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Muscle-tendon pain and outcome of hip-preserving surgery in patients with hip dysplasia

Prospective investigations applying clinical examinations, ultrasonography, patient-reported outcome and measurement of physical activity

One-year follow-up study

PhD dissertation

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Health
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Preface

The first draft of the work presented in this PhD dissertation started during my employment at the Department of Physiotherapy and Occupational Therapy at Aarhus University Hospital, Denmark. During this employment, I worked with physical rehabilitation of patients with hip dysplasia. Together with my excellent supervisors and invaluable colleagues, I identified a gap in knowledge related to the development of pain and use of outcome measures in hip dysplasia. My supervisors encouraged me to start working on this topic and with further invaluable support from the head of the Department of Physiotherapy at VIA University College, Denmark, I was enrolled as a PhD fellow at the Department of Clinical Medicine at Aarhus University, Denmark, in 2017.

I owe gratitude to a number of people who made this work possible. I owe Inger Mechlenburg a deep thanks for her ability to give inspiring professional and personal support and for continuously encouraging me to go further. Inger, you are truly a mentor. I have deep respect for you; and with you, the journey has been truly enriching. I also owe Kristian Thorborg a profound thanks for his ability always to ask spot-on questions, encouraging me to think deeper and explain my research more explicitly. Kristian, I admire your passion, energy and great knowledge. I also owe Kjeld Søballe a sincere thanks. Kjeld, we have been working together since 2008, and you have continuously supported and encouraged me to go one step further. I owe you deep gratitude for always believing in me. Inger, Kristian and Kjeld, I am grateful for your guidance throughout this journey.

Moreover, I owe gratitude to the members of the research team Stig Storgaard Jakobsen, Per Hölmich and Lars Bolvig. I am grateful for your commitment and important feedback. Together with my supervisors, you have made my PhD journey a pleasant one. I also send my gratitude to my colleagues from the Department of Physiotherapy and Occupational Therapy and the Department of Orthopaedic Surgery at Aarhus University Hospital, Denmark, for assisting me during patient enrolment and outcome assessments. Moreover, I send my gratitude to my colleagues from VIA University College, Denmark, for engaging in fruitful discussions and providing support. Lastly, I wish to thank my three children for reminding me of the important things in life and bringing me joy and energy. Also, a heartfelt thanks to my family for supporting me on my journey. To my husband, Kenneth, I also owe a deep thank for his patience and stable support.

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Julie Sandell Jacobsen, January 2020

List of papers

This PhD dissertation is based on the papers listed below.

(1) Jacobsen JS, Hölmich P, Thorborg K, Bolvig L, Jakobsen SS, Søballe K, Mechlenburg I. Muscle-tendon-related pain in 100 patients with hip dysplasia: prevalence and associations with self-reported hip disability and muscle strength. Journal of Hip Preserving Surgery 2018; 5(1): 39–46.

(2) Jacobsen JS, Bolvig L, Hölmich P, Thorborg K, Jakobsen SS, Søballe K, Mechlenburg I. Muscle–tendon-related abnormalities detected by ultrasonography are common in symptomatic hip dysplasia. Archives of Orthopaedic Trauma Surgery 2018; 138(8): 1059-1067.

(3) Jacobsen JS, Søballe K, Thorborg K, Bolvig L, Jakobsen SS, Hölmich P, Mechlenburg I. Patient-reported outcome and muscle-tendon pain after periacetabular osteotomy are related: 1-year follow-up study in 82 patients with hip dysplasia. Acta Orthopaedica 2019; 90(1): 40-5.

(4) Jacobsen JS, Thorborg K, Hölmich P, Bolvig L, Jakobsen SS, Søballe K, Mechlenburg I. Does the physical activity profile change in patients with hip dysplasia from before to 1 year after periacetabular osteotomy? Acta Orthopaedica 2018; 89(6): 622-627.

Contents

Abbreviations

ADL	Physical function in daily living
AI angle	Tönnis' acetabular index angle
CE angle	Centre-edge angle
CI	Confidence interval
COSMIN	COnsensus-based Standards for the selection of health Measurement INstrument
FABER	Flexion/Abduction/External Rotation test
FADIR	Flexion/Adduction/Internal Rotation
HAFAI	Horsens-Aarhus Femoro-Acetabular Impingement study
HAGOS	Copenhagen Hip and Groin Outcome Score
FAIS	Femoroacetabular impingement syndrome
HOOS	Hip disability and Osteoarthritis Outcome Score
HOS	Hip Outcome Score
ICF	International Classification of Functioning, Disability and Health
iHOT-12	International Hip Outcome Tool-12
iHOT-33	International Hip Outcome Tool-33
IQR	Interquartile range
KI	Konfidenseinterval (DK)
MRI	Magnetic resonance imaging
MIC	Minimally important change
NRS	Numerical rating scale
PA	Participation in physical activity
PAO	Periacetabular osteotomy
PRO	Patient-reported outcome
PROMs	Patient-reported outcome measures
SEM	Standard error of measurement
SD	Standard deviation
Sport/recreation	Physical function in sports and recreation
SQUASH	Short QUestionnaire to ASsess Health-enhancing physical activity
QOL	Quality of life

1. English summary

Hip dysplasia is considered a joint disease where pain presents secondary to intra-articular lesions. Yet, previous studies indicate that this understanding may be insufficient, and it has been suggested that extra-articular structures such as muscles and tendons may play a role in relation to the development of pain in hip dysplasia. However, muscle-tendon pain and structural abnormalities have not been investigated in patients with hip dysplasia, and there is a lack of studies reporting outcome of periacetabular osteotomy (PAO) with outcome measures considered relevant for the typical young and active patient.

A prospective case series study was conducted in 100 patients with hip dysplasia with follow-up 1 year after PAO. PAO outcome was investigated, applying the Copenhagen Hip and Groin Outcome Score (HAGOS), accelerometer-based measures of physical activity and standardised clinical examinations. Clinical examinations were used to identify muscle-tendon pain in specific anatomical regions (i.e. clinical entities). Moreover, prior to PAO, structural abnormalities in hip tendons were identified with standardised ultrasonographic examinations, while hip muscle strength was assessed with a handheld dynamometer.

Prior to PAO, the majority of patients experienced muscle-tendon pain, primarily affecting the iliopsoas (56%; CI 46 - 66) and hip abductors (42%; CI 32 - 52). Muscle-tendon pain was negatively associated with patient-reported outcome (PRO) and hip muscle strength, and abnormal ultrasonographic findings were identified in the corresponding painful structures. However, only weak to moderate correlations between abnormal ultrasonographic findings and clinically identified pain were found for the iliopsoas and hip abductors. One year after PAO, the proportion of patients with muscle-tendon pain had fallen by 39% points, while patients reported moderate to very high improvements across all subscales of the HAGOS. However, for patient-reported participation in physical activity and physical function in sport/ recreation, about half of patients reported change scores lower than the minimally important change, indicating that these patients did not experience clinically relevant improvements after PAO. Moreover, despite considerable improvement in patient-reported physical activity, no changes in accelerometer-based physical activity were found.

Muscle-tendon pain and structural abnormalities were common in hip dysplasia; and 1 year after PAO, muscle-tendon pain decreased parallel with improvements in PRO. However, the level of daily physical activity did not change after PAO. Based on these results, hip dysplasia appears to be a joint disease that is associated with muscle-tendon pain and structural abnormalities in muscle-tendon tissue.

2. Danish summary

Hoftedysplasi anses som en ledsygdom, hvor smerte opstår sekundært til intraartikulære skader. Tidligere studier har dog indikeret, at denne forståelse kan være mangelfuld. Det er blevet antydet, at ekstraartikulære strukturer såsom muskler og sener kan spille en rolle i relation til smerteudvikling. Ingen studier har dog undersøgt muskelsenesmerter og strukturelle forandringer hos patienter med hoftedysplasi, og der er mangel på studier, som rapporterer resultater af periacetabulær osteotomi (PAO) med resultatmål, som vurderes relevante til den typiske unge, aktive patient.

Et prospektivt case-seriestudie blev gennemført på 100 patienter med hoftedysplasi med opfølgning 1 år efter PAO. Resultatet af PAO blev undersøgt med Copenhagen Hip and Groin Outcome Score (HAGOS), accelerometerbaserede metoder til at måle fysisk aktivitet og standardiserede kliniske undersøgelser. Sidstnævnte undersøgelser blev anvendt med henblik på at identificere muskelsenesmerte i specifikke anatomiske regioner (i.e. kliniske enheder). Strukturelle forandringer i hoftesener blev endvidere identificeret ved standardiseret ultralydsskanning, og muskelstyrke blev målt med et håndholdt dynamometer.

Størstedelen af patienterne oplevede muskelsenesmerter forud for PAO, hvor smerterne primært var relateret til iliopsoas (56%; KI 46 - 66) og hofteabduktorerne (42%; KI 32 - 52). Muskelsenesmerterne var negativt associeret med patientrapporteret resultat (PRO) og muskelstyrke. Samtidig blev strukturelle forandringer identificeret i de samme smertegivende strukturer ved ultralydsskanning. De strukturelle forandringer var dog kun svagt til moderat korreleret til klinisk identificeret smerte for iliopsoas og hofteabduktorerne. Andelen af patienter med muskelsenesmerte blev reduceret med 39% procentpoint 1 år efter PAO, og patienterne rapporterede moderate til meget store forbedringer for alle HAGOS subskalaer. På trods af dette rapporterede cirka halvdelen af patienterne ændringer i deltagelse i fysiske aktiviteter, samt ændringer i funktion i sports- og fritidsaktiviteter, der var lavere end mindste kliniske relevante ændring. Dette indikerer, at patienterne ikke oplevede en klinisk relevant forbedring for disse subskalaer efter PAO. På trods af betydelige forbedringer i patientrapporteret fysisk aktivitet var det derudover ikke muligt at påvise ændringer i accelerometer-baseret fysisk aktivitet.

Muskelsenesmerte og strukturelle forandringer var hyppige fund hos patienter med hoftedysplasi. Efter PAO blev muskelsenesmerterne mindre udtalte samtidig med, at der sås forbedringer i PRO. På den anden side ændrede mængden af daglig fysisk aktivitet sig ikke efter PAO. Disse resultater giver anledning til at forstå hofteledsdysplasi både som en ledsygdom og som en lidelse, der kan medføre muskelsenesmerte og strukturelle forandringer i muskelsenevævet.

3. Introduction

Hip dysplasia in the mature hip is worldwide one of the most common hip disorders (5–7). It can be asymptomatic (5,6), but is also related to pain, gait adaptations and early osteoarthritis and may require surgical correction (8–11). The stable dysplastic hip is seldom diagnosed and will only be discovered if pain presents (12). The aetiology of hip dysplasia is multifactorial, and many causative risk factors have been proposed, including gender (12), familial predisposition (12,13), breech presentation (12) and primiparity (5,12).

Historically, hip dysplasia is considered a joint disease and little attention is paid to extra-articular structures such as muscles and tendons. In this PhD dissertation, I will review the present knowledge and hopefully extend our knowledge by investigating muscle-tendon pain and structural abnormalities, and change in muscle-tendon pain after hip-preserving surgery.

Prevalence of hip dysplasia

Despite the fact that hip dysplasia is common, only few studies have investigated the prevalence of hip dysplasia in background populations with and without pain. In Danish citizens, radiological findings associated with hip dysplasia range from 3-13% with equal prevalences among men and women (5,6). Similarly, 2-20% of 19-year-old Norwegians have radiological findings associated with hip dysplasia with higher prevalences among women (4%) than among men (2%) (14). However, in background populations with hip symptoms, considerably higher prevalences have been reported (7,15), ranging from 8-32% with equal prevalences among men and women, and higher prevalences among subjects with hip osteoarthritis (7,15). Variations in prevalence are primarily due to differences in diagnostic criteria used (5,6,14), whereas environmental factors and ethnicity explain extreme variations in prevalence among African, Japanese and Saami people (12). Despite these findings among background populations, up to 80% of patients with hip dysplasia are women (16), indicating shortcomings in our current understanding of hip dysplasia. However, before considering this further, I will describe how we understand hip dysplasia today.

Pathology of hip dysplasia

Hip dysplasia is a pathological development of the hip joint that can cause pain (9,16,17). This development involves both the acetabulum and the femur (18). The dysplastic acetabulum is shallow and oblique with a reduced weight-bearing area (19) (Figure 1). This leads to lack of anterior, lateral and occasionally also posterior acetabular support to the femoral head (20). Hip dysplasia is also commonly accompanied by femoral deformities, covering cam deformity, increased anteversion

and insufficient head-neck offset (21). The incongruency between the acetabulum and the femur leads to increased pressure per unit of area and increased shear forces at the acetabular rim (10,22,23). Left untreated, hip dysplasia is associated with hypertrophy of the acetabular labrum and ligamentum teres (22). It has been proposed that these structures undergo hypertrophy secondary to the bony instability in order to keep the femoral head within the shallow and oblique acetabulum (22,24,25). In symptomatic hip dysplasia, the shear forces persist, and the supporting role of the acetabular labrum increases from 1-2% to 4-11% (26). This compensation can fail and result in labral and ligamentum teres lesions, cartilage delamination and accelerated development of hip osteoarthritis (5,6,8,11,27). Yet, only a case-control study and a retrospective cohort study have shown an increased risk of progression from no osteoarthritis to manifest osteoarthritis in patients with hip dysplasia (8,11). However, despite lack of prospective studies, several studies do indicate a relationship between hip dysplasia and hip osteoarthritis (5,6,8,11,27,28).

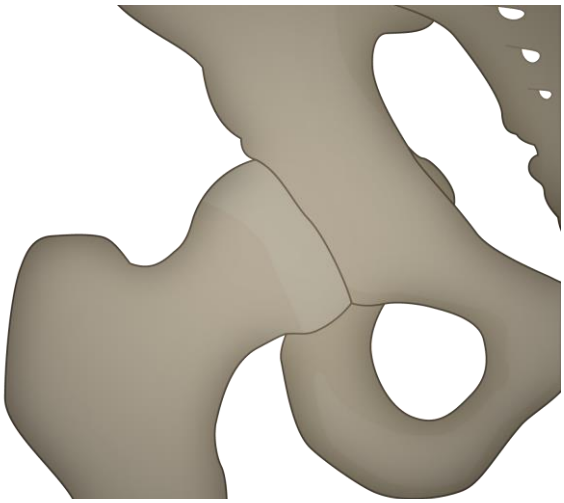


Figure 1. Dysplastic hip joint with reduced coverage of the femoral head.

Cartilage and labral lesions are common in hip dysplasia (22,26), whereas ligamentum teres lesions are less common (22). The cartilage has no pain receptors, and labral lesions have therefore been suggested to cause pain when hip dysplasia becomes symptomatic (22). However, results of other studies suggest differently. The results of a systematic review on cross-sectional and case series studies showed a high prevalence of labral lesions in pain-free subjects (29), while results from a cohort study showed that pain level was not related to the degree of labral lesions in patients with dysplastic and borderline dysplastic hips (30). Consequently, pain may also derive from other structures than the acetabular labrum as explained in the below section on the clinical manifestation of hip dysplasia.

Clinical manifestation of hip dysplasia

Symptomatic hip dysplasia normally presents in young female patients from the age of 24-35 years (9,16,17). The clinical manifestation is longstanding activity-related pain and night pain (9,17,31), presenting bilaterally in 52% (18). In many cases, the pain is located to more than one anatomical region, most commonly the groin and the lateral hip region (9,31). The quality of the pain is sharp to dull with moderate to severe pain intensity (9,31). The pain often presents insidiously over a longer period of time (9) and causes symptoms that vary from fatigue to clear weakness of the hip

abductors (32). Therefore, many patients experience both delay and inaccurate diagnosis (9,33). Common impairments associated with hip dysplasia are gait adaptations (33,34), muscle strength deficits (35,36), pelvic instability (37), low patient-reported function and decline in patient-reported quality of life (33). Of these, impaired muscle strength and pelvic instability seem important and indicate that the muscle-tendon support to the hip joint could play a role in relation to the development of pain (38).

Muscle-tendon pain and structural abnormalities

The hip abductor muscles support the hip joint in the frontal plane (39,40) (Figure 2); and in hip dysplasia, the lack of bony support is associated with an increased role of these muscles (34,41,42). Using triaxial accelerometry in patients with unilateral affection, Maeyama et al. (41) reported increased magnitude of acceleration in dysplastic compared with contralateral healthy hips. The magnitude of acceleration was largest in the lateral direction (41) where the hip abductors are the primary active supporters. Likewise, higher medially directed joint reaction forces were found among patients with hip dysplasia than among pain-free references due to lateralization of the hip joint centre (42). From a biomechanical perspective, lateralization of the hip joint centre requires higher force generation of the hip abductor muscles due to their reduced moment arms (42). This matches the results by Skalshøi et al. (34), who reported an increased hip abductor torque during the late stance phase of walking. Similarly, increased and earlier hip abductor activation has been reported in patients with chronic anterior hip pain (including hip dysplasia) during a step-down exercise (38). These observed movement adaptations probably respond to a biomechanical necessity and are maybe consistent with a pain-protective behaviour as documented in subjects with low-back pain (43). These adaptations have short-time benefits, but long-time consequences may cause pain and structural abnormalities due to overuse (38). This could explain why Sucato et al. (35) and Sørensen et al. (36) found that patients with hip dysplasia had weaker hip abductors than pain-free references when maximal voluntary moments were measured in a isokinetic dynamometer. In other words, patients have sufficient capacity to generate the hip abductor moments necessary for walking (36), but their maximal voluntary capacity is impaired either due to weaker muscles, pain or both.

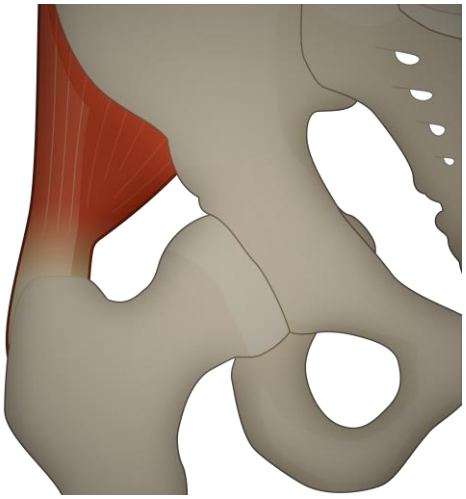


Figure 2. Gluteus medius & minimus muscles (primary hip abductors).

The iliopsoas muscle supports the hip joint in the sagittal plane, resting directly over the acetabular labrum (44) (Figure 3). In hip dysplasia, anterior acetabular support is

lacking (20), possibly causing compensatory loading of the iliopsoas as documented for the hip abductors (34,45); we speculate that this may also cause tendinopathy. These effects may be further aggravated by the close anatomical proximity of the iliopsoas and the acetabular labrum due to increased mechanical compression secondary to acetabular labrum lesions and hypertrophy. However, no studies have reported altered activation of the iliopsoas muscle or increased mechanical compression in patients with hip dysplasia. Still, gait adaptations in the sagittal plane have been reported (33,34), showing that patients with hip dysplasia walk with smaller hip extension angles and reduced hip flexor moments in the late stance phase of walking (33,34). Reduced hip extension leads to a more vertical walking pattern with a smaller load on the anterior hip structures including the iliopsoas (34). This is probably consistent with a pain-protective behaviour. In line with what was mentioned above, patients with hip dysplasia also have weaker hip flexors than pain-free references (35,36), indicating lack of maximal voluntary capacity as described for the hip abductors. In summary, the iliopsoas muscle may be prone to pain and structural abnormalities due to altered muscle activation and mechanical compression and, among other factors, this may explain the documented gait adaptations and muscle weakness (33,35,36).

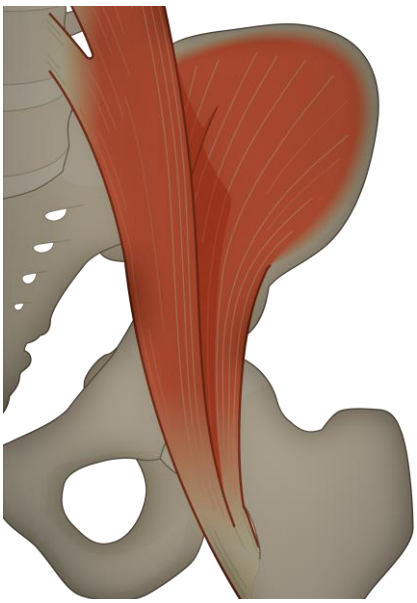


Figure 3. Iliopsoas muscle crossing the dysplastic hip joint.

Muscle-tendon abnormalities have been documented in patients with hip dysplasia examined with hip arthroscopy (46) whereas knowledge of muscle-tendon pain in this population has apparently not been reported. Moreover, presence of muscle-tendon abnormalities were identified in small samples and only as secondary outcomes (46). Therefore, the plausible role of muscle-tendon pain and structural abnormalities in hip dysplasia remains uninvestigated. Among athletes with longstanding groin pain, different anatomical structures, also described as clinical entities, have been suggested to play a role in the development of pain (47,48). Clinical examinations (49,50), magnetic resonance imaging (MRI) (51) and ultrasonography (52) have been used to identify pain and structural abnormalities in specific clinical entities. In athletes, groin pain was most commonly related to the hip adductors (50–52), the iliopsoas (49,50), the symphyseal joint (51) and the inguinal region (49–51). The hip abductors were not examined and knowledge of pain in these muscles is therefore non-existent. Nevertheless, abductor-related pain was the most commonly self-reported painful anatomical region among young active patients following hip arthroplasty (53), indicating the relevance of these muscles among patients with a hip joint disease.

Muscle-tendon pain assessed with clinical examinations

Muscle-tendon pain can be assessed by standardised clinical examinations and by patient reports. Hölmich et al. (47,49,54) were the first to describe specific clinical entities as the origin of pain among athletes with groin pain. In 2015, the Doha agreement meeting on terminology and definitions of pain in athletes was published (48). Twenty-four international experts reached agreement on a classification system for groin pain. According to this system, athletic groin pain was divided into three major categories. The categories were defined clinical entities, hip-related groin pain and other causes of groin pain. The defined clinical entities for groin pain were: adductor-related, iliopsoas-related, inguinal-related and pubic-related pain (example, Figure 4) (48). To identify pain in these clinical entities, standardised pain-provocation tests, viz. anatomical palpation, resistance testing and stretching, were defined (48). A similar approach has been used in patients with lateral hip pain, where anatomical palpation and resistance testing among other criteria were used to identify pathology in the gluteal muscles (55).

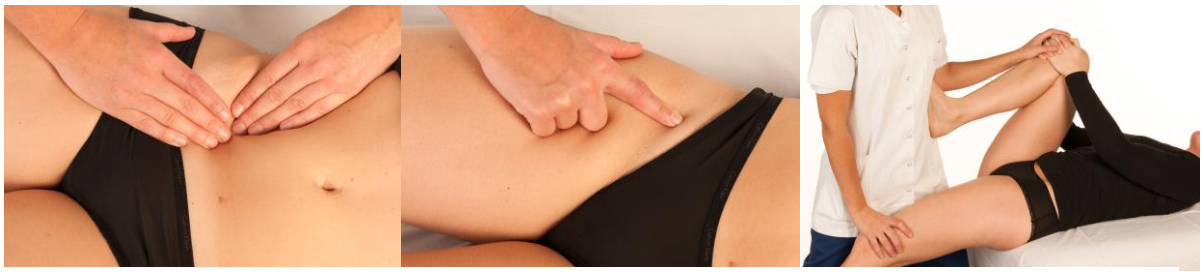


Figure 4. Illustrating diagnostic criteria for iliopsoas-related pain: Palpatory pain of the muscle through the lower lateral part of the abdomen and/or just distal of the inguinal ligament and pain with passive stretching during modified Thomas' test (1).

Muscle-tendon pain recorded with patient reports

Muscle-tendon pain can also be assessed by pain drawings, where pain is identified in specific anatomical regions (53,56). Both advantages and disadvantages of patient reports as opposed to clinical examinations exist. The advantage of a patient report is the possibility to assess large populations (53,56). The disadvantage is that the reporting cannot be controlled by health professionals, introducing a risk of both under- and overestimation and low reproducibility. Therefore, in order to control potential risk of bias, a standardized clinical examination seems superior. However, the disadvantage of clinical examinations and patient reports is the possibility that pain presents as part of referred joint pain or chronic pain unrelated to any structural abnormalities (57).

Muscle-tendon abnormalities examined with ultrasonography

Muscle-tendon abnormalities can be visualised with ultrasonography and MRI (55,58,59). Ultrasonography is a diagnostic imaging technique where images are made by high-frequency sound waves, ultrasound. Ultrasonography has both advantages and disadvantages compared to MRI (58). The most important advantages are higher spatial resolution (60), quantification of structural

abnormalities, real-time scanning (59–61), rapid comparison to symptoms (59–61) and low costs (59,60). The higher spatial resolution with ultrasonography enables quantification of structural abnormalities; thus, the microanatomy of tendons, ligaments and muscles can be visualized (61). This makes it possible to detect minor structural abnormalities as seen in tendinopathy (60) where loss of a normal parallel hyperechoic fibrillar pattern indicate pathology. Moreover, ultrasonography can detect minor tears or calcifications in tendons, ligaments and muscles (60), which is considered difficult by MRI (55). However, MRI also outperforms ultrasonography in some respects; for example, gluteal tendon pathology has been confirmed by MRI in patients with lateral hip pain, where increased signal intensity and tendon thickening were diagnostic criteria (55). Despite many advantages of ultrasonography, limitations do exist. The most important disadvantages are the inability to assess intra-articular structures completely, operator dependence, a long learning curve and artefacts that may be misinterpreted as minor structural abnormalities (59,61). Therefore, using ultrasonography requires experience, a standardised protocol and only few examiners. Acknowledging these known limitations, hip ultrasonography is considered relevant to visualise potential muscle-tendon abnormalities in patients with hip dysplasia.

The above-mentioned known impairments related to hip muscles and tendons suggest that extra-articular structures may play a role in the development of pain in hip dysplasia. However, one must also consider if muscle-tendon pain change after treatment.

Treatment options today

Today, symptomatic and radiologically verified hip dysplasia are treated with hip-preserving surgery. Hip-preserving surgery covers different procedures depending on geography, age and severity of hip dysplasia (32,62,63), and surgery may include single, double, triple, spherical, chiari and PAO (32,63). PAO has become the most frequently performed procedure for surgical treatment of hip dysplasia in Western Europe and North America (64) and covers numerous approaches and modifications (32,65–68) (Table 1). PAO reorientates the acetabulum through three separate osteotomies (32), aiming to improve the coverage of the femoral head to a centre-edge (CE) angle of 30-40 degrees and a Tönnis acetabular (AI) angle of 0-10 degrees (32,67) (Figure 5). PAO is indicated in skeletally mature patients with preserved articular cartilage and an active lifestyle (31,69). Patients should be healthy and <40 years of age because PAO is a highly

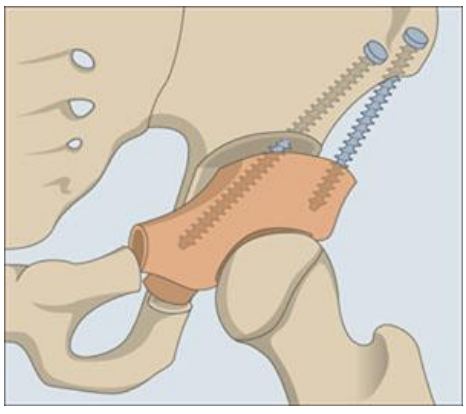


Figure 5. Correction of the hip joint with periacetabular osteotomy. Photo: Soballe.com

invasive procedure (69) and because poor outcome is associated with higher age (70). Moreover, adequate hip range of motion and hip joint congruency are also considered important as PAO reduces hip range of motion (69).

Table 1. Different PAO approaches and how they affect muscles and tendons around the hip joint

Smith-Petersen	Modified Smith-Petersen	Minimally invasive	Minimally invasive
Ganz et al. (1988) (62).	Leunig et al. (2001) (32).	Troelsen et al. (2008) (67).	Khan et al. (2016) (68).
Tensor fascia lata is detached from the ilium. The capsule is freed from the attachment of the gluteus minimus.	The ASIS is osteotomised with preservation of muscle attachments.	The inguinal ligament is cut at the attachment to the anterior superior iliac spine.	The abdominal muscles and the soft tissue at the level of the ASIS are dissected off the bone.
The iliacus and sartorius muscles are elevated from the anterior iliac spine and from the iliac wing. The direct tendon of the rectus femoris is detached from the anterior inferior iliac spine, and fibres of the iliacus muscle are dissected off the capsule.	The indirect head of the rectus femoris is tenotomised and the direct head is separated from the anterior inferior iliac spine.	The sartorius muscle is divided parallel with the direction of its fibres, and the deep fascia of the muscle is cut.	
The hip joint capsule can be opened.	The hip joint capsule is routinely opened.	The hip joint capsule is not opened.	The hip joint capsule is not opened.
Length of incision: 15-20 cm.	Length of incision: 15 cm.	Length of incision: 7 cm.	Length of incision: 9 cm.
10 kg weight-bearing 3th day after surgery.	30 kg weight-bearing 1th day after surgery.	30 kg weight-bearing on the day of surgery.	Not described.
No active movement of reinserted muscles in 6 weeks.	No hip flexion in 6 weeks.		

The ilioinguinal and direct anterior approach is not listed as these approaches are less frequently used nowadays. Abbreviation. PAO (periacetabular osteotomy), ASIS (anterior superior iliac spine).

Radiographic indications for PAO most commonly involve a CE angle <20-25 degrees and AI angle of >10 degrees (32,67,68). It has been anticipated (personal correspondence) that more than half of Danish patients are not candidates for PAO and receive no alternative treatment in the public sector. On the other hand, candidates for PAO receive an expensive and advanced surgical treatment including physical rehabilitation (67,71). After PAO, these patients can expect significant improvement in patient-reported pain, function, physical activity and quality of life (16,64,68,70,72–75). Furthermore, the hip joint remains preserved in 85% of patients after 10 years (73,76), in 60% after 20 years and in 29% after 30 years (64,72). Moreover, leg power also improves after PAO, indicating positive muscle adaptation secondary to acetabular correction (77). Nevertheless, surgery is not without risk,

and complications have been reported after PAO procedures. Minor complications like haematoma, symptomatic hardware, wound infection and minor heterotopic ossification have been reported in 2-41% of cases (65,67,68,73,78–83). The lateral cutaneous nerve is affected in many cases (62,65,78,80,81) and is negatively associated with PRO (83). Major complications have been reported among 0-37% (65,67,68,73,78–83), including avascular necrosis, nerve dysfunction, major bleeding, fracture of the posterior column, major heterotopic ossification and delayed or non-union of the pubic, ischial or iliac bone (83). Despite complications and high costs, 196 Danes underwent hip-preserving surgery due to hip dysplasia in 2018 (84,85). On average, they were hospitalised for 2 days (84,85), and each joint-preserving procedure had a cost of 8,710 Euros (86). However, only about 40 Norwegians and 40 Swedes undergo PAO a year (personal correspondence) despite equal prevalences of hip dysplasia in Denmark and Norway (5,6,14). This indicates that hip dysplasia may be managed with other treatments than hip-preserving surgery.

Exercise therapy is an alternative to surgery and may be a relevant treatment option for those who are not candidates for surgery or do not wish to undergo surgery. The body of evidence to support exercise therapy to treat hip dysplasia is sparse in contrast to the numerous studies reporting outcome of surgery. In a prospective case series study, Kurado et al. (37) showed improved gait, hip abductor strength, patient-reported pain and function 3 months after a hip abductor-strengthening program. Similarly, improvements in patient-reported and performance-based function were reported in a study examining the feasibility of 8 weeks of progressive resistance training in patients with hip dysplasia (87). Interestingly, the outcome of exercise therapy has been investigated in hip osteoarthritic patients with and without hip dysplasia for whom surgery was not recommended due to their level of pain, activity impediments, x-rays and in cases where patients did not want to undergo surgery (88). Despite absence of statistical significance, most outcome items had improved at 6 months of follow-up, suggesting a tendency towards general improvement (88). In line with this, Harris-Hayes et al. (89) showed a positive treatment effect of 6 weeks of movement-pattern training compared with wait-list in a feasibility study of 35 patients with chronic hip pain (including hip dysplasia). The positive effect was shown in relation to patient-reported symptoms and daily life. Moreover, in a case series study of 28 patients from the population described above, significant improvements in patient-reported and performance-based function were found after movement-pattern training (90). However, the long-time outcome of exercise therapy remains unknown. Even so, in patients with hip and knee osteoarthritis, exercise therapy is an established alternative to surgery and improves patient-reported and performance-based function (91–93). The low number of adverse effects of exercise therapy and the possibility to practice exercise almost anywhere at little cost (94–96) signify the role of exercise therapy for patients with hip dysplasia. Nevertheless, eligible patients have to be selected, and the effect of exercise therapy has to be

investigated with appropriate outcome measures as some patients probably require surgical correction. The degree of muscle-tendon pain or the level of physical activity could possibly be of relevance when choosing treatment.

How to measure outcome of treatment

Treatment can be evaluated with performance-based and PRO measures (PROMs). Performance-based measures include three-dimensional motion capture analyses, functional performance tests such as hop tests, single leg squats and muscle strength tests and accelerometer-based measures of physical activity (97,98). PROMs refer to self-administrated standardised questionnaires. These are well-established gold standards investigating the outcome of treatment, and they capture how patients feel and function in relation to health status and treatment without health professional interpretation (99). Traditionally, PROMs designed for older osteoarthritic patients have been used to investigate the outcome of treatment in patients with hip dysplasia (64,70,72,73,100). Preferably, PROMs designed for young and active patients should be the first-line choice in all patients with hip dysplasia. At present, the Hip Outcome Score (HOS), the International Hip Outcome Tool-12 (iHOT-12), the International Hip Outcome Tool-33 (iHOT-33) and the Copenhagen Hip and Groin Outcome Score (HAGOS) are recommended when assessing outcome of treatment in young to middle-aged patients with hip pain (101), and they all have adequate clinimetric quality for this population (101). Nevertheless, important differences between performance-based and PROMs of physical activity have been reported in previous studies (102,103) with no considerable change in level of daily physical activity despite considerable improvements in PROMs. This is not surprising since patient-reported physical activity refers to self-perceived ability to complete a given task and may not reflect actual physical performance (104). Accelerometer-based measures of physical activity, on the other hand, deliver a neutral measure of actual physical performance (104). This is considered important as patients compared with references report reduced ability to participate in preferred physical activities (97) and report using less time on physical activities at higher intensity levels (105). However, no studies have investigated the actual level of physical activity in patient with hip dysplasia.

In summary, the traditional understanding of hip dysplasia as solely a joint disease seems insufficient. Hence, there is a need to extend our knowledge and consider if hip muscles and tendons could play a role in relation to the development of pain. We also ought to investigate the outcome of hip-preserving surgery with outcome measures considered relevant for the typical young, active patient.

4. Aim of the dissertation

The overall aim of this dissertation was to investigate muscle-tendon pain and structural abnormalities in hip dysplasia and outcome of hip-preserving surgery in a prospective study applying clinical tests, ultrasonography, PROs and measurement of physical activity. The aims of the four papers included in the dissertation are listed below.

(1) The aim was to identify muscle-tendon pain in 100 patients with hip dysplasia in the following clinical entities: (i) iliopsoas, (ii) abductors, (iii) adductors, (iv) hamstrings and (v) rectus abdominis. Furthermore, the aim was to investigate if PRO and muscle strength were associated with muscle-tendon pain in patients with hip dysplasia.

(2) The aim was to report abnormal ultrasonographic findings related to muscles and tendons in 100 patients with symptomatic hip dysplasia. Furthermore, the aim was to investigate correlations between abnormal ultrasonographic findings and clinically identified pain related to muscles and tendons.

(3) The aim was to investigate changes in PRO, changes in muscle-tendon pain, and any association between them from before to 1 year after periacetabular osteotomy.

(4) The aim was to investigate whether patients with hip dysplasia change physical activity profile from before to 1 year after periacetabular osteotomy, measured by accelerometer-based sensors and patient-reported physical activity. Furthermore, the aim was to investigate association between change in accelerometer-based physical activity and change in patient-reported participation in preferred physical activities.

5. Design

This PhD dissertation is based on data collected from a prospective case series study in patients with hip dysplasia scheduled for hip-preserving surgery with 1-year follow-up. Throughout the dissertation, the case series study will be referred to as this study, and individual papers will be referred to as Paper 1-4 (1–4). This study was registered at ClinicalTrials.gov (ID: 20140401PAO) and conducted and reported in accordance with the WMA declaration of Helsinki and the STROBE statement.

6. Materials & methods

Ethical issues

Ethical aspects are important to consider when including patients in a study. This study was initiated at a time marked by a lack of studies investigating muscle-tendon pain and structural abnormalities in hip dysplasia and outcome of surgery with outcomes measures considered relevant for the typical young, active patient. Only few studies have reported outcome of the PAO with relevant PROMs (68,97), and abnormal findings in muscles and tendons have only been reported as secondary findings (46), and no studies have reported level of daily physical activity with accelerometer-based methods. Therefore, it was considered ethically right to invite patients to participate in this study. To impose as little burden on patients as possible, only outcome assessments that were absolutely essential to this study were collected. Moreover, economic compensation for transportation to the hospital was given. This study was notified to the Central Denmark Region Committee on Biomedical Research Ethics on 14 January 2014 (5/2014), who waived the request of approval since observational studies need no ethical approval in Denmark. The handling of personal data was authorised by the Danish Data Protection Agency (1-16-02-47-14), and all participating patients gave informed consent to participate by signing an informed written consent form.

Patients

Patients with bilateral and unilateral hip dysplasia were recruited consecutively from May 2014 to August 2015 from the Department of Orthopaedic Surgery at Aarhus University Hospital, Denmark (1–4). Patients were screened for initial eligibility by specialised orthopaedic surgeons. Eligible patients were given oral and written information about the mandatory procedures for participation. Patients agreeing to participate were hereafter contacted and enrolled if they fulfilled the inclusion and exclusion criteria. Criteria for inclusion were scheduled PAO due to symptomatic and radiologically verified hip dysplasia, applying Wiberg´s centre-edge (CE) angle <25° (106). Patients were excluded if they had conditions and/or a history of

previous surgical interventions affecting the function of their hip (Figure 6). Moreover, only patients <45 years of age, with a BMI <30, with normal hip range of motion and with non-arthritic hips were operated on.

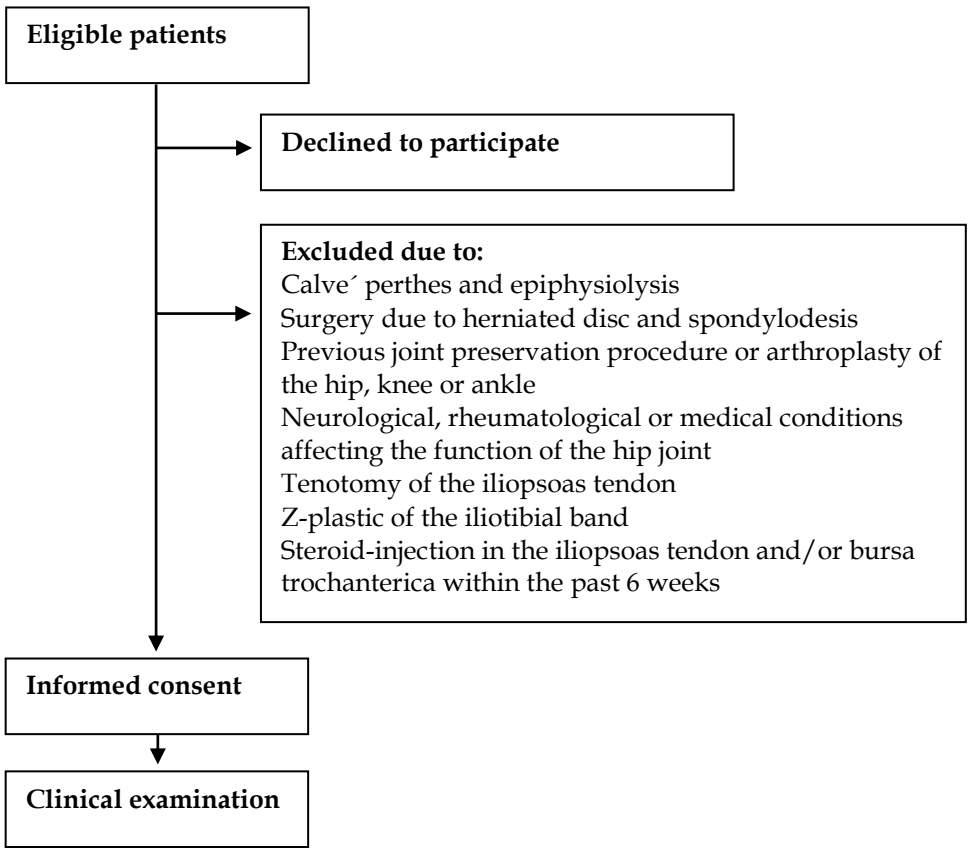


Figure 6. Flowchart of the process of inclusion.

Patient characteristics

Patient characteristics were collected at a clinical examination before and 1 year after PAO by two experienced physiotherapists with 5-7 years of experience assessing patients with hip dysplasia (1–4). The examinations took place in a closed examination room at the Department of Physiotherapy and Occupational Therapy, Aarhus University Hospital. The physiotherapists randomly assessed patients with hip dysplasia with equal distribution between the two. Patient characteristics were recorded from standardised questions and/or medical records. The highest pain at rest was measured on a numerical rating scale (NRS) while the patient was lying down. Using anteroposterior radiographs, a single rater measured the following radiological angles: the CE angle (106), the AI angle (107) and the degree of osteoarthritis according to Tönnis' grading (107). Unilateral and bilateral affection and co-morbidities were recorded from medical records. Back pain intensity was recorded with the Oswestry Disability Index, section 1 (108). Hip-related pain was assessed by the Flexion/Adduction/Internal Rotation (FADIR) test and the Flexion/Abduction/External Rotation test (FABER) test (109,110). Occurrence of internal snapping hip was assessed using a standardised clinical test (111). Finally,

the springing palpation test for pain provocation over the lumbar spinous processes and the sacroiliac joints was used to assess whether springing palpation tests led to local pain in the back and/or in the hip and/or groin (112).

Hip-preserving surgery

Patients were surgically treated with the minimally invasive approach for PAO by two experienced orthopaedic surgeons (3,4). A 7 cm incision was made alongside the sartorius muscle, beginning at the anterior superior iliac spine. The sartorius muscle was cut parallel with its muscle fibres, and the medial part of the divided muscle was retracted medially together with the iliopsoas muscle. Osteotomies were hereafter performed. Patients were hospitalised for approximately 2 days. At the ward, they were given patient information and instructed in a rehabilitation programme including pain management, nutrition and mobilisation. Additionally, they were instructed in a home-based exercise programme involving unloaded hip exercises. Patients were allowed partial weight bearing the first 6-8 week with a maximum load of 30 kg. Additionally, patients were offered an individualised exercise programme, consisting of two weekly physiotherapist-supervised training sessions. The sessions started when full weight bearing was allowed and ended after 2-4 months.

Outcomes

Outcomes were collected at the two clinical examinations (1–4). The HAGOS was completed first, followed by ultrasonography, clinical examination of muscle-tendon pain and clinical assessment of hip muscle strength. Before ending the clinical examinations, patients were instructed to wear an accelerometer-based sensor the following 7 days.

Patient-reported outcome

The HAGOS was used to measure PRO in all patients (1–4). This questionnaire was developed to measure perceived and actual outcome in physically active, young-to-middle-aged patients with longstanding hip and/or groin pain (113). The HAGOS consists of six subscales measuring pain, symptoms, physical function in daily living (ADL), physical function in sports and recreation (sport/recreation), participation in physical activity (PA) and quality of life (QOL) during the past week. The individual subscales measure PRO from 0-4 through 37 individual items. The raw score can be transformed to a total score of 0-100 points, and 100 points indicate highest possible outcome. The HAGOS has been developed from the Hip disability and Osteoarthritis Outcome Score (HOOS) after translation and cross-cultural adaptation to Danish. Items from the HOOS were supplemented with three sports-specific items from the HOS to form the full HAGOS (113). The psychometric properties of the HAGOS have been evaluated in three prospective case series studies (113–115) in the following patients: (i) patients with hip and/or groin pain (n=101) (113), (ii) patients who had

undergone hip arthroscopic surgery 1-2 years previously (n=50) (114), (iii) healthy pain-free references (n=50) (114), and (iv) patients with femoroacetabular impingement syndrome (FAIS) scheduled for hip arthroscopy (n=502) (115). The test-retest reliability of the HAGOS is high. The interclass correlation coefficients range from 0.81 to 0.97 across all subscales, and the measurement error ranges from 1 to 5 points at the group level (113–115). Moreover, the HAGOS has adequate construct validity. The correlation coefficients range from 0.23 to 0.73 across all subscales when correlated to relevant constructs (113–115); with the HAGOS, relevant differences between patients and references can be detected (114). The responsiveness of the HAGOS, measured as effect size, range from 0.77 to 1.87 points across all subscales in patients with hip and/or groin pain and FAIS that reported improved condition (113,115). The interpretability of the HAGOS, measured as minimally important change (MIC), ranges from 9 to 13 points across all subscales in patients with FAIS who underwent hip arthroscopy 4 months earlier (115).

Methodological considerations

The HAGOS is not the only PROM developed to measure PRO in young-to-middle-aged patients with hip pain. Evidence from recent systematic reviews (101,116), a Delphi study (117) and statements from an international agreement paper (118) also recommend the iHOT-12, iHOT-33 and HOS (101,116–118). Based on the COnsensus-based Standards for the selection of health Measurement INstrument (COSMIN) list, iHOT-12, iHOT-33, HOS and HAGOS are the most systematically investigated PROMs. However, the HOS and iHOT-33 are associated with the highest ratings of poor study methodology (46% in both studies), while the HAGOS and iHOT-12 are associated with the lowest ratings of poor study methodology (23% and 31%) (101). The responsiveness of the HAGOS and iHOT-12 is similar when comparing the HAGOS subscales pain, sport/recreation and PA with the total score of the iHOT-12 (116). Contrary to this, the HAGOS subscale symptoms and ADL are associated with poorer responsiveness, while the HAGOS subscale QOL is associated with higher responsiveness (116,119). Nevertheless, the six dimensions of the HAGOS provide precise and specific knowledge on PRO in specific domains, which cannot be obtained from the combined total score of the iHOT-12 (119). Furthermore, only the HAGOS measures PRO related to the hip and/or groin, and the HAGOS is therefore considered suitable for patients with hip dysplasia as the clinical manifestation of hip dysplasia is activity-related pain in the hip and groin.

Muscle-tendon pain

Muscle-tendon pain was examined in specific clinical entities as described above (47,48,54). In this study, standardised examinations consisting of five pain provocation tests covering palpation, resistance testing and passive muscle strength were used (1–3) (Table 2) (Supplementary files). The order of the tests was as follows: adductor-related pain, iliopsoas-related pain, rectus-abdominis-related pain,

abductor-related pain and hamstring-related pain. Unlike the defined clinical entities from the Doha classification system (48), we subsequently obtained information about abductor- and hamstring-related pain (1–3). These clinical entities were considered important in patients with hip dysplasia since patients have a hip abductor strength deficit (35,36) and hip abductors and extensors seem to be negatively affected by hip dysplasia in walking (33,34). Additionally, rectus-abdominis-related pain (47,54) was used instead of inguinal-related pain from the Doha classification system (48). Inguinal-related pain is less relevant in patients with hip dysplasia as the majority of patients are females who have a different inguinal canal anatomy than males. Muscle-tendon pain was reported in each of the five individual clinical entities and as the sum of painful clinical entities for each patient, ranging from 0-5. The outcome of each entity test was "yes" or "no" to the following question, "Did you feel known pain during the test?"

Table 2. Standardised examination of muscle-tendon pain in individual clinical entities

Clinical entities	Assessment
Iliopsoas-related pain	Palpatory pain of the muscle through the lower lateral part of the abdomen and/or just distal of the inguinal ligament and pain with passive stretching during modified Thomas' test (47,48,54).
Abductor-related pain	Palpatory pain at the insertion point at the greater trochanter and pain with side-lying abduction against resistance (55).
Adductor-related pain	Palpatory pain at the muscle origin at the pubic bone and pain with adduction against resistance (47,48,54).
Hamstring-related pain	Palpatory pain at the muscle origin at the tuber ischii and pain with extension against resistance.
Rectus abdominis-related pain	Palpatory pain of the distal tendon and/or the insertion at the pubic bone, and pain at contraction against resistance (47,54).

Similar table published in paper 1, Table 1 (1).

The reliability of the standardised clinical examinations was investigated in a previous study, reporting acceptable intra- and inter-rater reliability with kappa coefficients ranging from 0.57 to 0.94 (54). The reliability was investigated in athletes with groin pain who are considered somewhat different from patients with hip dysplasia. Therefore, in this study, the inter-rater reliability of the standardised examinations was investigated since the examinations were carried out by two raters (A and B) for practical reasons (sick leave and holidays) (1).

Two physiotherapists examined 25 patients with hip dysplasia, surgically treated with PAO 6 weeks previously. The patients were examined on two occasions with 2 days between the first and the second examination, and patients were randomised according to whether rater A or B performed the first examination. The patients were instructed not to do physical training prior to the examinations.

Methodological considerations

Patients with hip dysplasia may show a higher day-to-day variation in pain than athletes with groin pain as physical activity one day affects both hip joint and muscle-tendon pain the following days. Moreover, examining patients with two raters could probably also increase the random variation in findings between patients. In this study, the inter-rater reliability was investigated with a period of two days between each examination in surgically treated patients (1). Optimally, the inter-rater reliability should have been examined the same day and in non-surgically treated patients. Nevertheless, the present procedure was chosen as the included patients already had two weekly scheduled training sessions at the hospital, enabling smooth inclusion into the investigation of inter-tester reliability.

Hip muscle strength

Hip muscle strength was assessed with a handheld dynamometer (Powertrack II commandor, JTECH Medical, Salt Lake City, Utah), using a standardised and reliable procedure (1). Two physiotherapists with experience in using the dynamometer performed the muscle strength tests at the baseline examination. The procedure included isometric strength test of the hip adductors and abductors in supine position, the hip flexors in sitting position and the hip extensors in prone position. These test positions were chosen as they were associated with small measurement variation (3-8%) (120) and considered comfortable for patients with a hip joint disorder. The order of the individual tests was random to avoid systematic bias. Resistance was applied 5 cm proximal to the lateral malleolus for hip adductor, hip abductor and hip extension tests, while resistance in hip flexion was applied 5 cm proximal to the proximal border of patella (Figure 7). Patients were instructed to stabilise themselves by holding on to the examination table.

In all tests, patients were informed about the procedure, and this was followed by a sub-maximal practice contraction and a maximal voluntary practice contraction. In all tests, patients performed a 5-s maximum voluntary contraction against the dynamometer, and the highest voluntary contraction out of four repeated measurements in each test was used in the analysis. When the last measurement was the highest recorded value, another measurement was performed until no higher values were measured. A 30-s pause between each measurement was included to avoid fatigue. The recorded strength values were body-size-normalised (lever arm and body mass) and reported as newton metres per kilogram of body weight. The muscle strength for the hip scheduled for PAO was used in the analyses. Two raters assessed patients, and therefore the inter-rater reliability was investigated using the same procedure as described for clinical examination of muscle-tendon pain with 2 days between test and re-test (1).

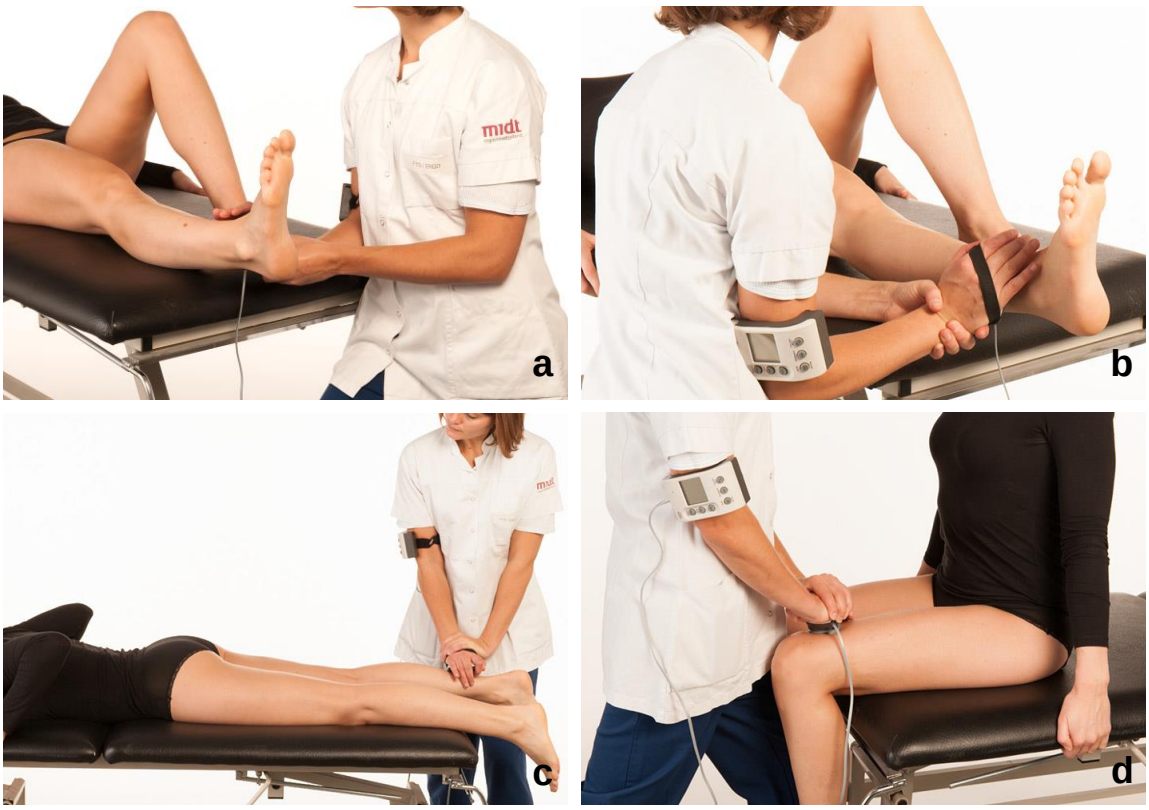


Figure 7. Muscle strength test of the right adductors (a), abductors (b) and extensors (c) and left flexors (d).

Methodological considerations

As described earlier, it would have been preferable to limit the muscle strength assessment to one rater and preferably a male rater since female raters seem to measure 4-13% lower hip strength values than their counterparts (121). In this study, both raters were females (1), and therefore systematic differences are not expected. However, it is possible that the patients' strength values will be related to the female raters' strength. However, in the chosen test positions, the body mass was behind the dynamometer to give extra support and stability; and in hip adduction, abduction and extension, patients had to resists the force from the rater using a long lever. The latter gave the rater advantage over the person being tested. Another approach to limit possible systematic differences would have been to use external belt fixation. This would have eliminated a possible negative effect of insufficient strength on the part of the rater as reported in a previous study (122).

Ultrasonographic findings

Abnormal ultrasonographic findings related to muscles and tendons were visualised with ultrasonography at the clinical examination scheduled before PAO (2). In ultrasonography, sound waves are generated in a high-resolution linear transducer, which transforms voltage into ultrasound via an array of piezo-electrical crystals (123). When ultrasound meets tissue, a sound reflection is generated, and this reflected sound energy is transformed back into voltage via the piezo-electrical crystals in the transducer (123). The reflected voltage signal includes information necessary to form a 2-dimensional grey-scale image (123). These grey-scale images

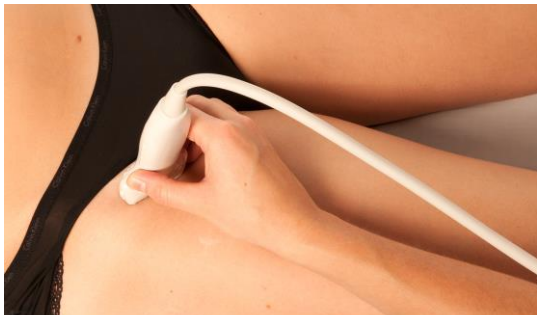


Figure 8. Illustrating ultrasonographic examination of the iliopsoas tendon (2).

display tissue of different densities, where high-density tissue (cortical bone) is displayed as bright grey-shades and low-density tissue (muscle) is displayed as dark grey-shades (123). In this study, a standardised protocol (Supplementary files) was used (2). The protocol was based on the review by Nestorova et al. (59) and included examination of the iliopsoas tendon, the adductor longus tendon, the hamstring tendons, the pubic symphysis and the acetabular labrum (example, Figure 8). Moreover, a Noblus, Hitachi-Aloka Medical (Zug, Switzerland) ultrasound system and a multi-frequency linear transducer (5–18 MHz) (EUP-L64, Zug, Switzerland) were used in all examinations (2).

Abnormal ultrasonographic findings were defined as heterogeneous echogenicity with loss of normal fibrillar pattern, abnormal fluid intra- and/or extra-substantial and irregular bone configuration, enthesophytes and/or calcifications. These findings were recorded as normal or abnormal in the index limb by the two physiotherapists (example, Figure 9). Images and movie sequences of the anatomical structures were recorded in all patients and stored on an external disc. Additionally, valid image reading was optimised through a two-phase procedure (2).

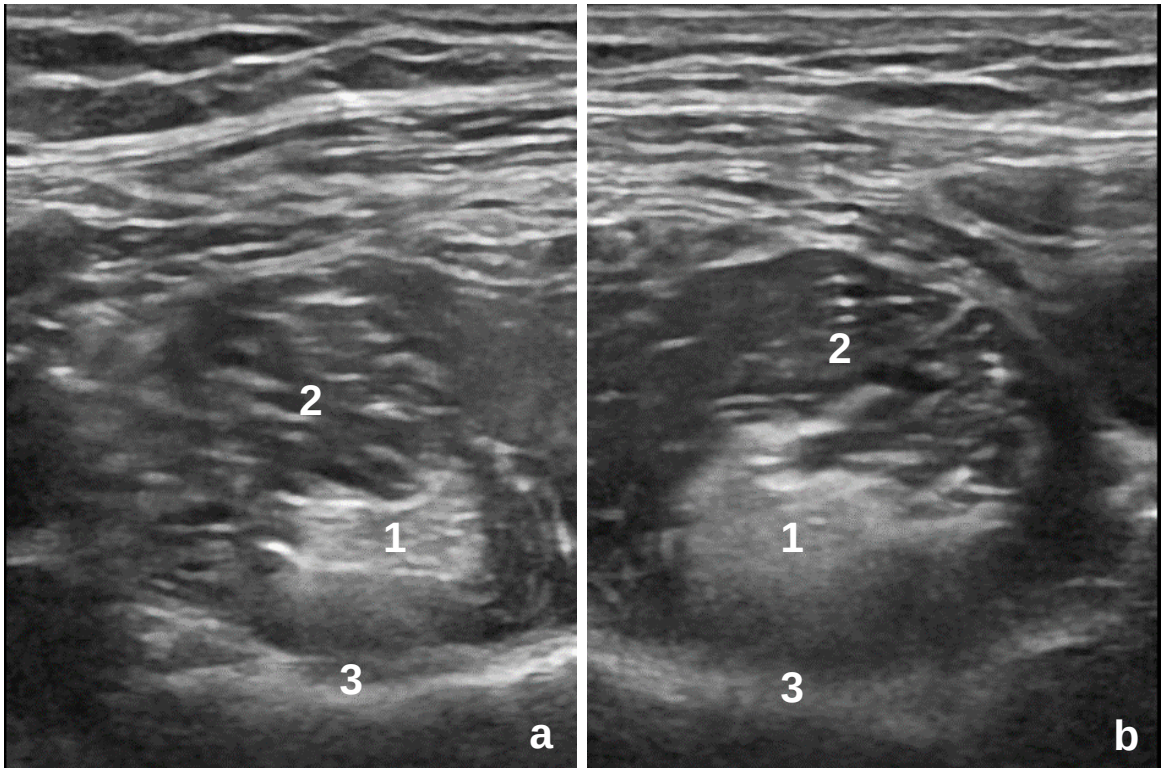


Figure 9. Transverse image of a normal and homogeneous tendon with normal fibrillar pattern [a]. Transverse ultrasound image of a thickened heterogeneous tendon with loss of normal fibrillar pattern and diffuse margin appearance [b]. Iliopsoas tendon [1], iliopsoas muscle [2] and acetabular rim [3] (2).

The first phase comprised a pilot phase, where the standardised protocol was tested in ten subjects, including five patients and five pain-free references. Additionally, a radiologist specialised in musculoskeletal ultrasonography supervised the ultrasonographic examination in five of the ten pilot subjects. The second phase comprised data collection, using the approach by Branci et al. (51), where image findings were based on consensus by three radiologists. After the ultrasonographic examinations, stored images and movie sequences of the initial 50 patients were evaluated a second time by all raters (two physiotherapists and the specialised radiologist). Eighteen percent of the initial recordings gave rise to discussion between raters before reaching final consensus. In the last 50 patients, rating was performed solely by the two physiotherapists. In case of any doubts, they had the possibility to contact the specialised radiologist. This was done in five cases.

Two raters carried out the ultrasonographic examinations, and the intra- and inter-rater reliability were investigated (2). Stored images and movie sequences of 50 patients were rated twice by one rater with a period of median 10 days (7-13) between each evaluation, and the intra-rater reliability was based on these ratings. On a later occasion, the specialised radiologist evaluated images and movie sequences of the same 50 patients, and the inter-rater reliability was calculated based on the first and the third rating. In each of the three ratings, each rater recorded whether the individual structures were normal or abnormal.

Methodological considerations

Ultrasonography is associated with operator dependency, a long learning curve and artefacts that may be misinterpreted as minor structural abnormalities. Therefore, one rater would have been preferable. In this study, patients were examined by two raters, which may have increased the random variation in findings between patients (2). In order to reduce this variation and to ensure valid image reading, images and movie sequences of the initial 50 patients were evaluated a second time by all three raters. Optimally, images and movie sequences of all 100 patients should have been evaluated a second time by all raters. Unfortunately, this was not possible due to practical reasons. Moreover, to ensure valid imaging reading and to reduce variation, a standardised protocol was developed and used (Supplementary files). This protocol included a description of the procedure and illustrations of transducer placement, and the protocol was considered appropriate. Ideally, this protocol should have included images and/or movie sequences of normal and abnormal structures, and in case of doubts, these could have been used as a guideline.

Accelerometer-based physical activity

The level of daily physical activity was measured with commercially available tri-axial accelerometer-based sensors (Gulf Coast Data Concepts, Mississippi, USA), using a validated procedure (4). The level of daily physical activity was measured

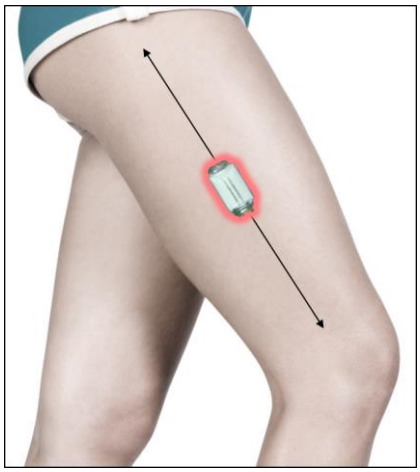


Figure 10. Accelerometer-based sensor taped between the lateral femoral condyle and the greater trochantor.

during seven consecutive days, including working and leisure days. Hypo-allergenic double-sided tape (3M, USA) was used to fasten the sensor to the patient's non-affected upper leg. The sensors were mounted halfway between the lateral femoral condyle and the greater trochantor (Figure 10) (124). Daily physical activity was measured during waking hours of minimum 8 hours per day, while physical activity at night and during swimming and showering activities was not measured. The sensor sampled data from -6 to 6g at 50 Hz. After 7 days of measurement, patients returned the sensors to the hospital by mail. The stored data were transferred to a computer, and the raw data were visually divided into separate days using a customised MatLab-script, removing non-worn days (125). Hereafter, all data were calibrated manually by selecting a period of level walking of each day. The data were calibrated in order to adapt variations in height, morphology, sensor placement, walking pattern and speed. After calibration, the data of each day were run through a customised and validated algorithm (Figure 11) (125). This algorithm was based on a decision tree, and decisions were based on acceleration vectors (static versus dynamic), inclination of the accelerometer (sitting versus standing), by low-pass filters (sedentary versus upright dynamic events) and by consecutive peaks (shuffling versus walking) (125).

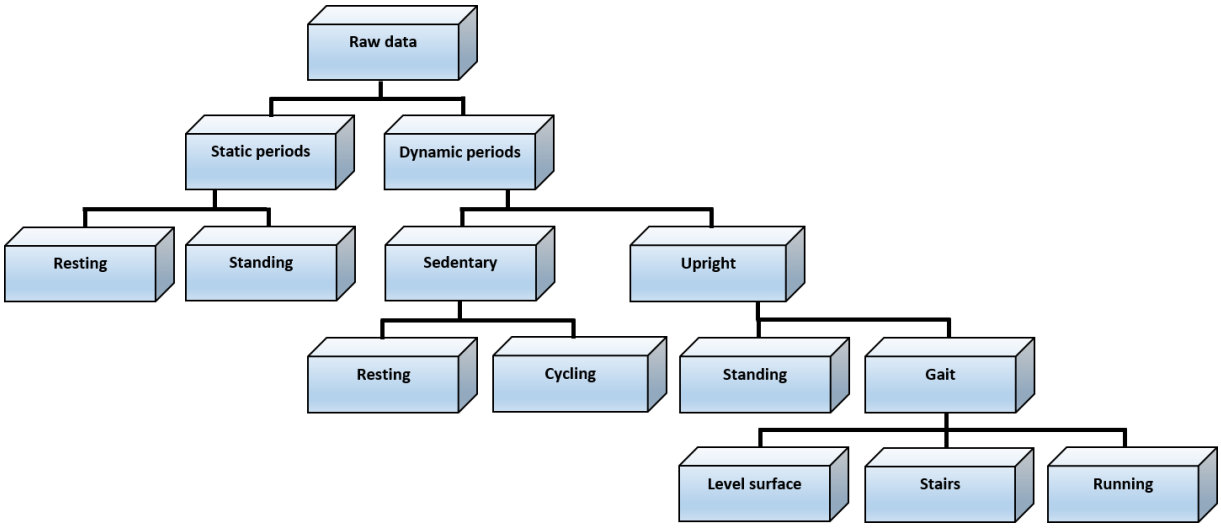


Figure 11. Illustration of algorithm, basing decisions on acceleration vectors, accelerometer inclination, low pass filters and consecutive peaks.

Based on these decisions, data could be divided into separate physical activities, including: resting, standing, cycling, level walking, walking on stairs and running (125). Additionally, the algorithm created an intensity variable based on the average data signal intensity in 10-second intervals grouped into four intensity levels (Table 3).

Table 3. The intensity of accelerometer-based physical activity grouped in four intervals

Intensity levels	Interpretation	Signal intensity, g
1. Very low intensity	Sitting and standing	0.00-0.05
2. Low intensity	Standing and shuffling	0.05-0.10
3. Moderate intensity	Slow walking and normal walking	0.10-0.20
4. High intensity	Brisk walking, running and jumping	>0.20

Methodological considerations

The discriminative ability of the used algorithm was considered important as patients with hip dysplasia are relative young and may therefore experience impairments only in demanding sport and recreational activities. A limitation of the method is, however, that fitness training is not quantified. Fitness training includes many different activities (e.g. strength training, rowing, jumping and dancing). Consequently, the level of daily physical activity could be underestimated as many young patients do fitness training. Moreover, it is possible that patients do more physical activity when they are monitored than during normal days, resulting in an overestimation of the level of daily physical activity. Nevertheless, the possible effect on the results is considered small since possible overestimation will exist at all measured time points, and this will not cause bias.

Statistics

In the four papers included in this PhD dissertation (1–4), numerical data were presented as means (SD) if normally distributed, and otherwise as medians with interquartile ranges (IQR) or 95% confidence intervals (CI). Categorical data were presented as numbers and percent with CI. In all analyses, estimated results were considered statistically significant if $p \leq 0.05$, and the STATA 14 (StataCorp, College Station, TX) software package was used for all data analyses.

Paper 1

The inter-rater reliability of the standardised clinical examinations was reported as percentage of agreement and Cohen´s κ-coefficient, while inter-rater reliability if the hip muscle strength tests was reported as intraclass correlation coefficient (ICC) and standard error of measurement.

Simple and multivariable linear regression analyses were performed to investigate whether PRO and muscle strength were associated with muscle-tendon pain. In all regression analyses, the sum of painful clinical entities (i.e. muscle-tendon pain) was the independent variable, while each subscale of the HAGOS (symptoms, pain, ADL, sport/recreation, PA and QOL) and each hip muscle strength test (adduction,

abduction, extension and flexion) were the dependent variables. Crude and adjusted β-coefficients were estimated, and adjustments were made for age and sex.

In this study, we aimed to describe muscle-tendon pain and association with PRO and hip muscle strength. This means that a sample size calculation may be less relevant. Therefore, a convenience sample of 100 patients was considered appropriate to describe muscle-tendon pain before and 1 year after PAO. Nevertheless, to ensure that the sample size was large enough to investigate whether muscle-tendon pain was associated with PRO, a sample size calculation was performed. Given a minimal clinically relevant difference of 11.8 HAGOS ADL points (115), an estimated SD of 18.5 HAGOS ADL points (114), a significance level of 5% and a power of 80%, 80 patients were needed to detect changes between patients with and without muscle-tendon pain. Considering the risk of dropouts, the convenience sample of the 100 patients seemed appropriate.

Paper 2

The reliability of the ultrasound examination was reported as percentage of agreement and Cohen´s κ-coefficient. For each anatomical structure, correlations between clinically identified muscle-tendon pain and abnormal ultrasonographic findings related to muscles and tendons were tested with Spearman´s rank correlation coefficient.

Paper 3

Changes from before to 1 year after PAO were investigated with paired t-tests for PROs, while the McNemar´s test was used to test changes in muscle-tendon pain. Additionally, estimated changes were supplemented with calculation of effect sizes. Cohen´s d was calculated from the paired t-test as: d = t statistic/$\sqrt{(n)}$ and Cohen´s w was calculated from McNemar´s test as: w = w statistics/$\sqrt{(n)}$. Moreover, floor and ceiling effects were checked in all subscales of the HAGOS and considered present if >15% reported the lowest or highest outcome score. Furthermore, we reported the proportion of patient reporting a HAGOS chance score lower than the MIC according to Thomee et al. (115). Finally, simple and multivariable regression analyses were performed to investigate whether changes in PRO were associated with change in the sum of painful clinical entities from before to 1 year after PAO. Based on knowledge from previous studies, potential co-variates were identified using causal diagrams for observational research (126). The identified co-variates were pre- and postsurgical CE angles (continuous), age (continuous) and sex (nominal). Crude and adjusted β-coefficients were estimated where the sum of painful clinical entities was the independent variable and each subscale of the HAGOS was a dependent variable.

Paper 4

Time in each physical activity (i.e. walking, cycling and running) and number of steps recorded at baseline were normalised to total accelerometer-based wear time recorded at baseline; time and steps recorded at 1-year follow-up were normalised to total accelerometer-based wear time recorded at 1-year follow-up. Changes in accelerometer-based physical activity and change in the HAGOS PA subscale were tested with paired t-tests if assumptions were met, and otherwise with the non-parametric Wilcoxon signed rank test. Estimated differences were supplemented with calculation of effect sizes. For parametric data, effect sizes were calculated as Cohen´s d from the paired t-test; for non-parametric data, effect sizes were calculated from Wilcoxon signed rank test as: z = z statistic/$\sqrt{(n)}$. Additionally, to investigate association between changes in accelerometer-based physical activity at four intensity levels (i.e. very low, low, moderate and high) and change in the HAGOS PA subscale from before to 1 year after PAO, simple linear regression analyses were performed. In the analyses, changes in accelerometer-based physical activity were the dependent variables; change in the HAGOS PA subscale was the independent variable.

Methodological considerations

In Paper 1, sex was included as a co-variate in the multivariable regression analyses. This was done because sex is associated with lesser improvement in PRO after PAO (16) and possibly also presurgical PRO, and furthermore because sex could be associated with muscle-tendon pain through the association between sex and morphology of the proximal femur and/or FAIS (127,128). Age was included as a co-variate in the multivariable regression analyses. This was done because age is associated with PRO of PAO (70), and therefore possibly also presurgical PRO, and because age and muscle-tendon pain could be associated via age-related changes of the muscle-tendon tissue (129). Nevertheless, age adjustments were indirectly done in all analyses as only patients with mature hips and patients under 45 years were included (criteria for the PAO). Therefore, age adjustments may not have been relevant.

In Paper 3, the post-surgical CE angle was treated as a co-variate in the multivariable regression analyses. This was done because the post-surgical CE angle is associated with outcome of PAO (64), and because the post-surgical CE angle could be associated with muscle-tendon pain; the latter because compromised joint stability has been suggested to increase in proportion to the severity of hip dysplasia (the CE angle) (41), thereby possibly increasing the risk of overuse injuries of hip muscles due to increased muscle force generation (34). Sex and age were considered relevant co-variates due to the above-mentioned associations described for Paper 1, and presurgical CE angle was considered a possible co-variate due to similar associations as reported for the postsurgical CE angle.

7. Results

In the study period, 100 consecutive patients fulfilled the in- and exclusion criteria and were included in this study (Figure 12) (1–4).

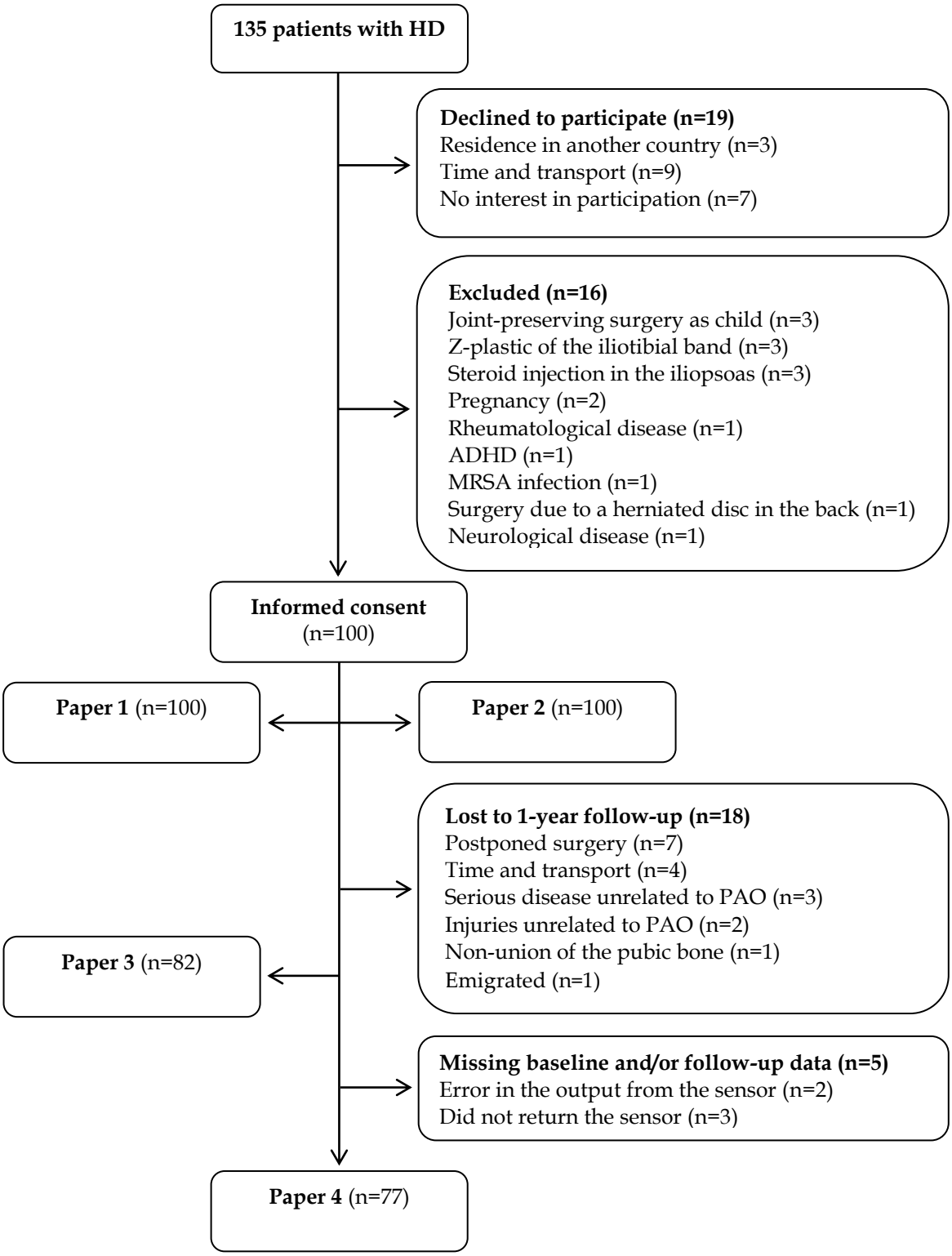


Figure 12. Flowchart of the study process. Abbreviations: HD (hip dysplasia), ADHD (attention deficit/hyperactivity disorder), MRSA (methicillin-resistant staphylococcus aureus).

One year after PAO, 18 patients were lost to follow-up, so 82 patients were available for analysis in Paper 3. In Paper 4, accelerometer-based physical activity data of five patients were missing, so 77 patients were available for analysis in that paper. The patients lost to follow-up did not differ from the analysed patients on any of the measured patient characteristics (data not shown).

Table 4. Characteristics of the included patients reported separately for the four papers

	Paper 1 & 2 (n=100)	Paper 3 (n=82)	Paper 3 (n=82)	Paper 4 (n=77)	Paper 4 (n=77)
Patient characteristics	Before PAO	Before PAO	After PAO	Before PAO	After PAO
Age, years (SD)	30 (9)	30 (9)	31 (9)	30 (10)	32 (10)
BMI, kg/m^2 (SD)	23 (3)	23 (3)	24 (3)	23 (3)	24 (3)
Men (%)	17	11 (13)	-	9 (12)	-
Pain, years (IQR)	3 (1 - 6)	3 (1 - 6)	-	3 (1 - 7)	-
NRS pain (IQR)	3 (2 - 5)	3 (2 - 5)	0 (0 - 2)	2 (1 - 4)	0 (0 - 1)
Bilateral affection (%)	89	74 (90)	-	69 (90)	-
CE angle, degrees (SD)	17 (5)	17 (5)	30 (5)	17 (5)	30 (5)
AI angle, degrees (SD)	14 (5)	14 (5)	3 (4)	14 (5)	3 (4)
Osteoarthritis grade 0/1	97/3	79/3	77/5	74/3	72/5
Pos. FADIR test (%)	83	70 (85)	55 (67)	66 (86)	52 (68)
Pos. FABER test (%)	74	62 (76)	47 (57)	58 (75)	45 (58)
Pos. i. snapping hip test (%)	30	25 (30)	16 (20)	23 (30)	15 (19)
Back pain intensity (0-5)					
No (%)	31	26 (32)	31 (38)	26 (34)	31 (40)
Very mild (%)	23	19 (23)	24 (29)	19 (25)	21 (27)
Moderate (%)	26	20 (24)	16 (20)	18 (23)	14 (18)
Fairly severe (%)	14	12 (15)	8 (10)	10 (13)	8 (10)
Very severe (%)	5	4 (5)	2 (2)	3 (4)	2 (3)
Worst imaginable (%)	1	1 (1)	0 (0)	1 (1)	0 (0)
Missing (%)	-	-	1 (1)	-	1(1)
Springing palpation test (SP)					
Hip pain (%)	12	10 (12)	2 (2)	10 (13)	2 (3)
Back pain (%)	35	30 (37)	31 (38)	28 (36)	30 (39)
No pain (%)	53	42 (51)	48 (59)	39 (51)	44 (57)
Missing (%)	-	-	1 (1)	-	1 (1)
Springing palpation test (SIJ)					
Hip pain (%)	18	17 (21)	3 (4)	14 (18)	3 (4)
Back pain (%)	14	13 (16)	12 (15)	13 (17)	12 (16)
No pain (%)	68	52 (63)	66 (80)	50 (65)	61 (79)
Missing (%)	-	-	1 (1)	-	1 (1)

Abbreviations: BMI (Body Mass Index), NRS (numerical rating scale), CE (centre-edge), AI (Tönnis' Acetabular Index), FADIR (flexion/adduction/internal rotation), FABER (flexion/abduction/external rotation). Pos. (positive), i. (internal), SP (spinous processes), SIJ (sacroiliac joints).

Patient characteristics

The characteristics of the included patients are reported separately for each paper in Table 4, whereas preferred physical activities of the patients are shown in Figure 13.

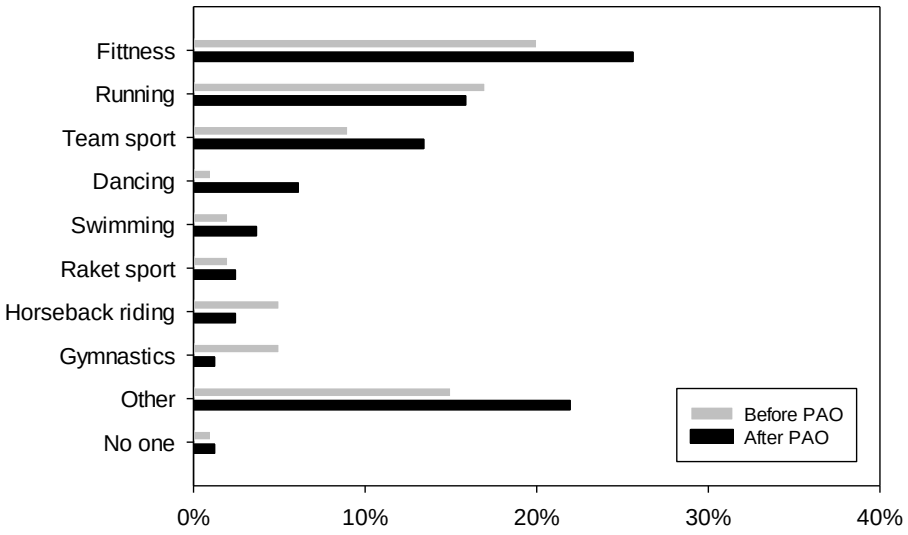


Figure 13. Distribution of preferred physical activities. Other covers different combat and self-defence sports, bicycling and hiking. Abbreviations: PAO (periacetabular osteotomy).

Paper I

The inter-rater reliability of the examination of muscle-tendon pain and assessment of hip muscle strength is reported in Table 5. The agreement between raters on recording each structure as painful or not as part of the standardised muscle-tendon pain examinations ranged from 64-100%.

Table 5. Inter-rater reliability on recording each structure as painful or not as part of the standardised muscle-tendon examinations (n=25)

Test	% Agreement	Kappa coefficient	Interpreted agreement (130)
Iliopsoas palpation LA[a]	84	*0.25*	*Fair*
Iliopsoas palpation DI	64	0.33	Fair
Iliopsoas stretching	79	0.52	Moderate
Abductor palpation	80	0.60	Moderate
Abduction against resistance	80	0.42	Moderate
Adduction palpation	80	0.53	Moderate
Adduction against resistance	84	0.60	Moderate
Hamstring palpation[a]	88	*0.36*	*Fair*
Hamstring against resistance[a]	80	*0.17*	*Slight*
Rectus abdominis palpation DT[b]	100	-	-
Rectus abdominis palpation PT	80	0.55	Moderate
Rectus abdominis against resistance[b]	100	-	-

[a] *Low prevalence, negatively affecting the kappa coefficient.*
[b] *Not possible to calculate kappa coefficient as no tests were positive.*
Abbreviation: LA (lower abdomen), DI (distal to inguinal band), DT (distal tendon), PT (pubic tubercle).
Similar table published in Paper 1, Table 3 in Supplementary data.

The kappa coefficients ranged from 0.17-0.60, defined as slight to moderate agreement. Of note, in five tests the number of positive tests was low (0-4), making the k values questionable. For all muscle strength tests, the ICC values were >0.70 and the standard error of measurement (SEM) was 10-16% across all muscle strength tests (Table 6).

Table 6. Inter-rater reliability of the hip muscle strength assessment reported in mean values in Nm/kg (n=25)

Hip strength	Rater A	Rater B	Mean difference		ICC (95% CI)	SEM	SEM%[a]
	Mean (SD)	Mean (SD)	(95% CI)	p-value			
Flexion	1.1 (0.4)	1.1 (0.3)	0.0 (-0.1 - 0.1)	0.9	0.7 (0.5 - 0.9)	0.2	15.8
Abduction	1.2 (0.4)	1.2 (0.3)	0.0 (-0.0 - 0.1)	0.3	0.9 (0.8 - 1.0)	0.1	9.8
Adduction	1.0 (0.4)	0.9 (0.4)	0.1 (0.0 - 0.1)	0.008	0.9 (0.9 - 1.0)	0.1	10.2
Extension	1.7 (0.6)	1.6 (0.5)	0.1 (-0.1 - 0.2)	0.3	0.8 (0.6 - 0.9)	0.3	15.4

Abbreviations: ICC (intra-class correlation coefficient), SEM (standard error of measurement) in Nm/kg.
[a]SEM divided by the mean average value of rater A and B, multiplied by 100.
Similar table published in Paper 1, Table 4 in Supplementary data.

Muscle-tendon pain

The proportion of patients with muscle-tendon pain in the defined clinical entities was as follows: iliopsoas-related pain 56% (CI 46 - 66), abductor-related pain 42% (CI 32 - 52), adductor-related pain 14% (CI 8 - 22), hamstring-related pain 6% (CI 2 - 13) and rectus abdominis-related pain 4% (CI 1 - 10) (Figure 14).

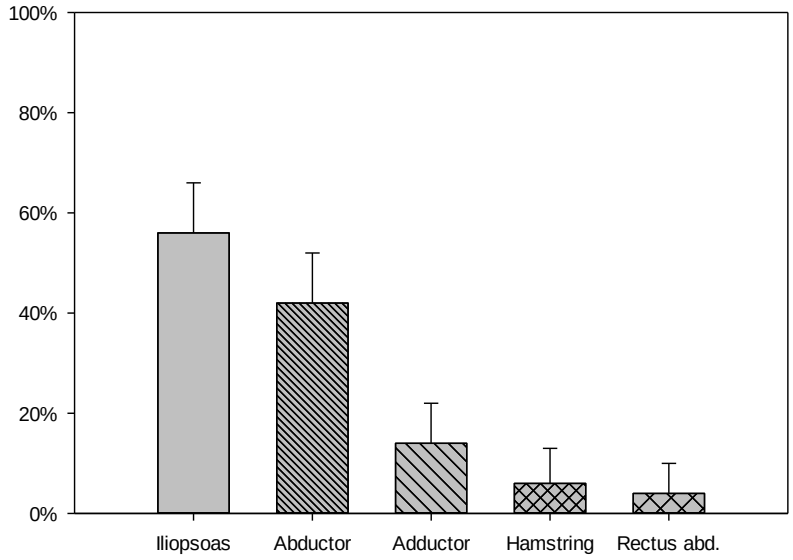


Figure 14. Proportion with 95% CI (error bars) of patients with muscle-tendon pain in defined clinical entities; iliopsoas, abductor, adductor, hamstring, rectus abdominis-related pain. Abbreviation: Abd. (abdominis).

Among the patients, 26% reported no muscle-tendon pain (negative tests in all clinical entities). Opposite this, 38% reported muscle-tendon pain in one clinical entity, 27% reported pain in two clinical entities, 6% reported pain in three clinical entities and 3% reported pain in four clinical entities.

Association between patient-reported outcome and muscle-tendon pain

The analyses showed that there was a statistically significant inverse linear association between HAGOS scores and the sum of painful clinical entities (Table 8). In patients of same age and sex, a difference of one painful clinical entity was associated with a 3-8-point lower HAGOS score across all subscales.

Table 8. Association between each HAGOS subscale and the sum of painful clinical entities (n=100)

	Crude		Adjusted	
Dependent variable	β Coefficient (95% CI)	p-value	β Coefficient (95% CI)	p-value
HAGOS Pain	-6.8 (-10.1 to -3.5)	<0.001	-6.9 (-10.2 to -3.6)	<0.001
HAGOS Symptoms	-6.3 (-9.5 to -3.0)	<0.001	-6.3 (-9.6 to -3.1)	<0.001
HAGOS ADL	-7.2 (-11.4 to -2.9)	0.001	-7.5 (-11.5 to -3.5)	<0.001
HAGOS Sport/recreation	-7.1 (-11.0 to -3.2)	<0.001	-7.4 (-11.2 to -3.6)	<0.001
HAGOS Participation	-5.7 (-10.6 to -0.9)	0.02	-6.1 (-10.9 to -1.3)	0.01
HAGOS Quality of life	-3.2 (-6.0 to -0.4)	0.03	-3.4 (-6.1 to -0.6)	0.02

Abbreviations: ADL (physical function in daily living), HAGOS (Copenhagen Hip and Groin Outcome Score). Adjustment were made for age and sex. Similar table published in Paper 1, Table 3.

Association between hip muscle strength and muscle-tendon pain

Similarly, a statistically significant inverse linear association was observed between isometric hip muscle strength and the sum of painful clinical entities (Table 9). In patients of same age and sex, a difference of one painful clinical entity was associated with 0.11-0.12 Nm/kg lower isometric hip muscle strength, corresponding to 9-11%.

Table 9. Associations between isometric hip muscle strength in four directions and the sum of painful clinical entities (n=100)

	Crude		Adjusted	
Hip muscle strength	β Coefficient (95% CI)	p-value	β Coefficient (95% CI)	p-value
Flexion	-0.12 (-0.23 to -0.02)	0.02	-0.11 (-0.21 to -0.01)	0.04
Abduction	-0.10 (-0.19 to -0.01)	0.02	-0.11 (-0.19 to -0.03)	0.01
Adduction	-0.12 (-0.21 to -0.03)	0.01	-0.12 (-0.20 to -0.03)	0.01
Extension	-0.14 (-0.28 to -0.01)	0.04	-0.12 (-0.25 to 0.01)	0.08

Adjustments were made for age and sex. Similar table published in Paper 1, Table 4.

The mean isometric hip muscle strength ranged from 1.1 Nm/kg to 1.8 Nm/kg across all strength tests (Figure 15).

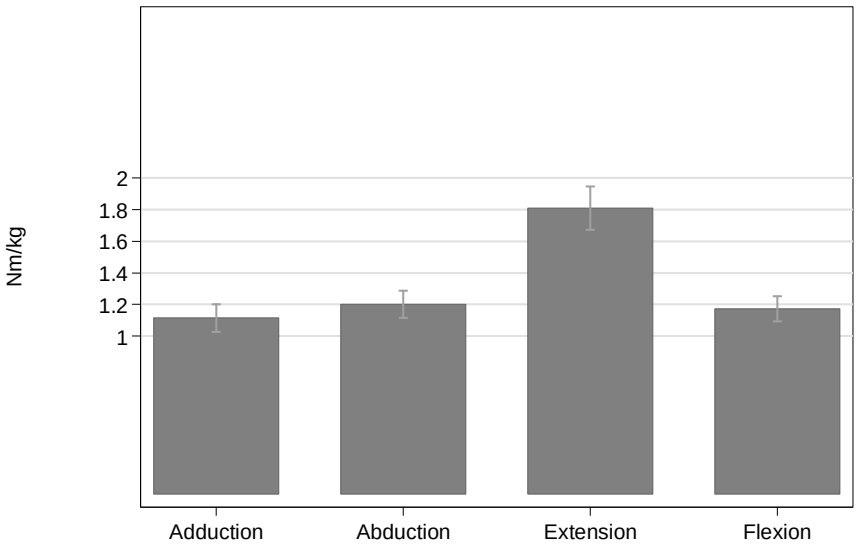


Figure 15. Mean isometric hip muscle strength with 95% CI (error bars).

Paper 2

The intra- and inter-rater reliability of the standardised ultrasonographic examinations are reported in Tables 10 and 11. The reliability analyses tested whether the same rater and two raters agreed on recording the individual structures as abnormal or normal.

Table 10. Intra-rater reliability on recording each structure as abnormal or not as part of the standardised ultrasonographic examinations (n=50)

Tissue	% Agreement	Kappa coefficient	Interpreted agreement (130)
Iliopsoas tendon	82	0.64	Substantial
Glut. med./min. tendons	92	0.70	Substantial
Adductor longus tendon	82	0.64	Substantial
Hamstring tendons	84	0.60	Moderate
Pubic symphysis	90	0.59	Moderate
Acetabular labrum	76	0.51	Moderate

Abbreviations: glut. med./min. (gluteus medius/minimus).
Similar table published in Paper 2, Table 2 in Supplementary material.

The agreement between the first and the second rating ranged from 76-92%, and the corresponding kappa coefficients ranged from 0.51-70, defined as moderate to substantial agreement. The agreement between rater B and the specialised radiologist ranged from 67-84% with kappa coefficients ranging from 0.19-46, defined as slight to moderate agreement.

Table 11. Inter-rater reliability on recording each structure as abnormal or not as part of the standardised ultrasonographic examinations (n=50)

Tissue	% Agreement	Kappa coefficient	Interpreted agreement
Iliopsoas tendon	73	0.46	Moderate
Glut. med./min. tendons	84	0.34	Fair
Adductor longus tendon	64	0.29	Fair
Hamstring tendons	74	0.42	Moderate
Pubic symphysis	68	0.19	Slight
Acetabular labrum	67	0.35	Fair

Abbreviations: glut. med./min. (gluteus medius/minimus).
Similar published in Paper 2, Table 2 in Supplementary material.

Ultrasonographic findings

Abnormal ultrasonographic findings most commonly involved the iliopsoas tendon, the adductor longus tendon and the gluteal medius and minimus tendons, but abnormality of the acetabular labrum was also common (Table 12). Analyses investigating correlations between abnormal ultrasonographic findings and clinically identified pain in the iliopsoas and gluteus medius/minimus tendons proved statistically significant correlations (Table 13). However, no statistically significant correlations were found for the other anatomical structures.

Table 12. Proportion of patients with abnormal ultrasonographic findings (n=100)

Anatomical structure	Transducer placement	% abnormalities (95% CI)
Iliopsoas tendon	Transverse scan with the femoral artery as medial landmark	50 (40 - 60)
Glut. med./min. tendons	Longitudinal and transverse scan with the greater trochanter as landmark	27 (18 - 36)
Adductor longus tendon	Longitudinal scan with the inferior ramus of the pubis as proximal landmark	31 (22 - 40)
Hamstring tendons	Longitudinal and transverse scan with the ischial tuberosity as landmark	15 (8 - 22)
Pubic symphysis	Transverse scan at the symphyseal cleft	9 (3 - 15)
Acetabular labrum	Longitudinal scan parallel to the long axis of the femoral neck	55 (45 - 65)

Abbreviations: glut. (gluteus), med. (medius), min (minimus). Similar table published in Paper 2, Table 4.

Table 13. Correlations between abnormal structures identified with ultrasonography and clinically identified pain in five clinical entities (n=100)

	Iliopsoas tendon US	
Clinical entity	Rho	p-value
Iliopsoas-related pain	0.24	0.02

	Glut. med./min. tendons US	
Clinical entity	Rho	p-value
Abductor-related pain	0.35	<0.001

	Adductor longus tendon US	
Clinical entity	Rho	p-value
Adductor-related pain	0.04	0.68

	Hamstring tendons US	
Clinical entity	Rho	p-value
Hamstring-related pain	0.04	0.69

	Pubic symphysis US	
Clinical entity	Rho	p-value
Rectus abdominis-related pain	0.11	0.26

Abbreviations: glut. med./min. (gluteus medius/minimus), US (ultrasonography). Similar table published in Paper 2, Table 3.

Paper 3

Patient-reported outcome

All subscales of the HAGOS improved statistically significantly from before to 1 year after PAO (Figure 16) with effect sizes ranging from 0.66-1.37 (Table 14). However, a floor effect was present for the HAGOS PA subscale, before PAO (33%) and after PAO (22%). After PAO, a ceiling effect was present for the HAGOS ADL subscale (20%). Moreover, about half of patients experienced no clinically relevant improvements in participation in physical activity and physical function in sport/ recreation after PAO, indicated by HAGOS change scores < MIC (115), and about half of patients reported a HAGOS sports/recreation score ≤70 points after PAO (Figure 17).

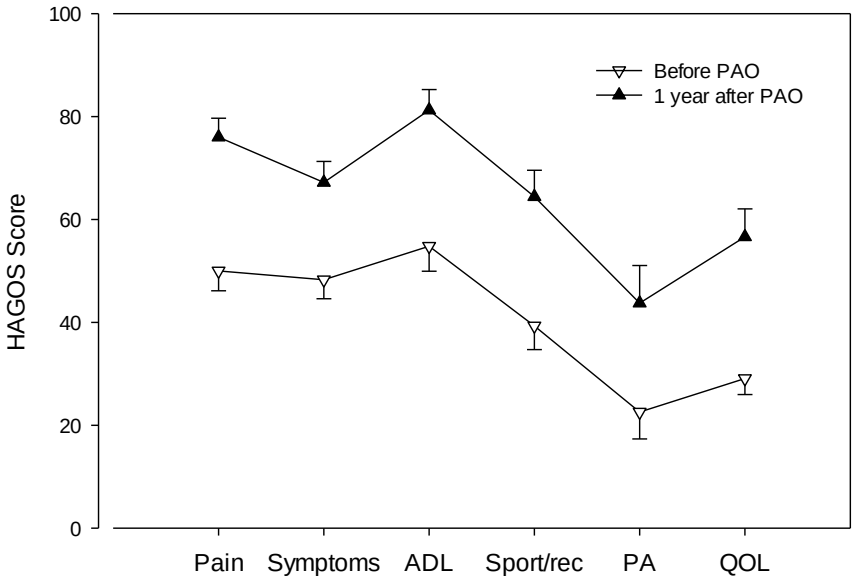


Figure 16. HAGOS mean scores in each subscale with 95% CI (error bars).

Abbreviations: ADL (physical function in daily living), PA (physical activity participation), rec (recreation), PAO (periacetabular osteotomy), HAGOS (Copenhagen Hip and Groin Outcome Score).

Table 14. Change in HAGOS subscales from before to 1 year after periacetabular osteotomy (n=82)

Outcome score	Change score Mean (95% CI)	Effect size Cohen´s d	MIC[1]	% above MIC
HAGOS Pain	26 (22 - 30)	1.37	10	82
HAGOS Symptoms	19 (15 - 23)	0.99	10	73
HAGOS ADL	27 (22 - 31)	1.25	11	72
HAGOS Sport/recreation	25 (20 - 31)	1.02	13	61
HAGOS PA	21 (14 - 28)	0.66	17	48
HAGOS Quality of life	28 (22 - 33)	1.11	13	73

Abbreviations: HAGOS (Copenhagen Hip and Groin Outcome Score), ADL (physical function in daily living), PA (physical activity participation), MIC (minimally important change). [1]MIC reported by Thomee et al. (115) in patients with femoroacetabular impingement syndrome undergoing hip arthroscopy.

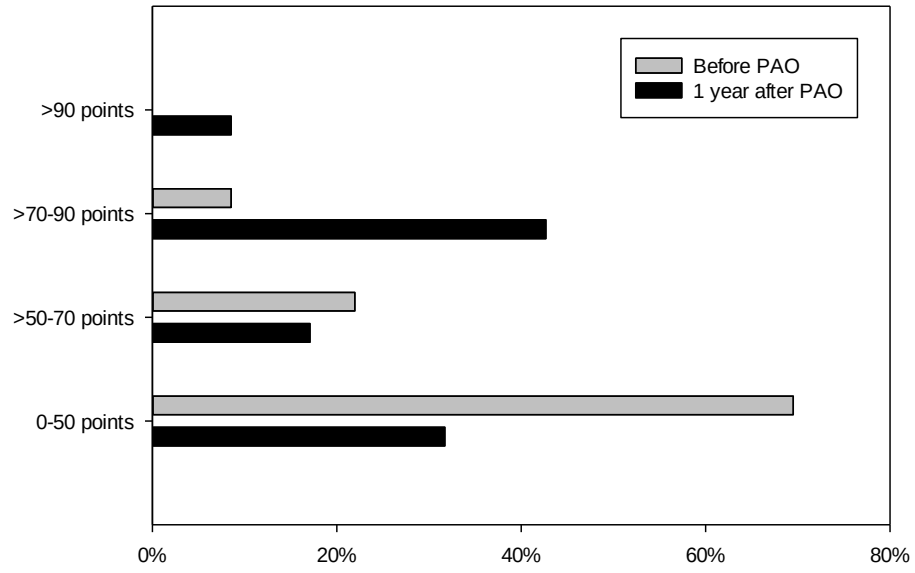


Figure 17. Distribution of patients reporting a HAGOS sport/recreation score within four defined intervals (n=82). Abbreviations: HAGOS (Copenhagen Hip and Groin Outcome Score), PAO (periacetabular osteotomy).

Muscle-tendon pain

Overall, hip muscle-tendon pain decreased statistically significantly 1 year after PAO, corresponding to an effect size of -2.46 (Table 15). In individual entities, only iliopsoas-related and abductor-related pain decreased statistically significantly, while no statistically significantly differences were found for the other clinical entities from before to 1 year after PAO.

Table 15. Change in muscle-tendon pain reported separately for each clinical entity and as the sum of painful clinical entities from before to 1 year after PAO (n=82)

Painful clinical entities	Before PAO	After PAO	Change		Effect size
	% (95% CI)	% (95% CI)	% points (95% CI)	p-value	Cohen´s w
Iliopsoas-related	54 (42 - 65)	22 (14 - 32)	-32 (-46 to -17)	<0.001	-1.96
Abductor-related	37 (26 - 48)	15 (8 - 24)	-22 (-36 to -8)	0.002	-1.12
Adductor-related	12 (6 - 21)	7 (3 - 15)	-5 (-16 to 6)	0.5	-0.11
Hamstring-related	6 (2 - 14)	1 (0 - 7)	-5 (-12 to 2)	0.2	-0.29
Rectus-abdominis-related	4 (0 - 10)	0 (0 to 0)	-4 (-9 to 2)	0.3	-0.33
Patients with minimum 1 positive clinical entity	74 (64 to 83)	35 (25 - 47)	-39 (-54 to -24)	<0.001	-2.46

Abbreviations: PAO (periacetabular osteotomy). Similar table published in Paper 3, Table 3.

Association between subscales of the HAGOS and muscle-tendon pain

Besides HAGOS PA, a statistically significant inverse linear association was observed between changes across all subscales of the HAGOS and change in the sum of painful clinical entities from before to 1 year after PAO (Table 16). In patients of same age, sex and pre- and postsurgical CE angle, a decrease of one painful clinical entity was associated with an increase of 5-8 HAGOS points across all subscales, besides HAGOS PA.

Table 16. Association between change in each subscale of the HAGOS and change in the sum of painful clinical entities from before to 1 year after periacetabular osteotomy (n=82)

	Crude		Adjusted*	
Outcomes	β Coefficient (95% CI)	p-value	β Coefficient (95% CI)	p-value
HAGOS Pain	-4.7 (-8.5 to -0.9)	0.02	-4.7 (-8.4 to -1.0)	0.01
HAGOS Symptoms	-4.8 (-8.6 to -1.0)	0.02	-4.7 (-8.6 to -0.9)	0.02
HAGOS ADL	-6.1 (-10 to -1.9)	0.005	-6.2 (-10 to -2.1)	0.004
HAGOS Sport/recreation	-5.9 (-11 to -1.0)	0.02	-6.0 (-11 to -0.9)	0.02
HAGOS PA	-1.2 (-7.9 to 5.5)	0.7	-1.2 (-7.9 to 5.6)	0.7
HAGOS Quality of life	-8.2 (-13 to -3.3)	0.001	-8.2 (-13 to -3.3)	0.001

*Adjusted for pre- and postsurgical Centre-edge angles, age and sex. Abbreviations: HAGOS (Copenhagen Hip and Groin Outcome Score), ADL (physical function in daily living), PA (preferred physical activity participation). Similar table published in Paper 3, Table 4.

Paper 4

Accelerometer-based physical activity

The accelerometer-based physical activity was measured during median 7 days (IQR 3-8); in six patients, physical activity was measured during less than 5 days. From

before to 1 year after PAO, changes ranged from -0.66% (CI -2.2 – 0.89) to 1.6% (CI -0.89 – 4.0) across all intensity levels (from very low to high intensity) (Table 17). Furthermore, patients were sedentary in about 75% of their time, while only about 5% of their time was spent on activities at high intensity level (Figure 18). A general physical activity profile, measured before and 1 year after PAO, is reported in Table 18 in patients with full accelerometer-based data.

Table 17. Change in accelerometer-based physical activity at four intensity levels from before to 1 year after surgery (n=77)

Outcomes	Change (95% CI)	p-value	Effect size
Change in percent of time			
Very low intensity	1.6 (-0.89 – 4.0)	0.2	0.14
Low intensity	-0.66 (-2.2 - 0.89)	0.4	-0.096
Moderate intensity	-0.40 (-1.1 - 0.31)	0.3	-0.13
High intensity	-0.32 (-0.77 - 0.13)	0.2	-0.16

Table values reported in Paper 4, Table 2.

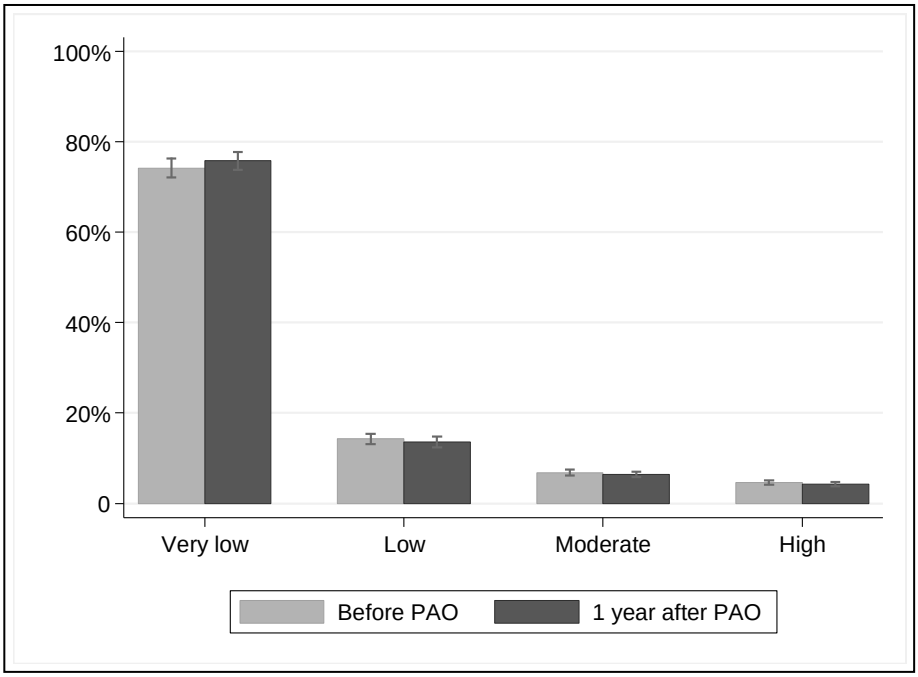


Figure 18. Percentage of time with 95% CI (error bars) at four intensity levels measured objectively before and 1 year after periacetabular osteotomy (n=77). Abbreviations: PAO (periacetabular osteotomy).

Patient-reported physical activity

Patient-reported participation in physical activities increased statistically significantly with 22 (CI 14 – 29) HAGOS PA points, corresponding to an effect size of 0.67 (Figure 19).

Table 18. General physical activity profile measured with accelerometer-based sensors before and 1 year after periacetabular osteotomy

	Before (n=97)		1 year after PAO (n=78)	
Outcomes	Median	95% CI	Median	95% CI
Cadence as steps/min	99	98 - 100	100	98 - 102
Numbers of events/day				
Total steps	7404	6645 - 8418	7925	6637 - 8612
Steps (level)	6923	6192 - 7709	7322	6081 - 8217
Steps (up)	266	194 - 403	235	171 - 313
Steps (down)	155	134 - 183	146	123 - 169
Time in hours/day				
Total wear time	14	14 - 15	15	14 - 15
Time as percent				
Resting	64	61 - 68	63	59 - 66
Standing	23	22 - 27	26	23 - 27
Walking	11.2	9.9 - 12.5	11.0	9.3 - 12.5
Cycling	0.15	0.063 - 0.33	0.084	0.046 - 0.18
Running	0.011	0.0042 - 0.020	0.0078	0.0040 - 0.025

Abbreviations: PAO (periacetabular osteotomy). Similar table published in paper 4, Table 3.

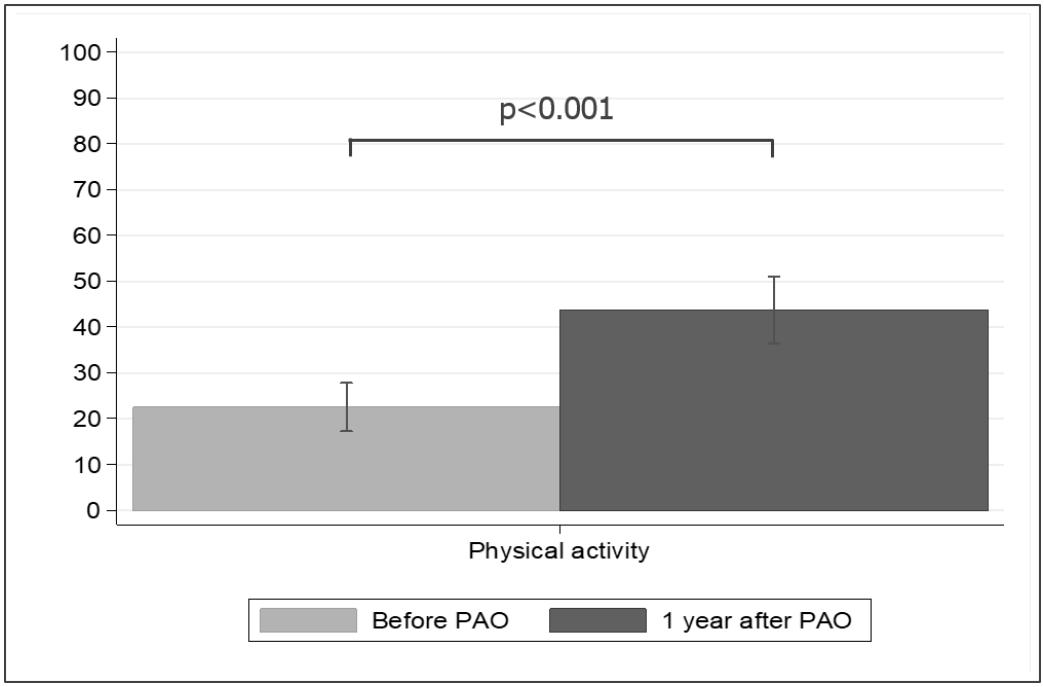


Figure 19. Mean values with 95% CI (error bars) measured with the Copenhagen Hip and Groin Outcome Score using the subscale participation in physical activity (0-100 points). Abbreviations: PAO (periacetabular osteotomy).

Association between accelerometer-based and patients-reported physical activity

Change in accelerometer-based physical activity was not statistically significantly associated with change in the HAGOS PA subscale as illustrated in Figure 20. The associations correspond to a percentage change in physical activity of only 0.022% for a change in 10 HAGOS PA points, covering very low, low, moderate and high intensity from before to 1 year after PAO (Table 19).

Table 19. Association between change in accelerometer-based physical activity and change in the HAGOS PA subscale from before to 1 year after periacetabular osteotomy (n=77)

Outcomes	β Coefficient (95% CI)	p-value
Very low intensity	-0.00011 (-0.00087 -0.00065)	0.8
Low intensity	-0.000022 (-0.00050 - 0.00046)	0.9
Moderate intensity	0.000044 (-0.00018 - 0.00027)	0.7
High intensity	0.000072 (-0.000066 - 0.00021)	0.3

Abbreviations: HAGOS (Copenhagen Hip and Groin Outcome Score), PA (preferred physical activity participation).

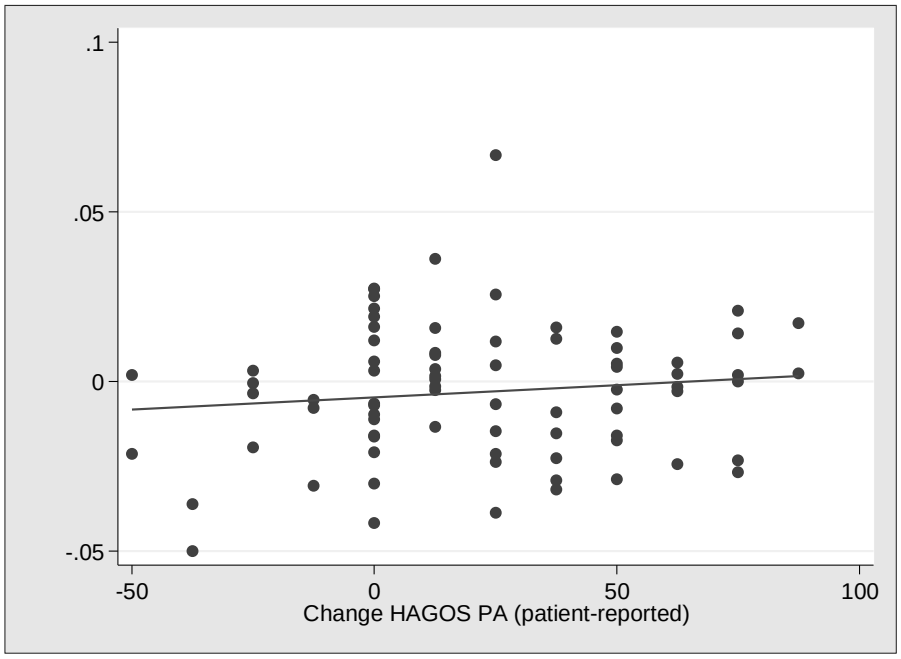


Figure 20. The prediction of change in accelerometer-based physical activity at high intensity as a linear function of change in the HAGOS PA subscale from before to 1 year after periacetabular osteotomy. Abbreviations: HAGOS (Copenhagen Hip and Groin Outcome Score), PA (physical activity). Similar figure published in Paper 4, Figure 2.

8. Discussion

Key findings

The overall aim of this PhD dissertation was to investigate muscle-tendon pain and structural abnormalities and outcome of hip-preserving surgery in patients with hip dysplasia. The overall results showed that muscle-tendon pain and structural abnormalities were common in hip dysplasia, and that muscle-tendon pain was negatively related to PRO and isometric hip muscle strength. Moreover, PRO improved after surgery; however, accelerometer-based physical activity did not change from before to 1 year after hip-preserving surgery.

Prior to PAO, muscle-tendon pain and abnormal ultrasonographic findings were common and primarily affected the iliopsoas and hip abductor muscles. The subscales of the HAGOS were negatively related to muscle-tendon pain and hip muscle strength. One year after PAO, patients reported medium to very high improvements across all subscales of the HAGOS, and improvements were related to decreased muscle-tendon pain. Nevertheless, about one-third of patients still experienced muscle-tendon pain 1 year after PAO, while about half of patients experienced no clinically relevant improvements in participation in physical activity and physical function in sport/recreation after PAO, indicated by HAGOS change scores < MIC for each subscale (115); and they reported a HAGOS sports/recreation score ≤70 points after PAO. Noteworthy, the HAGOS PA score was not related to change in muscle-tendon pain despite statistically significant improvements, and the improvement in the HAGOS PA did not manifest itself in any change in accelerometer-based physical activity either at low-intensity or high-intensity levels.

Comparison with the existing literature

Study results will be compared to the existing literature and the body of evidence will be evaluated in accordance with the Method Guidelines for Cochrane Musculoskeletal Group Systematic Reviews and Metaanalyses (131).

Muscle-tendon pain in the hip and groin

Hip dysplasia has been described as a cause of increased micro-instability of the hip joint. Especially the iliopsoas, gluteal muscles and hip adductors are considered important dynamic stabilisers in the dysplastic hip joint (132,133). Even so, Papers 1-3 are the first papers systematically reporting muscle-tendon pain and structural abnormalities in hip dysplasia. Clinically identified muscle-tendon pain has been described in five studies (47,49,50,55,134), and these studies are tabulated in Table 20. Among athletes, adductor-related pain was the most common painful clinical entity followed by iliopsoas- and abdominal/inguinal-related pain (47,49,50). This fit well with the primary sports of the athletes, comprising kicking and change of directions

which involve high tensile and compressive loads to the adductors (50). However, the combined body of evidence to support this relationship is low. Adductor-related pain was less common in our patients (1,3), which makes good sense, as the patients' preferred sports were far more heterogeneous (4).

Table 20. Studies reporting clinically identified muscle-tendon pain in the hip and groin

Study	Design	Population	Methods	Results
Hölmich (2007) (47)	Cross-sectional study	207 athletes (196 males) with longstanding groin pain, age 26 (16–48).	Pain examined with the clinical entity approach (palpation, testing against resistance, flexibility, and/or cough impulse).	119 (58%) patients had adductor-related pain and 73 (35%) iliopsoas-related pain.
Woodley et al. (2008) (55)	Cross-sectional study	40 patients (3 males) with lateral hip pain, age 54 (33–78).	Clinical examinations (palpation GT, FABER test, Ober´s test and resisted hip abduction).	36 (90%) patients reported pain in gluteal muscles and tendons, where GT palpation identified 32/40 symptomatic hips.
Hölmich et al. (2014) (49)	Cohort study	998 sub-elite male soccer players during a 10-month season, age 25 (SD 5).	Pain examined with the clinical entity approach (palpation, testing against resistance, flexibility, and/or cough impulse).	30 (51%) patients had adductor-related pain, 11 (19%) abdominal-related pain, and 18 (30%) iliopsoas-related pain.
Adib et al. (2018) (134)	Case series	252 patients (94 males, 37%) undergoing hip arthroscopy, age 22 (10–57).	Clinical examination (pain with resisted hip flexion in seated position OR pain during psoas stretch test).	60 (24%) patients had post-operative iliopsoas tendinopathy.
Taylor et al. (2018) (50)	Cross-sectional study	100 athletes (98 males) with acute (n=31) and gradual onset (n=68) of groin pain, age 28 (15–52).	Clinical examinations, using Doha Agreements (palpation, testing against resistance, stretching, and/or Valsalva/cough.	61% patients had adductor-related pain, 40% inguinal-related pain and 31% iliopsoas-related pain.

Abbreviations: GT (greater trochantor), FABER (flexion/abduction/external rotation).

In patients with lateral hip pain, pain in gluteal muscles and tendons has been reported in 90% of the patients (55). This result is only supported by one low-quality study and the evidence is therefore considered very low. Nevertheless, gluteal pathology has also been identified with MRI and ultrasonography in patients with lateral hip pain (55,135), suggesting that gluteal pathology could be a possible extra-articular source of pain in patients with lateral hip pain. Iliopsoas tendinopathy has been found in 24% of patients undergoing hip arthroscopy due to labral lesions (134). Again, the evidence to support iliopsoas tendinopathy rests on a single case series study, and the evidence is therefore considered very low. In patients with lateral hip pain, hip abductor deficit and increased hip adduction during walking were

associated with lateral hip pain (136,137), where iliopsoas tendinopathy in patients with labral lesions might be explained by the anatomical proximity of the acetabular labrum and the iliopsoas tendon (44). In this study (1,3), pain in the gluteal and iliopsoas muscles and tendons was also frequent in patients with hip dysplasia, and similar mechanisms as those described above may be evident. Coexisting intra-articular pathology has been reported in the above-mentioned study populations. In athletes with long-standing adductor-related groin pain, radiological signs of FAIS were found in 94% (138). Hip osteoarthritis was found in 20% of patients with lateral hip pain (55), while 92% of patients undergoing hip arthroscopy presented with bone morphology, either hip dysplasia or FAIS (134). The above-mentioned results support our findings since our patients all had an intra-articular joint disease and coexisting muscle-tendon pain (1,3).

Noteworthy, about 20% of our patients reported severe and worst imaginable back pain, and this pain did not improve considerably after PAO. Moreover, when applying the springing palpation test to the spine and sacrum, we found that 10-15% of the patients reported known hip pain. However, this pain improved after PAO and affected 3-4% of the patients after PAO. These findings indicate a possible relationship between hip dysplasia and back pain. However, the role of back pain in hip dysplasia needs to be assessed further in future prospective studies.

Abnormal ultrasonographic findings in the hip and groin

Abnormal ultrasonographic findings have been reported in two studies (52,135) (Table 21). In patients with longstanding groin pain, muscle-tendon abnormalities were most commonly located to the tendons of the hamstrings, the hip adductors, the rectus femoris and the gluteal muscles (52). In most cases (28/36), abnormal ultrasonographic findings were located to the painful anatomical regions. However, the body of evidence to support muscle-tendon abnormalities in these patients is very low. Abnormal findings have also been reported among patients with lateral hip pain, most commonly located to the gluteal tendons and the iliotibial band. Noteworthy, only 8% of the patients had isolated trochanteric bursitis. Again, studies are lacking, and evidence to support findings in these patients is considered very low (131).

Patient-reported outcome after PAO

Several studies have shown clinically relevant improvements in PRO after PAO, using both generic and disease-specific PROMs. In Paper 3, outcome 1 year after PAO was investigated with the HAGOS; and as mentioned before, HAGOS was originally developed from the HOOS (139) and three items from the HOS (140). The HAGOS, HOOS and HOS report outcome in individual subscales, covering body function and structure, activity and participation according to the International Classification of Functioning, Disability and Health (ICF) (113). In patients with hip

Table 21. Studies reporting abnormal ultrasonographic findings in hip and/or groin disorders

Study	Design	Population	Methods	Results
Kälebo et al. (1992) (52)	Cross-sectional study	36 patients (28 males) with longstanding groin pain, age 27 (14–57).	Ultrasonographic examinations of the tendons of the hamstrings, adductors, rectus femoris, gluteal muscles and rectus abdominis muscles.	Abnormal findings primarily involving the hamstring tendons followed by the tendons of the adductors, rectus femoris, gluteal muscles and rectus abdominis muscles.
Long et al. (2013) (135)	Cross-sectional study	877 patients (275 males) with lateral hip pain, age 54 (15-87).	Ultrasonographic examinations. Retrospective review of gluteal tendon abnormalities, iliotibial band abnormalities and trochanteric bursitis.	438 (50%) patients had gluteal tendinopathy, 250 (29%) thickened iliotibial band, 177 (20%) trochanteric bursitis and only 70 (8%) isolated bursitis.

dysplasia, PRO after PAO using either the HAGOS, HOOS or HOS are reported in seven studies (Table 22). HAGOS was used as PROM in the studies by Jacobsen et al. (97) and Mechlenburg et al. (77), reporting HAGOS change scores similar to those reported in Paper 3. However, both the pre- and postsurgical HAGOS scores are higher in these studies than reported in this study (3), indicating that the patients may experience more pain and disability. In the previous studies (77,97), 32 and 41 patients were included over a period of 10 and 15 months, respectively. Compared to these study populations, this study included 100 patients over a period of 16 months (1–4). These differences could indicate that patients included in the previous studies represent a more selective study population than the patients in this study. In this study (3), outcomes were collected at two time points, while outcomes were collected at three time points in the previous studies (77,97). This may explain why patients with lower PRO may have been harder to recruit in the two previous studies. Moreover, one inclusion criterion also differed between this study (1–4) and the study by Mechlenburg et al. (77). In the latter study, only patients living less than 70 km away from the hospital were included (i.e. patients living close to a large Danish city), while all Danish patients with hip dysplasia - scheduled for PAO in Aarhus - were invited to participate in this study (1–4). In five studies, PRO after PAO was investigated with either the HOOS (16,141–143) or the HOS (144). Comparing the pre- and postsurgical HOOS and/or HOS scores with the postsurgical HAGOS scores reported in this study (3), we found that the HOOS and/or HOS scores were generally higher, which makes sense since the HAGOS covers more demanding physical, sport and recreational tasks (113). However, the body of evidence to support the above-mentioned findings is considered low as the majority of the studies are case series studies.

Table 22. Studies reporting patient-reported outcome of the PAO

Study	Patients	Follow-up	PROM	Results		Effect size
				Mean pre PAO	Mean post PAO	
Jacobsen et al. (2014) (97) *Case series*	29 patients. Age 34 (18-53).	1 yr.	HAGOS	Pain[1]: 50 (20-95) Sym[1]: 50 (21-96) ADL[1]: 60 (5-100) Sp/rec[1]: 38 (3-91) PA[1]: 25 (0–100) QOL[1]: 40 (0–80)	Pain[1]: 78 (20-100) Sym[1]: 71 (25-93) ADL[1]: 90 (30-100) Sp/rec[1]: 63 (6-100) PA[1]: 50 (0-100) QOL[1]: 65 (10-100)	NC
Mechlenburg et al. (2018) (77) *Case series*	41 patients. Age 29 (SD 9).	1 yr.	HAGOS	Pain[2]: 57 (46-68) Sym[2]: 53 (43-67) ADL[2]: 62 (53-78) Sp/rec[2]: 43 (32-66) PA[2]: 12 (0-38) QOL[2]: 35 (26-45)	Pain[2]: 75 (65-92) Sym[2]: 72 (61-86) ADL[2]: 90 (70-95) Sp/rec[2]: 67 (50-88) PA[2]: 37 (13-76) QOL[2]: 57 (40-80)	NC
Bogunovic et al. (2014) (141) *Case series*	36 patients. Age 25 (15-45). Pre UCLA score ≥7.	1.5-5 yr.	HOOS	Pain: 61 Sym: 64 ADL: 73 Sp/rec: 48 QOL: 38	Pain: 86 Sym: 85 ADL: 94 Sp/rec: 80 QOL: 71	NC
Clohisy et al. (2017) (16) *Case series*	950 patients. Age 25 (10-54).	3 (2-5) yr.	HOOS	Pain: 56 Sym: 59 ADL: 68 Sp/rec: 46 QOL: 35	Pain: 84 Sym: 79 ADL: 90 Sp/rec: 77 QOL: 70	Pain: 1.3 Sym: 1.0 ADL: 1.0 Sp/rec: 1.0 QOL: 1.3
Maeckelbergh et al. (2018) (142) *Case series*	42 patients. Age 27 (14-50).	3 (1-5) yr.	HOOS	Pain[3]: 41 (0-93) Sym[3]: 39 (5-80) ADL[3]: 53 (0-99) Sp/rec[3]: 28 (0-81) QOL[3]: 34 (0-81)	Pain[3]: 84 (48-100) Sym[3]: 79 (40-100) ADL[3]: 89 (57-100) Sp/rec[3]: 74 (19-100) QOL[3]: 73 (31-100)	NC
Boje and Caspersen et al. (2019) (143) *Case series*	321 patients. Age 31 (22-39).	1 yr.	HOOS	Pain: 53 (SD 18) Sym: 52 (SD 20) ADL: 64 (SD 20) Sp/rec: 43 (SD 23) QOL: 33 (SD 16)	Pain: 78 (SD 20) Sym: 71 (SD 22) ADL: 84 (SD 18) Sp/rec: 69 (SD 25) QOL: 59 (SD 25)	Pain: 1.1 Sym: 0.8 ADL: 1.0 Sp/rec: 0.9 QOL: 1.0
Ricciardi et al. (2017) (144) *Cohort study*	*Mild HD* n=27. Age 25 (15-43). *Severe HD* n=50. Age 23 (12-41).	1 yr.	HOS	*Mild HD* ADL: 72 (SD 13) Sport: 53 (SD 21) *Severe HD* ADL: 72 (SD 14) Sport: 53 (SD 20)	*Mild HD* ADL 93 (SD 8) Sport 82 (SD 19) *Severe HD* ADL: 92 (SD 12) Sport: 85 (SD 20)	*Mild HD* ADL: 1.4 Sport: 1.0 *Severe HD* ADL: 1.1 Sport: 1.1

Abbreviations: PAO (periacetabular osteotomy), PROM (patient-reported outcome measure), HAGOS (Copenhagen Hip and Groin Outcome Score), sym (symptoms), ADL (physical function in daily living), sp/rec (sport/recreation), QOL (quality of life), PA (participation in preferred physical activities), HOOS (Hip Osteoarthritis Outcome Score), UCLA (University of California Los Angeles activity score), HOS (Hip Outcome Score), HD (hip dysplasia). [1]Median (range), [2]Median (interquartile range), [3]Mean (range), NC (not calculated), SD of chance score was not reported or could not be calculated (e.g. no reported standard error or 95% CI).

Noteworthy, in this study (3), 20% of patients reported the highest possible outcome for the HAGOS ADL subscale after PAO, indicating a ceiling effect of this subscale. In line with this finding, Boje and Caspersen et al. (143) reported a ceiling effect for the HOOS ADL subscale. This suggest the presence of some limitations of the HAGOS ADL subscale despite the fact that the HAGOS was developed to measure PRO in young and active subjects. Similarly, 33% of our patients reported the lowest possible outcome for the HAGOS PA subscale before PAO, and 22% reported the lowest outcome 1 year after PAO, indicating a considerable floor effect for the HAGOS PA subscale (3). Floor and ceiling effects for the HAGOS ADL and PA subscales have also been reported in patients with hip and/or groin pain, in patient undergoing hip arthroscopy and in patients with FAIS (101,114,115). This suggests that certain limitations should be considered when measuring PRO with the HAGOS PA and ADL subscales.

The iHOT-12 and iHOT-33 are also recommended as PROMs in young-to-middle-aged patients with hip pain (101,116–118). However, the iHOT-12 and iHOT-33 report outcome in one composite score. The latter is opposed to the HAGOS, making comparison more difficult. However, Ricciardi et al. (144) reported outcome of the PAO using the iHOT-33 in 77 patients grouped as having mild or severe hip dysplasia. Patients improved from 35 and 36 point before PAO to 79 and 78 points 1 year after PAO, corresponding to effect sizes of 1.8 and 1.4, respectively. These effect sizes are higher than the effect sizes reported in this study (3). However, the effect size for the HAGOS pain subscale was 1.4 (3), which is similar to the results reported in the study using the iHOT-33 in patients with severe hip dysplasia.

Accelerometer-based physical activity

Contrary to the large improvements in all subscales of the HAGOS (3), no changes in accelerometer-based physical activity were found after PAO in this study (4). Changes in accelerometer- and pedometer-based physical activity have been reported in patients with hip dysplasia, hip osteoarthritis and FAIS (77,103,145–150) (Table 23). Clinically relevant improvements were reported in three studies (149,151,152) measuring changes in daily steps, daily strides and accelerometer-based physical activity from before to after hip or knee arthroplasty. However, in one study (151), physical activity was measured during 2 days, which raises questions concerning the validity of the results since physical activity should be measured over at least 3 days to represent daily physical activity (153). Moreover, in another study, 40% of patients were lost to follow-up, and these patients had other characteristics than the patients who completed the follow-up (152). Their baseline PRO were higher, and they took more steps than patients completing the follow-up (152). This suggests that the observed changes could have been overestimated. Of note, in the Horsens-Aarhus Femoro-Acetabular Impingement (HAFAI) study (103), minor changes in resting and standing were reported after hip arthroscopy.

Table 23. Accelerometer-based physical activity after surgery in subjects with hip and/or groin pain

Study	Design	Population	Follow-up	Outcomes	Results
De Groot et al. (2008) (151)	Case series	80 patients scheduled for THA or TKA. Age 62 (SD 11).	0.5 yr.	2 days daily PA with 3 accelerometer-based activity sensors. PRO by WOMAC, HHS, KSS and SF-36 PASIPD.	%PA improved for total group by 0.7%, p=0.03. STS improved for total group, p<0.001). PRO improved, p<0.001.
Vissers et al. (2011) (145)	Case series	30 patients scheduled for THA. Age 60 (SD 13). 30 references. Age 60 (SD 13).	0.5 yr.	Daily PA by 3 accelerometer-based activity sensors.	No changes in overall PA, in %walking, walking periods or chair rises. References did more overall PA, %walking and walking bouts, p<0.05.
Fujita et al. (2013) (152)	Case series	38 patients scheduled for THA. Age 61 (43-82). 38 references. Age 62 (41-83).	1 yr.	7 days PA with a pedometers. PRO by SF-8 and OHS.	Steps/day improved, 4,632 (SD 2,246) to 6,163 (SD 2,410), p<0.001. Time in light/moderate PA increased (p<0.01). At 12 mo., references did more vigorous PA than patients (p=0.003). PRO improved, p<0.001.
Lin et al. (2013) (146)	Case series	12 adult females scheduled for THA. Age 58 (SD 4).	0.5 yr.	7 days PA with RT3 accelerometer. PRO with HHS.	No changes in PA. HHS improved, p=0.03.
Harding et al. (2014) (147)	Case series	44 patients scheduled for THA (n=19) or TKA (n=25). Age 69 (SD 8).	0.5 yr.	7 days PA with ActiGraph GT1M accelerometer. PRO with NRS, OHS, SF-12 and UCLA score.	No changes in daily PA, 149 (SD 133) versus 161 (SD 86) cpm, p=0.12. PRO improved, p<0.01.
Jeldi et al. (2017) (148)	Case series	30 patients scheduled for THA. Age 67 (50-82).	1 yr.	6 days PA by activPAL3. PRO with HHS, OHS.	No change in daily PA. PRO improved (p<0.01).
Höll et al. (2018) (149)	Case series	46 patients scheduled for THA. Age 63 (SD 11).	0.25 yr.	7 days daily strides by a Stepwatch activity monitor PRO by HHS and WOMAC.	Strides/day and strides/hour improved by 18 and 15% (p<0.05). PRO improved (p<0.01).

Mechlenburg et al. (2018) (77)	Case series	23 patients with HD undergoing PAO. Age 29 (SD 9).	1 yr.	5 days PA by 3D accelerometers. PRO with HAGOS.	No changes in sitting, standing, walking and running time or STS transfers or cadence from 4 mo. to 12 mo. after PAO. Less cycling at 12 mo. compared to 4 mo., p=0.04.
Kierkegaard et al. 2019 (103)	Case series	60 patients with FAIS scheduled for hip arthroscopy. Age 36 (SD 9). 30 references. Age 36 (SD 9).	1 yr.	5 days PA by a tri-axial accelerometer. PRO with HAGOS.	No change in overall PA. Patients rested less (p=0.01) and stood more (p=0.02) after surgery. References were bicycling and running more (p<0.01). All HAGOS subscales improved (p<0.001).
Birch et al. 2020 (150)	Case series	37 patients scheduled for THA Age 75 (70 – 82). 29 age-matched references.	1 yr.	7 days PA by a tri-axial accelerometer. PRO with OHS.	No change in time, frequency or intensity of PA after THA. 12 mo. after THA, no differences in walking, standing, sitting or cycling between references and patients. At 12 mo., patients did fewer sit-to-stand transfers per hour than references, 0.2 (95%CI -0.8 - 0.4).

Abbreviations: THA (total hip arthroplasty), TKA (total knee arthroplasty), PAO (periacetabular osteotomy), PA (physical activity), PRO (patient-reported outcome), WOMAC (Western Ontario and McMaster Universities Arthritis Index), HHS (Harris Hip Score), KSS (Knee Society Score), SF (Short Form health survey), PASIPD (Physical Activity Scale for Individuals with Physical Disabilities), STS (sit-to-stand), OHS (Oxford Hip Score), NRS (numeric rating scale), UCLA (University of California–Los Angeles activity score), cpm (counts per minute), HD (hip dysplasia), FAIS (femoroacetabular impingement syndrome).

These changes are believed to be small and considered less clinically relevant. Therefore, only Höll et al. (149) seem to show valid improvements in daily strides 3 months after surgery in patients undergoing hip arthroplasty (149). Hence, a low level of evidence supports that no changes and/or only minor changes in accelerometer-based physical activity can be expected after hip surgery. This is supported by a systematic review from 2017, concluding "There is no statistically significant difference in physical activity levels before and up to one year after unilateral primary total hip replacement" (102). Contrary to this, large improvements can be expected if physical activity is patient-reported.

Noteworthy, in four studies (103,145,150,152), accelerometer-based physical activity was compared between patients and pain-free references. Across studies in patients

undergoing arthroplasty (145,150,152), references performed more overall physical activity, walked more, performed more sit-to-stand transfers per hour and performed more vigorous accelerometer-based physical activity than patients at 12-month follow-up. In the HAFAI study (103), references ran and bicycled more than patients undergoing hip arthroscopy at 12-month follow-up. In summary, the above findings indicate that patients do not reach the references level of daily physical activity. However, the references from the HAFAI study were volunteers responding to an advertisements at Aarhus University and Aarhus University Hospital (103). These volunteers may share different characteristics than the rest of the healthy Danish population. They might volunteer because they are more health conscious and therefore more active, which may lead to overestimation of the differences between patients and references. However, Vissers et al. (145) and Birch et al. (150) found that references did more overall physical activity and did more sit-to-stand transfers per hour than patients. The references were included via an existing database (145) and via the Danish Central Person Register (CPR) (150), which is probably less impacted by healthy volunteer bias than the references in the HAFAI study (103). Hence, differences between patients and references probably do exist.

Interestingly, if the physical activity profile of our patients is compared to the physical activity profile of the references from the HAFAI study, we see that our patients also did more resting and less running 1 year after PAO (4,103). This comparison indicates that patients with FAIS and patients with hip dysplasia have a similar level of physical activity 1 year after surgery. This is supported by Harris-Hayes et al. (21), reporting no differences in daily strides between patients with hip dysplasia and FAIS.

Possible mechanism and explanations

Muscle-tendon pain and structural abnormalities in hip dysplasia

The causal relationship between hip dysplasia and muscle-tendon pathology is difficult to investigate and remains unanswered by our papers (1–3). However, the findings indicate a possible mechanism. In hip dysplasia, the acetabular weight-bearing area is reduced with reduced acetabular coverage of the femoral head (154). The reduced weight bearing area allows more anterior, superior and lateral migration of the femoral head, and patients with dysplastic hips therefore have to rely more on extra-articular structures (i.e. acetabular labrum, ligaments and muscles) (133). An example of this has recently been reported, showing an association between the degree of acetabular coverage and the length of the acetabular labrum (25). However, in another study, it was demonstrated that the level of pain was not related to the degree of labral lesions (30), which suggests that other structures may also compensate and cause pain.

Reduced acetabular coverage in hip dysplasia has been associated with an increased role of the hip abductors (34,41,42). In hip dysplasia, the hip joint centre lateralizes secondary to the dysplastic acetabular coverage. This leads to reduced moment arms of the hip abductors (42), which implies that they have to generate higher medially directed forces to stabilise the femoral head in the socket (34,42). Hence, the hip abductors are prone to pain and structural abnormalities secondary to compensatory loading. Likewise, the iliopsoas muscle-tendon unit is located directly anterior to the hip joint (44). With reduced anterior acetabular coverage, the iliopsoas may therefore also be prone to pain and structural abnormalities secondary to compensatory loading, as shown for the hip abductors. Moreover, the iliopsoas muscle/tendon unit may also be prone to pain and structural abnormalities due to increased mechanical compression secondary to labral lesions and hypertrophy, which may explain why patients with hip dysplasia walk with reduced hip extension and a lower hip flexor moment (33).

Interestingly, after PAO, the hip joint centre is translated medially, which improves the anterior and lateral acetabular coverage of the femoral head (155) and the biomechanical conditions. Hypothetically, the PAO should reduce compensatory loading of the hip abductors and iliopsoas, leading to decreased muscle-tendon pain after PAO. The latter was confirmed in Paper 3, showing significant decreases of muscle-tendon pain in the iliopsoas and hip abductors. Additionally, the results of Paper 3 showed an association between improved PRO and decreased muscle-tendon pain, indicating a relationship between hip dysplasia, muscle-tendon pain and PRO.

The results of Papers 1-3 do not answer any questions about causality. However, the results do suggest that reduced acetabular coverage in hip dysplasia is related to pain and structural abnormalities primarily involving the iliopsoas and hip abductors. However, it remains unanswered if acetabular coverage is responsible for pain and structural abnormalities in hip dysplasia. The opposite pathway, where muscle-tendon pain and abnormalities cause bony morphology, seems unlikely and further support that acetabular coverage may partially be responsible for muscle-tendon pain in hip dysplasia.

Association between patient-reported outcome and muscle-tendon pain

In Paper 1 and 3, statistically significant associations between muscle-tendon pain and HAGOS subscales were reported. Before PAO, a difference of one painful clinical entity was associated with a 3-8 points lower HAGOS score across all subscales (1). Similarly, 1 year after PAO, a decrease of one painful clinical entity was associated with an increase of 5-8 HAGOS points across all subscales (3). These associations are considered clinically relevant for patients as regression coefficients were in line with the MIC of the HAGOS (113,115), indicating that the severity of

pain is associated with PRO. This is supported by Terwee et al. (156), who reported that PROMs are more influenced by pain than performance-based measures of physical function. In patients with hip dysplasia, Boje and Caspersen et al. (143) proved statistically significant associations between changes in HOOS subscales and changes in the level of pain measured from before to 2 year after PAO. In line with this finding, Dierckman et al. (157) investigated associations between PROMs and VAS (0-10) in patients with FAIS. The results of the study showed that one unit difference in preoperative VAS was associated with 1 point lower score in PROMs. The results of the above-mentioned studies support our findings and indicate that PRO is related to severity and/or level of pain. Performance-based function such as accelerometer-based physical activity, on the other hand, covers a different aspect of physical function, which is also considered relevant.

Accelerometer-based physical activity

Patients with hip dysplasia experienced reduced pain and increased physical capacity after PAO (3), but the level of daily physical activity remained unchanged (4). Similar results have been reported in patients with hip osteoarthritis (77,145–149,158), where the level of physical activity was so low that it was considered a threat to patients´ health (147). Therefore, measuring physical activity with accelerometer-based measures is important, as patient-reported methods would never recognize the actual, low level of daily physical activity in patients with hip osteoarthritis. However, in patients with hip dysplasia, the level of physical activity was within the levels recommended for healthy populations for both steps and cadence (4), indicating a level of physical activity from which patients may gain health benefits. Therefore, spending time and resources on motivating patients to increase their level of physical activity may not be relevant. On the other hand, hip dysplasia is a leading precursor of hip osteoarthritis (8,11), and the estimated prevalence of hip dysplasia in patients with hip osteoarthritis is 20-40% (159). Consequently, many patients with hip dysplasia will most likely adjust their physical activity to a low level over time; in older age, this could be a threat to their health. Minor differences in resting and running time seem to exist between patients with hip dysplasia and pain-free references when comparing our patients´ physical activity profiles with those of pain-free references reported in the HAFAI study (4,103). This could indicate early adjustments in the patients´ level of physical activity. Hence, patients with hip dysplasia should be encouraged to increase and/or preserve their level of physical activity. However, changing a lifestyle behaviour such as physical activity to boost health is difficult (160) and is influenced by perceptions and beliefs (160,161). Harding et al. (160) explored this matter 6 months after hip and knee arthroplasty, showing that patients recognised the importance of being physically active, but remained physically inactive due to other barriers than pain (147). Barriers to physical activity in patients with osteoarthritis are multifactorial and include: not perceiving a sedentary behaviour as harmful,

adjusting physical activity to a low level over time, perceiving physical activity as harmful or non-effective and finding other barriers than pain to physical activity (160,161). Similar barriers probably exist in patients with hip dysplasia. Therefore, health professionals should be aware of these barriers and try to facilitate daily physical activity by explicitly describing the physical and social gains of physical activity. Moreover, health professionals may engage in social policy to create facilitating environments where patients can engage in physical activity with people with similar physical capacities and age (161).

Key points - what this study adds

1. Muscle-tendon pain and structural abnormalities are common in hip dysplasia, primarily involving the iliopsoas and hip abductor muscles (1,2).
2. Muscle-tendon pain is negatively associated with patient-reported outcome (1).
3. 1 year after PAO, patients experience medium to very large patient-reported improvements which is associated with decreased muscle-tendon pain (3).
4. The level of daily physical activity does not change 1 year after surgery despite increased physical capacity (4).

Methodological limitations

Papers 1-4 are based on data from a prospective case series study, and some limitations do exist. The internal validity will be discussed systematically with regard to study design, measurement error, selection bias, information bias and confounding. The external validity will be discussed under the subheading generalisability.

Study design

Cohort and case series studies are often mislabelled and distinction between the two can be difficult (162). This study was labelled a case series study. Patients with hip dysplasia were sampled and observations were made before and after all patients underwent PAO. In cohort studies, patients have to be sampled based on a specific *a priori* exposure (e.g. muscle-tendon pain); and occurrence of outcome (e.g. HAGOS or muscle strength) has to be assessed over a specific period and risk should be compared between exposure groups (162). However, categorising muscle-tendon pain into exposure groups was not considered relevant in this study. Instead, the aim was to investigate if extra-articular structures such as muscles and tendons could be sources of pain and if structural abnormalities could be identified, and to investigate the outcome of PAO.

However, case series studies are associated with inherited biases, the most serious of which is the lack of pain-free reference groups. The lack of references implies lack of knowledge of muscle-tendon pain, structural abnormalities and physical activity in pain-free references. In Papers 1 and 3, we examined if muscle-tendon pain could be a source of known pain, implying a history of pain. References categorising themselves as pain-free do not have known pain. Thus, the lack of pain-free references most likely had no impact on these results. On the other hand, the lack of pain-free references in Paper 2 may be considered a weakness of the study. The results of Paper 2 showed a weak-to-moderate correlation between pain and abnormal ultrasonographic findings in the iliopsoas tendon and the gluteus medius/minimus tendons, whereas pain and structural abnormalities were not correlated for the other investigated structures. Abnormal ultrasonographic findings have been detected among pain-free subjects (51,163). Consequently, structural abnormalities can present due to previous injuries and/or excessive use, and this may not be related to present symptoms. Therefore, estimates of structural abnormalities in hip dysplasia may have been overestimated as abnormalities unrelated to the present symptoms may have been recorded. Similarly, pain-free references were lacking in Paper 4. However, the patients' physical activity profile was similar to that of the pain-free references included in the HAFAI study (103) and in two other previous studies (21,164), implying that the patients followed current health recommendations regarding regular physical activity. However, compared to the references included in the HAFAI study (103), patients in this study seemed to rest more and run less (4). As mentioned before, this could indicate early adjustment in the patients' level of physical activity, which may be an important indicator. Consequently, the lack of pain-free references may blur minor deviations from normality that may be important. However, this has no impact on the estimated changes of the accelerometer-based and patient-reported physical activity and the estimated associated between them.

Another limitation in Papers 3 and 4 was that no attempt was made to monitor physical rehabilitation after PAO. However, the aims of the papers were to investigate muscle-tendon pain and abnormalities and outcome of PAO in a setting comparable with usual practice. Therefore, physical rehabilitation was not monitored. Even so, all patients were instructed in a home-based exercise programme and offered an individualised exercise programme, ending 2-4 months after PAO. We therefore do not know if the changes in the measured outcomes exist due to surgery or time or are the result of intensive physical rehabilitation. This should be investigated in future studies, optimally comparing the effect of different rehabilitation approaches.

Finally, Papers 1-4 are based on data from one study population, and one may argue that this is tantamount to salami slicing. However, reporting all data in one paper

was considered inappropriate as the contents was too comprehensive for one paper. Hence, *a priori*, separate aims and methods were defined and described for each paper, and the original publication has been cited in all papers to ensure transparency. On the other hand, data from each paper will to some extent be interdependent, and per chance it is likely that drawing a sample from another study population would provide other results. However, in this case, it was considered ethical, economic and time-wise appropriate to disturb only one group of patients rather than collecting data from different patient samples. Bearing this in mind, dividing data in Papers 1-4 is not considered salami slicing.

Measurement error

The analysis of inter-rater reliability for the isometric hip muscle strength assessments showed measurement errors at group level of 10-16% (1). To our knowledge, no consensus about acceptable cut-off values has been reported, but cut-off values of 10% of variance have been suggested (165). Moreover, it has been recommended only to use strength assessment tools associated with limits of agreement < 15% in order to be able to detect small but clinically relevant changes in strength (166). Thus, in Paper 1, the measurement errors were a little higher than the suggested cut-off levels, indicating that measurement error might blur clinically relevant findings. However, Papers 1-4 included a large study population. Hence, measurement error has less impact on the results since the overall variation reduces with increasing sample size. Still, in one regression analysis (1), the association between isometric hip extension and the sum of painful clinical entities failed to reach statistical significance. This can probably be explained by the large measurement error (15%) for this assessment, blurring the underlying association.

Selection bias

In the study period, 138 consecutive patients were assessed for eligibility (1), approximately 100 patients per year. According to the Danish National Patient Register (DNPR), this number corresponds to the number of PAOs performed a year at Aarhus University Hospital (84). This indicates that all eligible patients were identified and that they most likely represent the target population. Among them, 19 patients declined to participate, and perchance these patients may share different characteristics than those of the included patients, which would introduce selection bias. However, patients declined to participate either due to time and/or transport (n=9) or due to lack of interest (n=7); they did not differ in age, gender or severity of hip dysplasia. Hence, the risk of selection bias in this context is considered low. However, the risk of selection bias may also arise due to missing data, which would introduce random selection bias. In Papers 3 and 4, data on 18% and 23%, respectively, were lost to follow-up due to different reasons (3,4). These numbers are considered high, which may lead to selection bias. However, patients lost to follow-

up did not share different patient characteristics than the analysed patients, and therefore the risk of selection bias due to missing data is considered low.

Information bias

In Papers 1-3, pain and/or structural abnormalities were identified in specific clinical entities with standardised clinical and ultrasonographic examinations. Patients were examined by experienced physiotherapists and they were aware of the study aims and were therefore not blinded. Possibly, they could have been prone to overestimation of pain and/or abnormal ultrasonographic findings (too many false positive). Nevertheless, for the standardised clinical examinations, patients had to confirm known pain when performing two separate tests, which reduces the risk of rater-depended overestimation (1). However, the analyses of inter-rater reliability of standardised clinical and ultrasonographic examinations revealed only slight to moderate agreement (1,2). In five clinical entity tests and in one ultrasonographic examination, kappa values were considered questionable due to a low prevalence of pain and/or structural abnormalities. For the other tests, the agreement was fair to moderate, indicating some risk of non-differential misclassification which could blur the calculated estimates. For the estimated associations between the HAGOS scores and the sum of painful clinical entities, overestimation of muscle-tendon pain and/or non-differential misclassification would most likely underestimate the associations since patients with muscle-tendon pain could have been diluted by false positives, indicating low risk of misclassification bias for these analyses.

In Paper 4, all activity data were calibrated manually by choosing a period of level walking of each day. This procedure may introduce non-differentiated misclassification as by mistake the researcher may choose cycling instead of level walking (the raw data signal looks similar). Again, this will not affect the results but may increase overall variation. Moreover, fitness training was not quantified with the accelerometer-based algorithm (4), and since most patients reported fitness training as their primary preferred physical activity, the level of daily physical activity may have been underestimated.

Confounding

In Papers 1 and 3, estimated associations between the sum of painful clinical entities and HAGOS scores and hip muscle strength may be explained by unknown confounding. To be a confounder for the above-mentioned associations, a co-variate has to be associated with both the exposure (sum of painful clinical entities) and the outcome (HAGOS and hip muscle strength). As described in the method section in Paper 1, associations were adjusted for sex and age as they were considered possible association confounders. Moreover, estimated associations - reported in Paper 3 - were also adjusted for pre- and postsurgical CE angles. Adjusted analyses were associated with slightly narrower 95% CI, indicating the relevance of adjusting (1–3).

Nevertheless, unknown confounding may also be relevant and may also explain reported associations and/or correlations in the individual papers (1–4). Overweight has been reported as an independent predictor of PRO after PAO (16). Therefore, the impact of overweight on outcome of treatment should be investigated in future studies.

Key points - important limitations	
Study design	No pain-free references, implying that structural abnormalities may also be common among pain-free references.
	No pain-free references, implying that minor deviations from normality in the level of daily physical activity may not be detected.
Measurement error	The analyses of inter-rater reliability show fair to moderate agreement of the clinical and ultrasonographic examinations, implying that relevant changes or associations may be blurred due to measurement error.

Generalisability

The external validity is considered high and a strength of the papers included in this dissertation. All patients were included consecutively during a study period of 16 months, and the flow of identified eligible patients (Figure 12) was similar to the general flow of patients at Aarhus University Hospital (84), indicating that most patient were identified. The study population hereby represents the target population, which - in other words - represents the general population of Danish patients with hip dysplasia scheduled for PAO. As a result, patients were heterogeneous, including patients on sick leave, young physically active students, employed middle-aged patients living alone and/or with families, patients with low and high income jobs and patients with and without overweight, leading to a high overall variation. Thus, the patients represented the target population, and future studies may investigate if separate analyses of some subgroups may be relevant.

9. Conclusion

Muscle-tendon pain and abnormal ultrasonographic findings were common in hip dysplasia, primarily involving the iliopsoas and the hip abductor muscles (1,2), and pain was negatively associated with PRO (1).

After hip-preserving surgery, patients with hip dysplasia experienced medium to very large improvements in PRO, which was associated with decreased muscle-tendon pain (3). Consequently, the understanding of hip dysplasia as solely a joint disease should be reconsidered since muscle-tendon pain seems to play an important role in relation to PRO before and after PAO (1,3).

Patients with hip dysplasia did not change their physical activity profile 1 year after hip-preserving surgery when activity was measured with accelerometer-based sensors. This is interesting as patient-reported physical activity indicated that patients' ability to participate in physical activities increased, suggesting that this increased self-reported participatory capacity was not manifested as increased accelerometer-based physical activity.

10. Perspectives and future research

The severity of pain seems important and most likely describes how patients with hip dysplasia experience their physical well-being. Therefore, improving muscle-tendon pain through specific interventions - focusing on reducing muscle-tendon pain - seems relevant for patients with hip dysplasia. As stated previously, no studies have investigated the effect of exercise therapy in patients with hip dysplasia, nor have any studies investigated the effect of PAO. However, in a newly registered randomised controlled trial (RCT), the authors aim to investigate if PAO - followed by 4 months of usual care and 8 months of progressive resistance training - is superior to 12 months of progressive resistance training in terms of self-reported pain measured with the HAGOS (ClinicalTrials.gov ID: NCT03941171). The progressive resistance training will focus on exercises in machines that strengthen the hip abductors, flexors and extensors. Potentially, these exercises will have a positive impact on muscle-tendon pain, as exercises are performed slowly including an eccentric emphasis with a relatively heavy load. Similar interventions have been found to be effective in reducing pain in relation to Achilles (167) and patellar tendinopathy (168). In a few years, the efficacy of PAO followed by progressive resistance training compared with progressive resistance training will be reported, and knowledge on expected effects, complications and risk factors will be obtained. This is considered highly relevant. In a case series study on 321 patients with hip dysplasia, treatment satisfaction was investigated 2 years after PAO (143). Although improvements exceeded the MIC measured with the HOOS, 36% of patients were not satisfied with their outcome in relation to patient-reported pain, symptoms, daily life, physical function and quality of life. However, 84% of patients would have undergone PAO again if they knew their result in advance, whereas 16% would not. These findings raise the question whether the unsatisfied patients share other characteristics than the satisfied patients, and, if so, whether knowledge of these characteristics be used in advance when planning treatment. This is considered relevant to investigate because it would provide relevant data on which patients should undergo surgery and which patients should not. Possibly, such data can be provided from the ongoing RCT (ClinicalTrials.gov ID: NCT03941171); if this is not the case, this issue should certainly be investigated in future studies.

Nevertheless, as stated previously, not all patients are offered surgical treatment. Patients with a BMI above 25, age above 45 years, manifest osteoarthritis, reduced hip range of motion and low level of pain are not candidates for PAO (69,169,170). In Denmark, these patients – and patients who do not want to undergo surgery – receive no other any treatment in the public sector. The consequence is that they find themselves left with no treatment options despite similar levels of pain, physical function and risk of osteoarthritis as candidates for surgery. Worldwide, osteoarthritis is the leading cause of pain and low physical function, and

osteoarthritis is associated with an inactive lifestyle, threatening patients' overall health (147). The prevalence of hip dysplasia in hip osteoarthritic populations is 20-40% (159), indicating that patients with hip dysplasia may develop osteoarthritis later in life. It is likely that the dysplastic patients of today, who are left with no treatment option, may be at high risk of poor health later in life. Possibly, they will adjust their level of daily physical activity to their pain and over time develop an inactive lifestyle. Therefore, to improve physical function and muscle-tendon pain and to preserve an active lifestyle, an alternative treatment option should be developed, and the effect of this treatment should be investigated and proved in a RCT. As stated previously, exercise treatment could be an alternative for patients who are not candidates for surgery. Currently, co-authors and I work on designing a relevant treatment option for these patients. We will investigate the feasibility of progressive exercise therapy in a feasibility study starting in 2020; based on that study, a RCT will be designed and the effectiveness and cost-effectiveness of progressive exercise therapy will be tested against usual practice. Hopefully, this RCT will be running in late 2020, and the first results will be published in 2024. To our knowledge, such an RCT study will be the first study investigating short- and long-term effectiveness of exercise therapy for patients who are not candidates for PAO. We will investigate patient-reported and performance-based function, costs of interventions and muscle-tendon pain. Hence, valuable knowledge will be provided to health professionals, patients and health policy makers by highlighting the benefits, adverse events and cost of such exercise therapy. Moreover, the intervention will be simple and home-based, allowing implementation at large scale if the results show that the intervention is effective and/or cost-effective. Nevertheless, this RCT will not fully describe how the intervention should be implemented, nor will it investigate if specific characteristics lead to poor outcome. Likewise, the RCT will not investigate if other treatment options are more effective. Such questions should be addressed in future studies.

11. References

1. Jacobsen JS, Hölmich P, Thorborg K, Bolvig L, Jakobsen SS, Søballe K, Mechlenburg I. Muscle-tendon-related pain in 100 patients with hip dysplasia: prevalence and associations with self-reported hip disability and muscle strength. J Hip Preserv Surg 2018;5:39–46.
2. Jacobsen JS, Bolvig L, Hölmich P, Thorborg K, Jakobsen SS, Søballe K, Mechlenburg I. Muscle–tendon-related abnormalities detected by ultrasonography are common in symptomatic hip dysplasia. Arch Orthop Trauma Surg 2018;138:1059–1067.
3. Jacobsen JS, Søballe K, Thorborg K, Bolvig L, Storgaard Jakobsen S, Hölmich P, Mechlenburg I. Patient-reported outcome and muscle–tendon pain after periacetabular osteotomy are related: 1-year follow-up in 82 patients with hip dysplasia. Acta Orthop 2019;90:40–45.
4. Jacobsen JS, Thorborg K, Hölmich P, Bolvig L, Storgaard Jakobsen S, Søballe K, Mechlenburg I. Does the physical activity profile change in patients with hip dysplasia from before to 1 year after periacetabular osteotomy? Acta Orthop 2018;89:622–627.
5. Jacobsen S, Sonne-Holm S. Hip dysplasia: A significant risk factor for the development of hip osteoarthritis. A cross-sectional survey. Rheumatology 2005;44:211–218.
6. Jacobsen S, Sonne-Holm S, Søballe K, Gebuhr P, Lund B. Hip dysplasia and osteoarthrosis A survey of 4 151 subjects from the Osteoarthrosis Substudy of the Copenhagen City Heart Study. Acta Orthop 2005;76:149–158.
7. Morvan J, Bouttier R, Mazieres B, Verrouil E, Pouchot J, Rat AC, Guellec D, Guillemin F, Coste J, Saraux A. Relationship between hip dysplasia, pain, and osteoarthritis in a cohort of patients with hip symptoms. J Rheumatol 2013;40:1583–1589.
8. Murphy SB, Ganz R, Müller ME. The prognosis in untreated dysplasia of the hip. A study of radiographic factors that predict the outcome. J Bone Joint Surg Am 1995;77:985–9.
9. Nunley RM, Prather H, Hunt D, Schoenecker PL, Clohisy JC. Clinical presentation of symptomatic acetabular dysplasia in skeletally mature patients.

J Bone Joint Surg Am 2011;93 Suppl 2:17–21.

10. Cooperman D. What is the Evidence to Support Acetabular Dysplasia as a Cause of Osteoarthritis? J Pediatr Orthop 2013;33:S2–S7.
11. Wyles CC, Heidenreich MJ, Jeng J, Larson DR, Trousdale RT, Sierra RJ. The John Charnley Award: Redefining the Natural History of Osteoarthritis in Patients With Hip Dysplasia and Impingement. Clin Orthop Relat Res 2017;475:336–350.
12. Lee CB, Mata-Fink A, Millis MB, Kim YJ. Demographic Differences in Adolescent-diagnosed and Adult-diagnosed Acetabular Dysplasia Compared With Infantile Developmental Dysplasia of the Hip. J Pediatr Orthop 2013;33:107–111.
13. Jashi R El, Gustafson MB, Jakobsen MB, Lautrup C, Hertz JM, Søballe K, Mechlenburg I. The association between gender and familial prevalence of hip dysplasia in danish patients. HIP Int 2017;27:299–304.
14. Engesæter IØ, Laborie LB, Lehmann TG, Fevang JM, Lie SA, Engesæter LB, Rosendahl K. Prevalence of radiographic findings associated with hip dysplasia in a population-based cohort of 2081 19-year-old Norwegians. Bone Joint J 2013;95-B:279–85.
15. Birrell F. Syndrome of symptomatic adult acetabular dysplasia (SAAD syndrome). Ann Rheum Dis 2003;62:356–358.
16. Clohisy JC, Ackerman J, Baca G, Baty J, Beaule PE, Kim YJ, Millis MB, Podeszwa DA, Schoenecker PL, Sierra RJ, Sink EL, Sucato DJ, Trousdale RT, Zaltz I. Patient-reported outcomes of periacetabular osteotomy from the prospective ANCHOR cohort study. J Bone Jt Surg - Am Vol 2017;99:33–41.
17. Hartofilakidis G, Karachalios T, Stamos KG. Epidemiology, demographics, and natural history of congenital hip disease in adults. Orthopedics 2000;23:823–7.
18. Jacobsen S, Rømer L, Søballe K. The other hip in unilateral hip dysplasia. Clin Orthop Relat Res 2006;446:239–46.
19. Mechlenburg I, Nyengaard JR, Rømer L, Søballe K. Changes in load-bearing area after Ganz periacetabular osteotomy evaluated by multislice CT scanning and stereology. Acta Orthop Scand 2004;75:147–53.
20. Nepple JJ, Wells J, Ross JR, Bedi A, Schoenecker PL, Clohisy JC. Three Patterns

of Acetabular Deficiency Are Common in Young Adult Patients With Acetabular Dysplasia. Clin Orthop Relat Res 2017;475:1037–1044.

21. Harris-Hayes M, Steger-May K, Pashos G, Clohisy JC, Prather H. Stride activity level in young and middle-aged adults with hip disorders. Physiother Theory Pract 2012;28:333–43.
22. Ross JR, Zaltz I, Nepple JJ, Schoenecker PL, Clohisy JC. Arthroscopic disease classification and interventions as an adjunct in the treatment of acetabular dysplasia. Am J Sports Med 2011;39 Suppl:72S–8S.
23. Wells J, Nepple JJ, Crook K, Ross JR, Bedi A, Schoenecker P, Clohisy JC. Femoral Morphology in the Dysplastic Hip: Three-dimensional Characterizations With CT. Clin Orthop Relat Res 2017;475:1045–1054.
24. Gupta A, Chandrasekaran S, Redmond JM, Hammarstedt JE, Cramer TL, Liu Y, Domb BG. Does Labral Size Correlate With Degree of Acetabular Dysplasia? Orthop J Sport Med 2015;3:1–5.
25. Garabekyan T, Ashwell Z, Chadayammuri V, Jesse MK, Pascual-Garrido C, Petersen B, Mei-Dan O. Lateral Acetabular Coverage Predicts the Size of the Hip Labrum. Am J Sports Med 2016;44:1582–1589.
26. Hartig-Andreasen C, Soballe K, Troelsen A. The role of the acetabular labrum in hip dysplasia. Acta Orthop 2013;84:60–64.
27. McCarthy JC, Noble PC, Schuck MR, Wright J, Lee J. The Otto E. Aufranc Award: The role of labral lesions to development of early degenerative hip disease. Clin Orthop Relat Res 2001;25–37.
28. Jacobsen S, Sonne-Holm S, Søballe K, Gebuhr P, Lund B, Surgeon O. Joint space width in dysplasia of the hip. A case-control study of 81 adults followed for ten years. J Bone Jt Surg [Br] 2005;87:471–478.
29. Heerey JJ, Kemp JL, Mosler AB, Jones DM, Pizzari T, Souza RB, Crossley KM. What is the prevalence of imaging-defined intra-articular hip pathologies in people with and without pain? A systematic review and meta-analysis. Br J Sports Med 2018;52:581–593.
30. Møse FB, Mechlenburg I, Hartig-Andreasen C, Gelineck J, Søballe K, Jakobsen SS. High frequency of labral pathology in symptomatic borderline dysplasia: a prospective magnetic resonance arthrography study of 99 patients. J Hip

Preserv Surg 2019;6:60–68.

31. Pascual-Garrido C, Harris MD, Clohisy JC. Innovations in Joint Preservation Procedures for the Dysplastic Hip "The Periacetabular Osteotomy". J Arthroplasty 2017;32:S32–S37.
32. Leunig M, Siebenrock KA, Ganz R. Rationale of periacetabular osteotomy and background work. Instr Course Lect 2001;50:229–38.
33. Jacobsen JS, Nielsen DB, Sørensen H, Søballe K, Mechlenburg I. Changes in walking and running in patients with hip dysplasia. Acta Orthop 2013;84:265–70.
34. Skalshøi O, Iversen CH, Nielsen DB, Jacobsen J, Mechlenburg I, Søballe K, Sørensen H. Walking patterns and hip contact forces in patients with hip dysplasia. Gait Posture 2015;42:529–533.
35. Sucato DJ, Tulchin-Francis K, de La Rocha A, Kulkarni V, Podeszwa DA. Improved functional outcome with no decrease in hip strength 2 years following Ganz periacetabular osteotomies for adolescent hip dysplasia. J Pediatr Orthop B 2015;24:99–105.
36. Sørensen H, Nielsen DB, Jacobsen JS, Søballe K, Mechlenburg I. Isokinetic dynamometry and gait analysis reveal different hip joint status in patients with hip dysplasia. HIP Int 2018;29:215–221.
37. Kuroda D, Maeyama A, Naito M, Moriyama S, Yoshimura I, Nakamura Y, Kiyama T. Dynamic hip stability, strength and pain before and after hip abductor strengthening exercises for patients with dysplastic hips. Isokinet Exerc Sci 2013;21:95–100.
38. Dieterich A V., Deshon L, Strauss GR, McKay J, Pickard CM. M-Mode Ultrasound Reveals Earlier Gluteus Minimus Activity in Individuals With Chronic Hip Pain During a Step-down Task. J Orthop Sport Phys Ther 2016;46:277–285.
39. Grimaldi A. Assessing lateral stability of the hip and pelvis. Man Ther 2011;16:26–32.
40. Retchford T, Crossley KM, Grimaldi A, Kemp JL, Cowan SM. Can local muscles augment stability in the hip? A narrative literature review. J Musculoskelet Neuronal Interact 2013;13:1–12.

41. Maeyama A, Naito M, Moriyama S, Yoshimura I. Evaluation of dynamic instability of the dysplastic hip with use of triaxial accelerometry. J Bone Joint Surg Am 2008;90:85–92.
42. Harris MD, MacWilliams BA, Bo Foreman K, Peters CL, Weiss JA, Anderson AE. Higher medially-directed joint reaction forces are a characteristic of dysplastic hips: A comparative study using subject-specific musculoskeletal models. J Biomech 2017;54:80–87.
43. van der Hulst M, Vollenbroek-Hutten MM, Rietman JS, Hermens HJ. Lumbar and abdominal muscle activity during walking in subjects with chronic low back pain: Support of the 'guarding' hypothesis? J Electromyogr Kinesiol 2010;20:31–38.
44. Alpert JM, Kozanek M, Li G, Kelly BT, Asnis PD. Cross-Sectional Analysis of the Iliopsoas Tendon and Its Relationship to the Acetabular Labrum: An Anatomic Study. Am J Sports Med 2009;37:1594–1598.
45. Kraeutler MJ, Garabekyan T, Pascual-Garrido C, Mei-Dan O. Hip instability: a review of hip dysplasia and other contributing factors. Muscles Ligaments Tendons J 2016;6:343–353.
46. Domb BG, Lareau JM, Baydoun H, Botser I, Millis MB, Yen YM. Is intraarticular pathology common in patients with hip dysplasia undergoing periacetabular osteotomy? Clin Orthop Relat Res 2014;472:674–80.
47. Hölmich P. Long-standing groin pain in sportspeople falls into three primary patterns, a 'clinical entity' approach: a prospective study of 207 patients. Br J Sport Med 2007;41:247–252.
48. Weir A, Brukner P, Delahunt E, Ekstrand J, Griffin D, Khan KM, Lovell G, Meyers WC, Muschaweck U, Robinson P, De Vos RJ, Vuckovic Z. Doha agreement meeting on terminology and definitions in groin pain in athletes. Br J Sport Med 2015;49:768–774.
49. Hölmich P, Thorborg K, Dehlendorff C, Krogsgaard K, Gluud C. Incidence and clinical presentation of groin injuries in sub-elite male soccer. Br J Sports Med 2014;48:1245–50.
50. Taylor R, Vuckovic Z, Mosler A, Agricola R, Otten R, Jacobsen P, Holmich P, Weir A. Multidisciplinary Assessment of 100 Athletes With Groin Pain Using

the Doha Agreement. Clin J Sport Med 2018;28:364–369.
51. Branci S, Thorborg K, Bech BH, Boesen M, Nielsen MB, Hölmich P. MRI findings in soccer players with long-standing adductor-related groin pain and asymptomatic controls. Br J Sports Med 2015;49:681–91.
52. Kalebo P, Karlsson J, Sward L, Peterson L. Ultrasonography of chronic tendon injuries in the groin. Am J Sports Med 1992;20:634–639.
53. Nam D, Nunley RM, Sauber TJ, Johnson SR, Brooks PJ, Barrack RL. Incidence and Location of Pain in Young, Active Patients Following Hip Arthroplasty. J Arthroplasty 2015;30:1971–5.
54. Hölmich P, Hölmich LR, Bjerg AM. Clinical examination of athletes with groin pain: an intraobserver and interobserver reliability study. Br J Sports Med 2004;38:446–51.
55. Woodley SJ, Nicholson HD, Livingstone V, Doyle TC, Meikle GR, Macintosh JE, Mercer SR. Lateral Hip Pain: Findings From Magnetic Resonance Imaging and Clinical Examination. J Orthop Sport Phys Ther 2008;38:313–328.
56. Branci S, Thorborg K, Bech BH, Boesen M, Magnussen E, Court-Payen M, Nielsen MB, Hölmich P. The Copenhagen Standardised MRI protocol to assess the pubic symphysis and adductor regions of athletes: outline and intratester and intertester reliability. Br J Sports Med 2015;49:692–699.
57. Izumi M, Petersen KK, Arendt-Nielsen L, Graven-Nielsen T. Pain referral and regional deep tissue hyperalgesia in experimental human hip pain models. Pain 2014;155:792–800.
58. Jansen JACG, Mens JMA, Backx FJG, Stam HJ. Diagnostics in athletes with long-standing groin pain. Scand J Med Sci Sports 2008;18:679–690.
59. Nestorova R, Petranova T, Porta F, Radunovic G, Micu MC, Iagnocco A. Ultrasonography of the Hip. Rev Med Ultrason Med Ultrason 2012;14:217–224.
60. Nazarian LN. Musculoskeletal ultrasound: applications in the hip. J Dance Med Sci 2011;15:173–176.
61. Finlay K, Friedman L. Ultrasonography of the Lower Extremity. Orthop Clin North Am 2006;37:245–275.
62. Ganz R, Klaue K, Vinh TS, Mast JW. A new periacetabular osteotomy for the treatment of hip dysplasias. Technique and preliminary results. Clin Orthop

Relat Res 1988;26–36.

63. Shibata KR, Matsuda S, Safran MR. Open treatment of dysplasia—other than PAO: does it have to be a PAO? J Hip Preserv Surg 2015;13:131–144.
64. Lerch TD, Steppacher SD, Liechti EF, Tannast M, Siebenrock KA. One-third of Hips After Periacetabular Osteotomy Survive 30 Years With Good Clinical Results, No Progression of Arthritis, or Conversion to THA. Clin Orthop Relat Res 2017;475:1154–1168.
65. Murphy SB, Millis MB. Periacetabular osteotomy without abductor dissection using direct anterior exposure. Clin Orthop Relat Res 1999;92–8.
66. Pogliacomi F, Stark A, Vaienti E, Wallensten R. Periacetabular osteotomy of the hip: the ilioinguinal approach. Acta Biomed 2003;74:38–46.
67. Troelsen A, Elmengaard B, Søballe K. A new minimally invasive transsartorial approach for periacetabular osteotomy. J Bone Joint Surg Am 2008;90:493–8.
68. Khan OH, Malviya A, Subramanian P, Agolley D, Witt JD. Minimally invasive periacetabular osteotomy using a modified Smith-Petersen approach. Bone Joint J 2017;99-B:22–28.
69. Coobs BR, Xiong A, Clohisy JC. Contemporary Concepts in the Young Adult Hip Patient: Periacetabular Osteotomy for Hip Dysplasia. J Arthroplasty 2015;30:1105–1108.
70. 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;470:2978–2987.
71. Sharifi E, Sharifi H, Morshed S, Bozic K, Diab M. Cost-effectiveness Analysis of Periacetabular Osteotomy. J Bone Jt Surgery-american Vol 2008;90:1447–1456.
72. Steppacher SD, Tannast M, Ganz R, Siebenrock KA. Mean 20-year followup of bernese periacetabular osteotomy. Clin Orthop Relat Res 2008;466:1633–1644.
73. Matheney T, Kim YJ, Zurakowski D, Matero C, Millis M. Intermediate to Long-Term Results Following the Bernese Periacetabular Osteotomy and Predictors of Clinical Outcome. J Bone Jt Surgery-American Vol 2009;91:2113–23.
74. Beaulé PE, Dowding C, Parker G, Ryu JJ. What factors predict improvements in outcomes scores and reoperations after the Bernese periacetabular osteotomy? Clin Orthop Relat Res 2015;473:615–22.

75. Hara D, Hamai S, Fukushi JI, Kawaguchi KI, Motomura G, Ikemura S, Komiyama K, Nakashima Y. Does Participation in Sports Affect Osteoarthritic Progression After Periacetabular Osteotomy? Am J Sports Med 2017;45:2468–2475.
76. Hartig-Andreasen C, Troelsen A, Thillemann TM, Gelineck J, Søballe K. Risk factors for the need of hip arthroscopy following periacetabular osteotomy. J hip Preserv Surg 2015;2:374–84.
77. Mechlenburg I, Jørgensen PB, Stentz-Olesen K, Tjur M, Grimm B, Soballe K. Leg power, pelvic movement and physical activity after periacetabular osteotomy. A prospective cohort study. Acta Orthop Belg 2018;84:163–171.
78. Hussell JG, Rodriguez JA, Ganz R. Technical complications of the Bernese periacetabular osteotomy. Clin Orthop Relat Res 1999;81–92.
79. Trumble SJ, Mayo KA, Mast JW. The periacetabular osteotomy. Minimum 2 year followup in more than 100 hips. Clin Orthop Relat Res 1999;54–63.
80. Murphy S, Deshmukh R. Periacetabular osteotomy: preoperative radiographic predictors of outcome. Clin Orthop Relat Res 2002;168–74.
81. Trousdale RT, Cabanela ME. Lessons learned after more than 250 periacetabular osteotomies. Acta Orthop Scand 2003;74:119–26.
82. Peters CL, Erickson JA, Hines JL. Early results of the Bernese periacetabular osteotomy: the learning curve at an academic medical center. J Bone Joint Surg Am 2006;88:1920–6.
83. Biedermann R, Donnan L, Gabriel A, Wachter R, Krismer M, Behensky H. Complications and patient satisfaction after periacetabular pelvic osteotomy. Int Orthop 2008;32:611–7.
84. The Danish National Biobank (2016). The Danish National Patient Registry. Available from http//www.esundhed.dk/sundhedsregistre/LPR/ Accessed 05 06 2019.
85. Schmidt M, Alba S, Schmidt J, Sandegaard JL, Ehrenstein V, Pedersen L, Toft Sørensen H. The Danish National Patient Registry: a review of content, data quality, and research potential. Clin Epidemiol 2015;7:449–490.
86. National Health Data Authority. The Diagnosis Related Group (DRG) system and the Danish Ambulant Grouping System (DAGS). Available from

https//sundhedsdatastyrelsen.dk/da/afregning-og-finansiering/takster-drg/takster-2019. Accessed 05 06 2019.

87. Mortensen L, Schultz J, Elsner A, Jakobsen S, Søballe K, Jacobsen J, Kierkegaard S, Dalgas U, Mechlenburg I. Progressive resistance training in patients with hip dysplasia: A feasibility study. J Rehabil Med 2018;50:751–758.
88. Uesugi Y, Koyanagi J, Takagi K, Yamaguchi R, Hayashi S, Nishii T. Exercise therapy interventions in patients with hip osteoarthritis: Comparison of the effects of DVD and website-based interventions. J Med Internet Res 2018;20:e10.
89. Harris-Hayes M, Czuppon S, Van Dillen LR, Steger-May K, Sahrmann S, Schootman M, Salsich GB, Clohisy JC, Mueller MJ. Movement-Pattern Training to Improve Function in People With Chronic Hip Joint Pain: A Feasibility Randomized Clinical Trial. J Orthop Sports Phys Ther 2016;46:452–61.
90. Harris-Hayes M, Steger-May K, Van Dillen LR, Schootman M, Salsich GB, Czuppon S, Clohisy JC, Commean PK, Hillen TJ, Sahrmann SA, Mueller MJ. Reduced Hip Adduction Is Associated With Improved Function After Movement-Pattern Training in Young People With Chronic Hip Joint Pain. J Orthop Sport Phys Ther 2018;48:316–24.
91. Paans N, Van Den Akker-Scheek I, Dilling R, Bos M, Van Der Meer K, Bulstra S, Stevens M. Effect of exercise and weight loss in people who have hip osteoarthritis and are overweight or obese: A prospective cohort study. Phys Ther 2013;93:137–46.
92. Fransen M, Mcconnell S, Harmer AR, Van der Esch M, Simic M, Bennell KL. Exercise for osteoarthritis of the knee: a Cochrane systematic review. Br J Sport Med 2015;49:1554–57.
93. Sampath KK, Mani R, Miyamori T, Tumilty S. The effects of manual therapy or exercise therapy or both in people with hip osteoarthritis: a systematic review and meta-analysis. Clin Rehabil 2016;30:1141–1155.
94. Pinto D, Robertson MC, Hansen P, Abbott JH. Cost-effectiveness of nonpharmacologic, nonsurgical interventions for hip and/or knee osteoarthritis: Systematic review. Value Heal 2012;15:1–12.
95. Tan SS, Teirlinck CH, Dekker J, Goossens LMA, Bohnen AM, Verhaar JAN, van

Es PP, Koes BW, Bierma-Zeinstra SMA, Luijsterburg PAJ, Koopmanschap MA. Cost-utility of exercise therapy in patients with hip osteoarthritis in primary care. Osteoarthr Cartil 2016;24:581–588.

96. Fernandes L, Roos EM, Overgaard S, Villadsen A, Søgaard R. Supervised neuromuscular exercise prior to hip and knee replacement: 12-month clinical effect and cost-utility analysis alongside a randomised controlled trial. BMC Musculoskelet Disord 2017;18:5.
97. Jacobsen JS, Nielsen DB, Sørensen H, Søballe K, Mechlenburg I. Joint kinematics and kinetics during walking and running in 32 patients with hip dysplasia 1 year after periacetabular osteotomy. Acta Orthop 2014;85:592–9.
98. Maeyama A, Naito M, Moriyama S, Yoshimura I. Periacetabular osteotomy reduces the dynamic instability of dysplastic hips. J Bone Joint Surg Br 2009;91:1438–42.
99. Patrick DL, Burke LB, Powers JH, Scott JA, Rock EP, Dawisha S, Neill RO', Kennedy DL. Patient-Reported Outcomes to Support Medical Product Labeling Claims: FDA Perspective. Value Heal 2007;10:S125–S137.
100. Wells J, Millis M, Kim YJ, Bulat E, Miller P, Matheney T. Survivorship of the Bernese Periacetabular Osteotomy: What Factors are Associated with Long-term Failure? Clin Orthop Relat Res 2017;475:396–405.
101. Thorborg K, Tijssen M, Habets B, Bartels EM, Roos EM, Kemp J, Crossley KM, Hölmich P. Patient-Reported Outcome (PRO) questionnaires for young to middle-aged adults with hip and groin disability: a systematic review of the clinimetric evidence. Br J Sports Med 2015;49:812–812.
102. Withers TM, Lister S, Sackley C, Clark A, Smith TO. Is there a difference in physical activity levels in patients before and up to one year after unilateral total hip replacement? A systematic review and meta-analysis. Clin Rehabil 2017;31:639–650.
103. Kierkegaard S, Dalgas U, Lund B, Lipperts M, Søballe K, Mechlenburg I. Despite patient-reported outcomes improve, patients with femoroacetabular impingement syndrome do not increase their objectively measured sport and physical activity level 1 year after hip arthroscopic surgery. Results from the HAFAI cohort. Knee Surgery, Sport Traumatol Arthrosc 2019;1–9.

104. Smuck M, Tomkins-Lane C, Ith MA, Jarosz R, Kao MCJ. Physical performance analysis: A new approach to assessing free-living physical activity in musculoskeletal pain and mobility-limited populations. PLoS One 2017;12:e0172804.
105. Sorensen L, Mikkelsen L, Jacobsen J, Mechlenburg I. Reliability of the Danish version of the short questionnaire to assess health-enhancing physical activity (SQUASH). Physiother Theory Pr 2015;34:637–642.
106. Wiberg G. Studies on dysplastic acetabula and congenital subluxation of the hip joint. Acta Orthop Scand Suppl 1939;58:1–132.
107. Tönnis D. Congenital dysplasia and dislocation of the hip in children and adults. Berlin Heidelberg, New York: Springer; 1987.
108. Fairbank JCT, Pynsent PB. The oswestry disability index. Spine (Phila Pa 1976) 2000;25:2940–2953.
109. Troelsen A, Mechlenburg I, Gelineck J, Bolvig L, Jacobsen S, Søballe K. What is the role of clinical tests and ultrasound in acetabular labral tear diagnostics? Acta Orthop 2009;80:314–318.
110. Martin HD, Kelly BT, Leunig M, Philippon MJ, Clohisy JC, Martin RL, Sekiya JK, Pietrobon R, Mohtadi NG, Sampson TG, Safran MR. The Pattern and Technique in the Clinical Evaluation of the Adult Hip: The Common Physical Examination Tests of Hip Specialists. J Arthrosc Relat Surg 2010;26:161–172.
111. Tibor LM, Sekiya JK. Differential Diagnosis of Pain Around the Hip Joint. Arthrosc J Arthrosc Relat Surg 2008;24:1407–1421.
112. Schneider M, Erhard R, Brach J, Tellin W, Imbarlina F, Delitto A. Spinal palpation for lumbar segmental mobility and pain provocation: an interexaminer reliability study. J Manipulative Physiol Ther 2008;31:465–73.
113. Thorborg K, Hölmich P, Christensen R, Petersen J, Roos EM. The Copenhagen Hip and Groin Outcome Score (HAGOS): development and validation according to the COSMIN checklist. Br J Sports Med 2011;45:478–491.
114. Kemp JL, Collins NJ, Roos EM, Crossley KM. Psychometric Properties of Patient-Reported Outcome Measures for Hip Arthroscopic Surgery. Am J Sports Med 2013;41:2065–2073.
115. Thomeé R, Jónasson P, Thorborg K, Sansone M, Ahldén M, Thomeé C,

Karlsson J, Baranto A. Cross-cultural adaptation to Swedish and validation of the Copenhagen Hip and Groin Outcome Score (HAGOS) for pain, symptoms and physical function in patients with hip and groin disability due to femoro-acetabular impingement. Knee Surgery, Sport Traumatol Arthrosc 2014;22:835–842.

116. Stone A V, Jacobs CA, Luo TD, Meadows MC, Nho SJ, Stubbs AJ, Makhni EC. High Degree of Variability in Reporting of Clinical and Patient-Reported Outcomes After Hip Arthroscopy. Am J Sports Med 2018;46:3040–3046.
117. Reiman MP, Thorborg K, Covington K, Cook CE, Hölmich P. Important clinical descriptors to include in the examination and assessment of patients with femoroacetabular impingement syndrome: an international and multi-disciplinary Delphi survey. Knee Surgery, Sport Traumatol Arthrosc 2017;25:1975–1986.
118. Griffin DR, Dickenson EJ, O'Donnell J, Agricola R, Awan T, Beck M, Clohisy JC, Dijkstra HP, Falvey E, Gimpel M, Hinman RS, Hölmich P, Kassarjian A, Martin HD, Martin R, Mather RC, Philippon MJ, Reiman MP, Takla A, Thorborg K, Walker S, Weir A, Bennell KL. The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): An international consensus statement. Br J Sports Med 2016;50:1169–1176.
119. Thorborg K, Ishøi L, Kraemer O, Reiman MP, Hölmich P. HAGOS Could Be Important in the Evaluation of Patients Undergoing Hip Arthroscopy—Why Ignore It in a Sports Medicine Update When the Scientific Data Suggests Otherwise? Letter to the Editor. Am J Sports Med 2018;46:NP6–NP7.
120. Thorborg K, Petersen J, Magnusson SP, Hölmich P. Clinical assessment of hip strength using a hand-held dynamometer is reliable. Scand J Med Sci Sports 2010;20:493–501.
121. Thorborg K, Bandholm T, Schick M, Jensen J, Hölmich P. Hip strength assessment using handheld dynamometry is subject to intertester bias when testers are of different sex and strength. Scand J Med Sci Sports 2013;23:487–493.
122. Thorborg K, Bandholm T, Hölmich P. Hip- and knee-strength assessments using a hand-held dynamometer with external belt-fixation are inter-tester

reliable. Knee Surgery, Sport Traumatol Arthrosc 2013;21:550–555.
123. Bolvig L, Fredberg U, Rasmussen OS. Textbook on Musculoskeletal Ultrasound. Copenhagen: Munksgaard Danmark; 2011.
124. van Laarhoven SN, Lipperts M, Bolink SAAN, Senden R, Heyligers IC, Grimm B. Validation of a novel activity monitor in impaired, slow-walking, crutch-supported patients. Ann Phys Rehabil Med 2016;59:308–313.
125. Lipperts M, van Laarhoven S, Senden R, Heyligers I, Grimm B. Clinical validation of a body-fixed 3D accelerometer and algorithm for activity monitoring in orthopaedic patients. J Orthop Transl 2017;11:19–29.
126. Greenland S, Pearl J, Robins JM. Causal Diagrams for Epidemiologic Research. Epidemiology 1999;10:37–48.
127. Noble PC, Professor Kamaric AE, Research Associate K Salama SJ, Tullos HS, Sugano N, Noble PC, Kamaric E, Salama JK, Ochi T, STullos H. The morphology of the femur in developmental dysplasia of the hip. J Bone Jt Surg [Br] 1998;80:711–720.
128. Duncan ST, Bogunovic L, Baca G, Schoenecker PL, Clohisy JC. Are There Sex-dependent Differences in Acetabular Dysplasia Characteristics? Clin Orthop Relat Res 2015;473:1432–1439.
129. Stenroth L, Peltonen J, Cronin NJ, Sipilä S, Finni T. Age-related differences in Achilles tendon properties and triceps surae muscle architecture in vivo. J Appl Physiol 2012;113:1537–1544.
130. Landis JR, Koch GG. An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. Biometrics 1977;33:363–74.
131. Ghogomu EAT, Maxwell LJ, Buchbinder R, Rader T, Pardo Pardo J, Johnston R V, Christensen RDK, Rutjes AWS, Winzenberg TM, Singh JA, Zanoli G, Wells GA, Tugwell P, Editorial Board of the Cochrane Musculoskeletal Group. Updated method guidelines for cochrane musculoskeletal group systematic reviews and metaanalyses. J Rheumatol 2014;41:194–205.
132. Harris JD, Gerrie BJ, Lintner DM, Varner KE, McCulloch PC. Microinstability of the Hip and the Splits Radiograph. Orthopedics 2016;39:e169-75.
133. Safran MR. Microinstability of the Hip-Gaining Acceptance. J Am Acad Orthop

Surg 2019;27:12–22.

134. Adib F, Johnson AJ, Hennrikus WL, Nasreddine A, Kocher M, Yen YM. Iliopsoas tendonitis after hip arthroscopy: prevalence, risk factors and treatment algorithm. J hip Preserv Surg 2018;5:362–369.
135. Long SS, Surrey DE, Nazarian LN. Sonography of greater trochanteric pain syndrome and the rarity of primary bursitis. Am J Roentgenol 2013;201:1083–1086.
136. Allison K, Wrigley T V., Vicenzino B, Bennell KL, Grimaldi A, Hodges PW. Kinematics and kinetics during walking in individuals with gluteal tendinopathy. Clin Biomech 2016;32:56–63.
137. Allison K, Vicenzino B, Wrigley T V., Grimaldi A, Hodges PW, Bennell KL. Hip Abductor Muscle Weakness in Individuals with Gluteal Tendinopathy. Med Sci Sports Exerc 2016;48:346–352.
138. Weir A, de Vos RJ, Moen M, Hölmich P, Tol JL. Prevalence of radiological signs of femoroacetabular impingement in patients presenting with long-standing adductor-related groin pain. Br J Sports Med 2011;45:6–9.
139. Klässbo M, Larsson E, Mannevik E. Hip disability and osteoarthritis outcome score. An extension of the Western Ontario and McMaster Universities Osteoarthritis Index. Scand J Rheumatol 2003;32:46–51.
140. Martin RRL, Kelly BT, Philippon MJ. Evidence of Validity for the Hip Outcome Score. Arthrosc - J Arthrosc Relat Surg 2006;22:1304–1311.
141. Bogunovic L, Hunt D, Prather H, Schoenecker PL, Clohisy JC. Activity Tolerance After Periacetabular Osteotomy. Am J Sports Med 2014;42:1791–1795.
142. Maeckelbergh L, Peeters T, Moskal J, Corten K. Normative Functional Outcomes as a New Outcome Assessment Tool Following Hip Procedures. Orthopedics 2018;41:e663–e670.
143. Boje J, Caspersen CK, Jakobsen SS, Søballe K, Mechlenburg I. Are changes in pain associated with changes in quality of life and hip function 2 years after periacetabular osteotomy? A follow-up study of 321 patients. J Hip Preserv Surg 2019;6:69–76.
144. Ricciardi BF, Fields KG, Wentzel C, Nawabi DH, Kelly BT, Sink EL.

Complications and Short-Term Patient Outcomes of Periacetabular Osteotomy for Symptomatic Mild Hip Dysplasia. HIP Int 2017;27:42–48.

145. Vissers MM, Bussmann JBJ, de Groot IB, Verhaar JAN, Reijman M. Walking and chair rising performed in the daily life situation before and after total hip arthroplasty. Osteoarthr Cartil 2011;19:1102–1107.
146. Lin BA, Thomas P, Spiezia F, Loppini M, Maffulli N. Changes in daily physical activity before and after total hip arthroplasty. A pilot study using accelerometry. Surgeon 2013;11:87–91.
147. Harding P, Holland AE, Delany C, Hinman RS. Do activity levels increase after total hip and knee arthroplasty? Clin Orthop Relat Res 2014;472:1502–11.
148. Jeldi AJ, Deakin AH, Allen DJ, Granat MH, Grant M, Stansfield BW. Total Hip Arthroplasty Improves Pain and Function but Not Physical Activity. J Arthroplasty 2017;32:2191–2198.
149. Höll S, Blum A, Gosheger G, Dieckmann R, Winter C, Rosenbaum D. Clinical outcome and physical activity measured with StepWatch 3™ Activity Monitor after minimally invasive total hip arthroplasty. J Orthop Surg Res 2018;13:148.
150. Birch S, Jensen S, Mosegaard S, Hansen T, Mechlenburg I, Tjur M, Stilling M. No improvement in objectively-measured physical activity 12 months after hip arthroplasty for osteoarthritis. HIP Int 2020;In review:1–8.
151. De Groot IB, Bussmann HJ, Stam HJ, Verhaar JA. Small increase of actual physical activity 6 months after total hip or knee arthroplasty. Clin Orthop Relat Res 2008;466:2201–2208.
152. Fujita K, Makimoto K, Tanaka R, Mawatari M, Hotokebuchi T. Prospective study of physical activity and quality of life in Japanese women undergoing total hip arthroplasty. J Orthop Sci 2013;18:45–53.
153. Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. Med Sci Sports Exerc 2005;37:S531-43.
154. Tannast M, Hanke MS, Zheng G, Steppacher SD, Siebenrock KA. What Are the Radiographic Reference Values for Acetabular Under- and Overcoverage? Clin Orthop Relat Res 2015;473:1234.
155. Clohisy JC, Barrett SE, Gordon JE, Delgado ED, Schoenecker PL. Medial translation of the hip joint center associated with the Bernese periacetabular

osteotomy. Iowa Orthop J 2004;24:43–8.

156. Terwee CB, van der Slikke RMA, van Lummel RC, Benink RJ, Meijers WGH, de Vet HCW. Self-reported physical functioning was more influenced by pain than performance-based physical functioning in knee-osteoarthritis patients. J Clin Epidemiol 2006;59:724–31.
157. Dierckman BD, Ni J, Hohn EA, Domb BG. Does duration of symptoms affect clinical outcome after hip arthroscopy for labral tears? Analysis of prospectively collected outcomes with minimum 2-year follow-up. J hip Preserv Surg 2017;4:308–317.
158. Engdal M, Foss OA, Taraldsen K, Husby VS, Winther SB. Daily Physical Activity in Total Hip Arthroplasty Patients Undergoing Different Surgical Approaches. Am J Phys Med Rehabil 2017;96:473–478.
159. Gala L, Clohisy JC, Beaulé PE. Hip Dysplasia in the Young Adult. J Bone Jt Surg 2016;98:63–73.
160. Harding PA, Holland AE, Hinman RS, Delany C. Physical activity perceptions and beliefs following total hip and knee arthroplasty: a qualitative study. Physiother Theory Pract 2015;31:107–113.
161. Kanavaki AM, Rushton A, Efstathiou N, Alrushud A, Klocke R, Abhishek A, Duda JL. Barriers and facilitators of physical activity in knee and hip osteoarthritis: a systematic review of qualitative evidence. BMJ Open 2017;7:e017042.
162. Mathes T, Pieper D. Clarifying the distinction between case series and cohort studies in systematic reviews of comparative studies: potential impact on body of evidence and workload. BMC Med Res Methodol 2017;17:107.
163. Robinson P, Grainger AJ, Hensor EMA, Batt ME, O'Connor PJ. Do MRI and ultrasound of the anterior pelvis correlate with, or predict, young football players' clinical findings? A 4-year prospective study of elite academy soccer players. Br J Sports Med 2015;49:176–182.
164. Tudor-Locke C, Craig CL, Aoyagi Y, Bell RC, Croteau KA, De Bourdeaudhuij I, Ewald B, Gardner AW, Hatano Y, Lutes LD, Matsudo SM, Ramirez-Marrero FA, Rogers LQ, Rowe DA, Schmidt MD, Tully MA, Blair SN. How many steps/day are enough? For older adults and special populations. Int J Behav

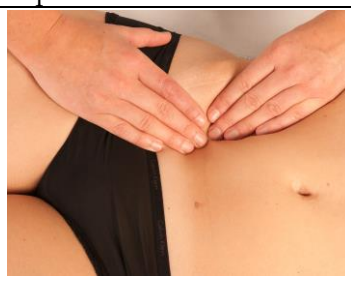
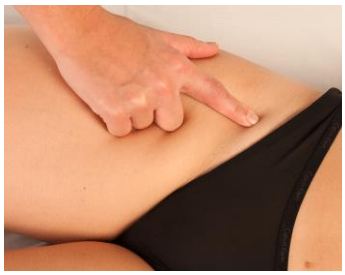
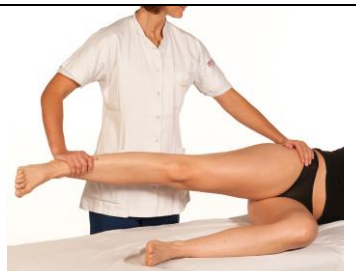
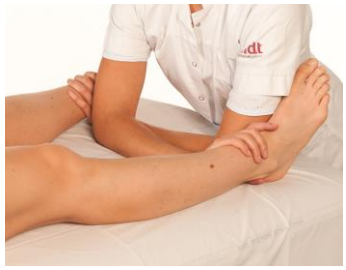
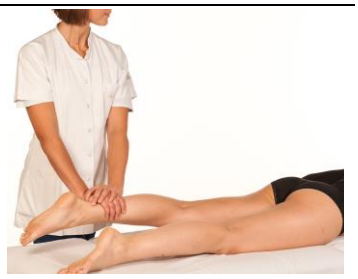
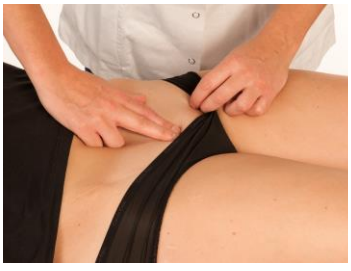
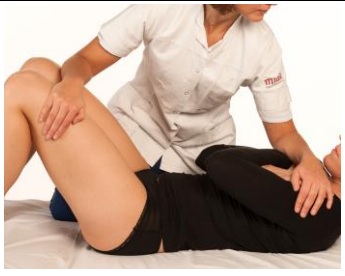
Nutr Phys Act 2011;8:80.

165. Mikkelsen LR, Mikkelsen S, Søballe K, Mechlenburg I, Petersen AK. A study of the inter-rater reliability of a test battery for use in patients after total hip replacement. Clin Rehabil 2015;29:165–74.
166. Chamorro C, Armijo-Olivo S, De la Fuente C, Fuentes J, Javier Chirosa L. Absolute Reliability and Concurrent Validity of Hand Held Dynamometry and Isokinetic Dynamometry in the Hip, Knee and Ankle Joint: Systematic Review and Meta-analysis. Open Med (Warsaw, Poland) 2017;12:359–375.
167. Beyer R, Kongsgaard M, Hougs Kjær B, Øhlenschlæger T, Kjær M, Magnusson SP. Heavy Slow Resistance Versus Eccentric Training as Treatment for Achilles Tendinopathy. Am J Sports Med 2015;43:1704–1711.
168. Larsson MEH, Käll I, Nilsson-Helander K. Treatment of patellar tendinopathy—a systematic review of randomized controlled trials. Knee Surgery, Sport Traumatol Arthrosc 2012;20:1632–1646.
169. Novais EN, Potter GD, Clohisy JC, Millis MB, Kim YJ, Trousdale RT, Carry PM, Sierra RJ. Obesity is a major risk factor for the development of complications after peri-acetabular osteotomy. Bone Joint J 2015;97-B:29–34.
170. Jakobsen SS, Overgaard S, Søballe K, Ovesen O, Mygind-Klavsen B, Dippmann CA, Jensen MU, Stürup J, Retpen J. The interface between periacetabular osteotomy, hip arthroscopy and total hip arthroplasty in the young adult hip. EFORT Open Rev 2018;3:408–417.

12. Appendix

13. Supplementary files

Standardised clinical examinations

Entity	Procedure	Palpation	Resistance or stretch
Iliopsoas-related pain	Palpatory pain of the muscle through the lower lateral part of the abdomen and/or just distal of the inguinal ligament and pain with passive stretching during modified Thomas' test (47,48,54).	 	
Abductor-related pain	Palpatory pain at the insertion point at the greater trochanter and pain with side-lying abduction against resistance		
Adductor-related pain	Palpatory pain at the muscle origin at the pubic bone and pain with adduction against resistance (47,48,54)		
Hamstring-related pain	Palpatory pain at the muscle origin at the tuber ischii and pain with extension against resistance		
Rectus-abdominis-related pain	Palpatory pain of the distal tendon and/or the insertion at the pubic bone and pain at contraction against resistance (47,54)		

Standardised ultrasonographic examinations

Tissue	Findings	Procedure	Illustration
Iliopsoas tendon Transverse scan with the femoral artery as medial landmark	Non-homogeneous echogenicity, diffuse margin appearance, abnormal fluid intra- and/or extra-substantial (iliopsoas bursitis), calcifications, and/or hypertrophy compared with the contralateral side.	Patient assessed is in the supine position with hip and knee in neutral position. The probe is placed in a sagittal oblique plane parallel to the long axis of the femoral neck with the acetabular rim centred. The probe is then rotated until it is parallel to the inguinal ligament with the femoral artery medial to the tendon. A movie sequence was recorded in this position.	
Gluteus medius/minimus tendons Longitudinal and transverse scan with the greater trochanter as landmark	Non-homogeneous echogenicity, abnormal fluid intra- and/or extra-substantial (trochanteric bursitis), calcifications, and/or hypertrophy compared with the contralateral side.	Patient assessed is in the side-lying position with hip and knee in neutral position. The probe is placed parallel to the femoral diaphysis. A movie sequence is recorded starting proximal to the greater trochanter and ending distal to the greater trochanter. Afterwards, the probe is rotated 90 degrees with the greater trochanter centred, and a movie sequence is recorded starting anterior to the greater trochanter and ending posterior to the greater trochanter	
Adductor longus tendon Longitudinal scan with the inferior ramus of the pubis as proximal landmark	Non-homogeneous echogenicity, abnormal fluid intra- and/or extra-substantial, calcifications, enthesophytes, and/or hypertrophy compared with the contralateral side.	Patient assessed is in the supine position with thigh abducted and externally rotated with 90 degrees knee flexion. The probe is placed parallel to the femoral diaphysis. A movie sequence is recorded starting at the myotendinous insertion and ending at the inferior ramus of the pubis.	

Hamstring tendons Longitudinal and transverse scan with the ischial tuberosity as landmark	Non-homogeneous echogenicity, abnormal fluid intra- and/or extra-substantial (ischiogluteal bursitis), calcifications, and/or enthesophytes.	Patient assessed is in the prone position with hip and knee in neutral position. The probe is placed perpendicular to the femoral diaphysis with the ischial tuberosity centred. A movie sequence is recorded starting proximal to the ischial tuberosity and ending distal to the ischial tuberosity. Afterwards, the probe is rotated 90 degrees and an image* is recorded with the probe parallel to the femoral diaphysis with the ischial tuberosity as the proximal landmark.	
Pubic symphysis Transverse scan at the symphyseal cleft	Irregular bone surfaces, non-homogeneous echogenicity, abnormal fluid intra- and/or extra-substantial, and/or calcifications.	The patient assessed is in the supine position with hip and knee in neutral position. The probe is placed over the symphyseal cleft perpendicular to the long axis of the body. An image* is recorded in this position.	
Acetabular labrum Longitudinal scan parallel to the long axis of the femoral neck	Non-homogeneous echogenicity, labrum tear, abnormal fluid intra- and/or extra-substantial, calcifications, and/or hypertrophy compared with the contralateral side.	Patient assessed is in the supine position with hip and knee in neutral position. The probe is placed in a sagittal oblique plane parallel to the long axis of the femoral neck. A movie sequence is recorded from medial to lateral visualising the anterior superior labrum.	

*Recording the movie sequence was time consuming. To reduce the total scan time, two entities were stored as images. Similar table published as supplementary material, Paper 2.

14. Declarations of co-authorship

AARHUS UNIVERSITY

Declaration of co-authorship concerning article for PhD dissertations

Full name of the PhD student: Julie Sandell Jacobsen

This declaration concerns the following article/manuscript:

Title:	Muscle-tendon-related pain in 100 patients with hip dysplasia: prevalence and associations with self-reported hip disability and muscle strength
Authors:	Julie Sandell Jacobsen, Per Hölmich, Kristian Thorborg, Lars Bolvig, Stig Storgaard Jakobsen, Kjeld Søballe, Inger Mechlenburg.

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

If published, state full reference: Jacobsen JS, Hölmich P, Thorborg K, Bolvig L, Jakobsen SS, Søballe K, Mechlenburg I. Muscle-tendon-related pain in 100 patients with hip dysplasia: prevalence and associations with self-reported hip disability and muscle strength. Journal of Hip Preserving Surgery 2018;5:39-46.

If accepted or submitted, state journal:

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

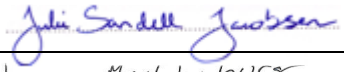
No ☒ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Has done most of the work (67-90 %)
C. Has contributed considerably (34-66 %)
D. Has contributed (10-33 %)
E. No or little contribution
F. N/A

Element	Extent (A-F)
1. Formulation/identification of the scientific problem	B
2. Development of the method	C
3. Planning of the experiments and methodology design and development	A
4. Involvement in the experimental work/clinical studies/data collection/obtaining access to data	A
5. Development of analysis plan and preparation of data for analysis	A
6. Planning and conducting the analysis of data	A
7. Interpretation of the results	B
8. Writing of the first draft of the manuscript	B
9. Finalization of the manuscript and submission	B

Signatures of first- and last author, and main supervisor

Date	Name	Signature
20.05.2019	Julie Sandell Jacobsen	
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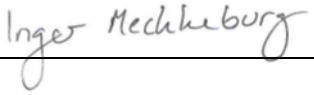
20.05.2019	Inger Mechlenburg	

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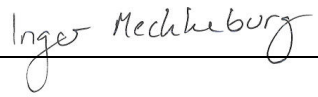
20.05.2019	Inger Mechlenburg	

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Authors:	Julie Sandell Jacobsen, Kjeld Søballe, Kristian Thorborg, Lars Bolvig, Stig Storgaard Jakobsen, Per Hölmich, Inger Mechlenburg.

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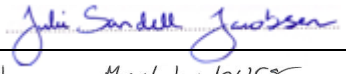
20.05.2019	Julie Sandell Jacobsen	
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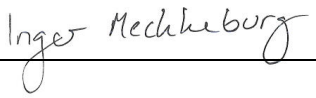
20.05.2019	Inger Mechlenburg	

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Authors:	Julie Sandell Jacobsen, Kristian Thorborg, Per Hölmich, Lars Bolvig, Stig Storgaard Jakobsen, Kjeld Søballe, Inger Mechlenburg.

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

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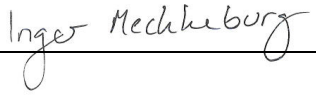
20.05.2019	Inger Mechlenburg	

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