Patient-reported outcomes, hip muscle strength and physical activity in patients with femoroacetabular impingement syndrome

- before and after hip arthroscopic surgery

PhD dissertation

Signe Kierkegaard

Health
Aarhus University
2018

Department of Orthopaedic Surgery
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Preface

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Content

Appendix

Not attached in online version.

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Signe Kierkegaard
Horsens, Denmark
September, 2018

"*Go, go, go*
Figure it out, figure it out, but don't stop moving
Go, go, go
Figure it out, figure it out, <u>you can do this</u>"

"**Flames**", Sia Furler and David Guetta, 2018

Papers in the dissertation

(1) Kierkegaard S, Langeskov-Christensen M, Lund B, Naal FD, Mechlenburg I, Dalgas U, Casartelli NC
Pain, activities of daily living and sport function at different time points after hip arthroscopy in patients with femoroacetabular impingement: a systematic review with meta-analysis.
British Journal of Sports Medicine 2017 Apr;51(7):572-579. doi: 10.1136/bjsports-2016-096618. Epub 2016 Nov 14

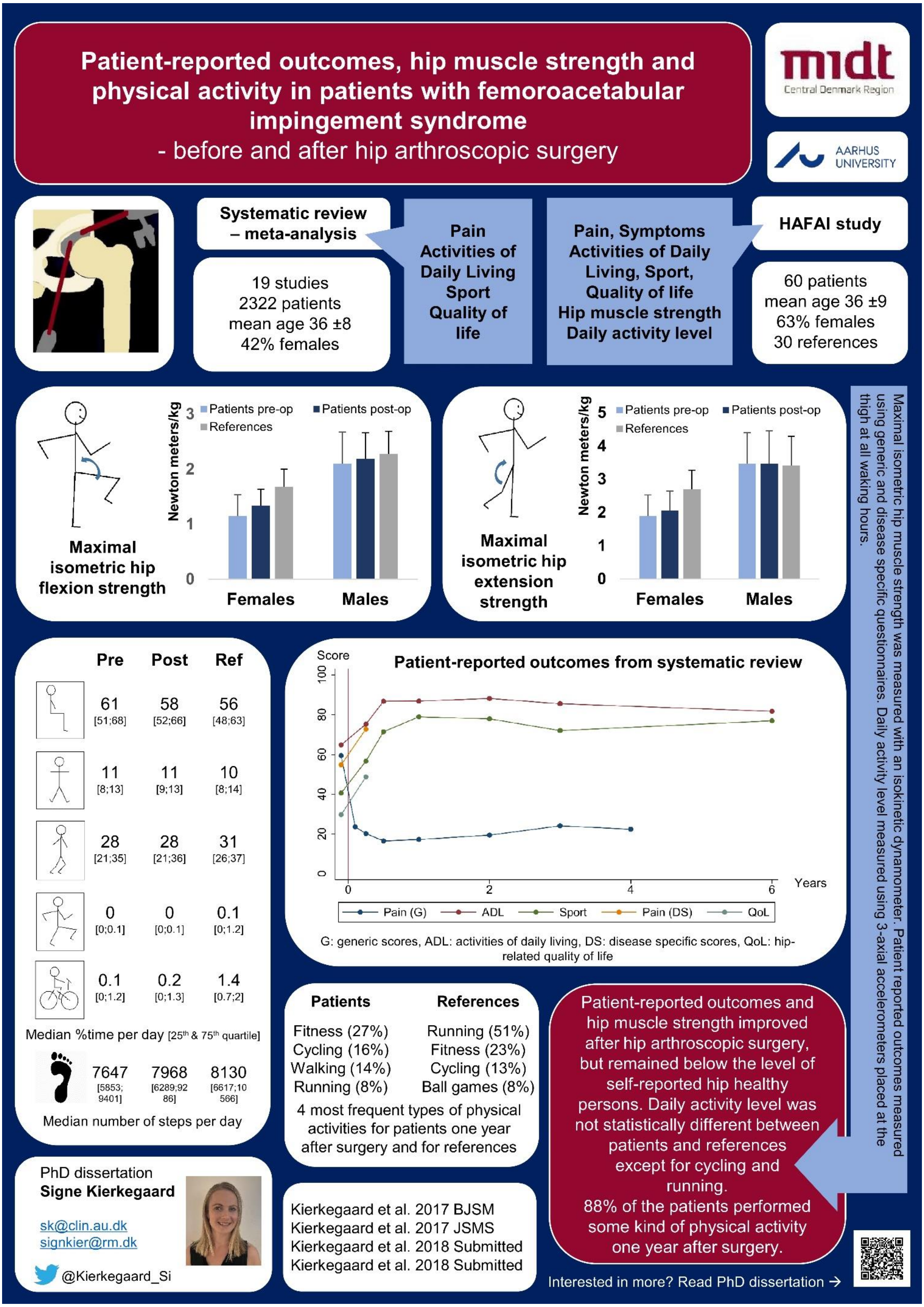
(2) Kierkegaard S, Mechlenburg I, Lund B, Søballe K, Dalgas U.
Impaired hip muscle strength in patients with femoroacetabular impingement syndrome.
Journal of Science and Medicine in Sport 2017 Dec;20(12):1062-1067. doi: 10.1016/j.jsams.2017.05.008. Epub 2017 May 25

(3) Kierkegaard S, Mechlenburg I, Lund B, Rømer L, Søballe K, Dalgas U.
Is hip muscle strength normalised in patients with femoroacetabular impingement syndrome one year after surgery? – results from the HAFAI cohort.
Journal of Science and Medicine in Sport. 2019 Apr;22(4):413-419. doi: 10.1016/j.jsams.2018.10.004. Epub 2018 Oct 17.

(4) 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, Sports traumatology, Arthroscopy. 2019 May 6. doi: 10.1007/s00167-019-05503-5.

Additionally, the protocol paper for the HAFAI study has been published (not a part of the dissertation):

(5) Kierkegaard S, Lund B, Dalgas U, Sørensen H, Søballe K, Mechlenburg I.
The Horsens-Aarhus Femoro Acetabular Impingement (HAFAI) cohort: outcome of arthroscopic treatment for femoroacetabular impingement. Protocol for a prospective cohort study.
BMJ Open. 2015 Sep 7;5(9): e008952. doi: 10.1136/bmjopen-2015-008952.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midt
Central Denmark Region
AARHUS UNIVERSITY
Systematic review – meta-analysis
19 studies
2322 patients
mean age 36 ±8
42% females
Pain
Activities of Daily Living
Sport
Quality of life
Pain, Symptoms
Activities of Daily Living, Sport,
Quality of life
Hip muscle strength
Daily activity level
HAFAI study
60 patients
mean age 36 ±9
63% females
30 references
Maximal isometric hip flexion strength
Newton meters/kg
Patients pre-op
Patients post-op
References
Females
Males
Maximal isometric hip extension strength
Pre
Post
Ref
61 [51;68]
58 [52;66]
56 [48;63]
11 [8;13]
11 [9;13]
10 [8;14]
28 [21;35]
28 [21;36]
31 [26;37]
0 [0;0.1]
0 [0;0.1]
0.1 [0;1.2]
0.1 [0;1.2]
0.2 [0;1.3]
1.4 [0.7;2]
Median %time per day [25th & 75th quartile]
7647 [5853; 9401]
7968 [6289;9286]
8130 [6617;10566]
Median number of steps per day
Score
Patient-reported outcomes from systematic review
Years
Pain (G)
ADL
Sport
Pain (DS)
QoL
G: generic scores, ADL: activities of daily living, DS: disease specific scores, QoL: hip-related quality of life
Maximal isometric hip muscle strength was measured with an isokinetic dynamometer. Patient reported outcomes measured using generic and disease specific questionnaires. Daily activity level measured using 3-axial accelerometers placed at the thigh at all waking hours.
Patients
References
Fitness (27%)
Cycling (16%)
Walking (14%)
Running (8%)
Running (51%)
Fitness (23%)
Cycling (13%)
Ball games (8%)
4 most frequent types of physical activities for patients one year after surgery and for references
Patient-reported outcomes and hip muscle strength improved after hip arthroscopic surgery, but remained below the level of self-reported hip healthy persons. Daily activity level was not statistically different between patients and references except for cycling and running.
88% of the patients performed some kind of physical activity one year after surgery.
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List of abbreviations

AI	Acetabular index
CE angle	Centre-edge angle
CI	Confidence Interval
CT	Computed axial tomography
FAI	Femoroacetabular impingement
FAIS	Femoroacetabular impingement syndrome
HAFAI	Horsens Aarhus FemoroAcetabular Impingement
HAGOS	Copenhagen Hip And Groin Outcome Score
HOOS	Hip disability and Osteoarthritis Outcome Score
HOS	Hip Outcome Score
HSAS	Hip Sports Activity Scale
MIC	Minimal important change
n	Number of participants
NRS	Numeric rating scale
OA	Osteoarthritis
RCT	Randomised controlled trial
UCLA	University of California at Los Angeles
VAS	Visual Analogue Scale
WMD	Weighted mean difference

English summary

Patient-reported outcomes, hip muscle strength and physical activity in patients with femoroacetabular impingement syndrome

- before and after hip arthroscopic surgery

Kierkegaard S

Background: Femoroacetabular impingement syndrome (FAIS) was first described ~ 15 years ago. Despite several publications investigating FAIS, it is still not clear what symptoms and limitations patients experience before and after undergoing surgical treatment.

Methods: A systematic review was conducted, quantifying previous studies reporting patient-reported outcomes in patients with FAIS before and after surgery. Furthermore, a prospective cohort study of 60 patients undergoing surgery at Horsens Regional Hospital was conducted, investigating patient-reported outcomes using the Copenhagen Hip and Groin Outcome Score (HAGOS), maximal hip muscle strength of the flexors and extensors and daily activity level using accelerometers. An age and gender matched reference group of 30 self-reported hip healthy persons was included for comparison.

Findings: Patients with FAIS demonstrate impaired patient-reported outcomes, maximal hip muscle strength and participation in cycling and running activities when compared to references. After hip arthroscopic surgery, patient-reported outcomes and hip muscle strength improved, but remained below the level seen in self-reported hip healthy persons. Daily activity level was not statistically different between patients and references except for cycling and running. Eighty-eight percent of the patients performed some kind of physical activity 1 year after surgery, but at a lower level than that of matched references.

Interpretation: Hip arthroscopic surgery improves outcomes in patients with FAIS. However, some patients remain impaired after surgery. This is most evident with regard to sport function. Future studies should investigate how treatment outcomes might be improved further.

Dansk resumé (Danish summary)

Patientrapporterede outcomes, hoftemuskelstyrke og fysisk aktivitet hos patienter med hofteimpingement

– før og efter hofteartroskopi

Kierkegaard S

Baggrund: Hofteimpingement blev først omtalt for ca. 15 år siden. På trods af mange videnskabelige publikationer om emnet, er det stadig ikke entydigt hvilke symptomer og begrænsninger patienter med hofte-impingement oplever før og efter operation.

Metoder: En systematisk oversigtsartikel blev udarbejdet over studier, der tidligere havde publiceret patient rapporterede outcomes for patienter med hofteimpingement før og efter hofteartroskopi. Derudover blev der udført et prospektivt kohortestudie af patienter med hofteimpingement, der fik ledbevarende hoftekirurgi. Formålet var at måle patient rapporterede outcomes via Copenhagen Hip and Groin Outcome Score, måle maksimal hoftefleksions- og ekstensions muskelstyrke samt dagligt aktivitetsniveau med accele-rometre. Alders- og kønsmatchede raske referencepersoner blev inkluderede til sammenligning.

Fund: Patienter med hofteimpingement oplever smerter, nedsat funktion, nedsat livskvalitet og deres maksimale hoftemuskelstyrke er nedsat sammenlignet med referencepersoner. Efter hofteartroskopi blev patienternes outcomes forbedret og deres muskelstyrke øget, men de forblev under niveauet for referencegruppen. Patienternes daglige aktivitetsniveau var ikke statistisk forskelligt fra referencerne med undtagelse af løb og cykling. 88% af patienterne deltog i en form for fysisk aktivitet efter operationen, men det var på et lavere performanceniveau end referencegruppen.

Fortolkning: Hofteartroskopisk behandling af hofteimpingement giver patienter smertelindring og øget funktionsniveau, men nogle patienter oplever stadig problemer – især under sportsaktiviteter. Fremtidige studier bør undersøge hvordan patient outcomes kan forbedres endnu mere.

Introduction

Osteoarthritis (OA) is a widespread disease in Denmark and all over the world. Approximately 14% of men and 21% of women in Denmark are affected by OA (6). The hip joint is a common site for OA, and it has been estimated that 11% of older adults have hip OA (7). Patients with hip OA experience pain, decreased function and decreased quality of life (8). Persons with end-stage hip OA may receive a total hip replacement (9), a procedure known to relieve symptoms. But since a total hip replacement is expected to last approximately 20 years, the procedure should preferably be offered to elderly patients. In 2015, more than 10,000 total hip replacements were performed in Denmark (6). As there is no cure for OA, it is of great importance to identify interventions that may slow down or prevent OA.

In 2003 Ganz et al. published the study: "*Femoroacetabular impingement – A cause for osteoarthritis of the hip*" (10), suggesting that femoroacetabular impingement (FAI) could be a cause for the development of OA of the hip. This suggestion generated a rapid development in research into FAI (Figure 1). Ten years later, the observation that FAI is a risk factor for OA gained further support (11). In a cohort of 1002 early symptomatic patients with OA with 2 and 5 years of follow-up (12) and in another cohort of 1000 women with 2 and 20 years of follow-up (13), cam morphology was associated with radiographic OA and hip replacement at both 5 and 20 years of follow-up. No similar associations were established between pincer morphology and OA in these cohorts (13, 14).

However, much still remains to be elucidated on how FAI develops, on how FAI should be treated, on which limitations patients with FAI experience, on what the outcomes of treatment are, and on how many patients with FAI progresses to hip OA (15).

This PhD dissertation will focus on which limitations patients with FAI experience and on what outcomes that can be expected after surgical treatment of FAI.

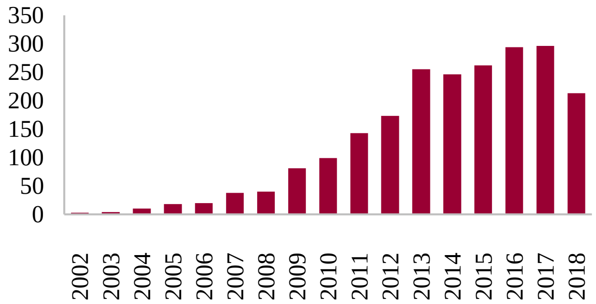


Figure 1: Number of papers on "femoroacetabular impingement" per year indexed in Medline up to 22 August 2018.

Background

This literature review aims to give an overall insight into what FAI is, including the aetiology, surgical treatment and self-reported and objectively measured outcomes in the patient group.

What is FAI?

The concept of femoroacetabular impingement

The theory behind FAI is that impingement occurs when bony abnormalities cause abutment inside the hip joint (10). The bony abnormalities exist either as an abnormal femoral head (cam morphology) or an abnormal acetabulum (pincer morphology). During movements, the abnormal femoral head jams into the acetabulum and causes deep chondral lesions and labral tears (10). Cam morphology is quantified using the alpha angle on radiographs, computed axial tomography (CT) scans or magnetic resonance imaging (16). In pincer morphology, either local or focal over-coverage causes impingement due to limited space for end-range motion. The damage to the cartilage is minor in pincer morphology compared to cam (10). Pincer morphology is quantified using several measures, e.g. the lateral centre-edge angle or the acetabular index (16, 17). Patients can present with cam, pincer or a combination of both (Figure 2).

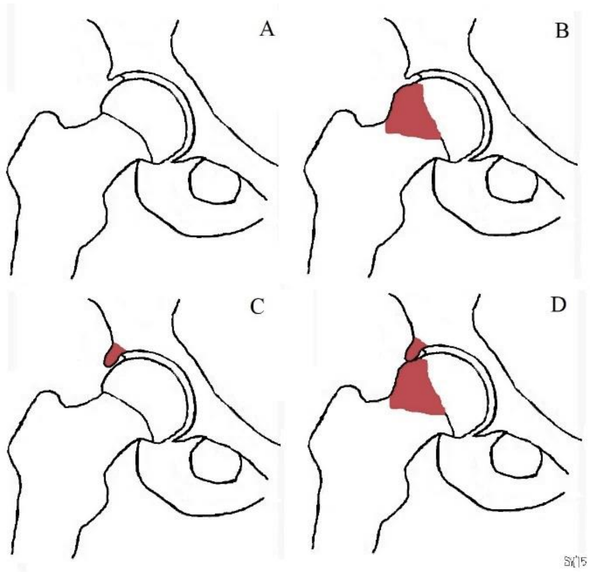


Figure 2: A: the normal hip joint. B: cam morphology. C: pincer morphology. D: combined morphology (drawing made by Signe Kierkegaard, 2015, not published before)

The prevalence of cam and pincer morphology is high in athletes. Especially, contact sport such as American Football (18), Ice Hockey (19), Basketball (20) and Football (21) have been associated with a high prevalence of morphological changes in the hip joint. Furthermore, activities in which the participants place the hip in end-range positions, e.g. ballet (22), have been associated with morphological changes of the hip joint. Systematic reviews have found the prevalence of cam morphology in athletes to be 41–75% (16) and the prevalence of pincer morphology to be approximately 50% (23, 24). Hence, much interest has been given to whether the morphological changes are a result of increased sport and other physical activities (25).

Zurmühle et al. (25) investigated a 5000-year-old skeleton of a male who died at the age of 30–50 years. The skeleton was so well preserved that cam morphology could be seen with a herniating pit. Further analysis with CT showed a zone with increased cortical density, which could be a result of increased stress from impingement and an early sign of degeneration (25). Hence, the description of FAI by Ganz et al. (10) might be relatively new, but the morphological changes in relation to FAI are ancient. If cam morphology has been prevalent in humans for 5000 years, but is not a normal part of the skeleton, then what causes it? Agricola et al. investigated the development of cam morphology in young Football players (26). Their theory was that repeated heavy loads on the open growth plate contributed to excessive bony formation. This theory is supported by the existence of only a few reported cases of cam morphology in patients younger than 13 years and the observation that the prevalence does not increase after the growth plate closes (27). The aetiology of pincer morphology is less well understood. Genetic factors may play a role, but solid evidence is lacking (16, 27). Although theories exist regarding the development of morphological changes of the hip joint, studies have still not demonstrated why some persons develop pain related to FAI.

The prevalence of cam and pincer morphology is high in asymptomatic persons. In a systematic review including 2114 asymptomatic hips (57% males and 43% females), asymptomatic cam and pincer deformities were found in 37% and 67% of the persons, respectively. Furthermore, some kind of hip labral injury was found in 68% of the population (23). Hence, having only imaging signs of FAI does not equal being impaired.

Femoroacetabular impingement syndrome

In 2016, the Warwick Agreement on femoroacetabular impingement syndrome (FAIS) was published (15). This agreement is a consensus statement from researchers and clinicians all over the world. In this statement, the concept of FAI is discussed. Since FAI is highly prevalent in the general population, the diagnosis of patients being symptomatic should be based on symptoms and on clinical and radiographic evaluation. The consensus group agreed upon calling the condition FAI syndrome (FAIS) and not just FAI, and this terminology will be used throughout this dissertation.

According to the Warwick agreement, FAIS is:

"… a motion-related clinical disorder of the hip with a triad of symptoms, clinical signs and imaging findings"

(Griffin et al. 2016)(15)

The symptoms can be many but most importantly, the primary symptom is:

"*… motion-related or position-related pain in the hip and/or groin area*."

(Griffin et al. 2016)(15)

Clinical signs of FAIS are positive impingement tests and limited end-range of hip motion typically during flexion, adduction and internal rotation (10, 15). Imaging findings consist of bony abnormalities as described above. Furthermore, many patients experience hip labral tears and cartilage damage. In a Danish study, it was found that the hip labrum was torn in more than 90% of patients undergoing hip arthroscopy for FAIS (28). In a group of 100 patients undergoing hip arthroscopy, cartilage defects at the acetabulum site were most commonly seen at the chondrolabral junction. There was an increased risk of severe cartilage and labral damage when cam morphology was present (29).

FAIS in relation to ICF

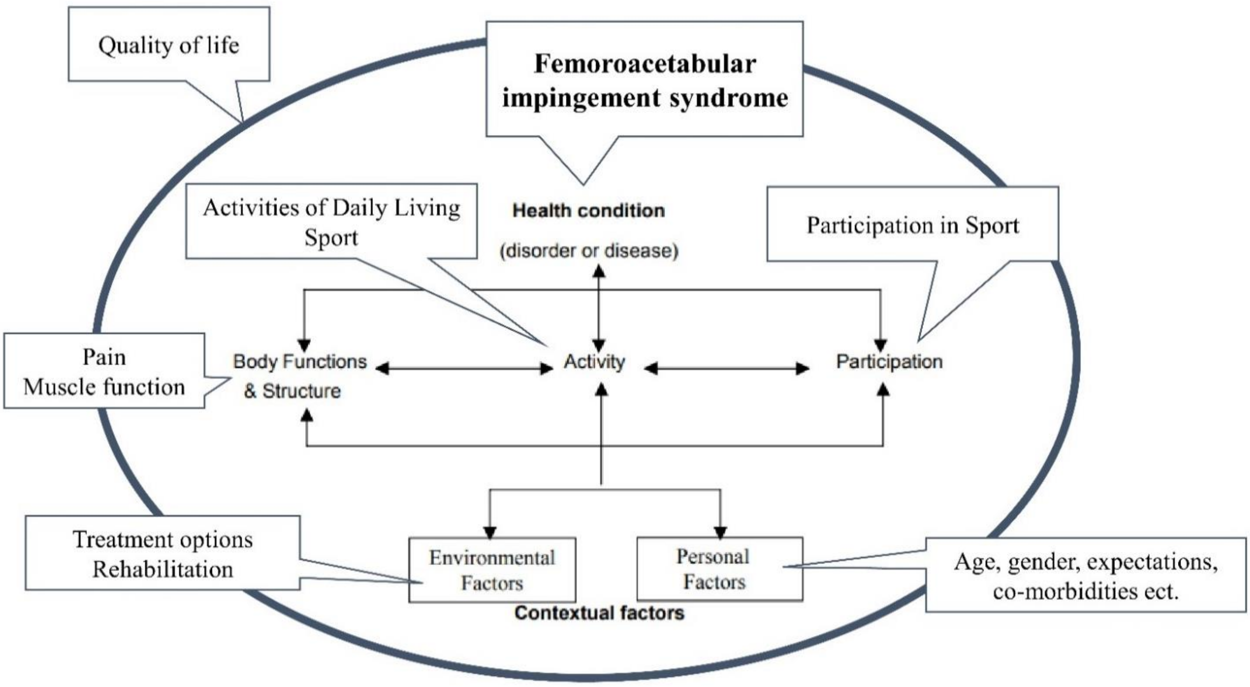


Figure 3. ICF Model with domains in relation to FAIS added. Reprinted with permission from "*World Health Organisation: Towards a Common Language for Functioning, Disability and Health. 2002*."(30) Accessed 23 July 2018.

Every disease limits its patients in a certain way. The World Health Organisation has made a model describing disability and health called the "ICF model" – International Classification of Functioning, Disability and Health (30). In Figure 3, the ICF model is shown with different aspects relevant to FAIS. The following chapters refer to the different parts of the ICF model in order to characterise the disabilities of patients with FAIS.

Body function and structure impairments

According to the ICF model, body structures are:

"… *anatomical parts of the body such as organs, limbs and their components*"

(WHO 2002)(30)

And impairments are:

"… *problems in body function or structure such as a significant deviation or loss*"

(WHO 2002) (30)

In patients with FAIS, the body function and structures of interest are located in the hip joint.

The hip joint is a ball and socket joint consisting of the acetabulum covered with cartilage and the head of the femur also covered with cartilage (Figure 4). The labrum serves to keep the femoral head in place. Furthermore, a thick joint capsule prevents

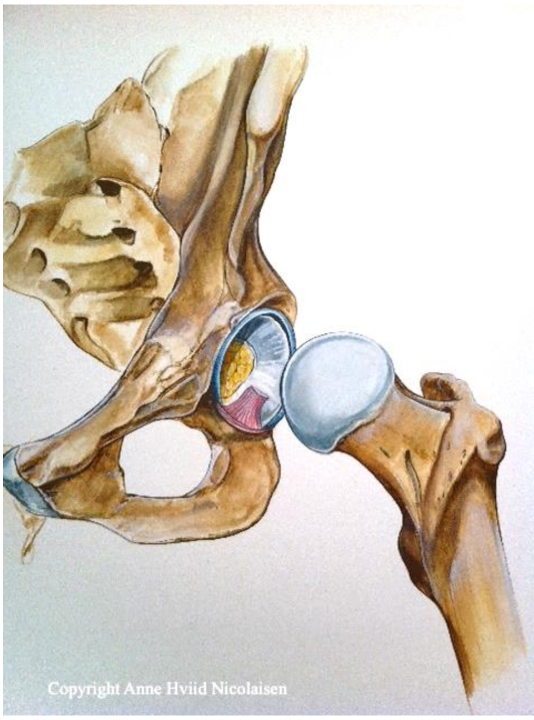


Figure 4: The hip joint. Drawing by Anne Hviid Nicolaisen. Re-printed with permission from PhD dissertation by Charlotte Hartig Andreasen.

dislocation of the hip. Fibres from the iliopsoas tendon further strengthen the joint capsule (31).

Patients with FAIS report pain from many different locations around the hip and groin (15). It can be pain deep in the hip joint (32), pain from superficial layers, pain during movement, during specific positions and at night (15). It is difficult to quantify the origin of these pain sensations. The deep pain could originate from intra-articular structures such as cartilage fibrillation at the labrum-cartilage interface or from the labrum (33), while the more superficial pain sensations may originate from muscles, tendons and ligaments. The overall pain level in patients with FAIS has been investigated in several studies (28, 34-40), demonstrating that patients experience moderate to severe pain from the hip and groin area.

The stability of the hip joint is maintained via a combination of soft tissue, muscles and nervous system. When damage occurs to one of these systems, increasing demand is placed on the other systems (41). When muscles are weak, the demand on the soft tissue increases with possible risk of injury (42). While the hip joint is capable of withstanding forces of more than four times a person's body mass, it is unknown when the soft tissue is at risk (42). In 2011, Casartelli et al. (43) published one of the first studies on hip muscle strength in patients with FAIS and reported that the patient group had reduced hip muscle strength compared to healthy reference persons (43). In the following years, more studies were published regarding hip muscle function in patients with FAIS (44-47). Casartelli et al. (43) and Diamond et al. (44) measured isometric hip muscle strength and compared patients with FAIS to healthy controls (Table 1). Diamond et al. (44) and Casartelli et al. (47) also included a few isokinetic measurements, but this aspect was less well investigated. Since patients with FAIS experience problems with pain during motion, further investigation into concentric and eccentric muscle function may further expand our understanding of impairments related to hip muscle function in this patient group. In an experimental study (42), it was found that reduced force contribution from the iliopsoas muscle during hip flexion and the gluteal muscles during extension could alter the hip joint forces. A clinical observation by the physiotherapists and medical doctors at our hospital was that especially the iliopsoas muscle caused problems in patients with FAIS.

Table 1: Isometric hip muscle strength deficits in patients with FAIS compared with reference persons (a positive number indicates deficit)

	Casartelli et al. 2011 (43) 22 patients, 22 controls		**Diamond et al. 2015 (44) 15 patients, 14 controls**	
	% difference	p-value	% difference	p-value
Flexion	26%	0.004	16%	0.11
Extension	1%	0.592	23%	0.10
Abduction	11%	0.028	20%	0.04
Adduction	28%	0.009	12%	0.23
Internal rotation	14%	0.076	24%	0.07
External rotation	18%	0.040	6%	0.48

% difference: Percentage difference between patients and controls.

The iliopsoas muscle is closely related to the hip joint (31) and contributes to flexion of the hip. Casartelli et al. demonstrated decreased hip muscle function during hip flexion and extension (43), while this was not found by Diamond et al. (44). Both studies were based upon relatively small sample sizes. Hence, variability in patient characteristics and research settings might have had a large impact on the findings from these studies.

Activity limitations

The next level of the ICF model is "activity limitations":

"… *difficulties an individual may have in executing activities*"

(WHO 2002)(30)

Several studies have investigated the patient-reported outcomes of activity limitations in patients with FAIS (28, 38, 39, 48-52), showing that patients experience problems with both daily activities and sport. However, none of the existing systematic reviews (53-57) had synthesised these studies. Other systematic reviews have quantified the objectively measured activity limitations in patients with FAIS (58-60). Using motion capture techniques, studies have quantified that patients with FAIS have altered biomechanics compared to healthy subjects during walking and squatting, while insufficient evidence exists regarding stair climbing, sit-to-stand and drop jump (60). However, it is difficult to assess limitations in patients with FAIS since there is a wide range in patient disability and limitations.

Participation restrictions

The next level of the ICF model is participation restrictions:

"*problems an individual may experience in involvement in life situations*"

(WHO 2002)(30)

For patients with FAIS, this level has been addressed mainly in relation to participation in sport. Since cam and pincer morphology is highly prevalent in athletes (24), much interest has been paid towards how FAIS limits athletes' ability to participate in sport (61) and studies describe that performance level is affected in athletes (62, 63). In a general population of patients with FAIS, Harris-Hayes et al. (64) investigated daily activity level and found that the number of daily steps and total daily activity was not different between patients with FAIS and healthy reference persons. Hence, it seems that patients with FAIS are capable of participating in daily activities at a level similar to that in reference persons. However, the study did not investigate activities other than walking.

Hence, further analysis of the daily activity level is lacking.

Environmental and personal factors

The last factors that may play a role in the ICF model are environmental and personal factors. This could be age, gender, co-morbidities, years with symptoms, sick leave, treatment options, etc. (30).

Earlier studies have investigated the effect of personal factors on FAIS. The disease pattern was different in females vs. males: males had larger alpha angles and more extensive intra-articular disease (65, 66). Worse outcome scores were found in females compared with males (65) and older age and presence of OA were associated with worse intra-articular hip disease (67).

Quality of life

Quality of life may be affected by all the parts involved in the ICF model. Hence, it is drawn as a circle around the other factors (Figure 3).

In patients with FAIS, quality of life has been assessed using different scores. The studies demonstrate that patients with FAIS have impaired quality of life (Table 2) because reference persons score around 100 points on the Copenhagen Hip and Groin Outcome Score (HAGOS) Quality of life scale (68, 69).

Table 2: Existing studies reporting quality of life in patients with FAIS on a 0–100 scale, with 0 indicating worst problems and 100 indicating no problems.

Scale	Study	Year	Number of patients	Mean ±Sd
HAGOS Quality of life	**Thorborg et al. (70)**	2018	97	27 ±2*
	Lund et al. (71)	2017	1835	30
	Sansone et al. (72)	2016	85	33 ±18
	Newcomb et al. (73)	2018	25	35 ±13
	Diamond et al. (44)	2015	15	42 ±20
iHot33	**Griffin et al. (74) (Group 1)**	2018	177	35 ±18
	Griffin et al. (74) (Group 2)	2018	171	39 ±21
	Newcomb et al. (73)	2018	25	47 ±14

Sd: standard deviation. HAGOS: Copenhagen Hip and Groin Outcome Score. iHot33: The International Hip Outcome Tool. *study reports standard error not standard deviation.

Treatment of FAIS

The treatment of FAIS relies on a mixture of conservative strategies, rehabilitation and surgery (15). Although all are of importance, the present dissertation has its focus on the surgical treatment of FAIS.

Surgical treatment of FAIS builds on the idea that removing bony abnormalities in the hip joint to create impingement-free motion and repairing damage to the hip joint labrum and cartilage will decrease patient symptoms (15).

In Switzerland, Ganz et al. (10) were among the first to introduce the surgical treatment of FAIS. When cam morphology exists, the approach is to remove bone at the femoral head-neck junction (osteochondro-plasty) and when pincer morphology exists to remove bone from the acetabular rim (75). The hip labrum can be either debrided or repaired. When surgery to treat FAIS was first performed, the labrum was debrided but development in surgical methods have allowed repair of the labrum, which theoretically should be an advantage because keeping the hip labrum preserves the proprioceptive function of the hip joint in which the hip labrum plays a role (76). Studies have found that patients with a repaired labrum have favourable outcomes compared to those with a debrided labrum (77, 78).

When the surgical treatment of FAIS was introduced, it was performed as an open procedure (10). Furthermore, since the method was new, there was no evidence to determine which patients would benefit the most from the surgical procedure and which surgical methods were the most optimal. In the following years, it was found that patients with a lesser degree of hip OA had better outcomes (50, 54). Furthermore, from being an open procedure, mini-open and arthroscopic surgery procedures were developed. In comparative studies of the procedures, it has been found that all methods have good outcomes, but there is a lower risk of complications if hip arthroscopy is performed (54). Hence, this is the standard surgical procedure today at Horsens Regional Hospital.

Outcome of surgery

Since the introduction of a surgical approach to treat FAIS, studies have collected data on the outcome of surgery to document and develop patient treatment. Systematic reviews have synthesised studies reporting patient-reported outcomes after surgery in patients with FAIS (53-57). However, no study has conducted a meta-analysis synthesising the changes from before to after hip arthroscopic surgery in patients with FAIS.

Table 3: Summary of identified studies on postoperative function in patients with femoroacetabular impingement syndrome (listed by time to follow up).

Study	Year	Number of participants	Follow up (years)	Compared with before surgery
Lamontagne et al.* (79)	2011	10 patients	0.7–2.7~	Squat performance improved.
Seijas et al. (80)	2017	22 patients	1	Contraction time of the gluteus maximus improved after surgery, while contraction time of the rectus femoris and adductor longus remained the same.
Rylander et al. (81)	2013	17 patients, 17 controls	1	Walking improved after surgery but stair climbing remained impaired.
Brisson et al.* (82)	2013	10 patients, 13 controls	1.8	Reduced range of motion during walking both before and after surgery compared to references.
Casartelli et al. (83)	2014	8 patients, 8 controls	2.5	Maximal isometric strength of six muscle groups improved. Deficits in isometric hip flexion strength compared with controls.

* Open or combined surgery. ~Only a range reported

Few studies have investigated the objectively measured outcome of surgery in patients with FAIS (Table 3). Two studies (80, 83) investigated hip muscle function before and after surgery and found some improvements but also that deficits still existed after surgery. Three biomechanical studies (79, 81, 82) investigated walking, stair climbing and squatting and found some improvements in walking and squatting but also that deficits still existed after surgery. The studies were generally small, and larger studies investigating both body function and activity limitations during both functional tests and daily living were lacking.

Several factors may affect both the disease and the outcome and hence are important confounders when evaluating the outcome of treatment. Accordingly, studies have investigated the impact of personal and environmental factors on the manifestations of FAIS and the effect of treatment (Table 4). While older age had some effect on the outcome of surgery, a gender implication was only prevalent to some extent. Workers' compensation claims, mental health problems, expectations and satisfaction all affected the outcome of surgery. Further analysis of which personal factors affect the disease and outcome may highlight specific subgroups of patients that should be given extra attention during treatment.

Table 4: Identified studies investigating specific factors that might affect the outcome of treatment of FAIS and associated disorders.

Factor	Study	Year	Negative effect	No effect
Older age	Dierckman et al. (84)	2017	X	
	Mygind-Klavsen et al. (85)	2018	X	
	Öhlin et al. (86)	2017		X
Female gender	Kemp et al. (87)	2014	X	
	Mygind-Klavsen et al. (85)	2018	X	
	Öhlin et al. (86)	2017		X
Large cartilage damage	Mygind-Klavsen et al. (85)	2018	X	
	Öhlin et al. (86)	2017		X
Large body mass index	Dierckman et al. (84)	2017	X	
Smoking	Cvetanovich et al. (88)	2017	X	
	Dierckman et al. (84)	2017	X	
Workers' compensation claims	Cvetanovich et al. (88)	2017	X	
Mental health problems	Cvetanovich et al. (88)	2017	X	
	Lansdown et al. (89)	2018	X	
Expectations and satisfaction	Dierckman et al. (84)	2017	X	
	Mannion et al. (90)	2013	X	
Duration of symptoms	Dierckman et al. (84)	2017	X	
	Öhlin et al. (86)	2017		X

Aim

The overall aim of the dissertation was to investigate self-reported and objectively measured outcomes in patients with FAIS undergoing hip arthroscopic surgery.

The specific aims and hypotheses were the following:

1. To investigate patient-reported outcomes in patients with FAIS before and after hip arthroscopic surgery.
   We hypothesised that patient-reported outcomes would improve after surgery.
2. To investigate maximal hip muscle strength in patients with FAIS compared with a reference group of self-reported hip healthy persons before and 1 year after hip arthroscopic surgery.
   We hypothesised that hip muscle strength would improve after surgery.
3. To investigate self-reported and objectively measured physical activity level in patients with FAIS compared with a reference group of self-reported hip healthy persons before and 1 year after hip arthroscopic surgery.
   We hypothesised that objectively measured activity would increase after surgery.

Sub aim

To investigate age and gender differences in patient-reported outcomes, hip strength and physical activity level among different age groups 1(age 18–29), 2(age 30–39) and 3(age 40–50) and genders.

We hypothesised that there would be a difference in outcomes between genders (males better than females) and among age groups (younger better than older).

Design of the dissertation

To investigate *aim 1*, a systematic review of previous literature reporting pre- and postoperative patient-reported outcomes in patients with FAIS undergoing hip arthroscopic surgery with regard to pain, function, quality of life and satisfaction was conducted. Furthermore, patient-reported outcomes were collected in the HAFAI study to enable comparison of results.

To investigate *aims 2 and 3*, a prospective cohort study of patients with FAIS undergoing hip arthroscopic surgery at our department was conducted (the HAFAI study). Primary measurement time points were before and 1 year after surgery.

The methods for the two types of study designs are explained separately in the following.

Methods (Systematic review)

Design

The systematic review (1) was designed in accordance with the PRISMA statement (91). Before searches began, a protocol was registered at the Prospero database (CRD42015019649).

Selection of studies

In the databases, EMBASE, MEDLINE, SportsDiscus, CINAHL, Cochrane Library and PEDro, a systematic search was performed by SK and co-author MLC, including studies from before the 20th of September 2015. The search words are presented in supplementary files for paper (1). Systematic reviews were screened to detect eligible studies that were not identified by the electronic search (1).

Inclusion criteria for studies (1):

Study design: Randomised controlled trials (RCTs), cohort studies, case-control studies or case series including >10 cases (1).

Patients: Patient age above 16 years, a diagnosis of FAIS (1).

Intervention: Patients had to be treated with hip arthroscopic surgery, and the surgical procedure had to be described.

Outcomes: Preoperative and postoperative hip pain and/or hip function during ADL and sport and/or quality of life and/or postoperative satisfaction absolute scores had to be reported (1).

Exclusion criteria (1):

Studies on combined arthroscopic and open surgical techniques were excluded (1). Patients without a diagnosis of FAIS but treated with hip arthroscopy, patients with hip dysplasia, slipped capital femoral epiphysis or the Legg–Calve–Perthes disease, patients with previous hip surgery and patients undergoing periacetabular osteotomy were excluded (1).

There were no language, publication date and publication status restrictions (1).

Signe Kierkegaard (SK) and co-author Martin Langeskov-Christensen (ML-C) independently screened titles and abstracts assessed study eligibility by reading the full text of the studies. Disagreement was resolved by consensus (1).

Methodological quality assessment

Due to the expected low level of evidence of the studies, a quality assessment tool developed for case series was used to evaluate the methodological quality of the included studies (1, 92).

The quality assessment tool evaluated (92):

- Study aims and design.
- Description of the study treatment protocol.
- Description of the study methods and therapeutic/side effects.
- Study conduction.

SK and ML-C individually evaluated each criterion as 1 (if the criterion was met) or 0 (if criterion was not met). The total score was the sum of all satisfied criteria and ranged from 0 to 13 (13 = highest methodological quality) (92). Studies with total scores <5 were considered to be of low methodological quality, 5–8 with moderate methodological quality and >8 with high methodological quality (1, 92, 93).

Data extraction

Data were extracted by SK and ML-C with the exception of surgical procedure data, which were extracted by SK and Bent Lund (BL). Preoperative and postoperative hip pain, ADL function, sport function, quality of life scores and postoperative satisfaction scores were extracted. Postoperative scores were grouped according to follow-up times: <3 months, 3 to <6 months, 6 months to <1 year, 1 to <2 years, 2 to <3 years, 3 to <4 years, 4 to <5 years and ≥5 years. The scores, which were used to assess hip arthroscopy outcomes in the included studies, are listed in Table 5 grouped by domain (1).

Table 5: Domain and scale with corresponding minimal important change

Domain	Scale	MIC
Pain	VAS and NRS (94)	30 points
Pain	HAGOS and HOOS (95)	9 points
ADL function	HAGOS, HOOS, and HOS ADL (95, 96)	9 points
Sport function	HAGOS and HOOS (95) HOS sport (96)	10 points 6 points
Quality of life	HAGOS and HOOS (95)	11 points

MIC: Minimal important change. VAS: visual analogue scale. NRS: Numeric rating scale. HAGOS: Copenhagen Hip and Groin outcome score. HOOS: Hip disability and Osteoarthritis Outcome Score. HOS: Hip Outcome Score.

After extraction, scores were converted to a 100-point scale, where 100 indicated the best possible score, except for the visual analogue scale (VAS) and numeric rating scale (NRS) where 0 indicated no pain (1). Please see Kierkegaard et al. 2017 (1) for further details on further data extraction.

Statistical analysis

Percentage agreement and Cohen κ statistics (mean and 95% confidence interval (CI)) were calculated to provide an estimate of the level of agreement between raters when scoring the methodological quality of the included studies. Weighted mean scores were calculated for all scores at the different follow-up times, adjusted to the number of patients. Weighted mean differences (WMD) were calculated for pain, ADL function, sport function and quality of life at the different follow-up times by subtracting the preoperative to the postoperative scores and adjusting to the number of patients. The meta-analysis of WMD was performed with random effects meta-analysis (1).

Hedges' g was applied adjusting for differences in sample size. Between-study variance and heterogeneity among studies were calculated (97, 98). Minimal important changes (MIC), which were calculated by previous studies in different patient populations (pain) (94) and specifically in young hip patients (hip pain, ADL function, sport function, quality of life) (95, 96), were used to evaluate the clinical relevance of the calculated WMD (1).

The significance of WMD was defined by the lower boundary of the WMD 95% CI being higher than the respective MIC. All statistical analyses were performed with Stata 13® (StataCorp, College Station, Texas, USA). The significance level was set at $p < 0.05$ (1).

Methods (HAFAI study)

Design

The HAFAI study consisted of a consecutively included cohort with a cross-sectional comparison with a reference group. The HAFAI study was registered at clinictrials.org (ID: NCT02306525). The purposes of the HAFAI study were published in 2015 in the Protocol Paper: "*The Horsens Aarhus Femoro Acetabular Impingement (HAFAI) cohort*" Kierkegaard et al. 2015 (5). The purpose of the HAFAI study was four-fold:

1. To investigate biomechanical movement pattern.
2. To investigate hip muscle function.
3. To investigate physical activity
4. To investigate patient-reported outcomes.

The HAFAI study included patients with FAIS undergoing hip arthroscopy and compared with a reference group of self-reported hip healthy persons (5). In the present dissertation, studies on purposes 2, 3 and 4 of the HAFAI study are presented.

Ethical aspects

There are several ethical aspects to consider when involving patients in a study. At the time the protocol was written (5), evidence was lacking regarding the outcome of hip arthroscopy in patients with FAIS. There were studies suggesting benefits from hip arthroscopy on pain and self-reported function (1), but the objectively measured functional results of surgery were sparsely reported (58, 59). Studies comparing patients with FAIS to healthy references were reported to some extent (81, 83), but in general the evidence was sparse. Hence, it was ethically appropriate to involve patients in a study of the functional outcome of surgery. The time spent at the test facilities was minimised as much as possible, and patients were compensated economically for their transport to the test facilities. A part of the study was to scan the patient hips with CT – this provided a more detailed description of the patients' hips. A low dose was used to decrease the exposure of radiation. The references were not scanned, as this was thought not to be ethically sound. All enrolled participants were offered a file with their personal test results after the trial.

The Central Denmark Region Committee on Biomedical Research Ethics (1-10-72-239-14) and the Danish Data Protection Agency (1-16-02-499-14) gave their permission to conduct the study (2-5). Before inclusion, all participants gave their written, informed consent in accordance with the Declaration of Helsinki II (2-5).

Participants

Patients

Inclusion criteria (5)

- Scheduled for primary hip arthroscopic surgery for FAIS by Consultant BL.
- A diagnosis of cam and/or pincer impingement.
- For patients with cam, an α angle ≥55° on an anteroposterior (AP) standing radiograph or axial view.
- For patients with pincer, a centre edge angle >25° on an AP radiograph.
- Osteoarthritis grade 0–1 according to Tönnis' classification (99).
- Joint space width of >3 mm.
- Age between 18 and 50 years.

Exclusion criteria (5)

- Previous corrective hip surgery of the included hip.
- FAIS secondary to other hip conditions.
- Alloplastic surgery at the hip, knee or ankle region (both legs).
- Cancer.
- Neurological diseases.
- Inability to speak Danish.

Self-reported hip healthy references

Inclusion criteria (5)

- Self-reported hip healthy.
- No known back, knee or ankle pain/problems.
- No limitations in walking.

Exclusion criteria (5)

- No match with patient.
- Previous major surgery in the hips, knees or ankles.
- Diseases that could affect functional performance (e.g. Neurological diseases).

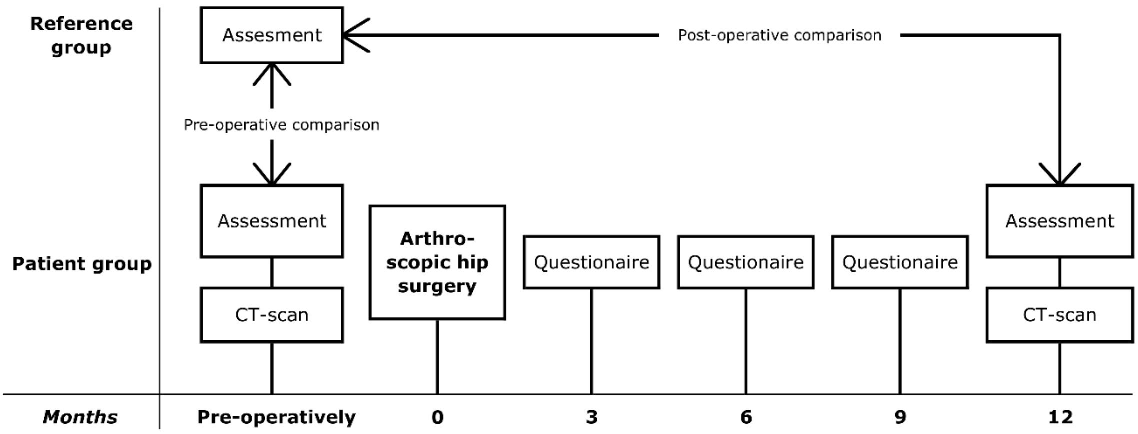


Figure 5: Study flow in HAFAI-study. Figure reprinted from Kierkegaard et al. 2015 (5)

Settings and study flow

Patients listed for hip arthroscopic surgery seen in the Department of Orthopaedic Surgery at Horsens Regional Hospital were invited to participate in the study if they fulfilled the inclusion criteria. If patients were scheduled for surgery on both hips, the first hip scheduled for surgery was chosen as the study hip. The other hip was named “the contralateral hip” (2, 3).

The pre-operative and 1-year post-operative assessments took place at Aarhus University, Department of Public Health, Section for Sport. First, in a gait laboratory, patients completed physical capacity tests, then had a break filling out questionnaires, and finally in another laboratory, they had their maximal hip muscle strength assessed. Before ending the test session, patients were instructed with regard to wearing a 3-axial accelerometer the following days. At 3, 6, 9 and 12 months after surgery, patients were emailed a questionnaire identical to the questionnaire they completed pre-operatively. One year post-operatively, patients underwent the same assessments as they had pre-operatively. Furthermore, between inclusion and surgery, patients underwent a CT scan. At their 1-year appointment with Consultant Bent Lund, they underwent CT again (Figure 5). In this dissertation, data from 3, 6 and 9 months which were not presented in the papers are included in the results.

Assessments

Participant characteristics

Participants had their body mass and fat percentage measured with a Tanita (SC-330MA, Tanita Corporation of America, Illinois, USA) (2). Their height was measured standing with their heels against a wall, not wearing shoes.

Patients were asked about their previous and present sport activities, years with pain, pain medication, previous treatment modalities, comorbidities, smoking habits, alcohol intake, education, employment and sick leave in a questionnaire (5).

Patients completed the Flexion, ABduction and External Rotation test (FABER) (100) and anterior impingement tests at 90 and 120 degrees of hip flexion (2, 3, 100).

Specific questionnaire

The Copenhagen Hip and Groin Outcome Score (HAGOS) questionnaire (68) was chosen to be the primary questionnaire to monitor patient outcome (5). The questionnaire has been developed for a young and physically active patient group with hip and/or groin problems. The questionnaire consists of six subscales: pain, symptoms, activities of daily living (ADL), sport, participation in physical activities (PA) and hip related quality of life (QoL) (68). The patients were asked to focus the questions towards the hip included in the study. The subscales "pain" and "symptoms" were independently filled in for the contralateral hip afterwards. Disease-specific questionnaires often target several aspects from the ICF model (30) in order to characterise patient problems. HAGOS has subscales aimed specifically at different ICF levels:

- Body Functions and Structure: HAGOS pain and symptoms.
- Activity: HAGOS Activities of daily living and sport.
- Participation: HAGOS Participation in Physical Activities.

Hence, using disease-specific questionnaires aimed at the specific patient group highlights some of the specific disabilities found in the patient group.

All questions were collected using the same electronic questionnaire system developed for the Clinical Orthopaedic Research Group at Aarhus University Hospital, Aarhus, Denmark. The system was set up in such a way that it could not be completed before all questions had been answered.

Physical capacity tests

Patients completed the following physical capacity tests (3):

1. A stair-climbing test, where patients were asked to walk up and down a three-step staircase three times.
2. A stair-climbing test, where patients were asked to walk up and down a three-cased staircase three times with dumbbells.

3. Stepping up and down a 40-cm box three times with each leg.
4. Stepping up and down a 40-cm box three times with each leg with dumbbells.
5. Jumping off the 40-cm box three times.

The dumbbells were equivalent to approximately 20% of the participants' bodyweight. A physical capacity test was considered "completed" if the participant was able to complete three trials according to the instructions. A test was considered "uncompleted", if a participant was unable to perform three repetitions, used hand support or was unable to carry weight corresponding to 20% of their bodyweight (3, 5).

The tests were conducted as an explorative investigation of functional limitations in the patient group. The tests were inspired partly by patient complains of functional problems when assessed in the clinic and partly by performance tests described for patients with hip OA (101) or early hip OA (102) and on functional limitations in patients with FAIS (58-60).

Maximal hip muscle strength

Before assessment of maximal hip muscle strength began, participants performed a 5-min warm-up on a bicycle ergometer. Also before initiating the test, the test order of the hips and the starting muscle group was determined by randomisation (2).

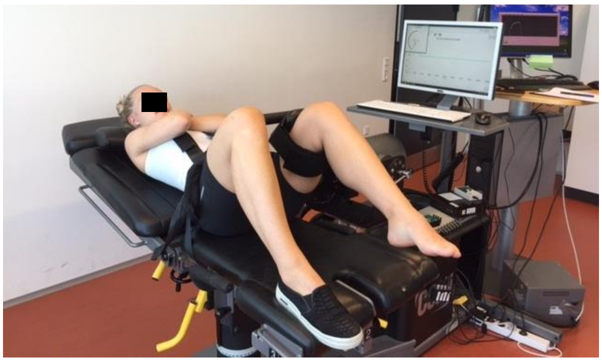


Figure 6: Maximal hip muscle strength test of the left leg (hip flexion) performed in an isokinetic dynamometer. Printed with permission from the patient.

For both hip flexion and extension tests, participants were supine on the dynamometer chair (Humac Norm, CSMi, Stoughton, Massachusetts, USA) with the chair back inclined 15 degrees and the dynamometer rotation axis aligned with the hip rotation centre (greater trochanter) (Figure 6) (43). Prior to the test, the mass of the tested limb was measured to adjust for gravity (2). The muscle groups were then tested in the following order: isometric, concentric and eccentric. For all three contraction types, participants completed two submaximal familiarisation trials followed by three Maximum Voluntary Contraction (MVC) trials (4 trials if the 3rd trial deviated >10% from number 1 and 2). Isometric testing was performed with participants lying with the hip flexed to 45° (43). Participants were instructed to perform maximally and build up the contraction as fast as possible. The contraction was held for 3–4 seconds, depending on when the participant reached a steady plateau. Standardised, verbal encouragement was provided. After isometric testing, participants had their isokinetic strength assessed in the range of hip motion from approximately 10 to 80° at an angular velocity of 60°/s. The participants were instructed to perform a concentric contraction as fast and hard as possible, immediately followed by an eccentric contraction at −60°/s. There was a resting period of 30 seconds between all tests. A measurement was excluded if the participant rotated the leg while performing a trial (2).

The reliability of isometric and isokinetic (60°/s) strength test of the hip flexors and extensors in healthy persons using an isokinetic dynamometer has been demonstrated to be high (ICC: 0.77–0.99) (103). Patients were asked to rate their pain during each test on a 0–100 mm visual analogue scale immediately after each test (2).

The maximal peak torque (Nm), sampled at 100 Hz, divided by body mass (kg) was calculated. In analyses of patient vs. references, differences in percentage were calculated as:

(reference right hip – affected patient hip) / reference right hip

and in analyses of affected hip vs. contralateral hip as:

(contralateral hip - affected hip) / contralateral hip (2).

Objectively measured daily activity level

Objectively measured daily level of activity was investigated using a tri-axial accelerometer (AX3 datalogger, Axivity, York, UK). Participants were asked to wear the accelerometer during all waking hours for five consecutive days. At least 1 of the days should be a weekend day.

The accelerometer was attached to the non-operative leg of the patients and the right leg of the reference persons (Figure 7) (4).

Participants were asked not to take off the accelerometer during the day, but report if they did so and why. After wearing the accelerometer, it was returned via mail and the data were downloaded using OpenMovement-GUI Application (Version 1.0.0.18, Newcastle, UK). Using a custom-made MatLab ® (MatLab R2014b, MathWorks, Inc., Natick, MA, US) script, data were separated into days. Hereafter, data

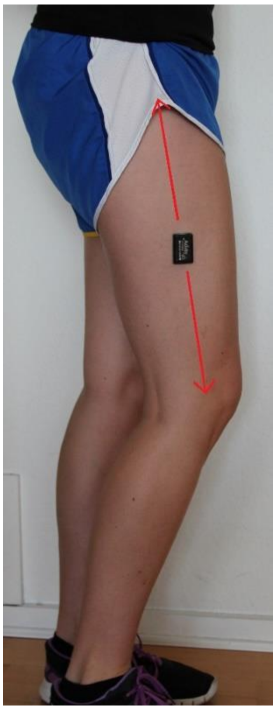


Figure 7: Placement of accelerometer on the lateral thigh

analysis was conducted as described by Lipperts et al. (104):

First, non-wear data were deleted. Second, a period of more than five steps uninterrupted walking was selected for calibration. The output of the analysis consisted of intensity categories and types of activity. Each 10-second data window was grouped into four intensity categories (104):

1. Very low activity as sitting or standing (0–0.05g).
2. Low activity such as standing or shuffling (0.05–0.1g).
3. Medium activity as slow and normal walking (0.1–0.2g).
4. High activity as fast walking, running and jumping (>0.2g).

Moreover, each activity was classified as resting, walking, standing, stair/slope climbing, bicycling and running. The frequency of these activities and the time spent within the activities were monitored. The intensity of walking (i.e. walking cadence) and number of steps were also determined (4, 104).

The algorithm has been validated and used in both healthy persons and in patient populations and has been shown to be accurate (104-106). In the Clinical Orthopaedic Research Group at Aarhus University Hospital, a reliability study investigating 27 persons was performed, showing a good relative reliability ($ICC_{2,1}$ = 0.88–0.99) (4).

Outcomes were calculated as a mean of 5 days of measurement. If a participant had recorded activity for less than 10 hours a day, that day was excluded (4, 5).

CT scans

Pre-operatively and 1 year post-operatively, patients underwent low dose CT scans of the pelvis and distal femur. The CT scans were acquired on a Philips Brilliance 64 (Philips Medical Systems, Best, the Netherlands) scanner with a low-dose at the Department of Radiology, Horsens Regional Hospital. The patients were scanned in supine position with parallel legs in slight internal rotation. The scanned area included both hip joints and the proximal femurs (4).

At Aarhus University Hospital, the CT scan data were transferred to a Philips Mx view station (Philips Medical Systems, Best, the Netherlands). On the reformatted images the centre-edge (CE) angle of Wiberg (107) and the acetabular index (AI) of Tönnis (99) were measured in the coronal slice passing through the centres of the femoral heads. The alfa angle of Nötzli (108) was measured on oblique axial views (4). All measurements were conducted by Consultant Lone Rømer.

Interventions

Surgery

All 60 patients with FAIS underwent hip arthroscopic surgery performed by Consultant BL. BL has performed more than 2300 hip arthroscopies in more than 10 years. Patients were operated on supine through antero-lateral and mid-anterior portals. After a small interportal capsulotomy was created, a diagnostic round was accomplished from both portals, and the relevant pathology was addressed. Labral tears were refixated with suture anchors. The number of anchors used for the repair depended on the quality of the labrum and the size of the tear. In patients with a grade 4 acetabular chondral defect, microfracture was performed. Bony deformities were addressed by osteoplasty using a motorised burr (3, 4).

Rehabilitation

The standard protocol after surgery included full weight bearing as tolerated and the use of crutches for 2 to 6 weeks. The patients followed a home-based rehabilitation programme supervised by specialised physiotherapists at the time points outlined in Figure 8. The rehabilitation programme progressed when tolerated by the patient.

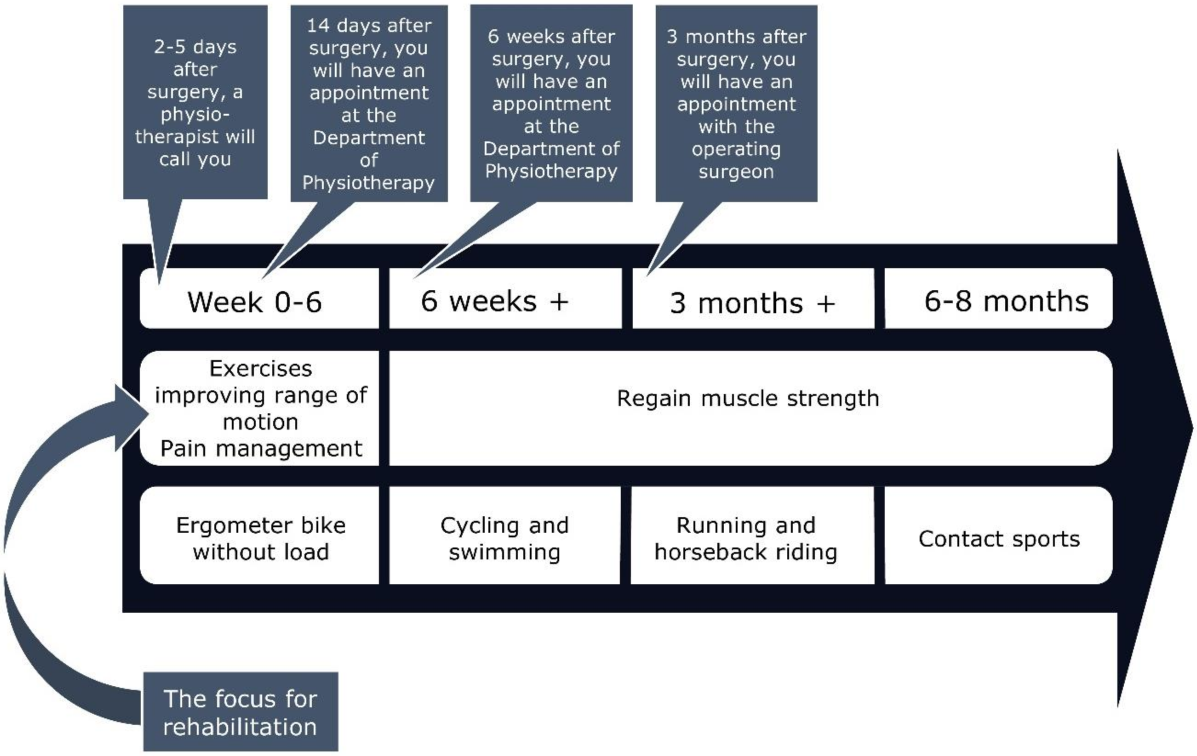


Figure 8: Focus for rehabilitation and return to sport adapted from the patient information at Horsens Regional Hospital made by Kirsten Olesen, Kasper Spoorendonk and Bent Lund (with permission)

Up to 2 weeks after surgery, rehabilitation mainly focussed on improving blood circulation using an ergometer bike with no load together with supine peristaltic pump exercises. After 2 weeks, bike load was increased, and exercises with focus on improving hip range of motion and hip and truncus strength were performed. At 6 weeks after surgery, patients were allowed to bicycle outdoor and to perform strength training at a gym if tolerated (3, 4). The rehabilitation programme was partly based upon that of Wahoff and Ryan (109).

Statistical methods

Before the statistical analyses were performed, it was determined whether data followed a normal distribution using the Shapiro–Wilk test, histograms and qq-plots. In papers (2) and (3), most data were normally distributed, while much data was not normally distributed in paper (4). All statistical tests were made with Stata 13 ®, and the significance level was set at $p < 0.05$. Statistical methods are presented in Table 6.

Table 6: Statistical methods in HAFAI-study

Type of data	Analysis
Binary data	*Presentation*: number of event (percentage). *Statistical tests*: Fisher's Exact test.
Normally distributed, continuous data	*Presentation*: mean and standard deviation, 95% confidence intervals *Statistical tests*: Comparisons between patients and references were conducted using multiple regression analysis, where results were adjusted for age and gender. This was performed since when using multiple regression analysis, a non-paired t-test is performed. But the patients and references were matched on age and gender. Hence, the most appropriate statistical test would be to adjust for age and gender in the analyses. Comparisons between pre-operative and post-operative measurements were conducted using paired t-tests.
Non-normally distributed, continuous data	*Presentation*: median and 25th and 75th quartile. *Statistical tests*: for paired data, Wilcoxon matched-pairs signed-rank test was used and for non-paired data Wilcoxon rank-sum test was used. Comparisons between three groups (age groups) were conducted using Kruskal–Wallis equality-of-populations rank test.
Associations	*Presentation:* coefficient, 95% confidence interval and R^2 *Statistical tests:* linear regression analysis

Results

Patient characteristics

Twenty-six studies were included in the systematic review (1). Overall characteristics of the patients included in the systematic review are presented in Table 7. For further details please, see Kierkegaard et al. 2017 (1). The overall characteristics of the patients included in the HAFAI study are presented in Table 8.

Table 7: Participant characteristics, systematic review

	Studies included in meta-analysis reporting pain, ADL, sport and/or QoL	Subgroup of studies reporting satisfaction
Studies (n)	19	7
Patients (n)	2322	494
Age (years)	36 ±8	37 ±14
Females (%)	42	29
Revision, n (%)	175 (7)	25 (5)
Lost to follow up, n (%)	319 (14)	8 (2)

Mean ±standard deviation, number of patients (percentage). ADL: activities of daily living. QoL: quality of life

Table 8: Participant characteristics, HAFAI study

	Self-reported hip healthy references	Pre-operative, patients	One-year post-operative, patients
Age at surgery (years)	36 ±9	36 ±9	36 ±9
Gender distribution (% females)	60	63	58
Body mass (kg)	68 ±9	76 ±15	77 ±13
Height (cm)	174 ±8	174 ±8	175 ±8
Fat mass (%)	23 ±12	27 ±10	27 ±9
Comorbidities (%)	27	25	
Positive FABER (%)		81	48
Positive 90-degree impingement (%)		86	77
Positive 120-degree impingement (%)		95	84
Alpha angle from CT		52 ±10	47 ±8
Centre-edge angle from CT		33 ±6	32 ±6
Acetabular index from CT		2 ±6	4 ±5
Use of pain killers (%)		58	30
Revision, n (%)			2(3)
Lost to follow up, n (%)			2(3)

Mean ± standard deviation or median and [25^{th}, 75^{th} quartile]. FABER: Flexion, ABduction and External Rotation test

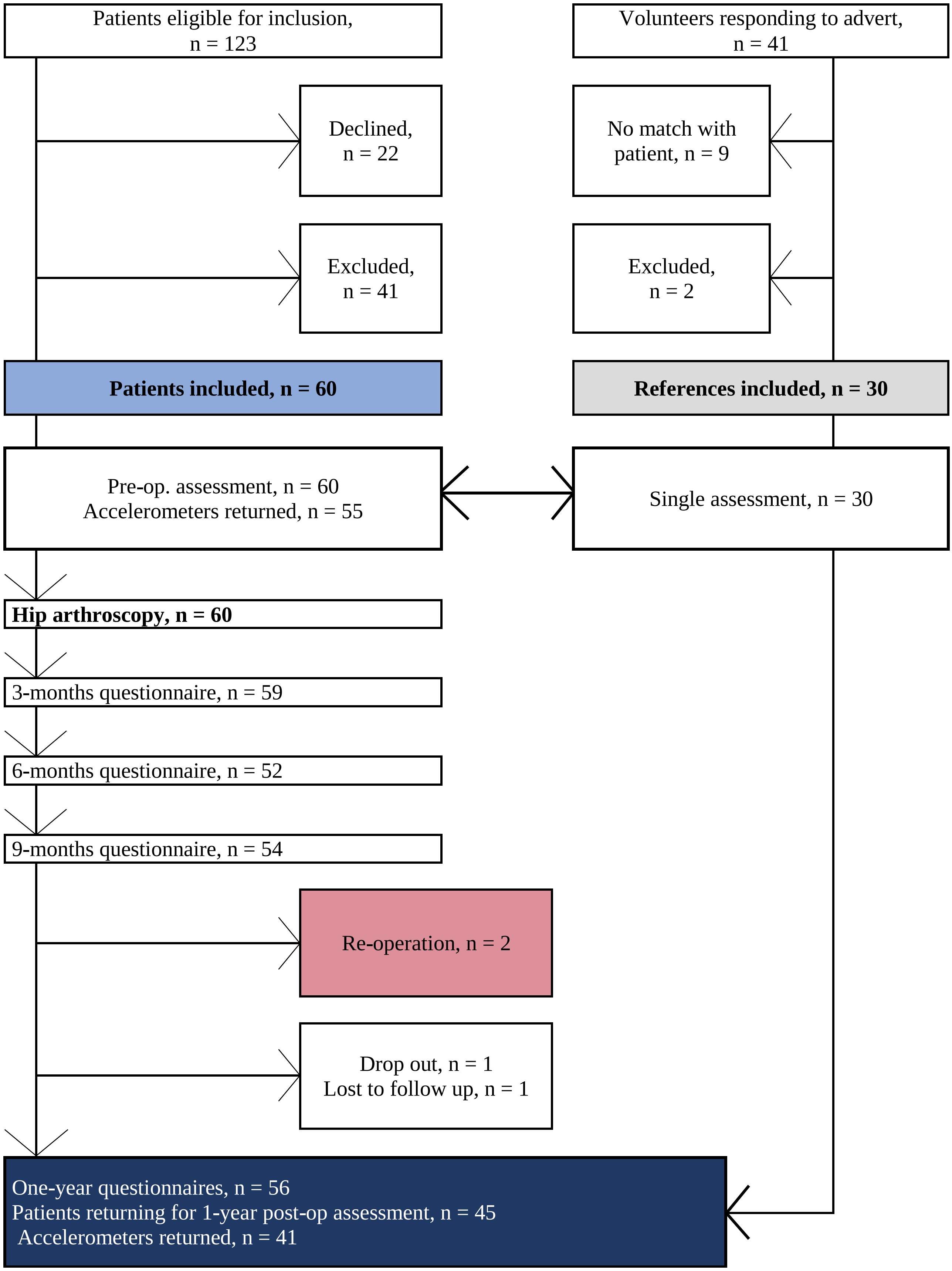


Figure 9: Patient flow in HAFAI study

Details related to the study flow in HAFAI study

Declining and excluded patients

In all, 22 patients declined participation in the study and 41 were excluded. The reasons for the 22 patients declining participation included:

- Living too far away (n = 8).
- Lack of energy to participate in a study (n = 7).
- Too busy to have time to participate in a study (n = 7).

The 41 patients who were excluded were excluded for the following reasons:

- Previous hip surgery (n = 14).
- Had surgery by another surgeon or at another hospital (n = 9).
- Declined hip surgery (n = 4).
- Neurological or systemic diseases (n = 4)
- Underwent hip surgery for other conditions than FAIS (n = 4).
- Unable to understand participant information (n = 3).
- Surgery too soon to allow test procedures preoperatively (n = 2).
- OA Tönnis Grade >1 (n = 1).

The mean age of the declining or excluded patients was 36 (range 20–50) years and 65% were females.

Re-operations and drop-outs

- One patient (female, 37 years at primary hip arthroscopy) had a re-operation due to a loosening of one anchor. Hence, the hip labrum was loose and displaced inside the hip joint. The anchor was replaced and the labrum refixated.
- One patient (male, 20 years at primary hip arthroscopy) had a second operation 11 months after hip arthroscopy due to necrosis of femoral head. The necrosis was existing before primary hip arthroscopy. Due to increasing symptoms 11 months after hip arthroscopy, a re-operation was performed.
- One patient (female, 41 years at primary hip arthroscopy) chose to drop out due to lack of energy to participate in the study.
- One patient (female, 37 years at primary hip arthroscopy) did not fill in the questionnaire 1 year after surgery. She was pregnant with due date shortly after the 1-year post-operative date and hence unable to participate in physical tests.

Summarising, 2 out of 60 patients (3%) had undergone revision surgery at 1-year follow-up and 2 out of 60 patients (3%) had missing questionnaires at 1-year follow up.

There were 11 patients, who completed the 1-year questionnaires, but did not participate in the post-tests for the following reasons:

- Pregnant (n = 3).
- Too mentally stressed to participate in post-tests (n = 4).
- Severe back pain (n = 2).
- Too busy to participate (n = 1).
- Moved to another country (n = 1).

Patient-reported outcomes

Pain

A significant and clinically relevant improvement in pain measured by VAS or NRS was found 6 months to <1 year after surgery in the systematic review (1). A significant and clinically relevant improvement in pain measured with HAGOS was found 3 months after surgery in the HAFAI study and 3 to <6 months after surgery in the systematic review (1). One year after surgery, the pain level of the median patient in the HAFAI study corresponded to "*mild*" (median 75) (3, 4).

Symptoms

A significant and clinically relevant improvement in symptoms assessed by HAGOS was found 3 months after surgery in the HAFAI study. One year after surgery, the median symptom level in the HAFAI study corresponded to "*mild*" to "*moderate*" (median 64) (3, 4).

ADL function

A significant and clinically relevant improvement in ADL function was found 3 to <6 months after surgery in the systematic review (1). A significant and clinically relevant improvement in ADL function was found 3 months after surgery in the HAFAI study. One year after surgery, the median difficulties with daily activities in the HAFAI study corresponded approximately to "*mild*" (median 80) (3, 4)

Sport function

A significant and clinically relevant improvement in sport function was found 3 to <6 months after surgery in the systematic review (1). A significant and clinically relevant improvement in sport function measured with HAGOS was found 3 months after surgery in the HAFAI study. One year after surgery, the median difficulty with sport activities in the

HAFAI study corresponded approximately to "*moderate*" (median 58)(3, 4).

Participation in physical activities

One year after surgery, 88% of the patients reported participation in physical activities (4). A significant and clinically relevant improvement in participation in physical activities assessed by HAGOS was found. The median answer to the ability *"to participate in your preferred physical activities as long as you like*" (68) and the ability to participate "*at your normal performance level*" (68) was "*Rarely*" (median score 25, IQR 13;63) (3, 4).

Quality of life

A significant and clinically relevant improvement in quality of life was found 3 to <6 months after surgery in the systematic review (1). A significant and clinically relevant improvement in quality of life was found 3 months after surgery in the HAFAI study. The median quality of life level 1 year after surgery in the HAFAI study was 50 (IQR 33–70) corresponding to "*moderately*" (68).

Satisfaction

Satisfaction with the overall outcome of the surgery was 68–100% in the systematic review (1).

Comparison with references

Neither mean scores from the systematic review (1) nor median or upper quartile HAGOS scores after surgery from the HAFAI study (3) reached reference group levels (3).

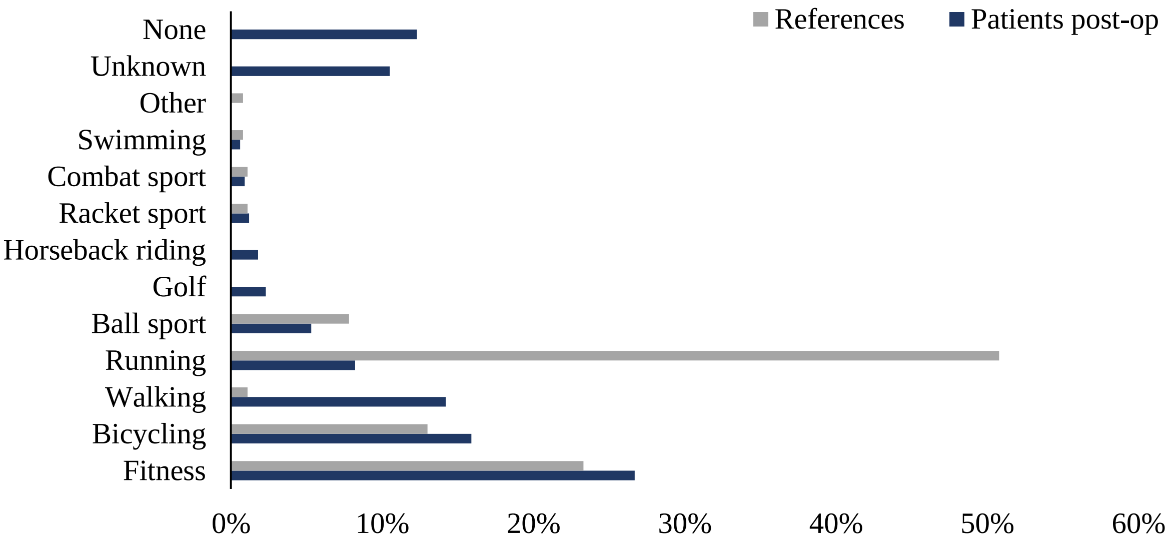


Figure 10: The distribution of favourite sport among patients 1 year after surgery and among self-reported hip healthy references (4).

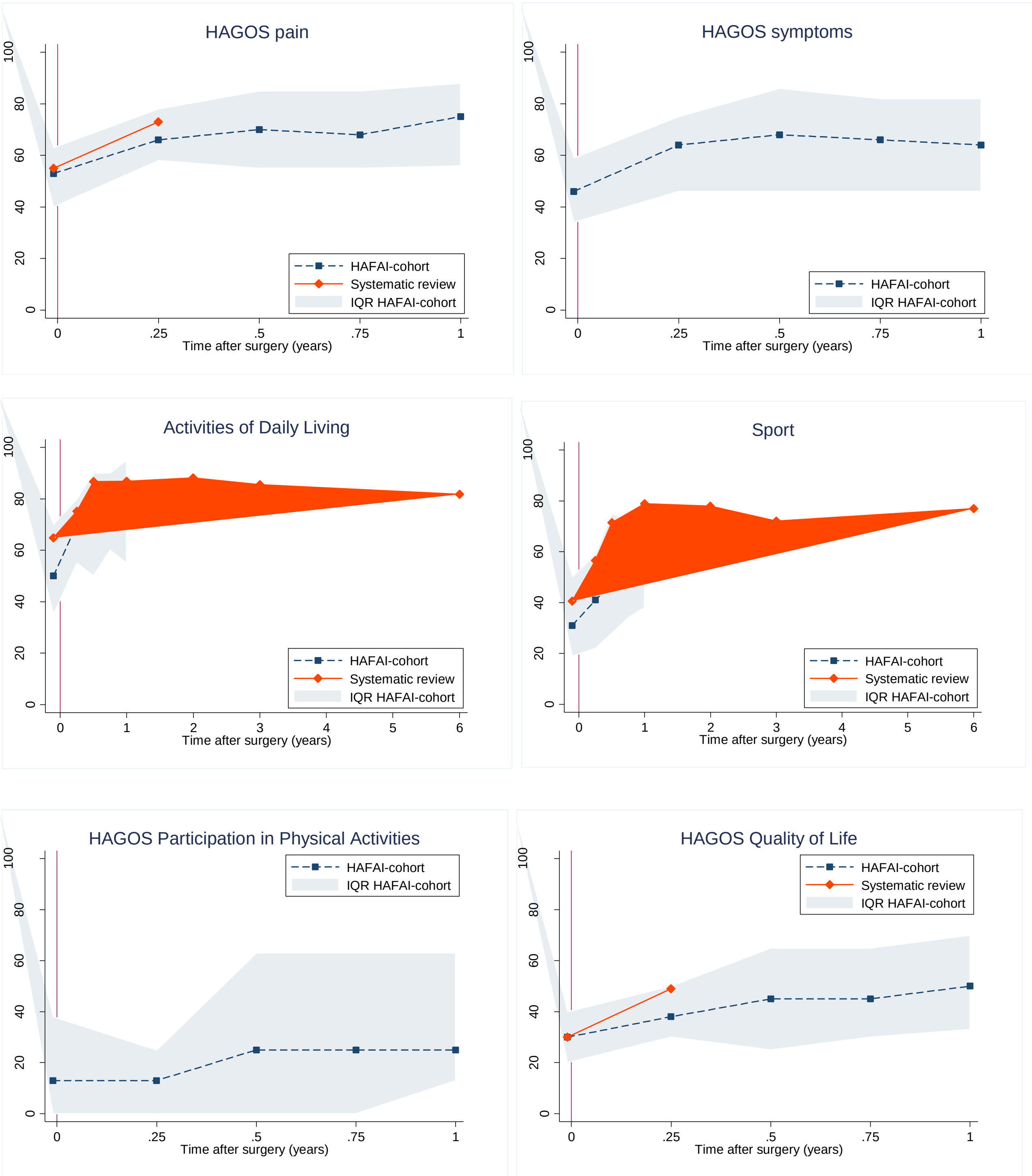


Figure 11: Patient-reported outcomes on a 0–100 scale (0 worst, 100 best) over time from systematic review (1) and from the HAFAI study. IQR: interquartile range

Objectively measured outcomes

Maximal hip muscle strength

Hip flexion and extension strength were impaired in patients with FAIS compared with self-reported hip healthy references (2). One year after surgery, maximal hip flexion strength during concentric, isometric and eccentric contraction improved as did maximal hip extension strength during concentric contraction (3). All measurements were still below those of the reference group (3).

Objectively measured activity level

Both pre-operatively and post-operatively, there were no significant differences in number of steps walked per day or total activity level between patients and references (4). Patients performed less cycling and running compared to references both pre-operatively and post-operatively (4).

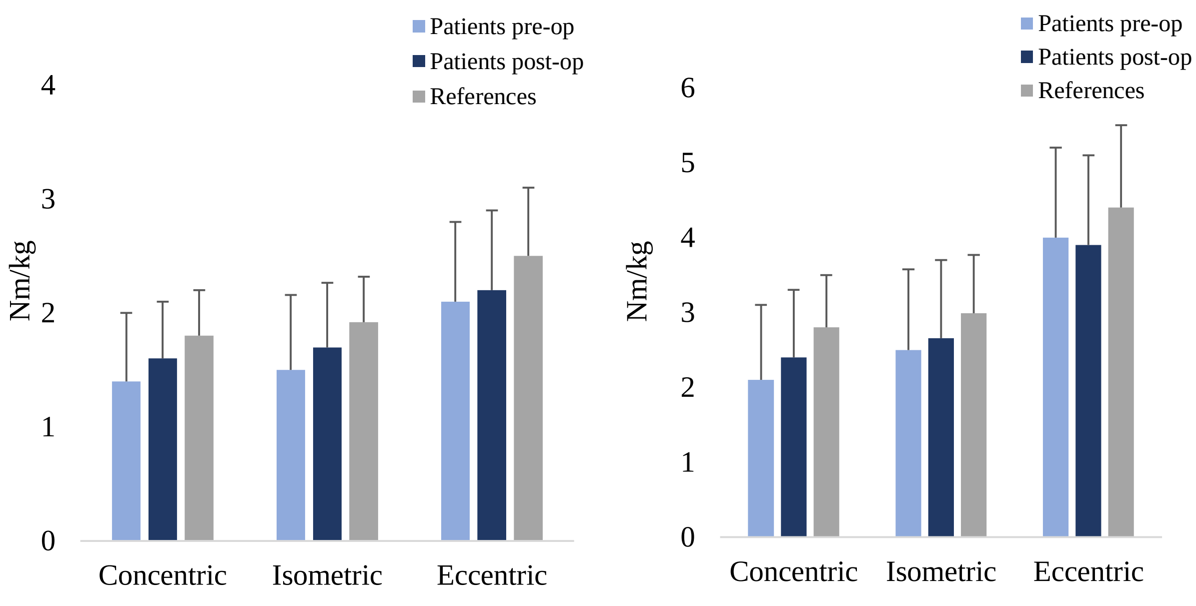


Figure 12: Maximal hip flexion strength (left) and maximal hip extension strength (right) (mean and standard deviation). Data from the HAFAI study. Pre-op: preoperatively. Post-op: postoperatively

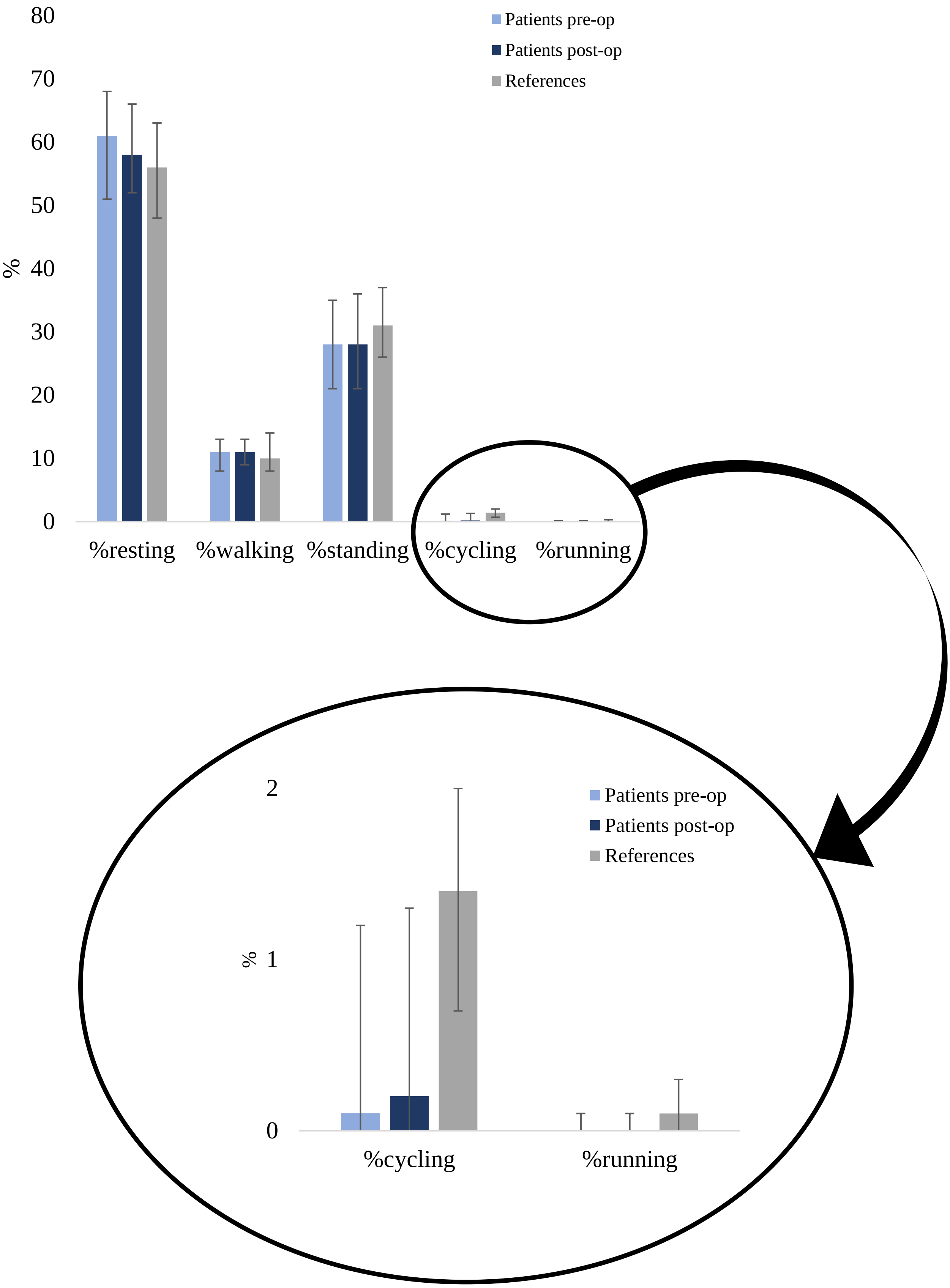


Figure 13: Distribution of daily activities measured with accelerometer (median, 25th and 75th quartile). Pre-op: preoperatively. Post-op: postoperatively

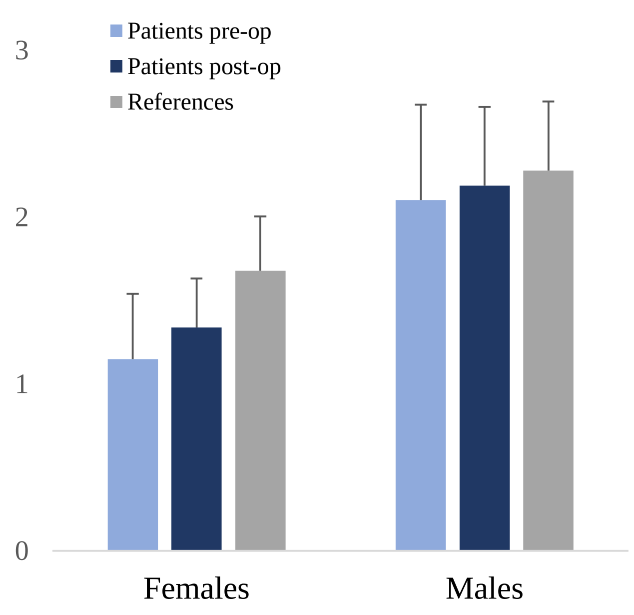
Subgroup analyses in HAFAI study

Age groups

There were no significant differences between the age groups in HAGOS scores pre-operatively or 1 year post-operatively. Changes in scores to a lesser degree was seen in patients aged 30 to <40 years for symptoms and ADL function compared to the younger and the older groups. (Symptom change: 7 vs. 25 and 17) (ADL function change: 10 vs. 23 and 22). Patients aged 40+ were significantly weaker than the two other age groups during isometric hip flexion both before and 1 year after surgery. The minor changes in activity from before to after surgery were primarily seen in patients aged 30 to <40 years, where there were significant changes in %standing (31→36%) and %resting (57→54%).

Genders

Neither HAGOS pre-operative scores nor 1-year post-operative scores differed between genders. For hip muscle strength, female patients were significantly more impaired than their reference counterparts both before and 1 year after surgery, while male patients were less impaired (3). There was not found a statistical significant difference in activity level between genders.



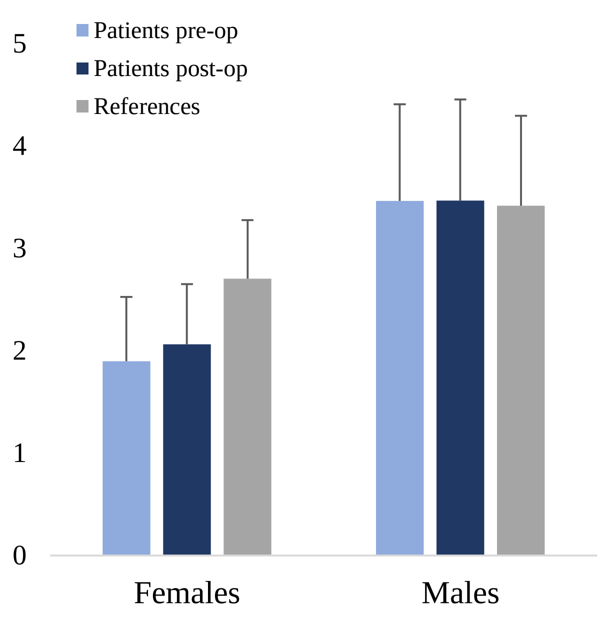


Figure 14: Isometric hip flexion (left) and extension (right) strength divided in genders (mean and standard deviation). Data from the HAFAI study.

Discussion

Key findings

Patients with FAIS experienced pain, decreased ADL and sport function, decreased participation in sport and quality of life. Furthermore, the maximal hip muscle strength of their hip flexors and extensors was decreased. Patients' daily activity level was not statistically different from that of self-reported hip healthy persons. After surgery, patients' pain levels decreased, their functional level and maximal hip muscle strength increased and their quality of life improved. However, patients remained impaired when compared to self-reported hip healthy reference persons. One year after surgery, 88% of the patients participated in physical activities but at a lower performance level than references (1-4).

Discussion of findings in relation to the literature

Pain and hip muscle strength

The findings of decreased hip muscle strength in patients with FAIS when compared to reference persons in the current study is tabulated together with findings from other studies in the literature (Table 12). Combining studies including patients with FAIS with studies of associated disorders consisting of patients with hip pain and/or labral pathology, there is increasing evidence supporting the notion that hip muscle strength is decreased in this combined patient group. Insignificant findings were predominantly seen in the studies with smaller numbers of patients,

Table 12: Percentage deficit in isometric hip muscle strength in patients with FAIS and in associated disorders compared to healthy controls. A positive number indicates deficit.

	Study	Year	Patients (n)	Controls (n)	Flex (%)	Ext (%)	Abd (%)	Add (%)	Int rot (%)	Ext rot (%)
FAIS	**Casartelli et al. (43)**	2011	22	22	**26**	1	**11**	**28**	14	**18**
	Diamond et al. (44)	2015	15	14	16	23	**20**	12	24	6
	Kierkegaard et al. (2)	2017	60	30	**21**	**16**				
Associated disorders	**Harris-Hayes et al. (110)**	2014	35	35			**22**		**21**	**22**
	Mendis et al. (111)	2014	12	12	**28**					
	Kivlan*et al. (112)	2016	15	13	9	**31**	10	5	19	11
	Freke*et al. (113)	2018	111	62	**34**	**35**	**28**	**29**	**34**	**32**

Bold indicates significant difference. FAIS: femoroacetabular impingement syndrome. Associated disorders: patients with hip chondropathy and/or hip pain * Percentage calculated from absolute numbers. Flex: flexion. Ext: extension. Abd: Abduction. Add: adduction. Int rot.: internal rotation. Ext rot.: external rotation.

which could simply be due to variation and too low a statistical power to show a difference.

It is difficult to investigate the causal relationship between decreased muscle strength and FAIS – which one caused the other? When a patient is not subject to trauma, it is difficult to know what came first – decreased muscle strength, hip pain or damage to the intra-articular structures. In joints other than the hip, both experimental and chronic pain contributes to altered muscle function around the joint (114-116). Hip pain is reported to be the main symptom of FAIS (15). Hence, it is relevant to hypothesise that hip pain might contribute to altered hip muscle function in patients with FAIS. Additionally, the previously mentioned theory of Lewis et al. (42) suggests that decreased hip muscle function may contribute to decreased stability of the hip joint, increasing the stability demands on the passive structures. This could possibly result in damage to the intra-articular structures (42). In Figure 15, the possible mechanisms are illustrated.

One of the unanswered questions regarding the pathogenesis of FAIS is how and why symptom-free persons with cam and/or pincer morphology develop FAIS (15). If we hypothetically suggest that symptom-free persons with cam and/or pincer morphology have a good hip muscle function, this may be one of the ways to stay free of symptoms

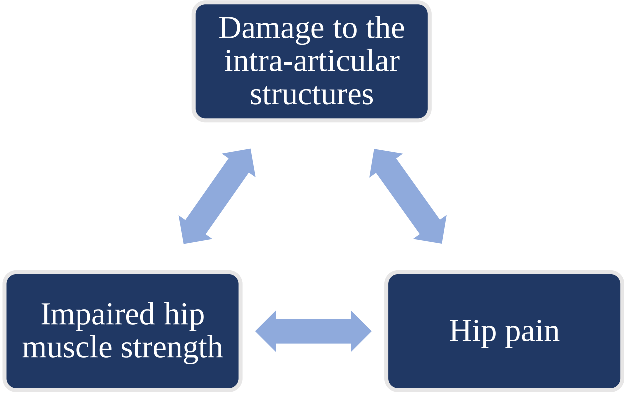


Figure 15: Co-existing findings in femoroacetabular impingement syndrome.

because muscles control the hip joint despite morphological changes being present. However, if this person, for some reason, experiences a tear of the hip labrum and experiences hip pain, then suddenly that person could alter movement pattern and lose hip muscle strength. Another situation could be loss of hip muscle strength, e.g. with age and decreasing participation in sport activities, and thus at a certain level, the muscles are no longer strong enough to stabilise a hip joint with morphological changes. A person could then – hypothetically – develop FAIS. This theory could be tested in cohort studies investigating the development in hip muscle function in symptom-free persons with cam and/or pincer morphology.

In the systematic review (1), a quick pain reduction (Figure 11) was found. This was also seen in the HAFAI study. These findings are in good correspondence with what could be expected after surgery: the quick decrease in pain suggests that the surgical procedure performed repaired/removed/fixed the structures that caused some of the pain inside the hip joint. It could be the repair of the labrum, removal of bone or some of the other procedures performed during surgery. It could also be with help from the post-operative programme of resting the joint and slowly rehabilitating it. Also, some psychological effects of the surgery could be present. Already 60 years ago, it was discussed whether there is a placebo effect of surgery (117).

To date, studies on so-called sham surgery in patients with FAIS are ongoing to investigate how much of the experienced effect after hip arthroscopy can be explained by placebo (118, 119).

One year after surgery hip muscle strength improved, but after surgery, several patients were still weaker than references persons (3). When taken together, some improvements do take place, but minor persistent deficits are reported in other studies of patients undergoing hip arthroscopy (Table 9).

Table 9: Studies investigating postoperative hip muscle function in patients with FAIS

	Study	**Year**	**Number of participants**	**Mean time to follow-up (years)**	**Comparison to pre-surgery level**	**Postoperative values compared with healthy references**
FAIS	**Seijas et al. (80)**	2017	22 patients	1	Time to contract the gluteus maximus improved after surgery	
	Kierkegaard et al. (3)	2018	45 patients, 30 controls	1	Improvement in isometric and isokinetic strength of the flexors and concentric strength of the extensors	Hip flexors and extensors remained impaired compared with references
	Casartelli et al. (83)	2014	8 patients, 8 controls	2.5	Maximal isometric strength of six muscle groups improved	Deficits in isometric hip flexion strength
Associated disorders	**Kemp et al. (87)**	2014	84 patients, 60 controls	1.5		Deficits in isometric strength for all hip muscles but the internal rotators

FAIS: femoroacetabular impingement syndrome

A possible mechanism could be that the decrease in pain and increase in muscle strength are simply interrelated and that hip muscle strength is still impaired because hip pain still exists.

As described earlier, the mere existence of pain in a joint can induce muscle inhibition (115). Hence, it could be argued that when patients are not pain-free after surgery, they will not gain muscle strength to a degree similar to that seen in reference persons. In the HAFAI study, an association between pain measured with HAGOS and hip muscle strength pre-operatively was found (2), while the picture was less clear after surgery (3). Trying to come to a deeper understanding of this, we first need to identify from which structures pain may arise in patients with FAIS.

As described in the Background section, patients with FAIS report pain from different locations around the hip and groin (15). It can be pain deep in the hip joint (32), superficially located pain, or pain during movement, in specific positions and at night (15). It is difficult to quantify the origin of these pain sensations. The deep pain may origin from the structures near the joint and the intra-articular structures (33), while the more superficial pain could origin from muscles, tendons and ligaments. When testing the patients in the HAFAI study, some patients mentioned that their deep hip pain had vanished after surgery, but pain more superficially located still existed. In surgery for FAIS, much attention is put on the intra-articular pathology. However, with the findings of muscle impairment both before and after surgery and the fact that the average patient still experiences some mild pain after surgery (1), it is important to further investigate the structures located around the hip joint. This could be done using the approach of Hölmich (120), who described how pain related to tendons and muscles around the hip and groin may be quantified. If the post-operative pain is mainly related to muscles and tendons, further interventions should be focused on these areas. However, to the best of our knowledge, the origin of postoperative pain has not been identified in patients with FAIS – only decreased muscle function has been documented as an involved parameter.

In general, muscular weakness has been associated with disability later in life (121). Patients with hip OA, gain improvements in pain and quality of life and reduce intake of painkillers after targeted rehabilitation (122). With the good results from rehabilitation in patients with hip OA (122) and the findings of hip muscle impairments in patients with FAIS who are at risk of developing OA, it is of great importance to look further into rehabilitation of the hip muscles in patients with FAIS.

Neither the HAFAI study (3) nor earlier studies of postoperative hip muscle strength in patients with FAIS (80, 83) and related disorders (87) monitored postoperative rehabilitation. This is a limitation and it is a knowledge gap in the literature since we do not know what parts of the current rehabilitation programmes are effective and which are not. Fortunately, there is an increase in the attention directed towards rehabilitation post-surgery in this patient group. During this summer (2018), there was a meeting in Coventry, United Kingdom, for researchers and clinicians working with patients with FAIS with the aim of producing a consensus statement about postoperative rehabilitation in patients with FAIS. Furthermore, a randomised controlled study by Bennell et al. has been published investigating the effect of additional rehabilitation post-surgery (123). However, the study was terminated prior to its completion and thus conclusions are vague. Although the study suggested a potential benefit, more research should be performed into the impact of rehabilitation in patients with FAIS and the effect of post-operative rehabilitation since knowledge is lacking.

Activity limitations

ADL function increased rapidly after surgery (Figure 11) (1). In the systematic review, a steady level was seen 6 months after surgery (1), while in the HAFAI study (where only 1-year post-operative follow-up was obtained) it looked as if a steady level was present from 9 months and onwards (Figure 11). The median patient in the HAFAI study was more impaired than the mean patient in the studies in the systematic review (Figure 11). Eight of 10 studies in the systematic review reported ADL scores using the HOS ADL and seven of nine studies used the HOS sport for sport function. Only one study used HAGOS and one HOOS. In studies of the psychometric properties of the scores, patients scored higher on the HOS than on the HAGOS, especially pre-operatively and during sport (Table 10). The differences in the scores used for evaluation of outcomes could produce different findings.

Table 10: Scores on different disease-specific scales from earlier studies

Measurement time	Domain	HOS (mean)	HAGOS (mean)
Pre-operative (124)	Activities of daily living	80	76
	Sport	59	46
Post-operative (95)	Activities of daily living	86	84
	Sport	75	69

HOS: Hip outcome score (125). HAGOS: Copenhagen Hip and Groin Outcome Score (68).

Another reason could be that the patients in the HAFAI study had greater impairments than those patients included in previous studies, and therefore, their outcomes were also poorer after surgery. Despite this, both in the systematic review and in the HAFAI study, patients scored reasonably on ADL function after surgery. This corresponds well with the objectively measured scores: patients walked a similar number of steps per day compared with references (4).

Table 11: Physical function after surgery in patients with FAIS and associated disorders (listed by time to follow-up)

	Author	Year	Number of participants	Mean time after surgery (years)	Compared with before surgery	Postoperative values compared with controls
FAIS	**Lamontagne et al.*(79)**	2011	10 patients	0.7–2.7~	Squat performance improved	
FAIS	**Rylander et al. (81)**	2013	17 patients, 17 controls	1	Walking improved	Stair climbing remained altered compared with references
FAIS	**Kierkegaard et al. (3)**	2018	45 patients, 30 controls	1	More patients completed physical capacity tests	Not all participants could complete physical capacity tests
FAIS	**Kierkegaard et al. (4)**	2018	45 patients, 30 controls	1		Patients performed less cycling and running compared with the references both before and after surgery
FAIS	**Brisson et al.* (82)**	2013	10 patients, 13 controls	1.8		Reduced range of motion during walking both before and after surgery compared to references
Associated disorders	**Kemp et al. (126)**	2016	71 patients, 60 controls	1.5		Worse single leg rise test, worse side bridge test, shorter hop distance
Associated disorders	**Hatton et al. (127)**	2014	63 patients, 60 controls	1.5		Worse single leg balance

FAIS: femoroacetabular impingement syndrome. ~Only reported a range

In Table 11, physical function findings from other studies are summarised. In biomechanical studies, some changes have been found in walking pattern after surgery (81), but it has also been shown that patients persisted in having an altered movement pattern after surgery (82). However, findings from biomechanical studies have generally disagreed regarding whether patients with FAIS experience a different walking pattern or not (81, 82). Similar to our measurements, Harris-Hayes et al. (64) found no difference in number of steps taken per day between patients with FAIS and references. With the fairly high scores in ADL function (1) and the findings from the HAFAI study (4), it seems that ADL function is not the main problem in patients with FAIS, which is in agreement with the observation that symptoms found in patients with FAIS are provoked mainly when engaging in end-range positions (15).

The findings from this dissertation suggests that sport function remain more impaired than ADL function after surgery (1, 3, 4). Objectively measured, patients did less running and cycling than references (4). Impairments were also seen in the sport scores from the systematic review on sport function (1), which did not reach as high levels as did ADL function (Figure 11). In the HAFAI study, the number of patients who completed physical capacity tests increased 1 year after surgery (3) and most patients participated in some kind of physical activity (4). In total, the current body of evidence (Table 11) suggests that physical function is still impaired in patients with FAIS and associated disorders after surgery.

In the HAFAI study, the level of sport was registered by asking the patients whether they participated in sport and what activity they performed (4). Other studies have published the mean level of sport in patients with FAIS 1 to 5 years after surgery (Table 12) using the Hip Sports Activity Scale (HSAS) (128). This scale is a 0–8 scale, where patients

Table 12: Hip Sports Activity Scale (0–8) in existing studies on patients with femoroacetabular impingement syndrome

Author	Year	n (patients)	Pre-operative	Post-operative	Years to follow-up
Lund et al. (71)	2017	2054	2.5	3.1	1
Lund et al. (71)	2017	2054	2.5	3.3	2
Sansone et al. (72)	2016	85	2.9	3.6	2
Naal et al.* (129)	2014	185	-	3.5	5

N: number of patients. *patients had open surgery.

with a single choice rate their current level of sport. Earlier studies reported a mean value after surgery between 3 and 4 on the scale (Table 12), which corresponds to "Recreational sport" like 3: "*Aerobics, Jogging, Lower extremity weight-training, Horseback riding, Cricket*" (128) and 4: "*Tennis, Downhill skiing, Snowboarding, Indoor sports, Baseball/Softball*" (128). In the study by Naal et al. (129), the type of activity was also registered. The four most common activities were cycling (23%), fitness (20%), skiing (18%) and jogging (11%). In the HAFAI study, the four most common activities were fitness (27%), cycling (16%), walking (14%) and running (8%). The activities performed by the patients in the study by Naal et al. are at a higher performance level than the activities in the HAFAI study. The study by Naal et al. was conducted in Switzerland and the HAFAI study in Denmark. Thus, natural geographic variation does not allow the Danes much skiing. Another difference was that the proportion of males/females was opposite that of the HAFAI study. A study reported males with FAIS having a higher activity level measured with the University of California at Los Angeles (UCLA) activity scale (65) and another study from the Danish Hip Arthroscopy Registry also demonstrated that females reported lower activity scores on the HSAS both 1 and 2 years after surgery (85). If this is partly the explanation to why females are more impaired in hip muscle strength than males (2, 3) needs further investigation.

The overall rate of return to sport was 88% in the HAFAI study. A similar rate was calculated in a recent systematic review (130). However, it has also been suggested that patients might return to sport, but not at a high-performance level (62, 63). These trends were also seen in the HAFAI study (4). Hence, expectations for surgery should be carefully discussed with the patients who have a specific interest in getting back to a high level of performance in sport because it might not be possible for them to engage in sport at the same level of performance as before symptom debut.

Quality of life

Quality of life was left out of the title of the systematic review (1) since not many studies addressed the change in this domain from before to after hip arthroscopic surgery. After completion of the systematic review, more studies on the change in quality of life after surgery using HAGOS have been published (Table 13). Generally, patients experience improvements in quality of life, but they are still very affected after surgery as seen on the HAGOS quality of life scale. Kemp et al. (131) investigated physical factors associated with quality of life after surgery in patients with hip

Table 13: Studies reporting quality of life after undergoing surgery for FAIS. Measurements are all performed by HAGOS

Author	**Year**	**Number of patients**	**Pre-operative**	**One-year follow-up**	**Two-year follow-up**
Sansone et al. (72)	2016	85	33		58
Lund et al. (71)	2017	1835	30	54	56
Thorborg et al. (70)	2018	77	27	59	
Kierkegaard et al. (3, 4)	2018	56	30	50	

chondropathy. They found that hip flexion range of motion and hip adduction strength were associated with better quality of life measured with HOOS and with iHot33 1 to 2 years after surgery (131). In the systematic review (1), it was chosen not to include iHot33 because it is a composite score containing several domains combined into one score (132). iHot33 was used in a recent RCT comparing arthroscopic hip surgery to conservative care/rehabilitation (74). Looking at data from the surgical part of this study which are comparable with data in the studies included in the systematic review (1) and the HAFAI study (3, 4), patients increased their quality of life compared to before surgery from 39.2 ± 20.9 to 58.8 ± 27.0 at a mean time after surgery of approximately 8.1 months (74). This improvement is comparable to that found with the HAGOS quality of life scale (Table 13). The results reflect some of the same findings as the other domains investigated with patient-reported outcomes: patients improve, but are still affected after surgery.

How to improve quality of life depends on the investigated "quality of life" domain. As described above, Kemp et al. (131) found associations between hip adduction strength and hip flexion range of motion and increased quality of life. In the HAFAI study, an association between increased hip muscle strength of the hip flexors and extensors and HAGOS quality of life before surgery was found (2), indicating that function is related to quality of life in this patient group. When using linear regression to investigate quality of life data from HAGOS 1 year after surgery, the quality of life score is closely related to the other scores derived from the questionnaire. Especially pain (R^2: 0.80, coef: 0.80 [0.70–0.92]), symptoms (R^2: 0.73, coef: 0.76 [0.64–0.89]) and sport (R^2: 0.75, coef: 0.95 [0.81–1.10]) are closely related but also the scores on ADL and PA were associated with quality of life (R^2: 0.63, coef: 0.81 [0.65–0.98]) and (R^2: 0.55, coef: 0.89 [0.67–1.10]), respectively. Hence, these data suggest that when pain, symptoms and sport function are improved after hip arthroscopic surgery, quality of life of the patients will likely also improve. A study similarly described how post-operative self-reported hip function correlated with general health-related quality of life in 88 patients (median 2 years after hip arthroscopy) (133). Further, it was described that satisfaction with surgery correlated strongly with hip-specific and general health outcomes in the patient cohort (133). Other authors have found that patient satisfaction with surgery had a large impact on the results of surgery (90).

Age and gender subgroups

In the HAFAI study, females suffered from more substantial hip muscle deficits than their healthy counterparts, while males very not similarly impaired (2). One year after surgery, females remained impaired, while there was no longer a significant deficit among males (3). Of note, the current study included fewer males than females and hence, the statistical power to detect differences is smaller in the male group. However, larger impairments among females have also been observed in other studies. Both Mygind-Klavsen et al. (85) and Nepple et al. (65) found worse outcome scores in females vs. males. The disease pattern was different in females vs. males: males had larger alpha angles and more intra-articular disease. Higher alpha angles in males were also found in another study (66). In the HAFAI study, higher alpha angles were similarly found in males vs. females. Hence, there is growing evidence suggesting differences between genders in both radiological presentation of FAIS and symptomatology. In the study by Nepple et al. (65), males had higher sport activity levels as judged by the UCLA activity scale. In the HAFAI study, no significant difference in activity level measured with accelerometers was found, but this could be affected by the large variations within the group. After surgery, Kemp et al. (87) found greater muscular impairments in females 1-2 years after hip arthroscopy in patients with hip chondropathy. The findings from the current study and earlier suggest that clinicians should be aware that different impairments may exist with regard to gender in patients with FAIS.

In the present dissertation, a small effect of age was observed: the oldest patients had lower isometric flexion strength both before and after surgery. Muscle strength decreases with age, and therefore this finding is meaningful. In the systematic review (1), age and gender subgroups were planned, but studies did not report separate outcomes for genders and age groups, and the mean age in the studies was quite similar in most studies. Hence, analyses of these factors were not possible in the systematic review (1). Multiple other confounders might have an impact on patient outcomes, but it is beyond the scope of this dissertation to investigate these further.

Methodological considerations

In the following, the internal validity will be discussed in relation to study designs, data collection, bias, confounding and missing data. The external validity will be discussed focussing on generalisability.

Study designs

Systematic review

A systematic review of high quality RCTs is considered one of the highest levels of evidence (134). One of the most important limitations of the present systematic review (1) is that it covers mostly case series, cohort studies and a few RCTs, not comparing effect of surgery but surgical methods. When conducting a systematic review of RCTs investigating the effect of surgery by comparing one intervention with placebo, no treatment or sham treatment, an actual treatment effect can be discussed. But, since none of the included studies, were of this type, the conclusions of the systematic review should be interpreted cautiously. Wall et al. (75) published a Cochrane review in 2014 describing that no RCTs investigating the effect of surgery on FAIS had been published. With that in mind, it was known that it would not be possible to conduct a systematic review based on such evidence. However, much could still be learned from the published case series, cohort studies and RCTs comparing different treatment options at the time. Currently (2018), there are still no published studies of the effect of the surgical treatment of FAIS compared with placebo or sham treatment. However, around the world, researchers are conducting studies into the field (119, 135), which might help demonstrate the efficacy of surgery in patients with FAIS.

HAFAI study

The design of the HAFAI study was a prospective cohort study with a cross-sectional comparison. Patients were enrolled consecutively and the research questions were published a priori (5). One may argue that it was actually a case-series investigation that was conducted since the outcomes of a specific intervention were reported in one patient group. However, since the aim of the HAFAI study was also to conduct further follow-up in the future, it was chosen to label it a cohort study. Other studies of function before and after surgery in patients with FAIS have used a similar study design and compared patients pre- and postoperatively with a control group without hip pathology (43, 79-82). One of these studies labelled itself a cohort study (80), while the others did not categorise their study. Regardless of how the authors have labelled the design of their study, a case series or a cohort, the study designs are associated with multiple risks of bias. Patients were not randomised to the treatment, and there was no comparison arm that included patients without treatment. The same was true regarding the studies in the systematic review (1). Hence, the results of this dissertation should be interpreted with this in mind: studies present possible trends, but not actual causal associations or effects. Consequently, the study designs allow investigation into trends that may be investigated in future studies in which patients are randomised into different groups.

The HAFAI study was conducted as a pragmatic study (136). The aim was to investigate current practice with as few disturbances as possible during the treatment of patients. Due to the study design, it was not possible to monitor rehabilitation of the patients. Two-thirds of the patients were referred to further rehabilitation in a community setting. It is unknown what kind of rehabilitation the patients undertook after surgery. Hence, we cannot know what the hip muscle strength and functional measures are based upon – patients participating actively in rehabilitation or not? Future studies ought to monitor both pre and postsurgical rehabilitation of the patients in order to identify areas that need to be optimised to best improve function.

Another consideration with regard to the study design is that no imaging was performed of the reference group. When designing the study in 2014 (5), the option of imaging the reference group was discussed. However, since a large number of asymptomatic persons in the general population are found to have radiological cam or pincer morphology, it was found most important to make sure that the reference persons had no hip pain or functional problems with respect to their hip. These reflections were supported by the Warwick agreement in 2016 (15), where it was determined that the main symptom of FAIS is pain. There is a risk that some participants from the reference group could develop FAIS over the years. There is no evidence to support what happens with persons currently asymptomatic but with cam or pincer morphology. Hence, there is a risk that our reference group could develop FAIS. Therefore, it was chosen to label it as a self-reported hip healthy “reference group” rather than as a “control group”.

Data collection

Systematic review

In the systematic review (1), the data collection consisted of extraction of data reported by others. The reporting in the studies included in the systematic review (1) was very poor. Hence, it was difficult to know how comparable the patients were and if scores measured the same thing. This latter was especially evident in the measurements of pain with VAS and NRS. The included studies rarely described the actual question asked, hence knowledge about whether it was pain at rest, during activity, after activity or whether the pain assessment was performed during a specific time frame are unknown (1). Hence, the analyses based upon the validated questionnaires seem more reliable. The participant flow in some of the studies was also very poorly described – in fact several authors had to be contacted to ask whether we interpreted their studies correctly (1). This finding inspired us to present our own collected data very openly with the actual number of patients mentioned often.

HAFAI study

In the HAFAI study, both patient-reported outcomes and objectively measured outcomes were collected (2-4). In the following, the different methods will be discussed.

Questionnaires

As the main questionnaire, HAGOS was chosen (68). The score has been developed and validated in young to middle-aged Danish patients with hip and groin pain (68). Another score that could have been used in the patient group is the iHot33 (132). iHot33 was like HAGOS developed in a group of patients with hip pain. One of the differences between the scores is that while HAGOS gives results as six separate subscales, iHot33 only gives one single composite outcome score. A composite score can be useful, e.g. when aiming at estimating effect sizes for RCTs or when determining the total quality of life of the patients. However, the aim of the HAFAI study was to investigate the changes in the separate subscales providing detailed information about pain, function and quality of life after surgery. Other scores have been used in the setting of hip arthroscopy, e.g. Harris Hip score, Non-Arthritic Hip Score and Hip disability and Osteoarthritis Outcome Score (55). However, none of these scores are developed for and tested in young patients with hip and/or groin pain (137).

Maximal hip muscle strength testing

The hip muscle strength tests were conducted in a gold standard isokinetic dynamometer. However, there were still several limitations to the equipment.

First, attention to compensatory strategies was important. In an isokinetic dynamometer, it is movements and not specific muscles that are tested. The aim was to test hip flexion and extension strength. When flexing the hip, several muscles may contribute to this action: m. iliopsoas, m. sartorius, m. rectus femoris and m. tensor facia lata (31). If the leg is rotated, the adductor group further contributes to the flexion of the hip (31). Hence, the picture of the muscle function in the patients is easily blurred when the patient uses compensatory strategies like rotating the leg. Attempts were made to spot whether the patient rotated the leg during testing, and the test was discarded if found to be influenced by compensatory movement.

Second, since the aim was to investigate hip muscle function both isometrically and isokinetically, it was not possible to test muscle function in all three planes. Originally, more tests than finally included in the test battery were conducted. However, pilot testing showed that performing one isometric and two isokinetic tests of each muscle group in the sagittal plane was at the limit of what healthy persons could perform while still being committed to the test session and without getting too tired. Hence, our hip muscle strength measurements focused on hip muscle function in the sagittal plane and it is uncertain if patient muscle function is impaired in the other planes. This is a limitation concerning the interpretation and further use of our results when planning rehabilitation programmes.

<u>Physical capacity tests</u>

The choice of physical capacity tests was made based on the literature available and the clinical experience in the project group. In 2014 when the HAFAI study was designed, there was not much evidence to support which functional problems patients were experiencing. Some biomechanical studies suggested problems with walking (82) and stair climbing (81). Furthermore, squatting was discussed (79). When assessing patients with hip dysplasia at the Clinical Orthopaedic Research Group in Aarhus, step tests were examined. The Osteoarthritis Research Society International published their recommended set of functional tests for persons with OA (101). The tests were, however, aimed at older patients. In patients with FAIS, it was further complicated by the expectation that some patients were able to run, while others were hardly able to walk. Hence, it was difficult to find good functional tests that could capture all patients – a difficulty which has also been reported by other researchers (102). We chose to include some easy physical tests (walking) (data not analysed yet) and some more advanced (jumping and stepping) and added dumbbells because it was the clinical experience of the project group that some of the patients found it difficult to carry weight due to their hip problems. Hence, the selection of tests was highly explorative. Later, Kemp et al. (126, 127) published a relevant selection of functional capacity tests which were quite good – possibly a result of many years of clinical experience before applying them in research. If these tests had been published when we initiated the HAFAI study, our functional tests had likely been inspired by the tests described by Kemp et al. (3, 126).

Accelerometers

In order to monitor daily physical activity level, accelerometers were used. Earlier studies have mainly focused on total energy expenditure and number of steps (64, 104). However, especially in orthopaedic patients, it is of great interest to know which other activities patients perform: stair climbing, cycling and running and in older patients: sit-to-stand, etc. To the best of our knowledge, the daily physical activity level has not previously been quantified in the same way in patients with FAIS.

A limitation with the accelerometer method used in the HAFAI study was that the quantification of walking, running and cycling was possible, whereas fitness training is difficult to monitor. Fitness training may consist of several functions: jumping, dancing, rowing, using machines, weightlifting etc. All these exercises contribute to strength and cardiovascular training, but it is difficult to quantify with the algorithm used in the accelerometer-based method. As this kind of physical activity was one of the most common among participants in the study (Figure 10) (4), it is a limitation that it cannot be exactly quantified. Applying heart-rate monitors could give more detailed information about cardiovascular fitness. However, strength training, which could be with small loads, is also not quantified well using this methodology. Hence, training diaries may be a way to quantify this. However, the validity and reliability of training diaries are very low (138). Hence, a combination of all three methods could be a choice.

Accelerometers were worn for 5 days. Harris-Hayes et al. (64) monitored activity for 7 days. The project group (Rachel Senden, Bernd Grimm and Matthijs Lipperts (104)) in the Netherlands, where the accelerometer method was developed, did an internal validation study (not published), where they examined how many days were necessary to give an approximate picture of the mean daily activity level. It was found that measurements over more than 5 days did not provide extra information regarding the mean estimate (personal communication, Rachel Senden). Hence, 5 days was chosen in the current study.

Selection bias

In a systematic review, the included studies are quality assessed in order to account for the risk of bias (134). When including RCTs in a systematic review, Grading of Recommendations Assessment, Development, and Evaluation (GRADE) may be used to assess the risk of bias in the studies, and subsequently to down- or upgrade the confidence in the estimates based on the assessment (139). However, in the systematic review (1), it was known from before initiation (140) that predominantly studies with a low level of evidence would be available for the synthesis. Hence, a scoring system primarily aimed for use in case series was chosen (92). In the systematic review (1), the conclusions were primarily based on studies that were rated to be of good quality. However, even the studies rated "good" using the Yang score (92) are still affected by several forms of bias due to their design.

First, selection bias is very likely in the studies. Selection bias occurs when the included sample arises from a specific group. Patients can either be better than the typical patient from the population or worse depending on what caused the selection. In many of the included studies in the systematic review (1), it was not clear who dropped out during the study and how the patients were selected to be included in the study. When collecting data retrospectively, patients cannot choose whether they want to participate or not, but then the researcher can be biased towards only selecting specific patients. When collecting data prospectively, there is a smaller risk of selection bias since the research question is stated first. However, there is a risk that patients with few personal resources will not participate in the study.

In the HAFAI study, data were collected for the patients deciding not to participate in the study: lived too far away (n = 8), lack of energy to participate in a study (n = 7), too busy to enable time to participate in a study (n = 7). These data suggest that it was both some of the weakest and the healthiest patients who refused to participate in the study.

The reasons for patients not participating in the 1-year post-operative assessment were many: re-operation (n = 2), pregnancy (n = 4), mental illness (n = 4), severe back pain (n = 2), too busy (n = 1), moved to other country (n = 1). Hence, from these data it does not look as if there was a systematic bias towards it being either the best or the weakest patients who failed to come back for retesting. We also did a sensitivity analysis investigating this (3) which supported these suggestions.

Confounding

Confounding is when an outside factor affects both the exposure and the outcome (141). As mentioned earlier, multiple factors might affect the outcome of surgery in patients with FAIS. In this dissertation, it was investigated how gender and age may affect manifestation of FAIS and the outcome of treatment of FAIS, suggesting that female gender might have an impact. Other potential confounders are body mass, co-morbidities, educational level, type of work and surgeon performing the hip arthroscopic treatment. It is, however, beyond the scope of this dissertation to investigate this further.

Missing data

Missing data were estimated in both the systematic review (1) and the HAFAI study. In the systematic review (1), it was difficult to assess the possible presence of missing data because data regarding patient flow was poor. However, a rate of 7% re-operations and 14% lost to follow-up was calculated in the studies included for meta-analysis. In the HAFAI study, re-operations were 3% and lost to follow-up 3% at 1-year follow-up. Hence, in the HAFAI study, data were not much affected by missing data, while there might be a larger effect in the systematic review (1). The study accounting for the largest proportion of re-operations and missing data in the systematic review (1) was that by Skendzel et al. (50). In this study, a mean follow-up of 6.1 years was performed, and many patients progressed to re-operations and total hip replacement. The study was from the United States and had 17% missing data, which must be considered acceptable in a healthcare system with less ability to keep track of former patients than is the case in the Nordic countries. Hence, from these numbers, missing data is not considered a substantial problem in the studies included in the dissertation.

Generalisability

The generalisability of the persons in the reference group vis-à-vis the population in Denmark is small. The reference group consisted of persons responding to notices posted at Horsens and Aarhus Hospitals and at Aarhus University in Denmark. Persons working in healthcare systems and at universities do likely not represent the general population of Denmark. They could be assumed to live a healthier and more active life than the general population. However, the patient group with FAIS consisted of young and middle-aged persons, many of whom live an active life and wish to engage in sport activities. Hence, their functional level could possibly be higher than that of the general population in Denmark. Therefore, it was found relevant to also include an active group as reference in the HAFAI study.

One of the strengths of a prospective, consecutively included patient cohort is that it represents most patients in a given clinical setting. It is hereby a reflection of all patients and not a selected group, which improves the generalisability of patients in the HAFAI study compared with the general population of patients with FAIS in Denmark. However, including all patients also increases the variation in the data collected. We included both patients with chronic pain on sick leave and patients who were top athletes. One can question whether it is meaningful to group these patients or whether they should be analysed separately. However, these different types of patients both represent patients with FAIS. The external validity could have been improved by conducting a multi-centre study with more surgeons participating. However, due to the steep learning curve in hip arthroscopy techniques (142), a single, very experienced surgeon (more than 2300 procedures) was chosen since this eliminated learning effect on the outcomes.

The findings from the systematic review (1) can be generalised to patients in many parts of the world. The systematic review (1) included data from Europe, North America, South America, Australia and Asia (1). Hence, data are lacking only from Africa with regard to coving individuals from most parts of the world. The majority of studies were from the United States and from Europe. Hence, the results from the systematic review (1) are mainly applicable to these populations.

Conclusion

The overall aim of the dissertation was to investigate self-reported and objectively measured outcomes in patients with FAIS undergoing hip arthroscopic surgery.

- Patients with FAIS experience pain and decreased function, quality of life and hip muscle strength. Their objectively measured level of activity was in general not statistically different from that of self-reported hip healthy persons (1, 2, 4).
- After surgical treatment and rehabilitation, patients experienced improvements in pain, function, quality of life and muscle strength (1, 3).
- Eighty-eight percent of the patients participated in some sport activity 1 year after surgery but at a lower level of performance than self-reported hip healthy persons (4).
- Patient-reported outcomes did not reach reference levels after surgery (1, 3, 4).
- Female patients still had impairments in hip muscle strength 1 year after surgery (3).

Perspectives

This dissertation focused on which limitations patients with FAIS experience and what the outcomes of surgical treatment are. It was found that pain, hip muscle function, functional level, sport function, participation in sport and quality of life improved to some extent after hip arthroscopic surgery, but also that patients could not be considered at the same level as reference persons after surgery.

These findings add to the growing body of evidence suggesting that the treatment of FAIS should be a combination of rehabilitation, surgery and further interventions. After completion of data collection in the HAFAI study, the first studies on additional rehabilitation in patients with FAIS as a replacement for surgery or in combination with surgery have been published. The results are not yet clear, but it looks as if some patients can gain improvements in pain, function and quality of life from rehabilitation only (74, 143-145) or from a combination of multiple treatment modalities (123).

It still remains to be elucidated on how FAIS develops, on how to treat FAIS, on what the outcomes of treatment are and on how many individuals progresses to hip OA (15), but researchers all over the world are trying to answer these questions at the moment, and hopefully we will soon know more.

The aim of this dissertation was to identify limitations and investigate the outcome of the current surgical treatment option. As deficits were still present after surgery, future research should focus on how to further improve outcomes in patients with FAIS.

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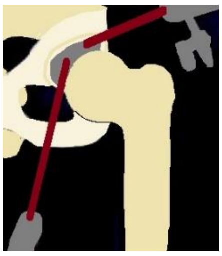
Patient-reported outcomes, hip muscle strength and physical activity in patients with femoroacetabular impingement syndrome
- before and after hip arthroscopic surgery



Systematic review – meta-analysis

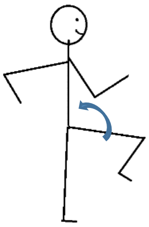
19 studies
2322 patients
mean age 36 ±8
42% females

Pain
Activities of Daily Living
Sport
Quality of life

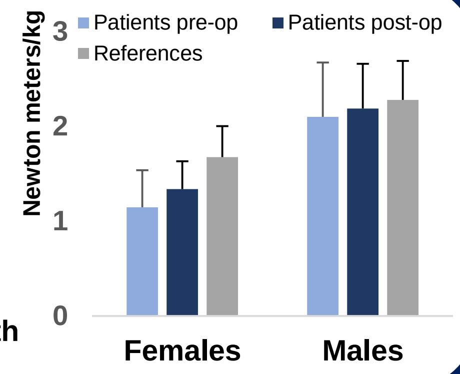
Pain, Symptoms
Activities of Daily Living, Sport,
Quality of life
Hip muscle strength
Daily activity level

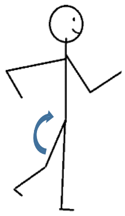
HAFAI study

60 patients
mean age 36 ±9
63% females
30 references

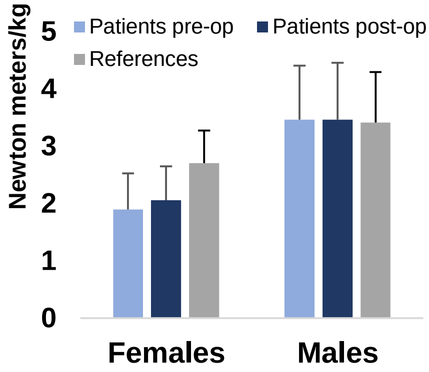


Maximal isometric hip flexion strength





Maximal isometric hip extension strength



Maximal isometric hip muscle strength was measured with an isokinetic dynamometer. Patient reported outcomes measured using generic and disease specific questionnaires. Daily activity level measured using 3-axial accelerometers placed at the thigh at all waking hours.

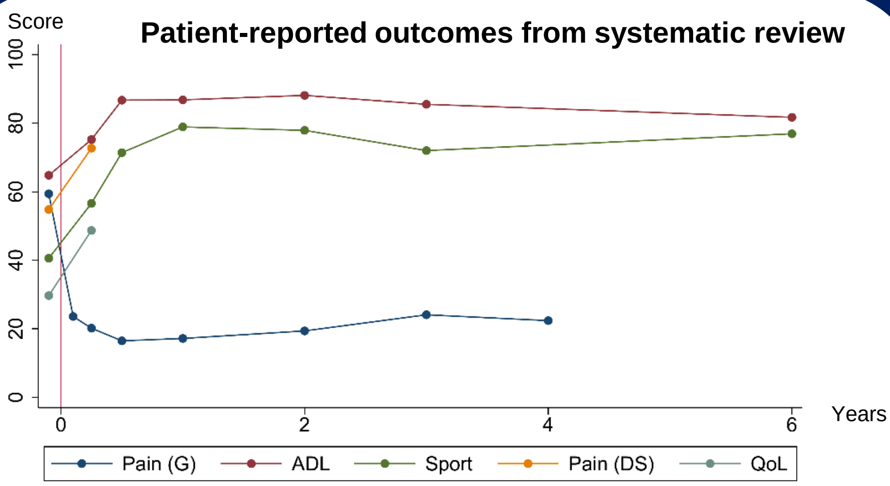
	Pre	Post	Ref
	61 [51;68]	58 [52;66]	56 [48;63]
	11 [8;13]	11 [9;13]	10 [8;14]
	28 [21;35]	28 [21;36]	31 [26;37]
	0 [0;0.1]	0 [0;0.1]	0.1 [0;1.2]
	0.1 [0;1.2]	0.2 [0;1.3]	1.4 [0.7;2]

Median %time per day [25th & 75th quartile]

	7647 [5853; 9401]	7968 [6289;92 86]	8130 [6617;10 566]

Median number of steps per day

Patient-reported outcomes from systematic review



G: generic scores, ADL: activities of daily living, DS: disease specific scores, QoL: hip-related quality of life

Patients	References
Fitness (27%)	Running (51%)
Cycling (16%)	Fitness (23%)
Walking (14%)	Cycling (13%)
Running (8%)	Ball games (8%)

4 most frequent types of physical activities for patients one year after surgery and for references

Patient-reported outcomes and hip muscle strength improved after hip arthroscopic surgery, but remained below the level of self-reported hip healthy persons. Daily activity level was not statistically different between patients and references except for cycling and running.
88% of the patients performed some kind of physical activity one year after surgery.

PhD dissertation
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Kierkegaard et al. 2017 BJSM
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