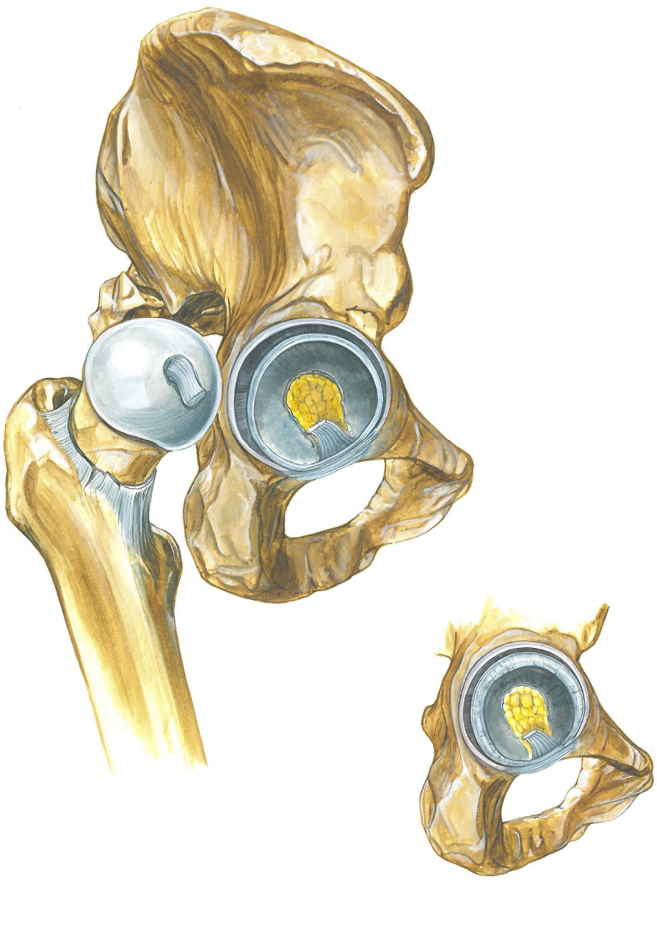
Assessment of Factors Influencing the Surgical Outcome of Periacetabular Osteotomy for Treatment of Hip Dysplasia in Adults

PhD Thesis

Charlotte Hartig-Andreasen



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Front: normal hip joint and a detail painting of a hypertrophic acetabular labrum,
watercolor drawing by illustrator Anne Hviid Nicolaisen

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Preface

This PhD thesis is based on clinical studies carried out at the Orthopedic Research Unit at Aarhus University Hospital during my employment as a PhD student from 2010 to 2013.

The dedications of my supervisors that made possible this PhD journey of three wonderful, instructive and memorable years is admirable. First of all, I want to thank Professor Kjeld Søballe for letting me being a part of the inspiring Orthopeadic Research Unit. Kjeld has a gift of making one feel very special and talented. He has supported me with great working conditions, guidance whenever needed, and most of all, I really appreciate his never-ending faith in my capabilities of doing research. I am deeply indebted to Anders Troelsen, who has been scrupulous in his role as a supervisor. His energy, supervision and constructive criticism have helped me in my daily work and during difficult times when I have questioned my ability to succeed. Finally, I thank Theis Thillemann, who has helped out with the protocol, the studies, and who showed endless patience in guiding me into the not always so fantastic world of statistics.

Also, a special thanks to John Gelineck. During several Fridays in his company with a cup of coffee in a really dark room, John introduced me to the interesting world of radiology and gave me insight into the interpretation of MRAs. A warm thank to Maiken Stilling, who with her knowledge has guided me in my analysis of THAs. She has been supportive, a great friend, and as bad as I am in finding our way running around in Tallinn.

Grateful thanks go to the people who make everything possible. The project coordinators, Rikke Mørup, Inger Krogh-Mikkelsen and Lone Løvgren Andersen, for helping out with the clinical studies and computer analysis of hip radiographs; the secretaries Dorrit Svarre and Karen Fousing, who kept track of my patients, and not least Tina Stenumgaard, who helped me out whenever I was in trouble. Thank you to the staff in the archives, Jette and Jette, who supplied me with patient records and radiographs, whenever needed.

Also, I want to thank all my colleagues in 10A. It has been a wonderful place to work and to share joy and frustrations throughout the years. Thank you to my amazing biostatic group, unbelievable what a biostatic course can lead to!

Finally, I owe a deep-felt thanks to my friends and family for supporting me and encouraging me to keep on going. Last but not least, I could not have done this without the love, support, and understanding from my lovely husband Jesper Vind Andreasen and our two wonderful children Emma and Celine.

Acknowledgements
Aarhus University, Denmark, the Danish Rheumatism Association, and the Orthopedic Research Fond, Aarhus.

List of papers

The PhD thesis is based on following three papers, and they will be referred to in the text by their Roman numerals (I-III)

I. Hartig–Andreasen C, Troelsen A, Thillemann TM, Søballe K.
What factors predict failure 4 - 12 years after periacetabular osteotomy?
Clin Orthop Rel Res 2012; 470:2978-2987

II. Hartig–Andreasen C, Troelsen A, Thillemann TM, Gelineck J, Søballe K.
Can the need for arthroscopy be predicted in patients undergoing periacetabular osteotomy?
Manuscript under preparation

III. Hartig–Andreasen C, Stilling M, Søballe K, Thillemann TM, Troelsen A.
Is cup positioning challenged in hips previously treated with periacetabular osteotomy?
Manuscript submitted.

Study I was awarded the 1st prize in the best paper competition at the yearly meeting of the Danish Orthopedic Society 2011, and awarded the 2nd prize in the best paper competition at the Nordic Orthopedic Federation 56th Congress, Tallinn 2012.

Contents

Abbreviations

In alphabetic order

AI	acetabular index angle
AP	anteroposterior
CE	center-edge angle
CI	confidence interval
CT	computer tomography scan
FABER	flexion, abduction, external rotation
FAI	femoroacetabular impingement
HHS	Harris Hip Score
JSW	joint space width
LCPD	Legg-Calvé-Perthes disease
OHS	Oxford Hip Score
MRA	magnetic resonance arthrography
PAO	periacetabular osteotomy
PROM	patient-reported outcome measurement
RLL	radiolucent lines
SF-36	short form-36
THA	total hip arthroplasty
UL	ultrasound
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index Questionnaire

English summary

Background

Hip dysplasia is a common cause of hip pain and functional disability in the 20 to 40 year old adult. It is characterized by a steep shallow acetabulum resulting in an insufficient coverage of the femoral head. Furthermore, the acetabulum may be retroverted. The proximal femur may be anteverted and exostoses can form at the proximal femoral head-neck junction as well. The abnormal biomechanics in the hip joint results in overload of the acetabular rim, which can lead to labral damage followed by cartilage delamination. The proximal bony abnormality of the femur may result in femoroacetabular impingement aggravating the stress to the rim, worsen the labral stress, and causing cartilage damage. The natural history of symptomatic hip dysplasia is well described in the literature, and if not treated hip dysplasia will lead to early development of osteoarthritis in the hip joint. The periacetabular osteotomy (PAO) is a well-established joint preserving surgical treatment. The procedure is known to relieve pain, increase hip joint functionality and to prevent or delay the development of osteoarthritis. Even though PAO is the preferred joint preserving treatment worldwide several issues remain unclear. The overall aim of the thesis was to assess intra- and extraarticular factors that could influence the surgical outcome after PAO for treatment of hip dysplasia in adults, and to determine whether a total hip arthroplasty, if necessary, can be inserted with a good result into hips after a previous PAO?

Material and Methods

This PhD thesis is composed of three studies. In study I, 316 patients undergoing PAO from December 1998 to May 2007 were evaluated. Demographic data and pre- and postoperative radiographs were evaluated to identify risk factors predicting failure in terms of a THA after PAO. The WOMAC questionnaire was used to evaluate possible pain in the preserved hips. By querying the National Registry of Patients, PAO hips converted to THA were identified. The hip joint survival rate was estimated by Kaplan-Meier analysis, and the Cox regression analysis revealed significant predictors of failure. Study II followed 99 patients (104 hips) prospectively scheduled for PAO. Patients underwent routine MRA prior to surgery. At 2-year follow-up, a clinical and radiological examination was performed. Logistic regression analysis was used to find odds ratios (OR) for significant risk factors that could predict failure in terms of the need for a hip arthroscopy after PAO. Study III was a descriptive study evaluating the hips in study I converted to a THA and with a minimum of 4 years follow-up. Clinical examination and radiographic evaluation were performed at follow-up.

Results

Study I The overall Kaplan-Meier hip survival was 74.8% at 12.4 years. A WOMAC pain score of $\geq$10 suggesting clinical failure was seen in 13% of the preserved hips.

Higher age, a preoperative Tönnis grade of 2, an incongruent hip joint, a postoperative joint space width ≤3 mm, and a postoperative center-edge <30° or >40° predicted conversion to THA.

Study II Analysis is still in progress (results presented are from the first 74 hips). Labral pathology was seen in 94% of the MRAs. Twenty of 74 hips (27%) had a hip arthroscopy after PAO. Preliminary predictors for the need of a hip arthroscopy after PAO are preoperative borderline dysplasia (center-edge angle >20° and <25°) and preoperative sign of acetabular retroversion. Borderline hip dysplasia in combination with a high α-angle (≥55°) were highly significant. The OR for labral detachment became statistically significant for failure after adjusting for age and borderline dysplasia; other types of labral pathology have not yet been shown to predict failure.

Study III None of the patient experienced any hip dislocation or had any revision surgery performed. The median scores were Harris Hip Score 96 (range 42 - 100), Oxford Hip Score 38 (range 8 - 48) and total WOMAC 78 (27 - 100). Mean cup anteversion and abduction angles were 22° (range 7°- 43°) and 45° (range 28°- 65°). Outliers of cup abduction were associated with persisting dysplasia (center-edge angle <25°) after PAO. Leg length was restored in 87% of the hips, and offset slightly increased.

Interpretation

In conclusion, PAO is an effective treatment for symptomatic hip dysplasia. Because of the identification of significant predictors of failure in study I, we expect the hip joint survival rate to increase further owing to an improved selection of the right patient candidate for PAO. Further, focus on the influence of intraarticular pathology and factors that may predict the need for intraarticular assessment may contribute to tailoring treatment of each patient in the future. Finally, if the PAO fails it is possible to insert a THA with a good functional outcome.

Danish summary

Baggrund

Hoftedysplasi er en almindelig kendt årsag til hoftesmerter hos yngre voksne i alderen 20 - 40 år. Sygdommen er kendetegnet ved en stejl hofteskål og et utilstrækkeligt dækket lårbenshoved. Hofteskålen kan være retroverteret. Den proksimale del af lårbenet kan være anteverteret og på overgangen mellem lårbenshoved og lårbenshals kan der være ekstra knoglevækst. Den unormale biomekanik i hofteleddet fører til overbelastning af hofteskålskanten, hvilket medfører at størstedelen af patienterne med hoftedysplasi har en ledlæbe- og/eller bruskskade. Den øgede knoglevækst på lårbenshalsen kan forårsage at ledlæben kommer i klemme og symptomer på femoroacetabular impingement opstår. Det resulterer i yderligere overbelastning af hofteleddet og forværring af en eventuel ledlæbe- og/eller bruskskade. Ubehandlet, medfører symptomatisk hoftedysplasi slidgigt i hoften i tidlig alder. Den periacetabulære osteotomi (PAO) er en anerkendt ledbevarende kirurgisk behandling for hoftedysplasi. Ved PAO, drejes hofteskålen og biomekanikken i hofteleddet optimeres. Det resulterer i, at smerterne i leddet lindres og funktionen i hofteleddet bedres. Operationen medfører, at behovet for en kunstig hofte (THA) udskydes og nogle helt undgår at få behov for en THA. Selvom PAO anvendes over hele verden, er der flere ubesvarede spørgsmål. Formålet med denne PhD afhandling er at belyse faktorer, enten uden for leddet eller inde i selve hofteleddet, der kan have betydning for slutresultatet af PAO. På trods af en veludført PAO, ender nogle patienter med en THA kort tid efter PAO. På dette område findes der kun sparsom litteratur, og vi vil derfor undersøge, om en THA kan indsættes med et godt resultat i hofter, hvor der tidligere er udført ledbevarende hoftekirurgi i form af PAO.

Materiale og fremgangsmåder

Denne PhD afhandling består af tre undersøgelser. I studie I indgik 316 patienter (PAO fra december 1998 - maj 2007). Demografiske data og præ- og postoperative røntgenbilleder blev undersøgt med henblik på at identificere risikofaktorer, der kunne forudse behovet for en THA til trods for den ledbevarende operation. Ved forespørgsel til Landspatient registret, blev de patienter der havde fået en THA efter PAO identificeret. For at vurdere hoftens funktion, fik alle med bevaret hofteled tilsendt et WOMAC spørgeskema. Hofteleddets overlevelsesrate blev estimeret ved Kaplan-Meier analyse. Cox regressionsanalyse belyste signifikante risikofaktorer for senere konvertering til THA. Studie II omfattede 99 patienter (104 hofter), der inden PAO fik foretaget rutinemæssigt magnetisk resonance artrografi (MRA). Ved den præoperative undersøgelse og ved 2-års kontrollen blev der udført klinisk og radiologisk undersøgelse. Logistisk regressionsanalyse anvendtes til at beregne odds ratioen for statistisk signifikante risikofaktorer, der kunne forudsige behovet for en kikkert undersøgelse af hofteleddet efter PAO. I studie III, blev de patienter, der i studie I havde fået en THA minimum 4 år tidligere, indkaldt til kontrol. Ved kontrollen blev der udført klinisk og radiologisk undersøgelse.

Resultater
Studie I Hofte overlevelsesraten blev beregnet til 74.8% efter 12.4 år. Blandt de bevarede hofter havde 13% en smertescore på ≥10. Ved Cox regressions analyse fandt vi at alder >40 år, asymmetri i hofteleddet, præoperative tegn på slidgigt, en forsnævret ledspalte bredde på 3 mm eller mindre, og en CE-vinkel ≤30° eller ≥40° efter PAO forøgede risikoen signifikant for konvertering til THA.
Studie II Resultaterne er foreløbige og omhandler 74 hofter. MRA påviste abnorm ledlæbe i 94% af hofteleddene. Tyve ud 74 patienter (27%) havde fået udført kikkertundersøgelse af hofteleddet efter PAO. Foreløbige beregninger viser, at grænse-hoftedysplasi vurderet ved CE-vinklen før PAO (CE-vinkel ≥20° og <25°), retroverteret acetabulum og grænse-hoftedysplasi kombineret med en høj α-vinkel (>55°) øger risikoen statistisk signifikant for behov for kikkertundersøgelse efter PAO. Arten af labrum patologi var overordnet ikke signifikant for kikkertundersøgelse efter PAO. OR for at en afreven ledlæben var dog signifikant for udfaldets efter justering for alder og grænse-hoftedyplasi.,
Studie III Fyrre patienter (44 hofter) indgik i studiet. Ingen havde haft hofteluksationer eller behov for revisionskirurgi. Median Harris hip score var 96 (interval 42 - 100), Oxford hofte score var 38 (interval 8 - 48) og total WOMAC score var 78 (27 - 100). Gennemsnitsvinklen for den isatte hofteskåls anteversionsvinkel og abduktionsvinkel var henholdsvis 22° (interval 7°- 43°) og 45° (interval 28°- 65°). Persisterende hoftedysplasi (CE-vinkel <25°) efter PAO øgede risikoen for, at vinklerne for den isatte protese i hofteskålen var udenfor normalområdet. Hos 87% af patients fandtes der ingen benlængdeforskel.

Konklusion
Generelt kan man konkludere, at PAO er en effektiv behandling af symptomatisk hoftedysplasi. På baggrund af resultaterne i studie I, forventes hofteoverlevelsesraten at stige efter PAO, da den øgede viden om faktorer, der prædikterer for behovet for THA efter PAO anskueliggøres. Dermed kan udvælgelsen af den rette patientkandidat til ledbevarende kirurgi bedres. Endvidere, kan den øgede viden om, hvordan graden af hoftedysplasi inden operationen, samt udseendet på lårbensknoglen påvirker resultat af PAO måske være med til at kunne skræddersy den kirurgiske behandling til hver enkelt patient i fremtiden. Sluttelig, opstår behovet for en kunstig hofte efter PAO, så er det muligt at indsætte en THA med et godt funktionelt resultat, i hvert fald inden for de første fire år.

Introduction

What is hip dysplasia?

Hip dysplasia

The term dysplasia of the hip is multifarious and includes several conditions with morphological changes around the hip joint. Primary developmental dysplasia of the hip is congenital, and secondary hip dysplasia is a consequence of congenital dislocation of the hip or other hip malformations such as Legg-Calvé-Perthes disease [1]. The etiology of hip dysplasia is multifactorial, and implicated are both mechanical and genetic factors [2, 3]. In this thesis the term used is hip dysplasia, and it covers both the developmental dysplasia of the hip and congenital dislocation of the hip.

The abnormal biomechanics in the dysplastic hip joint has proven to lead to osteoarthritis in the hip if left untreated. The natural course of hip dysplasia was first described by Wiberg [4]. He found that without treatment, osteoarthritis developed at a young age in patients with a dysplastic hip. Later Cooperman et al. [5], Murphy et al. [6], and Hartofilakidis et al. [7] supported these findings.

The exact pathway by which osteoarthritis develops in dysplastic hips is yet not fully understood. In hip dysplasia, the hip is characterized by structural abnormalities in the acetabulum and the proximal femur. The acetabulum is underdeveloped, with the acetabular roof being steep and shallow, resulting in insufficient coverage of the femoral head anteriorly and laterally. In addition, acetabular retroversion has been seen in up to one-third [8, 9] of dysplastic hips. On the femoral site, the femoral neck is often found to be extremely anteverted [10, 11] or to show excessive coxa valga [12]. The morphologic changes seen in hip dysplasia alter the normal biomechanics of the hip joint, resulting in decreased contact area between the acetabulum and the femoral head and causing overload to the acetabular rim [13, 14]. This increases the stress to the acetabular cartilage [15], which may lead to degeneration of the cartilage and later osteoarthritis [16]. Also, the rim may fracture and stress the acetabular labrum [17], resulting in tearing of the labrum, and eventually cartilage delamination [18, 19]. A tearing of the acetabular labrum seems to disrupt the natural seal between the acetabulum and the femoral head that is used to stabilize the hip joint. Without the seal, micromotion between the femoral head and the acetabulum occurs, stressing the labrum and the cartilage further by repetitive microtrauma [20, 21]. It has been shown in a poroelastic finite element hip model, how lack of a seal significantly increases the solid-on-solid contacts between the femoral head cartilage and the acetabular cartilage after removal of the labrum [21].

The diagnosis of hip dysplasia is by clinical and radiographic evaluation. Eighty percent of the symptomatic patients are female [22-24]; however, in a large population study, the prevalence was found to be same, with equal sex distribution in men (4.3%) and women (3.6%) [25]. The typical patient is between

20 and 40 years old and female, but why up to 80% of patients undergoing PAO are female remains unclear. Hip symptoms arise when the acetabular rim is overloaded due to the abnormal biomechanics in the hip joint. The typical sign is a sharp pain located deep in the groin, and can often be provoked by hip flexion and internal rotation [26]. The radiographic diagnosis is most commonly based on the presence of a reduced center-edge (CE) angle, as described by Wiberg 1939 [4]. The cut-off value for hip dysplasia varies between studies, but a generally accepted normal value for adults is $\geq 25^{o}$. Hip dysplasia is considered when the center-edge angle is $<20^{o}$ and a center-edge angle between 20^{o} to $<25^{o}$ is often referred to as borderline dysplasia of the hip [22, 27].

Surgical treatment of dysplasia of the hip

In 1984, Ganz revolutionized the surgical procedure for hip dysplasia. The limitations of the existing triple osteotomies gave rise to the periacetabular osteotomy [22]. The Ganz or Bernese osteotomy (now called periacetabular osteotomy, PAO) allows reorientation of the acetabulum in three dimensions, thereby enhancing the femoral head coverage and improving hip joint congruence. The blood supply to the acetabulum is maintained, the posterior column remains intact allowing immediate partial weight-bearing, and the shape of the true pelvis is unchanged [22]. The ultimate goal of the PAO is to reduce pain and to improve the function of the hip. The reorienting surgery reduces the contact pressures of the load bearing area in the hip joint, relieving the overload to the acetabular rim, and reduces stress to the acetabular labrum, thereby delaying or even avoiding the development of osteoarthritis [14-16, 23, 28-33].

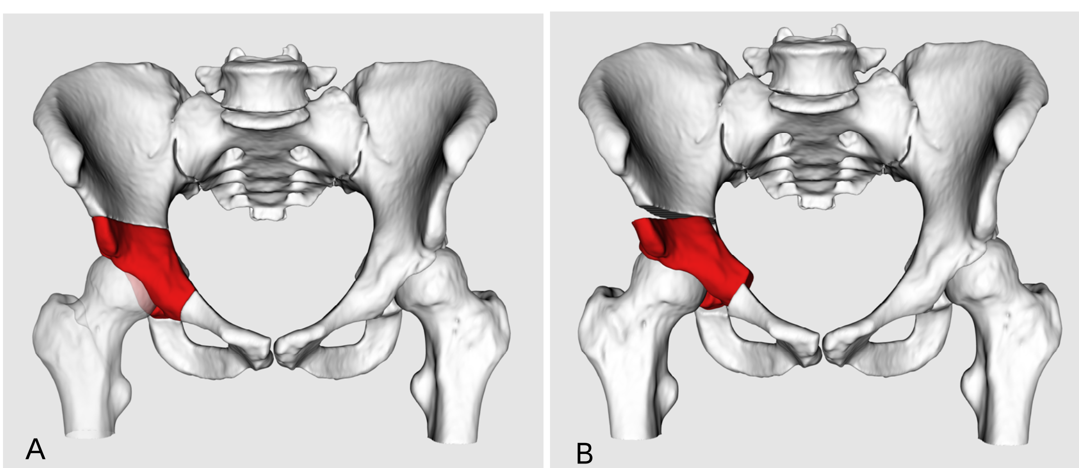


Figure 1. CT models of the pelvis illustrating the hip joint before (A) and after (B) PAO (illustrations kindly provided by Sepp de Raedt).

In 2003, the new minimally invasive approach to PAO was introduced by Søballe, and has been used at our institution since then [34]. Through an incision of only 7 cm and without muscle detachments it is possible to perform the reorientation of the acetabulum. This technique reduces the surgical trauma to the soft tissue, reduces blood loss and thereby the need for blood transfusion, and shortens the surgical time. This without an increase in complications, and optimal reorientation of the acetabulum is still possible [35].

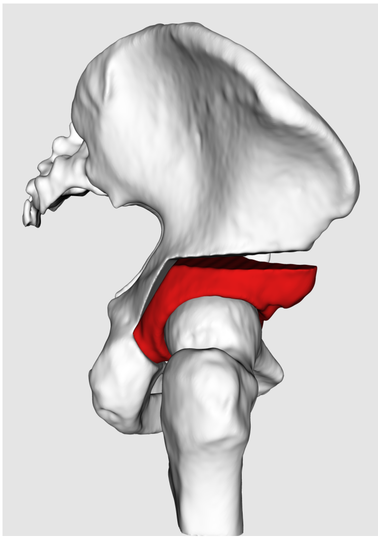


Figure 2. CT model illustrating the periacetabular osteotomy from the side. The posterior column is preserved. (illustration kindly provided by Sepp de Raedt).

What factors predict failure after periacetabular osteotomy?

Since the development of the PAO 25 years ago, the PAO has been the preferred treatment for symptomatic hip dysplasia in young adults. Several studies have reported high survival rates of the hip joint after joint preserving surgery. Assessed by Kaplan-Meier analysis with conversion to THA as end point, the 5-year and 10-year survival rates were 90% to 84%, and a long-term study revealed a survival rate of 60.5% after 20 years [31, 36, 37]. Several studies [28, 31, 36-39] have identified risk factors predicting failure in terms of THA after PAO. By identifying these factors, hip surgery candidates who will benefit from the PAO can be selected, and patients at risk of early failure can be offered a primary THA and be spared unnecessarily surgery.

Patient-related and radiographic-related predictors of failure

The goal with the PAO is to prevent or delay the development of osteoarthritis, and over the years, several studies have suggested predictors for failure in term of a THA after PAO. Increasing age at surgery has been found to be an independently predictor of failure. Matheney et al. [36, 40] found that age >35 years and Steppacher et al.[31] found that age >30 years were significant risk factors for failure. However one clinical study reported a 81% hip joint survival rate after 10 years in a group of patients 40 years old or older [41].

During the reorienting process the goal is to optimize the biomechanical condition in the hip, thereby delaying the development of osteoarthritis. Preoperative signs of osteoarthritis (Tönnis >1) (Table 1) have in several studies been found to be significant predictors for failure after PAO [16, 28, 37, 38, 42]; however, Murphy et al. report a good outcome even in Tönnis grade 3 hips, provided there is good joint congruency [38].

Table 1. Classification of osteoarthritis according to Tönnis[43]

Grade	
0	No signs of osteoarthritis
1	Increased sclerosis of the femoral head and acetabulum, slight narrowing of the joint space, slight lipping at the joint margins
2	Small cyst in the head or acetabulum, increasing narrowing of the joint space, moderate loss of sphericity of the head
3	Large cysts in the head or acetabulum, severe narrowing or obliteration of the joint space, severe deformity of the head, necrosis

Severe preoperative hip dysplasia (center-edge angle <0º) can impede optimal reorientation of the acetabulum during PAO surgery causing failure [37]. This correlates with the findings of Steppacher et al., who reported worse outcome after PAO if the acetabulum was undercorrected, resulting in a decreased coverage of the femoral head characterized by an extrusion index [31].The presence of an os acetabuli [37] and poor hip congruency [38-40] are also factors that have shown to predict failure after PAO.

The femoroacetabular impingement (FAI) concept has gained increased interest recently. The impingement leads to stress / overload of the articular cartilage or damage to the acetabular labrum [44, 45]. Proximal femoral abnormalities have been found in up 92.5% of the hips treated for hip dysplasia, and up to 73% of the hips have an abnormal head-neck offset ratio or abnormal high α-angle [12]. Improper reorientation of the acetabulum can cause impingement between the acetabulum and the femoral head after PAO [46, 47]. Acetabular retroversion, recognized on weight-bearing AP pelvis radiographs, has shown to cause hip pain and osteoarthritis [48-50]. Preoperatively acetabular retroversion has been found in one in six to one in three dysplastic hips [8, 9, 51]. Preoperatively, the surgeon must be aware of the presence of acetabular retroversion, since overcorrection of the acetabulum during PAO may aggravate the retroversion, thereby causing an iatrogenic femoroacetabular impingement [47]. Presence of acetabular retroversion postoperatively is not rare and a study has shown that 21 out of 33 hips with preoperative sign of retroversion remained retroverted after PAO; five of them with osteoarthritis in the hip joint to follow [52].

The acetabular labrum and hip dysplasia

The acetabular labrum plays an important role in the hip joint. It increases the depth of the acetabulum, thereby enhancing joint stability [20, 53]. It has free nerve endings, and the labrum is thought to be involved in pain sensation and proprioception [54]. Highly important, the labrum plays a role in load distribution of the hip joint. The intact labrum makes the fluid distribution during weight-bearing more equal in the hip joint, resulting in less cartilage deformation and low friction articulation [21, 55], whereas in hips with partial or removed labrum demonstrated higher resistance to rotation at the articular cartilage surface [56].

Labrum abnormalities rarely exist without bony abnormalities [57, 58]. In symptomatic hip dysplasia, a pathological labrum is found in up to nine-tenths of symptomatic dysplastic hips [59-62]. The typical location of the tears is in the anterior superior region of the acetabulum [63], and McCarthy found in his study that all patients with posterior located labral tears had anterior tears as well [18]. In hip dysplasia, the disturbance of the normal biomechanics in the hip joint and the increased load to the acetabular rim may result in degeneration of the labrum, tearing of the labrum, and sometimes detachment of the labrum from the rim [17, 64, 65]. Commonly, the labrum appears hypertrophic or bulbous [62].

Tears of the acetabular labrum are closely correlated with adjacent cartilage damage, thereby increasing the risk for development of osteoarthritis [66-68]. McCarthy et al. found a highly significant association between labral lesions and degeneration. The severity of the cartilage damage seems to be worse in hips with an abnormal labrum than in hips with an intact labrum [18].

Deep pain in the groin and mechanical symptoms such as clicking, locking, and giving away in the hip joint can indicate labrum pathology [69, 70]. Clinically, the impingement test and the FABER test are frequently used; however, the reliability of these tests is unclear. Narvani et al. found that three out of four patients with a MRA- diagnosed labral tear disliked the maneuver "internal rotation, flexion and axial compression"[71] and Troelsen et al. found a sensitivity of 59% and specificity of 100% [72]. In experienced hands ultra sound is reliable in detecting labrum pathology, with a sensitivity of up to 94%, but there is a significant learning curve [72]. Magnetic resonance arthrography (MRA) is considered the gold standard in diagnosing intraarticular pathology and sensitivity and specificity are high when MRA findings are compared to arthroscopic findings [73, 74].

Treatment of labral tear

Previously the labrum was resected, but today experts agree that the labrum should be preserved or refixed rather than debrided (Figure 3). Preserving the labrum contributes to the stability of the hip joint and improves the sealing function of the labrum. Refixing rather than debridement has shown superior results in FAI patients [75-79]. Much of the today's literature describes the treatment of labral tears seen in hips with femoroacetabular impingement. However, despite the fact that most the dysplastic hips have labral pathology, no consensus exists among PAO surgeons as to how to treat coexisting acetabular labral pathology in hip dysplasia [80]. Open arthrotomy during PAO was the first means of addressing intraarticular pathology during PAO [47]; later hip arthroscopy and simultaneous PAO have been described [81]. Hip arthroscopy alone without addressing the bony abnormalities in hip dysplasia is in general not recommended, and studies have reported failure in dysplastic hips undergoing arthroscopy alone [82].

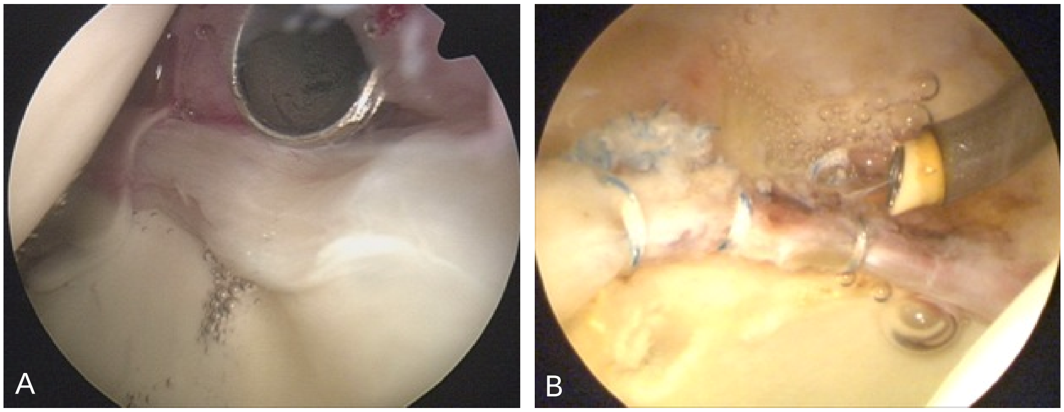


Figure 3. Photographs from a hip arthroscopy. A. A detached acetabular labrum with wave sign. B. The labrum is now fixated to the acetabular rim with three sutures. (The images were supplied by the Department of Sports Traumatology, Aarhus University Hospital, Denmark)

Last option – when the PAO fails

PAO is effective in relieving pain and in improving hip joint biomechanics, thus delaying the progression of osteoarthritis. However, despite an apparently well performed PAO, some patients develop pain and osteoarthritis after PAO, necessitating further surgery with total hip arthroplasty (THA).

Several considerations must be taken into account when planning THA surgery in a dysplastic hip. The patients are typically younger, more active, and have higher functional demands on the hip joint than the average older patient with coxarthritis. The bone quality and structure of the dysplastic hip joint may be different from the non-dysplastic arthritic hip because of the difference in morphology and loading of the hip joint, and this may complicate THA surgery. Studies report improvement in Harris Hip Scores and patient-reported outcome measures and good survivor ship analysis after THA insertion in dysplastic hip without prior PAO [83-87]. The results are comparable to patients receiving a primary THA in non-dysplastic hips [88, 89]. However, only little has been written about the outcome in patients receiving a THA after PAO [90, 91]. In the Danish population, the overall survival of THA after 16 years is 85.5%, with aseptic loosening registered as the most common cause for failure [92]. Several factors can contribute to failure, and especially younger age (<50 year) adds to the risk of early failure [92]. The acetabular components fail more often than do the femoral components, and wear particles and osteolysis play an important role for initiating aseptic loosening [93]. Similar results are seen in Sweden [94].

Recurrent dislocation of the THA is another complication that may cause the need for revision of a THA. A large-register based study found an increased risk (OR of 2.1) for early dislocation (<6 months) after THA in dysplastic hips as compared to patients receiving a THA due to primary osteoarthritis. However, in the long term (6 months to 12 year), no significant difference in dislocations events was found between the acetabular hip dysplasia group and the primary osteoarthritis group [95].

Anatomical and surgical considerations before converting the PAO hip to a THA
Scrupulous planning is mandatory before inserting a THA in a dysplastic hip. The altered morphology in the dysplastic hip, with a steep and shallow acetabulum and insufficient coverage of the femoral head, can challenge the insertion of an acetabular cup. Furthermore, the femoral neck may be excessively anteverted, the neck shaft angle increased, and the femoral canal can be narrow compared to non-dysplastic hip and ultimately a custom made-implant may be required [96-98]. Finally, despite previous PAO, some dysplastic hips present with remaining dysplasia after PAO surgery, and signs of acetabular retroversion have been reported to be present in 10% to 62% of the hips [32, 52, 99]. However, the PAO is believed to ease the insertion of the acetabular cup [90].

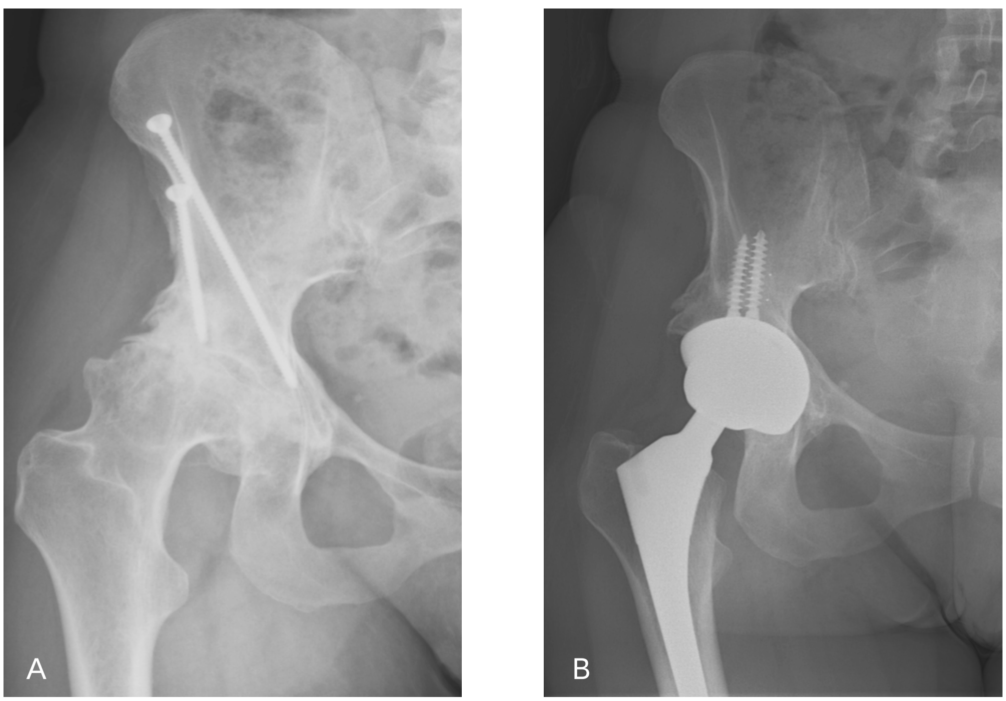


Figure 4. Section of a weight-bearing AP pelvic radiographs. A. Preoperatively before THA, 6½ years after PAO. B. 4½ years after THA.

In conclusion, the existing literature provides a good description of the condition hip dysplasia, and nowadays the most accepted treatment is PAO. However, the literature lacks clear information regarding factors that could predict failure after PAO, which factors may predict the need for intraarticular assessment concomitantly to the PAO, and finally, if the need of a THA rises, does previous pelvic surgery affect the outcome after a THA, and is a THA a safe solution after a PAO?

Aim of the thesis

The overall aim of thesis was to assess intra- and extraarticular factors that could have an influence on the surgical outcome of a PAO for treatment of hip dysplasia in adults; and if necessary, can a THA be inserted with a good result in hips with a previous PAO?

Study I
The aim of this study was to determine hip joint survival rates after PAO; to evaluate the preserved hips regarding pain by using the WOMAC pain score <10; and to determine what radiographic, clinical, and patient-related factors that could predict failure 4 to 12 years after the PAO.

Study II
The aim of this study was to identify risk factors predicting clinical failure in terms of the need for a hip arthroscopy after PAO, to assess outcome in a PAO cohort with MRA-diagnosed labrum pathology, and to assess any difference in outcome between a non-arthroscopy and an arthroscopy group.

Study III
Evaluate the outcome of THA following PAO at 4 to 10 years after THA insertion. Assess whether cup positioning was challenged in hips previously treated with periacetabular osteotomy. Assess what factors were associated with inferior cup position and increased polyethylene wear, and could offset and leg length be restored using conventional THA components.

Material & Methods

All PAOs performed at Aarhus University Hospital were registered in our institutional database of PAOs from December 1998 to 2007. Data includes baseline characteristics of the patients and data regarding the surgery. Further exposition of the content and validity of the database has been described by Troelsen et al.[100]. In the National Registry of Patients (NRP), all patients and their treatment can be followed by a unique personal identification number. The registry contains data concerning ICD8-10 diagnosis from all ambulatory visits and discharges from public and private hospitals in Denmark since 1977 [101]. By linking the patients in the PAO database to NRP, we identified all patients treated with a PAO and subsequent conversion to THA.

The patients followed in studies I, II, and III all underwent PAO. The general indications for PAO today are (1) persisting hip pain, (2) a center-edge angle of Wiberg <25°, (3) pelvic bone maturity, (4) absence of hip subluxation, (5) internal rotation >15°, (6) hip flexion <110° and (7) Tönnis grade of osteoarthritis 0-1. In the early period, patients with moderate to severe Tönnis grade ≥2 were also offered PAO.

Study I

The study cohort consisted of 354 patients (451 hips) undergoing PAO from Dec 1998 to May 2007. Patients were identified from our institutional database of PAOs. Hips converted to a THA were identified by inquiry into the NRP in May 2011. Nine-teen foreigners or emigrants were lost to follow-up (23 hips), two patients died (two hips), and 17 patients (25 hips) were excluded due to poor quality of radiographic images. This left 316 patients (401 hips) in the study cohort. Patient records were thoroughly reviewed and conventional radiographs taken pre- and postoperatively meticulous assessed. All patients with preserved hips received a Western Ontario and McMaster Universities Osteoarthritis Index Questionnaire (WOMAC).

Study II

The patient material consisted of 99 patients (104 hips) consecutively scheduled for PAO at two hospitals in Aarhus from January 2010 to August 2011. To get the most homogenous and well-defined study cohort, patients scheduled for PAO due to dysplastic changes in addition to developmental dysplasia of the hip or congenital dislocation of the hip were excluded. Because of language difficulties during the clinical follow-up and answering of the patient-reported outcome questionnaires, foreigners were not included in the study. Clinical data and questionnaires filled out by the patients were gathered preoperatively and at 2-year follow-up. Weight-bearing AP pelvic radiographs were taken preoperatively and at 2-year follow-up and were analyzed. For data analysis, patients were divided into a non-arthroscopy group (controls) and an arthroscopy group (cases).

Study III
Eligible for inclusion were those patients identified in study I who underwent PAO with a subsequent conversion to THA. Forty patients (44 hips) had a minimum 4-year follow-up after THA, but two patients (two hips) were excluded (one due to psychiatric disease; one due to cerebral palsy) and four patients were lost to follow-up. Hence the study group consisted of 34 patient (38) hips. Follow-up was performed at Aarhus University Hospital during January and February 2012. Four patients with residence on Zealand were followed up at Hvidovre Hospital in April 2012. At follow-up clinical and radiological examinations were performed and patient-reported outcome measures answered.

Design

Study I A register-based retrospective cohort study.
Study II A prospective follow-up study of patients scheduled for PAO.
Study III A descriptive cohort study of all patients identified in study I with a PAO hip converted to a THA.

Radiographic evaluation

Conventional radiographs
In all three studies, the routine pre- and postoperatively anteroposterior (AP) pelvic radiographs taken in connection to the PAO were analyzed. In study I, the radiographs were meticulous assessed for radiographic factors that could predict failure. The parameters measured were the center-edge angle of Wiberg [4], the acetabular index angle of Tönnis [43], the width of the sclerotic zone, the presence of an acetabuli [17], parameters characterizing the femoral head, signs of retroversion, hip congruence, and the minimal joint space width [102], and grade of osteoarthritis according to Tönnis[43].

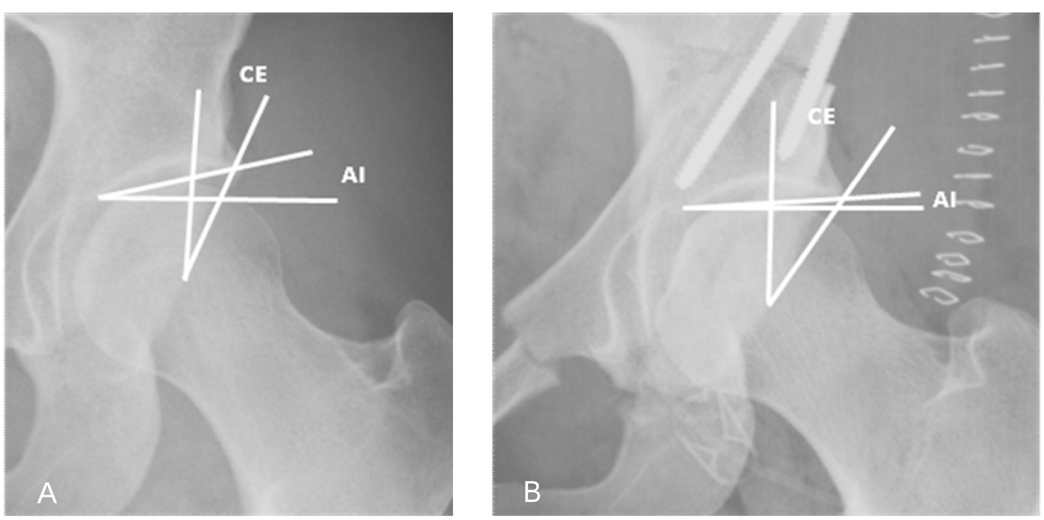


Figure 5. Measurement of the center-edge angle (CE) and acetabular index angle (AI) before (A) and after PAO (B). The measurement are performed on the full AP pelvic radiographs and with a reference line (not illustrated)

Hip congruence is described as being important for a good clinical outcome after joint-preserving surgery [39]. In study I, congruency was considered if the center of the best-fitted circle of the acetabulum drawn by a compass was concentric to the center of the femoral head identified by the use of Moses template on the AP pelvic radiographs.

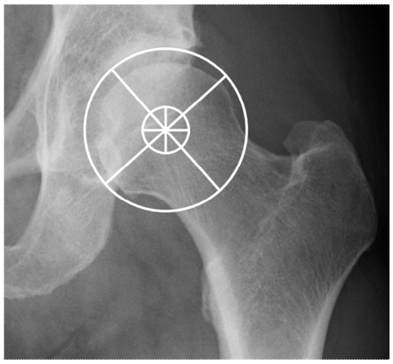


Figure 6. By the drawing of two circles the hip joint was considered congruent if the center of best fitted circle of the acetabulum was equal to the center of the femoral head.

Preoperative and postoperative signs of osteoarthritis were graded according to the Tönnis classification (grades 0 - 3) (Table 1) [43]. Previously, hips with advanced degeneration were offered PAO, but as studies proved that hips with preoperative signs of osteoarthritis (either by Tönnis grades 2 - 3 or decreased joint space width) deteriorated rapidly, with the need of conversion to THA, today only Tönnis grade 0 - 1 hips are normally offered PAO [16, 28, 31, 37, 42, 103]. Tönnis grading is widely used and referred to in the literature. However, using all four grades in characterizing the state of OA is subject to errors. A study has shown that dichotomizing the Tönnis scale into grades 0 - 1 and grades 2 - 3 have a higher agreement than using all grades 0 - 3 when osteoarthritis found on plain radiographs is compared to CT scans [104]. Furthermore, evaluation of osteoarthritis on conventional radiographs illustrates only one plane; hence areas with osteoarthritis may be missed.

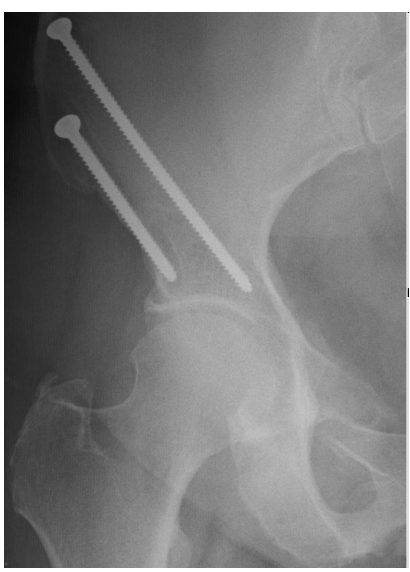


Figure 7. Two years after PAO. The acetabular roof is sclerotic, but despite an obvious preserved joint space, the patient had limited range of motion, severe pain, and a hip arthroscopy revealed severe grades 2 and 3 arthritis in the acetabulum and at the femoral head. Two months later, the hip was converted to a THA.

In studies I and III, the majority of the pre- and postoperative AP radiographs were routinely taken in the supine position. Studies have shown that going from supine to weight-bearing AP pelvic radiographs affects the presence of retroversion [105, 106]. However, this does not have substantial influence on the measurements of the center-edge angle and acetabular index angle. The identification of acetabular retroversion is crucial because studies have shown that acetabular retroversion may accelerate the development of osteoarthritis [48-50]. Thus, as standard today at our institution, the AP pelvic radiographs in study II and the follow-up radiographs in study III were taken in the weight-bearing position.

On hip radiographs, retroversion is diagnosed if the posterior wall sign [107], the cross-over sign [107, 108], or the ischial spine sign [109] is present. In studies I and II, retroversion was considered present if the cross-over sign was present on weight-bearing AP pelvic radiographs (Figure 8).

Figure 8. A section of a weight-bearing AP pelvic radiograph. The anterior rim (grey line) is seen crossing the posterior rim (black line). This cross-over sign indicates retroversion.

Magnetic resonance arthrography (MRA)

In study II, patients routinely underwent a magnetic resonance arthrography to determine any intraarticular pathology (Figures 9 & 10).

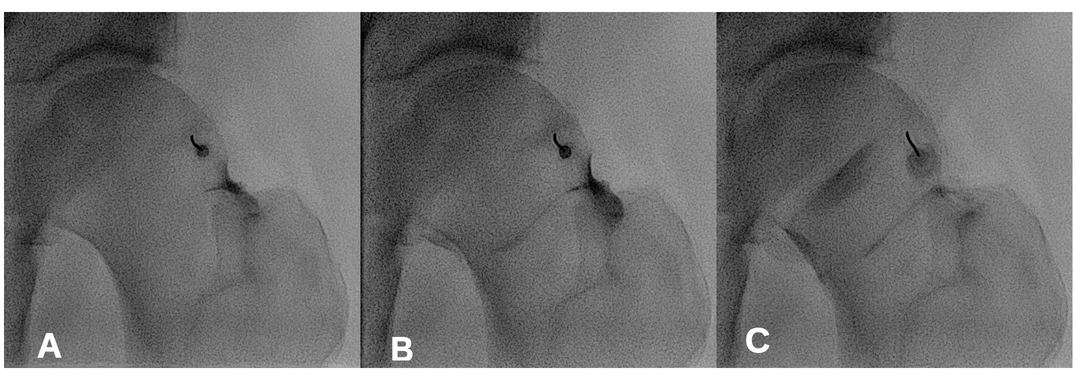


Figure 9. Fluoroscopy-guided injection-diluted gadolinium contrast medium (Gd-DTPA, 2 mmol/L) into a non-dysplastic hip joint. A) The needle is in place and 0.5 mL omnipaque is seen within the capsule. B + C) After injection of the contrast medium, the distribution of the fluid around the femoral neck stands out distinctly.

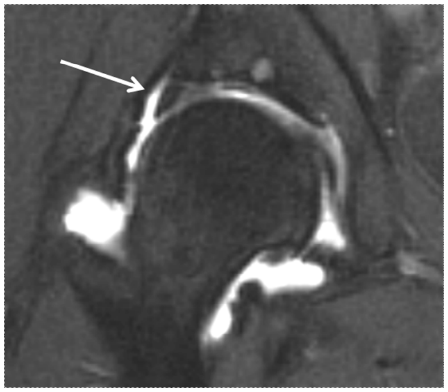


Figure 10. MRA. The contrast is dispersed in the hip joint. The arrow points to a Czerny IIIA lesion. The triangular labrum is detached from the acetabular rim, indicated by the line of contrast material between the labrum and the rim.

MRA is considered the gold standard in diagnosing intraarticular hip joint pathology and has been found to have a high sensitivity and specificity MRA findings are compared with findings found during hip arthroscopy [73, 74, 110, 111]. However, when interpreting MRA scans, the observer must be aware that age changes the appearance of the labrum, the labrum might be absent, and sometimes a physiological normal cleft between the rim and the labrum is erroneously interpreted as a tear [112-114]. A MRA-based definition of labral tears has been developed by Czerny et al. [111] (Table 2). Freedman et al. found high intraobserver reliability using the Czerny stages for grading labral tears. However, in a study comparing outcomes after hip arthroscopy in two groups with either Czerny stage II or stage III lesions, the Czerny stage was not found to be prognostic for outcome [110].

Table 2. Czerny classification based on MRA findings [115]

Grade	Description of the Czerny grades
Stage IA	Area with increased signal intensity, triangular in shape.
Stage IB	As stage IA, but thickened and deformed
Stage IIA	Tear with contrast into the labrum, but attached to the margin
Stage IIB	As stage IIA, but thickened and deformed
Stage IIIA	Triangular labrum, but detached from the acetabular margin
Stage IIIB	As stage IIIA, but thickened and deformed

The α-angle described by Nötzli [116] assessed on oblique plane MRA images is frequently used in quantifying proximal femoral head-neck junction abnormalities anteriorly. However, abnormal femoral head-neck junction abnormality may differ in the whole circumference around the femoral head-neck [117]. MR scans are considered being the most precise tool in evaluating the femoral head-neck junction compared to conventional radiographs [118]. However, Lohan et al. found a rather high interobserver variability of up to 30% in measuring the α-angle.

Under the consideration that most of the literature describes femoroacetabular impingement by referring to the α-angle of Nötzli, we decided to use that parameter. The ideal cut-off value for the α-angle remains uncertain. Nötzli et al.

determined a cut-off α-angle of 55° being abnormal, while other studies use a cut-off value of 50° [119-122].

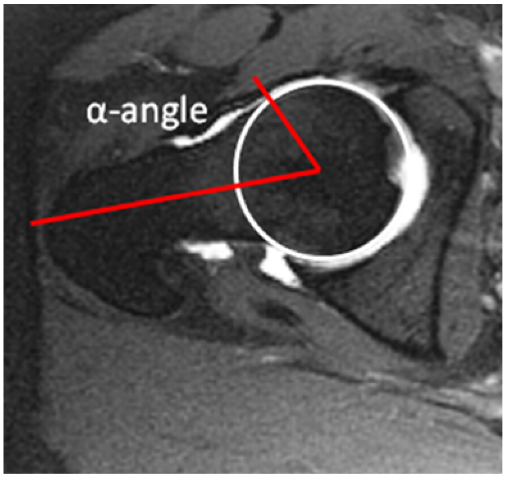


Figure 11. MRA measurement of the α-angle of Nötzli on the oblique plane. After identification of the center of the femoral head a line along the middle of the femoral neck and a line from the center to the point where the femoral head-neck junction "left" the best fitted circle of the femoral head makes up the α-angle.

Radiographic evaluation of the THA

In study III conventional radiographs were analyzed for signs of osteolysis, heterotopic calcifications, and the acetabular cup position. Aseptic loosening is defined as mechanical loosening of the implant without signs of infection. In connection with osteolysis, wear particles from the polyethylene liners, ceramic liners, or metal component from the prosthesis are released into the tissues surrounding the hip joint prostheses, and this is believed to activate the macrophages and facilitate bone loss [123, 124]. The process of osteolysis is rather complex, and it is beyond the scope of this thesis to describe this relation. However, it is important to understand that polyethylene wear particles released from the articulating surfaces of the prosthesis play a role in osteolysis, thus influencing the risk of loosening of the implant. Studies have shown that a wear rate above 0.2 mm / year leads to large osteolytic processes and bone destruction [125-127]. To assess any ongoing osteolysis, cup migration radiolucent lines, the follow-up radiographs in study III were compared with the initial postoperative radiographs in consensus between two observers. Both ballooning osteolytic destructions and radiolucent lines around the components were described by location, using the three defined zones around the acetabular cup, and the seven zones around the femoral stem as defined by Delee and Charnley [128] and Gruen et al.[129] respectively.

Heterotopic calcification was graded according to Brooker grades I-IV, depending on the severity of ectopic bone growth [130]. Class I has small islands of bone within the soft tissue around the hip, class II has bone spurs from pelvis or femur, but leaving at least 1 cm between the opposing bony surfaces, class III like II, but space between the opposing bones reduced to less than 1cm, and class IV indicates ankylosis of the hip, at least on radiographs.

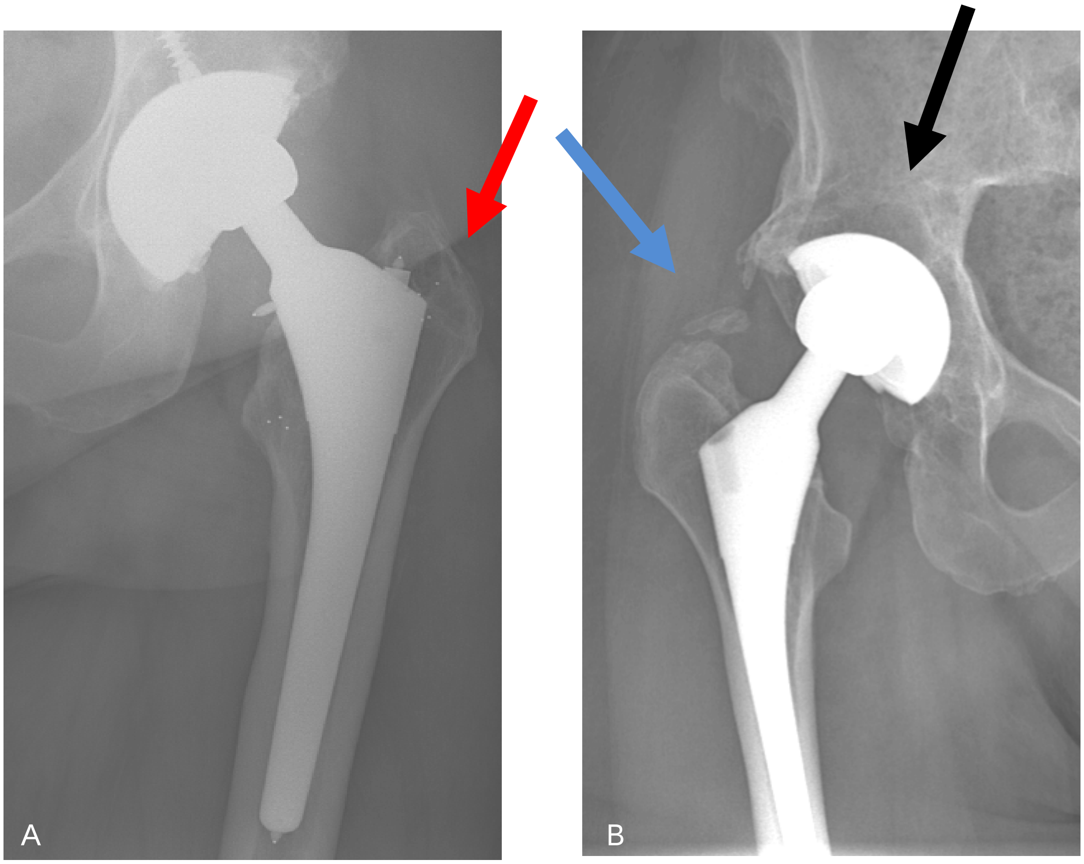


Figure 12. Evaluation of THA radiographs. Red arrow: bony absorption around the femur stem proximally in Gruen zone I. Black arrow: Signs of osteolysis around the cup in Delee zones I & II. Blue arrow: heterotopic calcification, Brooker grade I (represented by island of bone within the soft tissue)

The PolyWare Pro 3D Digital vs 5.10 (Draftware developers, Conway, SC), developed by Devane et al., was utilized to analyze cup abduction, cup anteversion, total linear (two dimensional) wear, and the corresponding wear rate. The strength of the computer program is that only the final follow-up radiographs are necessary for a precise estimate [131]. For metal-on-metal bearings, the software program was only used to measure the cup anteversion and cup abduction angles; however for five hips, the cup brand was not available in the software library and the position of these hips could therefore not be analyzed. The standard use of weight-bearing radiographs at our institutions implies that our results are not directly comparable to abduction and anteversion angles reported in the literature, since studies have shown that acetabular version changes from a supine to weight-bearing position [106, 132].

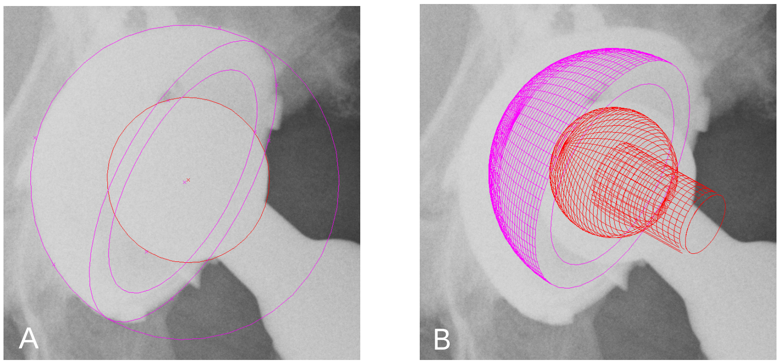


Figure 13. PolyWare wear analysis of the acetabular cup. A. Illustration of edge detection of the border of the acetabular cup and the head component. B. A solid model applied by the end of the analysis (the CAD model is not supposed to fit perfectly with the THA implant).

Failure outcomes after PAO

Hip joint survivor ship analysis

The prognosis of the durability of PAO in study I was assessed by using Kaplan-Meier survival analysis [133]. The Kaplan-Meier estimate is a commonly used estimate for a prognosis of a disease or, as in this case, the effect of a treatment in a cohort. Conversion to THA was considered a failure and the insertion of the THA was set as the end-point. All patients were included in the study at the time of the PAO, and followed until primary THA or last follow-up date, May 1, 2011.

In study II, we considered the need of a hip arthroscopy as failure. The follow-up in this study was 2 years after the PAO, and the patients referred to arthroscopic evaluation had spent time at (1) waiting for the effect of PAO; (2) waiting for examination, and (3) and if necessary another wait for surgery. This meant that some of the patients had waited several months before undergoing hip arthroscopy, and the Kaplan-Meier estimate after 2 years of follow-up may misrepresent the true result. Hence we choose to calculate risk factors of failure with the use of logistic regression.

Clinical evaluation and quality of life for patients after PAO with the use of questionnaires

Patient-reported outcome measures (PROMs) are a valuable tool in evaluating the clinical outcome after surgery. For hip patients, the hip-specific Oxford Hip Score (OHS) [134] and Western Ontario and McMaster Universities Osteoarthritis Index questionnaire (WOMAC)[135] are frequently used. Quality of life is often assessed with the use of the Short Form-36 (SF-36)[136]. The WOMAC questionnaire was used in all three studies. OHS and SF-36 questionnaires were used in studies II and III as well. In study III, the surgeon-specific Harris Hip Score was added to evaluate the function of the THA on the basis of pain, limping, leg length difference, and range of motion.

Statistics

General statistics

All data were tested for normality on histograms and with Q-Q-plots. In all three studies normally distributed data were presented as means with 95% confidence intervals and medians with interquartile ranges if normality could not be presumed. The level of significance was in all cases set at $p < 0.05$. The statistical analyses were performed with STATA 11 & 12 software package (StataCorp LP, College Station, TX, USA).

Study I

To identify possible predictors of failure after PAO, we used the Cox regression analysis model. The regression model is used in cohorts in which the observational time varies between the individuals observed. It is required that the hazard ratio is constant through follow-up time for all members of the cohort; hence all factors were tested for the proportional-hazard assumption by the use of log-log plots [133]. In the study, 13 parameters with a significant unadjusted hazard ratio (different from 1.0) were found in the Cox regression analysis. Furthermore, we adjusted for well-known confounding factors including sex, preoperative grade of osteoarthritis, a preoperative center-edge angle $<0^{o}$, and postoperative center-edge angle $>30^{o}$ or $>40^{o}$.

Study II

With the use of logistic regression, the odds ratios and 95% confidence intervals for failure between the non-arthroscopy group and the arthroscopy group were calculated. The crude odds ratios were adjusted for two possible confounders (age and preoperatively grade of dysplasia). The non-parametric tests (Wilcoxon sign-rank and rank-sum) and Fisher's exact test were used to test variables within and between the groups.

Study III

Descriptive statistic used in the study.

Intra- and interobserver variability

In study I and study III, intra- and interobserver variability of conventional radiographic parameters and α-angles measurements were assessed in a subset of 25 radiographs and 25 MRA scans, respectively. To estimate the intraobserver and interobserver variability, the differences between the two measurements were plotted against their mean in a Bland-Altman plot. This is also called the 95% limits of agreement (LOA) method [137, 138]. Considering the measured differences to be normally distributed, 95% of the observed differences would be lie with $\pm$ 2 SD. In study I, interobserver and intraobserver variation for the center-edge angle, the acetabular index angle, hip joint congruence, and minimal joint space width were evaluated. The MRA scans in study II were primarily assessed by an experienced senior radiologist for intraarticular pathology; however, the α-angle measurements were performed by the author of this thesis. Intra – and interobserver variability for measuring the α-angle between the author of this thesis and the senior radiologist is reproduced in figure 14.

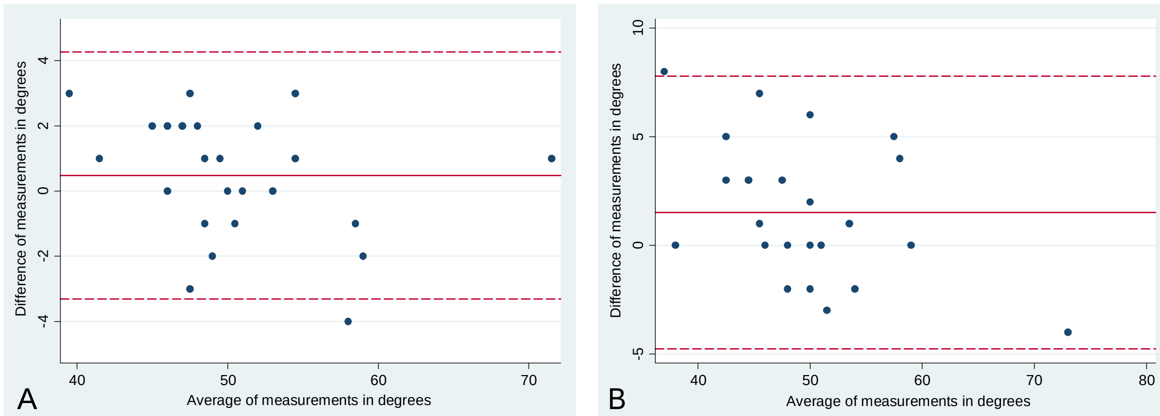


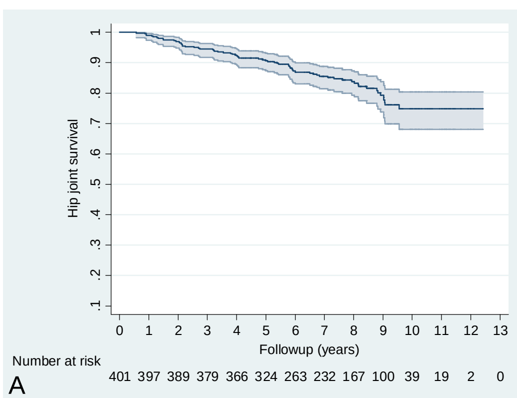
Figure 14. Bland-Altman plot for the intra-(A) and interobserver (B) variability of the α-angle measurements on MRAs. The difference of the mean is plotted against the average. The solid red line indicates the mean of difference and the dashed red lines present the 95% LOA.

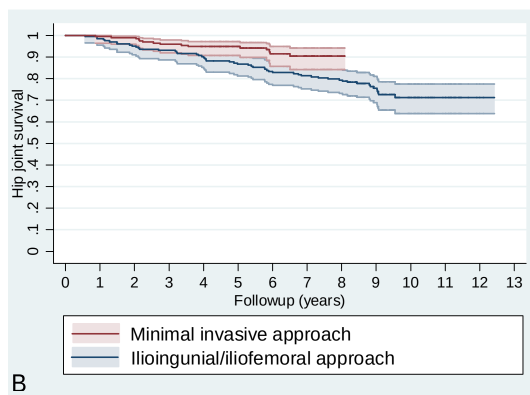
Summary of results

Study I

***Research questions:* We sought to (1) identify demographic, clinical, and pre- and** postoperative radiographic factors that could predict failure after PAO (2), assess the hip joint survival rate following PAO, and (3) to assess overall functional outcome and pain scores after PAO.

Results: Cox regression analysis found five significant predictors with crude hazard ratios of 2 or more (age $\geq$40 years, a minimal joint space width <3mm, center-edge angle <30º or >40º, postoperative lack of incongruence and a preoperative signs of severe osteoarthrosis Tönnis grade 2) (Table 3). The Kaplan-Meier hip survival rate was 74.8% at 12.4 years for all hips (Figure 15); however, dividing the cohort into surgery before and after the implementation of the minimal invasive approach in 2003 showed an improved survival rate at 8 years. Figure 16 shows how the grade of osteoarthritis preoperatively statistically significantly influenced the outcome after PAO; even hips with grade 1 osteoarthritis deteriorate rapidly. A WOMAC pain score $\geq$10 was observed in 13% of the preserved hip, meaning that 87% of the preserved hips were functioning well.





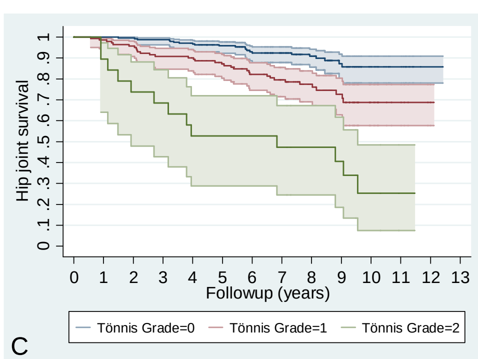


Figure 15. Kaplan-Meier survival hip joint survival curves (with 95% CI). Endpoint was conversion to THA. A. The hip joint survival for all hips in the cohort. At 12.4 years the hip joint survival rate was 74.8%. B. The hip joint survival curves divided in surgery before (blue) and after (red) April 2003. C. Kaplan-Meier hip joint analysis with hips divided into preoperative grade of osteoarthritis (Tönnis grades 0, 1, 2). Numbers of hips in the three groups were 241, 141, and 19.

Table 3. Hazard ratios in statistically significant predictors of conversion to THA.

Parameter	Crude Hazard Ratio (95% CI)	P-value	Adjusted Hazard Ratio* (95% CI)	P-value
Demographic data				
Age of ≥40 yr at time of surgery	1.97 (1.22-3.18)	0.005	2.10 (1.29-3.41)	0.003
Legg-Calvé-Perthes disease	1.39 (0.71-2.72)	0.337	1.96 (0.93-4.14)	0.077
Previous femoral surgery	2.22 (1.13-4.34)	0.020	1.91 (0.97-3.76)	0.063
Radiographic data				
Postop. center-edge angle <30º or >40º	2.20 (1.34-3.62)	0.002	2.00 (1.21-3.33)	0.007
Postop. acetabular index angle > 10º	2.31 (1.43-3.74)	0.001	1.57 (0.90-2.75)	0.116
Preop. presence of an os acetabuli	2.22 (1.21-4.06)	0.010	1.61 (0.84-3.11)	0.155
Postop. presence of an os acetabuli	2.26 (1.28-4.02)	0.005	1.64 (0.88-3.07)	0.119
Preop. min. joint space width <3.0 mm	3.54 (1.94-6.49)	<0.001	1.83 (0.92-3.66)	0.087
Postop. min. joint space width <3.0 mm	4.29 (2.57-7.17)	<0.001	2.57 (1.42-4.67)	0.002
Preop. Tönnis grade 2	5.66 (3.09-10.38)	<0.001	5.37 (2.92-9.88)	<0.001
Preop. congruence >0 mm†	2.11 (1.16-3.84)	0.015	1.75 (0.95-3.23)	0.074
Postop. congruence >0 mm†	2.54 (1.23-5.02)	0.004	2.08 (1.04-4.15)	0.039
Computed tomographic data				
Coronal center-edge angle <5º	2.02 (1.15-3.55)	0.015	1.49 (0.74-3.00)	0.261

The crude hazard ratio adjusted for sex, the preoperative grade of osteoarthritis according to Tönnis grade 2, pre- and postoperative center-edge angle; †Congruence not measured in Legg-Calvé-Perthes hips (43 hips excluded)

Conclusion: The PAO surgery had the effect that three out of four hips were preserved and with most hips functioning well at 4 to 12 years follow-up. At the time at PAO surgery, the surgeon should attempt to achieve hip congruence, and a center-edge angle of 30º to 40º to improve durability of PAO. The greater awareness of selection of the right patient candidate, improved skill of the surgeon, and the introduction of the new minimal invasive technique have possibly contributed to the positive development with an increased tendency toward increased hip joint survival.

Study II *(Preliminary results and conclusion)*

Research questions: We sought to (1) identify risk factors that possibly could predict failure in terms of the need for a hip arthroscopy after PAO, (2) to evaluate the outcome after PAO in a cohort with MRA-diagnosed intraarticular pathology, and (3) to evaluate any difference in outcome between a non-arthroscopy and arthroscopy group at 2-year follow-up be found.

Results: Within 2 years after PAO the need for a subsequent hip arthroscopy was performed in 20 out of 74 patients (27%) (Table 6). At hip arthroscopy, the majority of patient underwent trimming of the rim, labral reinsertion, and cheilectomy. Borderline dysplasia (center-edge angle $\geq 20^{o}$ -25^{o}), acetabular retroversion, and an abnormal high α-angle ($\geq 55^{o}$) combined with borderline dysplasia were risk factors for failure. Adjustment for age and borderline dysplasia changed the results significantly for labrum detachment (Table 4). The kinds of labral pathology (grading according to Czerny I A / B or II A / B, degeneration, or hypertrophy) were not prognostic for outcome. The patient-reported outcome measures were significantly better in the non-arthroscopy group than in the arthroscopy group (Table 5).

Table 4. Odds ratios for predictors of clinical failure in terms of hip arthroscopy

Parameter	OR (95% CI)	P-value	Adjusted OR** (95% CI)	P-value
Borderline dysplasia*	4.30 (1.42-13.00	0.010	4.49 (1.46-13.82)	0.009
Postop.AI-angle <0º or >10º	2.10 (0.68-6.53)	0.198	2.28 (0.68-7.65)	0.181
Preop. cross over sign	4.01 (1.31-12.73)	0.015	3.90 (1.17-13.04)	0.027
α-angle† ≥55º	2.11 (0.70-6.37)	0.185	2.05 (0.64-6.61)	0.229
α -angle <55º & borderline dysplasia	3.43 (0.87-13.48)	0.078	3.50 (0.88-13.85)	0.074
α -angle ≥55º & borderline dysplasia	9.00 (1.73-46.84)	0.009	9.13 (1.75-47.82)	0.009
Labrum detachment ‡	2.40 (0.76-7.55)	0.134	4.21 (1.12-15.78)	0.033
Labrum degeneration	1.05 (0.38-2.95)	0.921	1.39 (0.46-4.24)	0.560
Labrum hypertrophy	2.05 (0.41-10.28)	0.385	2.20 (0.41-11.90)	0.359
Presence of paralabral cyst	1.98 (0.50-7.81)	0.327	1.77 (0.43-7.43)	0.431

center-edge angle ≥20º to <25º **Adjusted for age (≤35 years)and borderline dysplasia
† Due to poor radiographic quality it was not possible to measured α -angle in four hip
‡Czerny IIIA/B lesions

Conclusion: Borderline dysplasia of the hip and acetabular retroversion was associated with an increased risk of a hip arthroscopy after PAO. Borderline dysplasia in combination with an abnormal high α-angle ($\geq 55^{o}$) increased the risk further. In these cases the surgeons could consider performing or planning hip arthroscopy simultaneous with the PAO.

Table 5. Patient-reported outcome measures for the arthroscopy and non-arthroscopy group

Parameter	Preoperative* All (n=74)	Postoperative All (n=74)	Postoperative Arthroscopy (n=20)	Postoperative Non-arthroscopy (n=54)	p-value
WOMAC†					
Pain					
Median (IQR)**	8 (4-10)	2 (0-5)	4 (1-9)	1 (0-5)	0.02
Range	0-20	0-14	0-14	0-12	
Stiff					
Median (IQR)	3 (1-4)	1 (0-2)	2 (1-3)	1 (0-2)	0.104
Range	0-8	0-7	0-7	0-6	
Physical Function					
Median (IQR)	20 (10-29)	4 (0-11)	8 (3-20)	2 (0-8)	0.01
Range	0-61	0-49	0-46	0-49	
Total Scores					
Median (IQR)	30 (15-41)	8 (1-21)	14 (6-31)	5 (1-14)	0.007
Range	1-89	0-67	0-67	0-66	
Normalized					
Median (IQR)	67 (54-79)	89 (79-98)	81 (65-90)	90 (81-100)	0.014
Range	3-100	25-100	25-100	33-100	
Oxford Hip Score ‡					
Total score					
Median (IQR)	27 (23-33)	43 (34-47)	37 (29-43)	44 (36-47)	0.007
Range	8-47	12-48	12-48	19-48	
SF-36 ¥					
Physical score					
Median (IQR)	38 (33-44)	48 (38-55)	40 (34-52)	50 (43-56)	0.014
Range	16-55	18-60	18-58	27-60	
Mental score					
Median (IQR)	54 (43-62)	58 (54-62)	57 (53-62)	59 (55-62)	0.797
Range	29-69	27-78	27-78	35-66	

The preoperative scores did not show any statistically significant differences between the arthroscopy and non-arthroscopy groups (p-values 0.157-0.934).
***** IQR interquartile range***
† Raw scores with "0" indicating best results. Normalized score with "100" indicating best result.
‡ Scores "0-48" with "48" indicating best results
¥ Component score" 0-100" with "100" indicating the best result

Table 6. Description of the 20 hips in study II undergoing hip arthroscopy (HA) after PAO

Nr	Time to HA**	MRA labrum diagnosis	MRA α-angle	HA findings	HA procedures
1	9 months	Czerny 3A	46°	Labrum damage anteriorly, mildly hypertrophic, pincer, CAM†	Rimtrim, labrum reinsertion, cheilectomy
2*	21 months	Czerny 3A, degeneration	55°	Frayed labrum, pincer, minor CAM	Rimtrim, labrum reinsertion, minor cheilectomy
3	13 months	Czerny 1A, degeneration	51°	Labrum-cartilage separation, pincer, CAM, loose cartilage	Rimtrim, labrum reinsertion, cheilectomy, mircrofracture treatment
4	6 months	Czerny 2B	53°	Labrum-cartilage separation, pincer, minor CAM	Rimtrim, labrum reinsertion, minor cheilectomy
5	16 months	Czerny 3A, degeneration	44°	Labrum-cartilage separation, pincer, minor CAM, area with osteoarthritis	Rimtrim, minor cheilectomy
6*	15 months	Czerny 3A, degeneration	58°	Labrum lesion with minor impact on the cartilage , pincer, bump on collum	Rimtrim, labrum reinsertion, minor cheilectomy
7	7 months	Czerny 3B, degeneration	44°	Labrum-cartilage separation, frayed labrum, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
8	4 months	No tears, mild hypertrophy	43°	Labrum-cartilage separation, synovitis, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
9	15 months	Czerny 3A	44°	Minor labrum-cartilage resection, minor pincer, CAM	Minor rimtrim, cheilectomy
10	12 months	Czerny 3A, degeneration	48°	Labrum-cartilage separation, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
11	8 months	Czerny 3A, degeneration	69°	Labrum-cartilage separation, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
12*	7 months	Czerny 3A, degeneration	58°	Voluminous labrum, labrum- cartilage separation, minor CAM	Labrum reinsertion, minor cheilectomy
13	5 months	No tears, crushed and degeneration	49°	Osteoarthritis acetabulum and caput femoris, labrum attached to the rim	Synovectomy
14	12 months	Czerny 2A	48°	Labrum-cartilage separation, minor pincer, minor CAM	Rimtrim, labrum reinsertion, cheilectomy

15	11 months	Czerny 3A, degeneration	42º	Labrum-cartilage separation, pincer, minor CAM	Rimtrim, labrum reinsertion, minor cheilectomy
16	11 months	Czerny 3A	37º	Labrum not described, pincer minor CAM	Rimtrim, labrum reinsertion, cheilectomy
17	7 months	Czerny 3B, degeneration, hypertrophy	61º	Labrum-cartilage separation, mild osteoarthritis, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
18*	18 months	Czerny 3B	66º	Degeneration of labrum, no tears, CAM osteoarthritis at acetabulum and femur	Cheilectomy
19	5 months	Czerny 3A	72º	Labrum-cartilage separation and influence of the cartilage, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
20*	7 months	Czerny 3A	57º	Not available	According to the patient “some bone work”. No effect.

(2) Repeat arthroscopy 11 months after first arthroscopy: refixation of labrum, minor rimtrim of the acetabulum and extended cheilectomy on femur

(6) Repeat arthroscopy 14 months after first arthroscopy: labrum healed, acetabular cartilage with wave-sign, minor rimtrim, minor cheilectomy, screw removal

(12) Repeat arthroscopy 8 months after first arthroscopy: labrum healed, minor pincer removed, minor cheilectomy, psoastenotomy

(18) Hip arthroplasty 6 months after hip arthroscopy

(20) Repeat arthroscopy 3 months after first arthroscopy due to no effect. Labrum attached but anterior lesion. Pincer and minor CAM. Detachment of the labrum, rimtrim, reinsertion of labrum and minor cheilectomy. Psoastenotomy.

***** Time passed between PAO and HA***

† CAM: term for the exostose on the femoral head-neck junction

Study III

Research questions: We sought to evaluate the overall clinical, radiographic, and patient-reported outcome of THA following PAO at 4 to 10 years. We asked whether it was possible to achieve an acceptable cup position, could any patient-related factors be identified with inferior cup positioning and increased polyethylene wear, and whether offset and leg length could be restored using primary conventional components when converting a PAO to THA.

Results: No dislocations or revision surgery were performed. Median scores were Harris Hip Score 96 (range 42 - 100), Oxford Hip Score 38 (range 8 - 48) and total WOMAC 78 (27-100). Mean cup anteversion and abduction angles were 22° (range 7° - 43°) and 45° (range 28° - 65°). Outliers of cup abduction were associated with persisting dysplasia (center-edge angle <25°) after PAO (Figure 16). Wear rates were below the critical level of 0.2 mm / year reported in the literature (Table 7). Leg length was restored in 87% (33 / 38) of the patients, and offset slightly increased.

*Table 7. Computerized acetabular cup and liner analysis **

Parameter	conventional PE	highly cross-linked PE
Mean linear wear		
Mean (95%CI)	1.39 (1.02-1.76)	0.60 (0.38-0.81)
Range	0.57-2.43	0.27-1.11
Wear Rate (mm/year)†		
Mean (95% CI)	0.16 (0.13-0.21)	0.13 (0.08-0.17)
Range	0.06-0.27	0.05-0.24
Follow-up (years)		
Mean (95% CI)	8.3 (7.4-9.2)	4.8 (4.5-5.2)
Range	6.1-10.1	4.2-5.4

12 liners were of the PE type, 9 liners were of the highly cross-linked PE type and 5 cups were not possible to analyze due to software restrictions (cup brand not available in software CAD library). MoM and CoC hips (16) were excluded from wear analyses.

Conclusion: The results illustrate that THA after PAO can be performed with good results, at least, as in this case, on a high volume and highly specialized orthopedic ward. Persisting acetabular dysplasia may result in to steep an abduction of the cup. However, in this study cups positioned outside the safe zones did not result in increased wear, dislocations, or revision surgery.

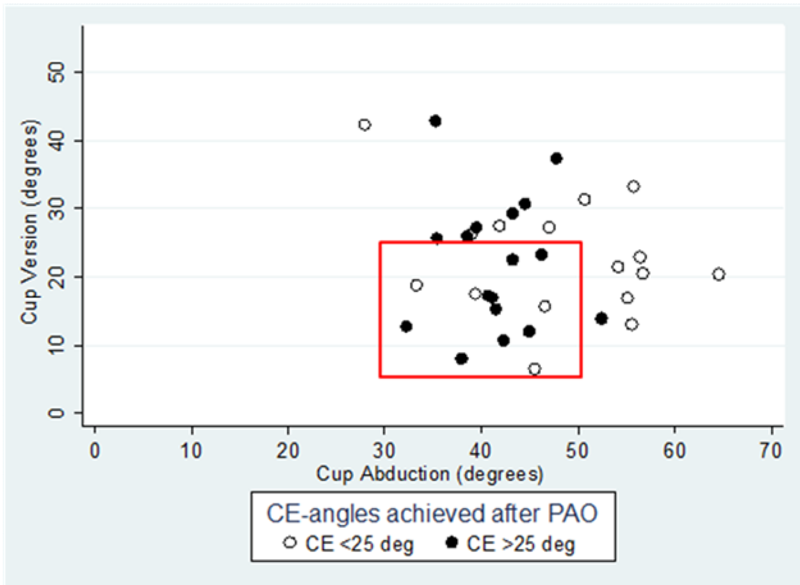


Figure 16. The cup abduction and anteversion angles in a scatterplot. The red box outlines the optimal ranges for cup placement according to Lewinneck et al.[139] *(anteversion 5° to 25° and abduction 30° to 50°). Circles indicates the center-edge angle (CE) achieved after PAO.*

Discussion

Since the Bernese group in 1988 presented the periacetabular osteotomy as a surgical procedure for treatment of symptomatic hip dysplasia, the technique has spread worldwide. Today, the PAO is the most used joint-preserving procedure for hip dysplasia in young adults, and several studies have shown that PAO relieves pain, improves physical function, and delays or even in some cases prevents the development of early osteoarthritis. However, continuous research is ongoing, trying to identify the patients who will benefit most from a PAO and spare other patients from unnecessary surgical procedures.

Who should be a candidate for PAO – what do we know?
In study I, we found a survival rate of 74.8% after 12.4 years. This is slightly less than results from other long-term studies; however, in Denmark it is possible by inquiry to the National Registry of Patients to perform a complete follow up of all patients living in Denmark, ensuring that no patients are lost to follow-up. Previous studies have reported 5-year survival rates of 90.5% to 96%, 10-year survival rates of 84% to 86.7%, and a survival rate of 60.5% after 20 years [31, 36, 37]; however, the sample size in these studies are low (68 hips to 135 hips). In contrast, 401 hips were included in study I, and this increases the validity of our results.

Continuing research has shed light on several patient-related and radiographic factors important for improvement of the outcome of PAO. In study I, we used the Cox proportional hazard model to analyze the association between possible predictors of failure in terms of a THA. In concordance with the existing literature [16, 28, 31, 37, 38, 42, 103], preoperative signs of osteoarthritis were found to be highly statistically significant, with an OR >5 for Tönnis grade 2. The result of this is that today only hips with no or minor signs of osteoarthritis (Tönnis grades 0 - 1) are commonly offered PAO. Age is another parameter examined frequently; however, the upper age limit for PAO suggested in the literature differs. We found that age $\geq$40 years increased the risk of failure in terms of a THA, with a hazard ratio of 2.10. Matheney et al. found age $\geq$35 years to be a risk factor of failure, but Teratani et al. [140] could not find any difference in the progression of osteoarthritis 5 years after PAO comparing patients $\geq$55 years with a younger group. Hence for the time being, no age limit exists for PAO surgery.

The goal of the PAO is to achieve a sufficient coverage of the femoral head in the hip joint. We aimed to achieve a postoperative center-edge angle between 30^{o} to 40^{o}, and the adjusted hazard ratio for failure was 2.00 if the postoperative center-edge angle was outside this interval. Steppacher et al. [31] evaluated the achieved femoral coverage by using the femoral extrusion index. They found an increased risk for conversion to THA following PAO if the femoral extrusion index postoperatively was >20%.

Computer tomography scans are considered valuable in characterizing the bony morphology and important in the surgical planning, at least for the complex dysplastic hip. Troelsen et al. reported that two CT parameters (the coronal center-edge angle and the acetabular anteversion angle) were significant predictors of conversion to THA following PAO [37]; however, in study I, CT findings were not statistically significant predictors of failure.

In summary, study I revealed some highly significant predictors of failure. In daily life, the clinician must, in counseling of the patient, be aware of the age and the degree of osteoarthritis in the affected hip joint. Also, the surgeon must recognize that severe hip dysplasia (judged by the center-edge angle) may hinder the possibility of achieving a postoperative center-edge angle within the interval 30º to 40º, thereby of achieving sufficient femoral head coverage postoperatively.

How to deal with intraarticular pathology

A recently published overview [80] of the literature did not reveal any consensus of treating labrum pathology in hips with symptomatic dysplasia. There is general agreement that an abnormal labrum is a frequent finding in hip dysplasia and is often seen in company with some kind of cartilage damage [66]. Study II supported this finding, since 94% of the labrums in the study showed labrum pathology. In the literature, Steppacher et al. [31] suggested labrum pathology to worsen the outcome after PAO, contrary to Matheney et al. [36], who did not found that labrum tears influenced the outcome negatively. In study II, unadjusted labrum pathology (Czerny I/II lesions, hypertrophy, or degeneration) did not predict failure in terms of the need for hip arthroscopy after PAO. However, after adjustment for age and borderline dysplasia, a detached labrum (Czerny IIIA/B grading) became statistically significant. Furthermore, labral tears are closely correlated to cartilage damage in dysplastic hips, and so far no studies clarify what happens long term if labral tearing and cartilage lesions are left untouched. However, a study by Mechlenburg et al. showed that cartilage thickness assessed on MRI preoperatively was unchanged 2½ years after PAO and at follow-up, indicating that osteoarthritis do not progress during follow-up even in the presence of a labral tear[141]. Finally, it is important not to rely only on MRA findings. Studies of 71 and 200 volunteers [112, 142] have shown that the MRA presentation of the labrum can vary widely in asymptomatic hips. This makes the diagnosis of a meaningful labrum lesion challenging, and the clinician must correlate the MRA result with the clinical symptoms and conventional radiological findings before drawing any conclusions.

Femoroacetabular impingement (FAI) is defined as pincer or CAM impingement. The two types of FAI can appear individually or simultaneously. In pincer FAI the relatively deep acetabulum results in conflicts between the acetabulum and the femoral head-neck junction. Pincer FAI after PAO happens if the acetabular fragment is overcorrected, which results in a negative acetabular index angle and/or in retroversion. In study II, an overcorrection resulting in a negative acetabular index angle (<0º) was not a statistically significant predictor of failure in terms of the need for a hip arthroscopy after PAO. However, presence of retroversion showed an OR of 4.01 for failure. The CAM type impingement results from asphericity of the femoral head-neck junction. In study II the extent of the bony malformation was judge by the α-angle and assumed pathological if the α-angle was >55º. We found an unadjusted OR of 2.11 (95% CI, 0.70 - 6.37) for failure, but the finding was not statistically significant (p = 0.185), probably because of the limited amount of study material. Furthermore, the standard measurement of the α-angle described by Nötzli using one plane can be questioned. Table 6 describes the findings at hip arthroscopy and the surgical procedures performed. It illustrates that basically all patients, no matter what the α-angle value, had some kind of CAM deformity and underwent cheilectomy during arthroscopy (Figure 17). Pfirrmann et al. [117] compared MRAs in a pincer group with a CAM group and found increased α-angles in several planes. We only performed the measurements in one plane, thereby possibly underestimating the extent of any CAM deformity. Of course the variability in the measurements of the MRAs must be acknowledged. However, even hips with rather small α-angles underwent cheilectomy.

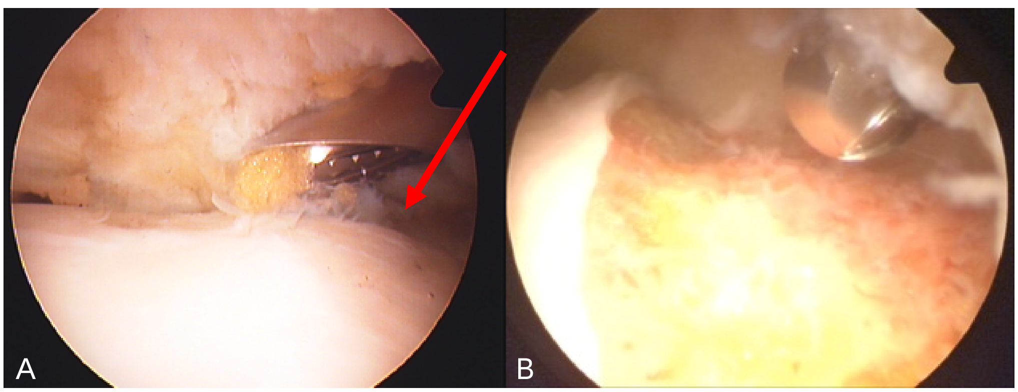


Figure 17. Arthroscopic treatment of CAM deformity. A. Before cheilectomy. B. After end of cheilectomy. The "bump" (red arrow) on the femoral neck was resected, and a normal head-neck junction performed. (The images were kindly provided by the Department of Sports Traumatology, Aarhus University Hospital, Denmark)

In the literature, hip dysplasia is defined by either a center-edge angle <20º or center-edge angle <25º [4, 27, 143]. In study II, we found that borderline dysplasia is highly significant for the need of a hip arthroscopy after PAO. Burnett et al. reports [70] that in selected patients with very mild hip dysplasia they consider performing hip arthroscopy alone. Another option could be performing an arthrotomy. Nassif et al. have evaluated the outcome after PAO combined with arthrotomy without finding an increased number of complications [46].

In conclusion, several issues remain unclear, and at present there is no evidence for an optimal treatment strategy for labral pathology in symptomatic hip dysplasia. Clinicians should assume that all hips have some sort of intraarticular pathology. To avoid an unnecessarily surgical procedure, the challenge is to find the hips that will need intraarticular assessment concomitant with the PAO. The preliminary data in study II show that extra attention must be taken when treating patients with borderline hip dysplasia or if signs of retroversion are present. Also, if MRA is available, signs of CAM deformity or a detached labrum should be taken into consideration when planning surgical treatment for symptomatic hip dysplasia patients. However, since several studies have shown excellent results after PAO without intraarticular assessment, we prefer at our institution to perform PAO first, and if the patient still has groin pain after 6 months, we will offer a hip arthroscopy. The preliminary results of study II show that by using this approach only 27% (20 hips out of 74) will need a hip arthroscopy on short-term follow-up, thereby sparing 73% of the hips for unnecessarily surgical trauma.

The last option – when the PAO fails

Only a few reports deal with the outcome after the insertion of a THA in hips with previous PAO surgery [90, 91]. Often the patients are young, with high demands to their THA, which is known to increase the risk of revision surgery [92]. The PAO alters the orientation of the native acetabulum, which potentially could influence the insertion of a THA after PAO surgery; however, the senior author of the three articles that make up this thesis finds, in agreement with other authors [90], that the reorientation of the acetabulum on the contrary facilitates the insertion of the THA.

Dislocations or loosening are feared complications after THA. To diminish the risk of complications, proper insertion of the acetabular cup is essential. The insertion of the acetabular cup is influenced by the 3D morphology of the acetabulum. Both retroversion and persistent dysplasia can be seen after PAO, which may complicate THA insertion. Different safe zones are reported for cup anteversion and cup abduction angles in the literature. The optimal cup anteversion angle is suggested to be between 5^{o} and 25^{o}, and the cup abduction angle should be between 30^{o} and 50^{o} [139, 144]. However, these limits are based radiographs taken in the supine position, whereas the AP pelvic radiographs in study III are on weight-bearing images. The cup version varies when repositioning from the supine to the standing position [106, 132], therefore our results are not directly comparable with the literature. The mean cup anteversion and mean cup abduction angles in study III are within the so-called safe zones. Figure 17 shows there is a tendency toward persistent hip dysplasia (center-edge angle <25^{o}) resulting in higher abduction angles. However, Callanan et al. [144] did show that the approach used for the THA insertion influence on the version of the acetabular cup, and that cups, as in this study, inserted through the posterolateral approach had a tendency toward being more anteverted and abducted even in non-dysplastic hips.

In study III the polyethylene liners of the acetabular cups were of conventional polyethylene (PE) and highly cross-linked polyethylene (XPE). Computer analysis revealed wear rates below 0.2mm / year. This is the wear rate level considered critical for osteolysis in the literature [126, 127]. Closer analysis of factors that possibly influence the wear level was not possible, due to the limited number of liners present for evaluation. The THA components used were all, except for one cup, conventional. In the majority of patients, had leg lengths differed less than 0 - 1 cm, and no patients had leg length discrepancies greater than 2 cm. This is in line with a previous report regarding THA performed in dysplastic hips with no previous PAO [87].

Patient-reported outcome measures

In all three studies, we used patient-reported outcome measures (PROMs). In study I, the WOMAC questionnaire was used to evaluate pain in the preserved hips 3.9 year to 12.4 years after PAO. Eighty-four percent reported no or a low pain scores (WOMAC pain score <10, scale 0 - 20). This is similar to Matheney et al., who reported clinical failure (WOMAC pain score $\geq$10) in 13% of the examined hips at a mean follow-up of 9.7 years.

In study II, the patients were evaluated by the WOMAC, the Oxford Hip Scores and the SF-36. Preoperative and 2-years scores were compared at follow-up, and in all parameters an improvement in the scores was seen from before to after PAO surgery. Ninety-two percent (68 of 74 hips) of the hips had a low pain score (WOMAC pain <10) at 2-year follow-up. Dividing the patients into a non-arthroscopy and arthroscopy group revealed that the arthroscopy group had a significantly worse outcome in all physical scores than did the non-arthroscopy group. However, the intention-to-treat analysis of the study evaluated outcome at 2-year follow-up after PAO, and the statistical difference found in patient-reported outcome measures may be a result of the arthroscopy group only having a mean of 11.5 months (range 4.5 - 20.5 months) of follow-up between hip arthroscopy and the 2-year follow-up after PAO. Thus, a longer follow-up is needed to evaluate the final clinical result after delayed hip arthroscopy.

In general, high satisfaction was seen in the group of patients receiving a THA after PAO. The median satisfaction score was 10 on a numerical rating scale (10 highest satisfaction ever). Baque [90] and Parvizi [91] used the Merle d'Aubigne score to evaluate outcome, so our results are not directly comparable. However, they found a statistically significant improvement in the score, indicating THA after PAO can be performed with a good result. Boyle et al. [145] conducted a large register-based evaluation comparing functional outcome scores in patient receiving a THA based on either hip dysplasia or osteoarthritis (OA). They found that the hip dysplasia group had significantly worse outcome scores (WOMAC, SF-12, Oxford) preoperatively than did the OA group. However, at 1-year follow-up the hip dysplasia group and the OA group had similar results. In the physical score of the SF-12, the hip dysplasia group even had a superior result compared with the OA group. In study III, we found after a minimum follow-up of 4 years (mean 6.4 years, range 4.2 - 10.1 years), a median Oxford Hip Score of 38 and a median WOMAC score of 78. These are slightly less than the mean 1-year Oxford

Hip Score of 42 and mean WOMAC score of 88 reported by Boyle et al.[145]. These lower scores possibly reflect the longer follow-up in our study.

Methodological considerations and limitations to the studies

Study population and design

Study I represents one of the largest follow-up studies reported, with 401 hips represented. Unfortunately we had to exclude 50 hips from follow-up, leaving 11% of the cohort unaccounted for. However, the majority of hips were still included, and we considered the cohort representative. The same concern is applicable in evaluating the response to the WOMAC questionnaires. The response rate was 83%, leaving the status of 17% of the hips unknown. The high number of included hips makes it possible to adjust for several confounders in the Cox regression analysis and increases the statistical strength. However, an even larger number of included hips would have increased the statistical strength further, and thereby further reduce the possible influence of unaccounted confounders (e.g. health awareness, smoking, physical activity level, BMI). In study I, the failure in terms of a THA was the hard core endpoint, and the patient-reported outcome was the WOMAC pain score. However, to optimize the evaluation of the effect of PAO as a treatment of symptomatic hip dysplasia, the study should have included a radiological follow-up, since we know from the literature that the natural history of symptomatic hip dysplasia without treatment leads to osteoarthritis. Lastly, the study deals with patients undergoing PAO over several years. The indications for surgery and the surgical approach have changed during the follow-up time and the surgeons' skills have improved; hence the effect of PAO may have improved over the past years, underestimating the survival rate of the hip joints.

In the design phase of study II, we expected that 40% - 80% of the patients would have labral pathology. We sought to compare the outcome after PAO without a concomitantly intraarticular surgical procedure in a group of hips with a normal labrum with a group of hips with unhealthy labrums. However, MRA revealed labrum pathology in 94% of the hips, making this approach impossible; hence the outcome in study II was defined as the need for hip arthroscopy. This study is the first one of its kind to examine the influence of labrum pathology in dysplastic hips, trying to answer the question, "which hips will need intraarticular surgery concomitantly with PAO or afterwards". The number of hips in this study is limited, and we can only adjust for a few confounders. However, 104 hips included is quite a large number in clinical studies and can set a precedent for future larger studies. At present, 74 hips have been followed; 20 hips have undergone hip arthroscopy, and 30 hips need to be followed further before final conclusions can be made. Finally, with the aim of having as homogenous study cohort as possible, we excluded patients with other backgrounds than developmental dysplasia or congenital dislocations of the hip, such as Legg-Calvé-Perthes disease (LCPD). In LCPD, the femoral head can be irregular and flattened, often resulting in an underdeveloped acetabulum followed by insufficient coverage of the femoral head. These hip joints are not expected to be as congruent as in hip dysplasia; hence the findings from study II cannot be directly applied to this patient group. A Danish hip arthroscopy register is under development. This will make future, larger studies possible by linking PAO patients with patients in the hip arthroscopy register.

Study III was limited by the rather low number of hips included. Six hips (14%) out of 44 possible hips had to be excluded, leaving only 38 hips to analyze. Despite a huge effort to get complete follow-up, it was not possible in all cases. As in all clinical studies, incomplete datasets are an important issue, and in study III the reader must keep this issue in mind when studying the results. Furthermore, the THAs were divided in four different articulations (MoP, MoM, CoP, and CoC), and the liners into conventional or highly cross-linked liners. The low number in each category hindered in-depth statistical analysis of risk factors predicting suboptimal insertion of the THA components in hips with previous PAO. Also, we sought to find an age-and diagnose-matched cohort of dysplastic hip patients receiving a primary THA without prior PAO. This was done to compare the patient-reported outcome measure after THA in two groups with or without previous PAO. However, the available patient material was limited, and the THAs were inserted at several different hospitals, which could increase potential confounders.

Finally, with the risk of being provocative, the PAO literature lacks randomized clinical trials. Randomized studies are believed to be the strongest research design. To my knowledge, no studies have randomized patients with symptomatic hip dysplasia to different kind of treatment such as conservative treatment, primary THA, or PAO. With the knowledge today regarding the natural history of untreated symptomatic hip dysplasia and with the knowledge about the success with PAO as a treatment, it would be unethical not to offer the patient with hip dysplasia a PAO treatment. Of interest would be randomized studies with focus on the treatment of the acetabular labrum. For example, a study randomizing patients with borderline hip dysplasia or retroversion into two groups, comparing one group undergoing PAO with a group undergoing PAO and arthrotomy / hip arthroscopy.

Radiological evaluations

In all three studies both the indication for surgery and some of the results of the studies were based on assessment of radiological parameters. Regarding the interpretation of the radiographs, one has to be aware of the inter- and intraobserver variability. One of the indications for PAO in the clinical setting is a radiographically measured center-edge angle $<25^{o}$ on AP pelvic radiographs. In study I, the mean difference (±SD) for the intra- and interobserver variability were -1.00^{o} ($\pm 3.6^{o}$) and -0.64^{o} ($\pm 3.5^{o}$), respectively; these results are similar to those found in other studies ([104, 146]. Several sources of errors are possible in assessing and making radiographic measurements. First of all, the quality of the radiographs might vary thereby making the identification of the landmarks used for the measurement difficult. Secondly, clinicians have different years of experience and typically have their own methods of doing the measurement, adding to the variability. Thirdly, as earlier described, the position of the patient is important to take into account, for example, in the interpretation of retroversion. In study I, in the majority of the patient radiographs were taken in the supine position, making deeper analysis of retroversion meaningless. At our institution, we routinely use only standardized weight-bearing anteroposterior exposures with the aim of limiting errors.

In the evaluation of the cup position and wear rate of the liners in study III, we used the PolyWare method. All analyses were performed by a person experienced in using the PolyWare software program. The measurements were performed twice and the mean values were used. We did not perform any further analysis of this variability. The computer program analyses the position of the cup without regard to pelvic tilt in the sagittal plan, but with the use of the standing exposures in our institution, we attempted to reduce this error. However, this approach reduces the possibility of comparing findings with those in the existing literature.

Magnetic resonance arthrography scans are sensible for distortions, and even small movements may disturb the images, making interpretation of the images difficult. So far in study II, four MRAs were excluded in the analysis of the α – angle. However the quality of the scan revealed no trouble in analyzing the labrum for tears, degeneration or hypertrophy. To evaluate the labrum, the radiologist looks at the color and homogeneity, and degenerated labrum will appear grayish. However, the radiologist may be unaware of the phenomena the “magic angle”. This is a MR artifact, which may cause false signal changes in the labrum.

Patient-reported outcome measures

Questionnaires are used extensively in evaluating patient-reported outcome measures. The hip-specific PROMs are developed for the elderly population receiving a THA and are also widely used in young patients undergoing PAO. However, studies have demonstrated that both the WOMAC and the SF-36 questionnaire adequately detect changes over time after PAO [147]. Also, Van Bergayk et al. reported a general significant improvement in the WOMAC and the SF-36 scores between preoperative and postoperative values in 26 patients undergoing PAO.

In studies I and III, we used questionnaires to evaluate the pain in the hips at medium- to long-term follow-up. At our institution, the questionnaires have not previously been routinely used preoperatively or postoperatively. Questionnaires make it impossible (1) to evaluate the patient-reported effect of the surgery by comparing outcome at follow-up with values preoperatively; and (2) to determine the onset of any possible pain at follow-up. Hence the optimal use of the PROMs must be regular retrieval of the PROM, and this with as high a response rate as possible.

A problem using PROMs in general is the ceiling and flooring effect, i.e. that some patients will get the highest possible or lowest possible scores. This means that within this group of patients it is not possible to detect changes, since answers are outside the sensitive ranges of the scale. For the SF-36, the ceiling and floor effects are documented [136]. Several patients in all three studies reported maximum best scores in both the WOMAC and the Oxford questionnaires. We have not calculated the percentage, but recognize the problem. For the WOMAC questionnaire, with references to other studies reporting outcome after PAO [36, 37], we used the pain subscore on a dichotomized scale. Failure was considered if the pain score was $\geq$10, meaning that the ceiling effect was not important in this context, since all higher scores were considered evidence of failure. Even though studies have justified the use of the traditional PROMs, also in the young population, we believe a PROM for used in patients undergoing joint preserving surgery needs to be developed. By tailoring a PROM specifically for the young patient, it may be possible to minimize the risk of the ceiling or flooring effect.

Perspective and future research

The perspective of the three studies represented in this thesis is to improve the surgical treatment and outcome for patients with symptomatic dysplasia of the hip. The studies have shown some easily interpretable criteria to apply in the clinical setting.

In study I, the greater awareness of the statistically significant risk factors for failure (increasing age, preoperative signs of osteoarthritis, postoperative hip joint incongruence, postoperative joint space width <3mm, and an achieved postoperative center-edge angle $<30^{\circ}$ to $>40^{\circ}$) can help the surgeon in selecting the patient who have the greatest probability of long-term benefit from the surgery. The surgeon will be better prepared to inform and guide the patient in the outpatient clinic. For example, by limiting PAO to hips with none or only mild osteoarthritis preoperatively has increased the hip joint survival. We expect that the enhanced knowledge on the risk factors for failure will improve the survival rate of the hip joint after PAO.

Study II will set a precedent for further studies. The study has identified some factors that increase the need for intraarticular assessment simultaneously with or following the PAO, but more research is needed. With larger studies and with longer follow-up, some day it may be possible to tailor the PAO to the needs of each patient. For the time being, the surgeon must, in patients with borderline hip dysplasia or signs of retroversion, be aware of the risk of possibly impingement postoperatively.

Study III shows that, at least in highly specialized orthopedic departments, it is possibly to insert a THA in hips with a previous PAO with good results. However, the surgeon must be aware of that possible dysplasia, despite the PAO, may be present challenging the procedure.

Studies I and II illustrate that the reorientation of the acetabulum must be performed meticulously, thereby avoiding overcorrection and acetabular retroversion and thus minimizing the risk of femoroacetabular impingement. Computer navigation-assisted surgery can illustrate the 3D view of the correction, in contrast to the traditional 2D view obtained with fluoroscopy. A study of this aspect has been initiated, and may in the future be an invaluable tool for both the skilled and unskilled PAO surgeon in optimizing the reorientation of the acetabulum.

The healing capability of the acetabular labrum is generally considered low. A 5-year follow-up study of the non-arthroscopy group in study II with a renewed MRA could potentially clarify what happens to the acetabular labrum after the reorientation procedure. What happens to the hypertrophic labrum after PAO and what happens to the detached labrums? Is reattachment possible? Unfortunately, with the MR scanners available today, it is not possible to redo the MRA without removing the screws, which would be ethical incorrect.

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Appendices

PhD and Doctoral Thesis from the Orthopaedic Research Group, www.Orthoresearch.dk, Aarhus University Hospital, Denmark

PhD Theses

1. In vivo and vitro stimulation of bone formation with local growth factors
   Martin Lind, January 1996
   www.OrthoResearch.dk

2. Gene delivery to articular cartilage
   Michael Ulrich-Vinther, September 2002
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3. The influence of hydroxyapatite coating on the peri-implant migration of polyethylene particles
   Ole Rahbek, October 2002
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4. Surgical technique's influence on femoral fracture risk and implant fixation. Compaction versus conventional bone removing techniques
   Søren Kold, January 2003
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5. Stimulation and substitution of bone allograft around non-cemented implants
   Thomas Bo Jensen, October 2003
   www.OrthoResearch.dk

6. The influence of RGD peptide surface modification on the fixation of orthopaedic implants
   Brian Elmengaard, December 2004
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7. Biological response to wear debris after total hip arthroplasty using different bearing materials
   Marianne Nygaard, June 2005
   www.OrthoResearch.dk

8. DEXA-scanning in description of bone remodeling and osteolysis around cementless acetabular cups
   Mogens Berg Laursen, November 2005
   www.OrthoResearch.dk

9. Studies based on the Danish Hip Arthroplasty Registry
   Alma B. Pedersen, 2006
   www.OrthoResearch.dk

10. Reaming procedure and migration of the uncemented acetabular component in total hip replacement
    Thomas Baad-Hansen, February 2007
    www.OrthoResearch.dk

11. On the longevity of cemented hip prosthesis and the influence on implant design
    Mette Ørskov Sjøland, April 2007
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12. Combination of TGF-β1 and IGF-1 in a biodegradable coating. The effect on implant fixation and osseointegration and designing a new in vivo model for testing the osteogenic effect of micro-structures in vivo
Anders Lamberg, June 2007
www.OrthoResearch.dk

13. Evaluation of Bernese periacetabular osteotomy; Prospective studies examining projected load-bearing area, bone density, cartilage thickness and migration
Inger Mechlenburg, August 2007
Acta Orthopaedica (Suppl 329) 2008;79

14. Rehabilitation of patients aged over 65 years after total hip replacement - based on patients' health status
Britta Hørdam, February 2008
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15. Efficacy, effectiveness, and efficiency of accelerated perioperative care and rehabilitation intervention after hip and knee arthroplasty
Kristian Larsen, May 2008
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16. Rehabilitation outcome after total hip replacement; prospective randomized studies evaluating two different postoperative regimes and two different types of implants
Mette Krintel Petersen, June 2008
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17. CoCrMo alloy, *in vitro* and *in vivo* studies
Stig Storgaard Jakobsen, June 2008
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18. Adjuvant therapies of bone graft around non-cemented experimental orthopaedic implants. Stereological methods and experiments in dogs
Jørgen Baas, July 2008
Acta Orthopaedica (Suppl 330) 2008;79

19. The Influence of Local Bisphosphonate Treatment on Implant Fixation
Thomas Vestergaard Jakobsen, December 2008
www.OrthoResearch.dk

20. Surgical Advances in Periacetabular Osteotomy for Treatment of Hip Dysplasia in Adults
Anders Troelsen, March 2009
Acta Orthopaedica (Suppl 332) 2009;80

21. Polyethylene Wear Analysis. Experimental and Clinical Studies in Total Hip Arthroplasty.
Maiken Stilling, June 2009
Acta Orthopaedica (Suppl 337) 2009;80

22. Step-by-step development of a novel orthopaedic biomaterial: A nanotechnological approach.
Thomas H.L. Jensen, September 2009
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23. Osteoclastic bone resorption in chronic osteomyelitis
Kirill Gromov, November 2009
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31. The applicability of metallic gold as orthopaedic implant surfaces – experimental animal studies
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32. Gene transfer for bone healing using immobilized freeze-dried adeno-associated viral vectors
Mette Juul Koefoed, June 2011
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33. Mobile or fixed bearing articulation in TKA? A randomized evaluation of gait analysis, implant migration, and bone mineral density
Michael Tjørnild, December 2011
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34. Hip resurfacing arthroplasty. Failures and complications investigated by a meta-analysis of the existing literature, and clinically by microdialysis, laser doppler flowmetry, RSA, DXA and MRI
Nina Dyrberg Lorenzen, March 2012
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35. Bone allograft and implant fixation tested under influence of bio-burden reduction, periosteal augmentation and topical antibiotics. Animal experimental studies.
Jeppe Barchman, January 2013
www.OrthoResearch.dk

Doctoral Theses

1. Hydroxyapatite ceramic coating for bone implant fixation. Mechanical and histological studies in dogs
   Kjeld Søballe, 1993
   Acta Orthop Scand (Suppl 255) 1993;54

2. Growth factor stimulation of bone healing. Effects on osteoblasts, osteomies, and implants fixation
   Martin Lind, October 1998
   Acta Orthop Scand (Suppl 283) 1998;69

3. Calcium phosphate coatings for fixation of bone implants. Evaluated mechanically and histologically by stereological methods
   Søren Overgaard, 2000
   Acta Orthop Scand (Suppl 297) 2000;71

4. Adult hip dysplasia and osteoarthritis. Studies in radiology and clinical epidemiology
   Steffen Jacobsen, December 2006
   Acta Orthopaedica (Suppl 324) 2006;77

5. Gene therapy methods in bone and joint disorders. Evaluation of the adeno-associated virus vector in experimental models of articular cartilage disorders, periprosthetic osteolysis and bone healing
   Michael Ulrich-Vinther, March 2007
   Acta Orthopaedica (Suppl 325) 2007;78

6. Assessment of adult hip dysplasia and the outcome of surgical treatment
   Anders Troelsen, February 2012
   Dan Med J. 2012 Jun;59(6):B4450. Review.

PAPER I

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SYMPOSIUM: PAPERS PRESENTED AT THE 2011 MEETING OF THE INTERNATIONAL HIP SOCIETY

What Factors Predict Failure 4 to 12 Years After Periacetabular Osteotomy?

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Abstract

Background The goal of periacetabular osteotomy (PAO) is to delay or prevent osteoarthritic development in dysplastic hips. However, it is unclear whether the surgical goals are achieved and if so in which patients. This information is essential to select appropriate patients for a durable PAO that achieves its goals.

Questions/purposes We therefore (1) determined hip survival rates; (2) determined how many preserved hips were functionally unsuccessful after PAO; and (3) identified demographic, clinical, and radiographic factors predicting failure after PAO.

Methods We retrospectively reviewed 316 patients (401 hips) who had PAO between December 1998 and May 2007. We evaluated radiographic parameters of dysplasia and osteoarthritis and obtained WOMAC scores. Through inquiry to the National Registry of Patients, we identified conversions to THA. Risk factors for conversion to THA were assessed. Minimum followup was 4 years (mean, 8 years; range, 4–12 years).

Results The overall Kaplan-Meier hip survival rate was 74.8% at 12.4 years. A WOMAC pain score of 10 or more, suggesting clinical failure, was observed in 13% of preserved hips at last followup. Higher age, preoperative Tönnis grade of 2, incongruent hip, postoperative joint space width of 3 mm or less, and postoperative center-edge angle of less than 30° or more than 40° predicted conversion to THA.

Conclusions PAO preserved three of four hips with most functioning well at 4- to 12-year followup. When planning surgery, surgeons should attempt to achieve hip congruence and a center-edge angle of between 30° to 40° to improve the durability of PAO.

Level of Evidence Level II, prognostic study. See Instructions for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution approved or waived approval of the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.
This work was performed at the Orthopaedic Research Unit, Aarhus University Hospital, Aarhus, Denmark.

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Introduction

Since the development of the periacetabular osteotomy (PAO) by Ganz et al. [12] more than 25 years ago, the applied surgical techniques have been refined by other surgeons [14, 22, 40, 45]. Many authors prefer a PAO for reorienting the acetabulum in young adults suffering symptomatic hip dysplasia [7, 13, 20, 28, 33, 35, 44, 45]. The reorientation enhances the insufficient acetabular coverage of the femoral head that characterizes hip dysplasia. The ultimate goals are to reduce pain, improve function, and delay or prevent the development of osteoarthritis causing need for THA [13, 28, 34, 35, 44, 45]. Assessed by Kaplan-Meier analysis with conversion to THA as end point, PAO is associated with survival rates of 90% and 84% at 5 and 10 years, respectively [21, 41], and 60.4% at 20 years [35].

Previous studies [20, 21, 24, 27, 35, 41] have identified factors influencing failure and conversion to THA after PAO. Among these patient-related radiographic factors are higher age at surgery [21, 35, 41], severe hip dysplasia [41], osteoarthritic changes (Tönnis grade > 1) [20, 35], presence of an os acetabuli [41], poor hip congruency [21, 24, 27], and small width of the sclerotic zone [41]. Knowing the factors predicting failure has the potential to improve selection of patients who will benefit from PAO and identify patients who might otherwise undergo unnecessarily surgery and should be offered primary THA. Thus, previously reported factors need to be confirmed.

We therefore (1) determined the hip survival rate after PAO (total and divided into subgroups according to surgical approach, degree of osteoarthritis, and achieved center-edge angle postoperatively); (2) determined how many preserved hips were functionally unsuccessful despite not being converted to THA; and (3) identified demographic, clinical, and pre- and postoperative radiographic factors predicting failure after PAO.

Patients and Methods

From our institutional database of PAOs, we identified 354 patients (451 hips) who consecutively underwent PAO in one or both hips from December 1998 to May 2007. Ninety-five of these 354 patients (116 of the PAOs in this study) were reported previously [41]. Throughout the study period, the indications for the PAO were (1) symptomatic dysplasia of the hip indicated by persistent hip pain, (2) center-edge angle of Wiberg of less than 25°, (3) pelvic bone maturity, (4) absence of hip subluxation, (5) internal rotation of greater than 15°, and (6) hip flexion of greater than 110°. The contraindications for PAO were (1) osteoarthritis (this contraindication has gradually changed to exclude any osteoarthritis above Tönnis Grade 1 from PAO surgery), (2) reduced ROM indicating joint degeneration, and (3) lack of hip congruence. We excluded 19 foreigners or emigrants (23 hips) lost to followup, two deceased patients (two hips), and 17 patients who had incomplete radiographic followup or poor radiographic material (25 hips). This left 316 patients (401 hips) in the study group. During May 2011, WOMAC questionnaires were collected from the patients and hips converted to THA identified. Minimum followup was 4 years (mean, 8 years; range, 4–12 years).

All surgeries were performed by one of two surgeons (KS, SO). Until March 2003, PAO surgeries were performed through either the ilioinguinal or the iliofemoral (modified Smith-Petersen) approach (204 procedures) [8, 14, 22, 45]. The osteotomies were performed as described by Ganz et al. [12], leaving the posterior column intact. From April 2003, the PAOs were performed using the minimally invasive transsartorial approach (197 procedures) developed by the senior author (KS) [39, 40]. Since September 1999, a measuring device was used for intraoperative evaluation of the achieved acetabular correction [38].

Patients were mobilized a few hours postoperatively, and a regimen of partial weightbearing using two crutches was prescribed the first 6 to 8 weeks. Physical therapy included instructions during hospitalization and a handout describing a home exercise program. At 6 to 8 weeks, full weightbearing was normally allowed.

WOMAC questionnaires [4] were mailed to all patients with preserved PAO hips and the response rate was 83% (277 of 332 hips). One questionnaire from each operated hip was intended. The WOMAC questionnaire consists of 24 questions in three different categories: (1) pain, (2) stiffness of the hip, and (3) physical function in daily activities. Raw scores of pain (0–20), stiffness (0–8), and physical function (0–68) were summarized into a total score (0–96), with a score of 0 indicating no pain or functional disability. To enhance the comparability with previous studies, each subscale was normalized, taking into account different scale lengths, and a total score on a 0- to 100-scale was calculated, with 100 indicating no pain or functional disability [4]. From our PAO database, we retrieved demographic and clinical data in terms of age, sex, height, and weight (missing for 47 patients), condition underlying hip dysplasia, and previous pelvic and/or femoral surgeries (Table 1). By inquiry to The National Registry of Patients, we identified the conversion of 69 PAOs to THAs in the study group. Complications related to the PAO were not addressed in this study.

One author (CHA), who was not aware of the status of the hip, assessed all conventional radiographs. Where preoperative CT scans were available, the evaluations of these were noted (Table 2). On conventional pre- and postoperative radiographs, the following radiographic parameters were measured: the center-edge angle of Wiberg [46]; acetabular index angle [37]; width of the sclerotic zone; x coordinate [33] and y coordinate [42] of femoral head translation; roundness index of the femoral head [26]; presence of an os acetabuli [19]; minimal joint space width [1], measured as the smallest width between the acetabular sclerotic zone and the femoral head; and femoral offset. We graded the degree of osteoarthritis pre- and postoperatively according to the Tönnis classification

Table 1. Demographic and surgical data for the 316 patients (401 hips)

Parameter	Value
Age of time of operation (years)	
Median (interquartile range)	33.9 (24.4–42.7)
Range	13.2–61.4
Sex (number of hips)	
Female	289 (72.1%)
Male	112 (27.9%)
BMI (kg/m^2)*	
Median (interquartile range)	24.2 (21.5–26.3)
Range	15.1–37.2
Diagnosis (indication for PAO) (number of hips)	
Dysplasia	353 (88%)
Legg-Calvé-Perthes disease	43 (11%)
Miscellaneous	5 (1%)
Previous surgery (number of hips)	
Femoral osteotomy	32 (8%)
Pelvic osteotomy	13 (3%)
Concomitant surgery (number of hips)	
Femoral osteotomy	26 (6%)
Surgical approach (number of hips)	
Ilioinguinal/femoral	204 (51%)
Minimal invasive surgery	197 (49%)

* BMI missing for 47 hips; PAO = periacetabular osteotomy.

(Grades 0–3) [37]. The congruence of the hip was evaluated by identifying the center of the femoral head using the Moses template. The best-fitted circle of the acetabulum was drawn with a compass. We considered the hip congruent if the centers of the femoral head and the acetabulum were concentric (Fig. 1). Lack of congruence was quantified by measuring the distance between the center of the femoral head and the center of the best-fitted acetabular circle. The measure was not performed in hips with Legg-Calvé-Perthes (43 hips) due to the inherent, severe incongruence observed in these hips. The minimal joint space width was measured with a scale loupe. Retroversion of the acetabulum was noted if a crossover sign (crossing of the anterior and posterior acetabular rims) was present on the radiographs [3, 18, 30]. Studies have shown the importance of standardized pelvic radiographs, preferably standing [11, 32, 42], for assessing retroversion. The majority of the radiographs in this study were supine exposures, and therefore we made no definitive conclusions regarding the importance of retroversion before and after PAO. The intra- and interobserver variability of radiographic parameters were assessed in a subset of 25 radiographs by two independent observers (CHA, AT). We computed mean of the difference and 95% limits of agreement according to the Bland-Altman approach [5, 6]. Intra- and interobserver assessments of key measures generally showed similar agreement to those reported in the literature [42] (Table 3).

On preoperative CT scans, the following parameters were assessed by a radiologist [2]: anterior and posterior acetabular sector angles, coronal and sagittal center-edge angles, acetabular version angle, neck-shaft angle, and neck version angle. CT scans were available for 314 of the 401 hips (78%).

Data are presented as means with 95% CIs when normally distributed and as medians with interquartile ranges when not normally distributed. Excluded patients were not a part of the analysis. We calculated crude hazard ratios using Cox regression analyses to identify possible predictors of failure after PAO. The hazard ratios were adjusted for sex, preoperative degree of osteoarthritis, and pre- and postoperative center-edge angles. In the case of a missing value when performing Cox regression analysis, the patient was excluded from the analysis. The proportional-hazard assumption requirements were tested using log-log plots. We calculated hip survivorship, with conversion to THA as an end point, using Kaplan-Meier survival analysis in the entire cohort and dividing operated hips into subgroups according to the surgical approach, Tönnis grade of osteoarthritis, and achieved acetabular reorientation. We used STATA® 11 software package (StataCorp LP, College Station, TX, USA) for all calculations.

Results

Sixty-nine of the 401 hips (17%) were converted to THA at 3.9 to 12.4 years postoperatively. The Cox regression analysis found 13 demographic and radiographic parameters that had a crude hazard ratio different from 1.0 (Table 4). After adjusting crude hazard ratios for potential confounders, including sex, preoperative center-edge angle of less than 0°, postoperative center-edge angle of less than 30° or more than 40°, and preoperative Tönnis grade of 2, we identified five predictors of conversion to THA: (1) age of 40 years or more at time of surgery (hazard ratio, 2.10; 95% CI, 1.29–3.41), (2) postoperative center-edge angle of less than 30° or more than 40° (hazard ratio, 2.00; 95% CI, 1.21–3.33), (3) postoperative minimal joint space width of less than 3 mm (hazard ratio, 2.57; 95% CI, 1.42–4.67), (4) preoperative Tönnis grade of 2 (hazard ratio, 5.37; 95% CI, 2.92–9.88), and (5) postoperative lack of hip congruence (hazard ratio, 2.08; 95% CI, 1.04–4.15) (Table 4). CT scan parameters available for 314 hips identified no risk factors for conversion to THA.

Eighty-four percent of the preserved hips had no pain or a low pain score at 3.9 to 12.4 years after PAO. The median normalized total WOMAC scores was 74.8 (range, 13–100) (Table 5).

Table 2. Radiographic characteristics of the 316 patients (401 hips)

Characteristic	Preoperative value	Postoperative value
Pelvic radiographs		
Center-edge angle (°)		
Median (interquartile range)	11 (6–18)	30 (27–35)
Range	−29 to 29	−5 to 50
Acetabular index angle (°)		
Median (interquartile range)	20 (14–25)	6 (0–10)
Range	3–57	−14 to 47
Horizontal width of the sclerotic zone (mm)		
Mean (95% CI)	31 (31–32)	34 (33–34)
Range	17–50	7–55
x coordinate of femoral head translation (mm)		
Mean (95% CI)	16 (15–17)	15 (15–16)
Range	2–40	0–37
y coordinate of femoral head translation (mm)		
Mean (95% CI)	103 (102–104)	98 (97–99)
Range	72–140	55–136
Roundness index of the femoral head		
Median (interquartile range)	0.51 (0.51–0.51)	0.51 (0.51–0.51)
Range	0.41–0.58	0.43–0.57
Tönnis grade of osteoarthritis (number of hips)		
0	241 (60%)	230 (57%)
1	141 (35%)	154 (39%)
2	19 (5%)	17 (4%)
Presence of an os acetabuli (number of hips)	42 (10%)	49 (12%)
Minimal joint space width (mm)		
Mean (95% CI)	4.6 (4.5–4.7)	4.2 (4.1–4.3)
Range	0.9–9.5	0.6–9.4
Congruence > 0 mm (number of hips)	261 (64%)	281 (69%)
Offset femur (mm)		
Mean (95% CI)	36 (35–37)	
Range	13–68	
CT scans*		
Anterior acetabular sector angle (°)		
Mean (95% CI)	45 (44–46)	
Range	13–73	
Posterior acetabular sector angle (°)		
Mean (95% CI)	86 (85–87)	
Range	2–108	
Acetabular anteversion angle (°)		
Mean (95% CI)	20 (20–21)	
Range	−6 to 38	
Coronal center-edge angle (°)		
Median (interquartile range)	12 (7–20)	
Range	−34 to 40	
Sagittal center-edge angle (°)		
Mean (95% CI)	51 (50–52)	
Range	13–87	

Table 2. continued

Characteristic	Preoperative value	Postoperative value
Neck-shaft angle (°)		
Median (interquartile range)	137 (130–146)	
Range	80–168	
Neck version angle (°)		
Mean (95% CI)	31 (30–33)	
Range	−25 to 77	

* Data available for 314 hips.

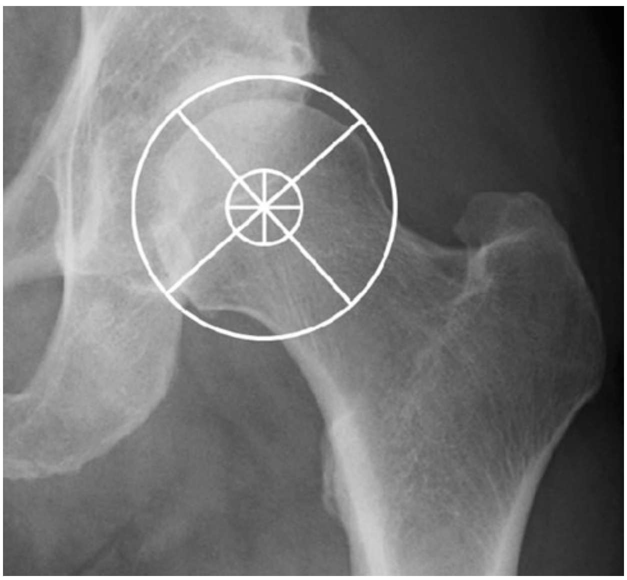


Fig. 1 Lack of hip congruence postoperatively was a factor predicting failure. Congruence was determined by the drawings of two circles. When the center of the best-fitted circle of the acetabulum sclerotic roof is concentric to the center of the femoral head, the joint is considered congruent as shown here. The distance between the two circle centers would thus be 0 mm.

Table 3. Interobserver variability of important radiographic indexes of hip dysplasia and joint degeneration

Radiographic parameter	Difference (mean)	SD	95% prediction interval
Center-edge angle	−0.64	3.5	−7.7 to 6.4
Acetabular index angle	−0.04	3.0	−6.1 to 6.1
Congruence	1.16	1.8	−2.5 to 4.9
Minimal joint space width	0.11	0.4	−0.6 to 0.9

In the entire cohort of 401 hips, we found a hip survival rate of 74.8% (95% CI, 68.1%–80.4%) at 12.4 years using conversion to THA as the end point (Fig. 2). The hip survival rate after 8 years was clearly improved after the implementation of the minimally invasive technique to 91% (95% CI, 84.3%–94.2%) (Fig. 3). Ten-year hip survival rates for Tönnis Grades 0, 1, and 2 were 85.7% (95% CI, 78.0%–90.9%), 68.7% (95% CI, 57.7%–77.3%), and 25.4% (95% CI, 7.5%–48.4%), respectively (Fig. 4). Correction of the acetabulum to a center-edge angle of between 30° and 40° showed a higher 10-year survival rate than correction to a center-edge angle of less than 30° or more than 40° (82.7% [95% CI, 73.3%–89.1%] and 67.0% [95% CI, 57.3%–75.0%], respectively) (Fig. 5).

Discussion

By identifying clinical and pre- and postoperative radiographic factors predicting failure after PAO, we could potentially refine patient selection for PAO and help in the counseling of future patients. We therefore investigated hip survival rates and potential clinical failures in preserved hips after PAO and identified demographic, clinical, and radiographic factors predicting failure after PAO.

Our study has limitations. First, 50 of 451 hips were excluded from followup, leaving 11% of the total cohort unaccounted for, but still 401 hips were represented. We presume those remaining would be representative of the whole since the percentage excluded was relatively small. Second, the WOMAC questionnaire was returned by 83% of the preserved hips, leaving the patient-reported status of 17% unknown. Again, we presume the data obtained would be representative of the entire cohort. Third, WOMAC questionnaires were not distributed preoperatively or routinely postoperatively. Therefore, the onset of the pain was unknown. Fourth, routine pre- and postoperative AP pelvic radiographs were taken with the patient supine for the majority of patients, thus making definite conclusions regarding the importance of retroversion impossible. Finally, even though most indications for PAO were the same during the study period, the increasing attention toward the early need for conversion to THA in osteoarthritic hips has led to a change in indications over the years.

Various studies have reported demographic, clinical, and radiographic factors as predictors of failure (Table 6).

Table 4. Crude and adjusted hazard ratios for predictors of conversion to THA

Parameter	Crude hazard ratio (95% CI)	p value	Adjusted hazard ratio* (95% CI)	p value
Demographic data				
Age at surgery ≥ 40 years	1.97 (1.22–3.18)	0.005	2.10 (1.29–3.41)	0.003
Legg-Calvé-Perthes disease	1.39 (0.71–2.72)	0.337	1.96 (0.93–4.14)	0.077
Previous femoral surgery	2.22 (1.13–4.34)	0.020	1.91 (0.97–3.76)	0.063
Radiographic data				
Postoperative center-edge angle < 30° or > 40°	2.20 (1.34–3.62)	0.002	2.00 (1.21–3.33)	0.007
Postoperative acetabular index angle > 10°	2.31 (1.43–3.74)	0.001	1.57 (0.90–2.75)	0.116
Preoperative presence of an os acetabuli	2.22 (1.21–4.06)	0.010	1.61 (0.84–3.11)	0.155
Postoperative presence of an os acetabuli	2.26 (1.28–4.02)	0.005	1.64 (0.88–3.07)	0.119
Preoperative minimal joint space width < 3 mm	3.54 (1.94–6.49)	< 0.001	1.83 (0.92–3.66)	0.087
Postoperative minimal joint space width < 3 mm	4.29 (2.57–7.17)	< 0.001	2.57 (1.42–4.67)	0.002
Preoperative Tönnis Grade 2	5.66 (3.09–10.38)	< 0.001	5.37 (2.92–9.88)	< 0.001
Preoperative congruence > 0 mm†	2.11 (1.16–3.84)	0.015	1.75 (0.95–3.23)	0.074
Postoperative congruence > 0 mm†	2.54 (1.23–5.02)	0.004	2.08 (1.04–4.15)	0.039
CT data				
Coronal center-edge angle < 5°	2.02 (1.15–3.55)	0.015	1.49 (0.74–3.00)	0.261

* The crude hazard ratio adjusted for sex, preoperative Tönnis Grade 2, and pre- and postoperative center-edge angle; †congruence not measured in hips with Legg-Calvé-Perthes disease (43 hips excluded).

Table 5. Results of WOMAC questionnaires (n = 277)

Domain	WOMAC score (points)		
	Median	Interquartile range	Range
Pain (0–20)*	4.7	1–7	0–19
Stiffness (0–8)*	2.3	0–4	0–8
Physical function (0–68)*	14.9	3–24	0–55
Total (0–96)*	21.9	6–35	0–78
Normalized (0–100)†	74.8	59.8–92.1	13–100

* Raw scores, with 0 indicating best results; †normalized scores, with 100 indicating best result.

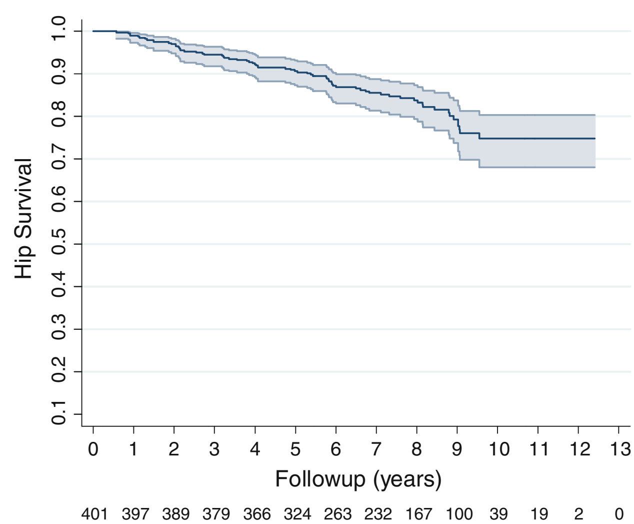


Fig. 2 A graph shows the Kaplan-Meier survivorship curve (with 95% CI) with conversion to THA as the end point for 401 hips after PAO. Each decrease in curve corresponds to a conversion to THA. The number of hips remaining for every year of followup is given below the x axis. Hip survival rate is 74.8% (95% CI, 68.1%–80.4%) at 12.4 years.

Consistent with the literature [21, 35], we found increasing age independently predicted failure after PAO with an adjusted hazard ratio of 2.10 (95% CI, 1.29–3.41). These observations support an upper age limit for performing PAO. However, one clinical study reported a 10-year hip survival rate of 90.8% in PAO patients older than 40 years [16], and another study reported no radiographic differences in the progression of OA 5 years after PAO when comparing patients 55 years or older to a group of younger patients [36]. Conclusions may be influenced by cultural differences in expectations and functional demands after PAO. The adjusted hazard ratios for joint degeneration in terms of Tönnis Grade 2 osteoarthritis or a joint space width of 3 mm or less found in our study is in agreement with the existing literature [20, 23, 33, 35, 44]. Today, hips with a Tönnis grade of 2 or more do not commonly undergo PAO, and we found even Tönnis Grade 1 hips had a lower long-term survival rate compared with Tönnis Grade 0 hips. Our data suggest the postoperative center-edge angle of Wiberg should be between 30° to 40°. We found the risk of failure to be doubled if acetabular reorientation was not confined to this interval. Steppacher et al. [35] also found insufficient coverage as a risk factor for

Fig. 3 A graph shows the Kaplan-Meier survivorship curves (with 95% CIs) with conversion to THA as the end point for 401 hips after PAO divided according to surgical approach. Hip survival rate after 8 years is clearly improved after the implementation of the minimally invasive technique in 2003 to 90.4% (95% CI, 84.3%–94.2%) compared to the traditional approach at 79.3% (95% CI, 73.1%–84.3%).

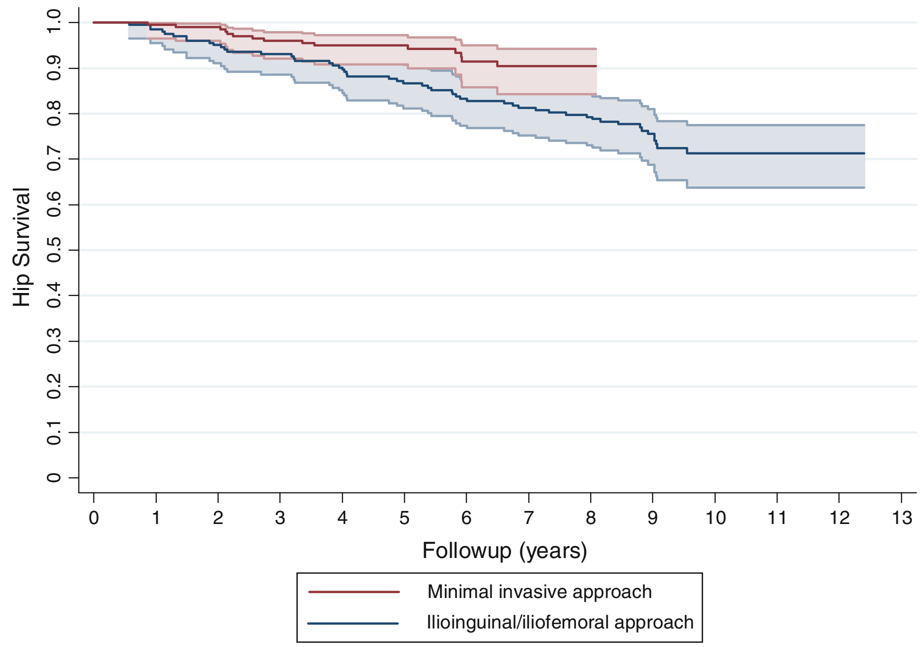
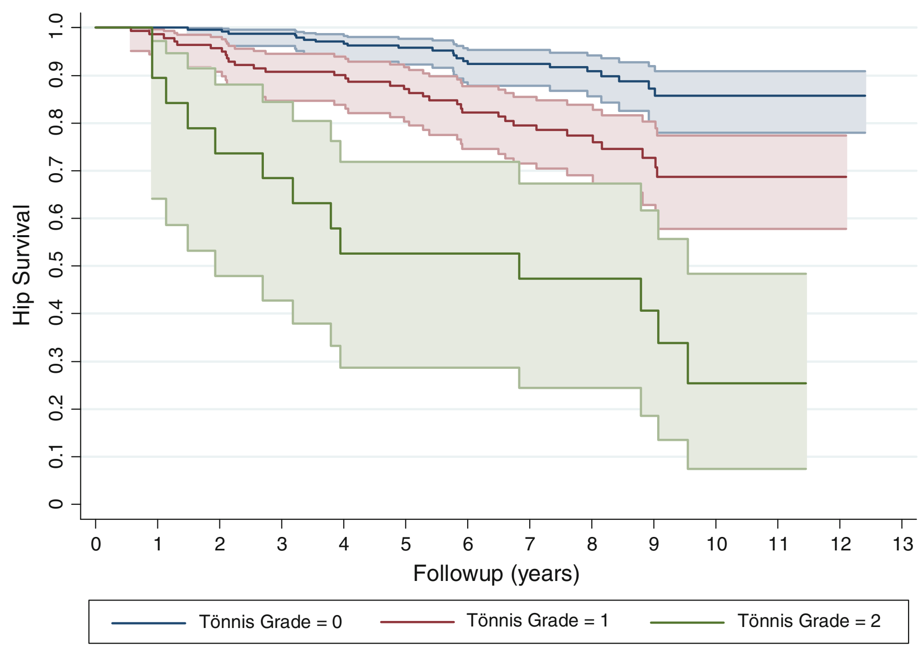


Fig. 4 A graph shows the Kaplan-Meier survivorship curves (with 95% CIs) with conversion to THA as the end point for 401 hips after PAO divided according to the preoperative Tönnis grade of osteoarthritis. Ten-year hip survival rates for Tönnis Grades 0, 1, and 2 are 85.7% (95% CI, 78.0%–90.9%), 68.7% (95% CI, 57.7%–77.3%), and 25.4% (95% CI, 7.5%–48.4%), respectively.



conversion to THA. Further, acetabular overcorrection has been associated with risk of femoroacetabular impingement after PAO [25]. Lack of hip congruence and instability are thought to induce repeated impaction between the femoral head and the acetabular labrum leading to labral tearing, increased local contact stresses, and degeneration. The biomechanical consequences of incongruence of the hip can therefore explain why postoperative hip incongruence predicted failure with an approximately doubled risk of conversion to THA. Okano et al. [27] also found postoperative hip congruence important for the function of the hip after PAO. Hips with Legg-Calvé-Perthes disease are characterized by inherent, severe incongruence; however, our analysis failed to show an increased risk for failure. In the existing literature, Clohisy et al. [9] reported 92% being satisfied at followup (mean, 4.3 years; range, 2.0–9.3 years) and no conversions to THA in 24 hips with Perthes-like deformities. Shinoda et al. [31] followed 17 hips for 3 to 19 years (mean, 6.6 years) and reported one conversion to THA. An os acetabuli is considered a sign of overload of the acetabular rim zone and may cause progressive degeneration of the

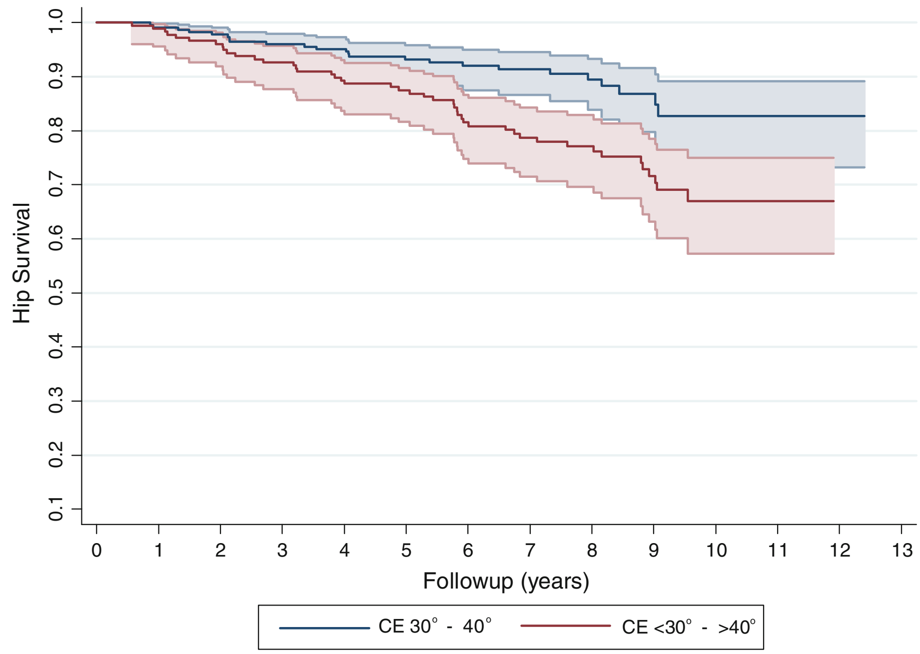


Fig. 5 A graph shows the Kaplan-Meier survivorship curves (with 95% CIs) with conversion to THA as the end point for 401 hips after PAO divided according to the achieved center-edge (CE) angle postoperatively. Correction of the acetabulum to a center-edge angle of between 30° and 40° (82.7% [95% CI, 73.3%–89.1%]) shows a higher 10-year survival rate than correction to a center-edge angle of less than 30° or more than 40° (67.0% [95% CI, 57.3%–75.0%]).

Table 6. Studies reporting predictors of failure using risk estimate statistics and survival rate after PAO

Study	Age at surgery (years)*	Number of hips with PAO	Number of failed hips†	Followup (years)*	Predictors of failure	Hip survival rate
Matheney et al. [21]	26.7 (10–45)	135	17	9	Age > 35 years, poor congruency	5 years: 96% 10 years: 84%
Steppacher et al. [35]	29.3 (13–56)	68	27	20.4 (19–23)	Age, preoperative score, positive impingement test, limb, osteoarthritis grade, insufficient acetabular coverage	5 years: 93.2% 10 years: 84.6% 20 years: 60.5%
Troelsen et al. [41]‡	29.9 (14.1–57.0)	116	17	6.8 (5.2–9.2)	Severe dysplasia, presence of os acetabuli, osteoarthritis, excessive lateral and proximal dislocation	5 years: 90.5% 9.2 years: 81.6%
Millis et al. [23]	43.6 (40–51)	87	21	4.9 (2–13)	Osteoarthritis	
Current study	33.9 (13.2–61.4)	401	69	7.9 (3.9–12.4)	Age, osteoarthritis, suboptimal achieved center-edge angle, reduced postoperative joint space width incongruence	12.4 years: 74.8%

* Values are expressed as mean, with range in parentheses; †failure in terms of conversion to THA; ‡reports the outcome of part (n = 116) of the same cohort as in the current study; PAO = periacetabular osteotomy.

joint [17, 19, 29], and we previously reported an os acetabuli predicted failure [41]. However, in the current study, after adjusting for the risk imposed by the grade of osteoarthritis, the pre- and postoperative center-edge angle, and sex, the presentation of an os acetabuli no longer predicted failure. Finally, CT conveys detailed information on the three-dimensional pathomorphology of hip dysplasia. It has been widely utilized to aid preoperative planning, but the prognostic value of the findings remains unexplored and could potentially convey important information about how to select patients who will benefit most from PAO.

Hip survival using Kaplan-Meier analysis showed a cumulative survival rate of 74.8% at 12.4 years. This is slightly less than reported in two other studies reporting long-term followup in smaller study cohorts [21, 35]. In Denmark, it is possible to perform complete followup of all patients by inquiry into The National Registry of Patients as all patients (and treatments) can be traced by the unique social security number of the patients. Thus, none of the patients living in Denmark would be lost to followup, making number of conversions to THA reliable. We have previously reported good hip survival rates (97% after

5 years) in patients operated on since April 2003 using the minimally invasive approach. Improvement in the surgical technique with sparing of the soft tissue, reduced blood loss, less impact at the blood supply to the acetabulum, together with refinement in patient selection have increased the hip survival rate [39, 40]. There is a learning curve when performing PAO [10, 12, 14, 15, 28, 43], and the cumulated experience of the senior author (KS) has added to the increased hip survival rate of 91% at 8 years after the introduction of the minimal invasive technique used since 2003.

The WOMAC questionnaires revealed 44 preserved PAOs with a pain score 10 or more (15.9%). Most studies reporting the outcome of a clinical scoring system after PAO have used the Merle d'Aubigné-Postel score or Harris hip score. Matheney et al. [21] reported similar findings, with clinical failure in 13% of the preserved PAO hips defined by a WOMAC pain score of 10 or more at mean followup of 9.7 years. The use of contemporary WOMAC total scores is still rare in followup of PAO.

In conclusion, PAO overall preserved three of four hips at 4 to 12 years' followup and the majority of the patients with preserved hips reported no or low pain. Patients should be carefully selected for joint-preserving surgery as higher age and preoperative Tönnis grade of osteoarthritis above 1 impose increased risk of failure. Also, failure to achieve proper acetabular correction and hip congruence will increase the risk of failure after PAO, and preoperative radiographs should be assessed to judge whether this can be achieved.

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PAPER II

Can the need for arthroscopy be predicted in patients undergoing periacetabular osteotomy?

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Ethical review committee statement*:*
The study follows the rules specified by the Helsinki-II Declaration. According to Danish legislation no obligation to notify the Research Ethics Committee existed.

ABSTRACT

Background: Despite the frequency of labral tears in symptomatic developmental dysplasia of the hip, no consensus exists regarding the treatment of co-existing DDH and tearing of the acetabular labrum. The purpose of this prospective, MR-arthrography (MRA) based 2-year follow-up study was to identify risk factors predicting clinical failure in terms of the need for a hip arthroscopy after PAO, to assess the clinical and radiographic outcome in a PAO cohort with MRA diagnosed labral pathology, and to assess any difference in clinical and radiographic outcome between patients requiring a subsequent arthroscopy compared with a non-arthroscopy group.

Methods: Seventy-six patients (79 hips) scheduled for PAO were evaluated preoperatively and at 2-year follow-up. MRA was performed in all patients prior to PAO. At follow-up patients were divided into a non-arthroscopy and arthroscopy group. The two groups were compared clinical and radiological, and risk factors for predicting failure in terms of a hip arthroscopy after PAO were calculated. Patient reported outcome measures (WOMAC, Oxford Hip and SF36) were filled out before PAO and at follow-up.

Results:
Twenty out of seventy-four patients (27%) required an arthroscopy within 2 years of the PAO. Risk factors for failure were preoperative borderline dysplasia, abnormal high α-angle ($\geq 55^{o}$) and acetabular retroversion. Labral tearing, degeneration or hypertrophy did not negatively affect the outcome of PAO. Patients not requiring an arthroscopy had a statistically significant better outcome measured by patients reported outcome measures.

Conclusions: Hip arthroscopy after PAO were required in patients with borderline dysplasia of the hip and /or, abnormal high α-angle ($\geq 55^{o}$) and acetabular retroversion. The patients not requiring an arthroscopy had an excellent clinical and radiographic outcome.

MANUSCRIPT

Introduction

The Bernese periacetabular osteotomy (PAO) has become the preferred joint preserving treatment for symptomatic developmental dysplasia of the hip (DDH) [10]. Due to technical advances and surgical modifications of PAO surgery it can be performed with a low operative complication rate and little overall morbidity [28]. Follow-up studies have reported high hip joint survivorships rates after PAO [12,17,26,30]. Dorrell and Caterall were among the first to report on the relationship between dysplastic osseous abnormalities and labrum pathology [8]. Since then literature describing how the osseous abnormalities and the resulting pathological joint biomechanics in developmental dysplasia of the hip (DDH) may frequently lead to damage of the acetabular labrum has been evolving [16,18,23,23]. Recently, Ross et al found only 5 normal labrums in 73 dysplastic hips [25].

Despite the frequency of labral tears in symptomatic DDH and the increasing literature concerning labrum pathology, no consensus exists regarding the treatment strategy for DDH with co-existing acetabular labral tear. Tearing of the labrum is recognized being involved in joint degeneration and may untreated lead to osteoarthritis [11]. This has lead to new concepts and treatment strategies regarding the treatment of labral tearing in DHH. Open arthrotomy during PAO was the first means of addressing intraarticular pathology during PAO surgery [20]. Later hip arthroscopy assisted PAO was introduced to assess and address any present intraarticular pathology [15]. There is no evidence that intraarticular assessment, open or arthroscopic, is superior to not assessing the joint during PAO. However, hip arthroscopy alone without addressing the bony abnormalities in DDH is in general not recommended, and studies have showed failure in DDH hips undergoing arthroscopy alone [22], and resulted in high reoperation rates comparing borderline DDH hips with normally covered hips [14]. Studies reporting the outcome of PAO performed without simultaneous assessment of the joint have showed high hip joint survival rates [12,30]. However, some patients will require a subsequent hip arthroscopy and it would be valuable to predict who requires intraarticular assessment and if these patients will suffer an inferior outcome.

The purpose of this prospective, MR-arthrography (MRA) based 2-year follow-up study was to identify risk factors predicting clinical failure in terms of the need for a hip arthroscopy after PAO, to assess the clinical and radiographic outcome in a PAO cohort with MRA diagnosed labral pathology, and to assess any difference in clinical and radiographic outcome between patients requiring a subsequent arthroscopy compared with a non-arthroscopy group.

Material and Methods

Seventy-six patients (79 hips) consecutively scheduled for PAO due to DDH were enrolled in the study. Patients were included from January 2010 to February 2011 and all surgeries were performed or assisted by the senior author at two hospitals in Aarhus, Denmark.

Three patients were excluded from the study, because of multiple complaints from several joints in the body and thus, were not considered being representative for this PAO cohort. Two patients failed to show up at 2-year follow-up. Hence, the study group consisted of 71 patients (74 hips, 67 females, 39 right hips). Mean age of the patients at the time of PAO surgery was 33.6 years (range 14.5 - 58.9 years). Before PAO eight hips had a hip arthroscopy (Table 1) and one patient had had a combined femoral and pelvis osteotomy. Eight-teen patients underwent PAO surgery on the opposite hip within the two year study period, and two patients had screws removed following PAO. One patient suffered an Obturator Nerve lesion during PAO resulting severe daily pain and paralysis of the abductor longus and magnus muscles. Bilateral dysplasia was seen in 56 of 71 (79%) of the patients. Indication for PAO were persisting hip pain, a center-edge angle of Wiberg [34]<25°, pelvic bone maturity, absence of hip subluxation, internal rotation >15°, hip flexion <110° and Tönnis grade of osteoarthritis <2. The minimally invasive transsartorial approach [29] was used in all cases. Preoperatively and at 2-year follow-up the clinical and radiographic outcome were evaluated. Follow-up was done primarily by one investigator (CHA), except for two patients seen by the senior author (KSO). For data analysis the patients were divided into an arthroscopy group (if a hip arthroscopy was required within the 2-year follow-up period) and a non-arthroscopy group. The two groups were comparable in terms of age at PAO surgery, sex, side affected and bilateral diagnosed DDH ($p = 0.060 - 0.763$).

Clinical evaluation

At 2-year follow-up patients were interviewed regarding continued mechanical symptoms (clicking, locking, and instability) from the hip joint, dysesthesia of the dermatome innervated by the lateral femoral cutaneous nerve, any kind of surgical and non-surgical treatment since the PAO. They were examined for signs of trochanteric bursitis, and signs of internal and external snapping hip. Preoperatively and at 2-year follow-up leg-length and range of motion were measured. At 2-year follow-up the impingement test and the FABER test (Flexion, ABduction, External Rotation) were performed, and assumed positive if pain deep in the groin were elicited [32]. In three hips the tests were not performed due to recent hip arthroscopy, and in one hip the test were left out due to severe hip pain). Preoperatively and at 2-year follow-up patients were requested to fill out the Western Ontario and McMaster Universities Osteoarthritis index (WOMAC) [2] , the Oxford hip score (OHS)[7] and the general health questionnaire short form 36, version 1 [3] . Each subscale of the WOMAC score was calculated. To enhance the comparability with other studies the summarized WOMAC total score were normalized with 100 indicating the best possible score. The OHS score was given as a total score with 48 indicating the best possible score. From the SF36 data the physical and mental component scores were subsequently calculated.

Radiographic evaluation

Conventional standing pelvic radiographs recorded preoperatively and at 2-year follow-up were analyzed. One person (CHA) assessed the following radiographic parameters: the center-edge (CE) angle of Wiberg [34], the acetabular index (AI) angle [27], the presence of an os acetabuli [16], the Tönnis grade of osteoarthritis [27] and signs of retroversion [24].

Hips were characterized dysplastic if the CE-angle was <20^{o} and borderline dysplastic when the CE-angle was between 20^{o} - 25^{o}. AI-angles were considered normal if within 0^{o} - 10^{o}. CE-angles and AI angles after PAO were for the hip arthroscopy group analyzed at the postoperative supine radiographs, justified by an earlier study showing no significant changes in these two angles when repositioning from the supine to the weight bearing position [31]. The acetabulum was considered retroverted if the crossover sign [13,24,33] was present. All patients had a magnetic resonance arthrography (MRA) performed before PAO surgery. The MRA were performed with a 1.5 Tesla Scanner (Siemens Magnetom Symphony) preceded by guided injection of 8 mL of diluted gadolinium contrast medium (Gd-DTPA, 2 mmol/L) into the hip joint. The MRA was assessed for labral pathology in terms of degeneration, hypertrophic changes, tears and paralabral cysts. Labral lesions were graded according to the Czerny grading [6]. Czerny stages the labrum into groups according to shape, homogeneity and attachment to the acetabular rim. When present, cyst in the femoral head or in the acetabulum, were noted. The α-angle was measured on oblique axial MRA images (Fig. 1)[21]. An α-angle $\geq$55^{o} was considered pathological. One senior radiologist (JG) performed all intraarticular injections and analysis of MRA scans. Measurement of the α-angles was also performed by the first author (CHA). In four hips the α-angle could not be assessed due to imprecise oblique MRA images. Intra- and interobserver variability of the α-angle measurement was assessed by the first author and the senior radiologist by doing re-readings of the MRA scan separated by 4 weeks. The mean of difference for intraobserver variability was 0.48^{o} (SD ±1.90^{o}). The 95% limits of agreement (LOA) were -3.31^{o} to 4.27^{o}, and for the interobserver variability the mean difference was 1.52^{o} (SD ±3.14^{o}), 95% LOA was -4.76^{o} to 7.80^{o}.

Indication for hip arthroscopy

Continuous groin pain after PAO, a positive impingement or Faber test were indications for hip arthroscopy. Labral pathology diagnosed on MRA supported the diagnosis and indications. All patients with continuous symptoms in this study were primarily referred to the Sports Traumatology unit at Aarhus University Hospital, Denmark and evaluated by two experts in hip arthroscopy. Except in two patients all hip arthroscopies were performed by one of the two experts.

Statistical Analysis

Normally distributed data were presented as means and 95% confidence intervals, and as medians with interquartile ranges when not. Odds ratios for failures were calculated using logistic regression analysis. Variables within and between the non-arthroscopy group and the arthroscopy group were tested by non-parametric tests (Wilcoxson sign rank and ranksum) and Fisher's exact test. Intra- and interobserver variability were assessed using the Bland-Altman approach [1,4,5], and data was presented as mean of the difference with standard deviations (SD) and 95% limits of agreement.

Results

Twenty of 74 hips had a hip arthroscopy within 2 years after PAO (mean time interval between PAO and arthroscopy 0.98 years; range 0.29 - 1.92 years), and one of these twenty hips was converted to total hip arthroplasty two months after hip arthroscopy (7 months after PAO)(Table 2). For all hips the median preoperative CE-angle for was 19^{o} (range 2^{o} to 24^{o}) and the AI-angle was 15^{o} (range 0^{o} to 28^{o}). The postoperative CE-angle and the AI-angle was 34^{o} (range 17^{o} to 46^{o}) and 1^{o} (range -8^{o} to 16^{o}), respectively. At follow-up the median CE-angle and AI-angle was 34^{o} (range 17^{o} to 40^{o}) and 3^{o} (range -4^{o} to 16^{o}), respectively. For the hip arthroscopy group both the CE-angle and AI-angle changed significantly after arthroscopy (Table 3). Eighteen of 74 hips were retroverted preoperatively, and four hips at follow-up, all in the non-arthroscopy group.

The median α-angle was 49^{o} (range 37^{o} – 72^{o}), with no significant difference between the non-arthroscopy and arthroscopy groups. The MRA analysis of the acetabular labrum revealed only four labrum (all in the non-arthroscopy group) without any signs of degeneration, hypertrophy or pathology according to the Czerny grading. Labrum pathology found on MRA is illustrated in Table 2. Significant unadjusted predictors of need for hip arthroscopy were (1) presence of the cross-over sign on preoperative radiographs (OR 4.01); and (2) a preoperative α-angle $\geq$55^{o} combined with preoperative borderline dysplasia (OR 9.00). Adjustment for age (<35 years at PAO surgery and borderline dysplasia) changed the results significantly for labrum detachment (Table 4). Analysis of the different Czerny grades of labral pathology did not show any significant difference between the non-arthroscopy and arthroscopy groups. Eleven hips showed a positive impingement and FABER tests; two hips had a positive FABER test and 15 hips had a positive impingement test. Twelve hips had clinical signs of trochanteric bursitis. Forty hips had persisting dysesthesia at follow-up. The arthroscopy and non-arthroscopy group were comparable with respect to the clinical findings (p-values 0.119 - 0.479).

Ninety-two percent (68 of 74 hips) of the hips had a low pain score (WOMAC pain <10) at 2-year follow-up. The median normalized WOMAC total score increased from 67 (range 3 - 100) to 89 (range 25 - 100) postoperatively and median Oxford hip score increased from 27 (range 8 - 47) to 43 (range 12 - 48). The overall SF36 physical and mental component scores increased from 38 (range 16 - 55) to 48 (range 18 - 60) and from 54 (range 29 - 69) to 58 (range 27 - 78) respectively (Table 6). Improvements between the preoperative and 2-year follow-up assessment were observed in 7 of 8 subscales of the SF36 (Fig.2). The preoperative scores for all patient reported outcome measures did not show any statistically significant differences between the arthroscopy and non-arthroscopy groups (p-values 0.157 - 0.934). At 2-year follow-up the total WOMAC score, the OHS, and the physical component score of the SF-36 differed statistically significant with superior results in the non-arthroscopy group compared to the arthroscopy group (p-values 0.007 - 0.014)(Table 4).

Discussion

Labral pathology is a very frequent finding in symptomatic DDH in young adults. No consensus exist concerning the treatment of labral tears in the setting of PAO surgery for DDH; labral or other intraarticular pathology can be addressed either during the PAO or following PAO by hip arthroscopy, if continuous symptoms are present. This study aims to indentify predictors for clinical failure after PAO, and to evaluate outcome in a cohort

with MRA diagnosed labral tears to asses any difference in outcome between a non-arthroscopy and arthroscopy group.
In borderline dysplasia only little reorientation is possible before overcorrection may occur, which could be the reason for the finding of a CE-angle of 20° to 25° being a significant predictor for failure. However, in this study a negative AI-angle is not a significant factor similar to earlier findings reported by Steppacher [26]. Borderline dysplasia combined with CAM deformity expressed by a high α-angle is highly associated with hip arthroscopy after PAO. Overcorrection and CAM deformity may result in femoroacetabular impingement with further chondrolabral damage. Femoroacetabular impingement after PAO for hip dysplasia is a well known complication [20].This advocates for a thorough intraoperative assessment of femoroacetabular impingement. By restricting simultaneously intraarticular surgery only to patients with borderline dysplasia and/or CAM deformity, the majority of the patients will avoid over-treatment and thereby the risk of unnecessary complications.

At 2-year follow-up the non-arthroscopy group and the arthroscopy group show improved WOMAC, OHS and the SF36 scores. For all scores the results for the non-arthroscopy group are superior to that in the arthroscopy group. The intention to treat analysis of this study evaluated outcome at 2 years after PAO. The statistical difference found in patient reported outcome measures may be a result of the arthroscopy group only having mean 11.5 months (range 4.5 - 20.5 months) of follow-up between hip arthroscopy and the 2-year follow-up after PAO. Thus longer follow-up is needed to evaluate the final clinical result after delayed hip arthroscopy. However, excluding four patients (four hips) who had a hip arthroscopy within 6 months from 2-year follow-up did not change the statistical significance.

Hip arthroscopy is offered to the patient by two experts at the Sport Traumatology unit, if the clinical findings suggest intraarticular pathology. However, the decision to offer a hip arthroscopy is multifactorial and it is difficult to apply narrow clinical indications regarding this end-point. MRA is considered the gold standard in imaging labral tears, but hip arthroscopy gives a direct view of the intra-articular status including any chondral damage. This means relying only on MRA findings and clinical tests, chondral damage may be overlooked. However, a study by Mechlenburg et al. showed unchanged status of cartilage thickness 2½ years after PAO assessed on MRI preoperatively and at follow-up indicating that osteoarthritis do not progress during follow-up even in the presence of a labral tear [19]. Czerny's classification of labral tears is in an earlier study found not to be prognostic for outcome [9] and Matheney et al. finds that a labral tear do not predict failure in terms of conversion to a THA after PAO [17], which is consistent with our findings. This indicates that the preoperative diagnose of a labral tear with the use of MRA is superfluous.

In conclusion, 27% (20 hips out of 74) of the hips undergo hip arthroscopy within the first two years after PAO. Predictors for hip arthroscopy are borderline hip dysplasia assessed on conventional radiographs, a sign of preoperative cross-over sign and a pathological α-angle on MRA. At follow-up two years after PAO the clinical outcome in the non-arthroscopy group is superior to that in the arthroscopy group with statistically significant differences in patient reported outcome measures. In borderline hip dysplasia and with signs of CAM deformity, the surgeon is at risk of over covering the femoral head resulting in FAI. In the majority of patients a PAO without intraarticular assessment results in joint preservation with excellent clinical outcome, and in patients at particular risk of FAI secondary to the PAO a hip arthroscopy may be undertaken during PAO surgery or as a subsequent following evaluation of the clinical outcome of the PAO.

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TABLES

Table 1. Description of the 8 hips undergoing hip arthroscopy (HA) prior to the PAO

Hip	Time**	HA findings	HA procedures	HA after PAO
12*	NA	NA	NA, but no effect of surgery	No
13	1 year	Torn labrum	Labrum resection, short term effect	No
15*	NA	NA	NA, but no effect of surgery	No
38*	NA	Labrum tear	Reinsertion of labrum	No
45	3 year	Intact labrum, cartilage pieces	Removal of several cartilage pieces	No
46	6 years	Thin cartilage, loose pieces of cartilage, labrum tear	Resection of the damaged parts	Yes
49	2.5 years	Labrum a little frayed	Resection of the frayed part of the labrum	Yes
59	4 years	Labrum-cartilage separation, hypertrophic labrum, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy	Yes

*Information from patient, journal records not available
** Time from HA to PAO

Table 2. Description of the 20 hips undergoing hip arthroscopy (HA) after PAO

Hip	Time from PAO to HA	MRA labrum diagnosis	MRA α-angle	HA findings	HA procedures
9	9 months	Czerny 3A	46°	Labrum damage anteriorly, mildly hypertrophic, pincer, CAM**	Rimtrim, labrum reinsertion, cheilectomy
10*	21 months	Czerny 3A, degeneration	55°	Frayed labrum, pincer, minor CAM	Rimtrim, labrum reinsertion, minor cheilectomy
22	13 months	Czerny 1A, degeneration	51°	Labrum-cartilage separation, pincer, CAM, loose cartilage	Rimtrim, labrum reinsertion, cheilectomy, mircrofracture treatment
26	6 months	Czerny 2B	53°	Labrum-cartilage separation, pincer, minor CAM	Rimtrim, labrum reinsertion, minor cheilectomy
31	16 months	Czerny 3A, degeneration	44°	Labrum-cartilage separation, pincer, minor CAM, area with osteoarthritis	Rimtrim, minor cheilectomy
33*	15 months	Czerny 3A, degeneration	58°	Labrum lesion with minor impact on the cartilage , pincer, bump on collum	Rimtrim, labrum reinsertion, minor cheilectomy
40	7 months	Czerny 3B, degeneration	44°	Labrum-cartilage separation, frayed labrum, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
46	4 months	No tears, mild hypertrophy	43°	Labrum-cartilage separation, synovitis, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
49	15 months	Czerny 3A	44°	Minor labrum-cartilage resection, minor pincer, CAM	Minor rimtrim, cheilectomy
50	12 months	Czerny 3A, degeneration	48°	Labrum-cartilage separation, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
52	8 months	Czerny 3A, degeneration	69°	Labrum-cartilage separation, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
54*	7 months	Czerny 3A, degeneration	58°	Voluminous labrum, labrum-cartilage separation, minor CAM	Labrum reinsertion, minor cheilectomy

59	5 months	No tears, crushed and degeneration	49°	Osteoarthritis acetabulum and caput femoris, labrum attached to the rim	Synovectomy
60	12 months	Czerny 2A	48°	Labrum-cartilage separation, minor pincer, minor CAM	Rimtrim, labrum reinsertion, cheilectomy
64	11 months	Czerny 3A, degeneration	42°	Labrum-cartilage separation, pincer, minor CAM	Rimtrim, labrum reinsertion, minor cheilectomy
65	11 months	Czerny 3A	37°	Labrum not described, pincer minor CAM	Rimtrim, labrum reinsertion, cheilectomy
67	7 months	Czerny 3B, degeneration, hypertrophy	61°	Labrum-cartilage separation, mild osteoarthritis, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
71*	18 months	Czerny 3B	66°	Degeneration of labrum, no tears, CAM osteoarthritis at acetabulum and femur	Cheilectomy
72	5 months	Czerny 3A	72°	Labrum-cartilage separation and influence of the cartilage, pincer, CAM	Rimtrim, labrum reinsertion, cheilectomy
75*	7 months	Czerny 3A	57°	Not available	According to the patient "some bone work". No effect.

*(10) Repeat arthroscopy 11 months after first arthroscopy: refixation of labrum, minor rimtrim of the acetabulum and extended cheilectomy on femur

(33) Repeat arthroscopy 14 months after first arthroscopy: labrum healed, acetabular cartilage with wave-sign, minor rimtrim, minor cheilectomy, screw removal

(54) Repeat arthroscopy 8 months after first arthroscopy: labrum healed, minor pincer removed, minor cheilectomy, psoastenotomy

(71) Hip arthroplasty 6 months after hip arthroscopy

(75) Repeat arthroscopy 3 months after first arthroscopy due to no effect. Labrum attached but anterior lesion. Pincer and minor CAM. Detachment of the labrum, rimtrim, reinsertion of labrum and minor cheilectomy. Psoastenotomy.

** CAM *term for the exostose on the femoral head-neck junction*

Table 3. Description of the changes in CE-angle in the arthroscopy group (n=18*)

Parameter	Before PAO	Before arthroscopy	After arthroscopy	p-value**
Center-edge angle				
Median (IQR)	20º (20º-21º)	35º (34º-39º)	34º (30º-37º)	p=0.003
Range	16º-24º	30º-46º	22º-40º	
Acetabular index angle				
Median (IQR)	13º (11º-17º)	1º(-2º-3º)	4º (0º-6º)	p<0.001
Range	8º-20º	-8º-6º	-4º-16º	

*One hip had only pre-arthroscopy radiographs and was left out for this analysis. In one hip with osteoarthritis at followup radiographs it was not possible to measure the CE-angle.
**Statistically significant difference between CE-angles and AI-angles before and after arthroscopy

Table 4. Magnetic resonance arthrography characteristics (results for all hips and in groups, number of hips)

Parameter	All hips	Arthroscopy group (n=20)	Non-arthroscopy group (n=53)
Degeneration labrum			
Yes	40	11	29
No	34	9	25
Hypertrophied labrum			
Yes	12	2	10
No	62	18	44
Paralabral cyst			
Yes	17	3	14
No	57	17	40
Classification of labrum pathology			
0	8	2	6
1A	3	1	2
1B	1	0	1
2A	13	1	12
2B	4	1	3
3A	34	12	22
3B	11	3	8

Table 5. Odds ratios for predictors of clinical failure in terms of hip arthroscopy

Parameter	OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Borderline dysplasia (CE-angle ≥20º to <25º)	4.30 (1.42-13.00	*0.010*	4.49 (1.46-13.82)	*0.009*
Postoperative AI-angle <0º or >10º	2.10 (0.68-6.53)	0.198	2.28 (0.68-7.65)	0.181
Preoperatively cross over sign present	4.01 (1.31-12.73)	*0.015*	3.90 (1.17-13.04)	*0.027*
α-angle ≥55º	2.11 (0.70-6.37)	0.185	2.05 (0.64-6.61)	0.229
α-angle <55º & borderline dysplasia (CE-angle ≥20º to <25º)	3.43 (0.87-13.48)	0.078	3.50 (0.88-13.85)	0.074
α-angle ≥55º & borderline dysplasia (CE-angle ≥20º to <25º)	9.00 (1.73-46.84)	*0.009*	9.13 (1.75-47.82)	*0.009*
Labrum detachment	2.40 (0.76-7.55)	0.134	4.21 (1.12-15.78)	*0.033*
Labrum degeneration	1.05 (0.38-2.95)	0.921	1.39 (0.46-4.24)	0.560
Labrum hypertrophy	2.05 (0.41-10.28)	0.385	2.20 (0.41-11.90)	0.359
Presence of paralabral cyst	1.98 (0.50-7.81)	0.327	1.77 (0.43-7.43)	0.431
*Adjusted for age (≤35 years)and borderline dysplasia				

Table 6. Patient reported outcome measures for arthroscopy and non-arthroscopy group

Parameter	Preoperative* All (n=74)	Postoperative All (n=74)	Postoperative Arthroscopy (n=20)	Postoperative Non-arthroscopy (n=54)	p-value
WOMAC†					
Pain					
Median (IQR)	8 (4-10)	2 (0-5)	4 (1-9)	1 (0-5)	*0.02*
Range	0-20	0-14	0-14	0-12	
Stiff					
Median (IQR)	3 (1-4)	1 (0-2)	2 (1-3)	1 (0-2)	*0.104*
Range	0-8	0-7	0-7	0-6	
Physical Function					
Median (IQR)	20 (10-29)	4 (0-11)	8 (3-20)	2 (0-8)	*0.01*
Range	0-61	0-49	0-46	0-49	
Total Scores					
Median (IQR)	30 (15-41)	8 (1-21)	14 (6-31)	5 (1-14)	*0.007*
Range	1-89	0-67	0-67	0-66	
Normalized					
Median (IQR)	67 (54-79)	89 (79-98)	81 (65-90)	90 (81-100)	*0.014*
Range	3-100	25-100	25-100	33-100	
Oxford Hip Score ‡					
Total score(0-48)					
Median (IQR)	27 (23-33)	43 (34-47)	37 (29-43)	44 (36-47)	*0.007*
Range	8-47	12-48	12-48	19-48	
SF36					
Physical score (0-100)					
Median (IQR)	38 (33-44)	48 (38-55)	40 (34-52)	50 (43-56)	*0.014*
Range	16-55	18-60	18-58	27-60	
Mental score (0-100)					
Median (IQR)	54 (43-62)	58 (54-62)	57 (53-62)	59 (55-62)	*0.797*
Range	29-69	27-78	27-78	35-66	

*No significant differences between the arthroscopy and non-arthroscopy groups preoperatively (p-values 0.157-0.934).**IQR interquartile range † Raw scores with "0" indicating best result. Normalized score with "100" indicating best result. ‡ Score with 48 indicating best results.

FIGURES

Fig 1. MRA measurement of the α-angle of Nötzli on the oblique plane. After identification of the center of the femoral head a line along the middle of the femoral neck and a line from the center to the point where the femoral head-neck junction “left” the best fitted circle of the femoral head make up the α-angle.

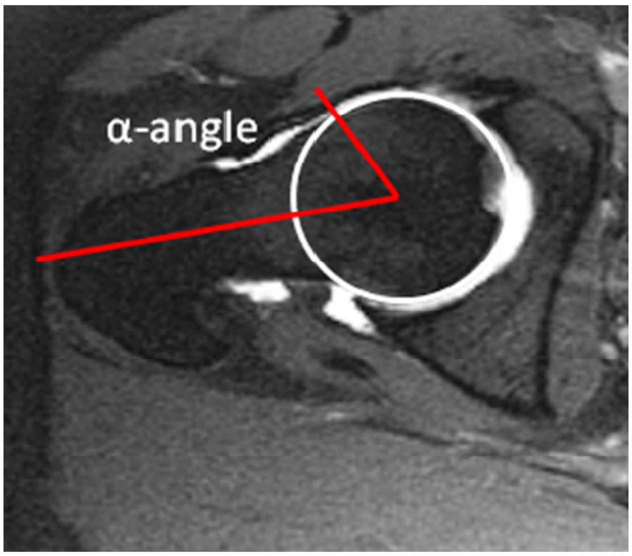
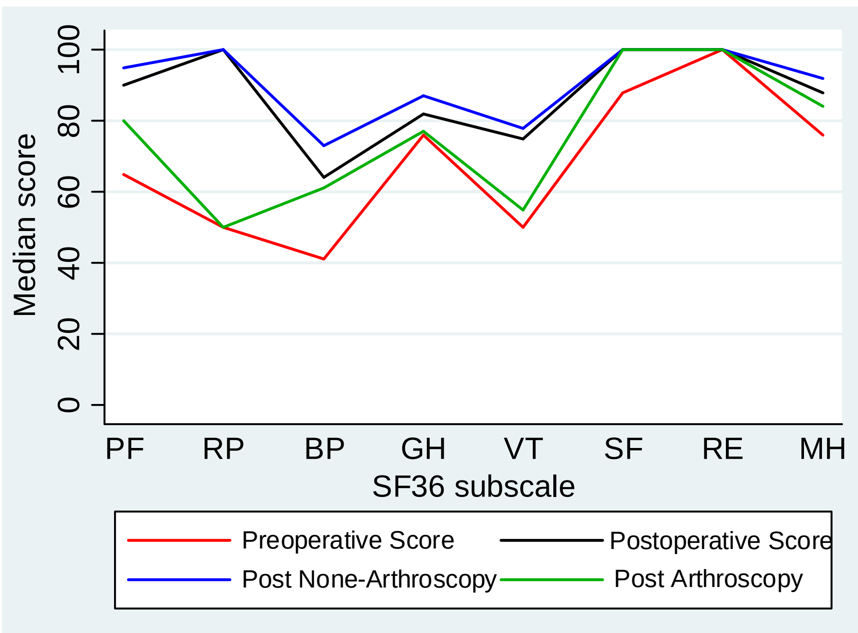


Fig 2. Changes in SF36 subscale parameters for all patients before PAO and at 2-years follow-up after PAO. The postoperative subscale parameters are also illustrated separately for the non-arthroscopy group (blue) and the arthroscopy group (green). The figure shows that except from the "Role-Physical" parameter in the arthroscopy group and the unchanged parameter "Role-Emotional", all patients experienced improved results 2-years after PAO. Specific for the "Role-Physical" and the "Vitality" parameters, the non-arthroscopy group had superior results. SF36 consist of eight subscales with health related parameters: Physical functioning (PF), Role-Physical (RP), Bodily Pain (BP), General Health (GH), Vitality (VT), Social Functioning (SF), Role Emotional (RE) and Mental Health (MH).



PAPER III

Is cup positioning challenged in hips previously treated with periacetabular osteotomy?

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Ethical review committee statement*:*

The study follows the rules specified by the Helsinki-II Declaration. According to Danish legislation no obligation to notify the Research Ethics Committee existed.

ABSTRACT

Abstract
After periacetabular osteotomi (PAO), some patients develop osteoarthritis with need of a total hip arthroplasty (THA). We evaluated the outcome of THA following PAO and explored factors associated with inferior cup position and increased polyethylene wear. Follow-up were performed 4 to 10 years after THA in 34 patients (38 hips) with previous PAO. Computer analysis evaluated cup position and wear rates. No patient had dislocations or revision surgery. Median scores were: Harris hip 96, Oxford hip 38 and WOMAC 78. Mean cup anteversion and abduction angles were 22^o (range 7^o - 43^o) and 45^o (range 28^o - 65^o). Outliers of cup abduction were associated with persisting dysplasia (CE <25^o). THA after PAO can be performed with good results. Persisting acetabular dysplasia may result in excessive cup abduction.

MANUSCRIPT

Introduction

Periacetabular osteotomy (PAO) is the preferred treatment for symptomatic hip dysplasia in adults if osteoarthritis is not present, and studies have reported high hip joint survival rates following PAO [1-4]. Despite an apparently successful PAO, some patients develop pain and osteoarthritis with a need for conversion of the PAO to total hip arthroplasty (THA) (Fig 1.). These patients receiving a THA are often relatively young with demands of a good functional outcome of the hip joint. Another challenge is the documented reduced durability of THA in younger populations [5].

The altered morphology of the acetabulum in hip dysplasia may complicate the insertion of the THA – even after PAO. The acetabulum is typically steep and shallow challenging correct positioning of the acetabular cup. Further, the acetabulum is seemingly retroverted in one out of three dysplastic hips [6]. The femoral neck can be excessively anteverted, the neck shaft angle increased, and the femoral canal can be narrower compared with non-dysplastic femurs [7-9]. PAO surgery in severely dysplastic hips may result in remaining dysplasia with a steep acetabulum and insufficient coverage of the femoral head. Further, signs of retroversion after PAO have been reported to be present in 10% to 62% of hips [10-12]. Thus, the placement of cups inside the suggested safe zones of cup abduction and anteversion may be challenged with the risk of instability due to abnormal stresses of the bone-implant interface and with adverse loading of the bearing surface leading to increased liner wear [13-15].

The literature reports improved outcome scores and good survivor ship analysis after THA surgery in hip dysplasia without preceding PAO [16-24]. The results are comparable to those reported by non-dysplastic patients receiving a THA [24, 25]. Only few reports describe the outcome of patients receiving a THA following PAO. Baque et al. reported immediate improvements in the Merle d’Aubigne score and no major complications at an average followup of 2.3 years, however only 8 patients were followed. The authors suggested that previous PAO can facilitate THA insertion [26]. Parvizi et al. also found improved functional scores and a low complication rate at 6.9 years followup [27]. The intention with this study was to gain increased knowledge on pitfalls of cup positioning and potential complications with this specific patient group. We asked what is the overall clinical, radiographic and patient reported outcome of THA following PAO at 4 to 10 years; what cup position were achieved and what patient factors were associated with inferior cup positioning and increased polyethylene wear; and whether offset and leg length could be restored using primary conventional components when converting a PAO to THA.

Patients and Methods

Patient eligible for inclusion were those who underwent PAO from December 1998 to May 2007 with a subsequent conversion to THA and a minimum 4-year followup after THA (40 patients/44 hips). Our institutional database contains information about all PAO’s and by inquiry to the National Registry of Patients in Denmark the PAO hips converted to a THA were identified. The inquiry was made in May 2011. Two patients were excluded from the study (one due to psychiatric disease; one due to cerebral palsy) and 4 patients were lost to followup. Thus, the study group consisted of 34 patients (26 females, 38 hips) with a mean age at THA surgery of 40.5 years (range 17.5 - 57.9 years). Followup was performed at Aarhus University Hospital during January and February 2012, except for four patients that were followed up at Hvidovre Hospital in April 2012. Treatment details from before PAO surgery to surgeries performed after THA were assessed (Fig.2).

The PAO's [28]were performed using the ilioinguinal or modified Smith-Petersen [29] approaches in 31 hips and from 2003 using the minimally invasive approach [30] in 7 hips. The median center-edge angle before PAO was 8º (range -26º to 35º) and after PAO 25º (range -5º to 42º), and the median acetabular index angle before PAO was 23º (range 11º to 57º) and after PAO 12º (range 0º to 47º) . CE-edge and AI-angles of the native hip were retrieved from our institutional PAO database. Due to poor quality of the preoperative radiographs the CE-angle and AI-angle were only available for 36 hips.
The interval from PAO to THA was mean 3.3 years (range 0.6 - 7.9 years).The indications for THA were increasing pain and secondary osteoarthrosis with decreasing joint space width. Except for three procedures all THA's were performed at Aarhus University Hospital. Meticulous preoperative templating was carried out. The posterolateral approach was used in all cases. All acetabular cups and femoral stems were uncemented primary components except in one case where a revision cup was used due to non-union in the superior pubic ramus after PAO. Eight cups were fixated with a median of 3 screws (range 2 - 6). Technical data regarding all the different THA components were noted (Table 1). Mean followup after THA was 6.4 years (range 4.2 - 10.1 years).

At the clinical examination any leg-length difference were evaluated clinically with the patient standing and the height of the two iliac crests were compared to each other. The surgeon reported Harris Hip score (HHS) including range of motion (ROM) were assessed [31]. Patients were asked to report any symptoms from the hip, participation in sporting activities and their ability to work. On a numeric rating scale (NRS) they were asked about pain (at rest and after 15 minutes of walking) and overall satisfaction with their treatment from PAO to present. Finally, patients were inquired to fill in the joint specific Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)[32], the Oxford hip score (OHS) [33] and the general health questionnaire short form 36, version 1 (SF36)[34]. Each subscale of the WOMAC score was calculated. To enhance the comparability with other studies the summarized total score were normalized with 100 indicating the best possible score. The OHS score is given as a total score with 48 indicating the best possible score [35]. From the SF36 data the physical and mental component scores were subsequently calculated.

Standardized weight bearing anterior-posterior pelvic and lateral hip radiographs were taken at followup. Cup abduction, cup anteversion, total linear (two dimensional) wear and the corresponding wear rate was measured digitally (PolyWare Pro 3D Digital version 5.10; Draftware developers, Conway, SC) using only the newest AP radiograph [36].

Abduction and anteversion angles were analyzed for 33 cups. Optimal cup position was considered with an anteversion angle between 5^{o} and 25^{o} and abduction angle between 30^{o} and 50^{o} [14]. Five cups could not be analyzed due to software restrictions (cup brand not available in the software). Liners were dichotomized into conventional polyethylene liners (PE)(12 hips) and highly cross linked polyethylene liners (XPE) (9 hips). Metal-on-metal (MoM) and ceramic-on-ceramic (CoC) hips were not analyzed for wear, only for cup position when this was applicable (cup brand available in software). All computer analyses were repeated, and the mean of the first and second assessment was used (Fig. 3). Offset were measured and defined as the distance from the center of the femoral head on a line perpendicular to a line along the center of the femoral shaft. The following radiographic parameters were evaluated in consensus between two observers by comparing postoperative radiographs with the followup radiographs: radiolucent lines (<1mm was considered significant), signs of osteolysis around the cup [37] and femoral stem [38], cup migration, and stem subsidence. Heterotopic ossification was classified according to Brooker [39].

Data are presented as means when normally distributed and as medians with ranges when not normally distributed. We used STATA 11 software package (StataCorp LP, College Station,TX, USA) for all calculations.

Results

No THA's were revised and no dislocations occurred. Good range of motion was achieved (median values): flexion 100^{o} (range 70^{o} - 130^{o}), abduction 40^{o} (range 25^{o} – 110^{o}), adduction 30^{o} (range 20^{o} - 50^{o}), internal rotation 20^{o} (range 0^{o} - 45^{o}) and external rotation 30^{o} (range 10^{o}-50^{o}). HHS (median) was 96 (range 42 - 100). Patients had little pain both at rest and during walking, and overall the satisfaction score was high. The WOMAC pain score was median 2.5 and below 10 in 32 hips (84%) at follow-up. The median normalized total WOMAC score was 78 (range 27 - 100). OHS (median) was 38 (range 8 - 48) (Table 3). The mean acetabular cup anteversion angle was 22^{o} (range 7^{o} - 43^{o}) and cup abduction angle was 45^{o} (range 28^{o} - 65^{o}). A scatter plot of abduction angles and anteversion angles shows the cup position achieved in each hip (Fig. 4). Outliers of cup anteversion were: 18 hips >25^{o}. Outliers of cup abduction were 1 hip <30^{o}, 14 hips >50^{o}. Total polyethylene wear was 1.39 mm and 0.60 mm respectively for PE and XPE liners, and wear rates were 0.16 mm / year and 0.13 mm / year respectively (Table 4).

Brooker grades of ossification were: Grade I in 7 hips (18%), grade II in 4 hips (11%) and grade III in 5 hips (13%). No hips showed complete ankylosis (grade IV), and the remaining 22 hips (58%) showed no signs of heterotopic ossifications. Signs of osteolysis were seen around 5 cups and 4 femoral stem (Table 3). Radiolucent lines were present around two cups (one MoM and one CoP). Using conventional THA components leg-length of the operated leg was confined within 1 cm in 33 hips and within 1-2 cm in the remaining 5 hips when compared to the contra lateral leg. Median offset before THA was 37 mm (range 22 - 56 mm) and after THA 46 mm (range 34 - 57 mm), a median difference of 11 mm (range -9 - 27 mm). One cup migration 5.5 years after surgery in a MoM type THA was seen comparing postoperative radiographs with radiographs at followup. In this cup anteversion had changed from 21º to 12º and abduction changed from 57º to 74º. Three femoral stems had subsided (1, 3, and 3.5 mm).

Conclusion

Despite the overall success of PAO some patients develop osteoarthritis and require a THA. There are few reports on the outcome of THA after PAO and challenges of cup positioning remains to be explored. We therefore asked what is the overall clinical, radiographic and patient reported outcome of THA following PAO at 4 to 10 years; what cup position were achieved and what factors were associated with inferior cup positioning and increased polyethylene wear; and whether offset and leg length could be restored using primary conventional components when converting a PAO to THA.

We recognize several limitations of this study. Four hips were lost to followup, and the outcome of their hip is unknown. However, 34 of 38 hips (86.4%) had complete followup. A matched cohort of patients with hip dysplasia receiving a THA without prior PAO would have been interesting and could potentially have added valuable information to clinical outcome, radiographic analysis and patient reported outcome measures. A preoperative value of both surgeon reported and patient reported outcome measures could have documented the effect of the THA. The computer software program analyzes cup position without regard for pelvic tilt in the sagittal plane or femoral stem rotation. The cup position angles reported in the literature is typically measured on supine pelvic radiographs. Our cup measurements are analyzed on weightbearing radiograph and may therefore not be directly comparable. Five hips were not possible to analyze due to software limitations (lacking the cup brand in the CAD library).

Parvizi [27] and Baque [26] reported significant improvement in the Merle D'Aubigné scores in PAO patients receiving a THA, with 39 of 45 hips, and 7 of 8 hips, respectively, being rated good or excellent at followup. Parvizi et al. reported a low complication rate using the transtrochanteric approach and Ganz cages in the acetabulum. They did report one dislocation, one with the need of excision of the ectopic bone and two needed revision surgery due to trochanter detachment. Baque et al. reported no dislocations or revisions at mean followup 2.3 years after surgery using the anterior approach. We show similar high postoperative outcome scores and no complications using the posterolateral approach and conventional THA components.

Different safe zones for cup abductions have been suggested [14, 15]. The safe zones reported in the literature are based on assessment of supine radiographs, and at followup we used weightbearing recordings. Pelvic recordings with the patient weightbearing are the standard at our institution [40]. As shown acetabular version vary when repositioning from supine to weightbearing, and thus, our results cannot be compared directly to the otherwise THA literature [40, 41]. The abduction and anteversion angles achieved in this study were not all always within the so called safe zones. In sixteen hips cup anteversion angles were greater than 25º and in 15 hips cup abduction angles were greater than 50º. Too much anteversion of the inserted cup can be attributed to the possible insufficient dysplastic anterior rim, and too steep cup abduction is likely to be related to the persisting dysplasia in these hips following PAO. However, Callanan et al. showed that placing the cup in excessive anteversion or especially in abduction angle higher that recommended is rather normal during THA surgery using the posterolateral approach. No dislocations occurred and wear analysis revealed wear rates below the suggested critical osteolysis level of 0.2 mm / year [42, 43]. The positioning of the acetabular cup is highly influenced by the 3D morphology of the acetabulum. The acetabulum might still be dysplastic and even slightly retroverted after PAO. Previous femoral osteotomy might impede insertion of the femoral component. Preoperative templating is crucial, and the surgeons should be aware of the special morphologic abnormalities in these hips. Most of the THAs reported in this study were inserted at a high volume and highly specialized orthopedic ward and by experienced THA surgeons, which may be the explanation that no mechanical failures occurred in this cohort.

In our cohort all THA components, except for one cup, were conventional. The offset was restored and slightly increased, and the majority of patients had leg length confined within in 0 - 1 cm, and no patients had leg length discrepancies greater than 2 cm. This is in line with that previously reported for THA performed in dysplastic hips with no previous PAO. In 35 dysplastic hips receiving THA Faldini et al. found increased HHS and leg length discrepancy <2 cm except in two hips [21].

In conclusion, clinical, radiographic, and patient reported outcomes were good and comparable to the literature reporting the outcome of THA in dysplastic hips with or without previous PAO. Analysis of the cup position showed that remaining acetabular dysplasia after PAO is seemingly associated with a risk of placing the cup too steep. Despite the young age of patients, we found after a minimum of four year followup low polyethylene wear rates and no patients experienced mechanical failures, such as dislocation, or need of revision surgery.

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TABLES

Table 1. Description of THA components

Parameter	Value
Joint articulation (number of hips)	
Metal on polyethylene (MoP)	16
Ceramic on polyethylene (CoP)	6
Metal on metal (MoM)	7
Ceramic on ceramics (CoC)	9
Head size (number of hips)	
MoM (46 mm, 48mm, 52 mm, 54 mm, 56 mm)	2, 1, 2, 1, 1
MoP, CoP, CoP (22,2 mm, 28 mm, 32 mm, 36 mm)	1, 17, 11, 2
Liner material (polyethylene composition)	
Conventional polyethylene	12
Highly crosslinked polyethylene	10
Femur stem (number of hips)	
Biomet Bi-metric (standard)	32
Biomet Bi-metric (lateralized)	2
B Braun Bikontakt S-stem	1
Zimmer Versys	2
Zimmer CPT	1

Table 2. Radiological findings

Parameter	Number of hips	THA type **
Osteolysis of the cup (number of hips)		
In one of the three Delee zones	3	CoC, CoC, MOP
In more than one Delee zones	2	CoC
Osteolysis of the femur stem (number of hips)*	3	
Gruen zone I	1	MoM, MoP, MoP
Gruen zone I & II	0	CoC
Gruen zone III, IV, V		
* Gruen 4 only visible around 20 femoral stems		
** *CoC Ceramic-on-Ceramic*	*MoP Metal-on-Polyethylene*	*MoM Metal-on-Metal*

Table 3. Results of patients reported outcome scores

Parameter	Results	Interquartile Range	Range
Median NRS (n=34 patients)			
At rest*	0	0-1	0-7
After 15 min. of walking*	0	0-2	0-8
Satisfaction with treatment**	10	9-10	0-10
Median WOMAC (n=38 hips)			
Pain score (0-20)†	2.5	0-7	0-15
Stiffness score (0-8)†	2.5	1-5	0-6
Physical Function score (0-68)†	14.5	3-25	0-54
Total scores (0-96)†	20	7-34	0-74
Normalized (0-100)††	78	56-89	27-100
Median Oxford Hip Score (n=38 hips)			
Total score (8-48)	37.5	30-45	8-48
Median component scores on SF36 (n=34 patients)			
Physical score (0-100)	44.47	34.02-53.44	14.11-59.07
Mental score (0-100)	58.99	50.98-61.34	27.59-65.72

*scale 0-10 (10 worst pain ever) **Scale 0-10 (10 highest satisfaction)
†Raw scores with "0" indicating best results ††Normalized score with "100" indicating best result.

Table 4. Computerized acetabular cup and liner analysis *

Parameter	Value	
	conventional polyethylene (n=12)	highly cross-linked (n=9)
Mean linear wear		
Mean (95%CI)	1.39 (1.02-1.76)	0.60 (0.38-0.81)
Range	0.57-2.43	0.27-1-11
Wear Rate (mm / year)†		
Mean (95% CI)	0.16 (0.13-0.21)	0.13 (0.08-0.17)
Range	0.06-0.27	0.05-0.24
Followup (years)		
Mean (95% CI)	8.3 (7.4-9.2)	4.8 (4.5-5.2)
Range	6.1-10.1	4.2-5.4

*5 cups not possible to analyze due to software restrictions (cup brand not available in software CAD library). MoM and CoC hips were excluded from wear analyses

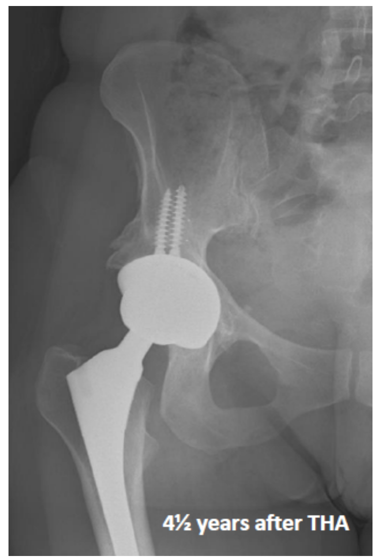
FIGURES

Fig. 1

The three radiographs illustrate an arthritic hip in a patient with previous PAO, who have accepted a THA. Figure A and C are standing exposures. The postoperative radiograph (Figure B) is a supine exposure. A. Status before THA surgery 6 years after PAO. The joint space is obliterated, and the PAO screws are in situ. B. Postoperative radiographs after insertion of a ceramic on ceramic type THA. C. Hip status at followup 4½ years after THA surgery.

A.

C.



B.

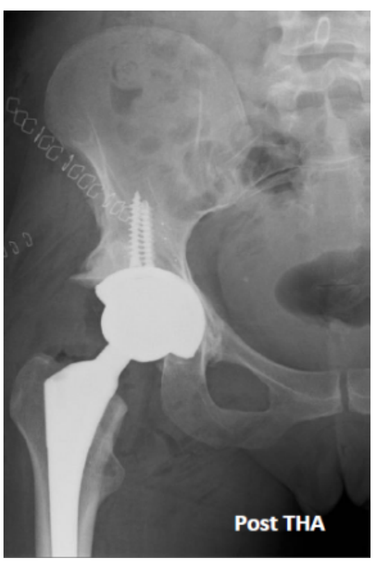


Fig.2
Diagram illustrating patient diagnosis and treatments before, during and after THA.

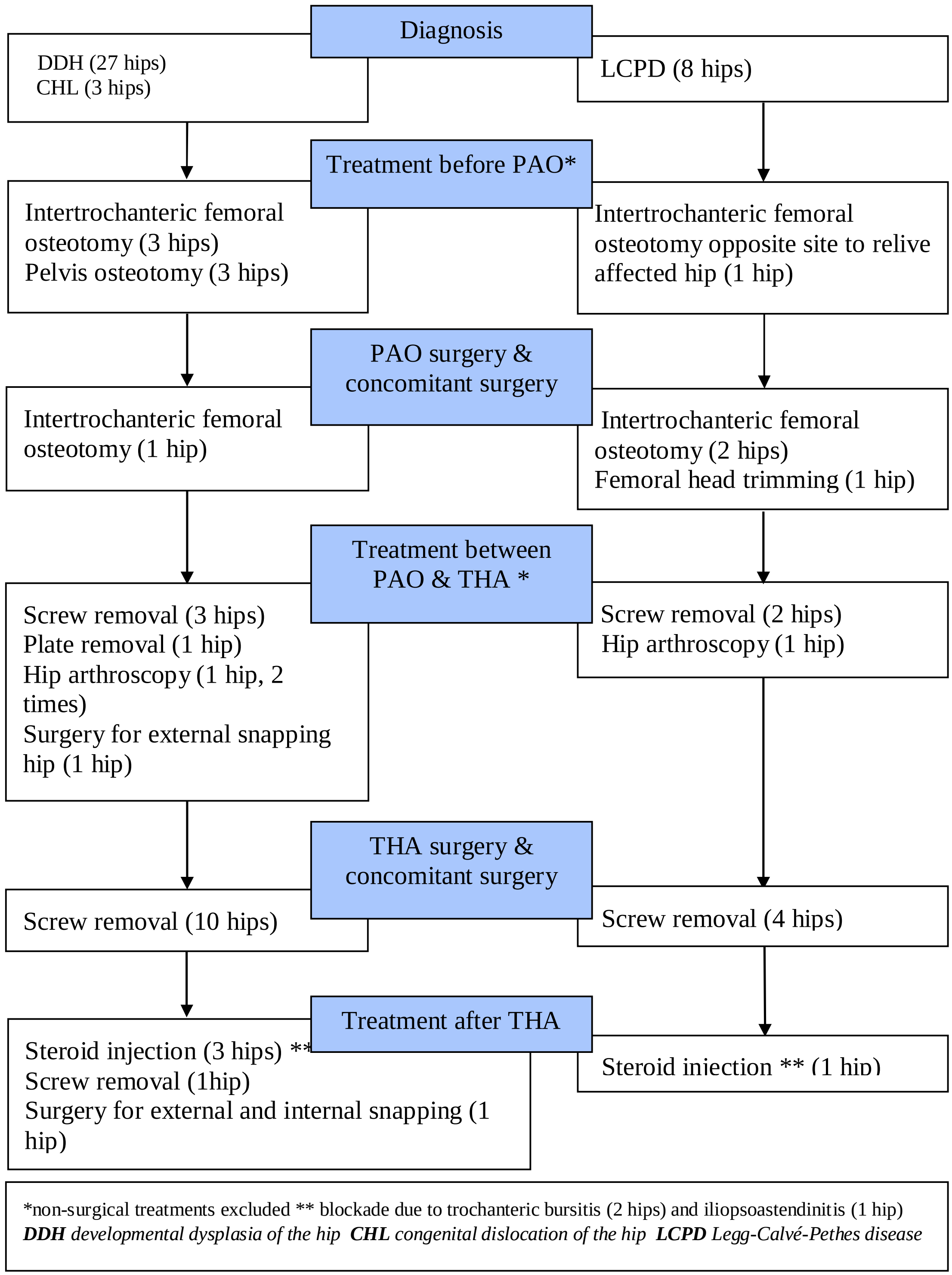


Fig. 3
PolyWare wear analysis. A. Illustration of edge-detection of the border of the acetabular cup and the head component. B. A solid model applied by the end of the analysis (the CAD model is not supposed to fit perfectly with the THA implant).

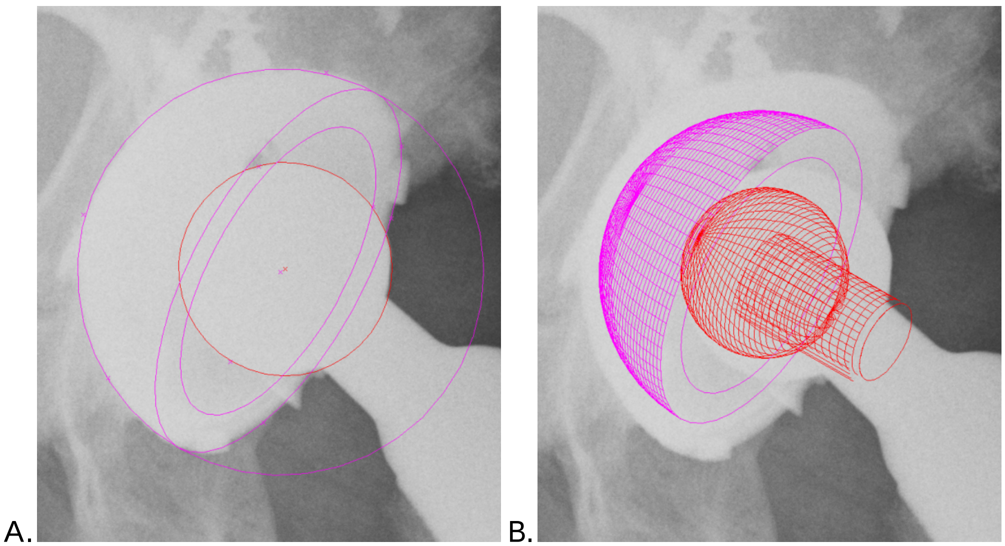
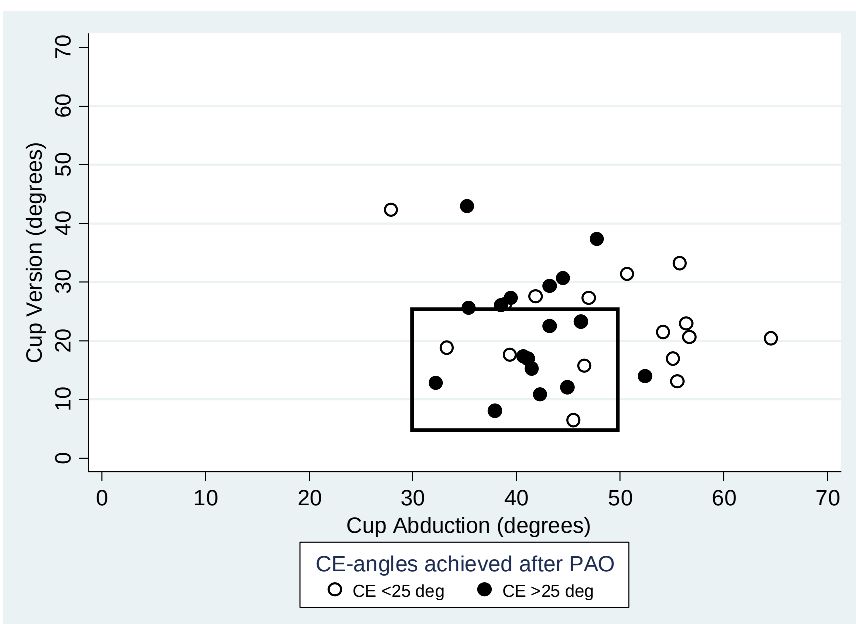


Fig. 4
A scatterplot of cup abduction and anteversion angles. The black box outlines the optimal ranges for cup placement according to Lewinneck et al.[14]. Circles indicates the center-edge angle (CE-angle) achieved after PAO. At PAO the target was to achieve a minimum CE-angle $\geq 25^{o}$.



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Declaration of co-authorship

Full name of the PhD student: Charlotte Hartig Andreasen

This declaration concerns the following article/manuscript:

Title:	What factors predict failure 4 to 12 years after periacetabular osteotomy? Follow-up study of 401 periacetabular osteotomies?
Authors:	Hartig-Andreasen C, Troelsen A, Thillemann TM, Søballe K

The article/manuscript is: Published ☒ Accepted ☐ Submitted ☐ In preparation ☐

If published, give full reference:
Hartig-Andreasen C, Troelsen A, Thillemann TM, Søballe K.
What factors predict failure 4 to 12 years after periacetabular osteotomy?
Clin Orthop Relat Res. 2012 Nov;470(11):2978-87. doi: 10.1007/s11999-012-2386-4.

If accepted or submitted, give journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

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B. Has contributed (10-30 %)
C. Has contributed considerably (40-60 %)
D. Has done most of the work (70-90 %)
E. Has essentially done all the work

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	C
2. Planning of the experiments and methodology design and development	C
3. Involvement in the experimental work/clinical studies	D
4. Interpretation of the results	D
5. Writing of the first draft of the manuscript	D
6. Finalization of the manuscript and submission	D

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