery in months; §No stem revision but cerclage and tibial strut graft was used because of poor femoral bone
BMI, body mass index; OA, osteoarthritis; BIG, bone impaction grafting; RA, rheumatoid arthritits; APC, anti-protrusio cage; CHD, congenital hip dysplasia; AVN, avascular necrosis of the femoral head; PT OA, post traumatic osteoarthritis; SED, spondyloepiphyseal dysplasia; SD Still's disease; RR, reinforcement ring; TM, trabecular metal.

Table 2.
Demographical and radiographical characteristics and results between serie I and II (Median [interquatile range first and third quartile]) and p-value of the difference

Values	Series I	Series II	P-value
Age	67 (60.75 to 73.75)	66 (59.00-74.75)	0.81
BMI (kg/m$^{2)}$	26 (25 to 29.75)	28 (26.25 to 30)	0.22
Number of revisions	2 (2 to 2.75)	3 (2.25 to 3.75)	<0.01
INCL PLAN (°)	44 (40.5 to 45)	45 (45 to 45)	0.07
INCL PostOP (°)	47 (45 to 48)	48 (45.5 to 50)	0.08
INCL Δ (°)	2 (1 to 3,75)	3.5 (2 to 4.75)	0.33
AV PLAN (°)	11 (15 to 19)	20 (20 to 20)	<0.01
AV PostOP (°)	11 (6.75 to 21)	17.5 (15.25 to 22)	0.03
AV Δ (°)	5 (2.25 to 7.75)	2.5 (1 to 4.75)	0.1
RO (°)	4 (2.025 to 9.725)	3.55 (0.2 to 7.475)	0.24
COR AP (mm)	1.35 (0.325 to 1.8)	1.75 (1.225 to 3.05)	0.15
COR LM (mm)	1.3 (0.8 to 2.475)	1.6 (1 to 3)	0.37
COR SI (mm)	2.4 (0.775 to 4.475)	3.4 (2.4 to 5.125)	0.11

Δ, delta: difference; PLAN, planned; PostOP,postoperative; AV, anteversion; INCL, Inclination,; RO, rotation; COR, centre of rotation; AP, anteroposterior; LM, lateromedial ; SI, superoinferior

Table 3.
Inclination (INCL) and anteversion (AV) differences. Differences ≥ 10° between planned and post-operative (Post-op) positions are marked in bold

	INCL (°)			AV (°)		
Case number	Planned	Post-op	Δ*	Planned	Post-op	Δ*
17	45	52	7	22	22	0
18	39	38	1	18	17	1
19	46	48	2	22	22	0
20	43	47	4	20	22	2
21	45	47	2	20	14	6
22	45	49	4	20	15	5
23	45	50	5	20	12	8
24	43	45	2	20	24	4
25	45	48	3	20	21	1
26	46	50	4	20	16	4
27	**45**	**59**	**14**	20	21	1
28	**45**	**58**	**13**	20	12	8
29	45	49	4	20	17	3
30	45	44	1	20	22	2
31	45	48	3	20	17	3
32	45	45	0	20	18	2

Δ, delta: difference

Table 4.
Rotation and centre of rotation (COR) differences

			COR (mm)		
Case number	**Treatment side**	**Rotation clockwise (°)**	**AP**	**LM**	**SI**
17	Left	4.2	0.7	-4.8	**9.5**
18	Right	-0.6	-1.5	0.6	-3.9
19	Right	-3.2	.1.0	-0.8	1.8
20	Left	**10.7**	1.9	0.9	3.0
21	Right	-0.2	1.9	1.3	1.5
22	Left	0.9	-1.2	3.7	3.6
23	Right	-6.3	0.3	1.8	2.2
24	Left	0.2	-1.3	5.0	2.4
25	Left	6.8	-2.3	-0.1	3.0
26	Right	-8.9	-2.9	1.4	3.2
27	Right	-9.4	-4.2	1.5	**8.4**
28	Right	-7.7	**-6.7**	1.4	**7.3**
29	Left	0.2	-3.1	3.0	3.9
30	Left	3.9	1.3	-1.7	2.4
31	Right	-1.0	-1.6	2.8	**5.5**
32	Right	0.3	3.8	3.0	4.0

Rotation differences ≥ 10° and differences in the centre of rotation (COR) ≥ 5 mm between planned and post-operative positions are marked in bold figures. AP, anteroposterior; LM, lateromedial ; SI, superoinferior

Discussion

In the current study the results of a second case series of 16 consecutive patients who received a 3-dimensional (3D) printed custom-made acetabular implant in multiple revised large acetabular defects is presented. The purpose of this study was to assess surgical accuracy and document complications to evaluate the results in a more difficult caseload. No statistical differences were found between both series, but the results do suggest a trend towards better surgical accuracy results. This is reflected by the number of parameters that are outside the threshold; 11 in the first series versus eight in the second series. Finally, in the second series we did not have any malpositioning for AV and we did not have any dislocations, compared to two dislocations in the first series. These improved results were found despite a more difficult caseload, which was reflected by a significantly higher number of previous revisions in the second series. This could have led to worse outcomes, more difficulty with cup placement and more dislocations[2, 16, 17].

Another interesting finding in our study was the significant difference between planned and postoperative AV between both series. Both were significantly higher in the current second series: 11° versus 20° for planned AV and 11° versus 17.5° for postoperative AV. This might explain why there were no dislocations in the second series versus two in the first series, even though hip dislocation is a multifactorial problem.[15-17] Bierdermann et al[15] showed that the AV is significantly lower in posterior dislocated hips and with a posterolateral approach this is the expected type of dislocation. When, in our study, postoperative AV deviated from the planned values it was mostly lower. Hence, by choosing a higher AV preoperatively, chances of a critical loss of anteversion and subsequent dislocation because of this, are lower. Comparing our dislocation rate (two out of 32) to other reports on custom-made implants[6-14] this appeared to be very low. This might be explained by adequate AV, INCL and COR preplanning and the use of a double mobility cup[22] in all our cases except for a constrained liner[23] in one case (case 24) with an abductor muscle insufficiency. Citak et al.[24], who also reported on the aMace implant, showed a high dislocation rate of three out of nine but the authors did not report on how accurate the implants were placed and which cup they cemented in the custom implant.

When comparing the accuracy of our cup replacement to other studies, we noticed that since the publication of our previous paper fewer studies have been published on the topic. When looking at cup accuracy concerning anteversion and inclination the results of the current study are similar to published studies who included patients with primary THA.[25-27] The current study results suggests that an acceptable surgical accuracy for AV and INCL can be achieved by using custom-made designs in multiple revised large acetabular defects.

Concerning the COR, the literature is scarce and only one other publication on custom-made constructions actually dealt with this aspect.[28] Barlow et al[28] found that the COR was lateralised by 11.85mm compared with the contralateral hip among all patients. In the current study we did not measure the lateralisation compared to the contralateral hip but took these into account whilst planning the COR of the implant and we did not find these high values of lateralisation of the COR postoperatively (table 4). Other reports on custom-made acetabular implants did not study the INCL, AV, rotation and restoration of the COR of the implant. [6-14] An in- depth comparison therefore cannot be done.

There are a few limitations of this study. First of all, the lack of statistical significance may be due to the small sample size of both case series. Another limitation is the relative short follow up, six weeks, of the complications and thus the dislocation rate. However, most dislocations (60-70%) occur early and are reported in the first four to six weeks after the procedure.[17]

Conclusion

For the difficult clinical issue of large acetabular defect revision a good reproducibility of surgical accuracy was observed and a low complication rate was shown with a custom-made implant, despite a higher complexity of cases illustrated by higher number of previous revisions in the second series. The improved surgical accuracy for anteversion in combination with a higher planned anteversion might be relevant to reduce dislocation, the most common complication in revision hip surgery.

Declaration of conflict of interest

Personal fees were received from faculty work from Materialise by three authors, from Smith and Nephew by one author, from ZimmerBiomet by one author and from Stryker tumor prosthesis design by one author. One author received a grant from Emerging implant Technologies.

References

1. Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplasty 1994;9:33-44.
2. Bischel O, Seeger JB, Krüger M, Bitsch BG. Multiple Acetabular Revisions in THA - Poor Outcome Despite Maximum Effort. Open Orthop J. 2012;6:488-494
3. Baauw M, van Hooff ML, Spruit M. Current Construct Options for Revision of Large Acetabular Defects: A Systematic Review. JBJS Rev. 2016 Nov 8;4(11).
4. Sheth NP, Nelson CL, Springer BD, Fehring TK, Paprosky WG. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. J Am Acad Orthop Surg 2013;21:128-139.
5. Goodman GP, Engh CA Jr. The custom triflange cup: build it and they will come. Bone Joint J. 2016 Jan;98-B(1 Suppl A):68-72.
6. Gladnick BP, Fehring KA, Odum SM, Christie MJ, DeBoer DK, Fehring TK. Midterm Survivorship After Revision Total Hip Arthroplasty With a Custom Triflange Acetabular Component. J Arthroplasty. 2018 Feb;33(2):500-504.
7. Berend ME, Berend KR, Lombardi AV, Cates H, Faris P. The patient-specific Triflange acetabular implant for revision total hip arthroplasty in patients with severe acetabular defects: planning, implantation, and results. Bone Joint J. 2018 Jan;100-B(1 Supple A):50-54.
8. Li H, Qu X, Mao Y, Dai K, Zhu Z. Custom Acetabular Cages Offer Stable Fixation and Improved Hip Scores for Revision THA With Severe Bone Defects. Clin Orthop Relat Res. 2016 Mar;474(3):731-40.
9. Berasi CC 4th, Berend KR, Adams JB, Ruh EL, Lombardi AV Jr. Are custom triflange acetabular components effective for reconstruction of catastrophic bone loss? Clin Orthop Relat Res. 2015 Feb;473(2):528-35.
10. Wind MA Jr, Swank ML, Sorger JI. Short-term results of a custom triflange acetabular component for massive acetabular bone loss in revision THA. Orthopedics 2013;36:e260-e265.
11. Taunton MJ, Fehring TK, Edwards P, Bernasek T, Holt GE, Christie MJ. Pelvic discontinuity treated with custom triflange component: a reliable option. Clin Orthop Relat Res 2012;470:428-434.
12. DeBoer DK, Christie MJ, Brinson MF, Morrison JC. Revision total hip arthroplasty for pelvic discontinuity. J Bone Joint Surg [Am] 2007;89-A:835-840.
13. Holt GE, Dennis DA. Use of custom triflanged acetabular components in revision total hip arthroplasty. Clin Orthop Relat Res 2004;429:209-214.
14. Joshi AB, Lee J, Christensen C. Results for a custom acetabular component for acetabular deficiency. J Arthroplasty 2002;17:643-648.
15. Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stöckl B. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br. 2005 Jun;87(6):762-9.
16. Moskal JT, Capps SG. Improving the accuracy of acetabular component orientation: avoiding malposition. J Am Acad Orthop Surg 2010;18:286-296.
17. Sanchez-Sotelo J and Berry JD. Epidemiology of instability after total hip replacement. Orthop Clin North Am. 2001Oct; 32(4):543-52.
18. Baauw M, van Hellemondt GG, van Hooff ML, Spruit M. The accuracy of positioning of a custom-made implant within a large acetabular defect at revision arthroplasty of the hip. Bone Joint J. 2015 Jun;97-B(6):780-5.
19. Gagnier JJ, Kienle G, Altman DG, Moher D, Sox H, Riley D et al. The CARE guidelines: consensus-based clinical case report guideline development. J Clin Epidemiol. 2014 Jan;67(1):46-51.
20. Gelaude F, Clijmans T, Delport J. Quantitative computerized assessment of the degree of acetabular bone loss (TrABL). Adv Orthop 2011:494382.
21. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg [Am] 1978;60-A:217–220.
22. Ohmori T, Kabata T, Maeda T, Kajino Y, Taga T, Hasegawa K et al. Increase in safe zone area of the acetabular cup using dual mobility cups in THA. Hip Int. 2017 Jul 25;27(4):361-367.
23. Van der Merwe JM. Comprehensive Review of Current Constraining Devices in Total Hip Arthroplasty. J Am Acad Orthop Surg. 2018 Jul 15;26(14):479-488.
24. Citak M, Kochsiek L, Gehrke T, Haasper C, Suero EM, Mau H. Preliminary results of a 3D-printed acetabular component in the management of extensive defects. Hip Int. 2018 May;28(3):266-271.
25. Jennings JM, Randell TR, Green CL, Zheng G, Wellman SS. Independent Evaluation of a Mechanical Hip Socket Navigation System in Total Hip Arthroplasty. J Arthroplasty. 2016 Mar;31(3):658-61.

26. Sariali E, Boukhelifa N, Catonne Y, Pascal Moussellard H. Comparison of Three-Dimensional Planning-Assisted and Conventional Acetabular Cup Positioningin Total Hip Arthroplasty: A Randomized Controlled Trial. J Bone Joint Surg Am. 2016 Jan 20;98(2):108-16.

27. Iwakiri K, Kobayashi A, Ohta Y, Minoda Y, Takaoka K, Nakamura H. Efficacy of a Pelvic Lateral Positioner With a Mechanical Cup Navigator Based on the Anatomical Pelvic Plane in Total Hip Arthroplasty. J Arthroplasty. 2017 Dec;32(12):3659-3664.

28. Barlow BT, Oi KK, Lee YY, Carli AV, Choi DS, Bostrom MP. Outcomes of Custom Flange Acetabular Components in Revision Total Hip Arthroplasty and Predictors of Failure. J Arthroplasty. 2016 May;31(5):1057-64.

VI

Good results at 2-year follow-up of a custom-made triflange acetabular component for large acetabular defects and pelvic discontinuity: a prospective case series of 50 hips

Marieke Baauw
Miranda L. van Hooff
Gijs G. van Hellemondt
Paul C. Jutte
Sjoerd K. Bulstra
Maarten Spruit

Acta Orthopaedica 2021 Jun;92(3):297-303

Abstract

Background and purpose
Custom triflange acetabular components (CTACs) are suggested as good solutions for large acetabular defects in revision total hip arthroplasty. However, high complication rates have been reported and most studies are of limited quality. This prospective study evaluates the performance of a CTAC in patients with large acetabular defects including pelvic discontinuity.

Patients and methods
Prospectively collected data of 49 consecutive patients (50 hips), who underwent an acetabular revision with a CTAC were analyzed. Follow-up (FU) was 2 years. The median age of the patients was 68 years (41–89) and 41 were women. Primary outcomes were re-revision of the CTAC and differences between the modified Oxford Hip Score (mOHS) preoperatively and at 2-year follow-up. Secondary outcomes included several patient reported outcomes (PROMs), radiological results, complications, and a comparison between hips with and without pelvic discontinuity (PD).

Results
1 patient (1 hip) was lost to the 2-year FU. No CTAC needed re-revision. The preoperative and 2-year FU mOHS were available in 40 hips and improved statistically significantly. All of the other secondary outcomes improved over time. 5 hips (of 45 with radiological 2-year FU) had loosening of screws. 8 hips had complications, including 3 persistent wound leakage, 3 pelvic fractures, and 1 dislocation. The mOHS and complication rate were similar in hips with and without PD.

Interpretation
Reconstruction of large acetabular defects with and without PD with this CTAC showed good improvement in patient-reported daily functioning, high patient-reported satisfaction, few complications, and no rerevisions at 2-year FU.

Introduction

Acetabular revision is challenging when facing severe host bone loss and poor remaining bone quality. Pelvic discontinuity (PD) increases the difficulty of reconstructing such defects.

Custom triflange acetabular components (CTATCs) have been repeatedly suggested as good solutions to deal with large acetabular defects, even when PD is present (Sheth et al. 2013, Baauw et al. 2016, De Martino et al. 2019, Szczepanski et al. 2019, Volpin et al. 2019, Chiarlone et al. 2020, Malahias et al. 2020). A proposed advantage is the ability to customize and individualize the implant to the defect in each individual case (Berasi et al. 2015). As such, an immediately stable initial implant fixation might be accomplished. This might be due to restoring anatomical dimensions and re-distributing load anatomically, choosing the optimal center of rotation, and supporting host bone contact and osseointegration. We feel that good design of the CTAC prior to surgery, trying to achieve implant support and fixation to the best host bone quality, is important as the implant cannot be modified intraoperatively.

A disadvantage of the use of CTACs is the reported high complication rate in terms of reoperation, infection, nerve damage, and especially dislocation (Volpin et al. 2019, Chiarlone et al. 2020, Malahias et al. 2020). However, these higher rates may relate to the difficulty of revisions and severity of the acetabular bone defects encountered when using CTACs (De Martino et al. 2019, Volpin et al. 2019). As might be expected, the risk of postoperative hip dislocation is increased in these complex cases with multiple previous surgeries, extensile approaches, pre-existent leg-length discrepancies, and frequently abductor weakness (De Martino et al. 2019). An option to reduce dislocation in revision total hip arthroplasty (THA) is by using a dual mobility design (Faldini et al. 2018) and its implementation has been recommended in acetabular revision with CTACs (De Martino et al. 2019, Malahias et al. 2020).

The use of CTACs remains controversial as many studies that evaluate the performance of these implants are retrospective small case series and as such of limited quality. There is a need for prospective studies with consistent reporting of clinical, radiological, and patient-reported outcomes.

This prospective single-center study evaluates the revision rate, patient-reported outcomes, complications, and postoperative radiographs in a consecutive series of patients with large acetabular defects treated with a CTAC in which either a dual mobility cup or a constrained liner was cemented.

Patients and methods

Prospectively collected data (questionnaires) of 49 consecutive patients (50 hips) was extracted and anonymized from the institution's THA revision database. Inclusion criteria were an acetabular revision with a custom-made acetabular revision system (Materialise, Leuven, Belgium) and a minimum of 2 years' follow-up. The study complied with the STROBE guidelines (von Elm et al. 2008).

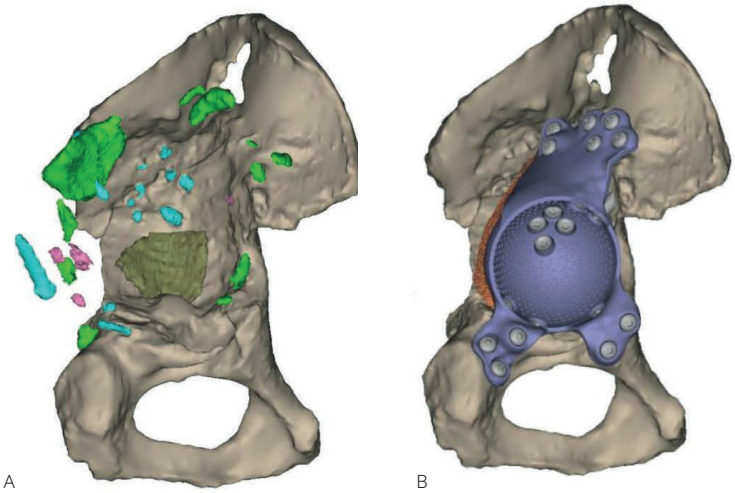
The indication for the CTAC was the presence of a Paprosky type 3B acetabular defect (Paprosky et al. 1994) with or without PD in a patient for whom other options with off-the-shelf implants were not thought feasible.

Surgery

Patients were operated on between February 2013 and September 2017. A preoperative CT scan was performed for defect analyses and reconstruction planning. The surgeons gave feedback on the defect analyses and the implant orientation, determining optimal anteversion, inclination, and center of rotation of the implant. Based on this information and feedback a porous metal augment and a triflange cage, with flanges on ilium, ischium, and pubis, were designed as a monoblock, with screw fixation planned into the best host bone quality (Figure 1). All patients were operated on by an orthopedic surgeon and either another orthopedic surgeon, a fellow, or a final-year resident. A posterolateral approach was used in all patients and surgeons had a printed hemi-pelvis, trial implants, and drill guides at their disposal during surgery. Allograft was used in case of voids and/or cavitary defects between host bone and implant. Taking into account the quality of the host bone, the implant was fixed with pre-planned trajectory screws using the patient-specific drill guides. Within the implant either a dual mobility cup (48 hips) or, in the case of abductor deficiency, a constrained liner (2 hips) was cemented in the same orientation as the implant (Figure 2). Further details concerning the acetabular defect analyses and the surgical technique have previously been described (Baauw et al. 2015, 2017). Postoperatively, patients were allowed 50% weight-bearing on the operated leg for the first 6 weeks. Systemic antibiotics were routinely used perioperatively and until results of intraoperative cultures were known and low-molecular-weight heparin (LMWH) was administered in the first 6 weeks postoperatively.

Figure 1.

Planning of case 17 with (A) the ultimate acetabular bone defect after substracting all parts of the existing reconstruction and (B) the expected postoperative situation with the complete construct.

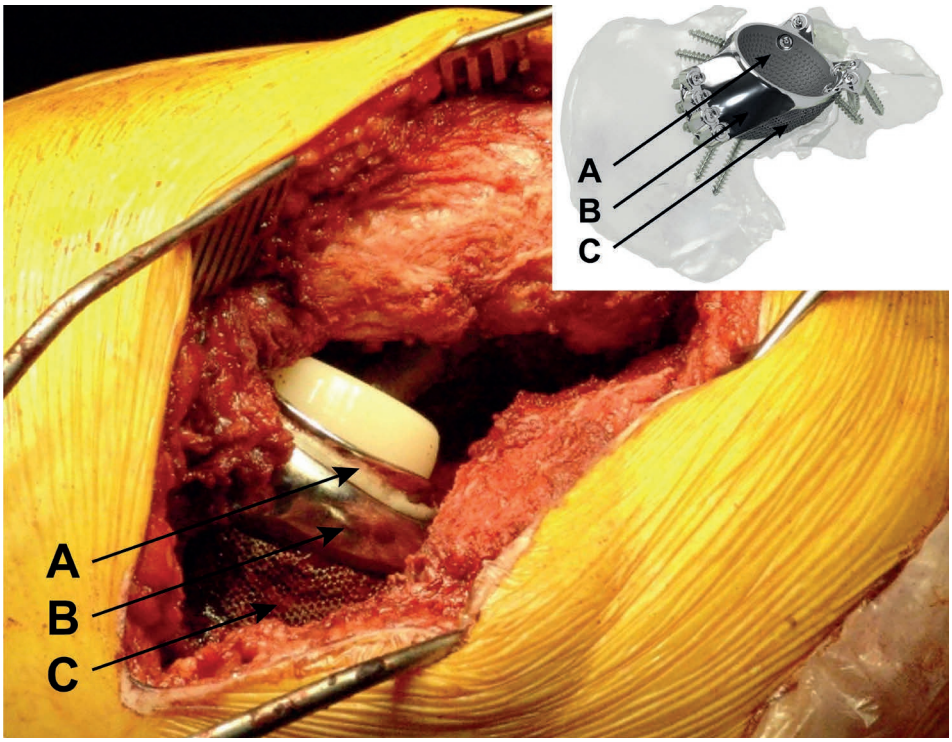


A B

Patients

Of the 49 included patients (50 hips), 41 were women. At the time of the hip revision surgery the median (range) age of the patients was 68 years (41–89) and their median (range) BMI was 27 (19–44). The ASA classification was 2 in most patients (30/50). The primary diagnosis was osteoarthritis (OA) in 26 patients, 41 were revised due to aseptic loosening, and the median (range) number of previous revisions was 2 (1–9). Based on preoperative analysis pelvic discontinuity (PD) was found in 16 hips. In 11 hips the stem was revised at the same time and bone graft was used in 32 hips. 2 patients (case 21 and 48) received a constrained liner instead of a dual mobility because of hip abductor deficiency. The median (range) time that patients stayed in hospital was 8 (4–28) days (Table 1, see Supplementary data).

Figure 2.
Dual mobility cup cemented into the custom-made implant.
A=(place of) dual monility cup. B = triflange cage. C = porus metal augment



Primary and secondary outcomes

Our primary outcomes were re-revision of the CTAC at 2-year FU and the change in daily functioning as experienced by patients. To measure daily functioning the patient-reported modified Oxford Hip Score (mOHS) was used (Gosens et al. 2005). The preoperative mOHS (70–14) was compared with the mOHS at 2-year FU and its clinical relevance was analyzed. At 2-year FU we also looked at the mean mOHS of all available patients, including those who did not complete the mOHS preoperatively.

Secondary clinical outcomes included a comparison between preoperative and 2-year FU values of the EuroQol 5 dimensions 3 level (EQ5D-3L) utility (-0.329–1), the EQ5D- 3L numeric rating scale (NRS) from 0–100 (EuroQol group 1990), and the visual analogue scale (VAS) for pain at rest and during activities (0–100). At 2-year FU the following additional clinical outcomes were measured: satisfaction with surgical result using VAS (0–100) and several core questions, which could be answered "yes" or "no."

Complications were registered during admission and until 2-year FU and all types of complications were registered. Anteroposterior (AP) radiographs were taken at 1-year FU and 2-year FU. These were reviewed by MSB and MS for: notable breakage of the component, screw loosening (defined by radiolucency around the screws) or breakage, and bony fractures.

Finally, to explore and indicate the potential influence of PD, the re-revision rate, mOHS, and the complications in cases with PD were compared with cases without PD.

Statistics

The primary outcome, the mOHS, was descriptively summarized, using medians and ranges, and non-parametrically tested with the Wilcoxon signed-rank test to evaluate clinical performance preoperatively versus the performance at 2-year FU. Clinical relevance of the change in mOHS was assessed using a distribution-based approach. This was calculated by taking 0.5 SD of the mean difference between the preoperative scores and the scores at 2-year FU. To further substantiate clinical relevance, the effect size was determined using Cohen's d, which is calculated by dividing the difference in scores from preoperative to 2-year FU by the SD of the preoperative scores (Norman et al. 2003, Copay et al. 2007). An effect size of 0.2 was considered small, 0.5 moderate, and 0.8 large (Cohen 1992). The secondary clinical outcome data was descriptively summarized using medians and ranges. Missing cases for the primary outcome, the mOHS, were compared to complete cases on baseline characteristics (age, sex, BMI, primary diagnosis, number of previous revisions, stem revision, and use of bone graft and presence of PD) using the Wilcoxon signed-rank test for continuous data and Fisher's exact test for categorical data. Statistical analyses were performed using STATA (version 13.1 for Windows; StataCorp, College Station, TX, USA). Statistical significance was defined as $p < 0.05$.

Ethics, funding, and potential conflict of interests

Ethical approval from the Institutional review board was not required, as the Dutch Act on Medical Research involving Human Subjects does not apply to screening questionnaires that are part of routine clinical practice. For this study, patient data were obtained as a part of routine outcome monitoring for use in daily practice. All data were anonymized and identified
for analyses and report.

Personal fees were received for faculty work from Materialise by MSB, GGvH, and MS, from Smith & Nephew by GGvH, from Zimmer Biomet by GGvH, and from DePuy Synthes by MS. SKB is the president of the Dutch Orthopedic Society and MS is chairman of the AOTK Spine.

Results

Primary outcomes

1 patient (1 hip) was lost to the 2-year FU (case 49) and did not respond to questionnaires or follow-up appointments due to her comorbidities. None of the remaining 49 CTACs needed re-revision at 2-year FU. The mOHS was missing in 7 cases at preoperative assessment (cases 10, 18, 24, 37, 38, 39, 50) and in 3 cases at 2-year FU (cases 21, 25, 49). In the remaining 39 patients (40 hips) with complete mOHS a statistically significant improvement was shown from 51 (24–67) to 28.5 (14–56) at the 2-year FU. The clinically relevant difference (0.5 SD) was 5 points and present in 37 out of 40 patients with complete mOHS. The effect size was large (d = 1.6). The mOHS of all available patients (n = 47) at 2-year FU, irrespective of (in-)complete baseline mOHS, was 29 (14–56).

Patients who had incomplete data for the mOHS differed statistically significantly from patients with complete data with regard to the number of previous revisions: 3.5 (1–9) previous revisions in patients with incomplete mOHS and 2 (1–9) in patients with complete mOHS. No other significant differences in baseline characteristics were shown between complete and incomplete cases.

Patient-reported clinical results

Our secondary outcome measures on EQ5D-3L utility, EQ5D-3L NRS, VASrest, and VASactivity improved between baseline and 2-year FU (Table 2). For these values we had 41/400 (10%) missing values.

Table 2.
Patient-reported outcomes in medians (ranges)

	Preoperative scores	Postoperaritive scores 2YRFU
EQ5D-3L utility (-0.329-1) [n]	0.228 (-0.128-0.893) [44]	0.769 (-0.204-1) [47]
EQ5D-3L NRS (0-100) [n]	50 (7-100) [43]	70 (40-100) [44]
VASrest (0-100) [n]	31 (0-100) [45]	2 (0-100) [46]
VASactivity (0-100) [n]	78 (0-100) [45]	11.5 (0-100) [46]

mOHS, modified Oxford Hip Score; EQ5D-3L, Euroqol 5 dimensions 3 level; NRS, numeric rating scale; VAS, visual analog scale

Satisfaction with the surgical result was reported in 45 cases and was 96 (0–100). The results of the core questions are described in Table 3.

Table 3.
Core questions at 2-year follow-up

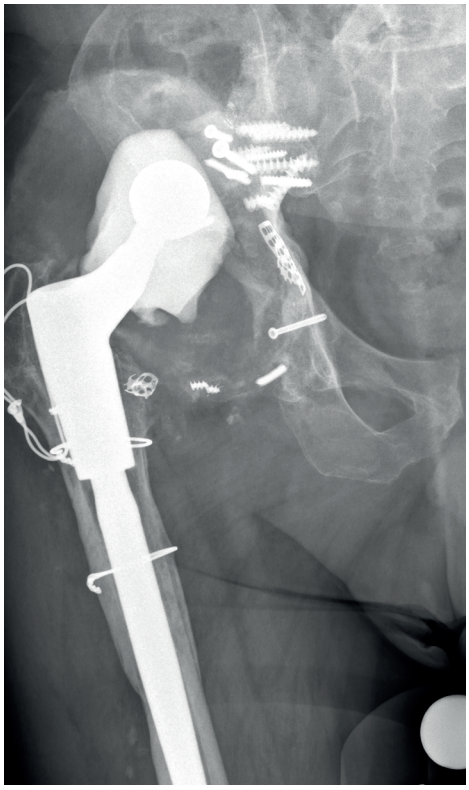
Core question (n = 47)	Yes
Has the operation improved the mobility or function of the hip? [47]	38
Has the pain in/ around the hip lessened since the operation?	45
Are you satisfied with the results of the operation?	42
Would you recommend the operation to a family member or friend?	47

Radiological results

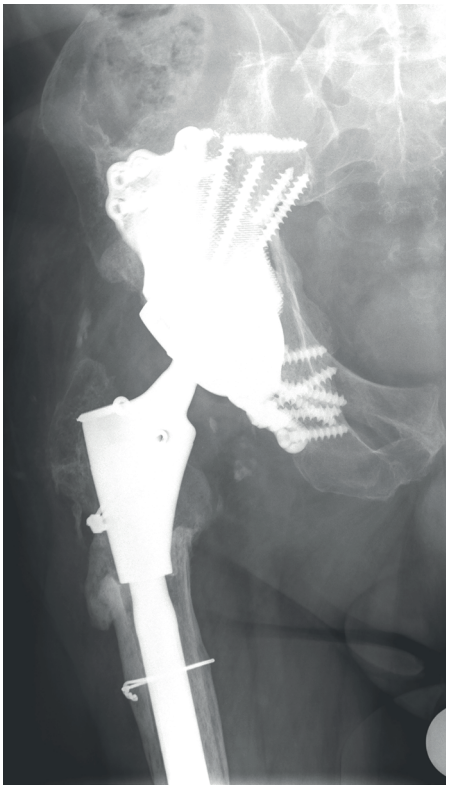
AP radiographs were available of 49 hips at 1-year FU and of 45 hips at 2-year FU (Figure 3). 5 hips had loosening of screws at 1-year FU with no signs of progression at 2-year FU (cases 10, 31, 32, 38, and 42). In all of these patients screw loosening was found in 1 or more ischium screws and in one of these hips there was also screw loosening of a pubis screw (case 10) (Figure 4). The missing 4 hips at 2-year FU (case 16, 41, 43, and 50) did not show any complications at 1-year FU.

Figure 3.

Case 17 (A) preoperatively and (B) at 2-year follow-up.

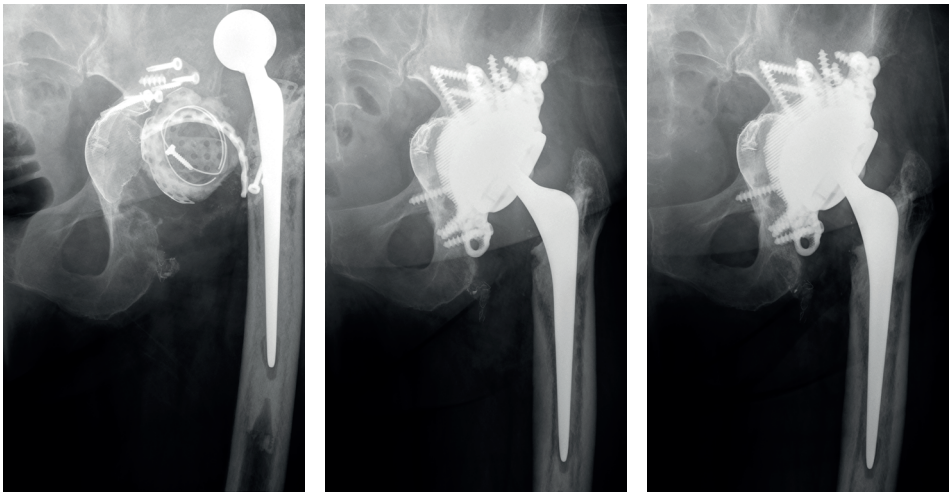


A



B

Figure 4.
Case 10 (A) preoperatively, (B) at 1-year follow-up, and (C) at 2-year-follow-up.



A B C

Complications

In 49 cases the complication registration was complete. 8 cases had complications. Of these, 3 cases had re-explorations for persistent wound discharge (cases 6, 16, and 28), with collection of intraoperative cultures. In 1 of these cases (case 16) cultures were found to be positive, which was treated with 3 months of antibiotics. During the re-exploration of this same case 3 loose ischium screws and 1 loose pubis screw were exchanged. In 3 other cases a fracture of the pelvis (cases 2, 27, and 45) occurred, 2 postoperatively and 1 stress fracture after 6 months. These 3 cases were treated conservatively. The stress fracture evolved into a pseudoarthrosis; the other 2 fractures healed. At 3 weeks postoperatively, in another case a hip dislocated (case 3), which was treated conservatively with closed reduction and a brace and the hip did not dislocate again at the 2-year FU. This patient had ischiatic nerve irritation due to the dislocation. In the 8th case with complications, a general complication occurred, which involved a cerebrovascular accident directly postoperatively (case 26).The rates of mOHS and complications were similar in patients with and without PD (Table 4).

Table 4.
Clinical and patient-reported outcomes of hips with and withoud PD

	No PD (n=33)	PD (n=16)
mOHS preoperative mean	52 (24-69)	53 (25-60)
mOHS postoperative	28 (14-48)	32 (17-56)
Overall clinical complication rate	5	3
Dislocation rate	1	0

PD, Pelvic discontinuity; mOHS, modified Oxford Hip Score

Discussion

To our knowledge this is the 1st prospective study on a large group of patients with this particular custom-made implant and in which pre- and postoperative patient-reported clinical outcome scores are compared (Colen et al. 2013, Baauw et al. 2017, Myncke et al. 2017). This study is the 2nd prospective case series, deBoer et al. (2007) being the 1st on the results of any CTAC for large acetabular defects. Furthermore, patient satisfaction is evaluated in more detail compared with most studies on CTACs and it is the 1st that reports on the clinical relevance of the improvement in patient-reported functioning over time (De Martino et al. 2019, Chiarlone et al. 2020).

In this study, all of the clinical patient-reported outcome scores improved over time, which is consistent with other studies on CTACs (De Martino et al. 2019, Chiarlone et al. 2020). The improvement in the mOHS between preoperatively and 2-year FU was also found to be clinically relevant.

When comparing our study with 2 recent review articles on CTACs, the revision rate, overall reoperation rate, and the complication rate were lower in our study (De Martino et al. 2019, Chiarlone et al. 2020). In particular, our low dislocation rate (1/49) is notable. Risks of a high dislocation rate in revision THA include multiple previous hip revisions (Kosashvili et al. 2011), abductor muscle deficiency, and severe acetabular bone loss (Faldini et al. 2018), all of which are often present in hips that are managed with a CTAC, the current study included. Another risk factor is the revision of only 1 component (Faldini et al. 2018), which was the case in 39/50 of the hip revisions in the current study. We believe that the low number of dislocations in our study is related to the preoperative planning of implant anteversion, with the use of either a dual mobility design or a constrained liner, in the case of abductor deficiency, in all of our cases (Faldini et al. 2018). This assumption is supported by 2 other studies on CTACs that reported no dislocations and either used a dual mobility cup in all cases (Colen et al. 2013) or a constrained liner in most of their cases (Berasi et al. 2015). To our knowledge, only 2 other studies have measured the accuracy of the placement of their custom-made implant (Weber et al. 2019, Zampelis and Flivik 2020). Both of them found similar good placement accuracy, as we have previously found (Baauw et al. 2016), and had 1 and 0 dislocations in 11 and 10 patients, highlighting the importance of accurate placement to diminish the dislocation rate.

Another notable finding in our study is the low deep infection rate, 1 of 49. Known risk factors for deep infections after total hip arthroplasty include an ASA score of 3 or higher, a longer duration of surgery (Urquhart et al. 2010) and a higher number of previous revisions (Kosashvili et al. 2011). In our patients the median (range) previous revisions were 2 (1–9) and 6 patients had an ASA classification of 3. However, the 1 patient with a deep infection (case 16) had an ASA classification of 2 and had 2 previous revisions. We did not report on the surgical time, but we assume this was relatively short compared with other hip revision surgeries because all operations were performed by 2 orthopedic surgeons and because of the precise preoperative planning. Other factors that might explain our low infection rate are the following measurements that are routinely done in all THA revisions in our clinic: preoperative infection workup with lab work and intra-articular aspiration, the routine use of antibiotics perioperatively for at least 24 hours, intraoperative betadine lavage and irrigation, and finally meticulous wound closure and low-suction wound dressing in patients with a BMI of over 30.

When comparing revisions with PD and without PD we found similar results. This is in line with findings of 2 recent review articles on the treatment of PD that have found CTACs to be a viable treatment option (Szczepanski et al. 2019, Malahias et al. 2020). In our study there were no mechanical failures and no dislocations and the overall complication rate was 3 out of 16 in cases with PD. These results are favorable, not only compared with other studies on CTACs for PD but also when compared with other treatment options for PD, including cup-cages, anti-protrusion-cages, acetabular shells with plates, and pelvic distraction techniques (Szczepanski et al. 2019, Malahias et al. 2020).

There are some limitations in this study. 1st, the relatively short FU of 24 months. The average FU was found to be 5 years (range 1–18) in previous studies on CTACs (De Martino et al. 2019, Chiarlone et al. 2020). We will continue to follow up our patients. Another limitation is the fact that we cannot comment on the migration of the implant, which is difficult to determine for this particular implant on conventional radiographs. Recently, Zampelis and Flivik (2020) have determined the migration of a similar implant, same cage but without an augment, at 1-year follow-up using CT scans. They found small measured migration values of less than 1 degree or 1 mm. To determine the secondary stability of these implants in the long run new CT-based migration research will be necessary.

In conclusion, this CTAC used in large acetabular defects with and without PD demonstrates a relevant improvement in patient-reported daily functioning, high patient-reported satisfaction, few complications and no re-revisions at 2-year FU.

Supplementary Table 1.
Patients characteristics per casa

Case	Sex	Age[a]	BMI	ASA[b]	Health preop.[c]	Primary diagnosis[d]	Revision reason	No. of revisions	Bone graft[e]	Stem revision	Pelvic discontinuity	Previous implant[f]
1	F	68	33	2	3	OA	Malpositioning	2nd	No	Yes	Yes	Uncemented jumbo cup
2	F	48	29	2	3	AN	Loosening	2nd	No	No	No	APC + bone graft + cemented dual mobility cup
3	M	59	25	2	3	RA	Loosening	2nd	Yes	No	No	BIG + mesh + cemented cup
4	F	71	24	3	3	RA	Loosening	2nd	Yes	No	No	BIG + mesh + cemented cup
5	F	60	25	1	2	OA	Loosening	2nd	No	No	No	BIG + mesh + cemented cup
6	F	65	33	2	3	OA	Loosening	3rd	No	No	No	BIG + mesh + APC + cemented dual mobility cup
7	F	63	24	1	3	OA	Loosening	3rd	Yes	No	No	BIG + mesh + cemented cup
8	F	50	24	1	2	CHD	Loosening	2nd	No	No	No	APC + cemented cup
9	F	73	22	2	3	OA	Loosening	3rd	Yes	No	No	BIG + mesh + cemented cup
10	F	60	33	2	-	CHD	Loosening	5th	Yes	No	Yes	BIG + medial/rim mesh + plate + cemented cup
11	F	51	25	2	3	CHD	Loosening	2nd	No	No	No	Cemented cup
12	M	76	29	2	1	OA	Loosening	3rd	Yes[e]	No	No	BIG + cemented cup
13	F	66	30	3	3	OA	Malpositioning	2nd	No	No	Yes	BIG + mesh + cemented cup + posterior column plate
14	F	64	28	2	2	CHD	Loosening	1st	Yes	No	No	Cemented cup
15	F	69	27	1	2	OA	Loosening	1st	No	No	No	Muller reinforcement ring + cemented cup
16	F	76	32	2	1	OA	Loosening	2nd	No	No	Yes	BIG + cemented cup
17	M	68	30	1	1	PT OA	Loosening	9th	Yes	No	No	Cement spacer on a ZImmer femoral stem / later girdlestone
18	M	74	20	2	-	OA	Loosening	4th	No	No	Yes	BIG + mesh + cemented cup/ later only femurcomponent
19	M	59	26	2	3	OA	Loosening	4th	Yes	No	No	TM augment + BIG+ APC + cemented cup
20	F	71	44	3	3	OA	Loosening	3rd	Yes	No	No	BIG+Ganz reinforcement ring +cemented cup
21	F	82	28	3	2	OA	Instability	5th	Yes	No	No	APC(Burch Schneider) + structural allograft + cemented cup
22	F	71	28	1	2	RA	Malpositioning	3rd	Yes	No	No	BIG + mesh + cemented cup
23	F	89	24	1	1	OA	Loosening	3rd	No	No	Yes	APC + cemented cup
24	F	67	27	2	-	OA	Infection	9th	No	Yes	No	Oblong cup/ later girdlestone
25	M	61	26	2	1	OA	Malpositioning	2nd	No	Yes	No	BIG+mesh+TM augment+cemented cup
26	M	70	28	2	3	RA	Loosening	3rd	Yes	No	No	BIG + mesh + cemented cup
27	F	81	38	2	1	OA	Loosening	1st	No	Yes	Yes	Uncemented cup
28	F	59	30	1	2	OA	Loosening	3rd	No	No	Yes	Mesh + BIG + cemented cup

29	F	56	28	2	3	SED	PE wear/ osteolysis	1st	Yes	Yes	No	Uncemented cup
30	F	62	34	2	1	PT OA	Loosening	3rd	Yes[e]	Yes	No	Mesh-Ganz reinforcement ring + BIG + cemented cup
31	F	82	23	2	2	OA	Loosening	2nd	Yes[e]	No	Yes	Cemented cup
32	F	77	30	2	2	CHD	PE wear/ osteolysis	3rd	Yes[e]	Yes	No	Uncemented Spotorno expansion cup/ later girdlestone
33	F	48	24	3	2	SD	Loosening	2nd	Yes	No	No	BIG + mesh + cemented cup + posterior column plate
34	F	41	29	2	2	RA	Loosening	3rd	Yes	No	No	Cemented cup
35	F	54	19	1	3	CHD	Loosening	3rd	Yes	No	No	Uncemented cup
36	F	77	24	3	3	RA	Loosening	1st	Yes[e]	Yes	Yes	Cemented cup
37	F	77	27	2	-	OA	Loosening	3rd	Yes[e]	No	Yes	BIG + mesh + APC + cemented cup
38	F	74	24	2	3	OA	Loosening	3rd	Yes[e]	No	Yes	BIG + mesh + cemented cup + posterior column plate
39	F	65	22	2	-	CHD	Loosening	4th	Yes[e]	No	No	BIG + mesh + cemented cup + posterior column plate
40	M	44	25	1	1	OA	Loosening	2nd	Yes[e]	No	No	BIG + mesh + cemented cup
41	F	79	25	2	2	OA	Loosening	2nd	Yes[e]	No	Yes	APC + cemented cup
42	F	46	26	2	3	CHD	Loosening	1st	No	No	No	Cemented cup
43	F	75	26	2	1	RA	Loosening	1st	Yes	Yes	No	Cemented cup
44	F	83	26	2	2	OA	Loosening	1st	Yes	Yes	No	Cemented cup
45	F	76	32	2	3	OA	Loosening	2nd	Yes[e]	No	No	Uncemented cup
46	F	57	32	3	3	SED	PE wear/ osteolysis	1st	Yes	No	No	Cemented cup
47	F	59	25	1	2	CHD	Loosening	1st	Yes	No	No	Uncemented cup
48	F	63	28	3	3	RA	Loosening	5th	Yes[e]	No	Yes	BIG + mesh + cemented cup + posterior column plate
49	F	68	24	3	3	AVN	Loosening	1st	No	No	No	BIG + mesh + cemented cup
50	F	79	25	2	-	OA	Loosening	2nd	No	No	Yes	BIG + uncemented cup

[a] Age at the time of the operation.
[b] American Society of Anaesthesiologists classification
[c] Health preoperatively: 1, unilateral hip problem; 2, bilateral hip problems; 3, other health issues besides hip problems
[d] AVN Avascular necrosis; CHD, Congenital hip dysplasia; OA, osteoarthritis; PT OA, Post traumatic OA; RA Reumatoid arthritis; SED, spondyloepiphyseal dysplasia
[e] Bone, grafted with chips, all grafted with allograft
[f] APC, anti-protrusio cage; BIG, bone impaction grafting, CC, cemented cup, DMC, dual mobility cup; PCP posterior column plate; TM, trabecular metal.
[g] Case 29 (right hip) and case 46 (left hip) are the same patient.

References

- Baauw M, van Hooff M L, Spruit M. Current construct options for revision of large acetabular defects: A systematic review. JBJS Rev. 2016 Nov 8;4.
- Baauw M, van Hellemondt G G, van Hooff M L, Spruit M. The accuracy of positioning of a custom-made implant within a large acetabular defect at revision arthroplasty of the hip. Bone Joint J. 2015 Jun;97-B:780-5.
- Baauw M, van Hellemondt G G, Spruit M. A custom-made acetabular implant for Paprosky type 3 defects. Orthopedics. 2017 Jan 1;40:e195-e198
- Berasi CC 4th, Berend KR, Adams JB, Ruh EL, Lombardi AV Jr. Are Custom Triflange Acetabular Components Effective for Reconstruction of Catastrophic Bone Loss? Clin Orthop Relat Res. 2015 Feb;473(2):528-35.
- Chiarlone F, Zanirato A, Cavagnaro L, Alessio-Mazzola M, Felli L, Burastero G. Acetabular custom-made implants for severe acetabular bone defect in revision total hip arthroplasty: a systematic review of the literature. Arch Orthop Trauma Surg. 2020 Mar;140:415-424.
- Cohen J. A power primer. Psychol Bull 1992;112:155–159.
- Colen S, Harake R, De Haan J, Mullier M. A modified custom-made triflange acetabular reconstruction ring (MCTARR) for revision hip arthroplasty with severe acetabular defects. Acta Orthop Belg. 2013 Feb;79(1):71-5.
- Copay A G, Subach B R, Glassman S D, Polly D W Jr, Schuler T C. Understanding the minimum clinically important difference: a review of concepts and methods. Spine J. 2007 Sep-Oct;7:541-6.
- DeBoer D K, Christie M J, Brinson M F, Morrison J C. Revision total hip arthroplasty for pelvic discontinuity. J Bone Joint Surg [Am] 2007;89-A:835–840
- De Martino I, Strigelli V, Cacciola G, Gu A, Bostrom M P, Sculco P K. Survivorship and clinical outcomes of custom triflange acetabular components in revision total hip arthroplasty: A systematic review. J Arthroplasty. 2019 Oct;34:2511-2518.
- von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP; STROBE Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE)statement: guidelines for reporting observational studies. J Clin Epidemiol. 2008 Apr;61(4):344-9.
- the EuroQol Group (1990). EuroQol-a new facility for the measurement of health related quality of life. Health Policy 16(3):199-208.
- Faldini C, Stefanini N, Fenga D, Neonakis E M, Perna F, Mazzotti A, Pilla F, Triantafyllopoulos I K, Traina F. How to prevent dislocation after revision total hip arthroplasty: a systematic review of the risk factors and a focus on treatment options. J Orthop Traumatol. 2018 Sep 10;19:17.
- Goodman G P, Engh C A Jr. The custom triflange cup: build it and they will come. Bone Joint J. 2016 Jan;98-B:68-72.
- Gosens T, Hoefnagels N H, de Vet R C, Dhert W J, van Langelaan EJ, Bulstra S K, Geesink R G. The “Oxford Heup Score”: the translation and validation of a questionnaire into Dutch to evaluate the results of total hip arthroplasty. Acta Orthop. 2005 Apr;76(2):204-11
- Kosashvili Y, Backstein D, Safir O, Lakstein D, Gross AE. Dislocation and infection after revision total hip arthroplasty: comparison between the first and multiply revised total hip arthroplasty. J Arthroplasty. 2011 Dec;26(8):1170-5.
- Malahias M A, Ma Q L, Gu A, Ward S E, Alexiades M M, Sculco P K. Outcomes of acetabular reconstructions for the management of chronic pelvic discontinuity: A systematic review. J Arthroplasty. 2020 Apr;35:1145-1153.e2.
- Myncke I, van Schaik D, Scheerlinck T. Custom-made triflanged acetabular components in the treatment of major acetabular defects. Short-term results and clinical experience. Acta Orthop Belg. 2017 Sep;83(3):341-350.
- Norman G R, Sloan J A, Wyrwich K W. Interpretation of changes in health-related quality of life: the remarkable universality of half a standard deviation. Med Care. 2003 May;41:582-92.
- Paprosky WG, Perona P G, Lawrence J M. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplasty 1994;9:33–44.
- Sheth N P, Nelson C L, Springer B D, Fehring T K, Paprosky W G. Acetabular bone loss in revision total hip arthroplasty: evaluation and management. J Am Acad Orthop Surg 2013;21:128-139.
- Szczepanski J R, Perriman D M, Smith P N. Surgical treatment of pelvic discontinuity: A systematic review and meta-analysis. JBJS Rev. 2019 Sep;7:e4.
- Urquhart DM, Hanna FS, Brennan SL, Wluka AE, Leder K, Cameron PA, Graves SE, Cicuttini FM. Incidence and Risk Factors for Deep Surgical SiteInfection After Primary Total Hip Arthroplasty: A Systematic Review. J Arthroplasty. 2010 Dec;25(8):1216-22.e1-3.

- Volpin A, Konan S, Biz C, Tansey R J, Haddad F S. Reconstruction of failed acetabular component in the presence of severe acetabular bone loss: a systematic review. Musculoskelet Surg. 2019 Apr;103:1-13.
- Weber M, Witzmann L, Wieding J, Grifka J, Renkawitz T, Craiovan B. Customized implants for acetabular Paprosky III defects may be positioned with high accuracy in revision hip arthroplasty Int Orthop. 2019 Oct;43(10):2235-2243.
- Zampelis V, Flivik G. Custom-made 3D-printed cup-cage implants for complex acetabular revisions: evaluation of pre-planned versus achieved positioning and 1-year migration data in 10 patients. Acta orthop. 2020 Sep; 15;1-6.

VII

General discussion and future perspectives

As mentioned in the introduction: the incidence of osteoarthritis (OA) has risen over the last few years and is expected to rise even further in the following decades. This will consequently lead to more people receiving a total hip arthroplasty (THA) as OA is the main indication for THA. The main failure mechanism for THA is wear accompanied by aseptic loosening and bone loss.[1] As more people receive primary THA, often at a younger age, and life expectancy increases; the burden of hip revision surgery, with its accompanying increasing bone loss, is expected to rise. Subsequently, this will lead to an increasing need for innovated reconstruction options in hip revision surgery with extensive acetabular bone loss.

The general aim of this thesis was to evaluate the current treatment options for large acetabular defects and to introduce and evaluate a new acetabular implant to treat these large acetabular defects. The present chapter presents a general discussion on the four research objectives formulated in the introduction, followed by overall conclusions and future perspectives.

To determine and evaluate the current treatment options for large acetabular defects.

Chapter two

In chapter two we researched the reconstruction options for large acetabular defects with a systematic review. Only studies that classified large acetabular defects by either the AAOS[2] or the Paprosky[3] classification, still the most cited classifications for large acetabular defects[4], were included. The definition of large acetabular defects were defects classified as either Paprosky type 3A, Paprosky type 3B, AAOS type III or AAOS type IV. The latter also being known as pelvic discontinuity (PD). Using these classifications, and after a quality assessment, 20 studies were included and seven different treatment options for large acetabular defects were found.

The antiprotrusio cage (APC) was found to be the most frequently reported technique in our review. It was used in eight of the included studies and it showed satisfactory results in a physically low demand elderly population. These findings in chapter two are validated by a more recent review article by Aprato et al.[5] that reported solely on cages in revision total hip arthroplasty (THA). Aprato et al. [5] concluded that the cages had good survival rates and functional scores in elderly patients with a mean age of 66.7. However, different articles compared to our review were included by Aprato et al. which is due to the fact that the review by Alprato et al. was performed later in time, had different inclusion criteria, and did not do a quality assessment of the studies.[5] This might explain that in contrast to their positive conclusion the aseptic loosening rate and overall acetabular revision rate was almost double the rates that we found in chapter two.

The usage of a hemispherical cup with hooks and flanges and that of an allograft or Trabecular Metal™ (TM) augment with cup, showed unsatisfactory results in all large acetabular defects in chapter two. Bone impaction grafting (BIG) with a metal mesh, used in two studies included in chapter two, seemed inappropriate for PD and Paprosky type 3B defects. This conclusion was highlighted in a recent review of Malahias et al..[6] They found BIG effective for patients with moderate bone loss and as well for some patients with large superolateral defects. But Malahias et al. concluded that BIG with metal mesh was associated with decreased survival rates in patients who required combined medial, and lateral meshes and in patients with Paprosky type 3B defects.[6]

In chapter two we concluded that the best results for large acetabular defects were found when TM augments and shells were used, as described in four of the included studies. Besides this it was concluded that a cup-cage solution or a custom-made triflange component might also be a good solution for large acetabular defects. Both techniques showed acceptable revision rates but higher rates of radiographic loosening, which might be explained by the fact that both were only used in the treatment of PD. But few studies on these techniques were available.

Porous metallic materials, as used in TM augments and shells, cup cage reconstructions, and custom-made triflange components, are irreplicable in the treatment of large acetabular defects. Especially after failure of grafting due to graft resorption.[7] This might be explained by the fact that metallic materials should ensure greater mechanical stability and fixation over time by avoiding some particular risks associated with allografting such as transmission of infection, variable mechanical characteristics, partial resorption and healing.[7]

Different types of porous metal are available nowadays, a systematic review of Migaud et al.[7] found six modular metallic materials with TM (Zimmer) being on the market the longest and thus published on the most. Modular applications include the augment and shell option as well as a cup-cage solution; both options, in which TM was used, were found to have promising results in our review. Drawbacks of these modular reconstructions include that often quite some bone needs to be removed to accommodate the component. And because of its modularity, the risk of release of tantalum fragments exists which entails a risk of tantalum metallosis.[7] These drawbacks are less evident in another kind of implant using porous metal material: custom-made implants. They are often monoblock implants and designed to precisely fit the existing defect without increasing the already extensive defect to allow the indispensable press-fit. However, press-fit and bone contact cannot be modified intraoperative as is possible with modular reconstructions which may make the procedure more difficult especially with large implants that also increase the risk of neural lesions.[7] Another drawback could be that in case of failure nothing of the implant can be conserved, leaving the defect at least as large as before. Furthermore, in case of infection without loosening, no simple techniques are available to remove custom-made acetabular implants increasing the risk of leaving an even more extensive acetabular defect.[7] A higher risk of infection might be suggested due to the volume of custom-made implants, but this was not found in a systematic analysis by Jain et al.[8] These possible drawbacks should be taken into consideration when designing a new custom-made acetabular implant.

In recent reviews on PD, the most extensive and challenging form of acetabular defects, all applications of porous metallic materials were found to have the best results.[9–11] Survival, revision, loosening, and complication rates vary between studies due to different study methods, inclusion criteria and follow-up times, making it difficult to determine which of these methods is the most effective. However, custom-made implants and cup-cage constructs show a tendency to do better in PD, as predicted in our review.[9–14] And a study that directly compared standard, cup-cage or augment and shell, versus custom-made acetabular implants in revision THA found better results of custom-made implants in uncontained defects and PD. Treatment of these defects with the standard options led to higher rates of aseptic loosening, consequently leading to re-revisions.[15]

In conclusion, the best treatment options for large acetabular defects are techniques using porous metallic materials such as TM augment and shells, cup-cage constructions and custom-made triflange components. Custom-made triflange implants might be the best solution for the most extensive and challenging defects classified as Paprosky type 3B or PD. However, review articles on large acetabular defects are limited by the heterogeneity and the quality of the included studies.[4,6,7,10–12,14] Subsequently the final conclusion of chapter two still stands: Prospective, preferable controlled, studies on treatment options for large acetabular defects are much needed.

- *The most optimal treatment options for large acetabular defects are construction options using porous metallic materials such as Trabecular Metal™ augment and shells, cup-cage reconstructions and custom-made triflange implants.*
- *In Paprosky type 3B acetabular defects in particular with pelvic discontinuity, the most extensive form of acetabular defects, custom-made acetabular implants might be the best solution.*
- *There is need for high quality studies on treatment options for large acetabular defects as current studies are of limited quality.*

To describe a new patient specific technique to treat large acetabular defects with a 3D printed custom-made acetabular implant.

Chapter three

Even though large acetabular defects are grouped in classification systems, each specific defect is different in each specific patient. This makes it logical to treat each large acetabular defect with a patient specific solution. In chapter three a new 3D-printed patient specific custom-made triflange acetabular implant for large acetabular defects was introduced. Not only the implant was described but the complete process was discussed including the pre-operative planning and the surgical technique. The use of 3D-printing technology in hip and pelvic surgeries can be divided in four categories[16], all of which are implemented in this process. First, 3D-printed models of the acetabular defects are provided, secondly patient specific instruments (PSI) are used, thirdly the implant is 3D-printed of highly porous metal and finally the implant is patient specific and thus custom-made.

Careful preoperative planning is crucial in the treatment of large acetabular defects. To design the implant described in chapter three a thin-sliced computed tomography scan (CT-scan) and special software to assess the ultimate bone defect and more importantly the quality of the remaining bone is used. Using the information this software provides and the surgeons' feedback, the implant is designed with precisely outlined flanges to match the surface of the ilium, ischium, and pubis. Screw fixation through the flanges is planned towards the best bone quality available. To ensure accurate placement of the custom-made implant a 3D-printed anatomical plastic model of the hemipelves and trial implants in modular and monoblock fashion as well as PSI drill guides are provided. Both have shown to have a positive effect on placement accuracy.[17,18] By planning and subsequently placing the implant with the optimal inclination, anteversion and center of rotation the chance of not only wear but also dislocation, one of the main complications and thus concerns of custom-made acetabular implants[4,13,14], is hopefully reduced. A dual mobility cup is cemented in the implant to further reduce the risk of dislocation.[19]

All the before mentioned features combined, are unique for this specific implant and are thought to improve the outcome of the implant in large acetabular defects. In chapter three some preliminary findings of the custom-made implant, which support the previous statement, are presented. However, it is a small retrospective case series with a short follow-up. In chapter six the implant is evaluated more extensively with a prospective case series of a larger group of patients with a two-year follow-up.

- *This new unique patient specific custom-made triflange implant has different features, including special software to assess the ultimate bone defect and bone quality, 3D-printed plastic models, and patient specific drill guides, to ensure the optimal placement of the implant and reduce the chance of complications and implant failure.*

To effectively evaluate the placement accuracy of this new custom-made acetabular implant.

Chapter four and five

The patient specific custom-made triflange implant described in chapter three provided several features to ensure the optimal placement. In chapter four and five the placement accuracy of this new custom-made acetabular implant was evaluated. Four of the patients that were retrospectively described in chapter three were not included in chapter four as they did not receive a CT-scan postoperatively. Positioning was evaluated by using thin sliced CT-scans to compare planned inclination (INCL), anteversion (AV), rotation and center of rotation (COR) with the postoperative position. In chapter four encouraging results were found in a case series of 16 implants. Because the complexity of the cases that received this custom-made acetabular implant increased over time another 16 cases were evaluated and compared to the previous 16 cases in chapter five. In this chapter we found a trend towards better surgical accuracy and less complications despite a higher complexity in cases. The higher complexity was highlighted by a higher number of previous revisions in the second series. An explanation for the trend towards better results in the second series despite a higher complexity in those cases might be the evolution of the learning curve: Peltola et al.[20] found that the first 15 operations with a new stem or cup had an increased risk of early revision surgery.

In the second series the AV was higher with a 20° planned and 17.5° postoperative versus 11° planned and postoperative AV in the first series. This might partially explain why there were no dislocations in the second series versus two dislocations in the first series.[21] However, the optimal acetabular cup orientation and its clinical consequences is still up for debate. Two review articles on optimal acetabular cup orientation looked at the ideal INCL and AV and whether achieving this goal limited dislocations rates. However, consensus on optimal cup positioning could not be reached due to the lack of uniformity in cup orientation assessment. The often-used Lewinnek's safe zone[22] of an INCL of 45° (±10°) and an AV of 15° (±10°) could not be justified, nor could any other proposed target zones. This is probably not because acetabular cup placement is not important but because of lack of uniformity in cup orientation assessment and the multifactorial nature of total hip arthroplasty (THA) dislocation.[23,24] In the last several years it is believed that the patients' native anatomy should be leading in choosing the optimal acetabular component orientation.[25] One study even found natural acetabular orientation to be outside of the Lewinnek 'safe zone' in 75% of arthritic hips.[26]

Most research done on acetabular cup orientation is done in primary THA. In revision THA ideal cup orientation is not only difficult to determine because of lack of consensus on the best cup orientation but also because of acetabular defects making it hard to determine the native anatomy. And despite the controversy on the precise parameters of ideal cup orientation there is consensus that suboptimal cup orientation can lead to luxation, wear and ultimately implant failure.[21,25] Therefore, the planning and subsequent execution of cup orientation is of great importance in acetabular surgery. In both series, described in chapter four and five, the COR was variable, and the surgeon gave feedback on the design to help and determine the ideal COR based on the contralateral hip. In the second series, described in chapter five, an AV of 20° and an INCL of 45° was planned in all patients and based on this position the defect that needed to be filled with titanium became clear. Whether these parameters give favorable clinical results and survival rates is discussed in chapter six.

- *Placement accuracy of this custom-made acetabular construct is satisfactory, and accuracy increases over time despite of a more difficult case load, illustrated by a higher number of previous revisions*
- *A higher anteversion might reduce dislocation: 20 degrees of anteversion remains the goal in future case planning*

To evaluate the short-term survival and clinical and radiological outcomes of this new custom-made acetabular implant.

Chapter six

In chapter six the short-time follow-up results of this new custom-made acetabular component were presented. Because the prospective database started a couple of years after the first patients were implanted with the custom-made acetabular implant in our clinic the first 12 patients that received the implant were not included in the database. Therefore the 12 patients discussed in chapter three as well as eight patients discussed in chapter four and five were not included in this chapter. In this prospective case series of 50 hips (49 patients) with a follow-up of two years, patient reported outcomes, radiological results and complications were presented. Only extremely large acetabular defects, Paprosky type 3B defects with and without pelvic discontinuity (PD), were treated with this implant. Only one hip was completely lost to follow-up and none of the implants were revised. Patient-reported daily functioning improved clinically relevant and statistically significant. and patient-reported satisfaction was high. There were few clinical and radiological complications.

Our study on this new custom-made acetabular implant was unique compared to previous studies on this custom-made implant [27–36]. Quite a few of the previous studies on this particular implant were case reports[27–30], which highlights the fact that this implant is mostly used in extreme cases of acetabular bone loss. In our study we did not only report on the largest cohort of hips that received this custom-made implant, it was also the only prospective study. Prospective studies are rare in all studies on the treatment options for large acetabular defects.[4,7,10]

When looking at the results of our study, a notable finding was the low complication rate.[13,14] Only one hip dislocated. This confirms the conclusion that choosing an anteversion of 20°, and precisely placing the implant reduces dislocations. We believe another key element of our low dislocation rate is the cementation of a dual mobility cup in the implant.

In general, the disadvantages of the use of a dual mobility cup were thought to be intra-prosthetic dislocation, aseptic loosening because of polyethylene wear increment, and increased infection rate. However, in a recent meta-analysis the use of a dual mobility cup was found to decrease the risk of implant failure at mid-term follow-up, to reduce early post-operative dislocation rates and total hip arthroplasty (THA) re-revision rates and to not increase the risk of infection, compared to fixed-bearing cups.[37] Our results seem to match that assumption, at least at the short term.

The post-operative infection rate, another devastating complication in hip revision surgery, was also low in our study with only one implant infection. This might be explained by the relatively short surgery time and the strict rules and precatory measurements to prevent infections used by our clinic preoperative. These measurements include infection workup with lab work and intra-articular aspiration, the routine use of antibiotics perioperatively for at least 24 hours, intraoperative betadine lavage and irrigation, and meticulous wound closure and low-suction wound dressing in patients with a BMI of over 30.

A main concern of custom-made implants in general is whether they provide enough value to justify the extra costs. Analyzing this can be very difficult as multiple factors are of influence including type of implant, insurance coverage, hospital stay, expected reoperation or complications. Even more difficult, most of these costs are country or even hospital depended. The single costs of the specific implant we analyzed is relatively high when compared to other custom-made acetabular implants that are available on the French market.[7] However, a health-economic comparison of the specific implant we analyzed compared to other custom-made acetabular implants in Belgium showed an excellent value for money when used in revision THA of Paprosky type 3B defects.[38]

Overall, chapter six showed a statistically significant and a clinically relevant improvement in patient-reported daily functioning, high patient-reported satisfaction, few clinical and radiological complications, and no re-revision in patients with Paprosky type 3B defects with or without PD. With this, our study underlines that a custom-made acetabular implant is a viable treatment option for PD and might even be the best option for uncontained defects and PD. Future research should address the two main limitations of chapter six: the relatively short two-year follow-up and the inability to comment on the migration of the implant.

- *Precise planning and accurate placement of an acetabular implant will lead to better survival rates and better clinical and radiological results.*
- *This custom-made acetabular implant is a viable or even the best option for uncontained acetabular defects and pelvic discontinuity*

Overall conclusions and future perspectives

In the current thesis a new custom-made, patient specific, triflange acetabular component for large acetabular defects was introduced. Its unique features, to facilitate precise preoperative planning of the optimal component position and accurate postoperative component placement, were described. The postoperative placement accuracy and the short-term clinical and radiological follow-up were presented. Overall, the results demonstrated the implant to be highly appropriate for large acetabular defects in hip revision surgery. For patients this implant has an enormous effect on their mobility, sometimes even making the difference between being wheelchair dependent or not, which is demonstrated by the patient-reported improvement of daily functioning and the high patient-reported satisfaction. In this thesis only the application of this patient-specific custom-made implant in hip revision surgery was researched. But the implant could and has been used for other indications in which large acetabular defects can be found, for example, after extensive acetabular tumor resection surgery.

The results presented in this thesis are on the short-time follow-up of this acetabular implant. New cases that receive this implant are still being included in a prospective database and in the future long-term follow-up will follow as data are collected at the following standard moments: preoperative, perioperative, and postoperative at four months, one year, two years, five years, seven and a half years, and ten years. During these follow-up clinical data, general health and radiological data will also be collected. These data are interesting, especially at the ten-year follow-up, as the average follow-up on custom-made acetabular implants is about five years in the current studies on custom-made acetabular implants.[10,11]

Another interesting aspect for future research is the primary and secondary stability of the implant. A review on radiostereometric analysis in acetabular implants, the current golden standard for migration measurements, found that cohorts that addressed larger acetabular defects were associated with a larger amount of early migration.[39] And they recommended to do migration studies early on (at one or two-year follow-up) as to identify poorly performing implants at a relatively early stage.[39] Previous studies found a migration of one mm after two-years of follow-up to be predictive for aseptic loosening of the implant in the future, varying from 10% per one mm per two years for primary THA[40] to 37-90% in revision THA[41,42] Based on these studies, migration of the implant of one mm or higher after two years of follow-up should be considered clinically relevant. It is imaginable that you can measure the migration in a similar fashion as we measured the placement accuracy in chapter four and five by using CT-scans. In fact, Zampelis and Flivik[43] already used our method to measure the migration after one year of a similar implant: the same cage but without an integrated augment. Zampelis and Flivik found very small migration values. However, their follow-up was only one year, and they only used descriptive statistics because of the small number of included patients. To completely assess the stability of the custom-made acetabular implant described in this thesis we would like to do a migration study after two- years of follow-up using CT-scan data.

In conclusion, this thesis described preliminary encouraging results of a new innovative implant design for large acetabular defects in hip revision surgery. We showed that in these cases it pays off to differ from the standard implant options and cater to the needs of the individual patient by using a newly developed patient-specific implant. For patients with these debilitating acetabular defects this custom-made solution is a lifesaver when it comes to mobility and pain relief. It is the perfect showcase that not every large acetabular defect can be fixed with off the shelf implants and that in selected cases disruptive innovation can solve the problem. Obviously, innovative solutions such as custom-made implants in large acetabular defects need careful evaluation and continued follow up.

References

1. Ferguson RJ, Palmer AJ, Taylor A, Porter ML, Malchau H, Glyn-Jones S. Hip replacement. Lancet. 2018;392(10158):1662-1671. doi:10.1016/S0140-6736(18)31777-X
2. D'Antonio JA, Capello WN, Borden LS, et al. Classification and management of acetabular abnormalities in total hip arthroplasty. Clin Orthop Relat Res. 1989;(243):126-137.
3. Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplasty. 1994;9(1):33-44. doi:10.1016/0883-5403(94)90135-X
4. Volpin A, Konan S, Biz C, Tansey RJ, Haddad FS. Reconstruction of failed acetabular component in the presence of severe acetabular bone loss: a systematic review. Musculoskelet Surg. 2019;103(1). doi:10.1007/S12306-018-0539-7
5. Aprato A, Olivero M, Vergano LB, Massè A. Outcome of cages in revision arthroplasty of the acetabulum: a systematic review. Acta Biomed. 2019;90(1-S):24-31. doi:10.23750/ABM.V90I1-S.8081
6. Malahias MA, Mancino F, Gu A, et al. Acetabular impaction grafting with mesh for acetabular bone defects: a systematic review. Hip Int. 2022;32(2):185-196. doi:10.1177/1120700020971851
7. Migaud H, Common H, Girard J, Huten D, Putman S. Acetabular reconstruction using porous metallic material in complex revision total hip arthroplasty: A systematic review. Orthop Traumatol Surg Res. 2019;105(1S):S53-S61. doi:10.1016/J.OTSR.2018.04.030
8. Jain S, Grogan RJ, Giannoudis P v. Options for managing severe acetabular bone loss in revision hip arthroplasty. A systematic review. Hip Int. 2014;24(2):109-122. doi:10.5301/HIPINT.5000101
9. Babis GC, Nikolaou VS. Pelvic discontinuity: a challenge to overcome. EFORT Open Rev. 2021;6(6):459-471. doi:10.1302/2058-5241.6.210022
10. Malahias MA, Ma QL, Gu A, Ward SE, Alexiades MM, Sculco PK. Outcomes of Acetabular Reconstructions for the Management of Chronic Pelvic Discontinuity: A Systematic Review. J Arthroplasty. 2020;35(4):1145-1153.e2. doi:10.1016/J.ARTH.2019.10.057
11. Szczepanski JR, Perriman DM, Smith PN. Surgical Treatment of Pelvic Discontinuity: A Systematic Review and Meta-Analysis. JBJS Rev. 2019;7(9). doi:10.2106/JBJS.RVW.18.00176
12. Wang C xin, Huang Z da, Wu B jian, Li W bo, Fang X yu, Zhang W ming. Cup-Cage Solution for Massive Acetabular Defects: A Systematic Review and Meta-Analysis. Orthop Surg. 2020;12(3):701-707. doi:10.1111/OS.12710
13. Chiarlone F, Zanirato A, Cavagnaro L, Alessio-Mazzola M, Felli L, Burastero G. Acetabular custom-made implants for severe acetabular bone defect in revision total hip arthroplasty: a systematic review of the literature. Arch Orthop Trauma Surg. 2020;140(3):415-424. doi:10.1007/S00402-020-03334-5
14. de Martino I, Strigelli V, Cacciola G, Gu A, Bostrom MP, Sculco PK. Survivorship and Clinical Outcomes of Custom Triflange Acetabular Components in Revision Total Hip Arthroplasty: A Systematic Review. J Arthroplasty. 2019;34(10):2511-2518. doi:10.1016/J.ARTH.2019.05.032
15. Tikhilov RM, Dzhavadov AA, Kovalenko AN, Bilyk SS, Denisov AO, Shubnyakov II. Standard Versus Custom-Made Acetabular Implants in Revision Total Hip Arthroplasty. J Arthroplasty. 2022;37(1):119-125. doi:10.1016/J.ARTH.2021.09.003
16. Woo SH, Sung MJ, Park KS, Yoon TR. Three-dimensional-printing Technology in Hip and Pelvic Surgery: Current Landscape. Hip Pelvis. 2020;32(1):1. doi:10.5371/HP.2020.32.1.1
17. Kavalerskiy G, Murylev V, Rukin Y, Elizarov P, Lychagin A, Tselisheva E. Three-Dimensional Models in Planning of Revision Hip Arthroplasty with Complex Acetabular Defects. Indian J Orthop. 2018;52(6):625-630. doi:10.4103/ORTHO.IJORTHO_556_16
18. Small T, Krebs V, Molloy R, Bryan J, Klika AK, Barsoum WK. Comparison of acetabular shell position using patient specific instruments vs. standard surgical instruments: a randomized clinical trial. J Arthroplasty. 2014;29(5):1030-1037. doi:10.1016/J.ARTH.2013.10.006

19. Faldini C, Stefanini N, Fenga D, et al. How to prevent dislocation after revision total hip arthroplasty: a systematic review of the risk factors and a focus on treatment options. J Orthop Traumatol. 2018;19(1). doi:10.1186/S10195-018-0510-2

20. Peltola M, Malmivaara A, Paavola M. Hip prosthesis introduction and early revision risk. A nationwide population-based study covering 39,125 operations. Acta Orthop. 2013;84(1):25-31. doi:10.3109/17453674.2013.771299

21. Biedermann R, Tonin A, Krismer M, Eibl G, Stöckl B. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br. 2005;87(6):762-769. doi:10.1302/0301-620X.87B6.14745

22. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am. 1978;60(2):217-220.

23. Snijders TE, Willemsen K, van Gaalen SM, Castelein RM, Weinans H, de Gast A. Lack of consensus on optimal acetabular cup orientation because of variation in assessment methods in total hip arthroplasty: a systematic review. Hip Int. 2019;29(1):41-50. doi:10.1177/1120700018759306

24. Seagrave KG, Troelsen A, Malchau H, Husted H, Gromov K. Acetabular cup position and risk of dislocation in primary total hip arthroplasty. Acta Orthop. 2017;88(1):10-17. doi:10.1080/17453674.2016.1251255

25. Moskal JT, Capps SG. Improving the accuracy of acetabular component orientation: avoiding malposition. J Am Acad Orthop Surg. 2010;18(5):286-296. doi:10.5435/00124635-201005000-00005

26. Goudie ST, Deakin AH, Deep K. Natural acetabular orientation in arthritic hips. Bone Joint Res. 2015;4(1):6-10. doi:10.1302/2046-3758.41.2000286

27. Hafez MA, Makram OM, Seth VJ. Satisfactory Outcome for a Challenging Case of Infected Native Pelvic Discontinuity with Significant Bone Loss: A Case Report. JBJS Case Connect. 2021;11(1):E2000365. doi:10.2106/JBJS.CC.20.00365

28. Yao A, George DM, Ranawat V, Wilson CJ. 3D Printed Acetabular Components for Complex Revision Arthroplasty. Indian J Orthop. 2021;55(3):786-792. doi:10.1007/S43465-020-00317-X

29. van Eemeren A, Vanlommel J, Vandekerckhove M. Acetabular reconstruction with a custom-made triflange acetabular component through direct anterior approach - A case report. J Clin Orthop Trauma. 2020;11(Suppl 2):S211-S213. doi:10.1016/J.JCOT.2020.02.006

30. Augustyn A, Stołtny T, Rokicka D, et al. Revision arthroplasty using a custom-made implant in the course of acetabular loosening of the J&J DePuy ASR replacement system - case report. Medicine. 2022;101(4):E28475. doi:10.1097/MD.0000000000028475

31. Myncke I, van Schaik D, Scheerlinck T. Custom-made triflanged acetabular components in the treatment of major acetabular defects. Short-term results and clinical experience. Acta Orthop Belg. 2017;83(3):341-350.

32. Citak M, Kochsiek L, Gehrke T, Haasper C, Suero EM, Mau H. Preliminary results of a 3D-printed acetabular component in the management of extensive defects. Hip Int. 2018;28(3):266-271. doi:10.5301/HIPINT.5000561

33. Gruber MS, Jesenko M, Burghuber J, Hochreiter J, Ritschl P, Ortmaier R. Functional and radiological outcomes after treatment with custom-made acetabular components in patients with Paprosky type 3 acetabular defects: short-term results. BMC Musculoskelet Disord. 2020;21(1). doi:10.1186/S12891-020-03851-9

34. Matar HE, Selvaratnam V, Shah N, Wynn Jones H. Custom triflange revision acetabular components for significant bone defects and pelvic discontinuity: Early UK experience. J Orthop. 2020;21:25-30. doi:10.1016/J.JOR.2020.01.053

35. Goriainov V, King LJ, Oreffo ROC, Dunlop DG. Custom 3D-Printed Triflange Implants for Treatment of Severe Acetabular Defects, with and without Pelvic Discontinuity: Early Results of Our First 19 Consecutive Cases. JB JS Open Access. 2021;6(4). doi:10.2106/JBJS.OA.21.00057

36. Colen S, Harake R, de Haan J, Mulier M. A modified custom-made triflanged acetabular reconstruction ring (MCTARR) for revision hip arthroplasty with severe acetabular defects. Acta Orthop Belg. 2013;79(1):71-75.

37. Placella G, Giulia B, Valerio P, Vincenzo S, Pierluigi A. Dual mobility for total hip arthroplasty revision surgery: A systematic review and metanalysis. SICOT J. 2021;7. doi:10.1051/SICOTJ/2021015

38. Tack P, Victor J, Gemmel P, Annemans L. Do custom 3D-printed revision acetabular implants provide enough value to justify the additional costs? The health-economic comparison of a new porous 3D-printed hip implant for revision arthroplasty of Paprosky type 3B acetabular defects and its closest alternative. Orthop Traumatol Surg Res. 2021;107(1). doi:10.1016/J.OTSR.2020.03.012

39. Abrahams JM, Callary SA, Munn Z, et al. Acetabular Component Migration Measured Using Radiostereometric Analysis Following Revision Total Hip Arthroplasty: A Scoping Review. JBJS Rev. 2020;8(4). doi:10.2106/JBJS.RVW.19.00170

40. Pijls BG, Nieuwenhuijse MJ, Fiocco M, et al. Early proximal migration of cups is associated with late revision in THA: a systematic review and meta-analysis of 26 RSA studies and 49 survivalstudies. Acta Orthop. 2012;83(6):583-591. doi:10.3109/17453674.2012.745353

41. Klerken T, Mohaddes M, Nemes S, Kärrholm J. High early migration of the revised acetabular component is a predictor of late cup loosening: 312 cup revisions followed with radiostereometric analysis for 2-20 years. Hip Int. 2015;25(5):471-476. doi:10.5301/HIPINT.5000246

42. Kim YS, Abrahams JM, Callary SA, et al. Proximal translation of > 1 mm within the first two years of revision total hip arthroplasty correctly predicts whether or not an acetabular component is loose in 80% of cases: a case-control study with confirmed intra-operative outcomes. Bone Joint J. 2017;99-B(4):465-474. doi:10.1302/0301-620X.99B4.BJJ-2016-0805.R1

43. Zampelis V, Flivik G. Custom-made 3D-printed cup-cage implants for complex acetabular revisions: evaluation of pre-planned versus achieved positioning and 1-year migration data in 10 patients. Acta Orthop. 2021;92(1):23-28. doi:10.1080/17453674.2020.1819729

ADDENDUM

Summary

Total hip arthroplasty (THA) is referred to as the operation of the century. In **chapter one** first the evolution of this successful orthopedic operation is described with emphasis on the treatment of the acetabulum. Next the increasing burden of primary THA, revision THA and especially acetabular revision surgery is highlighted. As well as the burden of the problems encountered with acetabular revision such as acetabular bone loss. From this background information the general aim of the thesis is formulated: To evaluate the current treatment options for large acetabular defects and to introduce and evaluate a new acetabular implant to treat large acetabular defects. And four research objectives are established.

To determine and evaluate the current treatment options for large acetabular defects.
Chapter two presents a review of the literature on the current treatment options for large acetabular defects. Large acetabular defects are defined as American Academy of Orthopaedic Surgeons (AAOS) type III or IV or Paprosky type 3A or 3B. We found seven different treatment options for large acetabular defects in 20 included studies: antiprotrusio cage (eight studies), Trabecular Metal™ (Zimmer) augment and shell (four studies), bone impaction grafting (BIG) with a metal mesh (two studies), hemispherical implant with hook and flanges (two studies), TM augment or structural allograft with cup (two studies), cup-cage reconstruction (one study), and custom-made triflange component (one study). TM augments and shells gave the most promising results in terms of the re-revision rate and radiographic loosening. Reconstruction with an antiprotrusio cage was the most frequently reported technique, with good results in a physically low demand elderly population. BIG seems not appropriate for pelvic discontinuity and prone to failure in patients with Paprosky type-3B defects. In those cases, a custom-made triflange implant or a cup-cage reconstruction might be the best alternative, but few reports of sufficient quality are available yet.

To describe a new patient specific technique to treat large acetabular defects with a 3D printed custom-made acetabular implant.
In **chapter three** a new custom-made acetabular implant for large acetabular defects is introduced including its surgical technique. It describes extensive preoperative planning with a detailed approach to defect analysis, including measurement of bone deficiency and bone quality using thin-sliced CT-scans. The implant is designed as a porous augment that fills up the defect and a cage with precisely outlined flanges to the host bones of the ilium, ischium, and pubis, taking into account the bone quality for optimal screw purchase. To ensure accurate placement of the custom-made implant a 3D-printed anatomical plastic model of the hemipelves and trial implants in modular and monoblock fashion as well as patient specific drill guides are provided during surgery. A dual mobility cup is cemented in the implant to reduce the risk of dislocation. A retrospective case series of the first 12 patients with a minimum follow-up of 18 months, showed promising clinical outcomes.

To effectively evaluate the placement accuracy of this new custom-made acetabular implant.
The accuracy of the placement of the implant is evaluated in **chapter four.** In a total of 16 patients who received the custom-made acetabular implant the planned inclination (INCL), anteversion (AV), rotation and centre of rotation (COR) of the implant are compared with the post-operative position using CT scans. Furthermore, intra-operative and early complications are reported. A total of seven implants are malpositioned in one or more parameters: 1 with respect to INCL, three with respect to AV, four with respect to rotation and five with respect to the COR. Four complications are described including two dislocations. In **chapter five** the placement accuracy is evaluated in another 16 patients and this second group is compared to the first group. In chapter five a trend towards better surgical accuracy and less complications in the second group is found, despite a higher complexity in cases. The higher complexity is highlighted by a higher number of previous revisions in the second series. In the second series no implants are malpositioned for AV and no dislocations occurred versus two dislocations in the first series.

The only parameters that differ significantly between both series are the planned and postoperative AV. In the second series the AV is higher with a 20° planned and 17.5° postoperative versus a planned and postoperative AV of 11° in the first series.

To evaluate the short-term survival and clinical and radiological outcomes of this new custom-made acetabular implant.

Chapter six is a prospective case series of 50 hips that received the custom-made acetabular implant and describes the clinical and radiological follow-up (FU) at two years. Prospectively collected data of 49 consecutive patients (50 hips), who underwent an acetabular revision with the custom-made acetabular implant are analyzed after two-year FU. Primary outcomes were re-revision of the implant and differences between the modified Oxford Hip Score (mOHS) preoperatively and at two-year FU. Secondary outcomes included several patient reported outcomes (PROMs), radiological results, complications, and a comparison between hips with and without pelvic discontinuity (PD). One patient (one hip) was lost to the two-year FU. No implants needed re-revision. The preoperative and two-year FU mOHS were available in 40 hips and improved statistically significantly. All of the other secondary outcomes improved over time. Five hips (of 45 with radiological two-year FU) had loosening of screws. Eight hips had complications, including three persistent wound leakage, three pelvic fractures, and one dislocation. The mOHS and complication rate were similar in hips with and without PD.

In conclusion, this thesis describes treatment options for large acetabular defects and good results of a new innovative implant design for large acetabular defects in hip revision surgery. From the four research objectives the following conclusions can be drawn:

- *The most optimal treatment options for large acetabular defects are construction options using porous metallic materials such as Trabecular Metal™ augment and shells, cup-cage reconstructions and custom-made triflange implants.*
- *In Paprosky type 3B acetabular defects in particular with pelvic discontinuity, the most extensive form of acetabular defects, custom-made acetabular implants might be the best solution.*
- *There is need for high quality studies on treatment options for large acetabular defects as current studies are of limited quality.*
- *This new unique patient specific custom-made triflange implant has different features, including special software to assess the ultimate bone defect and bone quality, 3D-printed plastic models, and patient specific drill guides, to ensure the optimal placement of the implant and reduce the chance of complications and implant failure.*
- *Placement accuracy of this custom-made acetabular construct is satisfactory, and accuracy increases over time despite of a more difficult case load, illustrated by a higher number of previous revisions*
- *A higher anteversion might reduce dislocation: 20 degrees of anteversion remains the goal in future case planning*
- *Precise planning and accurate placement of an acetabular implant will lead to better survival rates and better clinical and radiological results.*
- *This custom-made acetabular implant is a viable or even the best option for uncontained acetabular defects and pelvic discontinuit*

Samenvatting

De totale heupprothese (THP) wordt ook wel de operatie van de eeuw genoemd. In **hoofdstuk één** wordt eerst de evolutie van deze succesvolle orthopedische operatie beschreven met de nadruk op de behandeling van het acetabulum. Vervolgens wordt de toenemende last van primaire THP, revisie-THP en vooral acetabulaire revisiechirurgie belicht, evenals de last van de problemen die zich voordoen bij acetabulaire revisie, zoals acetabulair botverlies. Vanuit deze achtergrondinformatie is het algemene doel van dit proefschrift geformuleerd: Het evalueren van de huidige behandelingsmogelijkheden voor grote acetabulaire defecten en het introduceren en evalueren van een nieuw acetabulair implantaat voor de behandeling van grote acetabulaire defecten. Hiervoor zijn vier onderzoeksdoelstellingen vastgesteld.

Het determineren en evalueren van de huidige behandelingsmogelijkheden voor grote acetabulaire defecten.
Hoofdstuk twee geeft een overzicht van de literatuur over de huidige behandelingsopties voor grote acetabulaire defecten. Grote acetabulaire defecten worden gedefinieerd als American Academy of Orthopaedic Surgeons (AAOS) type III of IV of Paprosky type 3A of 3B. We vonden zeven verschillende behandelingsopties voor grote acetabulaire defecten in 20 geïncludeerde studies: antiprotrusio cage (acht studies), Trabecular Metal (TM) (Zimmer) augment en shell (vier studies), bone impaction grafting (BIG) met metal mesh (twee studies), hemisferisch implantaat met haak en flenzen (twee studies), TM augment of structurele allograft met cup (twee studies), cup-cage reconstructie (één studie) en op maat gemaakte triflange-component (één studie). TM augments en shells gaven de meest veelbelovende resultaten wat betreft het revisiepercentage en radiologische loslating. Reconstructie met een antiprotrusio cage was de meest gerapporteerde techniek, met goede resultaten in een fysiek weinig eisende oudere populatie. BIG lijkt niet geschikt voor bekkendiscontinuïteit en vatbaar voor falen bij patiënten met Paprosky type-3B-defecten. In die gevallen is een op maat gemaakt triflange implantaat of een cup-cage-reconstructie wellicht het beste alternatief, maar er zijn nog weinig rapporten van voldoende kwaliteit beschikbaar.

Het beschrijven van een nieuwe patiënt specifieke techniek om grote acetabulaire defecten te behandelen met een 3D-geprint op maat gemaakt acetabulair implantaat.
In **hoofdstuk drie** wordt een nieuw op maat gemaakt acetabulair implantaat voor grote acetabulum defecten geïntroduceerd, inclusief de chirurgische techniek. Het beschrijft een uitgebreide preoperatieve planning met een gedetailleerde benadering van het defect, inclusief de meting van het bot tekort en de bot kwaliteit met behulp van dunne CT-scans. Het implantaat is ontworpen als een poreus augment dat het defect opvult en een cage met precieze vleugels naar het ilium, ischium en pubis. Hierbij rekening houdend met de botkwaliteit voor een optimale grip van de schroeven. Om een nauwkeurige plaatsing van het op maat gemaakte implantaat te garanderen, zijn er tijdens de operatie verschillende hulpmiddelen beschikbaar waaronder een 3D-geprint anatomisch plastic model van de hemipelvis en proefimplantaten op modulaire en monoblock, evenals patiënt specifieke boorgeleiders. Een dual mobility cup wordt in het implantaat gecementeerd om het risico op dislocatie te verkleinen. Een retrospectieve casusreeks van de eerste 12 patiënten met een minimale follow-up van 18 maanden liet veelbelovende klinische resultaten zien.

Het effectief evalueren van de plaatsingsnauwkeurigheid van dit nieuwe op maat gemaakte acetabulumimplantaat.
De nauwkeurigheid van de plaatsing van het implantaat wordt beoordeeld in **hoofdstuk vier.** Bij in het totaal 16 patiënten die het op maat gemaakte acetabulaire implantaat hebben gekregen, worden de geplande inclinatie (INCL), anteversie (AV), rotatie en centrum van rotatie (COR) van het implantaat vergeleken met de postoperatieve positie, met behulp van CT-scans. Bovendien worden intra-operatieve en vroege complicaties beschreven. In totaal zeven implantaten zijn verkeerd gepositioneerd in een of meerdere parameters: één ten opzichte van INCL, drie ten opzichte van AV, vier ten opzichte van rotatie en vijf ten opzichte van de COR. Er worden vier complicaties beschreven, waaronder twee dislocaties.

In **hoofdstuk vijf** wordt de plaatsingsnauwkeurigheid geëvalueerd bij nog eens 16 patiënten en deze tweede groep wordt vergeleken met de eerste groep. In hoofdstuk vijf wordt een trend geconstateerd van betere chirurgische nauwkeurigheid en minder complicaties in de tweede groep, ondanks een grotere complexiteit van de gevallen. De hogere complexiteit wordt duidelijk door een groter aantal eerdere revisies in de tweede groep. In de tweede groep zijn er geen implantaten verkeerd gepositioneerd voor AV en zijn er geen dislocaties opgetreden in vergelijking met twee dislocaties in de eerste groep. De enige parameters die significant verschillen tussen beide series zijn de geplande en postoperatieve AV. In de tweede reeks is de AV hoger met een 20° geplande en 17,5° postoperatieve AV versus een geplande en postoperatieve AV van 11° in de eerste groep.

Het evalueren van de overleving op korte termijn en de klinische en radiologische resultaten van dit nieuwe op maat gemaakte acetabulumimplantaat.

Hoofdstuk zes is een prospectieve casusreeks van 50 heupen die het op maat gemaakte acetabulaire implantaat ontvingen en beschrijft de klinische en radiologische follow-up (FU) na twee jaar. Prospectief verzamelde gegevens van 49 opeenvolgende patiënten (50 heupen), die een acetabulumrevisie ondergingen met het op maat gemaakte acetabulaire implantaat, worden na twee jaar FU geanalyseerd. Primaire uitkomsten waren revisie van het implantaat en het verschil tussen de gemodificeerde Oxford Hip Score (mOHS) preoperatief en na twee jaar FU. De secundaire uitkomsten zijn verschillende door de patiënt gerapporteerde uitkomsten (PROM's), radiologische resultaten, complicaties en een vergelijking tussen de uitkomsten van heupen met en zonder bekkendiscontinuïteit. Eén patiënt (één heup) was verloren voor de tweejarige FU. Geen van de implantaten hoefde gereviseerd te worden. De preoperatieve en tweejarige FU mOHS waren beschikbaar in 40 heupen en verbeterden statistisch significant. Alle andere secundaire uitkomsten verbeterden in de loop van de tijd. Bij vijf heupen (van de 45 met radiologische FU van twee jaar) gingen schroeven los. Acht heupen hadden complicaties, waaronder drie met aanhoudende wondlekkage, drie met bekkenfracturen en één dislocatie. De mOHS en het aantal complicaties was vergelijkbaar bij heupen met en zonder bekkendiscontinuïteit.

Concluderend beschrijft dit proefschrift de behandelingsopties voor grote acetabulaire defecten en goede resultaten van een nieuw innovatief op maat gemaakt implantaat voor grote acetabulaire defecten bij heuprevisiechirurgie. Uit de vier onderzoeksdoelstellingen kunnen de volgende conclusies worden getrokken:

- *De meest optimale behandelingsopties voor grote acetabulumdefecten zijn constructie-opties met behulp van poreuze metalen materialen zoals Trabecular Metal™ augment en shells, cup-cage-reconstructies en op maat gemaakte triflange-implantaten.*
- *Bij Paprosky type 3B acetabulaire defecten, in het bijzonder die met bekkendiscontinuïteit (de meest uitgebreide vorm van acetabulaire defecten) kunnen op maat gemaakte acetabulaire implantaten de beste oplossing zijn.*
- *Er is behoefte aan studies van hoge kwaliteit over de behandelingsopties voor grote acetabulaire defecten, aangezien de huidige studies van beperkte kwaliteit zijn.*
- *Dit nieuwe, unieke, op maat gemaakte triflange-implantaat heeft verschillende unieke eigenschappen, waaronder speciale software om het uiteindelijke botdefect en de botkwaliteit te beoordelen, 3D-geprinte plastic modellen en patiënt specifieke boorgeleiders om de optimale plaatsing van het implantaat te garanderen en de kans op complicaties en implantaat falen te verlagen.*
- *De plaatsingsnauwkeurigheid van deze op maat gemaakte acetabulaire reconstructie is bevredigend, en de nauwkeurigheid neemt in de loop van de tijd toe ondanks een moeilijkere casusbelasting, geïllustreerd door een groter aantal eerdere revisies*
- *Een hogere anteversie kan dislocatie verminderen: 20 graden anteversie blijft het doel bij toekomstige casusplanning*
- *Nauwkeurige planning en plaatsing van een acetabulair implantaat leiden tot betere overleving en betere klinische en radiologische resultaten.*
- *Het op maat gemaakte acetabulaire implantaat is een goede of zelfs de beste optie voor grote acetabulaire defecten en bekkendiscontinuïteit*

Dankwoord

Het is bijna niet te bevatten dat, na ruim 10 jaar in de maak, dit boekje nu toch echt een feit is. Een heleboel mensen hebben mij hierbij geholpen en in ondersteund. Een aantal mensen wil ik hieronder in het bijzonder noemen.

Allereerst dr. M Spruit, beste Maarten. Zonder jou was dit boekje er zeker nooit gekomen. Jij hebt dit onderwerp bij mij niet alleen geïntroduceerd, maar me vervolgens ook tijdens elke stap begeleid. Je ideeën, je begeleiding, je zeer specifieke commentaren op mijn artikelen maar ook je geduld (het heeft ongetwijfeld langer geduurd dan je had gewenst) hebben allemaal bijgedragen aan dit boekje. Ik heb je eerlijkheid, directheid en je zeer vlugge reageren altijd enorm gewaardeerd. Ontzettend bedankt voor alles.

Prof. dr. S.K. Bulstra, beste Sjoerd. Bedankt dat je de potentie van mijn onderzoek zag en er vertrouwen in had dat het een promotie kon worden. Je betrokkenheid bij niet alleen mijn promotie maar ook bij mij persoonlijk is kenmerkend voor je. Ik heb, naast al je inspanningen voor mijn promotie, het ook zeer gewaardeerd hoe je bent om gegaan met mijn carrière keuzes. Ik prijs me gelukkig dat ik onder jouw leiding mag promoveren.

Prof. dr. P.C. Jutte, beste Paul. Bedankt dat ook jij de potentie van mijn onderzoek zag en wilde instappen als promotor. Ik heb naast je inhoudelijke sterke, je ook altijd positieve en opbeurende commentaren zeer gewaardeerd. Die steun heeft mede het extra zetje gegeven om het af te ronden.

G.G. van Hellemondt, beste Gijs. Samen met Maarten was jij de aanstichter van dit onderzoek. Op het einde meer vanaf een afstand maar zonder jou was dat onderzoek nooit van de grond gekomen.

Dr. M.L. van Hooff, beste Miranda. Bedankt voor je eindeloze geduld met dingen uitleggen en onze, vaak ook gezellige, (meestal telefonische) gesprekken. Je hebt me zo veel geleerd over methodologie, statistiek en eigenlijk alles wat je nodig hebt om onderzoeker te zijn. Ook al wilde ik het niet altijd allemaal weten en was je vaak het meest kritisch met je commentaar, niet alleen mijn proefschrift maar ook ikzelf ben er beter van geworden.

Leden van de leescommissie en de oppositie, hartelijk dank voor het beoordelen en toetsen van dit proefschrift.

Alle stafleden, onderzoekers en andere medewerkers van de Sint Maartenskliniek. Bedankt voor jullie bijdrage aan het onderzoek. In het bijzonder Bart Swierstra, Petra Heesterbeek, Bart Nienhuis, Katrijn Smulders, Jolanda Rubrech-van As en Saskia Susan.

Alle (orthopedisch) chirurgen en medewerkers van de afdelingen chirurgie en orthopedie in de Isala, het UMCG en het MCL en alle AIOS van de ROGO Noord. Bedankt voor de leuke en leerzame tijd bij jullie en de mogelijkheid om opleidingsuren ook aan onderzoek te besteden. Bedankt ook voor het sparren over het onderzoek, in het bijzonder met de experts op het gebied van heupchirurgie Joris (UMCG) en Wierd (MCL). Bedankt ook Paul (MCL) voor het inzicht dat er nu echt genoeg artikelen waren voor een promotie. En natuurlijk Els bedankt voor je hulp met het plannen van afspraken, het eindeloos verlengen van mijn nul aanstelling als onderzoeker in het UMCG en het beantwoorden van een hele hoop andere vragen.

Hiernaast wil ik natuurlijk ook al mijn vrienden en (schoon)familie bedanken voor jullie toevoeging in mijn leven en het (af en toe) aanhoren van verhalen over mijn onderzoek en promotie. Jullie weten wie jullie zijn!

Mijn paranimfen en mijn ouders wil ik hieronder nog apart noemen.

Lieve Victoria, we kennen elkaar al ruim drie keer zo lang als dat deze promotie heeft geduurd en ik ben blij dat tussen ons de promotie de afgelopen 10 jaar amper een onderwerp van gesprek is geweest. Er zijn zo veel belangrijkere dingen om samen te bespreken en als we elkaar spreken zitten we gelukkig nooit om gesprekstof verlegen. Ik kan me geen betere vriendin voorstellen om naast me te hebben staan dan jij deze dag. Heel bijzonder dat je zowel getuige bent geweest bij mijn huwelijk met Ramon en dat nu ook bent bij mijn huwelijk met de wetenschap.

Lieve Ramon, geen zorgen, dit wetenschappelijke huwelijk is echt geen concurrent (meer). Vanaf het moment dat we elkaar kennen heb je al moeten aanhoren: 'ik moet echt aan mijn onderzoek' en later: 'ik moet aan mijn promotie'. Volgens mij ben je nog verbaasder dan ik dat het er nu dan eindelijk echt van gaat komen en je gaat die zinnetjes vast niet missen. Je hebt al die jaren ervoor gezorgd dat ik eraan ging werken en twee kinderen later dat ik eraan kon werken. Daarnaast was jij mijn helpdesk als ik weer volledig vastliep in Word, Excel, Paint of welk programma dan ook en zagen, dankzij jou skills, de figuren en tabellen in mijn artikelen er professioneel uit. Dat dit boekje er zo mooi uitziet is ook geheel jouw verdienste. Op het einde was het zinnetje dan ook 'ik moet echt aan jouw promotie'. Mijn praatjes op congressen heb ik tot uit den treure op je geoefend en je weet inmiddels, als architect, verdacht veel van heuprevisies. Natuurlijk helpt dit als je op deze dag naast me staat, maar al had je totaal geen verstand van dit onderwerp gehad dan had ik jou ook naast me willen hebben. Lieve schat, met jou aan mijn zijde heb ik elke dag het het gevoel dat ik de wereld aankan.

Lieve mam, zoals je zelf zei heb je mijn onderzoek altijd vanaf de zijlijn gevolgd. Mijn onderzoek was toch meer papa's pakkie an. Maar je bent geweldig in het gat gesprongen de afgelopen maanden en hebt me super geholpen met de stellingen en het corrigeren van mijn Nederlands. Verder zie ik er dankzij jou tiptop uit tijdens de verdediging. Daarnaast ben je natuurlijk mijn allerliefste mama waarvoor je sowieso alle lof en dank verdient.

Lieve pap, wat mis ik je ontzettend veel, elke dag als vader, opa, docent en op dit moment nog net een beetje meer dan anders. Het moment is eindelijk daar: na ruim 10 jaar ga ik promoveren! Hoe vaak jij niet hebt gezegd: 'moet je niet aan je onderzoek werken?', 'hoe staat het ervoor met je promotie?' en 'het zou zonde zijn als je het nou niet afmaakt'. Helaas kan je er nu niet meer bij zijn maar ik heb je gelukkig nog wel kunnen vertellen dat het er nu echt van ging komen. Je reactie was tekenend: je moest een beetje lachen. Als bijzonder hoogleraar rechten van de mens in het strafrecht had je al vele promovendi begeleid. En bij je eigen dochter voelde je je volgens mij stiekem ook een beetje promotor. Je hebt vele uren besteed aan het doorlezen van al mijn artikelen tot en met de inleiding van dit boekje. Dankzij jouw taalgevoel werden zinnen een stuk korter en duidelijker. Je kon het niet laten er ook inhoudelijk commentaar op te hebben. Dit leidde nog wel eens tot discussies tussen ons maar ik moet toegeven dat het vaak begrijpelijker werd door jou input. Ook had je, in je hoedanigheid als emeritus-hoogleraar, graag in de corona willen zitten. Daarom heb ik speciaal voor jou twee stellingen toegevoegd. Eén op je vakgebied als professor in de mensenrechten en één uit je eigen proefschrift. Die laatste past perfect bij jou en ik hoop dat ik met dezelfde humor en eigenzinnigheid deze promotie en het leven verder aanga. Lieve pap ik hou van je!

Curriculum Vitae

Marieke Baauw werd geboren op 26 februari 1987 in Nieuwegein. Ze groeide op in Utrecht waar ze in 2005 haar diploma behaalde op het Utrechts Stedelijk Gymnasium. Hierna volgde zij de studie geneeskunde aan de Rijks Universiteit Groningen. Na een bestuursjaar, (extra) coschappen in Groningen, Deventer en Panama City en een aantal (verre) reizen behaalde zij in 2013 haar artsenbul.

Tijdens haar coschappen werd haar interesse voor verschillende vakgebieden gewekt waaronder de orthopedie. Tijdens haar keuze coschappen in de Sint Maartenskliniek in 2012 startte zij met het onderzoek dat uiteindelijk tot deze promotie zou leiden. Ze werkte een tijd als ANIOS in de orthopedie en startte in 2016 met de opleiding tot orthopeed in de ROGO Noord. Echter in het leven lopen de dingen soms anders dan van tevoren bedacht en in 2021 besloot zij met deze de opleiding te stoppen. Na een jaar als jeugdarts te hebben gewerkt is ze per maart 2023 gestart met de opleiding tot huisarts. Marieke woont samen met haar man Ramon Scharff en hun kinderen Dora en Jip, in hun zelfontworpen woning in Putten.

Research Institute SHARE

This thesis is published within the **Research Institute SHARE** (Science in Healthy Ageing and healthcaRE) of the University Medical Center Groningen / University of Groningen.
Further information regarding the institute and its research can be obtained from our internet site:
https://umcgresearch.org/w/share

More recent theses can be found in the list below.
(supervisors are between brackets)

2023

Gaalen AEJ van
Why so serious? Game-based learning in health profession education: State of the art and future directions
(Prof ADC Jaarsma, dr JR Georgiadis)

Yang X
Emphysema and lung cancer in population-based CT screening
(Prof GH de Bock, dr MD Dorrius, dr M Vonder, dr Y Du)

Voorwinden JS
Decision making, outcomes and result disclosure in the field surrounding genetic counselling
(Prof AV Ranchor, Prof IM van Langen)

Verhoeff M
Towards coordination and tailoring of hospital care for patients with multimorbidity
(Prof BC van Munster, Prof JS Burgers, dr JF de Groot)

Dokkum NH van
Towards improving neurodevelopmental outcomes in preterm infants. Efforts during NICU stay and beyond
(Prof SA Reijneveld, Prof AF Bos, Prof MLA de Kroon)

Damhuis SE
Diagnosis and management of late-onset fetal growth restriction
(Prof SJ Gordijn, dr JW Ganzevoort, dr H Groen)

Mol TI
The road to self-regulation
(Prof MWM Post, Prof CAM van Bennekom, dr EWM Scholten)

2022

Machlaurin A
Health economic evaluations of tuberculosis control in Indonesia
(Prof MJ Postma, Prof TS van der Werf, dr D Setiawan)

Quispel-Aggenbach DWP
Delirium in older outpatients; Detection, prevalence and prognosis
(Prof SU Zuidema, dr HJ Luijendijk)

Tanaka MJ
The medial patellofemoral complex: Surgical anatomy, dynamic assessment, and considerations for reconstruction in the treatment of patellofemoral instability
(Prof JN Doornberg, dr H van der Veen)

Tornetta P
Tibial Shaft Fractures: Challenges in Diagnosis and Management
(Prof JN Doornberg, dr FFA IJpma)

Man T
Genetic and Environmental Determinants of Blood Pressure: The Role of Obesity and the Autonomic Nervous System
(Prof H Snieder, dr H Riese, dr IM Nolte)

Straathof EJM
Neurological signs in infancy prevalence, pathophysiology and neurodevelopmental Outcome
(prof M Hadders-Algra, dr KR Heineman, dr EG Hamer)

Vanajan AC
Older workers' work limitations, vitality and retirement preferences: The differential effects of chronic health conditions
(Prof CJIM Henkens, Prof U. Bültmann)

Ding L
Optimization of breast cancer screening: informed decisions on benefits and harms
(Prof GH de Bock, Prof G Van Hal, dr MJW Greuter)

Dijkstra DJ
Fetal programming in preeclampsia-like mouse models
(Prof T Plosch, Prof SA Scherjon)

For earlier theses please visit our website


Research Institute
SHARE