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Ph.D. Thesis

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FemoroAcetabular Impingement Syndrome

Patient Acceptable Symptom State, Return to Sport, and Hip Muscle Strength after hip arthroscopy

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This thesis has been submitted to the Graduate School of Health and Medical Sciences, University of Copenhagen 11th January 2022

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"Don't worry about a thing, every little thing is gonna be all right"

—*Three Little Birds*, **Bob Marley**

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ABBREVIATIONS

PASS – Patient Acceptable Symptom State
HAGOS – Copenhagen Hip and Groin Outcome Score
iHOT-33 – International Hip Outcome Tool-33
DAG – Directed Acyclic Graph
FAI – Femoroacetabular Impingement
FADIR – Flexion Adduction Internal Rotation
LCEA – Lateral Center Edge Angle
BMI – Body Mass Index
DHAR – Danish Hip Arthroscopy Registry
AA – Alpha Angle
MRI – Magnetic Resonance Imaging
AI – Acetabular Index
JSW – Joint Space Width
ICRS – International Cartilage Research Society
REDCap - Research Electronic Data Capture
QOL – Quality of Life
ADL – Activities of Daily Living
NRS – Numeric Rating Scale
MCID – Minimal Clinically Important Difference
OR – Odds Ratio

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LIST OF PUBLICATIONS

This thesis is based on the following five studies, which all have been conducted at Sports Orthopedic Research Center – Copenhagen at Department of Orthopedic Surgery, Amager-Hvidovre Hospital, Copenhagen, Denmark. The studies are referred to using the Roman numerals, as presented below.

I. Ishøi, L., Thorborg, K., Kraemer, O., Lund, B., Mygind-Klavsen, B., & Hölmich, P. (2019). Demographic and Radiographic Factors Associated With Intra-articular Hip Cartilage Injury: A Cross-sectional Study of 1511 Hip Arthroscopy Procedures. The American Journal of Sports Medicine, 47(11), 2617–2625.

II. Ishøi, L., Thorborg, K., Ørum, M. G., Kemp, J. L., Reiman, M. P., & Hölmich, P. (2021). How Many Patients Achieve an Acceptable Symptom State After Hip Arthroscopy for Femoroacetabular Impingement Syndrome? A Cross-sectional Study Including PASS Cutoff Values for the HAGOS and iHOT-33. Orthopaedic Journal of Sports Medicine, 9(4), 2325967121995267.

III. Ishøi, L., Thorborg, K., Kraemer, O., & Hölmich, P. (2018). Return to Sport and Performance After Hip Arthroscopy for Femoroacetabular Impingement in 18- to 30-Year-Old Athletes: A Cross-sectional Cohort Study of 189 Athletes. The American Journal of Sports Medicine, 46(11), 2578–2587.

IV. Ishøi, L., Thorborg, K., Kemp, J. L., Reiman, M. P., & Hölmich, P. (2021). Maximal hip muscle strength and rate of torque development 6-30 months after hip arthroscopy for femoroacetabular impingement syndrome: A cross-sectional study. Journal of Science and Medicine in Sport. doi.org/10.1016/j.jsams.2021.05.006.

V. Ishøi, L., Thorborg, K., Kallemose, T., Kemp, J.L., Reiman, M.P., Nielsen M.F., Hölmich, P. Stratified care in hip arthroscopy – can we predict successful and unsuccessful outcomes? Development and external temporal validation of multivariable prediction models. *Submitted.*

THESIS IN SHORT FORM

Study	Aims	Methods	Results	Conclusion
I	To investigate the associations between hip joint morphology and hip joint cartilage injury.	Demographic, radiographic, and operative data from 1511 patients were extracted from the Danish Hip Arthroscopy Registry. Logistic regression models were used for analyses.	The severity of cam morphology and dysplasia increased the risk of moderate-to-severe cartilage injuries 2- to 4-fold.	Distinct hip bony morphologies increased the risk of degenerative cartilage injuries.
II	To investigate the proportion of patients with femoroacetabular impingement syndrome who achieve an acceptable symptom state 12-24-months after hip arthroscopy.	The Patient Acceptable Symptom State (PASS) was assessed 12-24 months after hip arthroscopy for femoroacetabular impingement syndrome. In addition, PASS cut-off values for the Copenhagen Hip and Groin Outcome Score (HAGOS) and International Hip Outcome Tool-33 (iHOT-33) were established via ROC analyses.	In total, 137 patients were included, and of those, 64 (46.7 %) patients reported PASS. Cutoff scores for HAGOS subscales (42.5-82.5) and iHOT-33 (67.00) excellent ability in predicting PASS (area under the curve, 0.82-0.92).	Approximately half of all patients undergoing hip arthroscopy for femoroacetabular impingement syndrome report acceptable symptoms 12-24 after surgery. HAGOS and iHOT-33 can be used to predict PASS.
III	To investigate return to sport rates and performance after hip arthroscopy for femoroacetabular impingement syndrome.	A questionnaire designed to assess self-reported return to sport status and associated sports performance was distributed to athletes who had undergone hip arthroscopy for femoroacetabular impingement syndrome in the previous 6 months to 6 years.	In total, 189 athletes were included. Of those were 108 (57.1 %) engaged in their preinjury sport at the preinjury level at the time of follow-up. Of the 108 athletes, 32 athletes reported optimal performance and full sports participation.	Fifty-seven percent of athletes returned to the preinjury sport at their preinjury level. However, only one-third reported optimal performance, constituting 16.9% of the total study sample.
IV	To investigate maximal and explosive hip muscle strength and associations with the return to sport status after hip arthroscopy for femoroacetabular impingement syndrome.	Maximal and explosive (rate of torque development) hip muscle strength was assessed in 45 patients 6-30 after hip arthroscopy for femoroacetabular impingement syndrome. Strength values were compared between the operated and non-operated hips and related to return to sport status.	No differences were observed for maximal strength, but explosive hip flexion strength was lower in the operated compared to non-operated hip. Higher hip extension strength of the operated hip was associated with return to sport status.	Minor differences in hip muscle strength exist between the operated and non-operated hips after hip arthroscopy for femoroacetabular impingement syndrome. Higher hip extension strength seems beneficial for the ability to participate in sports.
V	To develop and validate a prediction model to identify patients with a successful and unsuccessful outcome one-year after hip arthroscopy.	Data on pre-operative demographics, radiological findings, and self-reported measures were used to predict successful or unsuccessful outcomes 1-year after hip arthroscopy. All data were extracted from the Danish Hip Arthroscopy Registry. Clinical prediction models were developed using 1082 patients and validated in 464 patients using logistic regression analyses.	Unsuccessful outcomes could be predicted with adequate calibration (intercept: -0.18 [-0.41 to 0.05], slope: 0.99 [0.72 to 1.25] and acceptable discrimination (area under the curve: 0.75 [0.70-0.80]). Imprecise predictive performance was observed for successful outcomes.	Common clinical variables could predict the probability of having an unsuccessful outcome one year after hip arthroscopy. This prediction model can be used to support clinical evaluation and shared decision-making.

PRELUDE

When I embarked on this journey in early 2017, I did not know much about hips or femoroacetabular impingement syndrome. However, what I knew, from having been part of the Sports Orthopedic Research Center – Copenhagen (SORC-C) for two years, was that Per Hölmich and Kristian Thorborg were two very knowledgeable guys within the hip and groin world, great mentors, and most importantly all-round good guys.

Thus, when Per asked me, a late and dark afternoon in December 2016, just soon after I had submitted my M.Sc. dissertation, if I was interested in doing a Ph.D. on femoroacetabular impingement syndrome, I was very excited. The only "but's" were a lack of economy and a defined project, so these needed to get sorted out. Nevertheless, I did not hesitate to accept the opportunity, and I have never regretted that.

In the five papers in this thesis, we have attempted to answer some basic and clinically relevant questions surrounding hip-related pain, femoroacetabular impingement syndrome, and hip arthroscopy. I have delivered exercise-based treatment to many patients with femoroacetabular impingement syndrome during the past years. Most of these patients seem to have a similar curiosity for their diagnosis; they want to know what the deal is with the extra bone formation in their hip joint, what to expect after exercise-based treatment, and why they do not just go straight to hip arthroscopy if there is extra bone that needs removal – and if they go for surgery, will it resolve their symptoms?

When we planned this thesis, researchers and clinicians could not provide solid, confident, and detailed evidence-informed answers to all of these questions. Luckily, the hip world has come a long way in recent years, and I like to think that the papers in this thesis have been and will be a relevant contribution to the growing knowledge base.

This thesis ended up slightly different from initially planned, but I neither prepared for a global pandemic. I look forward to finishing up things that got postponed over the next coming years to further build on what is presented here, but for now, I am very proud and happy with the work in this thesis.

The journey, which started a late and dark afternoon in a small office at Hvidovre Hospital, have taught me quite a great deal so far. I have learned a lot since 2017, especially on femoroacetabular impingement syndrome, and part of this knowledge is written in this book.

I hope you will find it interesting and valuable in your clinical or research practice or simply that it will stimulate discussions and thoughts. Ultimately, I hope that the work in this book will, in some way, lead to improved patient care.

CHAPTER 1:

INTRODUCTION

Longstanding hip and groin pain are associated with disability, poor quality of life, and physical activity limitations.[1,2] Pain in the hip and groin region may span demographically different population groups and, thus, be present in both young to old and sedentary people to elite athletes. Hip and groin pain are particularly prevalent among young athletes in sports involving powerful repetitive activities such as changing direction, sprinting, kicking, and skating. It may affect up to two-thirds of players during a regular season in certain sports,[3,4] placing hip and groin pain among the most common causes of pain in many sports. Likewise, hip and groin pain are prevalent in middle-aged to older adults, probably because of degenerative changes within the hip joint (i.e., hip osteoarthritis) and surrounding structures (i.e., gluteal tendon pain).[5]

Since hip and groin pain span from young to old and sedentary people to elite athletes, many causes exist.[5–8] In young to middle-aged athletes, extra-articular reasons related to the muscles or tendons surrounding the hip joint, such as adductor- or iliopsoas-related pain, are among the most common causes affecting more than 2 out of 3 of these cases.[7,9,10] Conversely, in older adults, intra-articular causes of hip and groin pain, such as hip osteoarthritis, are prevalent, affecting up to 7.4 % of the general population in people aged 60-90 years old.[8]

In recent decades, intra-articular causes of hip and groin pain have gained increasing attention as a relevant source of pain in young to middle-aged physically active people [11] and as a potential precursor for the development of hip osteoarthritis.[12,13] This increased attention has facilitated several international consensus meetings on hip and groin pain in young to middle-aged individuals.[1,6,7,14–17] In 2015, the Doha Agreement meeting on the terminology of groin pain in athletes was published to establish uniform terminology in causes of groin pain.[7] The expert panel defined four main clinical entities related to extra-articular hip structures (adductor-, iliopsoas-, inguinal-, and pubic-related groin pain). The expert panel also acknowledged the need to include a fifth clinical entity: hip-related groin pain, for which no clear definition was made.[7] Later, in 2016 and 2018, hip-related pain in young and middle-aged individuals was on the agenda, first during the Warwick Agreement on femoroacetabular impingement syndrome [1] and subsequently during the International Hip-related Pain Research Network, Zurich 2018 on classification, definition, and diagnostic criteria for hip-related pain [6,14–16].

In the Zurich Consensus papers, the expert panel agreed on categorizing hip-related pain into (i) femoroacetabular impingement syndrome, (ii) acetabular dysplasia, and (iii) other causes such as cartilage and labrum injuries without a specific corresponding bony morphology.[6,14–16] The primary focus of this thesis is on femoroacetabular impingement syndrome, but the other categories are also briefly included.

What is Femoroacetabular impingement?

In 2016, the landmark paper, "*The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement,"* was published by a multidisciplinary panel of 22 leading researchers and clinicians.[1] In the Warwick Agreement, the term "*femoroacetabular impingement syndrome"* was introduced and defined as "*a motion-related clinical disorder of the hip with a triad of symptoms, clinical signs, and imaging findings*" (**Figure 1**).[1] An essential aspect of this definition is that the diagnosis relies on a combination of factors described below.

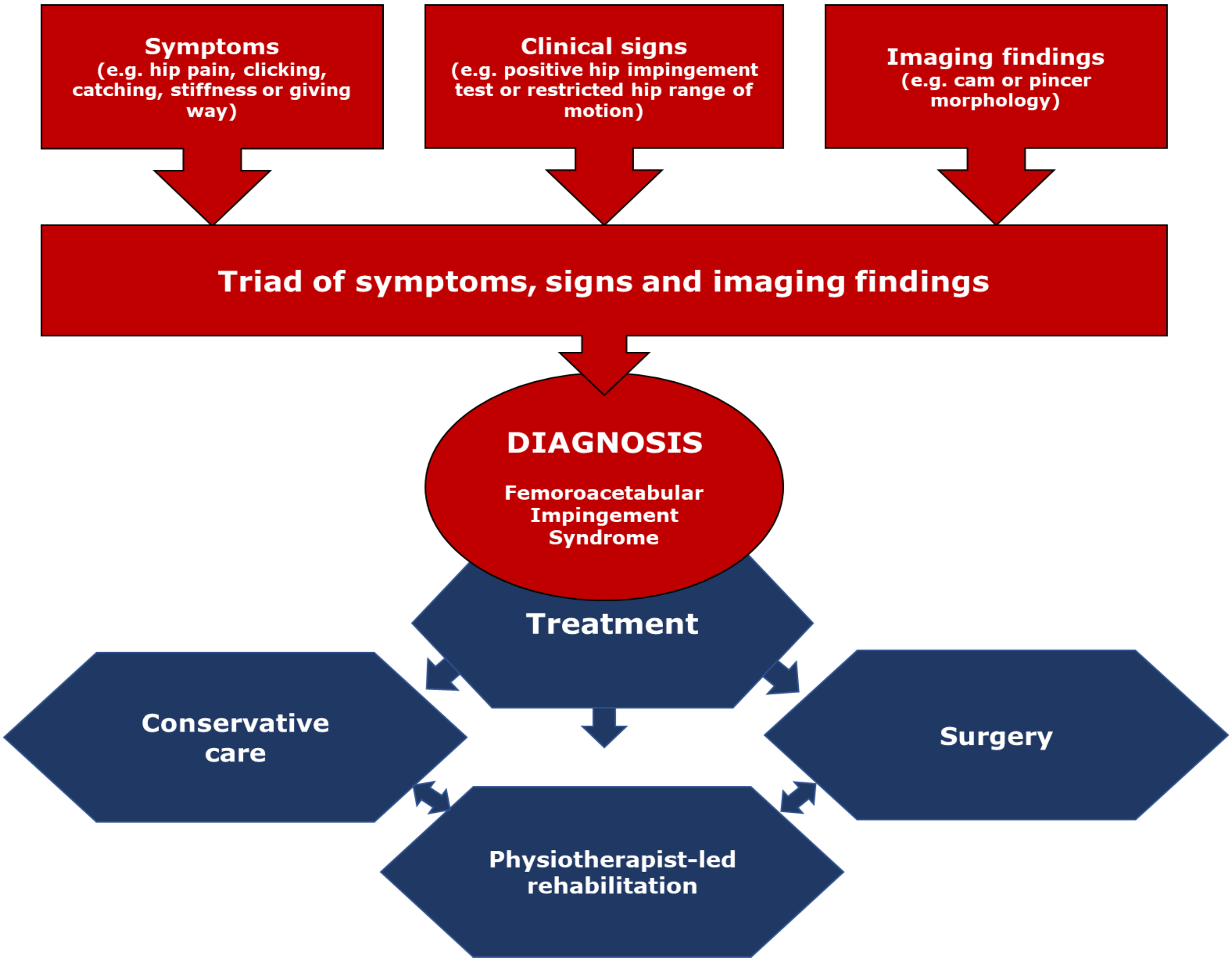

Figure 1. Diagnosis of femoroacetabular impingement based on a combination of symptoms, clinical signs, and radiological findings, and proposed treatment strategies. Reproduced from the Warwick Agreement by Griffin et al.[1]

Symptoms

The "symptoms" represent the patient's perspective.[1] The typical patient is in his or her mid-thirties presenting with longstanding groin pain in >80 % of cases with an insidious onset.[2,18] Many patients also experience concomitant pain in other areas, most commonly the buttock, lateral hip, anterior thigh, and lower back.[2,18] Notably, the distribution of pain across the groin and adjacent anatomical regions seems not specific to the patient with femoroacetabular impingement syndrome since many patients with other causes of groin pain present in a similar way.[2] This similarity complicates the diagnostic process and highlights the need to consider the complete clinical picture, including clinical signs and imaging findings, as highlighted in the Warwick Agreement.[1]

The patient with femoroacetabular impingement syndrome typically experiences aggravating pain during activity, with many patients having difficulties undertaking normal sporting activities such as running and changing direction.[18,19] However, it is not just sporting activities that pose a problem for these patients; activities of daily living such as walking, prolonged sitting, and standing seem to affect more than 50 % of patients.[18] Combining these limitations with the often longstanding nature of the pain, frequently being more than 6-12 months before receiving appropriate treatment,[18,20] it is not surprising that femoroacetabular impingement syndrome can have a significant impact on quality of life.[2]

Clinical signs

The "clinical signs" represent the clinician's perspective.[1] These signs cover the clinical examination findings of both special orthopaedic hip tests to reproduce to patient's symptoms and physical impairments such as restricted hip range of motion.[1] A recent international and multi-disciplinary Delphi survey investigated which components of the clinical examination were considered most likely to be helpful in the diagnostic process for femoroacetabular impingement syndrome.[21]

For special orthopaedic hip tests, the Flexion Adduction Internal Rotation (FADIR) test, the most commonly used test in hip-pain patients, met consensus; however, it was also noted that the test is only helpful for screening and cannot be relied upon as a confirmatory diagnostic test.[21] This finding aligns with a recent clinical statement on femoroacetabular impingement syndrome, where we found the FADIR test has a low diagnostic value.[22] Although, it may be helpful to rule out the diagnosis.[22] The limited diagnostic properties of the FADIR test stem from very high test sensitivity combined with very low test specificity.[22] A high test sensitivity means that the test is likely to (re)produce pain (i.e., high true positive rate) while having a low false-positive rate (i.e., if the test is negative, it is most likely true).[23] A low test specificity means that the test is not structure- or region-specific and, thus, is associated with high false-positive rates (i.e., we cannot trust a positive test).[23] In the clinical setting, this fact means that the FADIR test is often positive in patients with groin pain (i.e., high test sensitivity), regardless of whether femoroacetabular impingement syndrome represents the underlying condition (i.e., low test specificity). This point emphasizes the need for careful interpretation in situations with a positive FADIR test.[24] On the other hand, in cases with a negative FADIR test, one can be relatively confident that the patient does not have femoroacetabular impingement syndrome because of the low false-positive rate (i.e., we can trust negative tests).[24]

The Delphi participants also met consensus on restricted hip internal rotation to guide the diagnosis.[21] This consensus is in line with our clinical statement,[22] where limited internal rotation in prone with or without pain showed the best diagnostic effectiveness for ruling in femoroacetabular impingement syndrome because of high test specificity.[24] However, a positive test is still associated with substantial uncertainty.[22] The poor diagnostic accuracy of many clinical tests [22] complicates the diagnostic process. It emphasizes the need to rule out as many potential competing causes of groin pain as possible [25] before considering whether the clinical signs are consistent with the patient's symptoms, imaging findings, and lastly, femoroacetabular impingement syndrome.[1]

Imaging findings

The imaging findings concern alterations of the normal hip joint anatomy evident on plain radiographs or more advanced imaging modalities, specifically cam and pincer morphology.[1,17] Cam morphology represents extra bone formation anterolaterally at the femoral head and neck junction, which changes the shape of the femoral head from being spherical to becoming aspherical.[1,17] The severity is often quantified by the alpha angle, with an angle above 55-60° indicative of cam morphology (**Figure 2**).[1,17,26]

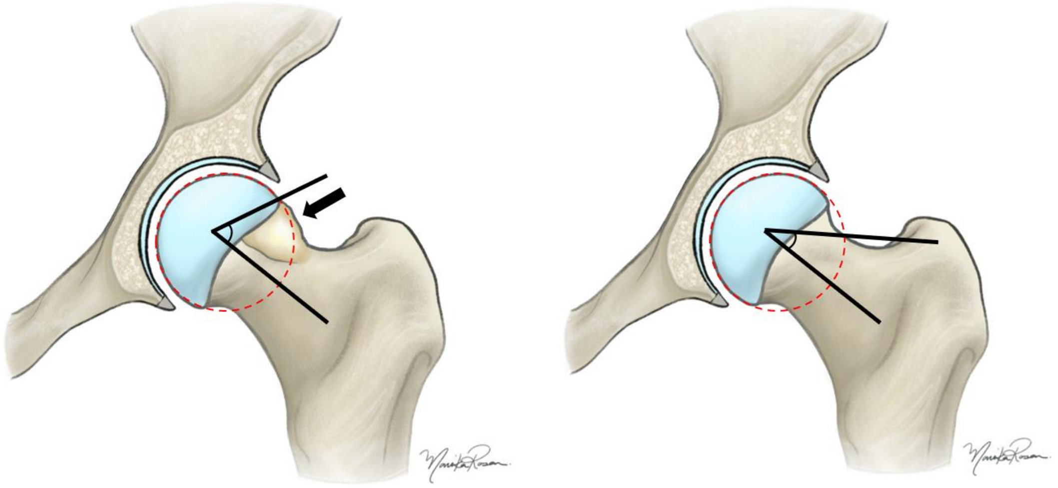

Figure 2. The alpha angle in a hip with cam morphology (left) versus a normal hip (right). The alpha angle represents the angle between 1) a line from the centre of the femoral head parallel to the axis of the femoral neck, and 2) a line from the centre of the femoral head to the point where the femoral head-neck junction extends beyond the margin of the circle along the periphery of the femoral head.[27] The black arrow illustrates the anterolaterally position of the cam morphology. Illustrations by Monika Rosen specifically for this thesis.

Pincer morphology represents over-coverage of the femoral head by the acetabulum because of either increased bone formation on the acetabulum or increased depth of the acetabulum.[1,17] The severity is often quantified by the Lateral Center Edge angle, with an angle above 39 degrees indicative of pincer morphology (**Figure 3**).[1,17]

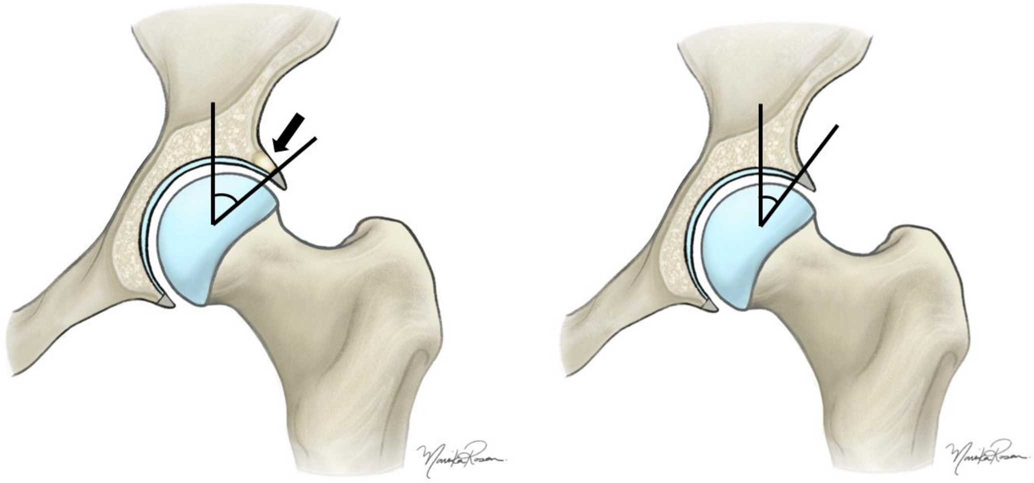

Figure 3. The Lateral Center Edge Angle (LCEA) in a hip with pincer morphology (left) versus a normal hip (right). The LCEA represents the angle between 1) the vertical line through the femoral head perpendicular to the line between the centres of the two femoral heads (or a similar horizontal line) and 2) the line between the centre of the femoral head and the lateral end of the sourcil.[27] The black arrow illustrates the pincer morphology. Illustrations by Monika Rosen specifically for this thesis.

Cam and pincer morphology may exist in isolation or combination. The distribution of morphologies in patients with femoroacetabular impingement syndrome varies across studies; however, in general, isolated cam morphology seems to be the most prevalent cause, followed by the combined cam and pincer morphology.[20,28,29] A recent investigation of the Danish Hip Arthroscopy Registry shows that isolated cam morphology is by far the most common morphology in patients undergoing surgery for femoroacetabular impingement syndrome in Denmark, accounting for 90 % (Ishøi et al., *unpublished*). Combined cam and pincer and isolated pincer represent 8 % and 2 %, respectively (Ishøi et al., *unpublished*). Therefore, in this thesis, femoroacetabular impingement syndrome covers those patients with at least cam morphology.

From early discoveries to conceptualization

While the Warwick Agreement popularized the term "*femoroacetabular impingement syndrome*" in 2016,[1] the underlying concept of femoroacetabular impingement dates back almost 5000 years.[30] In a historical overview, Matsumoto et al.[31] provide an excellent walkthrough of the evolution of femoroacetabular impingement, starting with the discovery of altered hip joint anatomy (now known as cam and pincer morphology) by early pioneers in 1824 investigating ancient anatomical specimens. In the early 2000s, Ganz et al.[12] formed our modern understanding by conceptualizing "*femoroacetabular impingement*" based on clinical experience from numerous hip surgeries. Ganz et al.[12] proposed how the extra bone formation at the femoral head-neck junction (cam morphology) or acetabular rim (pincer morphology) could lead to abutment during hip flexion activities, thus, resulting in mechanical impingement of soft-tissue structures, such as cartilage and labrum.[32]

Since Ganz et al.[12] influential paper in 2003, several different terminologies have been used to describe what is now known as femoroacetabular impingement syndrome.[33] The Warwick Agreement attempted to uniform the terminology by proposing "*femoroacetabular impingement syndrome*" to describe the diagnosis and cam and pincer morphology for describing the underlying altered hip joint anatomy.[1] This thesis follows these recommendations.

Development of cam and pincer morphology

The bony morphologies underpinning femoroacetabular impingement syndrome constitute cam and pincer morphology.[1] While the aetiology of these morphological variants is not fully elucidated, the development of cam morphology is reasonably well understood.[34] The underpinning factor of developing cam morphology is assumed to be high-impact sports activities during adolescence.[35–39]

In 2011, Siebenrock et al.[40] proposed an association between vigorous sports participation during adolescence and the development of cam morphology. A few years later, Agricola et al.[41] linked the development of cam morphology to the open proximal femoral growth plate, indicating that cam morphology develops as a growth-related bone modelling response to activity. Recent studies have extended these early observations. In a large cross-sectional study, Palmer et al.[37] investigated the presence of cam morphology across youth elite football players and non-elite controls. Across age groups, higher alpha angles were noted in elite football players versus non-elite controls, with cam morphology starting to form in 10-12-year-old players, reaching a plateau at approximately

14 years of age.[37] A subsequent longitudinal follow-up with the cohort confirmed these findings. In that follow-up, a strong positive association between higher physical activity level and change in the alpha angle (i.e., cam morphology) was observed [38] as implied by previous cross-sectional studies.[37,42]

Between ages 13-18, the proximal femoral growth plate closes.[36,37] This suggests that cam morphology is acquired during the skeletal maturation phase when the proximal femoral growth plate is open.[36,39,41] Consistent with this observation, a five-year follow-up of youth elite football players provides solid support for no to minimal cam morphology development after proximal femoral growth plate closure.[36]

The clinical findings of an association between vigorous sports activities and the development of cam morphology have further been supported by computational modelling of the open growth plate during loading.[43] By studying different scenarios, Roels et al.[43] observed how the open growth plate was susceptible to loading, corresponding to the specific location of the cam morphology, likely triggering a bone modelling response and the subsequent formation of extra bone (i.e., cam morphology).

The literature on pincer morphology development is scarce; however, in contrast to the development of cam morphology, no robust data suggests a similar mechanism related to the loading of the hip joint.[19,44]

Incidence and prevalence of femoroacetabular impingement syndrome

Before diving into the incidence and prevalence of femoroacetabular impingement syndrome, it is essential to know the prevalence of the underlying morphological variants (cam and pincer).[45] The prevalence of cam morphology in the general population is estimated to range from 20-35 % in males and 5-10 % in females, while the prevalence of pincer morphology is generally lower, ranging from 5-10 %.[46–48] Since the formation of cam morphology is assumed to be a normal physiological response to hip joint loading during the skeletal growth period,[35–39] the prevalence of cam morphology is even higher in certain athletic groups.[45] Thus, in a cohort of 445 professional football players, the prevalence of cam morphology in either hip was 72 %, while 68 % of the players presented with bilateral cam morphology.[49] A systematic review of asymptomatic athletes estimated a cam morphology prevalence of 54 % across different sports.[50] In line with this number, population-based studies have estimated that only 5-20 % of individuals with cam morphology experience pain,[46,48] reinforcing the importance of defining femoroacetabular impingement syndrome, according to the Warwick Agreement.[1]

While reliable data on cam and pincer morphology prevalence exist, there is only limited data on the incidence and prevalence of femoroacetabular impingement syndrome. In a large prospective epidemiological study of professional football players across two seasons, hip-related pain only constituted 1 % of all hip and groin injuries.[10] However, the authors of that study used a time-loss definition that may have underestimated the problem [51] since many athletes/patients often continue to play with symptoms. Thus, players would not be categorized as injured.[20] Femoroacetabular impingement syndrome may also be more likely to present after a professional sports career, since the average patient's age is in the mid-thirties.[20]

In the general population, the incidence of femoroacetabular impingement syndrome has increased gradually since the early 2000s, from 40 cases per 100000 individuals to 70 cases in the 2010s based on a population-based database from Minnesota, USA.[11] This increase is probably a sign of improved diagnostic expertise and the focus on the condition rather than an actual increase in the incidence.[31] In a Canadian population study, the prevalence of femoroacetabular impingement was estimated to be approximately 2-3 %.[46] In the study, femoroacetabular impingement syndrome was diagnosed according to the Warwick Agreement definition based on hip symptoms, a positive FADIR test (clinical sign), and imaging findings.[1,46] However, considering the high false-positive rate of the FADIR test,[22,52] even in patients with no hip and groin symptoms,[46,53,54] combined with the high prevalence of cam and pincer morphology in asymptomatic individuals,[45] the authors of that study may likely have overestimated the prevalence.[46] Importantly, no other attempts to classify the cause of groin pain were conducted,[46] introducing substantial diagnostic uncertainty regarding the actual cause of pain.[52]

Concomitant injuries and development of hip osteoarthritis

According to an early theory from Ganz et al.,[12] cam and pincer morphology may lead to mechanical impingement, resulting in subsequent cartilage and acetabular labrum injuries, thus, a precursor for hip osteoarthritis. This hypothesis is interesting because the concomitant injuries may likely be the ones causing the hip and groin pain.[55] Indeed, high-density nociceptive nerve fibres (also known as pain-generating fibres) exist in the anterior part of the acetabular labrum and capsule,[56] where the mechanical impingement is likely to occur.[57] The anterior labrum and capsule are innervated by the femoral and obturator nerves, which cover the anatomical regions of the anterior groin, medial and anterior thigh, and lateral hip.[56] These areas represent the normal distribution of pain in patients with femoroacetabular impingement syndrome.[2,20]

Only limited evidence supported the early theory that cam and pincer morphology would lead to cartilage and labrum injuries in young and middle-aged individuals when we started this thesis.[32,58,59] In older individuals, however, the first indications of a possible link between abnormal bone morphology in the hip and the development of hip degeneration (i.e., osteoarthritis) was presented by Murray in 1965.[60] In recent years, prospective cohort studies have established the association between bony hip morphologies and the development of osteoarthritis in older middle-aged adults to seniors.[61] Agricola et al.[62] studied 1002 mildly symptomatic middle-aged-to-elderly adults during a period of five years. Hips with cam morphology characterized by an alpha angle >60° and >83° were approximately 3.5 and 10 times more likely to develop end-stage osteoarthritis within five years.[62] Similar findings were observed in *The Chingford 1000 Women Study* [63] – a prospective cohort study with 20 years of follow-up – and in the *Rotterdam Study Cohort*, including more than 4000 adults followed for ten years.[64] Notably, pincer morphology does not seem to increase the risk of osteoarthritis.[61]

Treatment of femoroacetabular impingement syndrome

Once femoroacetabular impingement syndrome is diagnosed, the Warwick Agreement proposes three treatment approaches: wait-and-see or conservative, physiotherapist-led treatment, and hip surgery (**Figure 1**).[1] The proposed content of the wait-and-see approach consists of analgesics, rest, and activity modification; aspects often included in a physiotherapist-led treatment approach. Thus in this thesis, treatment for femoroacetabular impingement syndrome will be described from a non-operative perspective versus an operative one.[22]

Operative treatment

The popularization of the concept "femoroacetabular impingement" and the proposed mechanical cause of symptoms by Ganz et al.[12] in the early 2000s set the stage for operative treatment of femoroacetabular impingement syndrome. Since then, there has been an exponential rise in the number of hip arthroscopies performed globally,[65–67] becoming one of the most popular surgeries to perform for young orthopaedic surgeons.[67,68] In Denmark, the Danish Hip Arthroscopy Registry was established in 2012; thus, no systematic data on the number of hip arthroscopies performed before that time exist. It is, however, reasonable to expect a similar exponential pattern.[65–67] Interestingly, in Denmark, we have seen a steady decline in the number of hip arthroscopies to treat femoroacetabular impingement syndrome from 2014 to 2017, reaching a plateau after that (**Figure 4**).

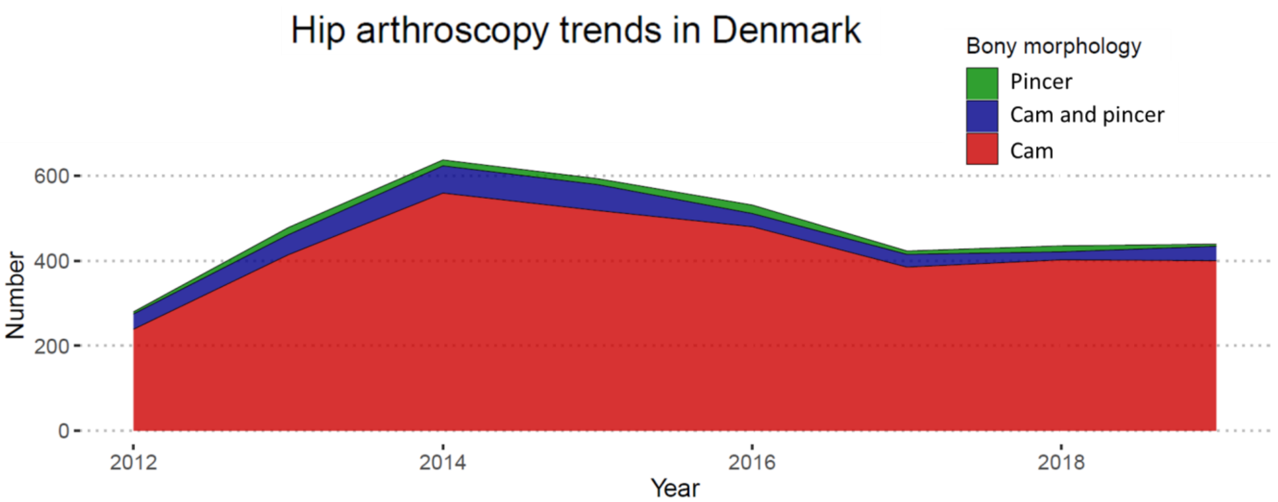

Figure 4. Hip arthroscopy trends in Denmark from 2012-2019. Data is extracted from the Danish Hip Arthroscopy Registry (Ishøi et al., unpublished).

A similar trend has recently been shown in Sweden,[69] while the number of hip arthroscopies seems to continue on an uptrend in UK and USA.[65,68,70–72] The reasons for these discrepancies in hip arthroscopy trends in recent years are unknown but may reflect different treatment and/or healthcare systems approaches.

Hip arthroscopy's primary rationale is to normalize hip joint anatomy to prevent further mechanical impingement and potential concomitant injuries of the cartilage and labrum.[12] That includes resecting the extra bony formations because of cam or pincer morphology.[12] Thus, it is no surprise that the main surgical indication is the presence of cam and/or pincer morphology.[73] However, there is diverging evidence whether resection of cam and or pincer morphology slows down the degenerative process of the cartilage,[74,75] although complete resection of the cam morphology may lower the risk of conversion to total hip arthroplasty or progression of cartilage injuries compared to inadequate resection.[76,77]

Despite the uncertainty of whether hip arthroscopy slows the degenerative process in the hip joint, substantial evidence suggests that hip arthroscopy is associated with improvement in self-reported hip and groin function and pain.[78] This result has been shown consistently in cohort studies [78] and recently in randomized controlled trials comparing the effectiveness of hip arthroscopy versus physiotherapist-led treatment.[28,29,75,79] Based on a meta-analysis of the effectiveness, hip arthroscopy shows a small superior effect at 8-12 months follow-up compared to physiotherapist-led treatment.[22] The effect was determined using the international Hip Outcome Tool-33 (iHOT-33), which measures the hip-related quality of life on a scale from 0 (worst) to 100 (best).[80] Across studies, the between-group difference is approximately 12-15 points,[22] considered a clinically relevant difference.[80] However, the lower confidence interval lies at 5 points, less than a clinically relevant difference.[80] Thus, the statistical superiority of hip arthroscopy versus physiotherapist-led treatment is still associated with uncertainty concerning the clinical benefit for the patient.[22]

Notably, both the groups receiving hip arthroscopy and physiotherapist-led treatment improved in hip-related quality of life (iHOT-33) from before to 8-12 months after treatment.[22] However, despite improvements over time, the hip arthroscopy groups scored between 49-72 points at 8-12 months follow-up, whereas the physiotherapist-led group scored 44-57 points.[28,29,75,79] Since iHOT-33 is a scale of 100, a score of 50-70 points signifies persistent impairments and pain to some degree.[81] Thus, it is unlikely that patients become pain-free and gain normal function after either treatment approach.[22,82] Thorborg et al.[82] investigated self-reported hip and groin function in a cohort of patients with femoroacetabular impingement syndrome or labral injury undergoing hip arthroscopy. Based on the minimal clinically important difference, they found that approximately 2 out of 3 patients got better from before to one year after surgery.[82] However, when comparing the one-year outcome with reference values from hip and groin pain-free controls, only a few patients reached a comparable level, suggesting that most patients had persistent hip and groin pain after hip arthroscopy.[82]

Non-operative treatment

While there is an abundance of literature published on hip arthroscopy outcomes for femoroacetabular impingement syndrome, the effectiveness of non-operative treatment is much more uncertain.[14] This uncertainty is partly caused by small studies, a high risk of bias, and the inclusion of patients from different settings (i.e., consecutive recruitment from a specialized orthopaedic setting versus public recruitment by study invitations).[22]

Despite shortcomings in the non-operative treatment literature, prescribed physiotherapy seems to be the best choice for a non-operative treatment approach.[22] However, the specific parts or exercises yielding the best effect are unknown.[22] In the Zurich Consensus Statement paper on hip-related pain, the panel group provides recommendations for physiotherapist-led treatment.[14] The duration of the treatment should be at least three months, with the treatment focused on patient-specific physical impairments,[14] such as reduced hip and trunk muscle strength,[83] and single-leg balance and hop performance. In one of the transparently reported non-operative treatment trials adhering to the consensus-recommended guidelines, Kemp et al.[84] randomized 24 patients with femoroacetabular impingement syndrome. One group was a physiotherapist-led exercise approach, while the control group consisted of supervised stretching and manual therapy.[84] The physiotherapist-led exercise group mainly focused on specific hip exercises for increasing hip muscle strength, trunk muscle endurance exercises, functional exercises focusing on balance and stability, and a cardiovascular program focusing on improving general fitness. The control group, also supervised by a physiotherapist, focused on increasing the flexibility of various lower extremity muscles.[84] The effect was evaluated with iHOT-33 at 12-weeks follow-up. The study included a small sample size, and did not detect a significant between-group difference; however, the physiotherapist-led exercise group improved 16 points more than the control group.[84] Noteworthy, the physiotherapist-led exercise group improved from 60 to 87 points,[84] which is markedly more than the randomized controlled trials comparing the effectiveness of hip arthroscopy versus physiotherapist-led treatment.[28,29,75,79] This result indicates that the effectiveness of physiotherapist-led treatment may yield worse results if patients are eligible for surgery, as was the case in the four randomized controlled trials.[28,29,75,79]

Stepped-care versus stratified care

According to the Warwick Agreement, treatment of femoroacetabular impingement syndrome is roughly divided into an operative or non-operative approach.[1] A recent consensus statement recommends that a non-operative treatment approach be offered as the first-line treatment to all patients with femoroacetabular impingement syndrome, potentially followed by surgery if symptoms have not resolved.[14] This approach represents a stepped-care model, which initially offers the least invasive and most cost-effective treatment before progressing to less cost-effective and specialized care.[85] In contrast to the stepped-care model is the stratified-care model, characterized by offering a specific treatment based on prior risk estimation of an outcome.[86] Clinically, this circumstance means that the treatment choice most likely to result in a positive outcome is based on patient characteristics during the clinical examination.

Some patients with femoroacetabular impingement syndrome respond excellent to hip arthroscopy,[82] while in contrast, others fail.[87] This seems to be the same for non-operative treatment.[88,89] Therefore, a stratified-care model may yield better outcomes than a stepped-care model. However, several steps described in the PROGRESS framework need to be undertaken to implement a stratified-care model effectively.[86,90–92] These include identifying prognostic factors associated with the outcome (*prognostic factor research*) [92] and testing if the outcome can be precisely predicted (*prognostic model research*),[91] before evaluating whether different treatment responses occur based on the presence or absence of the factor/factors in a randomized controlled trial (*stratified care research*).[86] The sequence of steps, ultimately aiming at improving patient outcomes, are described below.

Prognostic factor research represents the identification of factors associated with the outcome of interest following a specific treatment,[92] in this case, either non-operative or operative treatment of patients with femoroacetabular impingement syndrome. Prognostic factors are typically identified using prospective cohort studies.[92] Clinically, prognostic factors may serve as a gross guide for treatment decision-making; if the patient possesses a specific factor associated with a poor outcome, the clinician may attempt to target that, if modifiable.[92] However, prognostic factor research is performed at a group level, making it difficult for the clinician to apply the factor/factors at an individual level.[92] Therefore, *Prognostic factor research* is also used to inform the development of clinical prediction models.[92]

Prognostic model research represents the development and validation of clinical prediction models.[91] These models are often constructed based on several prognostic factors to create a clinical tool that can estimate the probability of a specific outcome following a specific treatment.[91] For example, in the context of hip arthroscopy, some patients seem to respond very well;[82] thus, the surgeon and the patient may wish to know the probability of this occurrence happening before undergoing surgery, or vice versa for a poor outcome. Once a clinical prediction model has been developed, it needs to undergo comprehensive validation before being implemented for clinical use.[93,94] In this process, which is termed *external validation*, the researcher applies the clinical prediction model on a different data set to estimate the predictive performance in future patients.[95] If properly validated, clinical prediction models may serve as a valuable tool to aid decision-making and guide treatment.[90] However, since clinical prediction models are often developed in patients who undergo a specific treatment, they cannot be used to predict the outcome of patients not undergoing the treatment nor be used to select the best treatment option.[91] In addition, prognostic factors included in the prediction model may not have a causal relationship with the outcome (i.e., predict treatment response) – this fact means that one cannot be sure that the treatment response changes if the factor is modified pripr to treatment.[91] Consequently, before using a prediction model to select the most appropriate treatment (i.e., stratified care), it must be tested in a randomized controlled trial.[86,91]

Stratified care research seeks to identify the treatment most likely to benefit the patient based on patient characteristics.[86] A simple example would be treatment stratification based on age, in which individuals above or below a certain age undergo different treatments. Stratified care research may be conducted based on prediction models, where individuals are allocated to a specific treatment based on their outcome probability.[86] The effectiveness of such allocation based on outcome probability may be tested in a randomized controlled trial by comparing outcomes between patients assigned to a specific treatment based on the prediction model versus all patients assigned to the same treatment.[86] A successful example is the STarT Back randomized controlled trial, where stratified treatment based on risk assessment at baseline was superior to usual care in patients with low back pain.[96]

Unfortunately, limited literature exists to guide a stratified-care model in patients with femoroacetabular impingement syndrome. Casartelli et al.[88] identified severe cam morphology as a potential prognostic factor for a poor outcome after 12 weeks of physiotherapist-led treatment. These results may indicate that patients with severe cam morphology are less suited for a non-operative treatment approach. However, the risk of a poor outcome at an individual level is unknown (since no prediction model exists), making it extremely difficult for the clinician to use such information for treatment decisions.[92]

In addition, simply having a poor prognosis of getting better from non-operative treatment does not translate to a good prognosis after hip arthroscopy.[91]

Several studies have investigated prognostic factors associated with good and poor outcomes after hip arthroscopy for femoroacetabular impingement syndrome (**Table 1**).[97]

Table 1. Overview of identified prognostic factors for a good and poor outcome after hip arthroscopy for femoroacetabular impingement syndrome, The prognostic factors are extracted from the systematic review by Sogbein et al.[97]

Prognostic factors for good versus poor outcome	
Good outcome	**Poor outcome**
Younger age	Older age (>45 years)
Male sex	Female sex
Lower BMI (<24.5 kg/m^2)	Higher BMI
Tönnis grade 0	Osteoarthritic changes
Increased joint space width	Decreased joint space (≤2 mm),
Pain relief from an anesthetic hip-joint injection	Chondral defects
	Increased Lateral Center Edge Angle
	Preoperative pain symptoms (>8 months)

BMI; body mass index

This wealth of information provides a solid foundation for developing and validating clinical prediction models.[95] Several studies have attempted to develop prediction models for estimating the outcome after hip arthroscopy;[98–104] however, none have been adequately validated and are therefore not suited for implementation in clinical practice.[95]

In conclusion, until properly validated clinical prediction models are developed to estimate outcome probability after non-operative and operative treatment, stratified care in patients with femoroacetabular impingement is not feasible but should follow a stepped-care approach.[14]

Evaluation of treatment outcomes

Evaluation of treatment outcomes relies on the use of relevant and valid measures. In the Zurich Consensus statement, the expert panel agreed on several outcome measures for patients with hip-related pain.[15,16] These span from patient-reported outcome measures, designed to capture the patient's perspectives, to objectively measured function, such as muscle strength or jumping ability.[15,16]

HAGOS and iHOT-33

Patient-reported outcome measures are considered an integral and necessary part of healthcare research to evaluate treatment outcomes.[105] Such measures aim to obtain the patients' perspective on symptoms, functional status, and quality of life at a designated time-point or repeatedly over time.[105] The information can guide recommendations of treatment approaches and support shared decision-making in circumstances where the patients' perspective is considered critical.[103] This is often the case in many musculoskeletal disorders, such as femoroacetabular impingement syndrome.[16]

Based on the Zurich Consensus statement [16] and associated scrutiny of the quality of psychometric properties, such as structural and content validity, reliability, responsiveness,[16] two disease-specific patient-reported outcome measures for young and middle-aged active patients with hip and/or groin pain are recommended. These include the Copenhagen Hip and Groin Outcome Score (HAGOS)[106] and the International Hip Outcome Tool-33 (iHOT-33),[80] where disability is scored on a 0-100 scale (0 worst, 100 best) based on a range of hip- and groin-related questions. HAGOS and iHOT-33 are described further in the "General method" section, Chapter 2.

Patient Acceptable Symptom State

Besides disease-specific patient-reported outcome measures, generic measures can also capture patients' perspectives on their health. One such measure is the Patient Acceptable Symptom State (PASS), defined as *"the highest level of symptom beyond which patients consider themselves well."*[107] In comparison to many patient-reported outcome measures that use a scale from worst to best,[80,106] PASS is dichotomous and thus essentially aims to capture whether a patient considers their current health status acceptable or not.[107] Therefore, PASS provides an additional critical perspective to HAGOS and iHOT-33 by providing information on whether patients feel well after treatment.[107] While numerous studies have established that patients often get better after hip arthroscopy,[22,78,82] fewer studies have included the PASS measure in their evaluation of outcome since its introduction in the hip arthroscopy literature in 2015.[108] This fact is interesting since patients seem to be more concerned with their current health status and whether they feel well after treatment than any potential improvements in symptoms and function over time.[109] By combining PASS with HAGOS and iHOT-33, one can also analyze the score for which patients typically obtain an acceptable symptom state [107] and, thus, provide additional context to the HAGOS and iHOT-33 score. For example, a previous study found what is referred to as the PASS iHOT-33 score (the iHOT-33 score beyond which patients consider having obtained an acceptable symptom state) to be 58 points 2 years after hip arthroscopy.[110] In the context of the randomized controlled trials mentioned previously, the hip arthroscopy groups had an iHOT-33 score of 49-72 points at 8-12 months.[28,29,75,79] Indeed, this finding suggests that many patients may find themselves below the 58 point PASS threshold after hip arthroscopy corresponding to an unacceptable symptom state.[110]

Return to Sport

After hip arthroscopy, the ability to return to sport is a priority for many patients with femoroacetabular impingement syndrome. The ability to do so seems to drive high treatment satisfaction.[111] Return to sport after hip arthroscopy has been extensively studied in the past from recreational to elite athletes across many different sports. The first systematic review on return to sport after hip arthroscopy for femoroacetabular impingement syndrome was published in 2015, showing a successful return to sport in 87

% of athletes.[112] In the included studies, and many of the following published in recent years, the return to sport definitions used was generally poorly defined, often dichotomous, and ranged from training participation to competitive match play [112–115] using different methods such as public registries for professional athletes and self-reported for recreational athletes.[116] In addition, the majority of literature concerns professional athletes operated by world-renowned surgeons limiting generalizability.[112–115] Collectively, it is difficult for clinicians and patients to know what to expect.

The seemingly high return to sport rate contrasts with studies investigating pre-operative expectations and fulfilment of those after hip arthroscopy.[117,118] Based on the high return to sport rates from systematic reviews, one would expect that pre-operative expectations would be easily fulfilled. However, Mannion et al.[117] showed that up to 61 % of patients with femoroacetabular impingement syndrome did not meet their pre-operative expectations regarding sporting ability 12-months after surgery. In addition, Jones et al.[118] also found a discrepancy between pre-operative expectations and the ability to participate in physical activities after surgery. This result indicates that the return to sport rates captured in previous studies using unclear dichotomous definitions may not tell the entire story. One reason for this circumstance is that return to sport is not a simple dichotomous outcome but rather a continuous process starting early in rehabilitation and ending with returning to sports performance (**Figure 5**).[119]

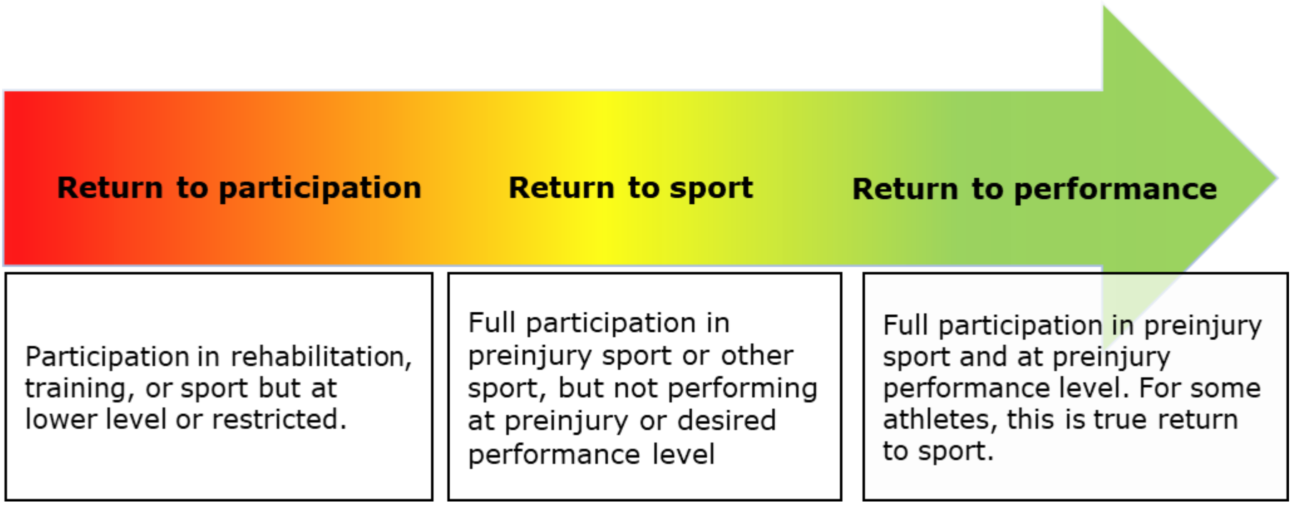

Figure 5. Return to sport continuum from the 2016 Return to Sport Consensus Statement. Figure and descriptions are adapted from Ardern et al.[119]

When we planned this thesis in 2017, limited data existed on return to sport as a continuous rather than dichotomous outcome after hip arthroscopy. However, a Swedish study in 85 Top-level athletes attempted to adopt a continuous definition of return to sport by categorizing athletes into (i) return to pre-injury professional/elite sport, (ii) return to competitive sport at a lower level, (iii) no return to competitive sport.[120] Interestingly, most athletes returned to at least competitive sports; however, only half of them returned to their pre-injury sport at professional/elite level.[120] This study was one of the first to provide a nuanced view on return to sport – in recent years, even more detailed evaluations of return to sport status after hip arthroscopy have also been published considering performance level.[111,121]

Muscle strength

Measurements of the objective function, such as hip muscle strength and jump performance, are considered a valuable aspect in addition to self-reported measures when managing patients with femoroacetabular impingement syndrome.[15] Specifically, assessing this data provides detailed insights into potential underpinning reasons for low self-reported measures observed in some patients.[83] In addition, these factors are often modifiable and, thus, provide a rationale for targeted treatment in cases where impairments are identified.[14,122]

Hip muscle strength is considered an important parameter to track consistently during the treatment period.[15,122] While advanced laboratory measures exist, such as isokinetic dynamometry,[123] reliable and valid measures of hip muscle strength can easily be obtained clinically using an externally-fixated hand-held dynamometer (**Figure 6**).[124,125]

Figure 6. Clinical setup for assessing hip flexion strength using an externally-fixated hand-held dynamometer.

In patients with femoroacetabular impingement syndrome who have not undergone surgery, lower maximal isometric hip muscle strength compared to either the opposite hip or healthy hip and groin pain-free controls is a consistent finding (**Table 2**).[123,126–131] This has led to a general focus on targeted hip muscle strengthening as a core component of non-operative treatment and post-operative rehabilitation.[22]

Table 2. Overview of studies investigating deficits in maximal isometric hip muscle strength in patients with femoroacetabular impingement syndrome who have not undergone hip arthroscopy.

	Deficits in maximal isometric hip muscle strength hips diagnosed with femoroacetabular impingement syndrome	
Studies	**Compared to contralateral hip**	**Compared to healthy controls**
Casartelli et al. 2011 [130]	Not measured	Adduction: -28 % Abduction: -11 % Flexion: -26 % Extension: -1 % Internal rotation: -14 % External rotation: -18 %
Nepple et al. 2015 [129]	Adduction: -5 % Abduction: -9 % Flexion: -8 % Extension: -4 %	Not measured
Diamond et al. 2016 [128]	Not measured	Adduction: -12 % Abduction: -20 % Flexion: -16 % Extension: -23 % Internal rotation: -24 % External rotation: -6 %
Kierkegaard et al. 2017 [123]	Flexion: -10 % Extension: -7 %	Flexion: -21 % Extension: -16 %
Frasson et al. 2020 [127]	Not measured	Adduction: -33 % Abduction: -12 % Extension: -34 % Flexion: -25 %
Pålsson et al. 2021 [131]	Not measured	Adduction: -28 % Abduction: -28 % Flexion: -25 % Extension: -21 % Internal rotation: -25 % External rotation: -27 %

Associations between hip muscle strength and hip and groin in patients with femoroacetabular impingement syndrome have been observed before [123,132,133] and after hip arthroscopy.[134] However, the underlying reason for this association and whether it is causal remains unknown. A prominent narrative is that the hip muscles, especially the deep external rotators, act as essential stabilizers of the hip joint because of their proximity to the joint center, thus facilitating effective load distribution and transfer.[135] However, the role of the deep hip muscles for joint stability has recently been questioned by Meinders et al.[136] using neuromusculoskeletal modeling of gait trials. They observed that the deep hip muscle did not affect hip joint stiffness (i.e., stability) in the sagittal plane regardless of the simulated level of muscle activity.[136]

Interestingly, the lower maximal hip muscle strength, often observed in all directions, seems not specific for the patient with femoroacetabular impingement syndrome but is also present in patients with extra-articular causes of groin pain.[131] In addition, no differences in maximal hip muscle strength between asymptomatic athletes with and without cam morphology could be detected in professional soccer players.[137] This result suggests that the presence of hip and groin pain, rather than femoroacetabular impingement syndrome *per se*, may drive reduced muscle strength around the hip joint to some degree. Interestingly, compressive forces are distributed across the joint when muscles contract, elevating joint contact forces.[138] This result also means that producing lower muscle force may dampen the load on the joints, thereby reducing the likelihood of aggravating the pain.[139] Indeed, patients with femoroacetabular impingement syndrome and hip osteoarthritis may undertake compensatory movement strategies to reduce the load on the hip joint.[140,141] Consequently, muscle strength in patients with femoroacetabular impingement syndrome may represent a gross proxy for load-bearing capacity; however, muscle strength after hip arthroscopy and its role for participating in high-demanding activities, such as sport, has only been sparsely investigated.[134,142,143]

Another muscular parameter of interest during rehabilitation is the rate of force development (i.e., explosive muscle strength).[144] The rate of force development is defined as the change in force during a defined contraction time, typically from 0 up to 200 ms. In other words, the rate of force development denotes how fast muscle force can be produced (i.e., *Newtons per second*; **Figure 7**).[145]

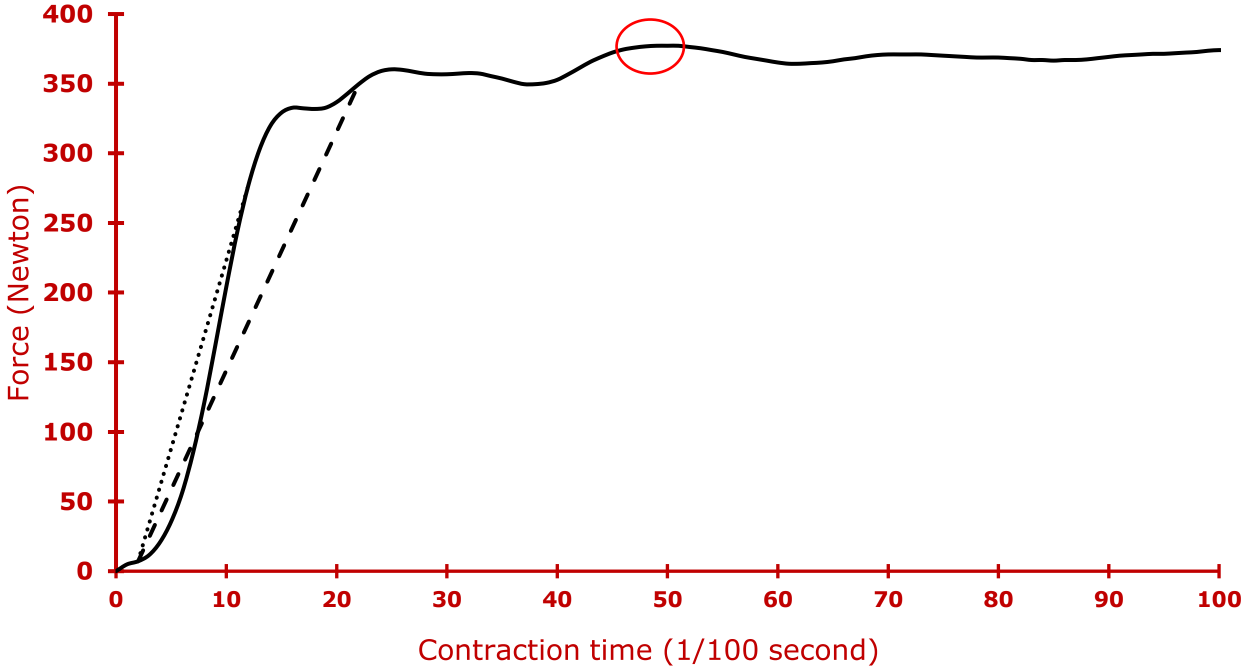

Figure 7. Example of a force-time curve for hip flexion based on data from Ishøi et al.[124] For practical application, the time is cut at 1 second. The red circle shows the peak force usually obtained between 300-1000 ms. The dotted line shows the linear force production from 0 (6.67 newtons) to 100 ms, while the stippled line shows the linear force production from time 0 to 200 ms. The rate of force development is calculated as the mean change in force per second during the time intervals 0-100 ms and 0-200 ms. This equals the slope coefficient for each line.

The ability the rapidly exert muscle force is governed by a complex interplay between neural (i.e., motor unit firing frequency, spinal excitability) and structural (cross-sectional area, fibre type composition, tendon structure) factors,[144] with motor unit firing frequency as an essential parameter.[146,147]

The rate of force development may be more sensitive than maximal strength to detect musculoskeletal impairments,[148,149] perhaps because of pain inhibiting motor unit firing frequency.[150] In addition, the rate of force development is often more related to sports performance than maximal muscle strength [151,152] because of the requirements to develop rapid force (<200 ms) in activities such as sprinting, changing direction, and kicking.

Regarding patients with femoroacetabular impingement syndrome, hip muscle rate of force development is a relatively unexplored area. Only a single study has investigated this in patients scheduled for hip arthroscopy, reporting lower hip extension rate of force development for time epochs 0-50, 0-100, and 0-200 ms in the affected hip compared to healthy controls.[123] In more degenerative hip joint diseases (e.g., osteoarthritis), Friesenbichler et al.[153] observed markedly reduced hip muscle rate of force development both before and six months after total hip replacement compared to the uninvolved leg.

AIMS OF THE THESIS

General aim

Based on existing literature concerning the potential role of hip joint morphology for intra-articular injuries in and subjective and objective outcomes following hip arthroscopy, the general aim of this thesis was to (I) investigate how hip joint morphology affects joint health in young to middle-aged people (II) investigate patient-centred outcomes and objective measures after hip arthroscopy, and (III) develop and validate multivariable clinical models to predict successful and unsuccessful outcomes after hip arthroscopy.

Specific study aims

Study I
Demographic and Radiographic Factors Associated With Intra-articular Hip Cartilage Injury: A Cross-sectional Study of 1511 Hip Arthroscopy Procedures.

Primary aim: To investigate the association between hip joint morphology and cartilage injuries using contemporary definitions of morphology and cartilage injury classifications to improve our understanding of disease progression.

Study II
How many patients achieve an acceptable symptom state after hip arthroscopy for femoroacetabular impingement syndrome? – a Cross-sectional Study Including PASS Cut-Off Values for HAGOS and iHOT-33

Primary aim: To investigate the proportion of patients with an acceptable function and symptoms state 1-2 years after hip arthroscopy for femoroacetabular impingement syndrome and establish cut-off values for validated patient-reported outcome measures for use in future studies.

Study III
Return to Sport and Performance After Hip Arthroscopy for Femoroacetabular Impingement in 18- to 30-Year-Old Athletes: A Cross-sectional Cohort Study of 189 Athletes.

Primary aim: To investigate return to sport rates and self-reported performance after hip arthroscopy for femoroacetabular impingement syndrome in young athletes using contemporary and clearly defined criteria for defining return to sport.

Study IV
Maximal hip muscle strength and rate of torque development 6-30 months after hip arthroscopy for femoroacetabular impingement syndrome: A cross-sectional study.

Primary aim: To investigate leg-to-leg differences in maximal and explosive hip muscle strength and drop-jump performance after hip arthroscopy for femoroacetabular impingement syndrome and its association with self-reported sports function and return to sport status.

Study V
Stratified care in hip arthroscopy – can we predict successful and unsuccessful outcomes? Development and external temporal validation of multivariable prediction models.

Primary aim: To develop and externally validate a clinically applicable multivariable prediction model for predicting outcomes after hip arthroscopy for hip-related pain.

CHAPTER 2:

GENERAL METHODS

Study designs

We included patient records from the Danish Hip Arthroscopy Registry (DHAR) for studies I and V. In studies II to IV, eligible patients were identified in DHAR and subsequently invited to participate by responding to a study-specific secure e-mail (E-boks®) invitation (**Table 3**).

Table 3. Overview of study designs and time points for data collection for the studies included in the thesis.

Study	Design	Sample	Data collection
I	Cross-sectional registry-based study	1511 patients who have undergone hip arthroscopy	Data on pre-operative demographics and radiological findings, and intra-articular cartilage injuries were extracted from the DHAR
II	Cross-sectional study	141 patients who have undergone hip arthroscopy for femoroacetabular impingement 12-24 months before study initiation.	Eligible patients were identified in the DHAR and subsequently invited via a secure e-mail system (E-boks®) to answer a questionnaire designed specifically to capture Patient Acceptable Symptom State.
III	Cross-sectional study	189 patients who have undergone hip arthroscopy for femoroacetabular impingement 6 months to 6 years before study initiation.	Eligible patients were identified in the DHAR and subsequently invited via a secure e-mail system (E-boks®) to answer a return to sport questionnaire designed specifically for study III.
IV	Cross-sectional study	45 patients who have undergone hip arthroscopy for femoroacetabular impingement 6-30 months before study initiation.	Eligible patients were identified in the DHAR and subsequently invited via a secure e-mail system (E-boks®) to participate in a data collection session aimed at measuring hip muscle strength at Hvidovre Hospital.
V	Retrospective with 1-year follow-up registry-based study	1546 patients who have undergone hip arthroscopy with 1-year follow-up outcomes.	Data on pre-operative demographics, radiological findings and self-reported measures, intra-articular cartilage injuries, and 1-year self-reported measures were extracted from the DHAR and used in the development of prediction models.

DHAR: Danish Hip Arthroscopy Registry.

Study settings

The Danish Hip Arthroscopy Registry was initiated in 2012 as a national hip arthroscopy database with web-based (www.hipjoint.dk) prospective registration of hip arthroscopies performed in Denmark. Currently, the registry collects information from 14 specialized public and private hospitals/clinics, including 21 orthopaedic surgeons.[87,154] The registry and data management is run by a steering committee, which publishes an annual report available at The Danish Society of Arthroscopy and Sports Traumatology homepage (www.saks.nu). The 14 hospitals and clinics cover yearly expenses.[154] The Danish Hip Arthroscopy Registry is considered valid and broadly generalizable, based on high completeness of registration concerning all hip arthroscopies performed in Denmark between 2012-2018 (77-93 %) **(Figure 8)**, with only marginal demographic differences of sex and age between responders and non-responders at one-year post-operatively.[155]

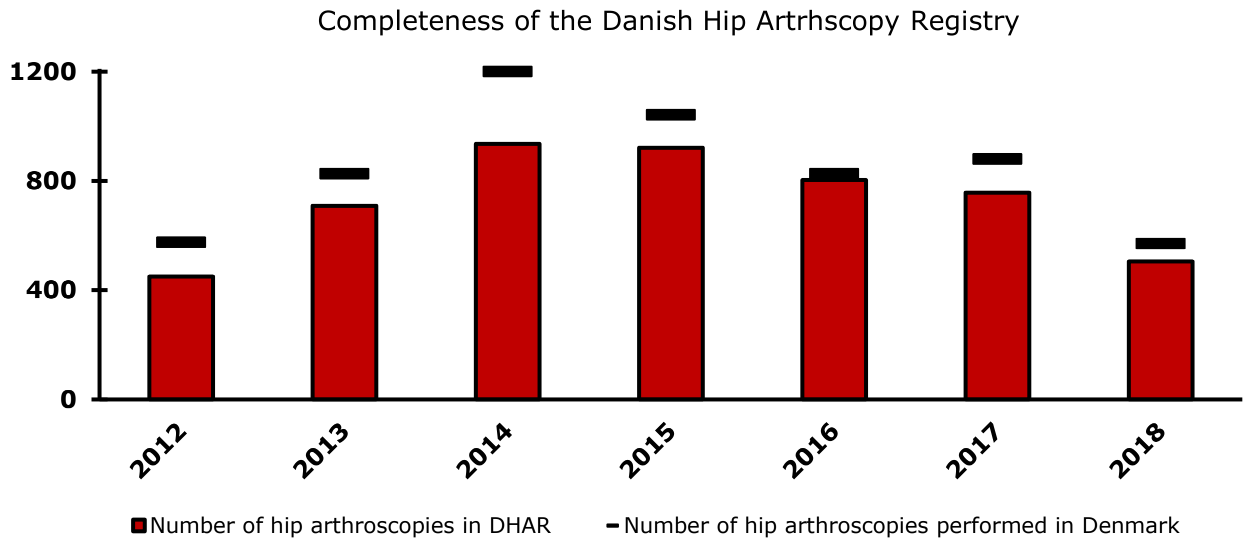

Figure 8. Completeness of the Danish Hip Arthroscopy Registry compared to hip arthroscopies registered in Denmark. The figure is reproduced based on data from Poulsen et al.[155] DHAR (Danish Hip Arthroscopy Registry).

Participants

All included paticipants in this thesis have been treated arthroscopically for various causes of hip-related pain (studies I and V) and femoroacetabular impingement syndrome, specifically (studies II to IV).[6] Since the Danish Hip Arthroscopy Registry contains data from several surgeons across several hospitals and clinics, the specific indications for surgery and the surgical procedures may vary; such information is not captured in detail.[154] Thus, the participants are included/described based on different morphological entities rather than specific diagnoses **Table 4**.

Table 4. Overview of radiological entities used in the present thesis based on radiological measures from the Danish Hip Arthroscopy Registry.

Morphological Entity	Radiological definitions
Normal morphology	AA <55° and LCEA between ≥25° to ≤39°
Cam morphology (FAI Syndrome)	AA >55° and LCEA between ≥25° to ≤39°
Pincer morphology (FAI Syndrome)	AA < 55° and LCEA >40°
Cam and pincer morphology (FAI Syndrome)	AA > 55° and LCEA >40°
Borderline dysplasia	AA <55° and LCEA <25°
Borderline dysplasia and cam morphology	AA >55° and LCEA <25°

AA (Alpha angle); LCEA (Lateral Center Edge Angle).

Recruitment of participants and sample characteristics

All participants and/or associated data were recruited/retrieved from the Danish Hip Arthroscopy Registry through study-specific application forms (one for each study) to the Steering Committee. These applications contained detailed information about the aim and rationale for the study, planned data analyses, information on variables needed, such as demographic, radiographic, and peri-operative data, and sample characteristics (i.e., inclusion and exclusion criteria for the data extraction procedure) (**Table 5**).

Table 5. Sample characteristics, and inclusion and exclusion criteria for the data extraction in the Danish Hip Arthroscopy Registry.

Study	Inclusion criteria	Exclusion criteria
I	- Age 15 to 50 years at the time of hip arthroscopy	- Previous periacetabular osteotomy - Revision hip arthroscopy - Previous hip pathology, such as: Perthes disease Slipped capital femoral epiphysis Avascular necrosis of the femoral head - Any rheumatoid disease in the hip joint
II	- Age 18 to 50 years at the time of hip arthroscopy - Cam morphology (alpha angle > 55°) - Minimal surgical procedures: Cam resection Labral surgery - Hip arthroscopy performed 12 to 24 months before study initiation	- Joint space width <3 mm - Borderline hip dysplasia (lateral center edge angle <25°) - Pure extra-articular surgical procedure - Previous periacetabular osteotomy - Revision hip arthroscopy - Total hip arthroplasty - Previous hip pathology, such as: Perthes disease Slipped capital femoral epiphysis Avascular necrosis of the femoral head - Any rheumatoid disease in the hip joint
III	- Age 18 to 30 years at the time of hip arthroscopy - Age 35 years or younger at the time of study initiation - Cam morphology (alpha angle > 55°) - Minimal surgical procedures: Cam resection Labral surgery - Hip arthroscopy performed 6 months to 6 years before study initiation	- Joint space width <3 mm - Grade 4 cartilage injuries on Becks or ICRS - Borderline hip dysplasia (lateral center edge angle <25°) - previous hip arthroscopy in the same hip joint - Previous hip pathology, such as: Perthes disease Slipped capital femoral epiphysis Avascular necrosis of the femoral head - Any of the following surgical procedures at any time: Extra-articular surgery of the hip joint (except capsular closure) Microfracture in the hip joint Periacetabular osteotomy Surgery to the ligamentum teres - Any rheumatoid disease in the hip joint
IV	- Age 18 to 40 years at the time of hip arthroscopy - Cam morphology (alpha angle > 55°) - Minimal surgical procedures: Cam resection Labral surgery - Hip arthroscopy performed 6 to 30 months before study initiation - Hip arthroscopy performed in the Greater Copenhagen	- Joint space width <3 mm - Hip dysplasia (lateral center edge angle <20°) - Previous hip arthroscopy - Any of the following surgical procedures at any time: Extra-articular surgery of the hip joint (except capsular closure) Microfracture in the hip joint Periacetabular osteotomy Surgery to the ligamentum teres - Previous hip pathology, such as: Perthes disease Slipped capital femoral epiphysis Avascular necrosis of the femoral head - Any rheumatoid disease in the hip joint
V	- Age 15 to 50 years at the time of hip arthroscopy	- Previous periacetabular osteotomy - Revision hip arthroscopy within 1 year - Previous hip pathology, such as: Perthes disease Slipped capital femoral epiphysis Avascular necrosis of the femoral head - Any rheumatoid disease in the hip joint

Study I and V were conducted as registry-based studies, using data solely from the registry. In studies II to IV, we identified eligible patients in the registry. Subsequently, we invited them to participate in the specific studies by responding to an email invitation sent through a password-secure email system (Eboks) using the personal identification number (CPR-number) for each patient. Reminder emails were sent once every week for 2-4 consecutive weeks to all non-responders on different weekdays and times of day to facilitate a high response rate.[156]

A timeline for data extraction/recruitment of participants is depicted in **Figure 9**, with the studies presented in the chronological sequence (note this timeline does not match the sequence in this thesis).

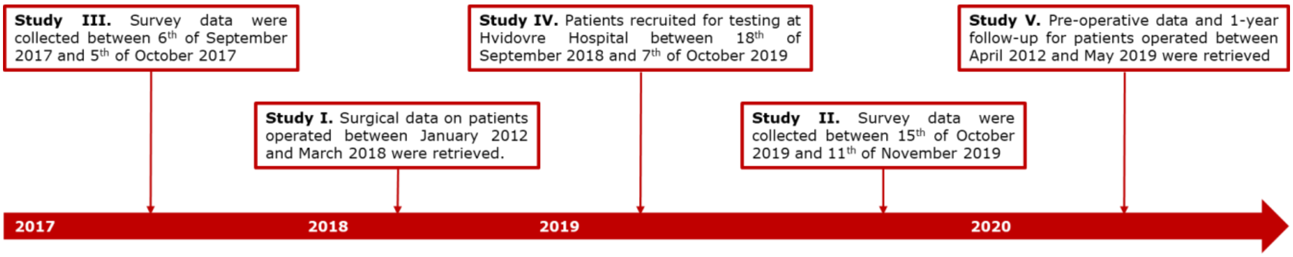

Figure 9. Timeline for studies included in the thesis.

Hip arthroscopy procedure

Since many surgeons are part of the Danish Hip Arthroscopy Registry, slight variations in the surgical procedure may exist between hospitals/clinics and among surgeons. However, most commonly, hip arthroscopies are performed under general anaesthesia in a supine position using a standard 2-portal technique (anterolateral and inferior mid-anterior),[82,134] with surgical procedures (e.g. rim trimming, labral repair, chondral debridement, cam resection, and capsular closure) performed when indicated. During traction, the hip joint is inspected, and acetabular rim trimming is performed as indicated with labral tears being re-fixated with a number of suture anchors, depending on the size of the labral tear. Chondral lesions are debrided combined with microfracture if indicated (most often in patients with grade 4 cartilage injury). Subsequently, cam morphology is treated by femoral osteoplasty, as indicated, without traction. Capsular closure is performed depending on the surgeon's preference and the size and location of the capsulotomy.[82,134]

Information on post-operative management is not included in the Danish Hip Arthroscopy Registry.[154] However, all patients are offered physiotherapist-led rehabilitation at the surgical facility or a local community physical therapy centre specializing in rehabilitation. The rehabilitation is commonly structured as an initial period of restricted weight-bearing and crutches depending on the surgical procedure [157] and immediate ergometer cycling to mobilize the hip joint. This initial period is followed by criteria- and/or time-based progression through mobility, stability, strength, and functional/sports-specific exercises for 3-5 months.[82,122,134,157]

Radiological and operative data from the Danish Hip Arthroscopy Registry

The operating surgeons facilitate data collection in the registry by recording and registering pre-operative radiological parameters related to hip-joint morphology and peri-operative data related to general surgical procedure, labral and cartilage injury status, complications, etc.[154,155] Although no inter-surgeon reliability data exists for the Danish Hip Arthroscopy Registry, previous studies indicate that 1) orthopaedic surgeons with clinical expertise in hip pain show fair to excellent agreement for the assessment of common radiological features of femoroacetabular impingement syndrome,[158] and 2) classification of cartilage injuries from normal cartilage (grade 0) to exposed bone (grade 4) identified during hip arthroscopy show high reliability.[159] In addition to registration of radiological and operative data, the operating surgeons invite patients to state pre-operative hip and groin function and pain using validated and recommended disease-specific patient-reported outcome measures [106] and generic health measures.[154,155] At 1-, 2-, 5-, and 10-year post-operatively, patients are invited to state self-reported hip and groin function using the same questionnaires electronically by responding to automatic email invitations.[154,155] An outline of the different variables retrieved from the registry for the different studies is presented below.

Radiographic measures

A radiographic investigation of the pelvic area constitutes the first-line imaging modality for patients with suspected hip-related pain. This process allows for a general evaluation of the morphological features of the pelvis and proximal femur and thus serves to provide an initial understanding of potential causes of pain.[1,6,17] In the registry, several pre-operative radiographic measures (described in detail below) obtained from plain radiography are registered on almost all patients. As recommended by a recent consensus statement, *the Lisbon Agreement on Femoroacetabular impingement Imaging*, the radiographic assessment includes a lateral view (i.e., cross-table lateral, Dunn 45° or frog lateral) and an anterior-posterior pelvic view (**Figure 10**).[17]

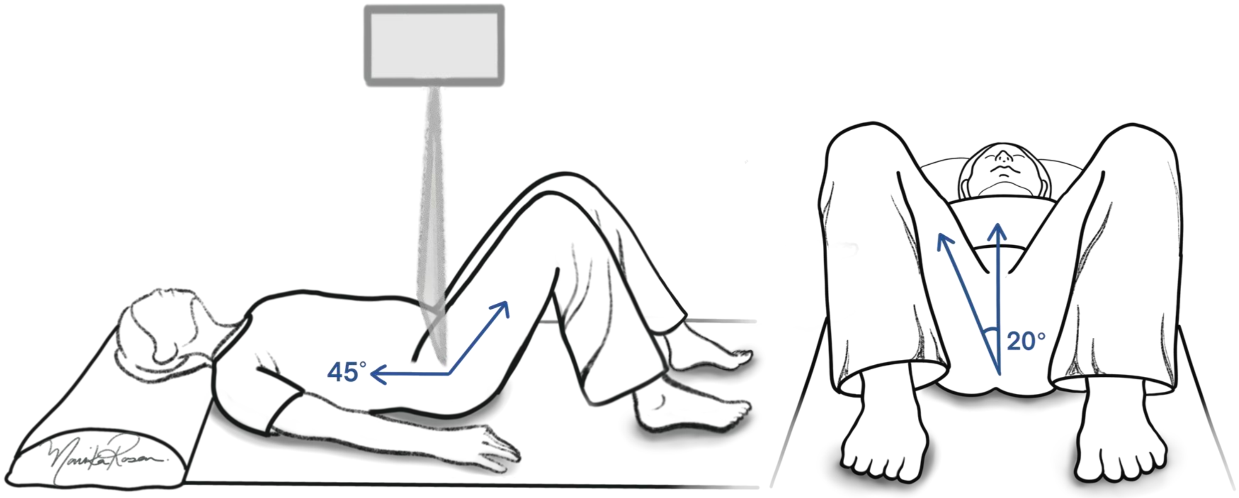

Figure 10. Dunn 45° setup using plain radiograph. Illustrations by Monika Rosen specifically for this thesis.

Lateral views have consistently shown better sensitivity for classifying femoral head-neck morphology, such as cam morphology, compared to the anterior-posterior pelvic view when using radial magnetic resonance imaging (MRI) as the reference standard.[160,161] In addition, it has recently been recommended that Dunn 45° view should be the first choice for initial radiographic assessment of femoral head-neck junction morphology,[17] because of higher sensitivity for capturing cam morphology in the anterior-superior region;[160,161] the most common location for cam morphology to develop.[17,32,37] While the lateral view is standard procedure in Denmark for patients with hip-related pain, the specific lateral view is not documented in the Danish Hip Arthroscopy Registry. Thus, we cannot guarantee that the Dunn 45° view has been applied to all patients.

Compared to the lateral view for assessing femoral head-neck morphology, the anterior-posterior pelvic view is best suited to assess acetabular orientation and morphology.[17]

Femoral head-neck morphology

Cam morphology can be measured using a variety of radiological measures. In the Danish Hip Arthroscopy Registry and this thesis, cam morphology is measured using the Alpha Angle, obtained from a lateral radiographic view.[17] The Alpha Angle is considered the most prevalent measure of cam morphology,[33] and has recently been recommended as the main criteria for defining cam morphology.[17] The Alpha Angle represents "*the angle between 1) the line from the centre of the femoral head parallel to the axis of the femoral neck, and 2) the line from the centre of the femoral head to the point where the femoral head-neck junction extends beyond the margin of the circle along the periphery of the femoral head*" (**Figure 11**).[27]

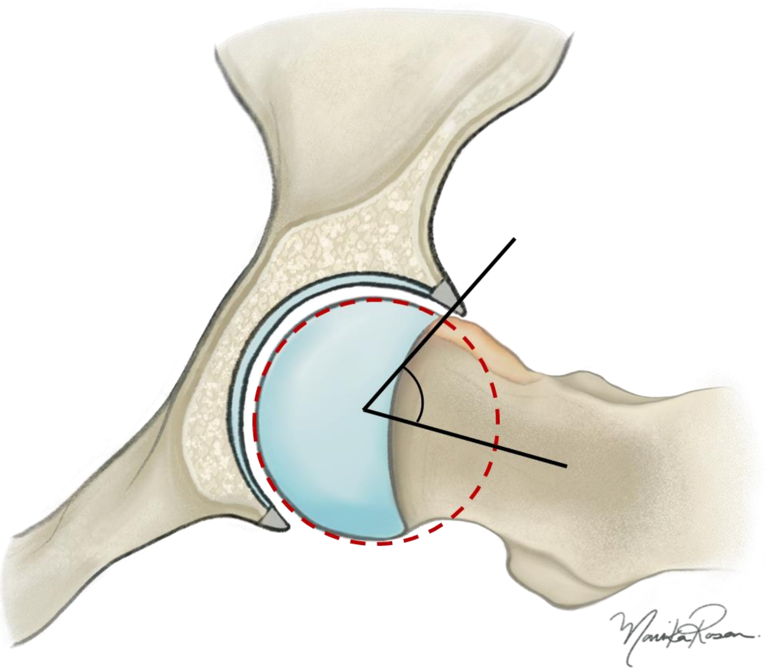

Figure 11. Measurement of alpha angle on a hip with cam morphology. The illustration represents a Dunn 45° view on a plain radiograph, the recommended projection for assessing cam morphology. Illustration by Monika Rosen specifically for this thesis.

Several cut-off angles have been used in the literature to define cam morphology, with the most commonly used being an Alpha Angle above 55°;[33] this thesis uses the same definition of cam morphology. However, a recent systematic review proposes a cut-off above 60° to define cam morphology based on a bimodal distribution of Alpha Angles in the general population.[26]

Acetabular morphology

The Lateral Center Edge Angle, Ischial Spine Sign, and Acetabular Index Angle represent measures to quantify the over- or under-coverage of the femoral head and acetabular retroversion (i.e., pincer morphology or dysplasia). These measures are included in the Danish Hip Arthroscopy Registry and are obtained using an anterior-posterior pelvic view.[17]

Over- and under-coverage

Over- or under-coverage of the femoral head by the acetabulum can be measured using the Lateral Center Edge Angle (LCEA) and the Acetabular Index (AI) angle. These measures are recommended as routine assessments in patients with suspected femoroacetabular impingement syndrome.[17] Over-coverage represents pincer morphology,[1,17] whereas under-coverage represents hip dysplasia.[17,162] The LCEA is measured as "*the angle between 1) the vertical line through the femoral head perpendicular to the line between the centres of the two femoral heads (or a similar horizontal line) and 2) the line between the centre of the femoral head and the lateral end of the sourcil*" (i.e., weight-bearing area of the acetabulum; LCEA of Wiberg) (**Figure 12**).[17,27] The AI angle is measured as "*the angle between the horizontal line and a line drawn through the medial end of the sourcil and the lateral end of the sourcil (acetabular rim)*" (**Figure 12**).[162,163]

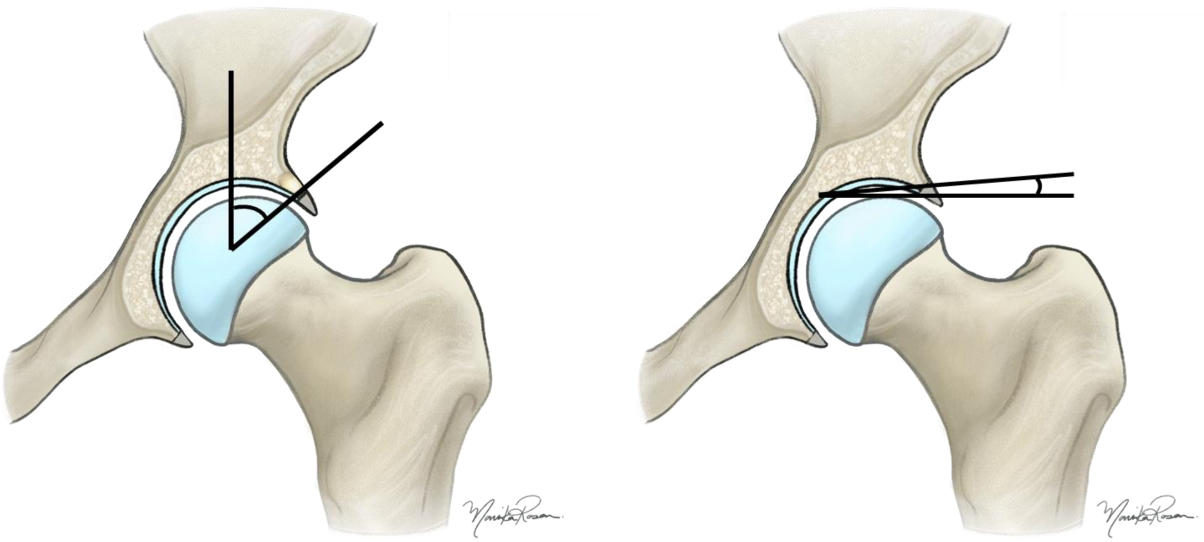

Figure 12. Measurements of the Lateral Center Edge Angle on a hip with pincer morphology (left) and the Acetabular Index Angle on a hip with normal morphology (right). Illustrations by Monika Rosen specifically for this thesis.

Based on a case-control study in 2015, Tannast et al.[162] proposed radiographic reference values for defining acetabular over- or under-coverage, such that over-coverage (pincer morphology) was defined as LCEA ≥34° or AI angle ≤2°, while under-coverage (hip dysplasia) was defined as LCEA ≤22° or AI angle ≥14°. Furthermore, a large population-based study provided reference values for LCEA (20.8–45.0°) and AI (-4.7-14.8°),[164] highlighting the discrepancy between studies. Based on scrutiny of reported cut-off and reference values, a recent consensus statement defined over-coverage (pincer morphology) as LCEA ≥40° or AI angle <0°, and under-coverage (hip dysplasia) as LCEA <20° or AI angle >13°.[17] This thesis adheres to the consensus-based definitions.

Acetabular version

The acetabular version refers to the orientation of the acetabulum. From a femoroacetabular impingement syndrome perspective, acetabular retroversion (acetabulum facing backwards) is of particular interest, as it represents one form of pincer morphology.[17] Retroversion can be described as global, indicated by the Ischial Spine Sign,[17,165] or focal, indicated by a positive cross-over sign.[17,165] The Ischial Spine Sign is considered positive if the projected shape of the Ischial Spine is visible medially to the pelvic brim,[17] as an indication that the acetabulum is retroverted globally such that over-coverage is present anteriorly, while under-coverage is present posteriorly (**Figure 13**).[165]

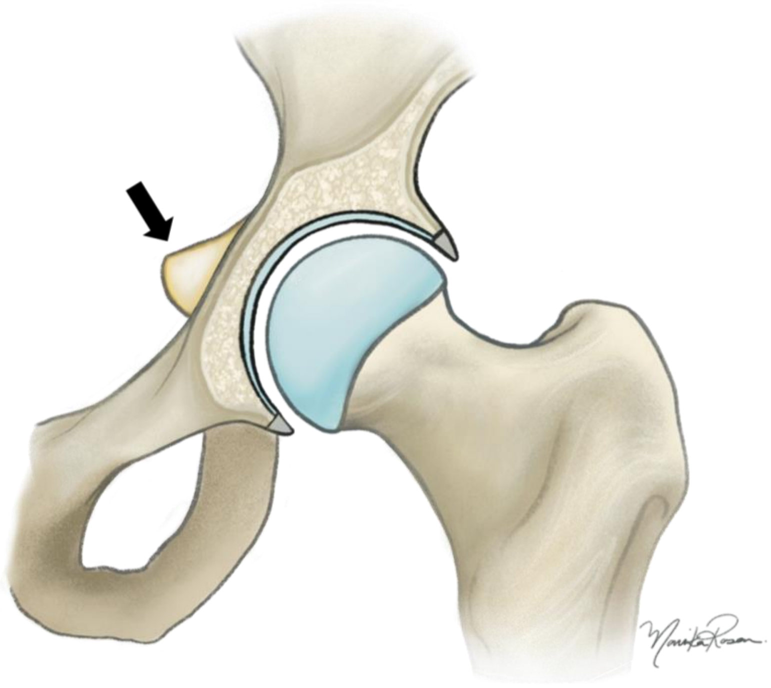

Figure 13. An anterior-posterior view showing an Ishial Spine Sign (black arrow). Illustration by Monika Rosen specifically for this thesis.

The cross-over sign is considered positive when the anterior rim of the acetabulum projects laterally in comparison to the posterior rim in the superior region, indicative of anterior over-coverage of the femoral head.[165] However, the cross-over sign may overestimate the proportion of hips with focal acetabular retroversion compared to 3D CT analyses,[165] which may stem from the generally poor reliability of the measure [158] and is therefore not included as a radiological parameter in this thesis. In comparison, the Ischial Spine Sign is associated with good reliability.[158]

Joint Space Width

The Joint Space Width is an indirect measure of cartilage injury [166,167] and osteoarthritis.[17] In the registry, the Joint Space Width is assessed using an anterior-posterior pelvic view as the distance between the femoral head and the lateral sourcil at the acetabulum, which shows good reliability.[17,27,168] The Joint Space Width is subsequently categorized as normal (JSW>4.0 mm), mild reduction (3.1 mm≤JSW≤4.0 mm), severe reduction (2.1 mm≤JSW≤3.0 mm) or osteoarthritis (JSW<2.1 mm).[168]

Cartilage grading

The operating surgeon grades the acetabular and femoral head cartilage injuries during surgery. The degree of cartilage injury is an indirect measure of osteoarthritis and has been associated with the outcome after hip arthroscopy.[169]

Acetabular cartilage

Acetabular cartilage injury is graded using a modified Becks cartilage classification system, showing high reliability.[159] Specifically, acetabular cartilage is graded as normal cartilage (grade 0), fibrillation (grade 1), wave sign (grade 2), cleavage tear between acetabular bone and cartilage (grade 3), or exposed bone (grade 4) (**Figure 14**).[159] In addition, cartilage injury size is graded as: no lesion (grade 0), <1 cm^2 (grade 1), 1-2 cm^2 (grade 2), or >2 cm^2.

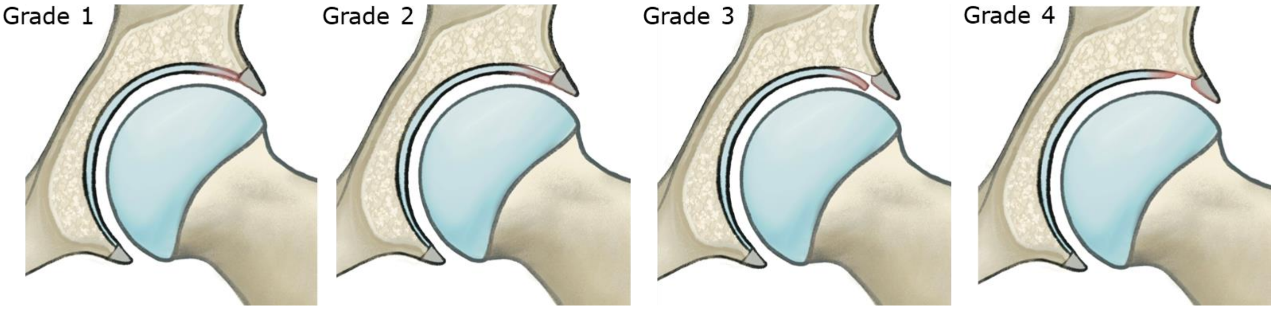

Figure 14. Becks cartilage injury classification system. Grade 1, fibrillation. Grade 2, wave sign. Grade 3, cleavage tear between acetabular bone and cartilage. Grade 4, exposed bone.[159] Illustrations by Monika Rosen specifically for this thesis.

Femoral head cartilage

Femoral head cartilage injury is graded using the International Cartilage Repair Society (ICRS) classification as: normal cartilage (grade 0), nearly normal (grade 1), abnormal (grade 2), partial loss of cartilage (grade 3), or exposed bone (grade 4) (**Figure 15**).[159] In addition, cartilage injury size is graded as: no lesion (grade 0), <1 cm^2 (grade 1), 1-2 cm^2 (grade 2), or >2 cm^2.

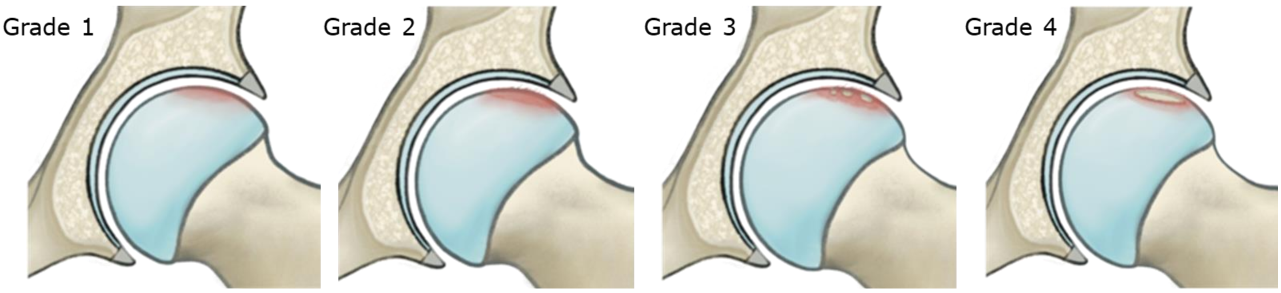

Figure 15. International Cartilage Repair Society classification system. Grade 1, nearly normal. Grade 2, abnormal. Grade 3, partial cartilage loss. Grade 4, exposed bone.[159] Illustrations by Monika Rosen specifically for this thesis.

Patient-reported outcome measures

This thesis includes different patient-reported outcome measures specified in detail below.

The Copenhagen Hip And Groin Outcome Score

In studies II to V, the Copenhagen Hip and Groin Outcome Score (HAGOS) was included as part of the outcomes. HAGOS is designed to measure current health state, physical function, and quality of life in young to middle-aged patients with hip and/or groin pain.[106] It consists of 37 items (question and associated answer) covering six dimensions (subscales), assessing pain, symptoms, physical function in daily living, function in sport and recreational activities, participation in physical activities, and hip-related quality of life. Each question is answered on a five-point Likert scale with a corresponding score of 0 (best) to 4 (worst). Subsequently, a separate score for each subscale is calculated, ranging from 0 (extreme symptoms) to 100 (no symptoms).[106] There is no composite score. Reference values for a mixed group of healthy individuals without hip and/or groin pain are available, with subscale scores above 75 (depending on the specific subscale) being equivalent to normal hip and/or groin function.[82]

Although HAGOS originally was developed using pen and paper,[106] we collected HAGOS electronically in this thesis using the Research Electronic Data Capture (REDCap) tool (v. 7.1.1; Vanderbilt University) hosted at the Capital Region of Denmark (Study II to IV) [170] or retrieved HAGOS directly from the Danish Hip Arthroscopy Registry (Study V). For data collection in REDCap, we adhered to the pen and paper version of HAGOS, including the layout of questions and answer boxes, instructions, and page shifts. Although this deviation may be seen as a limitation, near-perfect correlation and agreement between the paper and electronic version of the International Hip Outcome Tool-12 in patients with femoroacetabular impingement syndrome have recently been shown.[171]

International Hip Outcome Tool-33

In study II, the International Hip Outcome Tool-33 (iHOT-33) was included as part of the outcome measure. The Danish Hip Arthroscopy Registry did not contain an iHOT-33 score until recently, whereas it was decided not to include iHOT-33 in the remaining papers to limit the questionnaire burden.[156] The iHOT-33 consists of 33 items (questions and associated answers) originally framed to measure the hip-related quality of life. Each question is scored on a 0 to 100 mm visual analogue scale, with higher values indicating better hip-related quality of life. The overall score is calculated as the average score across items,[80] although specific subscales have been proposed and found valid, reliable, and responsive, covering dimensions of symptoms and functional; sports and recreational activities; job-related concerns; and social, emotional, and lifestyle concerns.[80,81]

Return to sport and performance

In studies III and IV, we measured return to sport and performance using a custom-made return to sport questionnaire. The questionnaire was developed to reflect the return to sport continuum – from no return to sport to return to performance – as presented in a 2016 consensus statement.[119] Before administering the questionnaire, it was pilot tested at our department by asking patients attending the outpatient clinic for a follow-up appointment 1-year after hip arthroscopy to fill out the questionnaire. The questionnaire was continuously adjusted based on patient interviews until we reached a final version.

The return to sport questionnaire categorized patients into four levels of the return to sport continuum based on their participation in sport during the previous three months (**Table 6**). "Preinjury" refers to before the onset of hip and groin problems, while "level" was categorized as: Elite, competitive, recreational. A brief overview of the flow of questions is provided in **Figure 16**.

Table 6. Return to sport categories and associated definitions in the custom-made return to sport questionnaire.[172]

Return to sport category	Definitions
No return to preinjury sport	Not engaged in preinjury sport
Impaired sports performance including restricted sports participation	Lower athletic performance including restricted participation in at least one element of the sport (e.g. match play)
Impaired sports performance but full sports participation	Lower athletic performance compared with preinjury but unrestricted participation in all elements of the sport
Optimal sports performance including full sports participation	Same or better athletic performance compared with preinjury including unrestricted participation in all elements of the sport

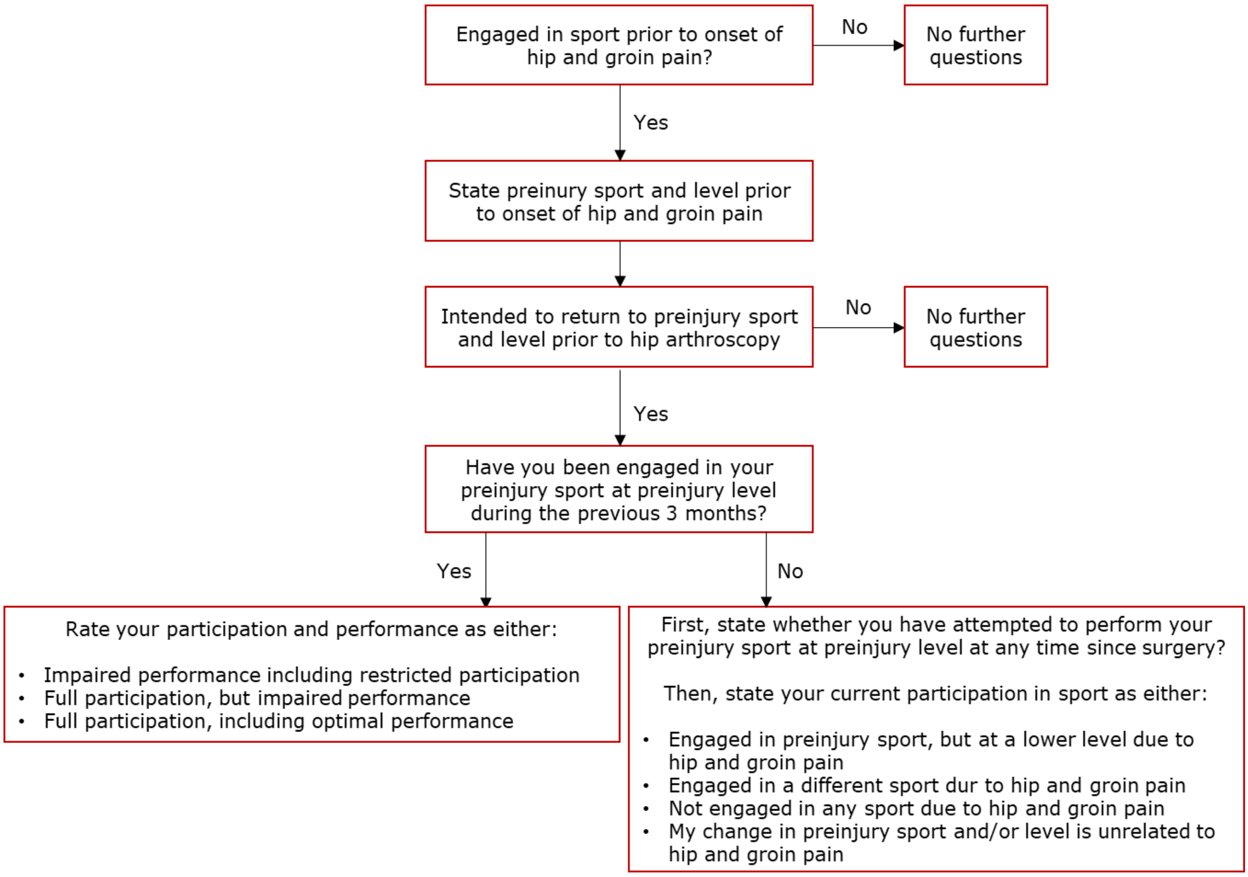

Figure 16. The flow of questions for assessing return to sport

Patient Acceptable Symptom State

In study II, we investigated the Patient Acceptable Symptom State (PASS), which measures whether patients consider their current health state acceptable when considering hip and groin function and pain and how it affects their daily life, social activities, and ability to participate in sport.[107,108] To measure PASS, we used the following question, inspired by previous studies,[108] answered with "yes" or "no":

"*Taking into account your hip and groin function and pain, and how it affects your daily life, including your ability to participate in sport and social activities, do you consider that your current state is acceptable if it remained like that for the rest of your life*?"

Since the above PASS question contains aspects of both daily life, sport, and social activities, one or more aspects may drive whether the patient considers their current state as acceptable or not. To explore this situation further, we constructed two additional PASS questions concerning only activities of daily living (first question below; $PASS_{ADL}$) and sports activities (second question below; $PASS_{Sport}$):

1) *"Taking into account your hip and groin function and pain, and how it affects your activities of daily living, do you consider that your current state is acceptable if it remained like that for the rest of your life?"*

2) *"Taking into account your hip and groin function and pain, and how it affects your ability to participate in sport, do you consider that your current state is acceptable if it remained like that for the rest of your life?"*

Performance measures

The author of this thesis conducted all measures presented below.

Hip muscle strength and rate of force development

In study IV, we measured isometric maximal and explosive (rate of force development) hip muscle strength of the operated and non-operated hip. Measures were conducted using an externally fixated handheld dynamometer with a sampling frequency of 100 Hz (Hoggan MicroFET2, Scientific L.L.C., Salt Lake City, USA) (**Table 7**).[124]

Table 7. Description of muscle strength tests utilized in study IV. The test descriptions and pictures are reproduced from Ishøi et al.[124]

Overall testing procedure

Two warm-up trials were followed to three maximal trials (MVC) interspersed with 60 seconds for each test. The starting test leg (operated vs. non-operated) and test sequence were randomized to minimize systematic intra-participant fatigue. Subjects were instructed, before each MVC trial, to push as "*fast and hard as possible to emphasize the "rate of force development" part of the MVC trials, and to keep pushing until instructed to relax*" (approximately 3-4 s). Standardized verbal encouragement was provided during each MVC trial by the tester: "3-2-1-go-push-push-push-and relax." During all test procedures, patients were instructed to stabilize themselves by holding on to the examination table with both hands.

Specific testing procedure

For hip abduction/adduction, the patient was in the supine position, with the test leg placed at the end of the examination table, and the opposite leg slightly flexed. The dynamometer was placed 5 cm proximal to the proximal edge of the lateral malleolus or 5 cm proximal to the proximal edge of the medial malleolus for hip abduction and adduction, respectively. The dynamometer was externally fixated by the tester's hand/arm placed between the wall and the dynamometer.

For hip flexion, the patient was sitting at the edge of the examination table, with the hips in 90° of flexion. The dynamometer was fixated 5 cm proximal to the proximal edge of the patella using a rigid belt fastened to a glass suction cup on the ground.

For hip extension, the patient was in the prone position, with the ankles placed at the edge of the examination table. The dynamometer was placed posteriorly at the ankle 5 cm proximal to the proximal edge of the lateral malleolus. The patient was instructed to perform a hip extension movement, rather than a knee flexion. The dynamometer was externally fixated using a rigid belt fastened to a glass suction cup on the ground.

Force data were acquired by connecting the dynamometer via Bluetooth with a commercial software program (TBS, Hoggan, Scientific L.L.C., Salt Lake City, USA), which recorded and stored the data. Subsequently, raw force data were exported and analysed using a custom-made spreadsheet (Microsoft Excel, USA). We identified peak force and early (0-100 ms) and late-phase (0-200 ms) rate of force development from the trial with the highest value, respectively. The rate of force development was calculated as the mean change in force per second during the time intervals 0-100 ms and 0-200, with the onset of force (t=0 ms) set at 6.67 Newton.[145]

For analyses purposes, maximal and explosive strength was standardized to Newton meter per body mass (Nm/kg or Nm/s/kg) by multiplying the force output with the length of the lever arm, defined as the distance from the anterior superior iliac spine to the placement of the dynameter, and dividing by the body mass. We have previously established high intra-tester reliability for all tests and outcomes (**Table 8**).

Table 8. Intra-tester reliability data (n=17) for the strength assessments used in study IV. The table is reproduced based on Ishøi et al.[124]

Isometric hip actions	ICC (2.1) * [CI 95%]	SEM	SEM (%)	MDC_{ind} (%)	MDC_{group} (%)
Peak Force (N)					
Abduction	0.93 [0.83;0.98]	12.2	7.1	19.8	4.8
Adduction	0.96 [0.88;0.98]	13.8	7.6	21.0	5.3
Flexion	0.95 [0.88;0.98]	18.8	5.9	16.4	4.0
Extension	0.93 [0.81;0.98]	19.4	7.3	20.2	5.2
RFD 0-100 ms (N/s)					
Abduction	0.93 [0.81;0.97]	152.5	15.1	41.8	10.1
Adduction	0.90 [0.73;0.96]	130.5	13.1	36.3	9.1
Flexion	0.87 [0.67;0.95]	261.5	10.6	29.3	7.1
Extension	0.82 [0.55;0.94]	227.8	15.5	43.1	11.1
RFD 0-200 ms (N/s)					
Abduction	0.86 [0.65;0.95]	80.0	13.8	38.2	9.3
Adduction	0.87 [0.66;0.95]	82.8	14.0	38.9	9.7
Flexion	0.92 [0.80;0.97]	103.6	7.4	20.5	5.0
Extension	0.85 [0.62;0.95]	125.6	12.3	34.1	8.8

RFD= rate of force development; N= Newton; N/s= Newton/second; ICC= Intraclass Correlation Coefficient; SEM= Standard Error of Measurement; MDC_{ind}= Minimal Detectable Change on an individual level; MDC_{group}= Minimal Detectable Change on a group level; SD= Standard Deviation; RFD_{100}= 0-100 ms rate of force development; RFD_{200}=0-200 ms rate of force development.

* ICC used for consistency assessment between sessions.

Copenhagen Five-Second Squeeze test

In study IV, we measured bilateral isometric hip adduction squeeze strength using a handheld dynamometer (Hoggan MicroFET2, Hoggan, Scientific L.L.C., Salt Lake City, USA); a procedure that has shown high intra-tester reliability.[173] This measurement was done adhering to the Copenhagen Five-Second Squeeze test, which was initially developed to measure hip and/or groin pain on an 11-point numeric rating scale.[174] However, it has since been successfully combined with hip adduction squeeze strength measures using a handheld dynamometer.[175] As previously described, the maximum hip adduction squeeze strength was recoded in newtons and subsequently standardized using lever arm and body mass (Nm/kg).

Reactive Strength Index

In study IV, we obtained the Reactive Strength Index from the operated and non-operated leg during a single leg drop jump test.[176] We used the procedure described by Markwick et al.,[176] where patients jump from a box with a height of 20-cm while holding a light pole behind the neck. Upon landing on a single leg, patients were instructed to "jump as fast and high as possible."[176] The reactive strength Index was calculated as the ratio between flight time (when jumping on a single leg) and contact time (from landing on a single leg to take-off) using the MyJump iPhone application,[177–179] which take advantage of the high-speed camera (240 Hz) in an iPhone 6 device.

Development and validation of clinical prediction models

In study V, we developed and temporal validated clinical prediction models. In this process, we followed the initial 3-steps of the PROGRESS framework introduced earlier in the thesis (**Figure 17**).[90] The final step in the PROGRESS framework (Step 4: stratified care research) is beyond the scope of this thesis but is included in **Figure 17** for illustrative purposes. In summary, we reviewed outcomes following hip arthroscopy in the literature supplemented with findings from study II to IV in this thesis to determine the outcomes of interest to be predicted (Step 1: Fundamental Prognosis Research).[90] We reviewed and identified potential prognostic factors for a good or poor outcome in previous literature and whether these could be extracted from the Danish Hip Arthroscopy Registry, as described in detail below (Step 2: Prognostic Factor Research).[92] Finally, we developed and externally validated the clinical prediction models following procedures described in *Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis (TRIPOD)* guideline [95,180] and by Steyerberg et al.[93] (Step 3: Prognostic Model Research).[91]

Framework for prediction model development and temporal validation in the thesis

Step 1: Fundamental Prognosis Research

Step 1 A: We identified outcomes after hip arthroscopy to establish the potential usefulness of a prediction model (i.e., if all patients respond well there is no need for a prediction model).

↓

Step 1 B: Based on identification of outcomes. we defined outcomes to be predicted that we considered clinically relevant and of interest to the patient (i.e., achievement of a patient acceptable symptom state, representing patients that respond well, or not improving in symptoms exceeding the Minimal Clinically Important Difference, representing patients in which surgery had no effect).

↓

Step 1 C: We identified the Danish Hip Arthroscopy Registry (DHAR) as a convenient and relevent source of data extraction for potential prediction model development due to its generalizability and large sample size. DHAR is a nationwide registry containing hip arthroscopy data since 2012.

↓

Step 2: Prognostic Factor Research

Step 2 A: We identified prognostic factors (i.e male sex, joint space witdth etc.) associated with outcomes after hip arthroscopy through literature search and based on expert opinion.

↓

Step 2 B: We reviewed the identified prognostic factors and compared them with variables contained in the DHAR, to understand if information in DHAR would be useful to build a prediction model.

↓

Step 2 C: We held an author consensus meeting to agree on which prediction variables to include in the prediction models based on availablity of variables in DHAR, existing literature, expert opinion, potential clinical usefulness, and available sample size.

↓

Step 3: Prognostic Model Research

Step 3 A: Prior to prediction model development, we inspected data and collapsed categorical variables if needed (i.e., to few events in each category) and to minimize the risk of overfitting. This was done based on previous literature and percieved clinical relevance of categorization. We used the "pmsampsize" Package in R Statistics to estimate the required sample size for inclusion of the identified predictors as suggested by Riley et al.* This was done to minimize overfitting.

↓

Step 3 B: We developed prediction models using logistic regression analyses in R Statistics and internally validated the models through bootstrapping. We applied a shrinkage factor to regression coefficients to improve prediction of new patients, and subsequently conducted preliminary temporal model validation to investigate if the developed prediction models could predict the outcomes of new patients.

↓

Step 3 C: We reported and illustrated the performance of the prediction models according to the framework presented by Steyerberg et al.** by providing calibration plots (and associated statistics), discrimination statistics (and associated histograms to visualize overlap between between those with and without the outcome) and sensitivity and specificity for a range of probability thresholds.

↓

Step 4: Stratified Care Research

↓

Step 4: Using of the externally validated prediction model to stratify treatment and investigation of the effect of this compared to usual practice.

Figure 17. Study process from initial idea to prediction model development inspired by The PROGnosis RESearch Strategy (PROGRESS) Framework.[86,90–92] * and ** refers to reference [181] and [93], respectively. This figure is reproduced from Ishøi et al.(unpublished)

Selection of prediction variables

All predictor variables were extracted from the Danish Hip Arthroscopy Registry and decided upon a-priori. In total, 26 predictor variables were selected based on previous studies regarding prognostic factors for outcomes after hip arthroscopy [97] combined with consensus among the authors. This selection was done by listing all the potential predictor variables in the Danish Hip Arthroscopy Registry, including items from HAGOS, and subsequently relating them to existing literature on prognostic factors for a poor or good outcome combined with the clinical experience of the authors. A complete list of predictor variables and reasons for selection is presented in **Table 9**.

Pre-operative self-reported variables of hip function, pain severity, and the psychosocial state were obtained using patient-reported outcome measures. We prioritized to include specific Items as predictors rather than composite scores, as single items can be easily implemented in the history-taking process. Thus, we selected specific items from HAGOS [106] and EQ-5D-3L [182] that we deemed valuable to reflect overall hip function based on previous literature and expert opinion **Table 9**. We selected the sports level using the Hip Sports Activity Scale, a 9-point scale representing different sporting categories and levels ranging from no sport participation to elite level participation in contact-based sports.[183] We selected the anxiety and depression item from the EQ-5D-3L health questionnaire to represent overall mental status.[182]

Table 9. Overview of a-priori defined predictor variables included in the prediction models.

Predictor variables	Scale	Reasons for selection of predictor variable
Demography		
Age	Continuous (years)	Younger age is associated with improved self-reported outcomes and lower revision rates.[97]
Sex	Dichotomous	Male sex is associated with improved self-reported outcomes.[97]
Hip Sports Activity Scale	Ordinal (9-point scale)	Sports participation reflects overall hip function, which is associated with self-reported outcomes.[97]
Context		
Hospital setting	Dichotomous (Private vs. public)	Patients in a private setting seem to have better pre-operative symptoms, which may reflect a specific subgroup of patients.[184]
Pre-operative radiography		
Lateral Center Edge Angle	Continuous (angle)	A higher angle is associated with lower failure rates.[97]
Ischial Spine Sign	Dichotomous	The acetabular version is associated with outcome.[97]
Alpha Angle	Continuous (angle)	Larger cam morphology is associated with revision surgery [97] and severe acetabular cartilage injuries.[166]
Joint Space Width	Ordinal (5-point scale)	Narrow joint space width is associated with severe cartilage injury, [166] worse self-reported outcomes, and conversion to total hip replacement,[97]
Acetabular Index Angle	Continuous (angle)	Less than 3 degrees is associated with revision surgery.[97]
Pre-operative self-reported hip function		
Overall rating of hip function	Continuous (0-100 VAS)	Better overall hip function pre-operatively is generally associated with better post-operative outcomes.[97]
Problems during running*	Ordinal (5-point scale)	Activities that reflect overall hip function and load-bearing capacity,[185] and thus may be associated with self-reported outcomes.[97] The ability to walk, run, participate in sport and get in or out of a car represents everyday activities that are often part of the history-taking process.
Problems during walking*	Ordinal (5-point scale)	
Problems get in/out of car*	Ordinal (5-point scale)	
Sports participation*	Ordinal (5-point scale)	
Pre-operative self-reported pain severity		
Pain frequency*	Ordinal (5-point scale)	Having less pain pre-operatively, indicative of better pre-operative status, may be associated with better post-operative outcomes.[97] Pain characteristics, such as stabbing and stiffness, and pain intensity during specific activities, are considered important for the diagnosis of hip pain [21] and are often part of the history-taking process.
Pain in other areas*	Ordinal (5-point scale)	
Stabbing sensation*	Ordinal (5-point scale)	
Morning stiffness*	Ordinal (5-point scale)	
Stiffness after sitting*	Ordinal (5-point scale)	
Night pain*	Ordinal (5-point scale)	
Pain during rest	Continuous (0-100 NRS)	
Pain during walking	Continuous (0-100 NRS)	
Pre-operative self-reported psychosocial factors		
Anxiety or depression#	Ordinal (3-point scale)	Pre-operative mental status and depression state are associated with worse self-reported outcomes.[97]
Awareness of hip*	Ordinal (5-point scale)	
Lifestyle changes*	Ordinal (5-point scale)	
Mood changes*	Ordinal (5-point scale)	
Peri-operative findings&		
ICRS Femoral head	Ordinal (5-point grading)	Degeneration of intra-articular structures, such as severe cartilage and/or labral injury, is associated with worse self-reported outcomes and conversion to total hip replacement.[97]
Femoral size lesion	Ordinal (4-point grading)	
BECKS acetabulum	Ordinal (5-point grading)	
Acetabulum size lesion	Ordinal (4-point grading)	
Labral injury	Dichotomous	

*Represent single Items from the Copenhagen Hip And Groin Outcome Score (HAGOS). Items are scored on a 5-point Likert scale ranging from extreme problems/pain to no problems/pain.[106] #Represent the anxiety and depression Item from the EQ-5D-3L Health questionnaire, which is scored on a 3-point Likert scale ranging from no anxiety/depression to extreme anxiety/depression.[182] &Predictor variables representing intra-articular findings identified during hip arthroscopy. These variables are only included in the supplementary prediction models.

Ethics

All studies were approved by the Steering Committee of the Danish Hip Arthroscopy Registry through separate study-specific applications. Studies I, II, III, and V were deemed exempt from review by the Danish Ethics Committee of the Capital Region since they were purely based on registry data and/or collected data through surveys. For study IV, approval was obtained from the Danish Ethics Committee of the Capital Region (Identifier: H-17019653). Data Protection Agency of the Capital Region approved all studies.

CHAPTER 3:

STATISTICAL METHODS AND RESULTS

Study I. Influence of hip joint morphology on cartilage injury

Demographic and Radiographic Factors Associated With Intra-articular Hip Cartilage Injury: A Cross-sectional Study of 1511 Hip Arthroscopy Procedures

The American Journal of Sports Medicine

Ishøi L., Thorborg K., Kraemer O., Lund B., Mygind-Klavsen B., Hölmich P.

Methods

Outcome measures

Study I aimed to investigate the association between hip joint morphology and demographic factors with cartilage injuries using contemporary definitions of hip joint morphology and cartilage injury classifications.

Associations were calculated as Odds Ratios with the dependent variables being acetabular and femoral head cartilage injury classified as grade 0-2 (no-to-minimal cartilage injury) versus grade 3-4 (moderate-to-severe cartilage injury). The independent variables were demographic (sex, age, and sports activity) and radiographic (alpha angle, lateral center edge angle, joint space width) factors.[166] The independent variables were based on previous indications of associations with hip cartilage injuries, and included: sex (male vs. female), age (15 to <30 years vs 30-50 years), sports activity (Hip Sports Activity Scale), Alpha Angle (<55° [normal] versus ≥55° to <78° [cam morphology] versus ≥78° [severe cam morphology]), Lateral Center Edge Angle (≥25° to ≤39° [normal], <25° [borderline dysplasia], >39° [pincer morphology]), Joint Space Width (>4.0 mm [normal], ≥3.1 to ≤4.0 mm [mild reduction], ≤3.0 mm [severe reduction]).

Sample size consideration

No a priori sample size calculation was performed. However, as suggested, we kept the number of independent variables (n=10) within the scope of 5-10 events of the dependent variable per independent variable to minimize the risk of overfitting.[95]

Statistical methods

Two multivariable logistic regression analyses were constructed with either acetabular cartilage injury or femoral head cartilage injury as dependent variables. All ten independent variables were entered in both models. The statistical analyses were performed in SPSS (v 23; IBM) with a significance level for independent variables set at 0.05. Hosmer and Lemeshow test, a measure of how well the model fits the data, showed adequate fit for both models with p>0.511.

Results

Participants

In total, 1511 out of 1923 eligible hip arthroscopies were included (**Table 10**). The remaining 412 had incomplete data.

Table 10. Overview of demographic, radiographic, and operative data on included subjects (n=1511). The table is reproduced from Ishøi et al.[166]

Demographic data	
Gender, no. females (%)	781 (51.7)
Mean age at surgery, years (SD)	34.9 (9.8)
Hip Sports Activity Scale score at the time of surgery (SD)	2.62 (2.02)
Radiographic data	
Alpha Angle (AA)	
Mean AA, ° (SD)	68.7 (13.3)
Normal (AA<55°), no. (%)	222 (14.7)
Cam morphology (55°≤AA<78°), no. (%)	836 (55.3)
Severe cam morphology (AA≥78°), no. (%)	453 (30.0)
Lateral Center Edge Angle (LCEA)	
Mean LCEA, ° (SD)	31.4 (5.0)
Normal (25°≤LCEA≤39°), no. (%)	1321 (87.4)
Pincer morphology (LCEA>39°), no. (%)	111 (7.3)
Borderline dysplasia (LCEA<25°), no. (%)	79 (5.2)
Joint space width (JSW)	
Normal (JSW>4.0), no. (%)	987 (65.3)
Mild reduction (3.1≤JSW≤4.0), no. (%)	472 (31.2)
Severe reduction (2.1≤JSW≤3.0), no. (%)	52 (3.4)
Surgical data	
Becks classification	
Grade 0-2, no (%)	901 (59.6)
Grade 3-4, no. (%)	610 (40.4)
ICRS classification	
Grade 0-2, no (%)	1439 (95.2)
Grade 3-4, no. (%)	72 (4.8)
Most common operative procedures	
Labral repair, no. (%)	1395 (92.3)
Reshaping of the femoral head-neck junction, no. (%)	1372 (90.8)

Acetabular cartilage status

Several independent variables were associated with a higher risk of grade 3-4 acetabular cartilage injuries, including age, male sex, cam morphology, and Joint Space Width (**Table 11**).

Table 11. Multivariate logistic analysis for the association between pre-surgery demographic and radiographic findings and moderate-to-severe acetabular cartilage injury (Beck grade 3-4) identified during hip arthroscopy. The table is reproduced from Ishøi et al.[166]

Independent predictor variables	Odds Ratio [95% CI] for identifying Beck grade 3-4 acetabular cartilage injury	p-value
Demographic data		
Higher age [a]	1.70 [1.30; 2.22]	p<0.001*
Increasing HSAS [b]	1.06 [1.00; 1.13]	p=0.074
Male gender	4.42 [3.47; 5.62]	p<0.001*
Radiographic data		
Alpha Angle (AA)		
Normal (AA < 55º)	Reference	
Cam morphology (55° ≤ AA < 78°)	2.23 [1.48; 3.34]	p<0.001*
Severe cam morphology (AA ≥ 78°)	4.82 [3.14; 7.41]	p<0.001*
Lateral center edge angle (LCEA)		
No pincer morphology (25° ≤ LCEA ≤ 39°)	Reference	
Pincer morphology (LCEA > 39°)	0.67 [0.42; 1.07]	p=0.091
Borderline dysplasia (LCEA < 25º)	1.28 [0.77; 2.14]	p=0.340
Joint space width (JSW)		
Normal (JSW > 4.0 mm)	Reference	
Mild reduction (3.1 mm ≤J SW ≤ 4.0 mm)	2.04 [1.58; 2.64]	p<0.001*
Severe reduction (2.1 mm ≤JSW ≤3.0 mm)	3.19 [1.62; 6.30]	p=0.001*

[a] 15-<30 years vs. 30-50 years

[b] per increase in score, HSAS (Hip Sports Activity Scale)

* statistically significant (p<0.05)

Femoral head cartilage status

Several independent variables were associated with a higher risk of grade 3-4 femoral head cartilage injuries, including age, sports activity, borderline dysplasia, and Joint Space Width (**Table 12**).

Table 12. Multivariate logistic analysis for the association between pre-surgery demographic and radiographic findings and moderate-to-severe femoral head cartilage injury (ICRS grade 3-4) identified during hip arthroscopy. The table is reproduced from Ishøi et al.[166]

Independent predictor variables	Odds Ratio [95% CI] for identifying ICRS grade 3-4 femoral head cartilage injury	p-value
Demographic data		
Higher age [a]	1.92 [1.03; 3.57]	p=0.041*
Increasing HSAS [b]	1.13 [1.00; 1.27]	p=0.047*
Male gender	1.22 [0.73; 2.06]	p=0.447
Radiographic data		
Alpha Angle (AA)		
Normal (AA < 55º)	Reference	
Cam morphology (55° ≤ AA < 78°)	0.67 [0.33; 1.34]	p=0.259
Severe cam morphology (AA ≥ 78°)	0.82 [0.39; 1.73]	p=0.597
Lateral center edge angle (LCEA)		
No pincer morphology (25° ≤ LCEA ≤ 39°)	Reference	
Pincer morphology (LCEA > 39°)	0.97 [0.38; 2.50]	p=0.949
Borderline dysplasia (LCEA < 25º)	3.08 [1.34; 6.61]	p=0.004*
Joint space width (JSW)		
Normal (JSW > 4.0 mm)	Reference	
Mild reduction (3.1 mm ≤J SW ≤ 4.0 mm)	2.63 [1.58; 4.38]	p<0.001*
Severe reduction (2.1 mm ≤JSW ≤3.0 mm)	3.04 [1.07; 8.45]	p=0.033*

[a] 15-<30 years vs. 30-50 years

[b] per increase in score, HSAS (Hip Sports Activity Scale)

* statistically significant (p<0.05)

Study II. Patient Acceptable Symptoms after hip arthroscopy

How many patients achieve an acceptable symptom state after hip arthroscopy for femoroacetabular impingement syndrome? – a Cross-sectional Study Including PASS Cut-Off Values for HAGOS and iHOT-33

Orthopedic Journal of Sports Medicine

Ishøi, L. Thorborg K., Ørum M.G., Kemp J.L, Reiman M.P., Hölmich P.

Methods

Outcome measures

The primary aim of study II was to investigate how many patients achieved an acceptable symptom state (PASS) 1-2 years after hip arthroscopy for femoroacetabular impingement syndrome, and establish cut-off values for validated patient-reported outcome measures.

Sample size consideration

No a priori sample size calculation was performed since the number of eligible participants in the Danish Hip Arthroscopy Registry and survey responders determined the sample size. However, the sample size required to obtain a precision of 10 % of the estimate was calculated to be 96 participants [186] based on the proportion of patients having PASS estimated to be 50 %.[28]

Statistical methods

The proportions of patients having PASS, $PASS_{ADL}$, and $PASS_{Sport}$ were calculated using percentages with 95 % Confidence Intervals (95 % CI). Self-reported hip and groin function (HAGOS and iHOT-33) at follow-up were compared between patients with and without PASS using independent t-tests to assess the construct validity of the PASS question. Effect sizes for between-group differences were calculated as Cohen's *d* using the formula:

$$Cohen's\ d = \frac{Mean\ difference\ between\ groups}{pooled\ standard\ deviation}$$

Cohen's *d* were classified as trivial (<0.2), small (≥0.2), medium (≥0.5), and large (≥0.8) effect.[187]

A logistic regression analysis was conducted to investigate the influence of activities of daily living ($PASS_{ADL}$) and sports function ($PASS_{Sport}$) on the likelihood of achieving PASS.

We constructed ROC curves to determine cut-off values for HAGOS subscales and iHOT-33 to best discriminate between patients with and without PASS.[188] A ROC curve aims to provide a classification plot for binary outcomes based on the true and false positive rate for all classification thresholds;[188] in this case for all HAGOS or iHOT-33 scores. Subsequently, we calculated the best-combined sensitivity and specificity, Youden Index (J = sensitivity þ specificity −1)[178], for each HAGOS and iHOT-33 score. The HAGOS and iHOT-33 score with the corresponding highest Youden Index was established as the most appropriate cut-off score to discriminate between patients with and without PASS in line with previous studies.[108,189] Discrimination, a measure of the predictive ability of the cut-off score to predict PASS, was assessed using the Area under the ROC curve (AUC).[61] AUC ranges from 0.5 to 1, representing no and perfect discriminative ability, respectively.[61] The statistical analyses were performed in SPSS V 23 (SPSS Inc), with the significance level set at $P < 0.05$.

Results

Participants

The survey was distributed to 232 patients between the 15th of October 2019 and the 11th of November 2019, of which 137 patients responded and were included. An overview of key characteristics for included patients and non-responders are provided in **Table 13**.

Table 13. Overview of included patients and non-responders reproduced from Ishøi et al.[190]

	Included (n=137)	Non-responders (n=92)
Gender, no. males (%)	63 (46)	68 (73.9) *
Mean age at surgery, years (SD)	35.4 (9.4)	33.3 (9.7)
Follow-up, months (SD)	18.5 (3.2)	
Radiological data		
Alpha Angle, grader (SD)	72.3 (10.7)	72.1 (10.2)
Lateral Center Edge Angle, grader (SD)	31.1 (4.3)	30.8 (4.6)
Joint space width, no. >4.0 mm (%)	104 (75.9)	71 (77.2)
Cross-over Sign, no. yes (%)	79 (57.7)	43 (46.7)
Becks classification (acetabulum)	**n=131**	**n=86**
Normal cartilage, no. (%)	1 (0.7)	0 (0)
Fibrillation, no. (%)	6 (4.6)	10 (11.6)
Wave sign, no. (%)	62 (47.3)	32 (37.2)
Cleavage, no. (%)	45 (34.4)	38 (44.2)
Exposed bone, no. (%)	17 (13.0)	6 (7.0)
ICRS classification (caput femoris)	**n=131**	**n=86**
Normal cartilage, no. (%)	103 (78.6)	56 (65.1)
Almost normal, no. (%)	10 (7.6)	7 (8.1)
Abnormal, no. (%)	10 (7.6)	13 (15.1)
Severe abnormal, no. (%)	7 (5.3)	7 (8.1)
Exposed bone, no. (%)	1 (0.7)	3 (3.5)
Pre-operative HAGOS Score	**n=102**	**n=59**
Pain (SD)	53.5 (19.0)	50.8 (18.8)
Symptoms (SD)	49.8 (18.2)	44.9 (15.5)
Physical function in daily living (SD)	56.4 (25.4)	50.0 (21.7)
Function in sport and recreation (SD)	37.2 (23.9)	33.6 (20.8)
Participation in physical activities (SD)	22.7 (26.2)	22.6 (20.2)
Quality of life (SD)	30.5 (15.7)	30.3(16.5)

HAGOS (Copenhagen Hip And Groin Outcome Score). * significant between-group difference in proportion ($p<0.001$).

Patient Acceptable Symptom State

The proportion of patients with PASS, $PASS_{ADL}$, and $PASS_{Sport}$ at follow-up are depicted in **Figure 18**.

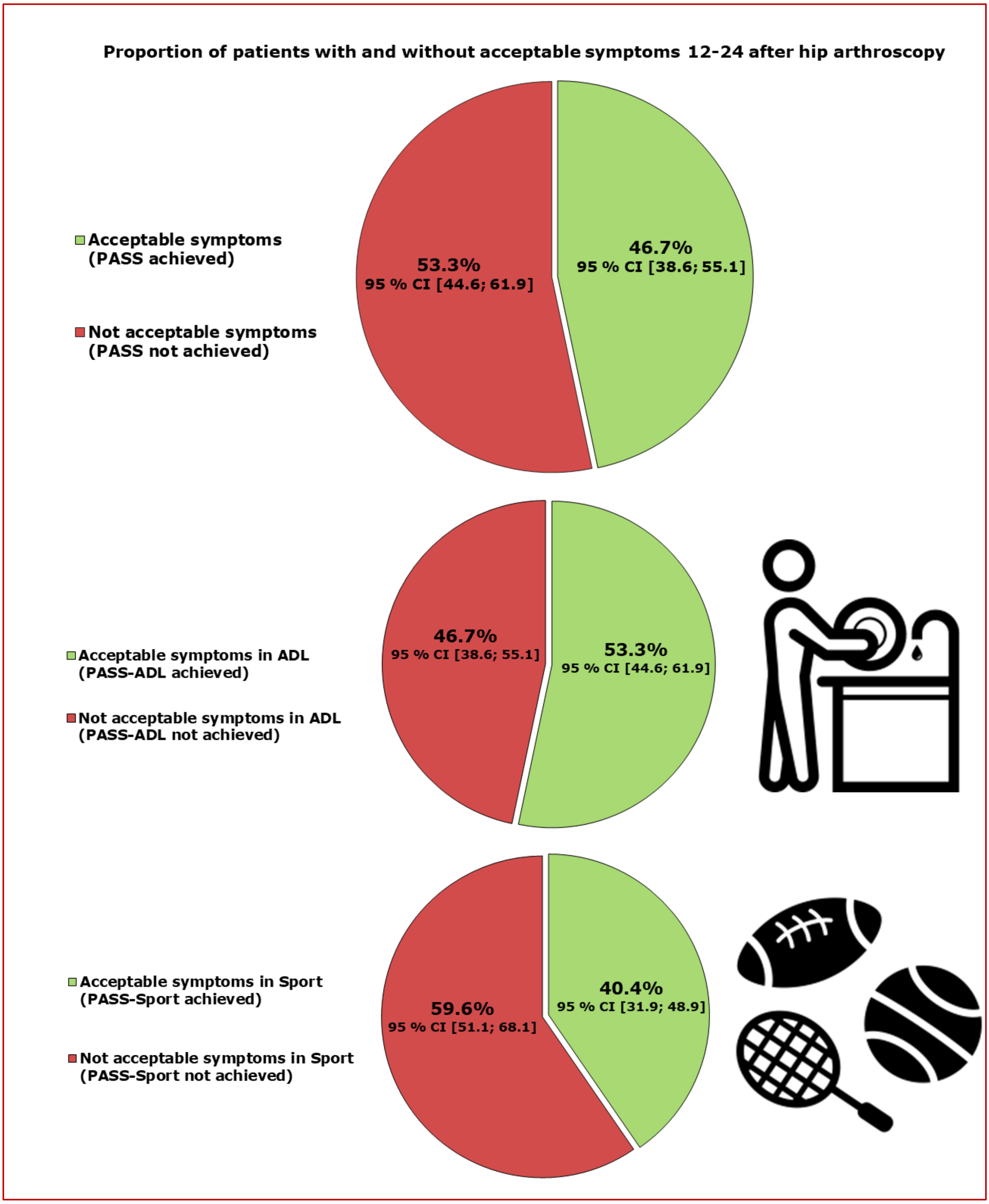

Figure 18. The proportion of patients with (green) and without (red) acceptable symptoms 12-24 months after hip arthroscopy for femoroacetabular impingement syndrome. The upper chart represents acceptable symptoms considering both activities of daily living (ADL) and sport.

Patients with $PASS_{Sport}$ or $PASS_{ADL}$ were more likely to report PASS corresponding to an odds ratio of 168.6 (95 % CI [35.9; 793.2]) and 30.4 (95 % CI [11.5; 80.2]), respectively.

Patient-reported outcome measures between subjects with and without PASS

Higher patient-reported outcome scores (HAGOS and iHOT-33) were observed for patients with compared to those without an acceptable symptom state corresponding to large effect sizes ($d \geq 1.06$; $p < 0.001$) (**Figure 19**, **Figure 20**).

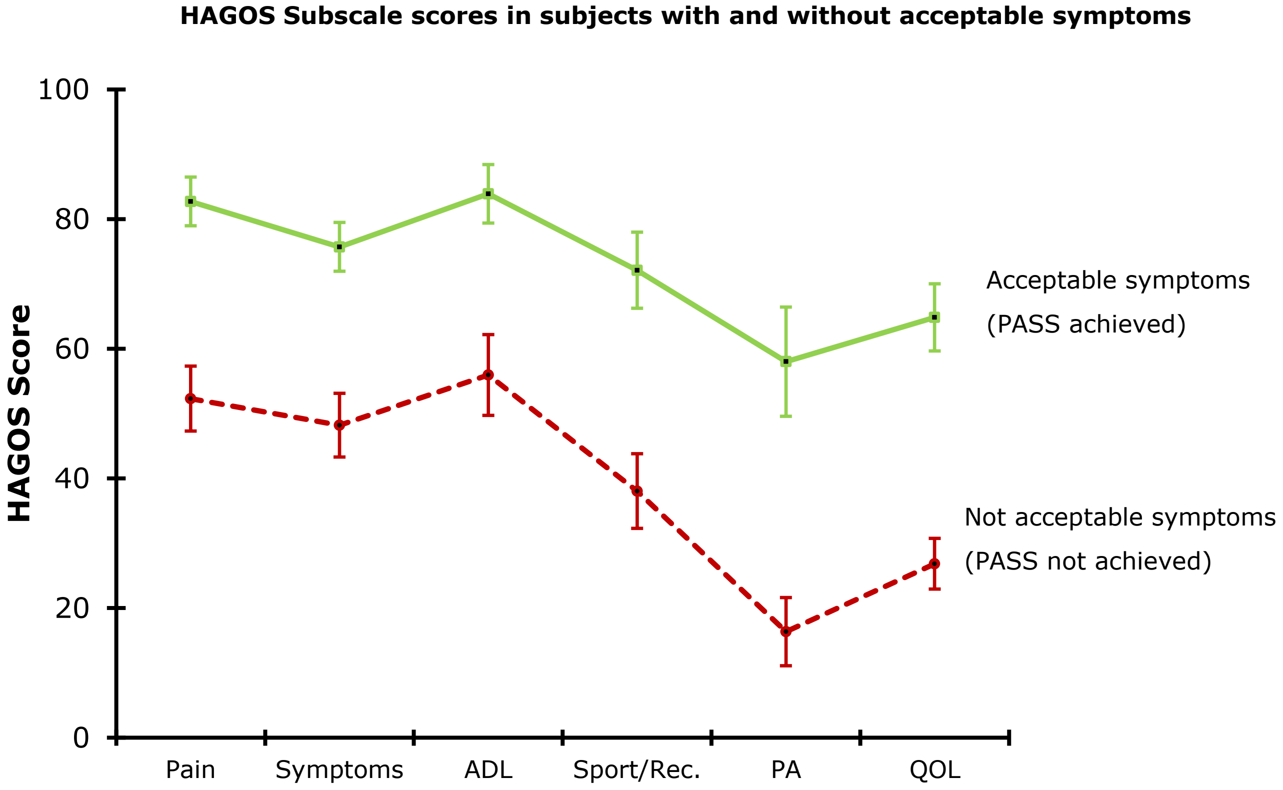

Figure 19. Self-reported hip and groin symptoms and function in subjects with (N=64, solid line) and without (N=68, dotted line) an acceptable symptom state at follow-up for subscales of the Copenhagen Hip and Groin Outcome Score (HAGOS). The x-axis shows the six subscales of HAGOS; ADL (physical function in daily living); Sport/Rec (function in sport and recreation); PA (participation in physical activities); QOL (quality of life). Error bars show 95% CI. Reproduced from Ishøi et al.[190]

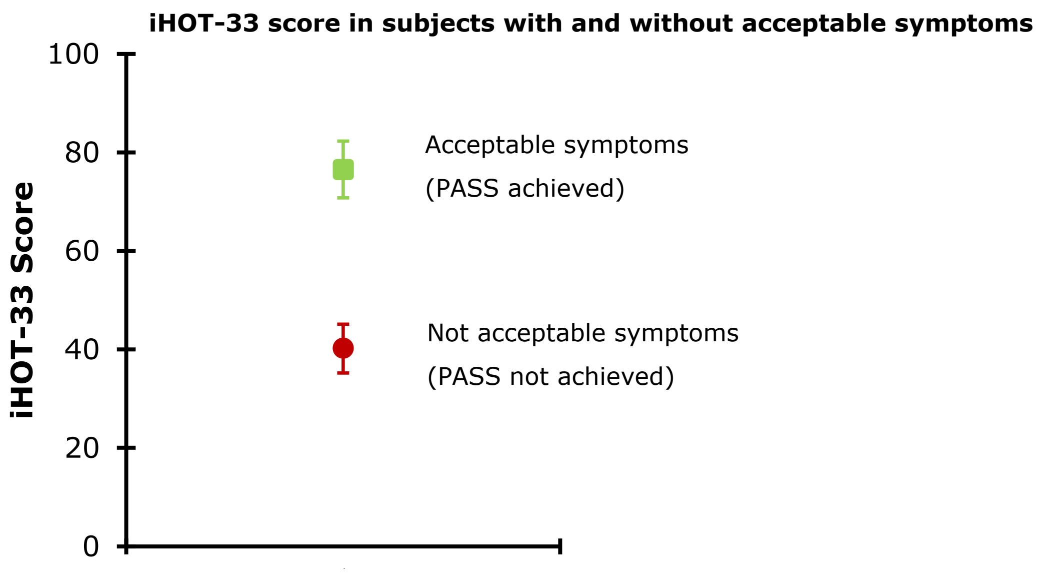

Figure 20. Self-reported hip symptoms in subjects with (N=53, square) and without (N=57, circle) an acceptable symptom state at follow-up for International Hip Outcome Tool-33 (iHOT-33). Error bars show 95% CI. Reproduced from Ishøi et al.[190]

Receiver Operating Characteristic curve analyses

ROC curves for all HAGOS subscales are depicted in **Figure 21** (for illustration purposes). The associated statistics, including cut-off values for predicting PASS for HAGOS and iHOT-33 are provided in **Table 14**.

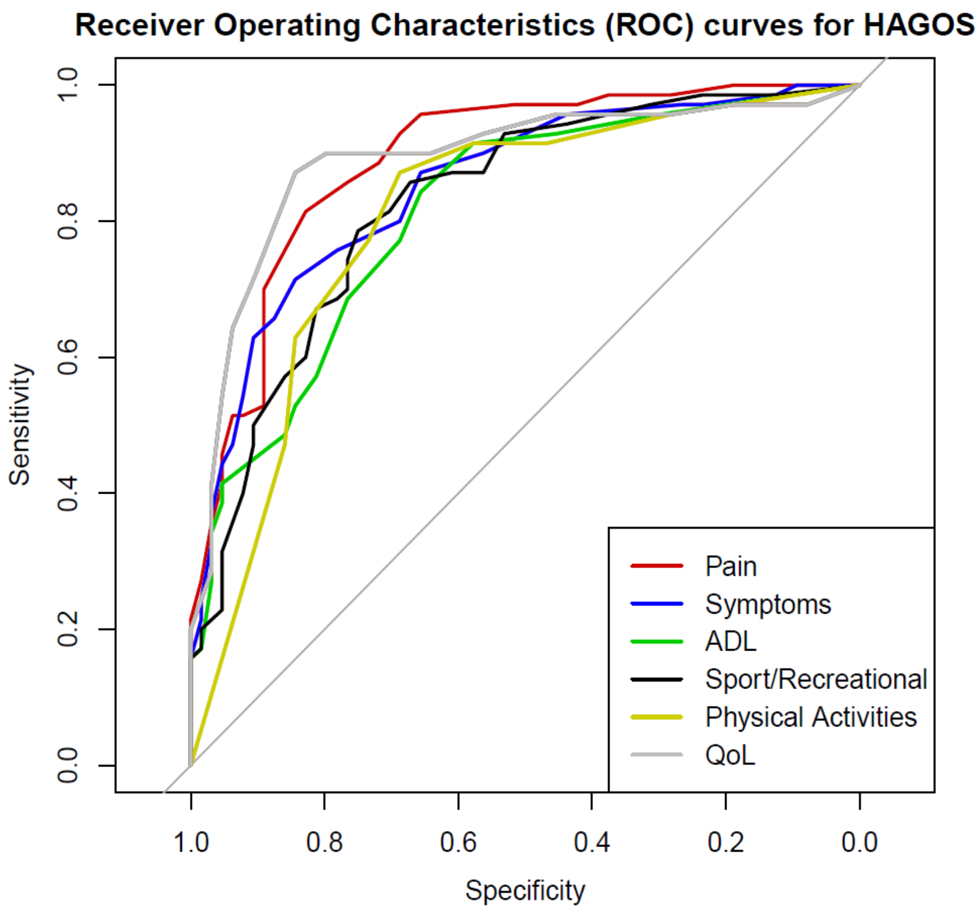

Figure 21. ROC curves for the six Copenhagen Hip and Groin Outcome Score (HAGOS) subscales related to having or not having an acceptable symptom state 12-24 month after hip arthroscopy for femoroacetabular impingement. ADL (Activities of Daily Living), QoL (Quality of Life).

Table 14. Area Under the Curve values derived from Receiver Operating Characteristic curve analyses and Patient Acceptable Symptom State (PASS) cut-off values, and their respective sensitivity and specificity, for HAGOS subscales and iHOT-33 scores. The cut-off values are derived using Youden's Index.* Table is reproduced from Ishøi et al.[190]

Patient-reported outcome measure	AUC [95% CI]	Cut-off value#	Sensitivity	Specificity
HAGOS Subscales				
Pain	0.89 [0.84; 0.95]	68.75	0.84	0.79
Symptoms	0.86 [0.80; 0.92]	62.50	0.84	0.74
ADL	0.82 [0.74; 0.89]	82.50	0.66	0.85
Sport/Rec.	0.84 [0.78; 0.91]	60.94	0.75	0.81
Physical Activity	0.83 [0.75; 0.90]	43.75	0.69	0.90
Quality of Life	0.92 [0.87; 0.97]	42.50	0.84	0.90
iHOT-33	0.88 [0.82; 0.95]	67.00	0.74	0.95

HAGOS (Copenhagen Hip and Groin Outcome Score); ADL (physical function in daily living); Sport/Rec (function in sport and recreation); AUC (Area Under the Curve).
* Youden's index (J = sensitivity + specificity -1) is based on the best combined sensitivity and specificity with a higher index score yielding a better combined sensitivity and specificity.[45] # The cut-off score represents the score beyond which a subject is more likely to have an acceptable symptom state.

Study III. Return to sport and performance after hip arthroscopy

Return to Sport and Performance After Hip Arthroscopy for Femoroacetabular Impingement in 18- to 30-Year-Old Athletes: A Cross-sectional Cohort Study of 189 Athletes

The American Journal of Sports Medicine

Ishøi L., Thorborg K., Kraemer O., Hölmich P.

Methods

Outcome measures

The primary aim of study III was to investigate return to sport rates and self-reported performance after hip arthroscopy for femoroacetabular impingement syndrome in young athletes using contemporary and clearly defined criteria for defining return to sport.

Sample size consideration

The number of eligible subjects in the Danish Hip Arthroscopy Registry and responders determined the sample size.

Statistical methods

Return to sport measures were calculated using percentages with 95% CI. Logistic regressions were used to analyze associations between being engaged in preinjury sport at a preinjury level as the dependent variable with contextual factors of time to follow-up (0.5 to <1 year, 1 to <3 years, 3 to <6 years), level of the sport (elite, competitive, recreational), and type of the sport (contact; noncontact, pivoting; noncontact, nonpivoting) as independent variables. In addition, a chi-square test of independence was applied to understand the potential influence of the level and type of sport for participation and performance in athletes engaged in their preinjury sport at the preinjury level.

For analyses of HAGOS subscale scores, we compared scores between athletes engaged in their preinjury sport at preinjury level versus athletes that were not, prior to surgery and at the time of follow-up using independent t-tests. Between-group differences in mean changes were also investigated using analyses of covariance (ANCOVA) with HAGOS scores prior to surgery as the covariate.[191] HAGOS scores between athletes at different levels of return to sport at follow-up were analysed using 1-way analysis of variance (ANOVA) with Games-Howell post hoc adjustments. Effect sizes for within- and between-group differences were calculated as Cohen’s *d* as previously described (see statistical method for study II).[187]

Results

Participants

Return to sport questionnaires was sent to 350 subjects from the Danish Hip Arthroscopy Registry, of which 189 were included in the final analyses (**Figure 22; Table 15**).

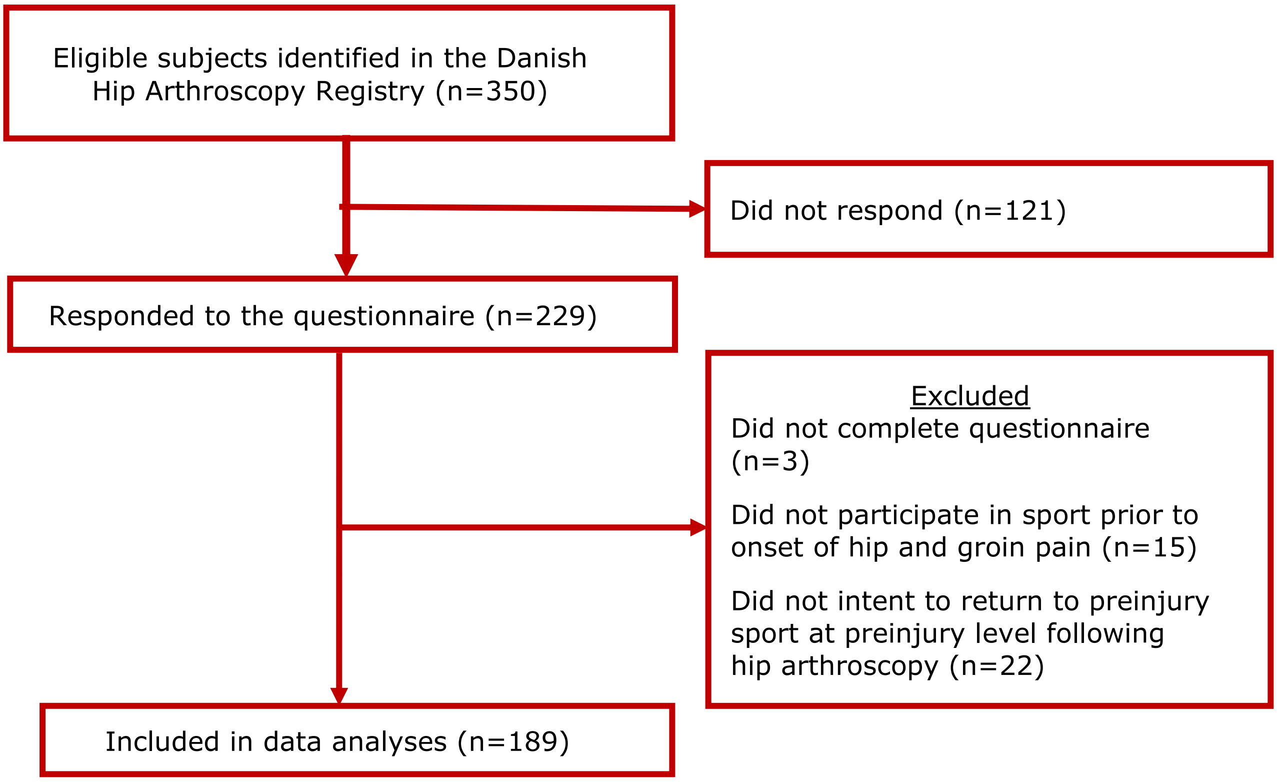

Figure 22. The flow of athletes. The figure is reproduced from Ishøi et al.[172]

Table 15. Demographic, radiological, operative, and self-reported hip and groin data on included athletes and non-responders. The table is reproduced from Ishøi et al.[172]

	Included in the study (n=189)	Did not respond to the survey (n=121)	p-value
Follow-up, months (SD), range	33.1 (16.3), 6.3-67.8	32.7 (15.1), 6.4-64.4	0.847
Gender, no. males (%)	96 (50.8)	82 (68)	0.003*
Mean age at surgery, years (SD)	23.6 (3.3)	24.1 (3.5)	0.239
Mean age at follow-up, years (SD)	26.9 (3.4)	27.4 (3.6)	0.224
Radiological data			
Alpha Angle, ° (SD)	72.8 (10.8)	74.5 (10.8)	0.183
Lateral Center Edge Angle, ° (SD)	32.6 (5.6)	32.9 (5.9)	0.644
Joint space width, no. >4.0 mm (%)	159 (84.1)	95 (78.9)	0.210
Operative data			
Operation side, right (%)	98 (51.9)	70 (57.9)	0.301
Bilateral operation, no. (%)	24 (12.7)	13 (10.7)	0.605
Becks classification			0.373
Normal cartilage, no. (%)	3 (1.6)	2 (1.7)	
Fibrillation, no. (%)	46 (24.3)	22 (18.2)	
Wave sign, no. (%)	79 (41.8)	47 (38.9)	
Cleavage tear between labrum and articular cartilage, no (%)	61 (32.3)	50 (41.3)	
ICRS classification			
Normal cartilage, no. (%)	140 (74.1)	98 (80.1)	0.159
Pre-operative HAGOS	**n=108**	**n=57**	
Symptoms (SD)	53.8 (18.7)	49.5 (19.0)	0.168
Pain (SD)	58.9 (18.6)	51.2 (19.2)	0.015*
Physical function in daily living (SD)	63.9 (23.4)	54.3 (24.7)	0.017*
Function in sport and recreation (SD)	42.5 (23.2)	32.8 (20.9)	0.007*
Participation in physical activities (SD)	20.0 (23.3)	21.6 (26.9)	0.695
Hip related quality of life (SD)	31.8 (16.3)	28.2 (16.1)	0.177

***** denotes a statistically significant (p<0.05) between-group difference.

Return to sport and self-reported hip and groin function

In total, 108 athletes (57.1%; 95% CI [50.0; 64.0]) were engaged in their preinjury sport at preinjury level, and this result was not significantly associated with time to follow-up, level of sport, and type of sport ($\chi2$ (6) = 8.459, p = 0.206) (**Table 16**).

Table 16. Proportion of athletes engaged in preinjury sport at preinjury level based on time to follow-up, level of sport, and type of sport. The table is reproduced from Ishøi et al.[172]

	Engaged in preinjury sport at preinjury level at follow-up	
	Yes	**No**
All subjects, no. (%) (n=189)	108 (57.1)	81 (42.9)
Time to follow-up (years)		
0.5 to <1, no. (%) (n=24)	12 (50)	12 (50)
1 to <3, no. (%) (n=88)	57 (64.8)	31 (35.2)
3 to <6, no. (%) (n=77)	39 (50.6)	38 (49.4)
Level of sport		
Elite level, no. (%) (n=34)	23 (67.6)	11 (32.4)
Competitive level, no. (%) (n=77)	38 (49.4)	39 (50.6)
Recreational level, no. (%) (n=78)	47 (60.3)	31 (39.7)
Type of sport		
Contact, no. (%) (n=85)	44 (51.8)	41 (48.2)
Non-contact, pivoting, no. (%) (n=37)	24 (64.9)	13 (35.1)
Non-contact, non-pivoting, no. (%) (n=67)	40 (59.7)	27 (40.3)

The comparison of self-reported hip and groin pain and function, measured with HAGOS, between athletes engaged versus not engaged in their preinjury sport at preinjury level showed differences in HAGOS scores at the time of follow-up for all subscales corresponding to small-to-large effect sizes ($p \leq 0.001$) (**Figure 23**); the difference in pre-surgery score for physical function in daily living (mean difference: 16.6, d=0.70, 95% CI [7.4;25.7], p=0.001); and differences in mean changes from pre-surgery to follow-up for all subscales, when adjusted for baseline values ($p<0.05$) (**Figure 24**). All differences favoured athletes engaged in their preinjury sport at the preinjury level at follow-up.

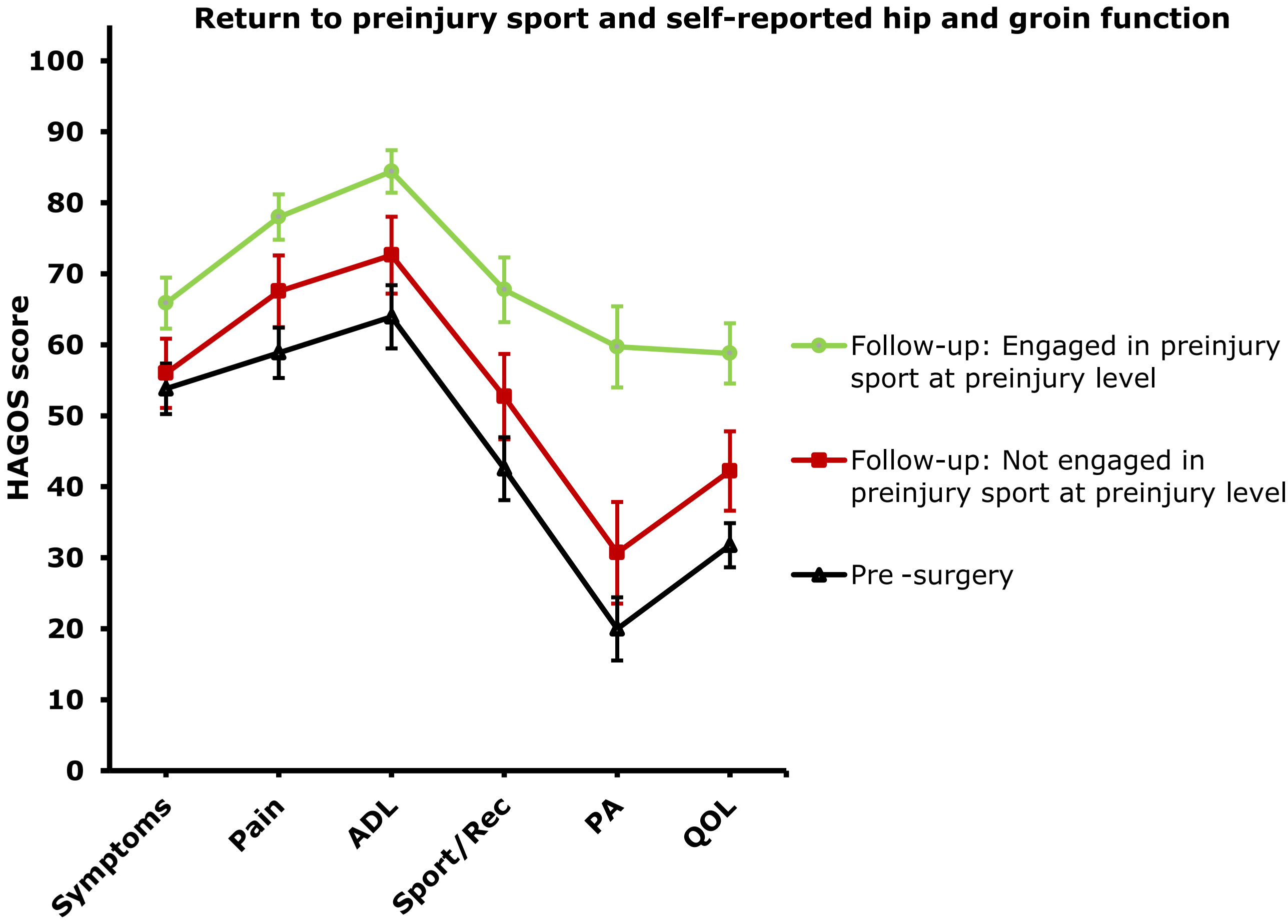

Figure 23. Self-reported hip and groin symptoms and function at pre-surgery (N=108; black line) and in athletes engaged in preinjury sport at the preinjury level at follow-up (N=108, green line) and athletes not engaged in preinjury sport at the preinjury level at follow-up (N=81, red line) for subscales of the Copenhagen Hip and Groin Outcome Score (HAGOS). ADL (physical function in daily living); Sport/Rec (function in sport and recreation); PA (participation in physical activities); QOL (quality of life). Pre-surgery HAGOS scores were only available for 108 athletes because of missing data. Error bars show 95% Confidence Intervals. The figure is reproduced from Ishøi et al.[172]

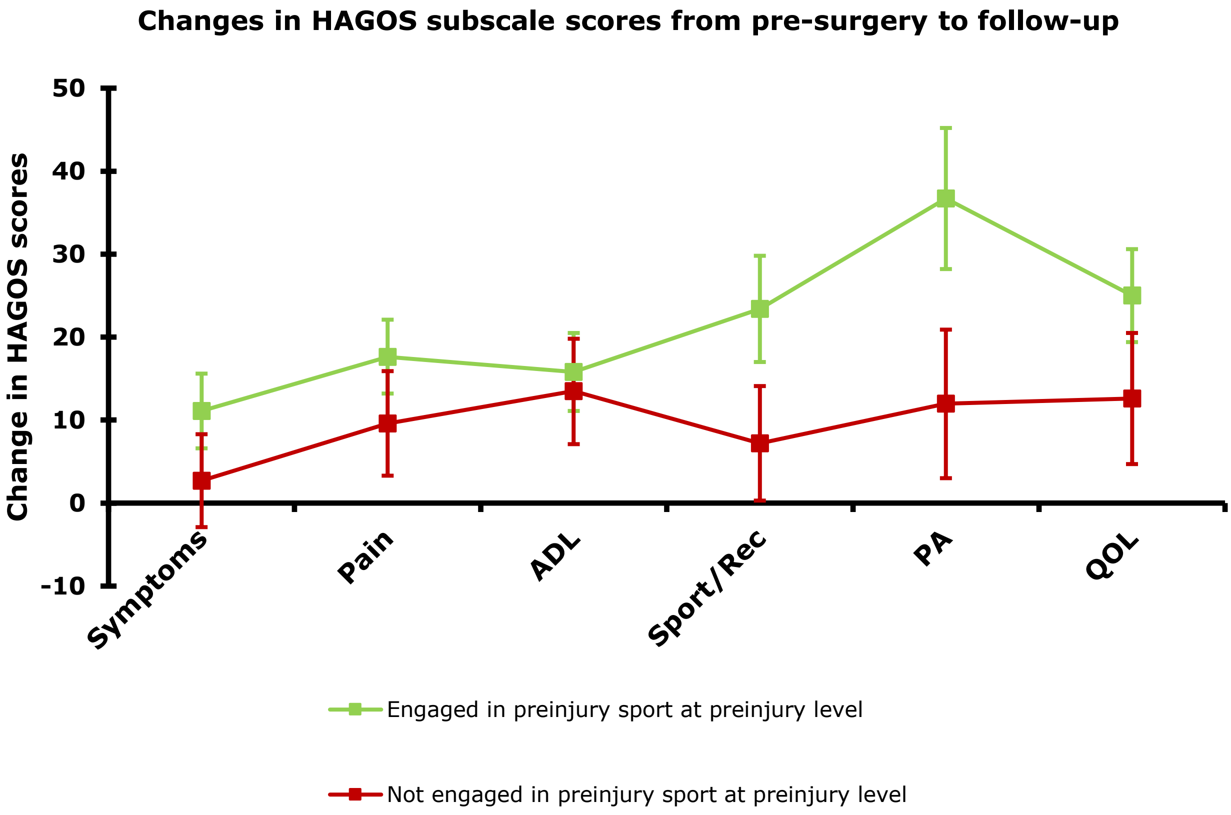

Figure 24. Mean changes (and 95 % Confidence Intervals) from pre-surgery to follow-up in self-reported hip and groin function measured with the Copenhagen Hip and Groin Outcome Score (HAGOS) in patients engaged (green line) versus not engaged (red line) in their preinjury sport at the preinjury level at the time of follow-up. ADL (physical function in daily living); Sport/Rec (function in sport and recreation); PA (participation in physical activities); QOL (quality of life).

Sports participation in athletes not engaged in their preinjury sport at preinjury level

Of the remaining 81 athletes not engaged in their preinjury sport at the preinjury level at the time of follow-up, 23 athletes had attempted to perform their preinjury sport at the preinjury level since surgery, but 16 (69.6%; 95% CI [49.1; 84.4]) of those discontinued because of hip and groin pain, while seven athletes (30.4%; 95% CI [15.6; 50.9]) discontinued because of other causes unrelated to hip and groin pain. The distribution of sports participation in the 81 athletes not engaged in their preinjury sport at the preinjury level at the time of follow-up is depicted in **Figure 25**. The main reason in 8 out of 10 athletes for not being engaged in preinjury sport at preinjury level was labelled as persistent hip and groin pain.

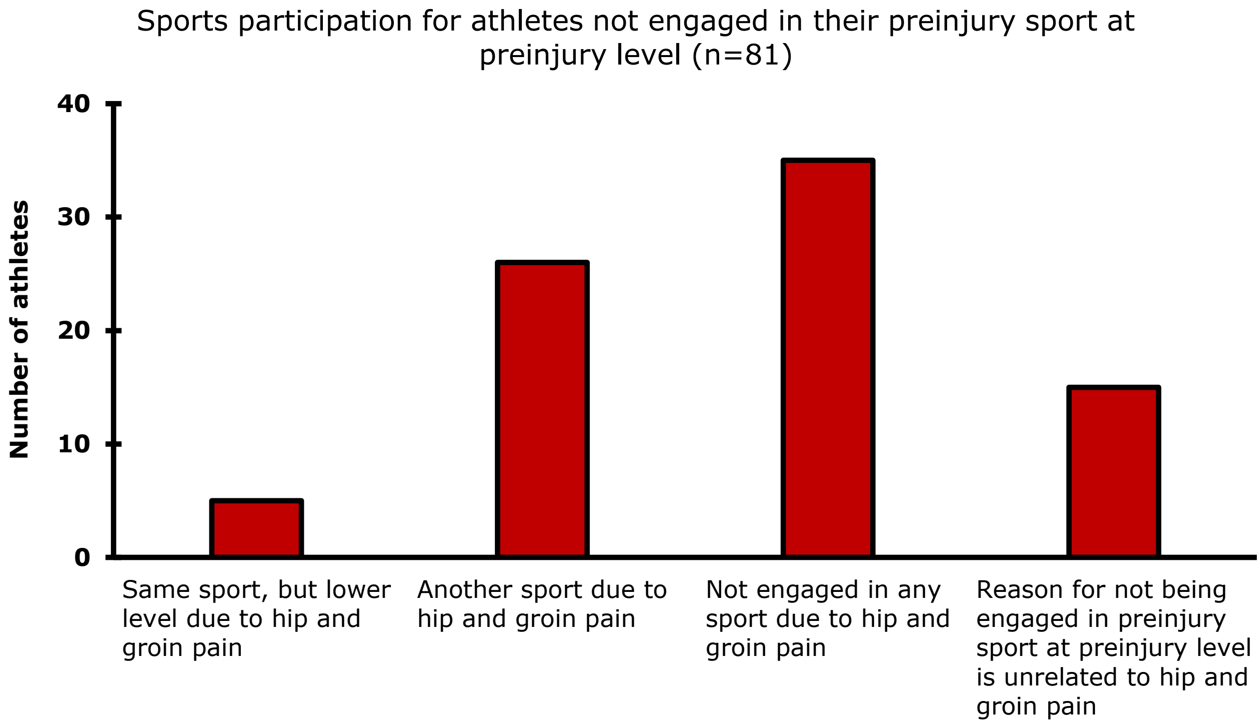

Figure 25. Distribution of sports participation of athletes not engaged in their preinjury sport at the preinjury level at the time of follow-up.

Sports performance and participation in athletes engaged in their preinjury sport at preinjury level

Only 32 of the 108 athletes (29.6%; 95% CI [21.8; 38.8]) engaged in their preinjury sport at the preinjury level at follow-up had optimal sports performance, including full sports participation, and this result was not associated with the level (χ^2 (4) = 6.732, p=0.151) or type of the sport (χ^2 (4) = 2.609, p=0.625) (**Table 17**). In total, 68 of the remaining 76 athletes (89.5%; 95% CI [80.6;94.6]) stated persistent hip and groin pain as the main reason for impaired performance.

Table 17. Proportion of athletes engaged in preinjury sport at preinjury level reporting different level of performance and participation based on time to follow-up, level of sport, and type of sport. The table is reproduced from Ishøi et al.[172]

Engaged in preinjury sport at preinjury level at follow-up	Sports performance and participation		
	Optimal performance including full participation	Impaired performance but full participation	Impaired performance including restricted participation
All subjects, no. (%) (n=108)	32 (29.6)	26 (24.1)	50 (46.3)
Time to follow-up (years)			
0.5 to <1, no. (%) (n=12)	1 (8.3)	2 (16.7)	9 (75)
1 to <3, no. (%) (n=57)	18 (31.6)	16 (28.1)	23 (40.4)
3 to <6, no. (%) (n=39)	13 (33.3)	8 (20.5)	18 (46.2)
Level of sport			
Elite level, no. (%) (n=23)	11 (47.8)	5 (21.7)	7 (30.4)
Competitive level, no. (%) (n=38)	8 (21.1)	12 (31.6)	18 (47.4)
Recreational level, no. (%) (n=47)	13 (27.7)	9 (19.1)	25 (53.2)
Type of sport			
Contact, no. (%) (n=44)	14 (31.8)	11 (25)	19 (43.2)
Non-contact, pivoting, no. (%) (n=24)	5 (20.8)	8 (33.3)	11 (45.8)
Non-contact, non-pivoting, no. (%) (n=40)	13 (32.5)	7 (17.5)	20 (50)

Self-reported hip and groin function, measured with HAGOS, were different at the time of follow-up across athletes with different performance levels and participation in sport ($p<0.001$). Higher self-reported hip and groin function was observed in athletes with optimal performance, including full participation, compared to all other groups ($p \leq 0.024$) (**Figure 26**).

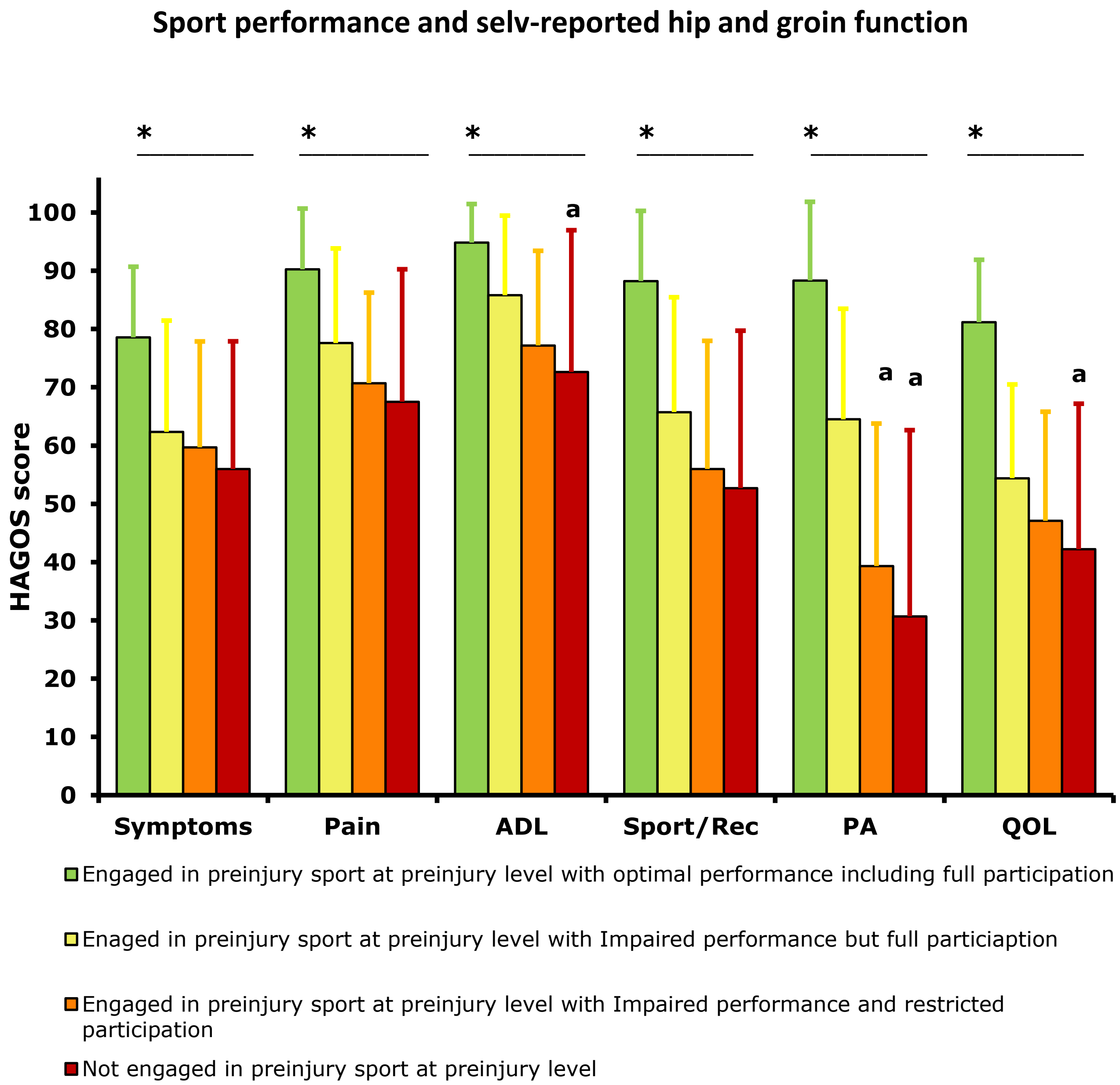

Figure 26. Differences at follow-up in self-reported hip and groin function between athletes with athletes engaged in preinjury sport at preinjury level with either 1) optimal performance including full participation (green bars), 2) impaired performance but full participation (yellow bars), 3) impaired performance including restricted participation (orange bars), and athletes not engaged in preinjury sport at preinjury level (red bars) for subscales of the Copenhagen Hip and Groin Outcome Score (HAGOS). * denotes a statistically significant ($p<0.05$) difference between athletes with optimal performance including full participation (white bars) and all other groups. [a] denotes a statistically significant ($p<0.05$) difference from athletes with impaired performance but full participation (grey bars). Error bars show standard deviation. The figure is reproduced from Ishøi et al.[172]

Study IV. Maximal and explosive hip muscle strength after hip arthroscopy

Maximal hip muscle strength and rate of torque development 6-30 months after hip arthroscopy for femoroacetabular impingement syndrome: A cross-sectional study

Journal of Science and Medicine in Sport

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Methods

Outcome measures

The primary aims of study IV were to investigate leg-to-leg differences in maximal and explosive hip muscle strength and drop-jump performance after hip arthroscopy for femoroacetabular impingement syndrome. In addition, we investigated the associations, using regression models, between maximal and explosive hip muscle strength with 1) self-reported hip and groin sports function and 2) participation in preinjury sport at preinjury (**Table 18**).

Table 18. Overview of regression models performed in study IV to investigate associations between performance measures of hip muscle strength and self-reported sports function and return to sport status.

Dependent variables	Independent variables
Linear regression models	
Copenhagen Hip and Groin Outcome Score Sport Subscale	
Unilateral strength model *	Maximal and explosive (early- and late-phase rate of torque development) hip muscle strength of the operated hip for adduction, abduction, extension, and flexion.
Adductor squeeze model *	Hip adduction squeeze strength and associated pain hip and/or groin pain (0-10 NRS) obtained during the Copenhagen Five-Second Squeeze Test.
Logistic regression models	
Full participation in preinjury sport at preinjury level at the time of follow-up (yes versus no)	
Unilateral strength model *	Maximal and explosive (early- and late-phase rate of torque development) hip muscle strength of the operated hip for adduction, abduction, extension, and flexion.
Adductor squeeze model *	Hip adduction squeeze strength and associated pain hip and/or groin pain (0-10 NRS) obtained during the Copenhagen Five-Second Squeeze Test.
Self-reported difficulties in "running as fast as you can" (yes versus no)**	
Unilateral strength model *	Maximal and explosive (early- and late-phase rate of torque development) hip muscle strength of the operated hip for adduction, abduction, extension, and flexion.
Adductor squeeze model *	Hip adduction squeeze strength and associated pain hip and/or groin pain (0-10 NRS) obtained during the Copenhagen Five-Second Squeeze Test.
Self-reported difficulties in "kicking, skating, etc." (yes versus no)**	
Unilateral strength model *	Maximal and explosive (early- and late-phase rate of torque development) hip muscle strength of the operated hip for adduction, abduction, extension, and flexion.
Adductor squeeze model *	Hip adduction squeeze strength and associated pain hip and/or groin pain (0-10 NRS) obtained during the Copenhagen Five-Second Squeeze Test.

* All models were adjusted for age, cartilage injury at the time of surgery, and symptom duration of hip and groin pain prior to surgery as fixed variables.
** Items from the Copenhagen Hip and Groin Outcome Score. Difficulties were defined as having moderate-to-extreme problems versus none-to-mild problems (defined as no difficulties).
NRS (Numeric Rating Scale).

All regression analyses were adjusted age, cartilage injury at the time of surgery, and symptom duration prior to surgery. These variables have previously been shown to influence the outcome after hip arthroscopy.[97] Thus, we adjusted the analyses to estimate the effect of hip muscle strength and provoked pain on the dependent variables.[192] Prior to adjustment, the variables, including sex, were entered in a causal Directed Acyclic Graph (DAG) (**Figure 27**), which serves the purpose of creating a theoretical framework and overview of how potential co-variates may influence the outcome and as well as interact with each other.[192] This analysis allowed us to identify the minimum number of co-variates that need to be adjusted to estimate the independent variables' influence on the dependent variable, thus, minimizing bias arising from unnecessary adjustment of co-variates.[192] To construct the DAG, we used freely available software (DAGitty; http://www.dagitty.net/).

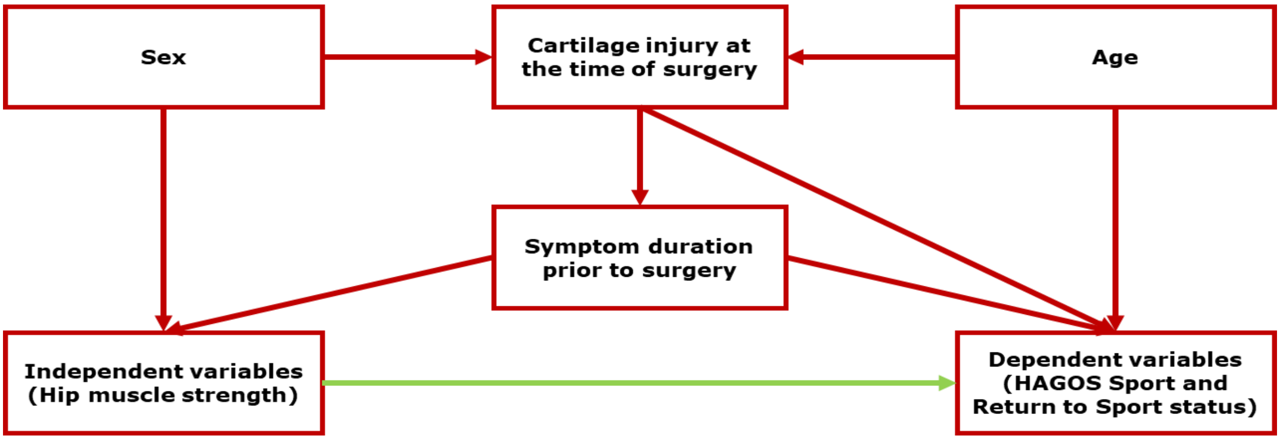

Figure 27. Causal directed acyclic graph (DAG) depicting potential co-variates that may influence (red lines) on the estimated effect of independent variables of hip muscle strength with the dependent variables of self-reported sports function and return to sport status (green line). Based on the DAG, the minimal sufficient adjustment sets for estimating the total effect of the independent variables on the dependent variables are: age, cartilage injury, and symptom duration.[192] The figure is reproduced from Ishøi et al.[193]

Sample size considerations

A priori, we hypothesized a difference in maximal hip muscle strength and rate of force development between the operated and non-operated hips of approximately 10-15 %,[194] corresponding to an effect size of 0.4.[124] With a power of 80 % and an alpha level of 5 %, 45 participants were needed (G*power software version 3.1, Heinrich-Heine-Universität, Düsseldorf, Germany).

Statistical methods

One-sample t-tests, using the strength and drop-jump mean values as the comparator, were applied to assess differences in maximal hip muscle strength, rate of torque development, and Reactive Strength Index between the operated and non-operated hips. Normality was inspected visually based on Q-Q plots.

The influence of maximal and explosive hip muscle strength with self-reported sports function and return to sport status were investigated using stepwise linear and logistic regression models (Unilateral strength models in **Table 18**). A correlation matrix was constructed to avoid multicollinearity of strength measures. Based on a correlation cut-off of ≥0.7 between strength measures, we included maximal hip extension strength (since this strength measure showed the strongest univariate correlation with the outcome) and early-phase rate of torque development for hip extension, flexion, and adduction. In step 1 of the regression analyses, co-variates were entered, which were kept in the models. In step 2, independent variables were entered stepwise and only kept in the model if significantly associated with the dependent variables ($p<0.05$). The Adductor squeeze models (**Table 18**) followed a similar procedure, although multicollinearity was not assessed. The statistical analyses were performed in SPSS (v. 23, IBM) with a significance level set at 0.05.

Results

Participants

In total, we contacted 89 patients, of which 45 agreed to participate. An overview of key demographic, radiographic, and peri-operative findings, including self-reported hip and groin function and pain, and return to sport status at inclusion, are presented in **Table 19**.

Table 19. Demographic, radiological, operative, and post-operative self-reported hip and groin function on included participants and non-responders/subjects who declined participation. The table is reproduced from Ishøi et al.[193]

	Included (n=45)	Non-responders/ subjects who declined participation (n=44)
Follow-up, months (SD), range	19.3 (5.4), 9.8-28.4	-
Gender, no. males (%)	34 (75.6)	30 (68.2)
Mean age at surgery, years (SD)	29.4 (5.8)	30.6 (6.1)
Mean age at follow-up, years (SD)	30.6 (5.9)	-
Symptom duration prior to surgery, months (SD)	34.8 (37.3)	-
Radiological data		
Alpha Angle, ° (SD)	69.0 (8.2)	69.2 (7.6)
Lateral Center Edge Angle, ° (SD)	32.7 (8.6)	29.6 (4.7)
Joint space width, no. >4.0 mm (%)	32 (71.1)	28 (63.6)
Operative data		
Becks classification[&]		
Grade 0-2, no. (%)	25 (58.1)	22 (53.7)
Grade 3-4, no. (%)	18 (41.9)	19 (46.3)
ICRS classification[&]		
Grade 0-2, no. (%)	39 (90.7)	38 (92.7)
Grade 3-4, no. (%)	4 (9.3)	3 (7.3)
Post-operative HAGOS		
Pain (SD)	77.9 (15.3)	-
Symptoms (SD)	67.7 (17.8)	-
Physical function in daily living (SD)	84.2 (18.6)	-
Function in sport and recreation (SD)	69.7 (23.5)	-
Participation in physical activities (SD)	52.8 (32.8)	-
Hip related quality of life (SD)	54.4 (21.5)	-
Return-to-sport status *		
Pre-injury sport at preinjury level, no. (%)	18 (58.1)	-
Optimal sports performance, no. (%)	3 (9.7)	-
Reduced sports performance, no. (%)	8 (25.8)	-
Restricted participation, no. (%)	7 (22.6)	-
Satisfaction with post-operative rehabilitation		
No need for further rehabilitation, no. (%)	9 (20)	-
Some need for further rehabilitation, no. (%)	27 (60)	-
Much need for further rehabilitation, no. (%)	9 (20)	-

[&]Missing data on two included participants and three non-responders. * Based on 31 participants who had intentions to return to preinjury sport at preinjury level after surgery.

Maximal hip muscle strength and rate of torque development

Statistically significant differences were observed for early- (mean difference: -1.58 Nm/kg/s, 95% CI [-2.78; 0.39], p=0.01) and late-phase (mean difference: -0.72 Nm/kg/s, 95% CI [-1.35; -0.09], p=0.027) rate of torque development for flexion with lower values in the operated hip corresponding to approximately 10 %. No other differences were observed (p≥0.178) **(Figure 28)**.

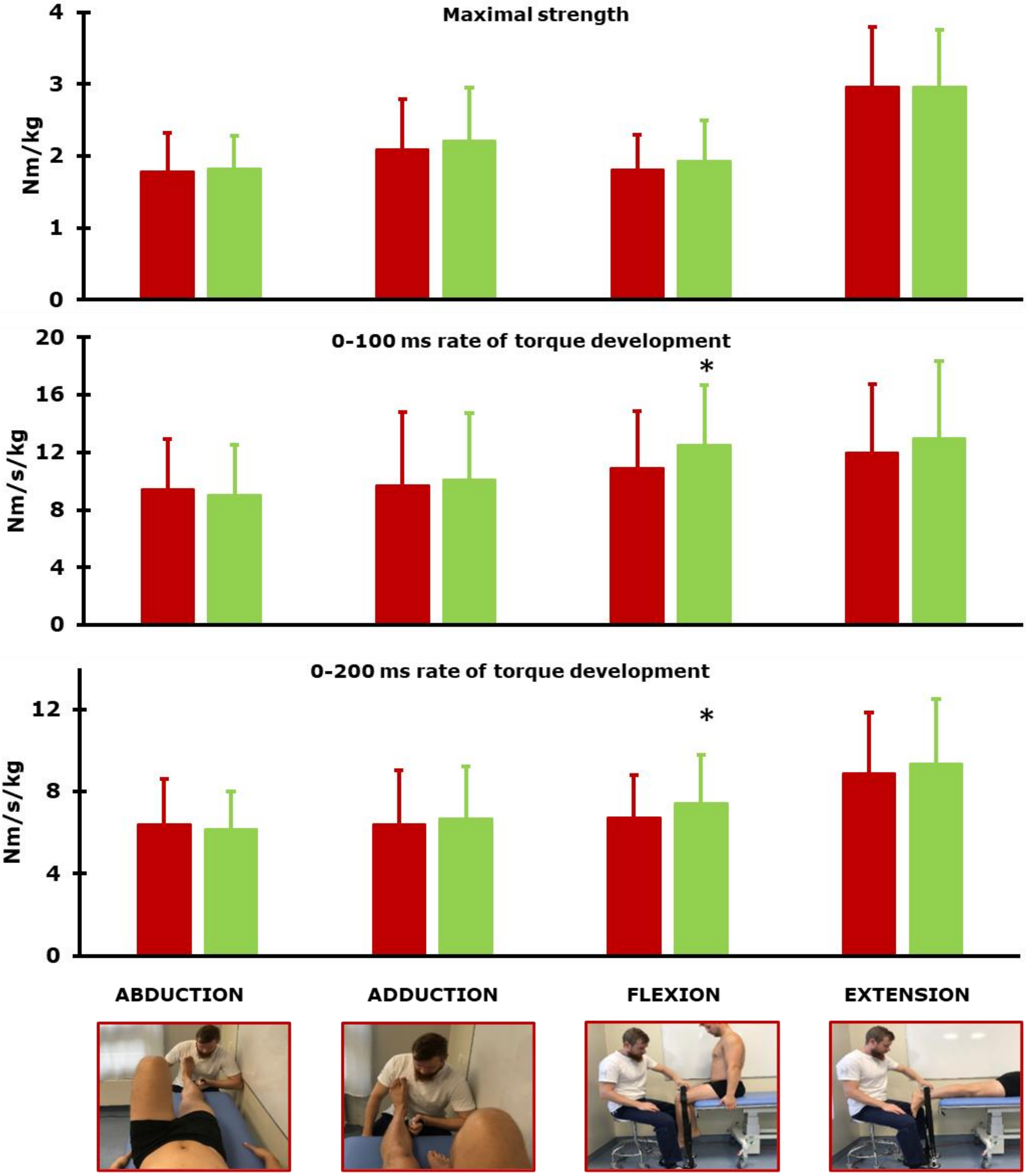

Figure 28. Hip muscle strength and rate of torque development in the operated (red bars) versus non-operated hip (green bars). Error bars denotes standard deviation. Nm/kg (Newton meter per. Body mass); Nm/s/kg (Newton meter per second per body mass). * denotes a statistically significant difference between hips (p<0.05).

Reactive Strength Index

Reactive Strength Index showed no difference between legs (mean difference: -0.06, 95% CI [-0.14; 0.017], p=0.123).

The associations between hip muscle strength and levels of sports function and participation

Hip extension strength was the only significant muscle strength variable retained in the regression models. In general, higher hip extension strength was associated with better HAGOS Sport scores (**Table 20**), greater odds of full participation in preinjury sport at preinjury level (**Table 21**), and none-to-mild difficulties in sports specific activities (**Table 22** and **Table 23**).

Table 20. Final step in the stepwise linear regression analysis of the influence of hip muscle strength on the Copenhagen Hip and Groin Outcome Score Sport Subscale.

Adjusted R^2	Variables in model	Unstandardized Beta-values	95% Confidence Intervals	p-value
0.27				
	Higher age (years)	-0.16	-1.43; 1.01	0.798
	Longer pain duration (months)	-0.12	-0.31; 0.06	0.183
	Grade 3-4 cartilage injury	-9.70	-24.07; 4.66	0.179
	Hip extension strength (Nm/kg)	18.07	8.31; 27.40	**<0.001**

Table 21. Final step in the stepwise logistic regression analysis of the influence of hip muscle strength on the ability to participate fully in preinjury sport at preinjury level.

Nagelkerke R^2	Variables in model	Odds Ratio	95% Confidence Intervals	p-value
0.48				
	Higher age (years)	1.00	0.85; 1.18	0.989
	Longer pain duration (months)	1.00	0.97; 1.04	0.848
	Grade 3-4 cartilage injury	0.15	0.11; 2.11	0.161
	Hip extension strength (Nm/kg)	17.71	1.71; 177.61	**0.015**

Table 22. Final step in the stepwise logistic regression analysis of the influence of hip muscle strength on the ability to perform ”running as fast as you can” with none-to-mild difficulties.

Nagelkerke R^2	Variables in model	Odds Ratio	95% Confidence Intervals	p-value
0.47				
	Higher age (years)	1.09	0.93; 1.28	0.296
	Longer pain duration (months)	0.98	0.96; 1.00	0.107
	Grade 3-4 cartilage injury	0.91	0.13; 6.28	0.923
	Hip extension strength (Nm/kg)	14.42	1.98; 104.87	**0.008**

Table 23. Final step in the stepwise logistic regression analysis of the influence of hip muscle strength on the ability to perform ” kicking, skating, etc” with none-to-mild difficulties.

Nagelkerke R^2	Variables in model	Odds Ratio	95% Confidence Intervals	p-value
0.55				
	Higher age (years)	0.95	0.82; 1.11	0.548
	Longer pain duration (months)	0.99	0.96; 1.01	0.215
	Grade 3-4 cartilage injury	0.19	0.02; 2.13	0.176
	Hip extension strength (Nm/kg)	58.18	2.34; 1444.10	**0.013**
	0-100 ms hip extension RTD (Nm/s/kg)	0.79	0.58; 1.09	0.156

RTD (rate of torque development)

Associations between Copenhagen five-second squeeze test and sports function

Hip adduction squeeze strength was retained in all regression models, whereas provoked hip and groin pain scores were retained in models concerning HAGOS Sport and difficulties in sports-specific activities. In general, higher hip adduction squeeze strength and lower provoked pain scores were associated with better HAGOS Sport scores (**Table 24**), greater odds of full participation in preinjury sport at preinjury level (**Table 25**), and none-to-mild difficulties in sports specific activities (**Table 26** and **Table 27**).

Table 24. Final step in the stepwise linear regression analysis of the influence of hip adduction squeeze strength and provoked hip and groin pain on the Copenhagen Hip and Groin Outcome Score Sport Subscale.

Adjusted R^2	Variables in model	Unstandardized Beta-values	95% Confidence Intervals	p-value
0.57				
	Higher age (years)	-0.78	-1.81; 0.24	0.129
	Longer pain duration (months)	-0.04	-0.18; 0.11	0.613
	Grade 3-4 cartilage injury	-9.50	-21.49; 2.48	0.117
	Hip adduction squeeze strength (Nm/kg)	14.22	5.94; 22.50	**<0.001**
	Hip and groin pain during squeeze (0-10 NRS)	-6.67	-9.78; -3.56	**<0.001**

NRS (Numeric Rating Scale).

Table 25. Final step in the stepwise logistic regression analysis of the influence of hip adduction squeeze strength on the ability to participate fully in preinjury sport at preinjury level.

Nagelkerke R^2	Variables in model	Odds Ratio	95% Confidence Intervals	p-value
0.56				
	Higher age (years)	1.03	0.86; 1.24	0.739
	Longer pain duration (months)	1.00	0.97; 1.04	0.853
	Grade 3-4 cartilage injury	0.10	0.01; 1.63	0.105
	Hip adduction squeeze strength (Nm/kg)	16.43	2.29; 117.76	**0.005**

Table 26. Final step in the stepwise logistic regression analysis of the influence of hip adduction squeeze strength and provoked hip and groin pain strength on the ability to perform ”running as fast as you can” with none-to-mild difficulties.

Nagelkerke R^2	Variables in model	Odds Ratio	95% Confidence Intervals	p-value
0.47				
	Higher age (years)	1.04	0.88; 1.21	0.664
	Longer pain duration (months)	0.99	0.97; 1.01	0.382
	Grade 3-4 cartilage injury	0.98	0.16; 6.05	0.978
	Hip adduction squeeze strength (Nm/kg)	8.33	1.72; 40.23	**0.008**
	Hip and groin pain during squeeze (0-10 NRS)	0.67	0.41; 1.10	0.114

NRS (Numeric Rating Scale).

Table 27. Final step in the stepwise logistic regression analysis of the influence of hip adduction squeeze strength and provoked hip and groin pain on the ability to perform ” kicking, skating, etc” with none-to-mild difficulties.

Nagelkerke R^2	Variables in model	Odds Ratio	95% Confidence Intervals	p-value
0.65				
	Higher age (years)	0.79	0.61; 1.01	0.065
	Longer pain duration (months)	1.00	0.97; 1.02	0.772
	Grade 3-4 cartilage injury	0.17	0.01; 2.61	0.206
	Hip adduction squeeze strength (Nm/kg)	15.67	1.76; 139.25	**0.014**
	Hip and groin pain during squeeze (0-10 NRS)	0.36	0.12; 0.81	**0.017**

NRS (Numeric Rating Scale).

An overview of maximal hip extension strength, hip adduction squeeze strength, and provoked hip and groin pain during squeeze in patients with full participation in preinjury sport at preinjury level versus patients unable to participate fully at the time of follow-up is provided in **Table 28**.

Table 28. Overview of hip extension strength, and bilateral hip adduction and hip and groin pain scores obtained during the Copenhagen five-second squeeze test in relation to returning to sport and difficulties in specific sports activities. The table is reproduced from Ishøi et al.[193]

	Full participation in preinjury sport at preinjury level	
	Yes (n=11)	**No (n=20)**
Hip extension strength (Nm/kg), Mean [95% CI]	3.45 [3.12; 3.77]	2.61 [2.31; 2.91]
Hip adduction squeeze strength (Nm/kg), Mean [95% CI]	3.15 [2.67; 3.64]	2.14 [1.85; 2.42]
Hip and groin pain during squeeze (0-10 NRS), Median (25-75th IQR)	2 (1-2)	2 (0-4)
	Self-reported difficulties in "running as fast as you can"	
	None-to-mild (n=29)	Moderate-to-extreme (n=16)
Hip extension strength (Nm/kg), Mean [95% CI]	3.25 [2.97; 3.52]	2.48 [2.13; 2.82]
Hip adduction squeeze strength (Nm/kg), Mean [95% CI]	2.76 [2.47; 3.05]	2.02 [1.74; 2.31]
Hip and groin pain during squeeze (0-10 NRS), (0-10 NRS), Median (25-75th IQR)	1 (0-3)	3 (0.75-4.25)
	Self-reported difficulties in "kicking, skating, etc."	
	None-to-mild (n=26)	Moderate-to-extreme (n=19)
Hip extension strength (Nm/kg), Mean [95% CI]	3.27 [2.95; 3.58]	2.57 [2.28; 2.86]
Hip adduction squeeze strength (Nm/kg), Mean [95% CI]	2.82 [2.52; 3.13]	2.05 [1.77; 2.33]
Hip and groin pain during squeeze (0-10 NRS), Median (25-75th IQR)	1 (0-2)	3 (1.5-4)

Nm/kg, Newton meter per body mass; SD, standard deviation; IQR, Interquartile range.

Study V. Development and external validation of prediction models

Stratified care in hip arthroscopy – Can we predict successful and unsuccessful outcomes? Development and external temporal validation of multivariable prediction models

Submitted.

Ishøi L., Thorborg K., Kallemose T., Kemp J.L, Reiman M.P., Nielsen M.F., Hölmich P.

Methods

Outcome measures

The primary aim of study V was to develop and externally validate clinically applicable multivariable models for predicting outcomes after hip arthroscopy for hip-related pain.

Specifically, we aimed to predict patients who, at one-year after surgery, had: 1) achieved a successful outcome or 2) an unsuccessful outcome. We defined a successful outcome as patients who surpassed PASS cut-off scores from study II [180] for all HAGOS subscales at one-year after hip arthroscopy. In contrast, we defined an unsuccessful outcome as patients who did not surpass a single HAGOS PASS cut-off score. Thus, patients with PASS cut-off scores for some HAGOS subscales were included as comparator groups in both prediction models.

In addition, we aimed to predict patients who, at one-year after surgery, had: 1) achieved an improvement or 2) not achieved an improvement in self-reported hip and groin function and pain compared to before surgery. We defined an improvement, or no improvement based on the Minimal Clinically Important Difference (MCID) [107] of the HAGOS questionnaire. MCID was calculated as 0.5 standard deviation of the pre-operative HAGOS subscale scores for each HAGOS subscale.[82] Patients were categorized as having an improvement if the change from pre- to- one-year post-operation on all HAGOS subscales surpassed the MCID scores, whereas patients were categorized as not having an improvement if no change above the MCID scores in any HAGOS subscale were observed from pre- to- one-year post-operation.

As explorative analyses, all models were also constructed by adding peri-operative data (findings of cartilage and acetabular labral injury). These models were considered supplementary since the additional predictor variables were not available when the models are intended to be used; that is, before undergoing surgery.[189]

Sample size considerations

The sample was restricted by the number of patients in the Danish Hip Arthroscopy Registry with sufficient data to be included. However, to understand if the sample was large enough to satisfy the purpose of the study, we calculated the required sample size using the "pmsampsize" (ver.1.1.0) package in R Statistics.[181] The sample size calculation involves a 4-step process based on calculating the minimum required sample size to obtain a precise estimate of the overall outcome risk with a margin of error ≤0.05 (Step 1), obtain predicted values with a small mean error across individuals (Step 2), minimize the risk of overfitting by targeting a shrinkage factor of ≥0.9 (Step 3), and minimize risk for optimism in apparent model performance (≤0.05) (Step 4).[181] For Steps 3 and 4, the anticipated R^2_{CS} (proportion of overall variation explained) needs to be prespecified. Since no previous prediction development study in hip arthroscopy has reported this measure, we estimated an $R^2_{CS\_adjusted}$ value based on C statistics (area under the curve) of 0.78 from previous studies [99,100,102,103] proposed by Riley et al.[195] Based on an outcome proportion of approximately 0.3 of the primary outcome measure (proportion of patients with a successful and unsuccessful outcome) and 26 a-priori defined predictors, 1043 patients were deemed adequate for model development, corresponding to 313 events and 12.03 events per predictor; we included 1082 patients in the development sample.[181] The remaining 464 patients were used in the temporal validation sample. With a similar outcome proportion for the primary outcome measure, the validation dataset had at least 100 events, which is considered the minimum required sample size in validation samples based on rules-of-thumb,[196] although larger sample sizes may be needed for precise estimates of calibration.[197] We, therefore, consider our temporal validation to be preliminary.

Statistical methods

Missing data for predictor variables were imputed by single imputation on both development and validation samples. Imputations models were based on all available data from the 26 predictor variables. Continuous variables were imputed by predictive mean matching and categorical variables by polytomous logistic regression. Both imputed data and complete cases fitted prediction models were analysed.[95]

Development and temporal validation of prediction models were analysed using logistic regression models including all 26 prediction variables as single terms with no interactions to minimize the risk of overfitting.[95] The supplementary prediction models included five additional predictors related to peri-operative findings **Table 9**. All continuous variables were kept continuous,[95] and ordinal scales were treated as continuous; both were linearly modelled. All analyses were performed in R (*R Foundation for Statistical Computing, Vienna, Austria, version 3.6.3*)

To evaluate predictive performance on the external temporal validation set, we calculated the predicted probability of each outcome and patient in the validation data set using the intercept and regression coefficients derived from the development data set after applying uniform shrinkage by bootstrapping, with 1000 replication bootstrapping and shrinkage.[95] The predictive model performance was investigated in line with the TRIPOD recommendations [95] using the framework presented by Steyerberg et al.[93]. This framework includes explained variance (Nagelkerke R^2), calibration plots (and associated statistics), and [94] discrimination statistics (Area Under the receiver operating characteristics Curve; AUC).[188] In addition, histograms to visualize the distribution of predicted probability between patients with and without the outcome [93] and sensitivity and specificity for a range of probability thresholds were calculated.[188]

Calibration refers to the agreement between observed outcomes and outcome predictions. It is a measure of the prediction model's ability to provide unbiased estimates.[95] We assessed calibration as defined by Van Calster et al.[94] as: 1) Mean calibration (calibration-in-the-large) reflecting if the observed outcome rate equaled the average predicted risk, 2) weak calibration reflecting if the model, on average, over- or underestimate the risk assessed by calibration intercept and slope, with a target value of 0 and 1, respectively, and 3) moderate calibration, reflecting if the estimated risks corresponded to the observed proportions, assessed graphically using a calibration plot, with the target being a smoothed calibration curve lying closely around the 45° line.[94] Calibration plots and associated parameters were produced using "*val.prob.ci.2*" package in R.[198] Discrimination was assessed using AUC (c-statistics), which quantifies the model's discriminative ability. This measure represents the probability that the model estimates higher risks for patients with the outcome than patients without the outcome.[188] AUC ranges from 0.5 to 1, representing no and perfect discriminative ability, respectively.[188]

Results

Participants

Of 2550 eligible patients, we included 1546 patients with complete outcome data at 1-year follow-up (**Figure 29)**. In general, minimal differences were observed between included and patients with missing outcome data for demographics, radiology, operative findings, and pre-operative symptoms (**Table 29**).

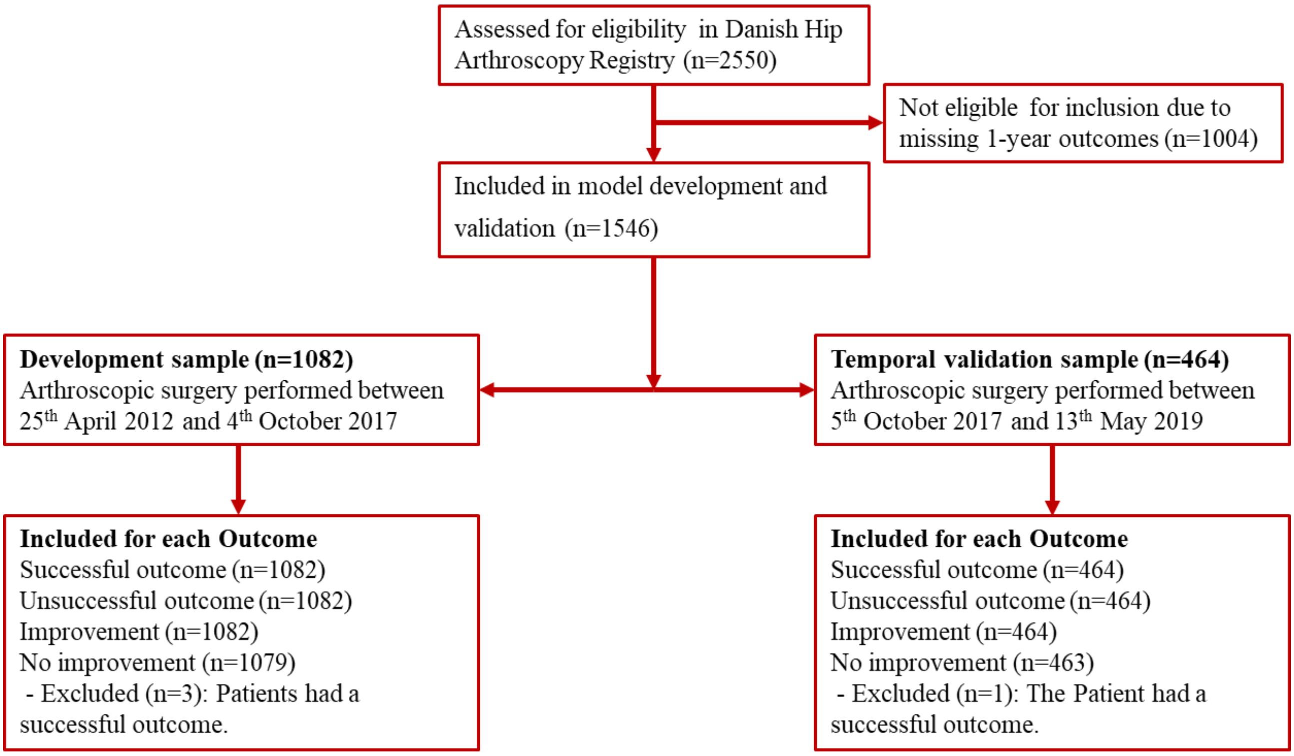

Figure 29. The flow of patients. The figure is reproduced from Ishøi et al.(unpublished).

Table 29. Summary of key study characteristics for included versus not included patients. The table is reproduced from Ishøi et al.(unpublished).

Characteristics	Included (n=1546)	Not included (n=1004)
Demographic data		
Sex, female, no. (%)		
Age at surgery	34.7 (10.1)	34.0 (10.1)
Hip Sports Activity Scale[&]	2.6 [IQR: 1-4]	2.5 [IQR: 1-4]
Radiographic data		
Alpha Angle	67.5 (13.6)	66.4 (13.5)
Lateral Center Edge Angle	31.1 (5.2)	31.1 (5.0)
Joint Space Width >4.0 mm, no. (%)	1039 (67.2)	689 (68.6)
Acetabular Index Angle	5.1 (3.9)	5.3 (4.3)
Peri-operative data		
Becks classification, grade 0-1, no. (%)	1107 (80.7)	735 (83.1)
ICRS Classification, grade 0-1, no. (%)	217 (15.8)	139 (15.7)
Labral injury, no. (%)	1422 (92.0)	907 (90.3)
Diagnostic entity based on morphology*		
Normal, no. (%)	330 (21.3)	207 (20.6)
Isolated cam, no. (%)	962 (62.2)	629 (62.6)
Cam and pincer, no. (%)	75 (4.9)	47 (4.7)
Cam and dysplasia, no. (%)	109 (7.1)	74 (7.4)
Isolated pincer, no. (%)	35 (2.3)	21 (2.1)
Isolated dysplasia, no. (%)	35 (2.3)	26 (2.6)
Pre-operative self-reported hip and groin function		
HAGOS Pain	52.5 [IQR: 37.5-65.0]	47.5 [IQR: 35.0-62.5]
HAGOS Symptoms	50.0 [IQR: 35.7-60.7]	46.2 [IQR: 35.7-59.8]
HAGOS Activities of Daily Living	55.0 [IQR: 35.0-70.0]	50.0 [IQR: 35.0-70.0]
HAGOS Sport and Recreational activities	34.4 [IQR: 18.8-53.1]	31.3 [IQR: 15.6-46.9]
HAGOS Physical Activities	12.5 [IQR: 0.0-37.5]	12.5 [IQR: 0.0-25.0]
HAGOS Quality of Life	30.0 [IQR: 20.0-40.0]	25.0 [IQR: 15.0-40.0]

HAGOS: Copenhagen Hip And Groin Outcome Score; ICRS: International Cartilage Repair Society. * Only based on patients with full data on alpha angle and lateral center edge angle. [&] Hip Sports Activity scale is measured on a 1-9 scale.

In total, 1082 patients were used for model development, whereas 464 patients were used for validation, with samples being comparable in terms of demographics, radiology, operative findings, pre-operative symptoms, and outcomes (**Table 30**).

Table 30. Summary of key study characteristics for the development and temporal validation samples. The table is reproduced from Ishøi et al.(unpublished).

Characteristics	Development sample (n=1082)	Temporal validation sample (n=464)
Study setting		
Data collection period	25th April 2012 to 4th October 2017	5th October 2017 to 13th May 2019
Study design	Retrospective	
Setting	Secondary care (public and private hospitals in Denmark)	
Inclusion criteria	Male/female undergoing a hip arthroscopy at the age of 15-50 years	
Demographic data		
Sex, female, no. (%)	640 (59.1 %)	283 (61.0 %)
Age at surgery	34.8 (10.0)	34.6 (10.2)
Hip Sports Activity Scale&	2.5 [IQR: 1-4]	2.6 [IQR: 1-4]
Radiographic data		
Alpha Angle	68.0 (13.4)	66.2 (14.2)
Lateral Center Edge Angle	31.6 (5.1)	29.8 (5.3)
Joint Space Width >4.0 mm, no. (%)	713 (65.9 %)	326 (70.3 %)
Acetabular Index Angle	5.2 (3.8)	4.7 (4.0)
Peri-operative data		
Becks classification, grade 0-1, no. (%)	811 (84.3 %)	296 (72.4 %)
ICRS Classification, grade 0-1, no. (%)	150 (15.6 %)	67 (16.3 %)
Labral injury, no. (%)	994 (91.9 %)	428 (92.2 %)
Diagnostic entity based on morphology*		
Normal, no. (%)	134 (13.7 %)	86 (22.4 %)
Isolated cam, no. (%)	717 (73.4 %)	233 (60.7 %)
Cam and pincer, no. (%)	64 (6.6 %)	9 (2.3 %)
Cam and dysplasia, no. (%)	39 (4.0 %)	39 (10.2 %)
Isolated pincer, no. (%)	16 (1.6 %)	7 (1.8 %)
Isolated dysplasia, no. (%)	7 (0.7 %)	10 (2.6 %)
Pre-operative HAGOS		
Pain	52.2 [IQR: 37.5-65.0]	50.3 [IQR: 35.0-65.0]
Symptoms	49.8 [IQR: 35.7-64.3]	47.1 [IQR: 35.7-60.7]
Activities of Daily Living	55.0 [IQR: 40.0-75.0]	52.6 [IQR: 35.0-70.0]
Sport and Recreational activities	37.1 [IQR: 18.8-53.1]	35.3 [IQR: 15.6-53.1]
Physical Activities	20.3 [IQR: 0.00-37.5]	21.1 [IQR: 0.00-37.5]
Quality of Life	30.3 [IQR: 20.0-40.0]	29.0 [IQR: 20.0-40.0]

HAGOS: Copenhagen Hip And Groin Outcome Score; ICRS: International Cartilage Repair Society. * Only based on patients with full data on alpha angle and lateral center edge angle. & Hip Sports Activity scale is measured on a 1-9 scale.

Model development

Calibration plots and associated statistics for the development sample are presented in **Appendix 1**. Since missing data in predictor variables were imputed, all patients with complete HAGOS at baseline and 1-year follow-up were included. The proportion of events was similar between the development and validation samples (**Table 31**).

Table 31. Number and proportion of events in the development and validation sample for the different outcome analyses. The table is reproduced from Ishøi et al.(unpublished).

	Development	Validation
Successful outcome, no (%)	339 (31.3)	137 (29.5)
Unsuccessful outcome, no. (%)	294 (27.2)	117 (25.2)
Improvement, no. (%)	333 (30.8)	161 (34.7)
No improvement, no. (%)	140 (13.0)	51 (11.0)

When stratified by the outcome, apparent differences were found between groups in post-operative HAGOS scores and changes in HAGOS scores from pre-to-post-surgery (**Figure 30**).

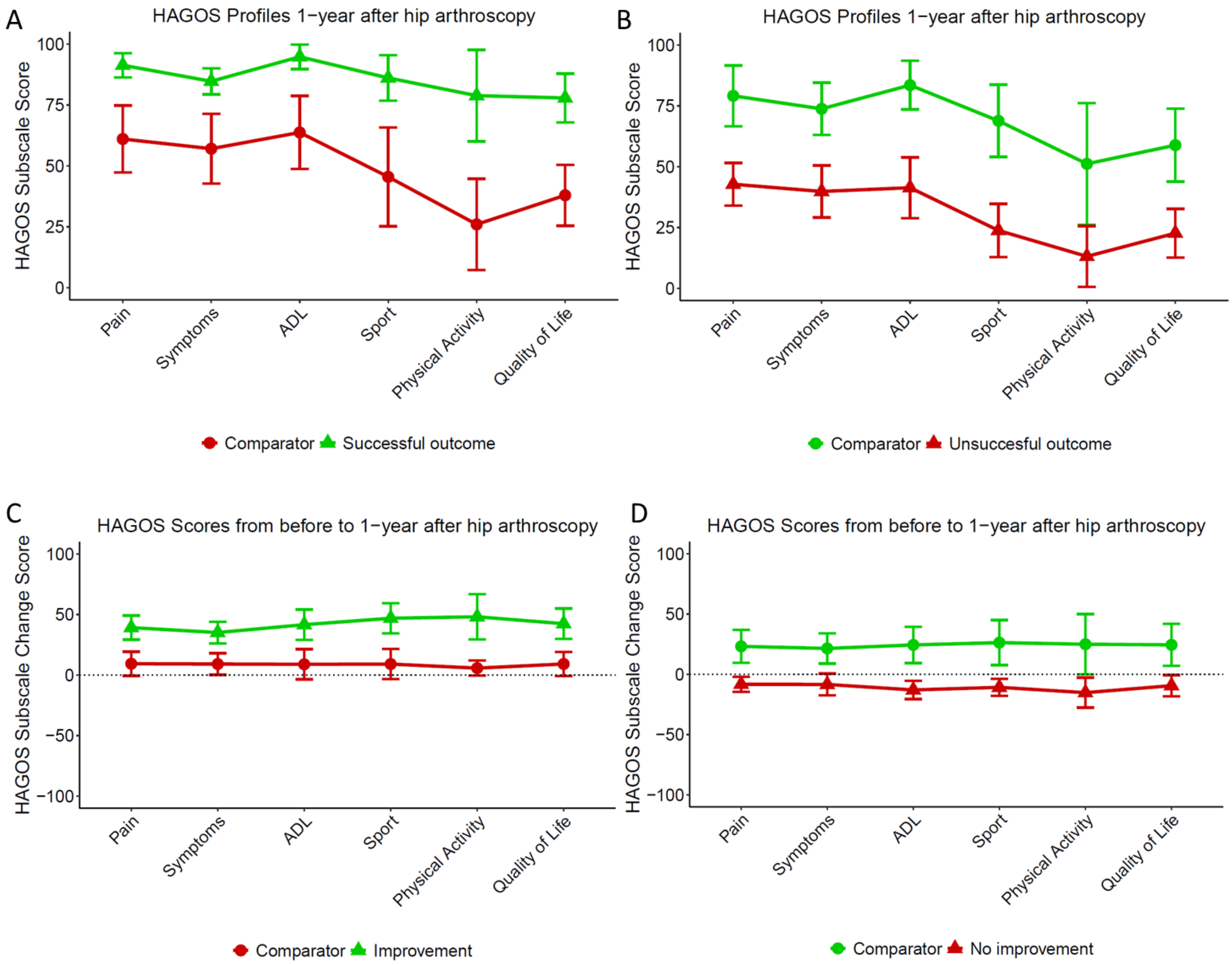

Figure 30. Self-reported hip and groin pain and function measured using the Copenhagen Hip and Groin Outcome Score (HAGOS) in A) patients with a successful outcome defined as having a Patient Acceptable Symptom State (PASS) in all HAGOS subscales versus in some/no subscales, B) patients with an unsuccessful outcome defined as having PASS in no HAGOS subscales versus in some/all subscales, C) patients who have achieved an improvement defined as exceeding the Minimal Clinically Important Difference (MCID) in all HAGOS subscales versus in some/no subscales, D) patients who have not achieved an improvement defined as not exceeding MCID in any HAGOS subscale versus in some/all subscales. Error bars show interquartile range. The figure is reproduced from Ishøi et al. (unpublished).

Model specification and performance

The best model performance was found for unsuccessful outcomes (Nagelkerke R^2: 0.27) which also showed adequate calibration (**Figure 31, Table 32**).

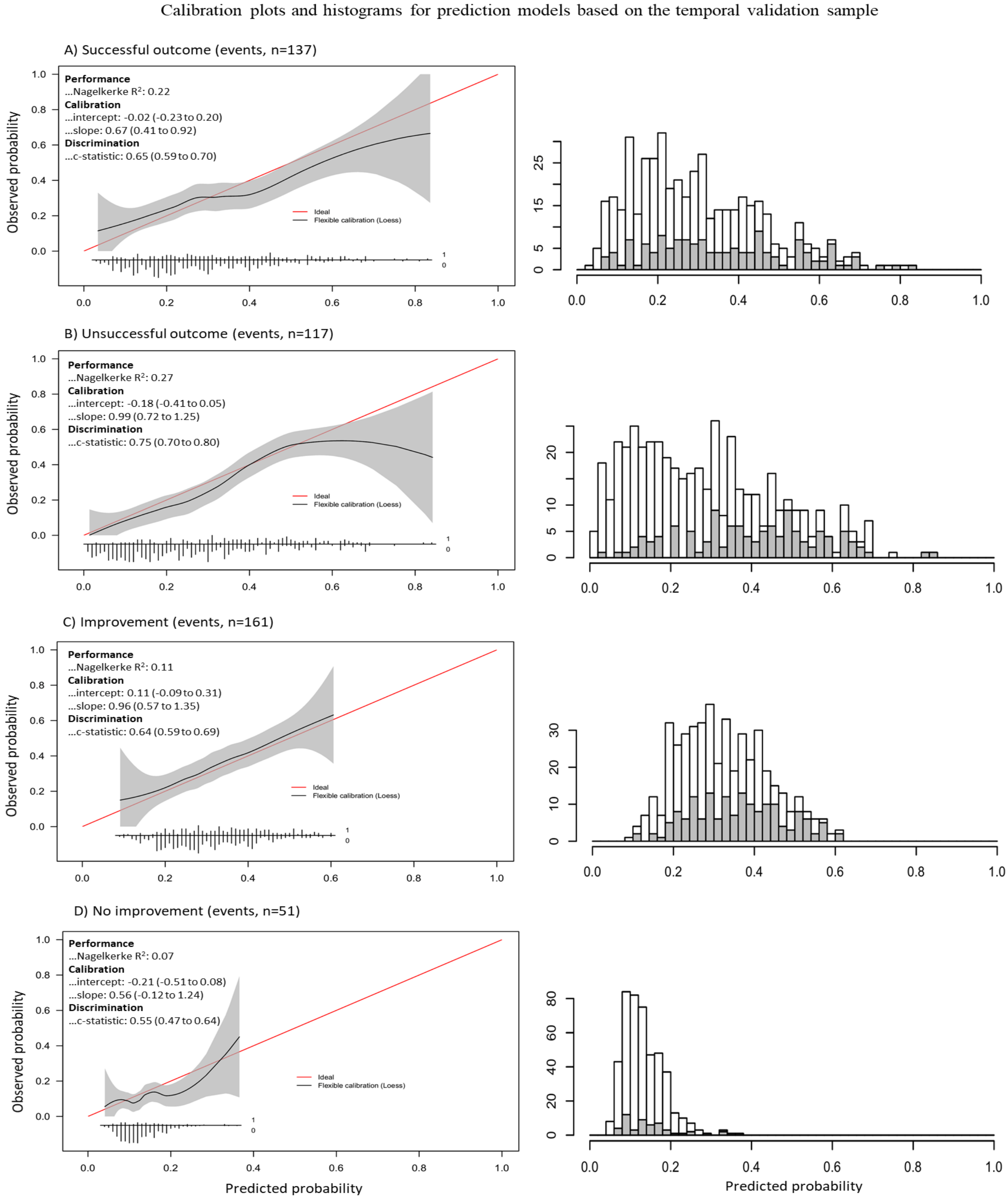

Figure 31. Calibration plots and histograms for predicting patients who have achieved a successful outcome (Patient Acceptable Symptom State [PASS] in all HAGOS subscales) (A) or an unsuccessful outcome (PASS in no HAGOS subscale) (B), achieved an improvement (Minimal Clinically Important Difference [MCID] in all HAGOS subscales) (C), and no improvement (not achieved MCID in any HAGOS subscale) (D). Grey bars in histograms represent frequency of patients with the outcome of interest for each predicted probability, whereas white bars represent control patients. Shaded area in calibration plots depicts 95 % Confidence Intervals. HAGOS; Copenhagen Hip and Groin Outcome Score. The figure is reproduced from Ishøi et al. (unpublished).

Table 32. Prediction model performance for temporal validation models for each outcome measure at 1-year after hip arthroscopy. The table is reproduced from Ishøi et al.(unpublished).

	Successful outcome (Events, n=137*)	Unsuccessful outcome (Events, n=117*)	Improvement (Events, n=161*)	No improvement (Events, n=51*)
Nagelkerke R^2	0.22	0.27	0.11	0.07
Discrimination				
AUC (c-statistics)	0.65 [0.59; 0.70]	0.75 [0.70; 0.80]	0.64 [0.59; 0.69]	0.55 [0.47; 0.64]
Calibration				
Calibration-in-the-large Predicted mean probability Actual mean probability	29.9 % 29.5 %	28.2 % 25.2 %	32.4 % 34.7 %	13.3 % 11.0 %
Calibration intercept	-0.02 [-0.23; 0.20]	-0.18 [-0.41; 0.05]	0.11 [-0.09; 0.31]	-0.21 [-0.51; 0.08]
Calibration slope	0.67 [0.41; 0.92]	0.99 [0.72; 1.25]	0.96 [0.57; 1.35]	0.56 [-0.12; 1.24]
Classification measures**				
Probability threshold: 0.3				
Sensitivity	0.57	0.74	0.66	0.04
Specificity	0.62	0.67	0.54	0.99
Probability threshold: 0.4				
Sensitivity	0.39	0.50	0.36	0.00
Specificity	0.79	0.83	0.79	1.00
Probability threshold: 0.5				
Sensitivity	0.22	0.27	0.14	0.00
Specificity	0.92	0.91	0.95	1.00

A successful outcome refers to having achieved the Patient Acceptable Symptom State (PASS) cut-off score for all HAGOS subscales at 1-year after hip arthroscopy; An unsuccessful outcome refers to not having achieved the PASS cut-off score for any HAGOS subscale at 1-year after hip arthroscopy; A clinical improvement refers to having achieved the Minimally Clinically Important Difference (MCID) for all HAGOS subscales from pre to 1-year after hip arthroscopy; No clinical improvement refers to not having achieved MCID in any HAGOS subscales from pre to 1-year after hip arthroscopy. * Events refer for the number of patients with the outcome.
** Probability thresholds refer to the probability of the outcome based on the prediction model and is used to estimate the associated sensitivity and specificity.
HAGOS; Copenhagen Hip And Groin Outcome Score.

A complete summary of model performance for all four models is available in **Appendix 2**, while sensitivity and specificity for probability thresholds (from 0.1 to 0.9) are presented in **Appendix 3**. The complete case analyses showed similar model performance for all outcomes. For the supplementary models, the addition of peri-operative findings (information on cartilage and labrum injuries) did not improve model performance (**Appendix 4**).

Online Calculator

For usage of the prediction models, an excel-based calculator is provided online (https://bit.ly/3avOcjJ), with an example of the calculator depicted in **Figure 32**.

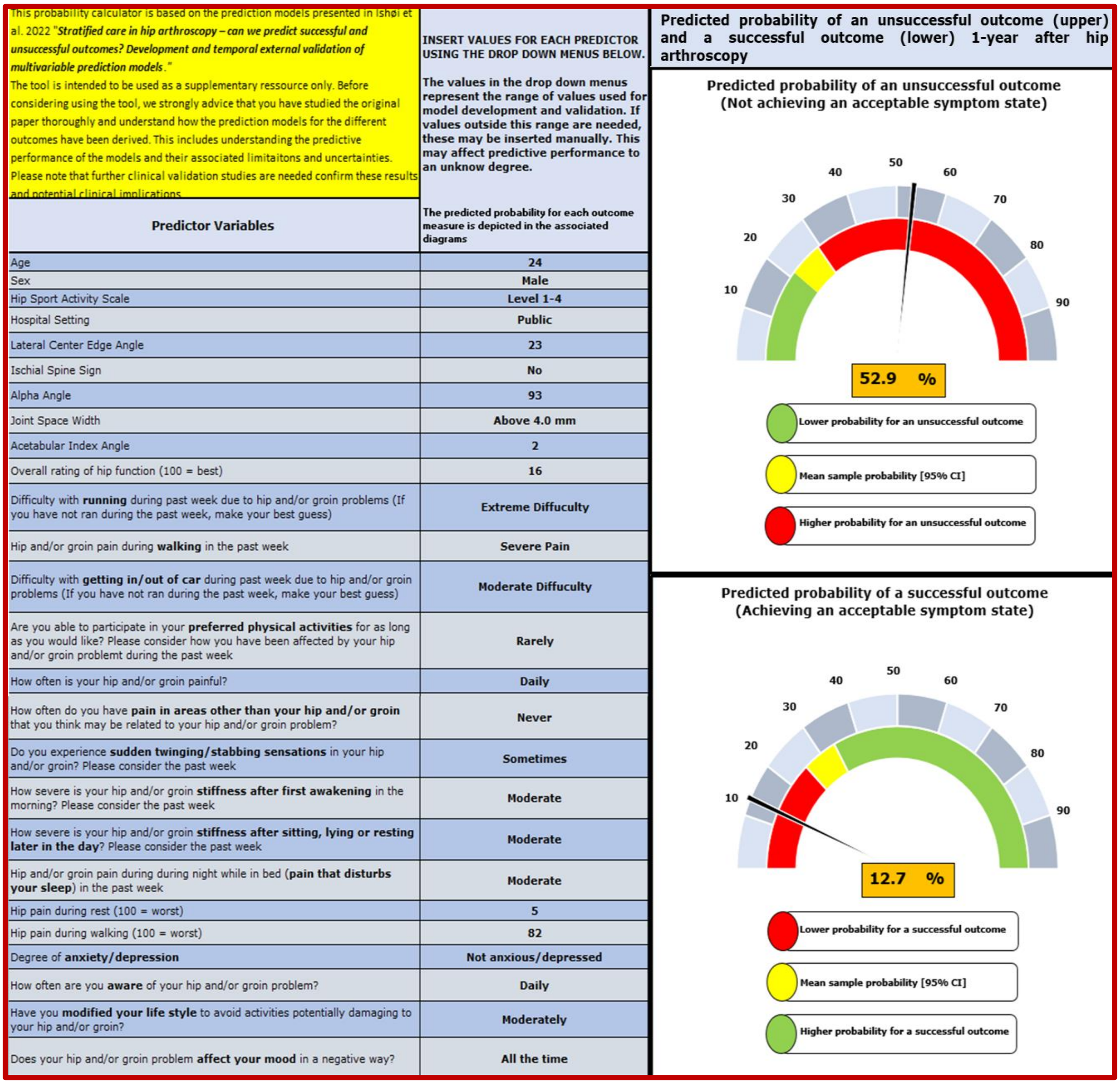

Figure 32. Probability of an unsuccessful and successful outcome after hip arthroscopy based on the clinical prediction model from study V. The left part of the figure lists the included predictor variables and associated values from which an estimated probability is calculated (right part). As depicted in the speedometer graph, the patient has a higher probability of an unsuccessful outcome and a lower probability of a successful outcome compared to the group average. Thus, this chart would represent a patient for whom hip arthroscopy may not be appropriate.

CHAPTER 4:

DISCUSSION

When we prepared this thesis in 2017, hip arthroscopy had been an established procedure for the treatment of hip and groin pain, particularly femoroacetabular impingement syndrome, in physically active young to middle-aged individuals for many years,[199] including in Denmark where the Danish Hip Arthroscopy Registry was initiated in 2012.[154] Nevertheless, several important and clinically relevant questions remained uncovered. This was brought to attention in 2016 when the Warwick Agreement on Femoroacetabular impingement Syndrome was published by a large group of leading experts within the field of hip and groin pain.[1] In this landmark paper, a supplementary file was provided with a list of 23 questions on diagnosis and management of femoroacetabular impingement syndrome agreed upon by the consensus group to represent relevant directions for future research.[1] Based on the list, it was clear that questions related to the treatment effect and factors associated with the treatment outcome were priorities for the consensus group. Moreover, areas such as the role of muscle strength for symptoms, role of morphology, and return to play were also deemed necessary to explore.

The Warwick Agreement provided the perfect steppingstone for this thesis, in which we set out to contribute with new knowledge for a small part of the 23-question list. This quest led to a thesis with the general aim to:

- **(I)** Improve our understanding of how hip joint morphology affects joint health in young to middle-aged people,
- **(II)** Provide a detailed overview of patient-centered outcomes after hip arthroscopy,
- **(III)** Develop and validate multivariable models to predict successful and unsuccessful outcomes after hip arthroscopy.

Summary of main findings

Specific hip joint morphology was associated with a distinct pattern of cartilage injuries, with more pronounced morphology associated with a higher risk of severe cartilage injuries.[166] A little more than half of the patients rated their symptoms as unacceptable 1-2 years after hip arthroscopy,[190] while 57 % were able to return to their previous sport activities, yet only 17 % with a performance level comparable to before the onset of hip pain.[172] No differences were found in maximal hip muscle strength or jump performance between the operated and non-operated hip 6-30 months after hip arthroscopy; however, the operated hip displayed less explosiveness for hip flexion. Furthermore, having higher hip extension strength was associated with the ability to be engaged in pre-injury sport.[193] Using 26 clinical variables collected prior to hip arthroscopy, it was possible to accurately predict the risk of ending up with an unsuccessful outcome (having unacceptable symptoms) one year after hip arthroscopy (Ishøi et al. *Submitted*).

Study I: The underlying pathology of femoroacetabular impingement syndrome

In study I, we found that a range of demographic and radiographic variables obtained immediately prior to surgery were associated with the presence of moderate to severe (grade 3-4) acetabular and femoral head cartilage injuries identified arthroscopically. Most interestingly, the size of cam morphology showed a positive dose-response association for the risk of having moderate to severe acetabular cartilage injury, with an alpha angle >55° [1] and >78° [200] increasing the risk by 2.23 and 4.82 times, respectively, compared to an alpha angle <55°. In addition, a Lateral Center Edge angle <25°, indicative of borderline acetabular dysplasia, increased the risk of moderate to severe femoral head cartilage injury by 3.08 times compared to a normal Lateral Center Edge angle between 25° to 39°.

These findings suggest that specific morphological variants of the acetabulum and femoral head-neck junction in patients with femoroacetabular impingement syndrome results in specific cartilage injury patterns within the hip joint, confirming Ganz et al's.[12] hypothesis from their landmark paper in 2003. Based on clinical experience from numerous surgical dislocations of the hip, Ganz et al.[12] popularized the term "femoroacetabular impingement" and speculated how altered hip joint morphology could be a mechanical precursor of early hip osteoarthritis in young to middle-aged physically active individuals. The author group suggested how the presence of cam morphology would lead preferentially to acetabular cartilage injuries following the so-called outside-in mechanism [201] because of a collision between the aspherical femoral head with the chondrolabral junction. This collision would result in detachment of the cartilage and the labrum from the acetabular bone caused by excessive shear forces (**Figure 33**).[12] Additionally, they suggested that pincer morphology preferentially injures the acetabular labrum because of repetitive direct collision between the femoral head-neck junction and the acetabular rim, leaving the acetabular cartilage with only one minor injury (**Figure 33**).[12]

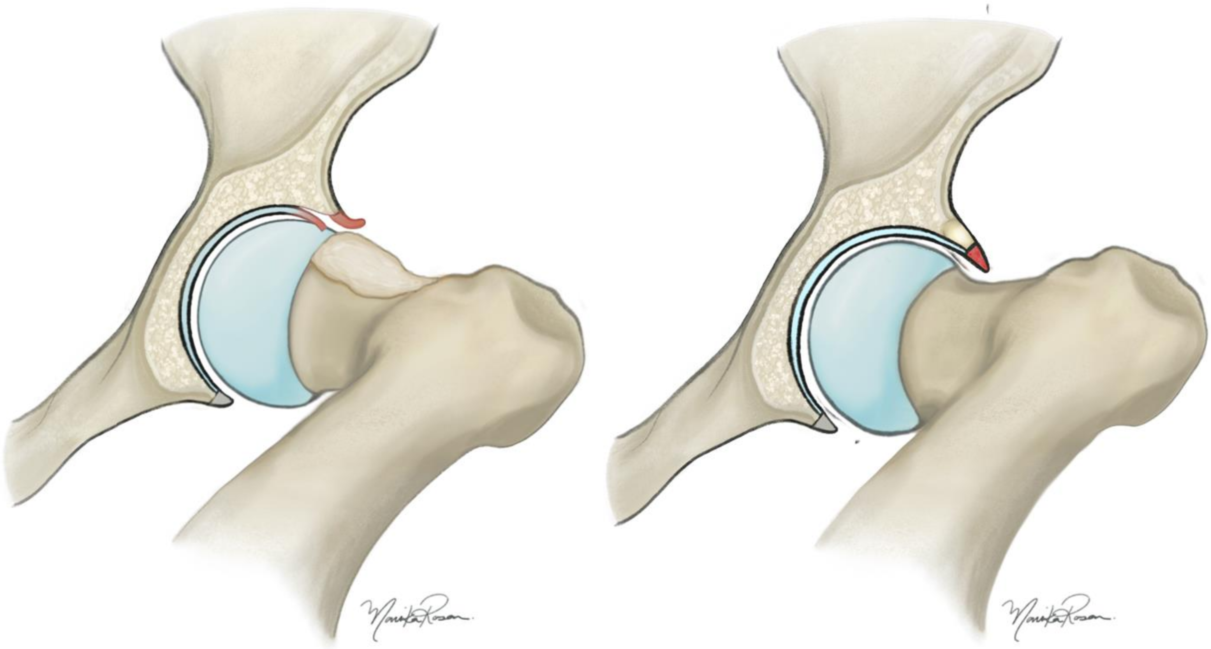

Figure 33. Proposed injury mechanism of the cam (Left) and pincer morphology (Right) during hip flexion. Illustrations by Monika Rosen specifically for this thesis.

When planning this thesis in 2017, only emerging literature to support the above hypotheses had been published. An early study by Beck et al. in 2005 [32] found, in a small cohort of 26 patients with isolated cam morphology and 16 patients with isolated pincer morphology, a higher proportion of wave-sign and cleavage lesion in the cam morphology group, thus, providing some of the first indications of a cartilage injury-specific pattern. Studies by Johnston et al.[202] Nepple et al.[58] and Beaulé et al.[59] followed, and while these supported the initial findings,[32] they were also associated with methodological shortcomings. These included failure to account for confounding variables [59,202] or the use of only a single cut-off value of >50° for defining cam morphology,[58] which precluded any strong assumptions of a link between the severity of cam and pincer morphology with cartilage injury to be established.

In Study I, we extended on previous work. We used a large sample size to minimize the risk of spurious associations,[95] included several potential confounding variables such as age, sex, activity level, and joint space width,[58] used contemporary cut-off values for defining increasing severity of cam morphology based on consensus agreement [1] and statistical modelling,[62,200] and included both acetabular and femoral-head cartilage injury as outcomes.[166] Since the publication of study I, several additional studies with varying methodology have explored the role of hip joint morphology with the risk of cartilage injuries (**Table 33**).[203–211] In general, these support the notion that the severity of cam morphology increases the risk of acetabular cartilage injuries. In contrast, the role of pincer morphology does not seem to elevate the risk of moderate to severe cartilage injuries. In a detailed study by Pascual-Garrido et al.[207] it was further highlighted that almost all hips with cam morphology presenting to hip arthroscopy showed acetabular cartilage injuries, preferentially in the peripheral area of the superolateral portion of the acetabulum, coinciding with the typical location of the cam morphology at the femoral head-neck junction.[37] A similar finding was recently observed in an experimental proof-of-concept animal study using a sheep model with induced cam morphology via an intertrochanteric varus osteotomy.[212]

Table 33. Overview of studies investigating the association between hip joint morphology and acetabular and femoral head cartilage injuries identified during hip surgery.

Study	Material	Main findings
Beck et al. 2005 [32]	26 patients with pistol-grip deformity (cam morphology) and 16 patients with coxa profunda (global pincer morphology) undergoing open surgery.	- In patients with cam morphology, mean depth of acetabular cartilage injury was 11 mm compared to a maximum depth of 4 mm in pincer group. - Debonding (wave-sign) was present in 10 cam hips (38 %) compared to 2 (13 %) pincer hips. - Cleavage lesion (thinning of the cartilage, flap) was present in 14 cam hips (54 %) compared to 3 (19 %) pincer hips.
Johnston et al. 2008 [202]	82 amateur and professional athletes diagnosed with FAI undergoing hip arthroscopy.	- Association between grade of acetabular cartilage injury and degrees of alpha angle (no OR reported). - Larger alpha angles (10°) in hips with grade 4 acetabular cartilage injury (exposed bone) compared to hips with no injury. - No association between alpha angle and femoral cartilage injury (no OR reported).
Nepple et al. 2011 [58]	Mixed group of 338 patients undergoing hip arthroscopy.	- Associations between presence of grade 3 or 4 acetabular cartilage injury (at least fissuring to the level of subchondral bone) with male sex (OR: 4.6), alpha angle >50° (OR: 3.0), increasing age* (OR:2.2), and Tönnis grade 1or 2 (OR: 3.7).
Beaulé et al. 2012 [59]	176 patients with a diagnosis of FAI due to cam morphology undergoing open surgery or hip arthroscopy.	- Associations between presence of Beck type 3 or greater cartilage injury (at least chondral delamination) with age (OR: 1.04), male sex (OR: 2.0), larger alpha angle (OR: 1.04), larger center-edge angle (OR: 0.94). - Higher odds for presence of Beck type 3 cartilage injury was found for hips with alpha angle 50-64.9° (OR: 1.44) and ≥65° (OR: 4.0) compared to hip with alpha angle <50°.
Studies published after initiation of study I		
McClincy et al. 2018 [204]	402 adolescent patients diagnosed with FAI undergoing hip arthroscopy.	**-** Patients with acetabular cartilage injury (defined based on surgical procedure) were older (OR: 1.7), predominantly males (OR: 2.5), had a higher body mass index (OR: 1.07), presented with larger alpha angles (OR: 1.77). - Association between presence of acetabular cartilage injury and alpha angle (OR: 2.02) and crossover sign (OR:0.24)
Kapron et al. 2018 [205]	100 patients diagnosed with FAI syndrome undergoing hip arthroscopy.	- Associations between presence of severe acetabular cartilage injury (debonding, cleavage, or defect) with larger alpha angle (OR: 1.06) and increasing age (OR: 1.07)
Bolia et al. 2018 [206]	305 patients with borderline dysplasia and 2124 without borderline dysplasia undergoing hip arthroscopy.	- Patients with borderline dysplasia (20≤ LCEA ≤25) were more likely to present with grade 3 or 4 femoral head cartilage injuries (OR: 10.0) compared to patients without borderline dysplasia.
Pascual-Garrido et al. 2019 [207]	802 patients diagnosed with FAI undergoing hip arthroscopy.	- Patients with cam FAI and mixed FAI had a higher proportion of acetabular cartilage injury compared to pincer FAI (>93% vs 75%), while no difference for femoral head cartilage injury. - Associations between increasing age and acetabular (OR:1.05) and femoral head (1.06) cartilage injury.
Utsunomiya et al. 2019 [209]	Mixed group of 2080 patients undergoing hip arthr0scopy	- Associstions between severe acetabular cartilage injuries (grade 3-4) and higher age, male sex, joint space narrowing, symptom duration, and alpha angle. - Associations between severe femoral head cartilage injuries (grade 3-4) and lower LCEA, higher age, joint space narrowing, and higher body mass index
Dumont et al. 2020 [210]	205 patients diagnosed with FAI undergong hip arthroscopy	- Associations between high grade acetabular cartilage injuries (grade 3-4) and higher age, alpha angle, and male sex. - Associations between high grade femoral head cartilage injuries (grade 3-4) and higher age.
Table continues on nex page.		

Tang et al. 2021 [208]	102 patients with cam FAI or mixed FAI undergoing hip arthrscopy	- Gradually higher alpha angles were observed with higher acetabular cartilage grading (grade 0: alpha angle, 45° to grade 4: alpha angle, 73° - Alpha angles above 70° were associated with higher the odds of grade 2-4 acetabular cartilage injuries (OR: 3.71).
Shapira et al. 2021 [211]	Mixed group of 1485 patients undergoing hip arthroscopy	- Patients with grade 3-4 acetabular cartilage injuries were older, heavier, predominantly male, and did not have coxa profuncda - Multivariable regression analysis showed higher odds for increasing age (OR: 1.04), male sex (OR: 3.73), and larger alpha angles (OR: 1.06), and lower odds for higher center egde angle (OR: 0.98).

OR: Odds Ratio; FAI: Femoroacetabular impingement; LCEA: Lateral center edge angle; *<30 years vs. 30 to 50 years vs. >50 years.

The dose-response association between the degree of cam morphology and risk of moderate to severe acetabular cartilage injuries observed in study I is further in line with observations of cam morphology as a risk factor for hip osteoarthritis in middle-aged to old individuals.[61] Conversely, pincer morphology has not been linked to the development of hip osteoarthritis in the previous literature;[61] a notion in line with study I.

The summary of existing literature, including study I, provides indications of a causal relationship between the presence of cam morphology and the development of acetabular cartilage injuries in young to middle-aged individuals as first proposed in 2003.[12] While the exact aetiology remains to be fully elucidated, mechanistic and computational modelling studies may offer some additional insights.

First, by using advanced in-vivo imaging techniques, Fernquest et al.[57] observed a strong inverse association between the hip flexion angle during a Flexion Adduction Internal-Rotation test at which osseous impingement occurred and the severity of the cam morphology, suggesting that a large cam morphology is more likely to result in a collision with the acetabulum during activities of hip flexion. Second, several computational studies have observed higher acetabular cartilage peak forces in hips with cam morphology versus controls hips during activities such as squatting, walking, and sitting/rising from a chair,[213–215] and this seems to follow a dose-response association with alpha angles >80° substantially accelerating peak forces at the acetabular cartilage during sitting down/standing up, but not during walking.[216] Third, by using subject-specific geometries and finite element analysis, Ng et al.[214,215] observed how hips with cam morphology were exposed to substantial stresses at the anterosuperior acetabular subchondral bone during squatting. Consequently, cam morphology has been linked to increased bone density and thickness of the acetabular subchondral bone in both symptomatic and asymptomatic individuals,[217,218] with bone density associated with activity level in patients with cam morphology but not in controls.[219] This result indicates that the cam deformity may be the reason for the increased density.[214,219] These findings are interesting since the increased bone density of the subchondral bone may represent a sub-clinical state of joint degeneration.[217] Higher bone density stiffens the subchondral bone compromising the absorption capacity, thus, shifting more load towards the more compliant acetabular cartilage, which is consequently exposed to higher peak pressure and potential accelerated degeneration over time.[220]

Collectively, these previous findings raise the question of whether concomitant intra-articular injuries, such as cartilage or labrum, are the underlying pathology of femoroacetabular impingement syndrome? Indeed, negligible associations between morphological variants, such as cam and pincer morphology with both the level and presence of hip and/or groin symptoms have been observed in numerous studies,[221–225] also indicated by the large proportion of asymptomatic individuals with morphological changes.[45,49,226] Conversely, cartilage injuries seem more prevalent in individuals with hip pain versus healthy controls.[227] At the same time, a positive association exists between cumulative intra-articular and labral findings based on magnetic resonance imaging and hip and/or groin pain.[228] As such, it seems plausible that while the morphological variants are needed to diagnose femoroacetabular impingement syndrome, the underlying problem and potential cause of symptoms are more related to concomitant intra-articular injuries.[55] Cannon et al.[55] proposed a theoretical framework for development of symptoms because of cam or pincer morphology. In the presence of morphological variants, this may lead to the bony abutment of varying degrees depending on the size of the cam morphology,[57] facilitating the cascade of chondrolabral injury,[166] and subsequent release of inflammatory markers indicative of joint degeneration.[229,230] Some support for cam morphology as a risk factor for developing hip and/or groin pain has been found,[224,231–234] with two studies highlighting associations between earlier age of symptom onset and larger cam morphology,[224,234] indicating that larger cam morphologies may be more likely to be an early trigger for the cascade of concomitant intra-articular injuries.[166] However, the relationship between cam morphology and development of symptoms is complex, with two studies in football players having failed to demonstrate clear associations.[235,236] Interestingly, higher neck-shaft angles may alleviate the higher acetabular cartilage stress associated with cam morphology, which could be speculated to dampen the degenerative process and development of symptoms.[215]

In study I, we found borderline dysplasia was associated with moderate to severe femoral head cartilage injuries. Although this morphological variant is not present in the regular patient with femoroacetabular impingement syndrome, borderline dysplasia may co-exist with cam morphology (approximately 6 % of patients in the Danish Hip Arthroscopy Registry, *Ishøi et al. unpublished*), which may set up the hip joint for a high risk of cartilage degeneration (**Figure 34**).

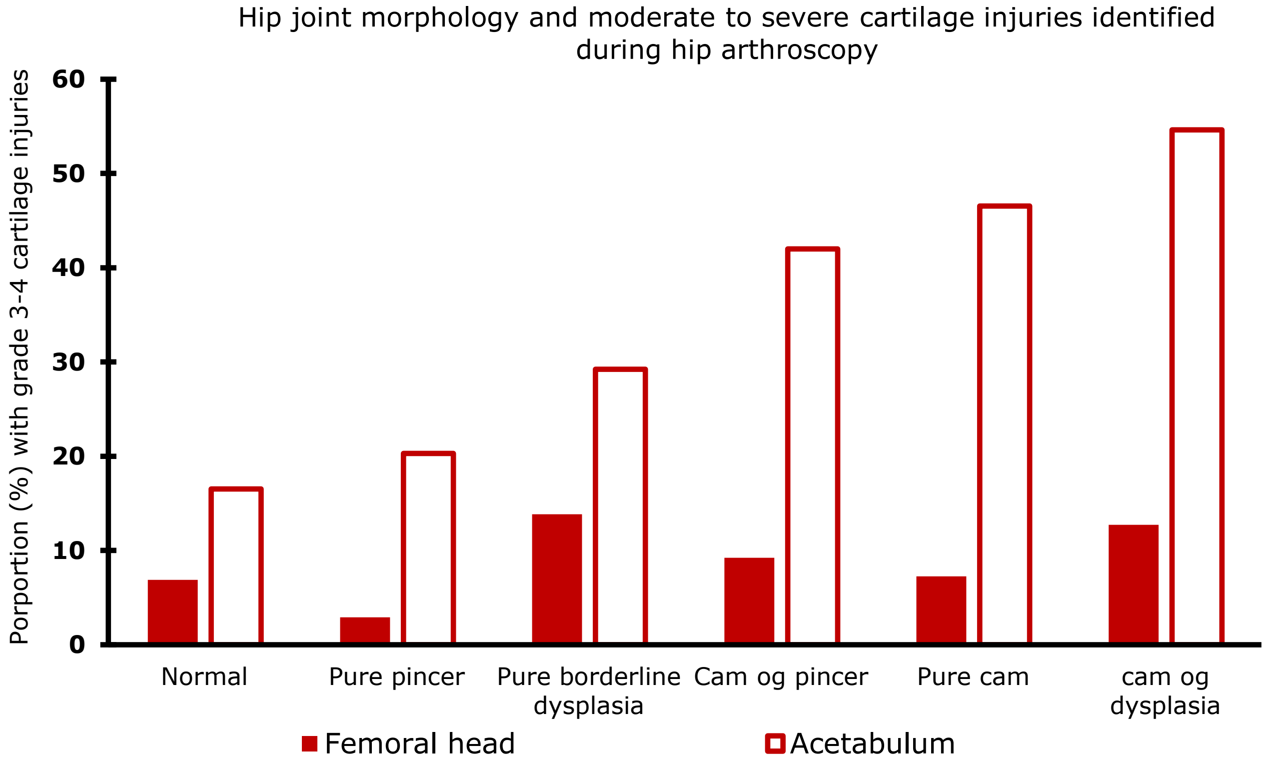

Figure 34. The absolute risk of moderate to severe (grade 3-4) femoral head and acetabulum cartilage injuries based on different morphological entities in 5294 patients undergoing hip arthroscopy. Data is based on the Danish Hip Arthroscopy Registry (Ishøi et al. *unpublished*).

Our findings are in line with Bolia et al.[206] who observed that 39 % of patients with borderline dysplasia were diagnosed with moderate to severe femoral head cartilage injuries during hip arthroscopy compared to only 6 % of non-borderline dysplastic hips. In addition, several prospective cohort studies have linked borderline dysplasia with the development of hip osteoarthritis.[61] One reason for the elevated risk of femoral head cartilage injuries in the borderline dysplastic hip may be that the load-bearing zone projects laterally because of the acetabulum's lack of bony support increasing the load on the acetabular labrum and the adjacent cartilage.[237,238] This process also elevates contact stresses at the femoral head due to a lower contact area (**Figure 35**).[237]

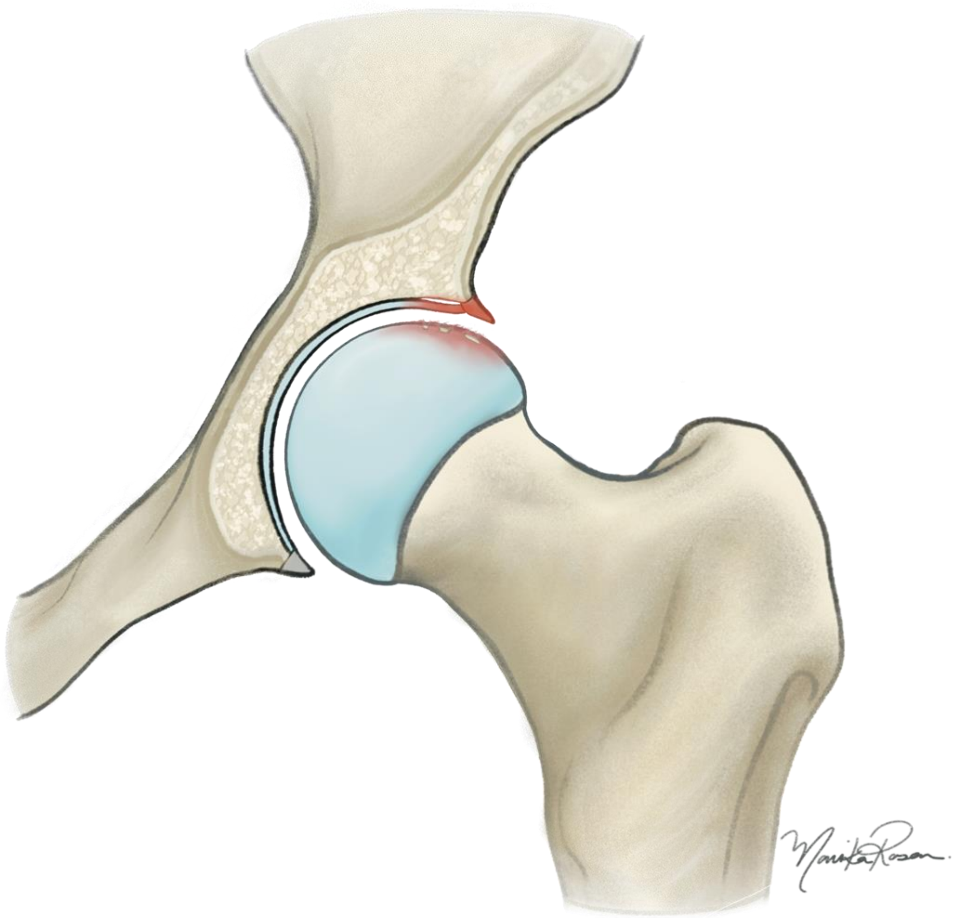

Figure 35. Proposed injury mechanism of femoral head cartilage in a borderline dysplastic hip. Because of the lack of bony support (acetabular coverage), the load-bearing zone shifts laterally, decreasing the femoral head's contact area, thus increasing contract stress. Injuries to the acetabular cartilage and labrum are also frequently seen. Illustration by Monika Rosen specifically for this thesis.

Key findings

In patients undergoing hip arthroscopy:

- **The severity of cam morphology was associated with higher risk of moderate to severe acetabular cartilage injuries in a dose-response pattern.**
- **Borderline dysplasia was associated with moderate to severe femoral head cartilage injuries.**
- **Pincer morphology showed no association to cartilage injuries.**

Study II: Patients get better after hip arthroscopy, but is it good enough?

In study II, we found that approximately 50 % of patients rated their symptoms as acceptable (PASS) 12-24 months following hip arthroscopy when considering activities of daily living and participation in social and sports activities. In addition, $PASS_{ADL}$ and $PASS_{Sport}$ were achieved by 53 % and 40 % of patients, respectively. Lastly, we identified cut-off values for having acceptable symptoms for the only two recommended patient-reported outcome measures (HAGOS and iHOT-33)[16] in young to middle-aged individuals with hip-related pain. These ranged from 42.5 (HAGOS QOL subscale) to 82.5 (HAGOS ADL subscale), whereas the iHOT-33 cut-off score was 67.[190]

Hip arthroscopy is well known to be associated with improvements in patients with femoroacetabular impingement syndrome.[78,82] We recently found moderate quality of evidence for a small effect of hip arthroscopy compared to physiotherapist-led exercise-based treatment in patients with femoroacetabular impingement syndrome.[22] However, despite improvements, patients are often left with residual symptoms and continued activity restrictions after hip arthroscopy.[78] The reasons for this outcome may be partly because of associated intra-articular cartilage injuries, as shown in study I, leaving the joint in a degenerate state.[166]

Concerning residual symptoms, Thorborg et al.[82] investigated patient-reported outcomes within the first year after hip arthroscopy, and subsequently whether patients had 1) achieved a minimal clinically important difference for each HAGOS subscale, and 2) achieved a score corresponding to reference values for healthy individuals (a score of 75-100 points depending on the subscale). In general, improvements across all HAGOS subscales were noted within the first year, with the most considerable improvements occurring within the initial three months.[82] At one-year, most patients (>66 %) exceeded the minimal clinically important difference, suggesting an improvement in function and pain, yet only 20-30 % reached a score equivalent to reference values of healthy controls.[82]

Although the likelihood of “getting better” is relevant for patients to know before undertaking a specific treatment, this improvement is often an arbitrary construct to comprehend. Therefore, “getting better” may only be considered satisfactory to patients if they reach a state of acceptable symptoms.[109] Thus, patients are often more concerned about how they feel after the treatment than the change in symptoms.[109] In addition, pain reduction has been labelled as the most important goal for treatment by patients with longstanding pain,[239] such as femoroacetabular impingement syndrome, where the symptom duration often exceeds several months.[20] Since PASS considers current pain and symptoms during several aspects of life, it is a relevant patient-centred measure to evaluate outcomes after treatment.[107]

A list of studies has reported on the PASS after hip arthroscopy for femoroacetabular impingement syndrome;[28,76,108,110,189,240–242] however, these are all based on cut-off values for various patient-reported outcome measures and not the PASS question directly. Nonetheless, the findings from study II are in line with a multi-centre randomized controlled trial, showing that 48 % in the hip arthroscopy group achieved an acceptable symptom state at 8-months follow-up.[28] Interestingly, single-centre cohort studies report slightly more favourable outcomes, with 58-73 % of patients achieving an acceptable symptom state.[76,108,110,189,240,241] Importantly, most studies determined PASS based on cut-off values for the Modified Harris Hip score or the Hip Outcome Score;[76,108,189,240] both not being recommended for use in young and middle-aged individuals with hip-related pain because of the lack of content validity.[16] In line with this notion, Domb et al.[76] reported the proportion of patients achieving an acceptable symptom state after hip arthroscopy based on the modified Harris Hip Score and the iHOT-12. Noteworthy, a discrepancy in the proportion was noted, with more patients achieving PASS if based on the modified Harris Hip Score (74 %) versus the iHOT-12 score (58 %).[76] Since patients answered both questionnaires, the modified Harris Hip Score not recommended for this population, seems to inflate the findings and be too optimistic. The reasons for this result may be the lack of content validity and celling effect, making it too easy to reach a high score and a categorization of PASS, when this outcome may not be the case.[16,243]

Therefore, to clarify the Patient Acceptable Symptom State following hip arthroscopy, study II reported the actual proportion based on the PASS question, and not cut-off values as done in all previous studies.[190] Together with $PASS_{ADL}$ and $PASS_{Sport}$, such information can be used to inform patients as part of the shared decision-making process prior to surgery. Considering that many patients tend to have unrealistic expectations of the hip arthroscopy outcome,[117,118] results from study II provide some context to what patients may expect, more relevant and important than simply the statement of "getting better."[109]

Study II is the first to categorize PASS into different domains, such as sport and activities of daily living.[190] While the validity of categorization remains to be investigated, such categorization may provide context-specific insights. Interestingly, only 4 in 10 patients reported an acceptable symptom state with sports activities, suggesting that achieving this may be an essential factor for an overall acceptable symptom state after surgery.[190] The finding is in line with a recent systematic review which, based on cut-off scores from the Hip Outcome Score Sports Subscale, classified 64 % of patients to have unacceptable symptoms after hip arthroscopy.[244] Consequently, these observations provide a different view on sports participation after hip arthroscopy than the return to sport rates more often discussed. Thus, in general,>75% return to some form of sports after hip arthroscopy.[113] Study II, however, indicates that most patients may still have unacceptable symptoms despite going back to the sport,[190] which may be attributed to difficulties and pain in specific sporting movements experienced by many.[185,245–247]

The cut-off scores for HAGOS and iHOT-33 can be used retrospectively to estimate the proportion of patients with PASS after hip arthroscopy as done in study V. To our knowledge, no studies have reported on PASS cut-off scores for HAGOS; however, few have investigated reference values for healthy individuals.[82] The PASS cut-off values in study II are lower than these (**Figure 36**), suggesting that patients do not need to reach a symptom state comparable to healthy individuals to feel well after surgery, with considerable discrepancies for "Sport," "Physical Activity," and "Quality of Life" Subscales. In line with this finding, satisfaction with the outcome after hip arthroscopy can be obtained without the patient reaching a pain-free symptom state.[242,248]

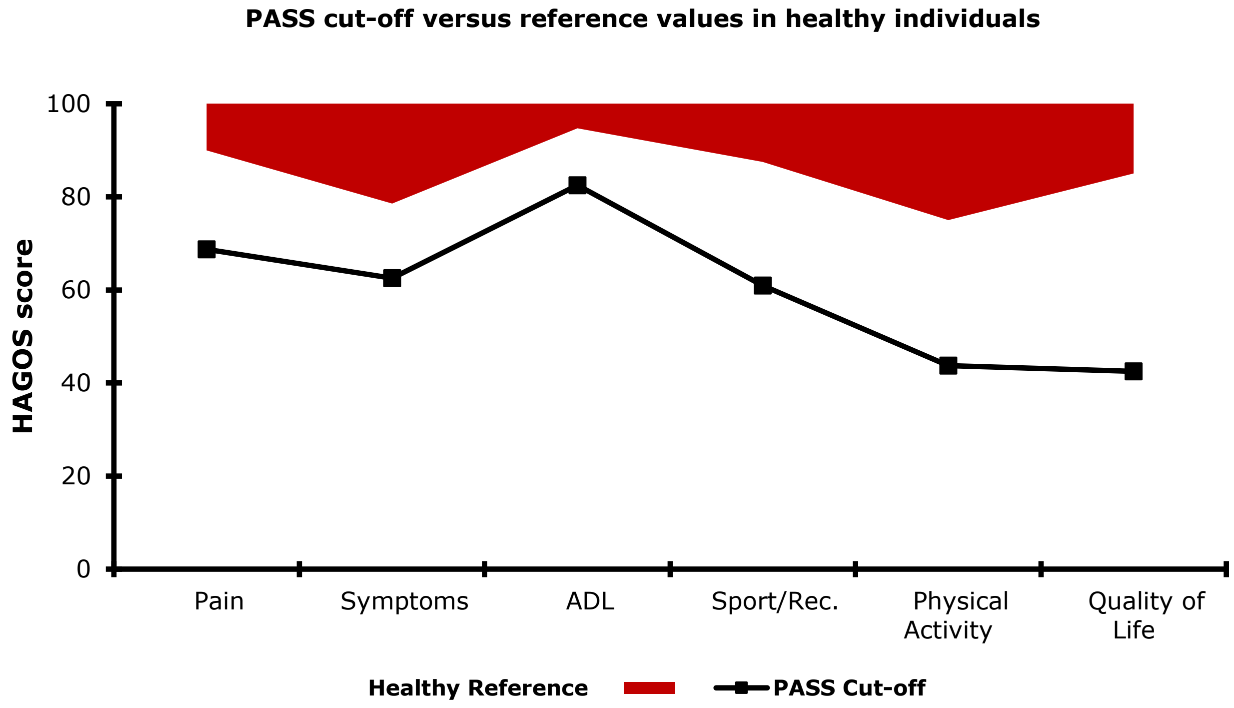

Figure 36. A comparison of Patient Acceptable Symptom State (PASS) cut-off values (black line) and reference values from hip and groin pain-free individuals (red area) for the Copenhagen Hip and Groin Outcome Score. Reference values are from Thorborg et al.,[82], while PASS cut-off values are from Ishøi et al.[190]

PASS cut-off values for iHOT-33, and the short iHOT-12 version, have previously been investigated in patients undergoing hip arthroscopy for hip-related pain, ranging ≥57-75 points,[110,241,242], which is in line with study II, where we found a PASS cut-off of ≥67 points. Similar to HAGOS, cut-off values for the iHOT-33/iHOT-12 are lower than reference values in pain-free individuals (≥90 points).[81]

Key findings

Following hip arthroscopy for femoroacetabular impingement syndrome:

- **Less than half (46 %) of patients consider their symptoms to be acceptable.**
- **Only 4 in 10 patients consider their symptoms to be acceptable in relation to sport activities – this number is higher for activities of daily living (53 %).**
- **Whether patients have acceptable symptoms or not can be accurately estimated using the Copenhagen Hip and Groin Outcome Score or the international Hip Outcome Tool-33.**

Study III: Hip arthroscopy in athletes – Is it a one-way ticket back to sport?

Study II found that only 40 % of a general hip arthroscopy population with femoroacetabular impingement syndrome reported acceptable symptoms 12-24 months after surgery.[190] Study III extends these findings by reporting on the return to sport status in a large group of young (18-30 years old) athletes.[172] For athletes, returning to sport after hip arthroscopy is often of high priority and one of the reasons to undergo surgery.[111,117,119]

We found that 57 % of athletes (108 of 189) were engaged in their preinjury sport at the preinjury level at a mean follow-up of 33 months after hip arthroscopy for femoroacetabular impingement syndrome. However, almost half (46 %) reported impaired performance, including restricted participation, whereas 29 % reported optimal performance, including full participation. For the remaining 81 athletes not engaged in their preinjury sport at the preinjury level at follow-up, persistent hip and groin pain was the main reason for being unable to return to preinjury sport at the preinjury level.[172]

When planning the thesis in 2017, the literature on return to sport after hip arthroscopy for femoroacetabular impingement showed promising results,[112] with a 2015 systematic review reporting a return to sport rate of 87 %.[112] Several additional reviews have reported similar findings in recent years.[113–115] This data has led to the general assumption that hip arthroscopy for femoroacetabular impingement syndrome secures athletes a fast [122,249] and trouble-free return to sport process.[249] Notably, the systematic reviews and associated studies mainly concern professional athletes operated by world-renowned surgeons limiting generalizability.[112–115] The return to sport definitions used were generally poorly defined and ranged from training participation to competitive match play.[112–115]

Study III questions the notion of an easy and trouble-free return to sport process and indicates that hip arthroscopy in athletes is indeed not a one-way ticket back to sport, as otherwise proposed.[249] An apparent reason for this outcome may arise from applying a clear and strict return to play-definition inspired by the 2016 *Return to Sport* consensus statement.[119] Thus, we defined return to sport as "being engaged in preinjury sport at the preinjury level in the previous three months."[172] Furthermore, we investigated associated participation and performance to provide a clear overview of the different stages of return to sport, from participation in training sessions to competing with optimal athletic performance.[119,172] Using such grading of return to sport, it becomes clear that using only return to sport as a dichotomous outcome without further exploration, as in most previous studies, tells only half the story. Thus, we show that almost half of athletes engaged in their preinjury sport at the preinjury level reported impaired performance, including restricted participation, indicating that they cannot perform in all aspects of their sport. Meanwhile, of those engaged in their preinjury sport at preinjury level, 29 % reported full participation, including optimal performance, equivalent to 17 % of the total study cohort. A Swedish study, published almost simultaneously, using a similar methodology for assessing return to sport, showed remarkably identical results,[111] with 50 % returning to preinjury sport at preinjury level, and 20 % of the total cohort returning to optimal performance.[111] In addition, The Swedish study found that return to any sport or level was achieved by 90 %,[111] whereas in study III, this result was 82 %.[172] These numbers are strikingly close to previous literature often suggesting that 85-100 % return to some form of sport,[112,113] suggesting that the return to sport is a matter of definition (**Figure 37**).[111]

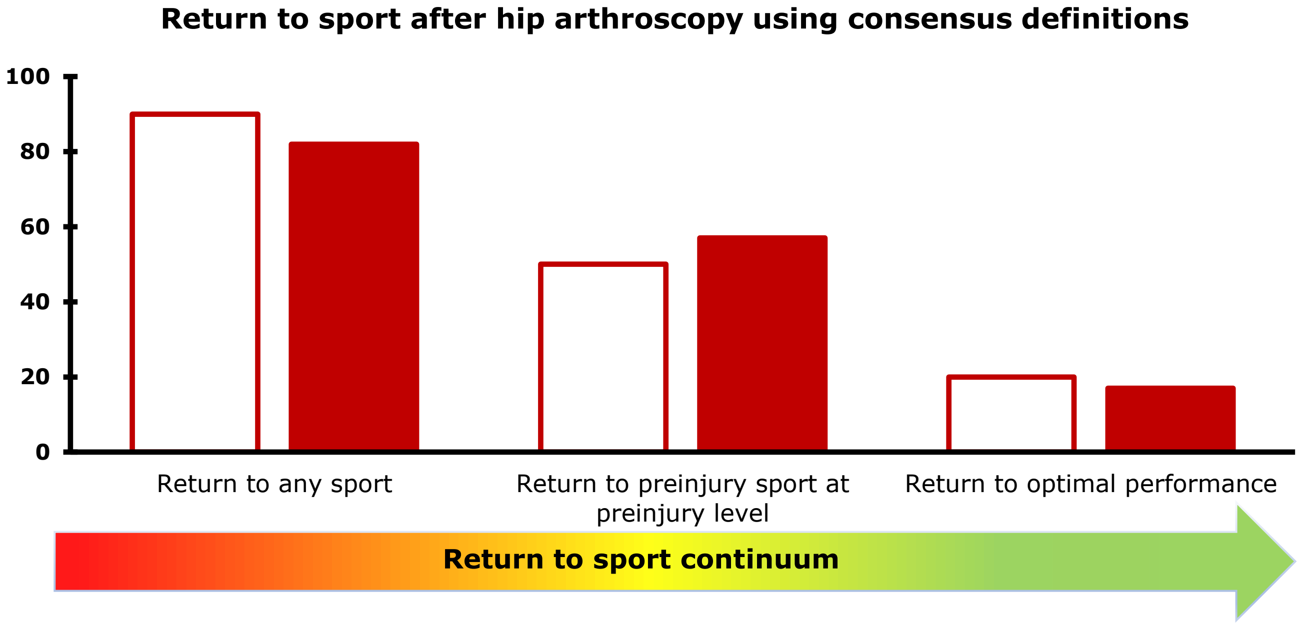

Figure 37. Overview of return to sport rates based on different definitions — data extracted from Worner et al.[111] (white bars) and Ishøi et al.[172] (red bars). The return to sport continuum is modified from Ardern et al.[119]

While study III applied a self-reported measure of sports performance and participation, attempts to quantify performance objectively have been applied in professional athletes. Based on sports-specific data on performance such as goals scored, passings completed, games played, and similar, Schallmo et al.[121] investigated return to sport and performance in 180 professional athletes from North American Baseball, Basketball, Football, and Hockey undergoing hip arthroscopy. While most athletes returned to the preinjury sport at the preinjury level (defined as being involved in at least one competitive match), substantial decrements in performance and games played were generally observed in the subsequent seasons.[121] Unfortunately, the proportion of athletes reaching their pre-injury level of performance was not reported.[121]

The main reason for not being engaged in preinjury sport at the preinjury level at follow-up, being unable to reach optimal performance, or ceasing sports participation was persistent hip and/or groin pain.[172] Although only a few studies have explored reasons for unsuccessful return to sport, this finding aligns with current literature.[250] In their meta-analysis, Weber et al.[250] found that half of the athletes unable to return to sport labelled persistent hip pain as the leading cause. At the same time, diffuse hip osteoarthritis observed during hip arthroscopy also contributed substantially.[250] It is reasonable to speculate if persistent hip pain also relate to the degenerative state of the hip joint, especially in athletes presenting with severe cam morphologies, as shown in study I.[166] In turn, this condition may reduce the hip joint load-bearing capacity, leaving athletes with less room for loading before surpassing tissue capacity and aggravating symptoms.[139,251] In line with this finding, many athletes have difficulties undertaking sporting activities such as running, explosive movements, kicking, or similar (**Figure 38**);[185,245–247] all of which are associated with substantial hip joint moments.[252–255] Since muscle forces are the primary driver of joint moments and contact forces,[138,256] we investigated maximal and explosive hip muscle strength and their associations with the return to sport in study IV.[193]

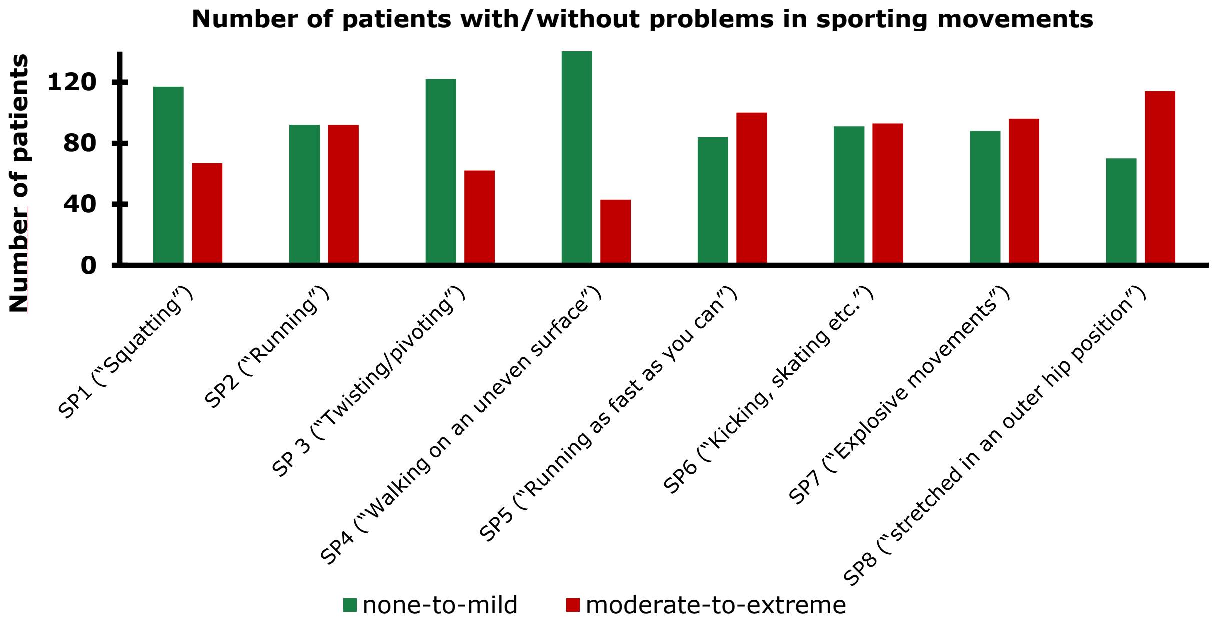

Figure 38. The number of athletes (n total = 184) with none-to-mild (green bars) vs. moderate-to-extreme (red bars) difficulties in specific sports activities derived using the items (SP1, SP2, etc.) of the Sport/recreational subscale of the Copenhagen Hip and Groin Outcome Score (HAGOS). The data is based on Ishøi et al.[185]

Weber et al.[250] also highlighted non-hip-related reasons for not returning to play, of which fear of reinjury was the most common. This finding coincides well with the recent development of a psychological readiness scale, *"Hip-Return to Sport after Injury scale (Hip-RSI),"* which has shown a strong correlation with the return to sport after hip arthroscopy for femoroacetabular impingement syndrome.[257] This emerging area emphasizes the necessity to look beyond structure-specific causes of return to sports failure after hip arthroscopy in future research.[258]

Key findings

After hip arthroscopy for femoroacetabular impingement syndrome in athletes:

- **Fifty-seven percent were engaged in their preinjury sport at preinjury level at the time of follow-up.**
- **Approximately half of the athletes engaged in their preinjury sport at preinjury level reported impaired performance and restricted participation, while 30 % had optimal performance.**
- **The results are in contrast to most previous return to sport literature on femoroacetabular impingement syndrome, which is likely due to applying clear and strict return to sport definitions in the present study.**

Study IV: Muscle strength after hip arthroscopy – how relevant is it?

In study IV, we found only limited differences in maximal and explosive hip muscle strength between the operated and non-operated hip 6-30 months after hip arthroscopy for femoroacetabular impingement syndrome.[193] The only difference was that explosive hip muscle strength was lower in the operated versus non-operated hip. Despite these findings, we observed that maximal hip extension strength of the operated hip and bilateral hip adduction squeeze strength was positively associated with sports function, the return to sport status, and no-to-minimal difficulties in sports-specific movements.[193]

Studies II and III show that several patients/athletes present with residual symptoms after hip arthroscopy;[172,190] study IV extends these findings by providing objective data of maximal and explosive hip muscle strength as potential reasons for this condition.[193] Noteworthy, despite substantial self-reported impairments, indicated by HAGOS scores and return to sport status, in study IV, only minimal muscle impairments were observed.[193] This result means that muscle strength impairments in the operated versus non-operated hip are unlikely to fully explain the self-reported deficits observed after hip arthroscopy. Nevertheless, tracking muscle strength is considered an essential parameter for guiding the progression in rehabilitation [157] and aiding the return to sport decision-making.[122] Consequently, measures of leg-to-leg difference are often used clinically and strength levels of the operated hip of >90 % compared to the healthy is proposed as a return to sport-criteria.[259] However, in study IV, most patients reached that criteria (**Figure 39**) without being able to return. In addition, post hoc analyses showed no associations between strength symmetry and self-reported hip and groin function (**Figure 40**).[193] Collectively, this questions the usefulness of leg-to-leg hip muscle strength differences for decision-making in rehabilitation and return to sports perspective.

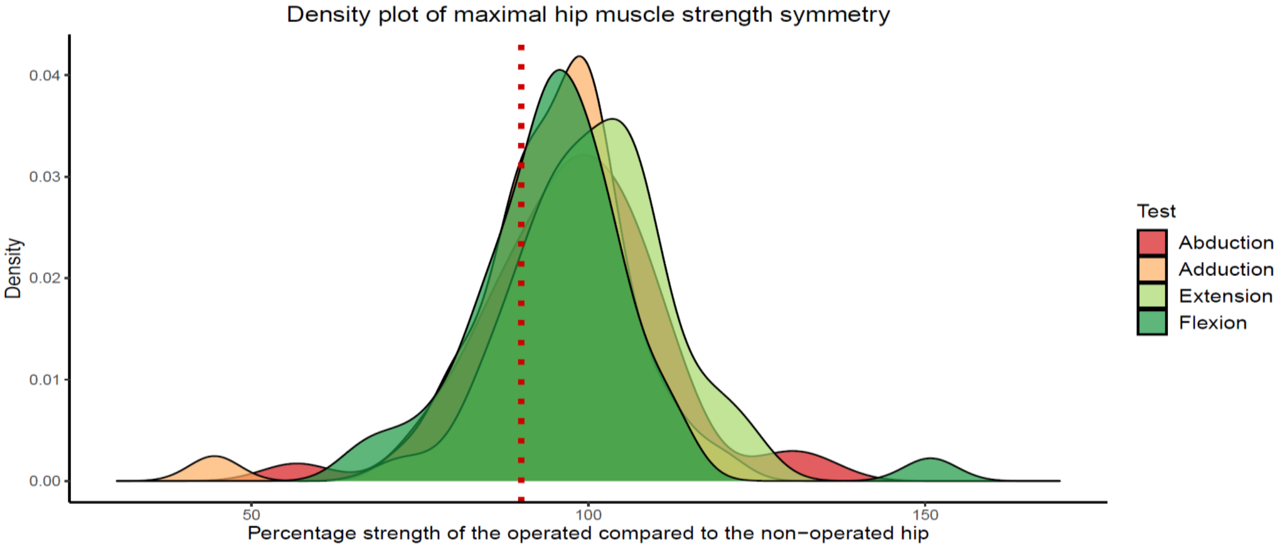

Figure 39. Density plot of maximal hip muscle strength after hip arthroscopy for femoroacetabular impingement syndrome. The vertical dotted line represents the 90 % threshold suggested as a return to sport criteria. Data is based on Ishøi et al.[193]

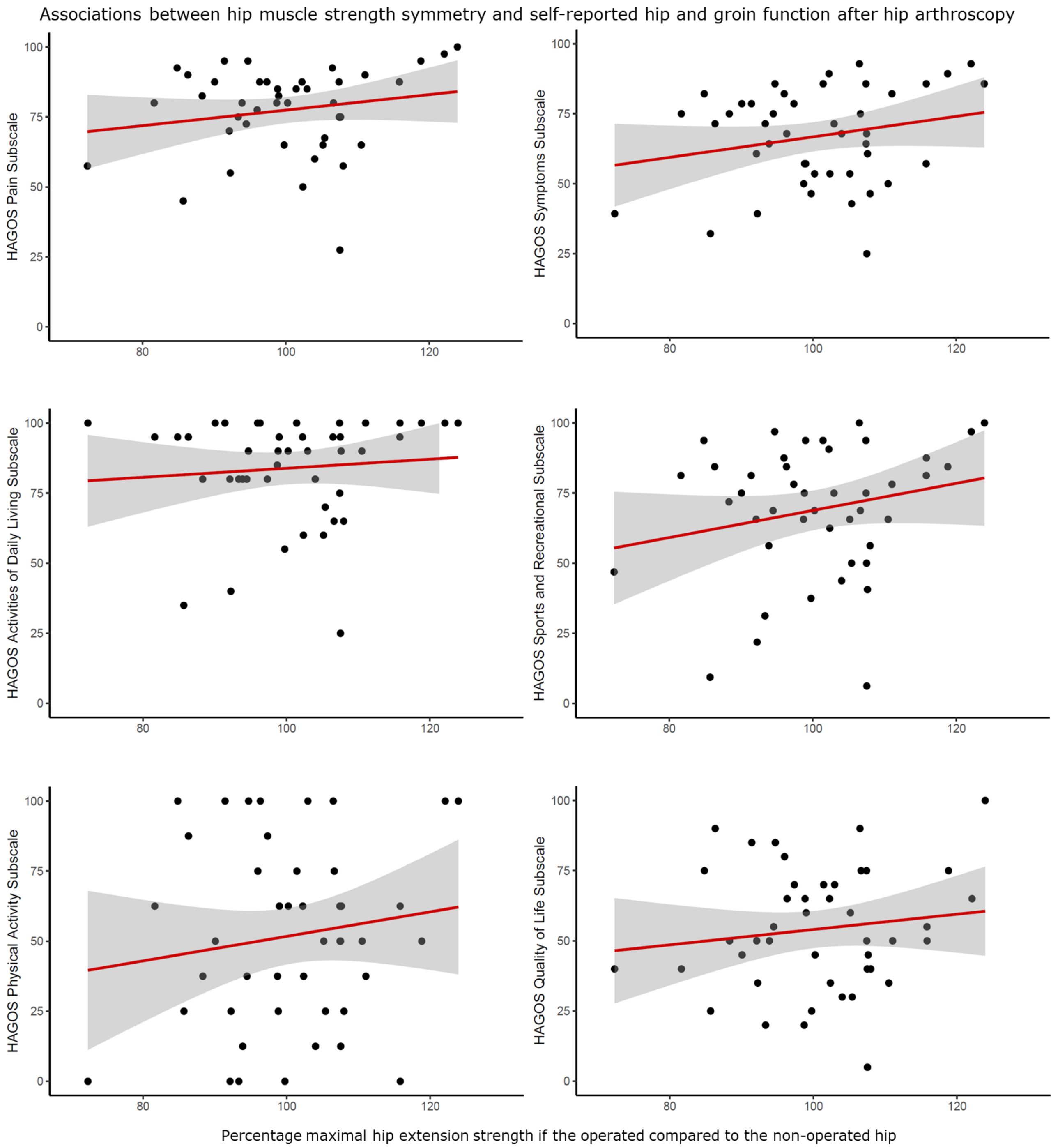

Figure 40. Associations between maximal hip extension muscle strength symmetry of the operated versus non-operated hip and self-reported hip and groin function obtained using the Copenhagen Hip and Groin Outcome Score (HAGOS) after hip arthroscopy for femoroacetabular impingement syndrome. The shaded area represents 95 % Confidence Intervals. Similar and non-significant associations were found for maximal hip adduction, abduction, and flexion strength, including early- and late-phase rate of torque development. Data is based on post hoc analyses from Ishøi et al.[193]

A Possible reason for the lack of association between relative muscle strength of the operated hip and self-reported function and return to sport status may be related to deconditioning of the non-operated hip because of the cessation of physical activity,[20,172] leaving the non-operated hip as an invalid comparator. In support of this, lower hip muscle strength of the operated hip has been observed compared to healthy controls;[134,142,260] yet recent studies suggest the differences may be small at ~10 %, questioning the clinical relevance.[134,142] It is also likely that persistent hip and groin pain plays a more critical role than reaching a strength level of >90 % compared to the healthy hip for the ability to return to sport. As discussed previously and shown in study III, persistent hip pain may be the most common reason for not returning to sport.[172,250,258]

Despite negligible differences in hip muscle strength between the operated and non-operated hip, we found hip extension strength of the operated hip and hip adduction squeeze strength to be positively associated with sports function, including the return to sport status, and no-to-minimal difficulties in sports-specific movements.[193] This suggests that absolute rather than relative hip muscle strength may be critical for sports function following hip arthroscopy. Functional impairments, such as lower hip muscle strength, have been linked to lower self-reported hip function after surgery.[134,261] However, when planning this thesis, this association had only been established in a mixed cohort of patients diagnosed with various causes of hip-related pain.[261] In that study, Kemp et al.[261] showed positive associations between iHOT-33 and hip strength in all directions 12-24 months after hip arthroscopy for chondropathy; however, only hip adduction strength was retained in the multivariable regression model. A more recent study found hip extension strength associated with better self-reported hip and groin function at 1-year after hip arthroscopy for femoroacetabular impingement syndrome; however, these associations were unadjusted for potential confounding variables.[134] The slight discrepancy in associations between studies and the notion that Kemp et al.[261] found strength in all hip directions associated with self-reported hip function in univariable analyses, coupled with study IV, where we excluded strength variables because of multicollinearity,[193] may point toward a general role of hip strength rather than being direction specific.

The positive associations between hip muscle strength with self-reported hip and groin function, return to sport status, and no-to-minimal difficulties in sports-specific movements may be explained by muscles' potential to attenuate joint contact forces, thus, protecting the joint.[262–264] The classic simulation study by Lewis et al.[262] in 2007 set the scene for the implications of optimal muscle function as a potential factor for attenuating hip joint contact forces. During musculoskeletal simulation of prone hip extension and supine hip flexion with different levels of iliopsoas and gluteus maximal muscle force, Lewis et al.[262] reported gradually increasing anterior hip joint contact forces during trials with low iliopsoas and gluteus maximus muscle force. Likewise, simulated hip extension weakness is associated with higher anterior hip joint forces during bodyweight squatting.[264] While these results are intriguing and provide some evidence for the role of muscle force production in protecting the hip joint against excessive contact forces, both simulation studies are limited by only evaluating low-load activities in healthy individuals.[262,264] Thus, extrapolation to more demanding and dynamic activities, such as running, and to patients with femoroacetabular impingement syndrome may be limited.

An alternative, and more valid explanation for the positive associations observed in study IV, is based on the contribution of muscle force production as an essential driver of increasing joint contact forces.[138,256,265] This may suggest that the ability to produce high muscle force equals successful handling of high joint contact forces without experiencing pain.[265] Thus, high hip muscle strength may be a surrogate for having an adequate load-bearing capacity of the hip joint to cope with sporting activities. While load-bearing capacity after hip arthroscopy remains to be elucidated, the ability to cope with high loading demands may indeed be limited because of substantial reductions in compressive stiffness of the acetabular cartilage shown in patients undergoing surgery for cam morphology.[266] Furthermore, patients with femoroacetabular impingement syndrome or hip osteoarthritis seem to undertake different strategies to offload the hip joint as a protective mechanism, which seem more pronounced as the loading demands increase.[140,141,265]

Hip flexion early- and late-phase rate of torque development was lower in the operated versus non-operated hips.[193] Study IV is the first to report on explosive strength after hip arthroscopy for femoroacetabular impingement syndrome limiting the comparison to previous studies. However, Kierkegaard et al.[123] reported lower hip flexion and extension rate of torque development in patients scheduled for surgery compared to healthy controls. In study IV, measures of explosive hip strength were conducted to provide additional insights into muscle function beyond maximal strength. In this regard, the rate of torque development is generally stronger associated with sports performance [145,151] which often is impaired in patients with femoroacetabular impingement syndrome.[172,185] However, in the regression models, the rate of torque development was not associated with return to sport or the ability to perform sports-specific activities with no-to-minimal symptoms. Thus, the clinical implications for specifically targeting hip flexion rate of torque development during post-operative rehabilitation are unknown. It may simply be that the lower explosive hip flexion strength reflects persistent hip pain in a direction often associated with evoked pain in this population, refraining patients from contracting the hip flexors rapidly.[129,267]

Because of the proposed importance of restoring the load-bearing capacity of the hip joint and improving hip muscle strength,[134,193] post-operative rehabilitation is considered a cornerstone in the treatment process,[122] although evidence for its effectiveness remains low quality.[22] Nonetheless, rehabilitation parameters such as frequency and length of the sessions, including perceived importance of the home program, have been associated with better self-reported hip function after hip arthroscopy for femoroacetabular impingement syndrome.[268] Strikingly, in study IV, only nine patients (20 %) felt no further need for rehabilitation, while the remaining felt some (n=27, 60 %) or much (n=9, 20 %) further need.[193] Interestingly, this grouping trended towards a dose-response association with muscle strength of the operated hip (post hoc analyses), supporting the role of high-quality rehabilitation after hip arthroscopy (**Figure 41**).

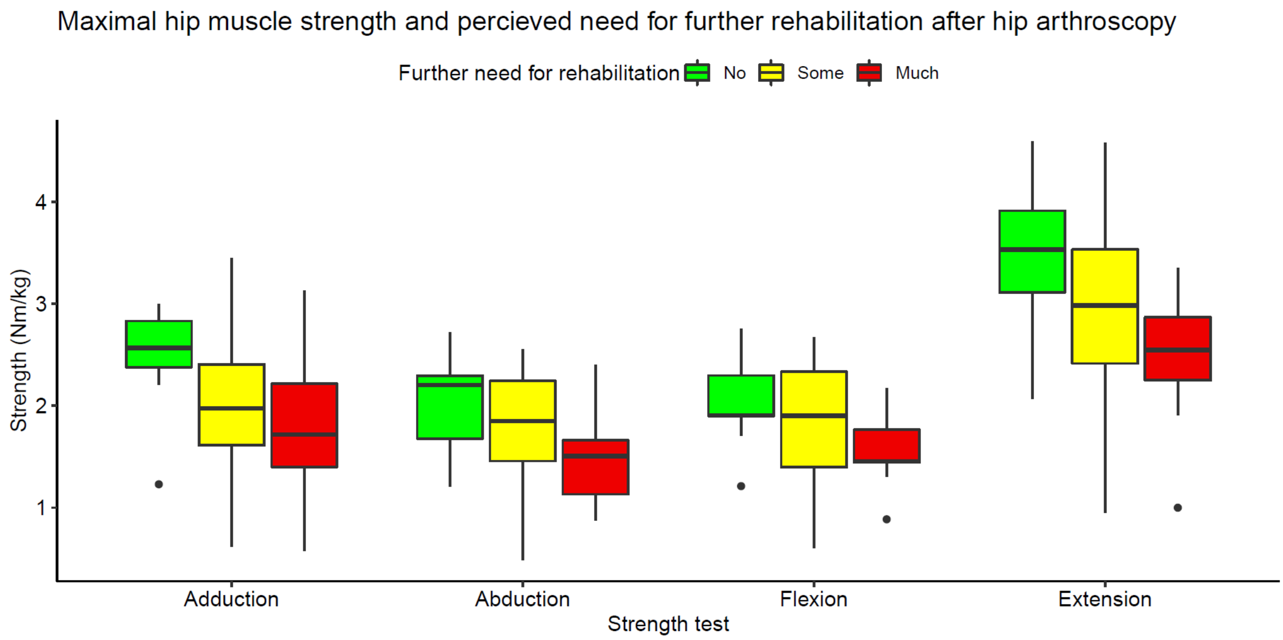

Figure 41. Maximal isometric hip muscle strength 6-30 months after hip arthroscopy for femoroacetabular impingement syndrome in patients who perceived no (green), some (yellow), and much (red) need for further rehabilitation. Data is based on post hoc analysis from Ishøi et al.[193]

Key findings

After hip arthroscopy for femoroacetabular impingement syndrome:

- **Minimal differences in maximal and explosive hip muscle strength exist between the operated and non-operated hips.**
- **Early and late-phase hip flexion rate of torque development is ~10 % lower in the operated versus the non-operated hip.**
- **Maximal hip extension strength of the operated hip and bilateral hip adduction squeeze strength is positively associated with sports function, return to sport status, and no-to-minimal difficulties in sports-specific movements.**

Study V: Rockin' the boat - Picking winners or identifying losers in hip arthroscopy

In study V, we found that 26 common clinical variables, including demographics, radiographic parameters of hip morphology, and self-reported measures, were able to estimate the probability of patients with an unsuccessful outcome (one-year mean HAGOS Subscales scores ranging 13-43 points). This result was achieved with acceptable discrimination and adequate calibration. However, calibration was imprecise towards higher predicted probability because of a few events.

Study V extends on the existing literature regarding prediction modelling for hip arthroscopy. Although several models have been published, these are associated with critical methodological shortcomings, resulting in too optimistic and unstable predictive performance (**Table 34**).[98–104,269]

Table 34. Overview of studies that have developed multivariable models for prediction of outcomes in patients with hip-related pain undergoing hip arthroscopy.

Study	Aim	Material	Outcomes	Validation method	Predictive performance
Stephan et al. 2018 [100]	Development and internal validation of multivariable model to predict 1-year outcome after hip arthroscopy using demographic, radiographic, and PROMs as predictors.	203 patients undergoing hip arthroscopy for hip-related pain (cam and/or pincer morphology or suspicion of labral tear).	Improvement of >23 points from before to 1-year after surgery or a 1-year score of >80 at HOS-ADL (n=133).	Internal validation using 500 bootstrapping procedures.	AUC of 0.71 (fair discrimination) and calibration visualized with plot (Hosmer-Lemeshow goodness-of-fit test, p=0.48).
Nwachukwu et al. 2020 [99]	Development and internal validation of multivariable model to predict 2-year outcome after hip arthroscopy using demographic, radiographic, and PROMs as predictors.	368-388 patients undergoing hip arthroscopy for FAI syndrome.	Three separate models with improvement of >9.8, >14.4, and >9.1 points from before to 2-years after at HOS-ADL, HOS-SSS, and mHHS, respectively.	Internal validation using ten-fold cross validation using a random data-split (90:10).	Mean AUC of cross-validation of 0.78 (acceptable discrimination), 0.72 (acceptable discrimination), and 0.66 (poor discrimination). No measure of calibration.
Ramkumar et al. 2020 [269]	Development of a multivariable model to predict 1- and 2-year outcome after hip arthroscopy using demographic and radiographic predictors.	665-1266 patients undergoing hip arthroscopy for FAI syndrome.	Eight separate models with improvement of >9.1, >9.8, >14.4, and 14.6 points from before to 1- and of 2-year at mHHS, HOS-ADL, HOS-SSS, and iHOT-33, respectively.	No methods of internal validation described.	AUC ranging between 0.49-0.56 (poor discrimination) for all eight models. No measure of calibration
Kunze et al. 2021 [102]	Development and internal validation of multivariable model to predict 2-year outcome after hip arthroscopy using demographic, radiographic, and PROMs as predictors.	818 patients undergoing hip arthroscopy for hip-related pain (cam and/or pincer morphology and labral tear).	Improvement of >9.8 points from before to a minimum of 2-years after at HOS-ADL (n=608).	Internal validation using random data-split (80:20) into training set (n=655) and testing set (n=163). Ten-fold cross-validation on training set.	AUC of 0.84 (excellent discrimination) and calibration visualized with plot (intercept: 0.2 indicating underestimation and slope: 0.83 indicating too extreme risk estimations).
Hevesi et al. 2021 [98]	External validation of multivariable model to predict conversion to hip arthroplasty at a minimum of 2-years after hip arthroscopy using an existing model with demographic, radiographic, PROMs, and surgical findings as predictors.	187 patients undergoing primary (n=178) and revision (n=9) hip arthroscopy for hip-related pain (symptomatic labral tear).	Conversion to hip arthroplasty at a minimum of 2-years after hip arthroscopy (n=13).	External validation using an external dataset.	AUC of 0.89 (excellent discrimination) and calibration measured as Brier score (0.04).

Table continues on next page

Kunze et al. 2021 [103]	Development and internal validation of multivariable model to predict 2-year satisfaction after hip arthroscopy using demographic, radiographic, and PROMs as predictors.	935 patients undergoing hip arthroscopy for FAI syndrome.	Satisfaction at 2-years after hip arthroscopy defined as a Visual analog scale (VAS) satisfaction score of 52.8.	Internal validation using five different machine learning strategies with random data-split (80:20) into training set (n=749) and testing set (n=186). Ten-fold cross-validation on training set.	AUC of 0.84-0.94 (excellent discrimination) and calibration visualized with plot (intercept: -0.67-0.12 indicating underestimation and slope: 0.73-1.86 indicating too extreme risk estimations).
Kunze et al. 2021 [101]	Development and internal validation of multivariable model to predict 2-year sports function after hip arthroscopy using demographic, radiographic, and PROMs as predictors.	1118 athletes (recreational to professional level) undergoing hip arthroscopy for FAI syndrome.	Improvement of >14.4 points from before to a minimum of 2-years after at HOS-SSS (n=860).	Internal validation using six different machine learning strategies with random data-split (80:20) into training set (n=895) and testing set (n=223). Ten-fold cross-validation on training set.	AUC of 0.70-0.77 (acceptable discrimination) and calibration visualized with plot (intercept: -0.01-0.82 and slope: 0.74-1.25 indicating too extreme risk estimations for some models).
Haeberle et al. 2021 [104]	Development of multivariable model to predict subsequent hip surgery after hip arthroscopy using demographic, radiographic, and PROMs as predictors.	3147 patients undergoing hip arthroscopy for hip-related pain (cam and/or pincer morphology and labral tear).	Subsequent hip surgery; revision hip arthroscopy (n=104), total hip arthroplasty (n=43), hip resurfacing arthroplasty (n=27), periacetabular osteotomy (n=8)	Internal validation using using a random data-split (90:10).	AUC of 0.62-0.80 (poor to good discrimination). No measure of calibration

AUC: Area under the Receiver Operating Characteristics (ROC) curve, defined as the probability that a random patient with the target condition has a higher estimated risk/probability than a random patient without the target condition [188]. HOS-ADL: Hip Outcome Score – Activity and Daily Living subscale; HOS-SSS: Hip Outcome Score – Sports Specific Subscale; mHHS: modified Harris Hip Score; iHOT-33: International Hip Outcome Tool-33.

First, only one of eight existing prediction models has been attempted externally validated;[98] however, this was only based on 13 patients with the outcome of interest (a minimum of 100 events are recommended for external validation).[196,197] Since prediction models show the best performance on the development sample, external validation is needed to adjust optimism and improve the application to future patients.[95] In study V, this is illustrated by c-statistics for all models being lower in the validation sample than the development sample (predictive performance in the test sample can be found in **Appendix 4)**. Another significant limitation in previous studies is the lack of sample size consideration, resulting in events per predictor ranging from 3-8.[99–103] While this may not seem very different from study V (events per predictor for the primary outcome: 11-13), most published prediction models have been developed using machine learning strategies.[99,101–103] Importantly, such require >200 events per predictor before low optimism and stable performance measures are reached.[270] Thus, the existing prediction models for hip arthroscopy patients are associated with a high risk of overfitting and potentially unreliable predictions when applied to future patients.[181]

Although further external validation is needed to improve the precision of our prediction model, the results may have significant clinical implications. Considering the results from studies II and III, up to 50 % of patients have unacceptable symptoms at 1-2-year follow-up [190] or cannot return to their preferred sports activities because of persistent hip and groin pain.[172] While these results have several nuances, they also highlight the clinical relevance of identifying patients for whom surgery may not be beneficial. In line with this, failure to achieve PASS based on the iHOT-12 score increases the likelihood of revision hip arthroscopy,[110] and revision surgery only seems to get patients marginally better than before the initial surgery.[87]

By identifying patients for whom surgery may not be beneficial, the proportion of patients with residual symptoms may decrease, and the overall outcome of hip arthroscopy improves. Thus, the prediction model is an initial step towards stratified care for patients with hip joint-related pain;[86] however, the model's effectiveness needs further testing in a randomized controlled trial before stratified care can be recommended (Step 4 of the PROGRESS Framework).[86] Since the prediction models were derived from hip arthroscopy data only, it would not be appropriate to use the models for stratifying patients between operative or non-operative treatment. Even in the case of an estimated very low probability of an unsuccessful outcome, suggesting the patient would be a good candidate for surgery, it is essential to note that this does not exclude that the patient could do equally well or better following non-operative treatment. Thus, some of the predictors in study V may represent general predictors independent of the specific treatment applied rather than moderating the effect of a specific treatment; for example, more severe cam morphology increases the probability of an unsuccessful outcome after both surgery (study V) and exercise-based treatment.[88] Therefore, treatment is best based on a stepped-care approach until stratified care is recommended. The least invasive approach, that is, targeted physiotherapist-led rehabilitation, should be offered as the initial treatment.[14] While the evidence for physiotherapist-led treatment is currently low,[22] some patients seem to respond well.[88] This notion has led to the recommendation of at least three months of supervised physiotherapist-led treatment [14] since this may lead to better outcomes compared to shorter interventions.[271] This recommendation should also be seen in the context that physiotherapist-led treatment is more cost-effective than hip arthroscopy and carries a lower risk of adverse effects.[29] Furthermore, the cartilage quality determined using advanced MRI does not seem to deteriorate after physiotherapist-led treatment at 1-year follow-up.[75] Thus, joint degeneration may not in all cases be accelerated by undergoing structured physiotherapist-led rehabilitation before considering hip arthroscopy.

The prediction model can support clinical evaluation and shared decision-making by informing the orthopaedic surgeon and patient about the risk of an unsuccessful outcome. In practice, the probability is derived using the prediction formula (provided online: https://bit.ly/3avOcjJ), which combines the odds ratios for all 26 predictors into a single probability from 0 to 100 %. This means that although statistically significant, single predictors should not be used in isolation for prediction, as the prediction model's performance relies on all predictors regardless of p-values for individual predictors. Furthermore, since the prediction model is developed and validated on patients who underwent surgery, the prediction model is best used once the orthopaedic surgeon has decided on surgery. In such instances, the model can be used as a data-driven "second opinion" to estimate the risk of an unsuccessful outcome and indicate if surgery is still beneficial or not. In clinical practice, the prediction model is suited to be used in the final stages of a stepped-care approach,[85] starting with targeted exercise-based treatment and followed by potential surgery if symptoms have not resolved (**Figure 42**).[1,14]

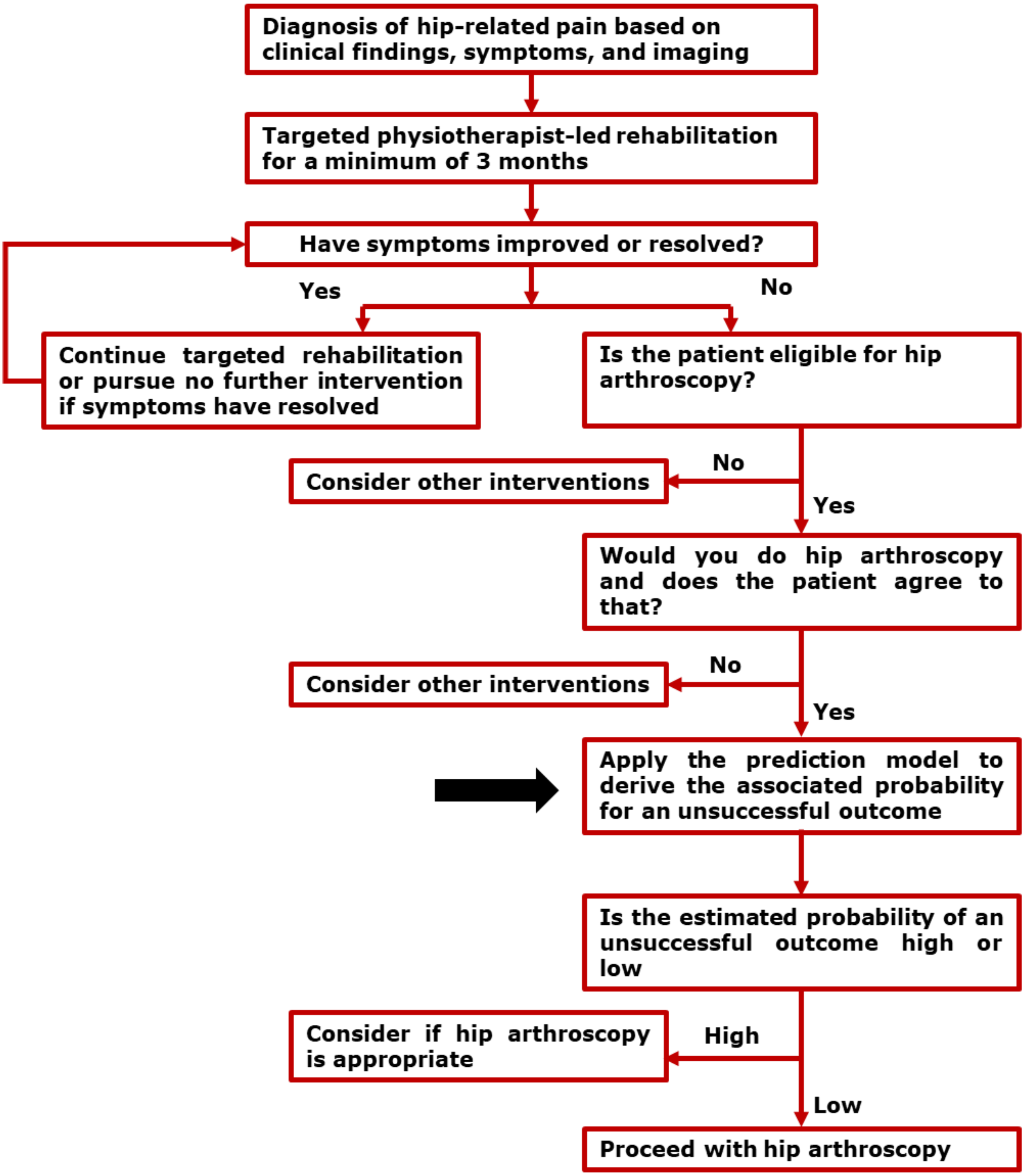

Figure 42. Proposed stepped-care model for treatment of hip-related pain based on best current evidence. The prediction model from study V is best used after the decision for hip arthroscopy has been taken (Black arrow) to reflect the setting in which the model was developed.

Suppose the prediction model is used for dichotomous decisions in clinical practice (surgery versus no surgery); In that case, the predicted probability should be combined with the sensitivity and specificity measures presented in **Appendix 3.** This allows the false positive and negative rates of the specific probability threshold for misclassification of patients to be considered part of the probability estimation.

Key findings

By using the PROGRESS framework, we:

- **Developed a clinical prediction model for predicting unsuccessful outcomes after hip arthroscopy based on 26 common clinical variables.**
- **External temporal validation showed adequate calibration and discrimination for estimating the probability of an unsuccessful outcome.**
- **The model may be used as a supplementary tool in the shared decision-making process, to help identify those patients for whom surgery may not be beneficial.**

Methodological considerations

Some inherent limitations of this thesis must be acknowledged. First, in studies I-IV, we adopted a cross-sectional study design, and thus we cannot conclude on causations. This fact is particularly relevant for studies I and IV, where we applied regression analyses to explore the relationship between variables.[166,193] For studies II and III, the cross-sectional study design may have led to over- or underestimating the actual proportions of patients having an acceptable symptom state (study II) [190] or being engaged in pre-injury sport (study III) [172] because of examining only a single time point. Second, since patient data were retrieved from the Danish Hip Arthroscopy Registry, we relied on data collected from several institutions across Denmark.[154] While hip arthroscopy is a relatively small field in Denmark and general uniformity exists between surgeons, we cannot exclude that minor differences in surgical indications and measurements of hip joint morphology exist, affecting eligible patients. This point could especially have affected the findings of studies I and V that relied solely on registry data.[166] Finally, in studies II-IV, we invited participants to respond to an email invitation and, thus, we cannot exclude selection bias. However, in all studies, the response rate was above 50 %.[172,190,193]

In study I, we categorized morphology into distinct groups rather than using the continuous measure of Alpha and Lateral Center Edge Angles.[166] Although categorization of continuous measures is not recommended for prediction research because of the loss of statistical power,[95] we chose this approach as we were interested in the association between hip joint morphology and cartilage injury using consensus-based and data-driven cut-off values.[1,62]

The positive association between the severity of cam morphology and higher risk of cartilage injuries may be confounded by rigorous sports participation. A higher risk of osteoarthritis has been reported in previous elite sports athletes;[272] a cohort where cam morphology is also highly prevalent.[50] Therefore, we cannot exclude that the association between hip joint morphology and cartilage injuries may be driven by sports participation rather than hip morphology *per se*.[166] Indeed, a recent study showed cartilage quality to be negatively affected by rigorous sports activity during adolescence, however, this effect seemed to diminish in skeletally mature athletes.[273]

In study II, we asked patients to consider if their current health status was acceptable if it remained like that for the rest of their life.[190] Several PASS questions exist in the literature, with no consensus on the best approach.[107] While no previous study investigating PASS after hip arthroscopy has included a specific time frame (i.e., "*the rest of your life*"), we chose this approach since symptoms are unlikely to change much beyond one year after hip arthroscopy (Thorborg et al. unpublished). However, we acknowledge that this may cause patients to be more reluctant to state "yes" than if the PASS question did not include this specific instruction.

In study III, return to sport, and associated performance was assessed as self-reported.[172] While this is often the procedure unless objective data is available in rare circumstances,[116] we acknowledge this may introduce recall bias, related explicitly to the pre-injury level of sport and performance. To minimize the risk, we clearly stated the different definitions of level and performance in the questionnaire and pilot tested this prior to study initiation. In addition, we acknowledge that the questionnaire has not been validated but was developed based on consensus recommendations.[119] However, HAGOS scores showed a dose-response association with the different levels of return sport and performance, suggesting some form of construct validity.[172]

In study IV, we did not include a healthy hip and groin pain-free control group for reference values of strength and rate of torque development.[193] By not doing so, we may have missed minor strength deficits.[134,142]

In study V, we defined a successful and unsuccessful outcome based on PASS cut-off values for HAGOS. We acknowledge that our definition may have underestimated the proportion of patients with PASS, compared to a single question approach (31 % in study V versus 47 % in study II).[190] However, we chose these definitions to minimize the risk of categorizing patients in the wrong group improving clinical applicability. Thus, we believe that patients who have exceeded the cut-off scores of all HAGOS subscales at one-year follow-up are likely to represent a subgroup of patients that feel very well after surgery (a successful outcome) and vice-versa for patients who do not surpass a single subscale score (an unsuccessful outcome).[109] In addition, since the prediction models were developed based on the Danish Hip Arthroscopy Registry data,[154] we cannot exclude that additional variables may improve the predictive performance.

CHAPTER 5:

CONCLUSIONS AND PERSPECTIVES

Conclusions

Five studies were included in the thesis. In study I, we showed that, in a large group of patients undergoing hip arthroscopy, specific hip joint morphology was associated with distinct hip cartilage injuries. Specifically, we showed a dose-response association between severity of cam morphology with moderate to severe acetabular cartilage injuries, with an alpha angle >55° and >78° increasing the risk by 2.23 and 4.82 times, respectively, compared to an alpha angle <55°. Contrary, acetabular borderline dysplasia (Lateral Center Edge Angle <25°) increased the risk of moderate-to-severe femoral head cartilage injuries by 3.08 times.

In study II, we found that approximately 50 % of patients rated their symptoms as acceptable (PASS) 12-24 months following hip arthroscopy when considering activities of daily living and participation in social and sports activities. In addition, when considering only activities of daily living and sports activities in isolation, the proportions were 53 % and 40 % of patients, respectively. Lastly, we identified cut-off values for having acceptable symptoms for the only two recommended patient-reported outcome measures (HAGOS and iHOT-33) in young to middle-aged individuals with hip-related pain. These ranged from 42.5 (HAGOS QOL subscale) to 82.5 (HAGOS ADL subscale), whereas the iHOT-33 cut-off score was 67. The cut-off values showed excellent discriminative performance with Area Under the ROC curve >0.84, and can be used retrospectively to estimate the proportion of patients with acceptable symptoms.

In study III, we found that approximately 57 % of athletes (108 of 189) were engaged in their preinjury sport at the preinjury level at a mean follow-up of 33 months after hip arthroscopy for femoroacetabular impingement syndrome. However, almost half (46 %) reported impaired performance, including restricted participation, whereas 29 % reported optimal performance, including full participation. For the remaining 81 athletes not engaged in their preinjury sport at the preinjury level at follow-up, persistent hip and groin pain was the main reason for being unable to return to preinjury sport at the preinjury level. The results provide a new perspective on return to sport rates after hip arthroscopy using a return to sport continuum and strict and precise definitions of return to sport.

In study IV, we observed that, despite markedly reduced self-reported hip and groin function, only minor differences in maximal and explosive hip muscle strength between the operated and non-operated hip exist 6-30 months after hip arthroscopy for femoroacetabular impingement syndrome. The only difference was explosive hip muscle strength being ~10 % lower in the operated versus non-operated hip. Despite these findings, maximal hip extension strength of the operated hip and bilateral hip adduction squeeze strength was positively associated with sports function, the return to sport status, and no-to-minimal difficulties in sports-specific movements. These associations highlight that absolute rather than relative hip muscle strength may be relevant for post-operative function and pain.

In study V, we showed that common clinical variables, including demographics, radiographic parameters of hip morphology, and self-reported measures, could predict the probability of having an unsuccessful outcome 1-year after hip arthroscopy. The externally temporal validated prediction model can be used to support clinical evaluation and shared decision making by informing the orthopaedic surgeon and patient about the risk of an unsuccessful outcome, and thus when surgery may not be beneficial. This information may reduce unsuccessful outcomes and could therefore improve the overall outcome of hip arthroscopy in the future.

Perspectives

Since the early 2000s, our knowledge of femoroacetabular impingement syndrome has expanded rapidly.[31] In line with a gradually improved understanding of the presumed cause of pain being linked to cam and pincer morphology,[1] there has been an explosion in the number of hip arthroscopies performed globally.[199] It is well established that hip arthroscopy is associated with improvements in pain and function,[22] yet many patients are still not satisfied with the outcome.[190] This fact calls for action.

In this thesis, we first provided an overview of the role of bony hip morphology for cartilage injuries.[166] We show that the severity of cam morphology in young and middle-aged individuals is related to the risk of moderate to severe cartilage injuries in a dose-response manner.[166] This association strengthens the hypothesis of mechanical impingement [12] and further highlights that the degeneration of the hip joint, even from an early age, may be the underlying cause of pain and problems. Since the development of cam morphology seems to follow a normal physiological adaptation to loading,[38] associated cartilage injuries may be an inevitable part of sports participation.[274] There is, however, currently ongoing research aiming to understand if factors, such as hip muscle strength and hip kinetics and kinematics, can change the course of cartilage degeneration in the presence of cam morphology.[275] In addition, large prospective cohort studies may investigate why only some patients/athletes with cam morphology and associated cartilage injuries develop symptoms. The onset of hip and groin pain in the presence of cam morphology and cartilage injuries likely occur due to a complex interaction of physiological, biological and psychological factors, however, improved knowledge in this space may help guide potential prevention and treatment stretegies.

Preventive hip arthroscopy (surgery in patients with no symptoms) is generally not recommended,[1] however, in young patients with a large cam morphology, very early intervention may be crucial to avoid excessive degeneration of the joint.[204] Nevertheless, there is insufficient data to suggest at what age and at what rate cartilage starts to deteriorate because of cam morphology.[273] Thus, prospective cohort studies may investigate this using advanced imaging modalities to track cartilage health from adolescence to adulthood,[273] thereby providing valuable knowledge on the etiology and impact of cartilage degeneration. In middle-aged individuals, where cartilage degeneration has already begun, long-term follow-up studies of cartilage injury progression after hip arthroscopy and non-operative treatment are needed. Luckily, such studies are already ongoing and will help understand if either treatment approach reverses, slows down, or accelerates joint degeneration, and thus if treatment prevents hip osteoarthritis.[29,75]

In this thesis, we also provided a detailed overview of outcomes after hip arthroscopy,[172,190,193] which can be used in clinical practice to guide decision-making and inform the patient about the most realistic scenario if they decide to undergo surgery. A detailed outcome overview seems to be a necessary next step in hip arthroscopy research, considering that many patients are still overly optimistic about the treatment.[118] We now have level one evidence that patients undergoing hip arthroscopy improve more than patients undergoing non-operative treatment, but we need to look beyond improvements.[22] Patients care more about whether they feel well after treatment, not how much they have improved.[109] Future studies may investigate in more detail which activities or situations patients value the most concerning their painful hip joint. Such information will help to understand what matters the most for patients. In study II, we showed that approximately 50 % considered their symptoms unacceptable. While this is highly relevant information, the Patient Acceptable Symptom State asks the patient to consider many different aspects of their life, and thus,[107] it would be beneficial to study the underpinning reasons for responding "*yes*" or "*no*" to the question. Having such detailed information may strengthen the decision-making prior to surgery by better understanding if the patient's main/most crucial problem/concern is likely to be resolved by the surgical procedure.

Post-operative rehabilitation is an integral part of hip arthroscopy in patients with femoroacetabular impingement syndrome,[14] yet the evidence for its effectiveness remains low.[22] Rehabilitation aims to restore potential physical impairments, and the inability to do so may drive persistent hip and groin pain.[14] Although study IV found an association between hip extension strength of the operated hip and sports function and return to sport status,[193] the causality remains unknown due to the cross-sectional study design. Future prospective studies investigating if changes in hip muscle strength and function mediate changes in self-reported outcomes after hip arthroscopy would provide valuable insights on the importance of addressing and restoring physical impairments during rehabilitation.

Prognostic research - the study of the risk of future health outcomes - is an integral part of the current healthcare system,[90] aiming at developing prediction models to aid clinical decision-making,[91] ultimately resulting in stratified care [86] and better outcomes for patients.[90] In study V, we developed and externally temporal validated a prediction model to identify patients at risk of an unsuccessful outcome, thereby providing a foundation for stratified care for patients with hip-related pain.[86] We are currently working on further external validation studies to facilitate effective implementation in clinical practice. An avenue of relevant research is further to understand which patients respond to non-operative treatment and if specific patient characteristics moderate the effectiveness (are causal) of either non-operative or operative treatment.[86] In such cases, these can be targeted prior to treatment to enhance the treatment response further.[92] For example, hip extension strength prior to hip arthroscopy has been associated with 6-month outcomes.[276]

SUMMARY

Introduction

Hip-related pain is a leading burden of disability globally. Femoroacetabular impingement syndrome is a cause of hip-related pain typically diagnosed in young to middle-aged physically active individuals. It is caused by altered hip joint morphology (i.e., the shape of the bones), which, in the middle-aged to elderly, has been linked to the development of osteoarthritis. Femoroacetabular impingement syndrome is often treated surgically using an arthroscopic procedure. While hip arthroscopy effectively alleviates pain and improves function, less is known about how patients consider their function after surgery and whether factors before surgery can help predict the outcome. In this thesis, you will find five papers with the overarching aim of investigating 1) the influence of hip joint morphology as a precursor for early osteoarthritis, 2) subjective and objective outcomes after hip arthroscopy for femoroacetabular impingement syndrome, and 3) if factors before surgery can help predict how patients end up after surgery.

Methods

We first investigated the associations between different characteristics of hip joint morphology with surgically defined hip cartilage injuries using data from the Danish Hip Arthroscopy Registry (Paper I). Second, we surveyed patients who had undergone hip arthroscopy for femoroacetabular impingement syndrome with regards to their current symptoms and sports function by asking whether they considered their symptoms as acceptable (141 patients, Paper II) and whether they were able to engage in their pre-injury sport (189 patients, Paper III). Subsequently, we measured objective function – hip muscle strength and jump performance – in 45 patients who had undergone hip arthroscopy for femoroacetabular impingement syndrome (Paper IV). Finally, we developed and externally temporal validated clinical prediction models to predict a successful or unsuccessful outcome after hip arthroscopy using data from the Danish Hip Arthroscopy Registry (1546 patients, Paper V).

Results

Specific hip joint morphologies were associated with distinct cartilage injury patterns. More severe morphology was associated with a higher risk (4-fold) of severe cartilage injuries. A little more than half of the patients rated their symptoms as unacceptable 1-2 years after hip arthroscopy, while 57 % were engaged in their previous sport activities, yet only 17 % had a performance level comparable to before the onset of hip and groin pain. No differences were found in maximal hip muscle strength or jump performance between the operated and non-operated hip 6-30 months after hip arthroscopy. However, the operated hip displayed less explosiveness for hip flexion. Furthermore, having higher hip extension strength was associated with being engaged in pre-injury sport. By using 26 clinical variables collected prior to hip arthroscopy, it was possible to accurately predict the risk of ending up with an unsuccessful outcome (having unacceptable symptoms) 1 year after hip arthroscopy.

Conclusions

In this thesis, we have provided an overview of the role of different bony hip joint morphologies for the risk of cartilage injuries, presented a detailed picture of what patients can expect after hip arthroscopy for femoroacetabular impingement syndrome, and developed and validated a clinical prediction model that can be used in clinical practice to guide if hip arthroscopy is beneficial for the patient. We show that the severity of cam morphology increases the risk of cartilage injuries, suggesting that cartilage injuries may be the underlying pathology in these patients. After hip arthroscopy, patients can expect to get better, but up to half of all patients continue to rate their symptoms as unacceptable, and only a few can resume sporting activities without hip and groin problems. By using a clinical prediction model based on typical clinical variables collected prior to surgery, the orthopedic surgeon can estimate the likelihood of the patient ending up with unacceptable symptoms one-year after surgery. This information can be used to guide the decision of whether hip arthroscopy is beneficial for the individual patient and, thus, can help improve hip arthroscopy outcomes in the future.

SAMMENFATNING PÅ DANSK

Baggrund

Hofterelaterede smerter er en hyppig årsag til funktionsnedsættelse. ”*Femoroacetabular impingement syndrom*” (herefter betegnet ”*indeklemningsyndrom i hoften*”) er den hyppigste årsag til hofterelaterede smerter hos unge og midaldrende fysisk aktive personer. Tilstanden tænkes at skyldes ændret hofteledsmorfologi (dvs. knoglernes form), som hos ældre er blevet forbundet med udvikling af slidgigt i hoften. Indeklemningssyndrom i hoften behandles ofte kirurgisk ved hjælp af en artroskopisk procedure (kikkertoperation), hvor man forsøger at genskabe den oprindelige knogleform. Der er efterhånden solid data der viser, at hofteartroskopi er en effektiv behandlingsform til patienter med indeklemningssyndrom i hoften med hensyn til at nedsætte smerter samt øge funktionsniveau. Derimod ved man mindre om hvordan patienterne klarer sig efter operation og om de finder deres tilstand tilfredsstillende, samt om faktorer før operationen kan benyttes til at forudsige resultatet efter operation. Dette Ph.D.-projekt indeholder fem artikler med det overordnede formål at undersøge 1) betydningen af hofteledsmorfologi for bruskskader i hofteleddet, 2) subjektive og objektive udfald efter hofteartroskopi for indeklemningssyndrom i hoften, og 3) hvorvidt faktorer før operation kan hjælpe med at forudsige, hvordan patienter klarer sig efter operation.

Metoder

Vi undersøgte først sammenhængen mellem forskellige karakteristika for hofteledsmorfologi med kirurgisk-definerede bruskskader ved hjælp af data fra Dansk Hofteartroskopi Register (1511 patienter, Studie I). Dernæst undersøgte vi om patienter, der havde gennemgået hofteartroskopi for indeklemningssyndrom i hoften, anså deres nuværende symptomer som værende acceptable (141 patienter, Studie II), samt deres evne til at returnere til deres tidligere sportsgren (189 patienter, Studie III). Efterfølgende målte vi objektiv funktion – hoftemuskelstyrke og et-bens hopevne – hos 45 patienter, der havde gennemgået hofteartroskopi for indeklemningssyndrom i hofte (Studie IV). Til sidst udviklede og testede vi et klinisk værktøj til at prædiktere henholdsvis et vellykket eller dårligt resultat efter hofteartroskopi ved hjælp af data fra Dansk Hofteartroskopi Register (1546 patienter, Studie V).

Resultater

Der var en sammenhæng mellem bestemte typer af hofteledsmorfologi og bruskskader i hoften med mere alvorlig morfologi forbundet med en højere risiko for alvorlige bruskskader (studie I). Lidt over halvdelen af patienterne vurderede deres symptomer som uacceptable 1-2 år efter hofteartroskopi (studie II), mens 57 % var i stand til at vende tilbage til deres tidligere sportsaktiviteter, dog kun 17 % med et præstationsniveau, der var på niveau med før debut af hoftesmerter (studie III). Der var ingen forskel i maksimal hoftemuskelstyrke eller hopevne mellem den opererede og ikke-opererede hofte 6-30 måneder efter hofteartroskopi, dog var den opererede hofte mindre eksplosiv for hoftefleksion. Derimod var patienter med høj hofteekstensionsstyrke i den opererede hofte i højere grad i stand til at deltage i sportsaktiviteter uden problemer (studie IV). Ved hjælp af 26 kliniske variable indsamlet før hofteartroskopi var det muligt præcist at forudsige risikoen for et dårligt resultat (med uacceptable symptomer) 1 år efter hofteartroskopi (studie V).

Konklusioner
I denne afhandling er der givet 1) et overblik over hvordan knoglemorfologi i hoften påvirker risikoen for bruskskader, 2) præsenteret et detaljeret billede af, hvad patienter kan forvente efter hofteartroskopi for indeklemningssyndrom, og 3) udviklet og valideret et klinisk værktøj til at prædiktere effekten af operation. Sværhedsgraden af konglemorfologi øger risikoen for bruskskader, hvilket tyder på, at bruskskader kan være det underliggende problem hos patienter med indeklemningssyndrom i hoften. Efter hofteartroskopi kan patienter forvente at få det bedre, men op mod halvdelen af alle patienter vurderer fortsat deres symptomer som uacceptable, og kun få kan genoptage sportsaktiviteter uden hofte- og lyske smerter. Ved at bruge et simpelt værktøj baseret på almindelige kliniske variable indsamlet før operationen, kan ortopædkirurgen estimere sandsynligheden for, at patienten ender med uacceptable symptomer et år efter operationen. Denne information kan bruges til at afgøre, om hofteartroskopi er gavnligt for den enkelte patient.

ACKNOWLEDGEMENTS

Several people have had a direct or indirect impact on this work, and I would like to thank you all for making this journey so much more than “just” a Ph.D.

First of all, the work in this thesis would not have been possible without the tremendous help and guidance from my two main supervisors, **Per Hölmich** and **Kristian Thorborg**.

Per, I do not know if you recall, but as a shy 2nd-year physiotherapist student, I introduced myself at the Football Medicine Strategies conference in Milano 2013 as the one who had been sending you emails regarding a bachelor study idea. Thank you for inviting me to be part of your research group 7 years ago. At that time, I could only hope for where this would take me, and the journey has exceeded all my expectations. Thank you for always being positive in my things and letting me pursue my research career. Thank you for involving me in stuff, such as book chapters, conferences, The Zurich Consensus Statements etc. While this from time to time messed up my schedule, I am positive it has given me so many invaluable experiences and advantages as a young researcher, and I am grateful for that. The last five years, starting at your office in December 2016 when you asked me to do a Ph.D., has been an immense pleasure of mine. Developing the hip-research strategy for Sports Orthopedic Research Center with you and Kristian has been unreal. Your clinical and research expertise are impressive and second to none in the hip and groin area, and having daily access to that hidden knowledge just down the corridor has been more than I could ask for as a Ph.D. student. Thank you for never being too busy to share your thoughts when knocking on your office door. Lastly, thank you for being my supervisor and putting my name on the hip and groin map. I look forward to continuing this journey.

Kristian, I do not know where to start and end. One thing I know, though, is that you have had a profound impact on me as a young researcher – more than I can put to words. I feel privileged working with you every day. Thank you for always supporting me and putting in the extra hours to finetune every single manuscript, even if it was not always related to this Ph.D. Your dedication to research is impressive and inspiring! Thank you for always being honest in your feedback, whether it concerns a manuscript or else. Thank you for constantly raising the bar, spotting the details, and for pushing me to do my best in every manuscript. Thank you for trusting me in other roles and for involving me in the muscle-tendon M.Sc. University Courses, the Sports Physical Therapy Statement Papers, and the Sports Kongress as an invited speaker. Your engagement over the last 5-6 years has greatly influenced me, and there is no doubt this will transfer to any future work I do. We have a lot of exciting stuff in the pipeline, and I look forward to working on that soon.

Joanne Kemp and **Mike Reiman**, you complete what I consider to be “*the hip and groin supervisor dream team*.” Thank you for being involved and for sharing your immense expertise. Unfortunately, COVID-19 made it impossible to stick to the plan, but I feel privileged to have you on board for the next chapter to continue the work that we started so that I can get a decent chance to pick your brains even more.

Otto Kraemer, my unofficial co-supervisor, thank you. From being a little afraid entering the grumply old orthopedic surgeon’s office in the beginning, I have no clue how many times I have found myself sitting in your office for a discussion or advice. Thank you for your input as co-author, but more importantly, thank you for your always open office door, positivity,

and willingness to share your knowledge when I needed clarification of some hip-related stuff. It has been a pleasure.

Mathias "Gamle" Nielsen and **Kasper Krommes**, my office mates and fellow research nerds, beer bodies, and good friends. It has been a pleasure sharing the office with you for the past years, and I hope it will be the case for the following years to come. Thank you for always ensuring that the SORC-C office is *"The best and funniest office at the Hvidovre Hospital!"* I feel fortunate to work not only with great and smart colleagues like you but good friends. Having you in the office has undoubtedly contributed enormously to the Ph.D. through positive vibes and good karma. Now, there is only one thing to say: "ca-ca-ca-ca-ca-cake, ca-ca-ca-ca-ca-cake…"

Co-authors, **Bjarne Mygind-Klavsen**, **Bent Lund**, and **Marie Ørum**, thank you for providing your expertise and time commitment.

Co-author, **Thomas Kallemose**, you have been part of what is with no doubt the most theoretically demanding study, I have conducted to date. I am grateful for your inputs, expertise, and statistical knowledge.

During my Ph.D. I have been lucky enough to be involved in other research and working environments, and for that, I would like to thank the team at F.C. Nordsjælland, **Jacob Penalver, Kasper Thornton, Anders Lund, Sam Feringa, Christian Rønsgård, Joakim Dilling**. Thank you, Jacob and Kasper, for inviting me into your football family and for allowing me to challenge myself in different ways. It has been an absolute please of mine, and I look forward to exploring what the future brings.

Mikael Sansone, Thank you for letting me stay at your research group and department. Even though the time was short, I appreciate your hospitality, your willingness to share your knowledge, and the effort you put in to facilitate the best possible stay for me. I can with no doubt say that despite the short time, I learned a lot, and I am grateful for that. I hope someday, we will co-author a paper.

Thank you, **Andreas Serner**. While not directly impacting this Ph.D. work, my research career was sparkled back in 2013 while working with you at the F.C. Copenhagen youth academy. I am grateful that you took your time to supervise my bachelor dissertation (still my most cited paper to date) and, two years later, my master dissertation, even though you were at Aspetar working hard on your Ph.D. Thank you for being my lead-man into research when I was just a 2nd-year physiotherapist student, for supporting me in writing my first paper, and not least for introducing me early on to your supervisors at that time, Kristian and Per. I am confident that I could not have had better preparation and foundation for completing a Ph.D. than having you as an early career supervisor.

24Hunnar, thanks for just being you around. You know who you are.

My conference buddy and good friend, **Andreas Bjerregaard**, "Skål!"

Anni and Christian, thank you for your endless positivity and always open doors. Thank you for being interested in what I do and helping out with the boys.

Tommy, thank you for being around, spending time with the boys, and for being straight-up honest in everything you say.

Sara, Therese, Marie, Katrine, Rikke, Nanna, Anne-Birgitte, Anna, and Anders Bo, thank you for helping out with the boys when needed.

Family, **Anders, Astrid, Lille A, mum** and **dad**, thank you for just being around; it means everything. Mum and Dad, thank you for always having taken good care of me! You once said: "Whatever you do, just try to put in your best effort." I do not do that in everything, but for this thesis, I certainly did. Thank you for helping out with the boys, and for spending time with them. And, **dad** and **Anders**, once the world is ordinary again, I will look forward to climbing the Alpes again.

Last, and most importantly, the biggest support I could ever ask for, **Amalie**. I know the last couple of years have not always been what you signed up for – I am forever grateful that you endured, stood by me, and even set aside your priorities so that I could do long working hours, evening work, and weekend work to follow this dream. Thank you! Thank you for listening to my frustrations and worries every other evening for the last five years. Thank you for always supporting me. Thank you for trying to remember twitter names. Thank you for sharing my excitement when a paper got accepted for publication and frustrations when rejected. Thank you for being so interested in what I do, even if sometimes it is only pretending. But what outshines everything – thank you for being the best mom to **Lille B** and **Ankermus** – they do not know quite yet how lucky they are, having you in their life, but they will find out soon enough! Our life took an unexpected turn in September 2020 when the scan showed two babies. Thank you for giving birth to the two most wonderful and cute little boys I could ever imagine. Thank you for being so incredible in everything you do and for taking care of them, allowing me to finish up this book.

I love you.

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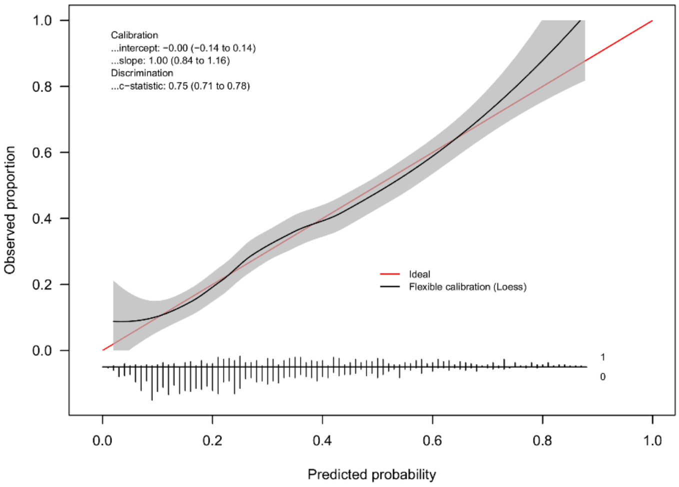
APPENDIX

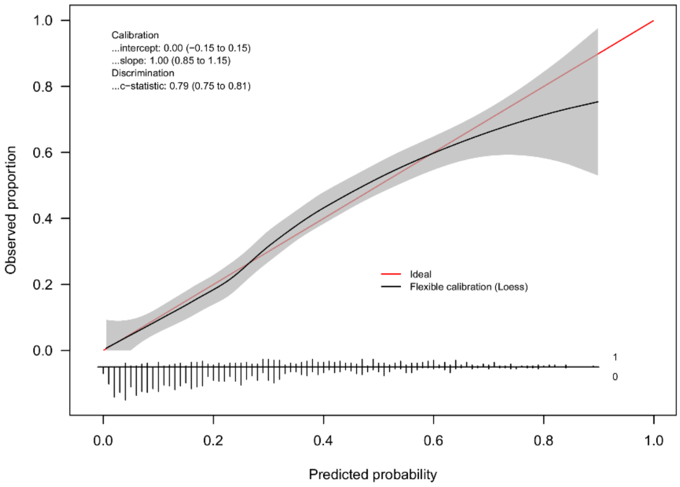
Appendix 1

CALIBRATION PLOTS AND ASSOCIATION STATISTICS FOR THE PRIMARY PREDICTION MODELS (NO PERI-OPERATIVE VARAIBLES) DERIVED BASED ON THE DEVELOPMENT SAMPLE WITH MISSING DATA IMPUTATION.

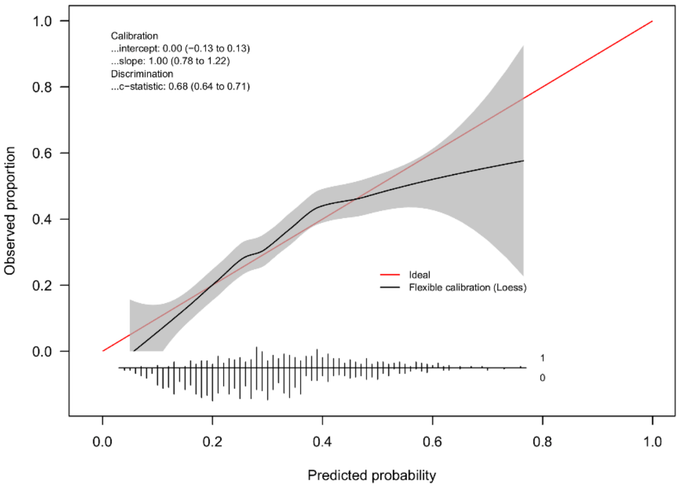
Successful outcome



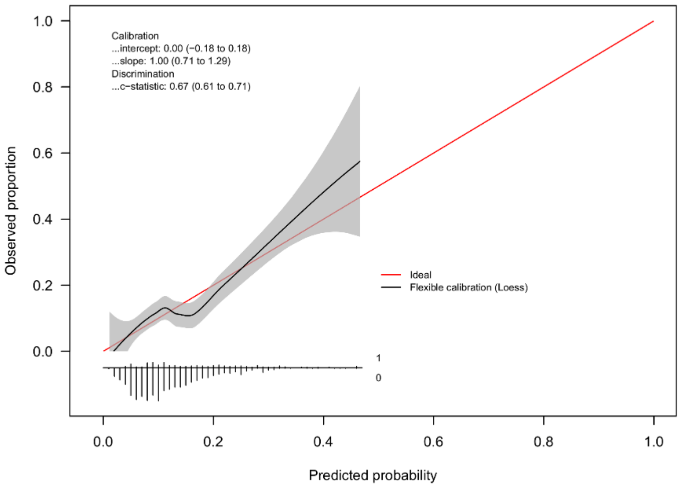
Unsuccessful outcome



Improvement



No improvement



Appendix 2

Table 1. Full prediction model (derived using logistic regression) for predicting patients who at 1-year after hip arthroscopy have achieved PASS in all HAGOS subscales (successful outcome)

Intercept and predictor	Beta Coefficient	Odds ratio	95% CI
Intercept	3.6629		
Age (range: 15-50 years old)	0.0015	1.00	0.99 - 1.02
Male sex	-0.1374	0.87	0.63 - 1.20
Hip Sports Activity Scale (treated as continuous variable in categories: 1; 2-5; 6-7; 8-9)	0.0109	1.01	0.93 - 1.10
Hospital setting (public vs. private)	-0.3369	0.71	0.53 - 0.96
Lateral Center Edge Angle (range: 14-45)	0.0058	1.01	0.97 - 1.04
Ischial Spine Sign (yes vs. no)	0.4509	1.57	1.14 - 2.16
Alpha Angle (range: 45-105)	-0.0148	0.99	0.97 - 1.00
Joint Space Width (treated as continuous variable in categories: < 3 mm; 3.1-4 mm; >4 mm)	0.0055	1.01	0.77 - 1.31
Acetabular Index Angle (range: (-5 to 22)	-0.018	0.98	0.94 - 1.03
Overall rating of hip function (0-100, 0 = best)	-0.0063	0.99	0.98 - 1.00
Problems during running (none to extreme)**	-0.1443	0.87	0.74 - 1.01
Problems during walking (none to extreme)**	-0.112	0.89	0.73 - 1.09
Problems get in/out of car (none to extreme)**	0.0916	1.10	0.92 - 1.31
Able to participate in preferred sport (always to never)**	0.0128	1.01	0.85 - 1.21
Pain frequency (never to always)**	0.0036	1.00	0.75 - 1.34
Pain in other areas (never to always)**	-0.1029	0.9	0.79 - 1.02
Stabbing sensation (never to all the time)**	-0.1258	0.88	0.74 - 1.05
Morning stiffness (none to extreme)**	0.0692	1.07	0.89 - 1.29
Stiffness after sitting (none to extreme)**	-0.2162	0.81	0.65 - 0.99
Night pain (none to extreme)**	-0.0638	0.94	0.80 - 1.10
Pain during rest (0-100, 0 = best)	0.0027	1.00	0.99 - 1.01
Pain during walking (0-100, 0 = best)	-0.009	0.99	0.98 - 1.00
Anxiety or depression (no to extremely)***	-0.5425	0.58	0.37 - 0.91
Awareness of hip (never to always)**	-0.1309	0.88	0.64 - 1.20
Lifestyle changes (not al all to totally)**	-0.1846	0.83	0.69 - 1.00
Mood changes (not at all to all the time)**	-0.1014	0.90	0.75 - 1.09

** Based on single Items from the Copenhagen Hip and Groin Outcome Score (HAGOS)

*** Based on the Depression and Anxiety Item for EQ5D-3L Health questionnaire

Table 2. Full prediction model (derived using logistic regression) for predicting patients who at 1-year after hip arthroscopy have not achieved PASS in any HAGOS subscales (unsuccessful outcome)

Intercept and predictor	Beta Coefficient	Odds ratio	95% CI
Intercept	-5.1434		
Age (range: 15-50 years old)	0.0017	1.00	0.98 - 1.02
Male sex	-0.0641	0.94	0.66 - 1.32
Hip Sports Activity Scale (treated as continuous variable in categories: 1; 2-5; 6-7; 8-9)	-0.0612	0.94	0.85 - 1.04
Hospital setting (public vs. private)	0.1862	1.21	0.87 - 1.67
Lateral Center Edge Angle (range: 14-45)	0.0108	1.01	0.98 - 1.05
Ischial Spine Sign (yes vs. no)	-0.1705	0.84	0.59 - 1.20
Alpha Angle (range: 45-105)	0.0104	1.01	1.00 - 1.02
Joint Space Width (treated as continuous variable in categories: < 3 mm; 3.1-4 mm; >4 mm)	-0.2094	0.81	0.62 - 1.06
Acetabular Index Angle (range: (-5 to 22)	0.0371	1.04	0.99 - 1.09
Overall rating of hip function (0-100, 0 = best)	-0.0005	1.00	0.99 - 1.01
Problems during running (none to extreme)**	0.1082	1.11	0.93 - 1.34
Problems during walking (none to extreme)**	0.2429	1.28	1.03 - 1.58
Problems get in/out of car (none to extreme)**	-0.0299	0.97	0.80 - 1.17
Able to participate in preferred sport (always to never)**	-0.0525	0.95	0.78 - 1.16
Pain frequency (never to always)**	0.1719	1.19	0.84 - 1.68
Pain in other areas (never to always)**	0.002	1.00	0.87 - 1.16
Stabbing sensation (never to all the time)**	0.1803	1.20	0.98 - 1.46
Morning stiffness (none to extreme)**	0.1688	1.18	0.98 - 1.43
Stiffness after sitting (none to extreme)**	0.3498	1.42	1.14 - 1.77
Night pain (none to extreme)**	-0.0673	0.94	0.79 - 1.11
Pain during rest (0-100, 0 = best)	-0.0052	1.00	0.99 - 1.00
Pain during walking (0-100, 0 = best)	0.0056	1.01	1.00 - 1.02
Anxiety or depression (no to extremely)***	0.1867	1.21	0.82 - 1.78
Awareness of hip (never to always)**	0.084	1.09	0.76 - 1.57
Lifestyle changes (not al all to totally)**	0.1051	1.11	0.90 - 1.37
Mood changes (not at all to all the time)**	0.1869	1.21	0.97 - 1.50

** Based on single Items from the Copenhagen Hip and Groin Outcome Score (HAGOS)

*** Based on the Depression and Anxiety Item for EQ5D-3L Health questionnaire

Table 3. Full prediction model (derived using logistic regression) for predicting patients who at 1-year after hip arthroscopy have achieved MCID in all HAGOS subscales (improvement)

Intercept and predictor	Beta Coefficient	Odds ratio	95% CI
Intercept	-0.1131		
Age (range: 15-50 years old)	0.00022	1.00	0.98 - 1.02
Male sex	-0.07898	0.92	0.68 - 1.26
Hip Sports Activity Scale (treated as continuous variable in categories: 1; 2-5; 6-7; 8-9)	0.03215	1.03	0.95 - 1.12
Hospital setting (public vs. private)	-0.22727	0.8	0.60 - 1.06
Lateral Center Edge Angle (range: 14-45)	-0.01843	0.98	0.95 - 1.01
Ischial Spine Sign (yes vs. no)	0.19606	1.22	0.89 - 1.65
Alpha Angle (range: 45-105)	-0.01141	0.99	0.98 - 1.00
Joint Space Width (treated as continuous variable in categories: < 3 mm; 3.1-4 mm; >4 mm)	0.1791	1.20	0.92 - 1.55
Acetabular Index Angle (range: (-5 to 22)	-0.03899	0.96	0.92 - 1.00
Overall rating of hip function (0-100, 0 = best)	-0.00404	1.00	0.99 - 1.01
Problems during running (none to extreme)**	0.05786	1.06	0.90 - 1.24
Problems during walking (none to extreme)**	-0.11317	0.89	0.74 - 1.08
Problems get in/out of car (none to extreme)**	0.29151	1.34	1.13 - 1.58
Able to participate in preferred sport (always to never)**	0.15456	1.17	0.98 - 1.39
Pain frequency (never to always)**	0.08493	1.09	0.81 - 1.46
Pain in other areas (never to always)**	0.02333	1.02	0.90 - 1.16
Stabbing sensation (never to all the time)**	-0.01219	0.99	0.83 - 1.17
Morning stiffness (none to extreme)**	0.03929	1.04	0.88 - 1.23
Stiffness after sitting (none to extreme)**	0.03104	1.03	0.85 - 1.25
Night pain (none to extreme)**	0.09767	1.10	0.95 - 1.28
Pain during rest (0-100, 0 = best)	-0.00147	1.00	0.99 - 1.01
Pain during walking (0-100, 0 = best)	-0.00248	1.00	0.99 - 1.01
Anxiety or depression (no to extremely)***	-0.2361	0.79	0.54 - 1.17
Awareness of hip (never to always)**	-0.08734	0.92	0.67 - 1.26
Lifestyle changes (not al all to totally)**	-0.00017	1.00	0.83 - 1.20
Mood changes (not at all to all the time)**	-0.17565	0.84	0.70 - 1.01

** Based on single Items from the Copenhagen Hip and Groin Outcome Score (HAGOS)

*** Based on the Depression and Anxiety Item for EQ5D-3L Health questionnaire

Table 4. Full prediction model (derived using logistic regression) for predicting patients who at 1-year after hip arthroscopy have not achieved MCID in any HAGOS subscale (no improvement)

Intercept and predictor	Beta Coefficient	Odds ratio	95% CI
Intercept	-3.0163		
Age (range: 15-50 years old)	0.014	1.01	0.99 - 1.04
Male sex	0.016	1.02	0.68 - 1.53
Hip Sports Activity Scale (treated as continuous variable in categories: 1; 2-5; 6-7; 8-9)	-0.023	0.98	0.87 - 1.10
Hospital setting (public vs. private)	0.124	1.13	0.76 - 1.68
Lateral Center Edge Angle (range: 14-45)	-0.008	0.99	0.95 - 1.04
Ischial Spine Sign (yes vs. no)	-0.303	0.74	0.47 - 1.16
Alpha Angle (range: 45-105)	0.013	1.01	1.00 - 1.03
Joint Space Width (treated as continuous variable in categories: < 3 mm; 3.1-4 mm; >4 mm)	-0.079	0.92	0.67 - 1.28
Acetabular Index Angle (range: (-5 to 22)	0.026	1.03	0.97 - 1.08
Overall rating of hip function (0-100, 0 = best)	0.000	1.00	0.99 - 1.01
Problems during running (none to extreme)**	-0.092	0.91	0.74 - 1.12
Problems during walking (none to extreme)**	0.090	1.09	0.85 - 1.41
Problems get in/out of car (none to extreme)**	-0.068	0.93	0.74 - 1.18
Able to participate in preferred sport (always to never)**	-0.145	0.86	0.70 - 1.07
Pain frequency (never to always)**	0.016	1.02	0.69 - 1.50
Pain in other areas (never to always)**	0.023	1.02	0.86 - 1.22
Stabbing sensation (never to all the time)**	0.075	1.08	0.85 - 1.37
Morning stiffness (none to extreme)**	0.002	1.00	0.79 - 1.27
Stiffness after sitting (none to extreme)**	0.013	1.01	0.78 - 1.32
Night pain (none to extreme)**	-0.130	0.88	0.71 - 1.09
Pain during rest (0-100, 0 = best)	-0.003	1.00	0.99 - 1.01
Pain during walking (0-100, 0 = best)	0.004	1.00	0.99 - 1.02
Anxiety or depression (no to extremely)***	0.385	1.47	0.94 - 2.30
Awareness of hip (never to always)**	-0.041	0.96	0.64 - 1.45
Lifestyle changes (not al all to totally)**	0.012	1.01	0.80 - 1.28
Mood changes (not at all to all the time)**	0.128	1.14	0.88 - 1.47

** Based on single Items from the Copenhagen Hip and Groin Outcome Score (HAGOS)

*** Based on the Depression and Anxiety Item for EQ5D-3L Health questionnaire

Appendix 3

Table 1. Precision, sensitivity, and specificity for probability threshold for the primary model of outcome measure, successful outcome. Data based on temporal validation dataset with imputed missing data. No inclusion of peri-operative predictor variables.

Probability Threshold	Precision	Sensitivity	Specificity
0.1	0.349	0.949	0.098
0.2	0.504	0.818	0.376
0.3	0.603	0.569	0.618
0.4	0.675	0.394	0.792
0.5	0.716	0.219	0.924
0.6	0.72	0.117	0.972
0.7	0.705	0.022	0.991
0.8	0.705	0.007	0.997
0.9	0.705	0	1

Table 2. Precision, sensitivity, and specificity for probability threshold for the primary model of the outcome measure, unsuccessful outcome. Data based on temporal validation dataset with imputed missing data. No inclusion of peri-operative predictor variables.

Probability Threshold	Precision	Sensitivity	Specificity
0.1	0.405	0.974	0.213
0.2	0.584	0.863	0.49
0.3	0.688	0.735	0.671
0.4	0.748	0.504	0.83
0.5	0.748	0.274	0.908
0.6	0.741	0.111	0.954
0.7	0.75	0.017	0.997
0.8	0.752	0.017	1
0.9	0.748	0	1

Table 3. Precision, sensitivity, and specificity for probability threshold for the primary model of the outcome measure, improvement. Data based on temporal validation dataset with imputed missing data. No inclusion of peri-operative predictor variables.

Probability Threshold	Precision	Sensitivity	Specificity
0.1	0.349	1	0.003
0.2	0.44	0.938	0.175
0.3	0.58	0.658	0.538
0.4	0.64	0.36	0.789
0.5	0.672	0.143	0.954
0.6	0.655	0.012	0.997
0.7	0.653	0	1
0.8	0.653	0	1
0.9	0.653	0	1

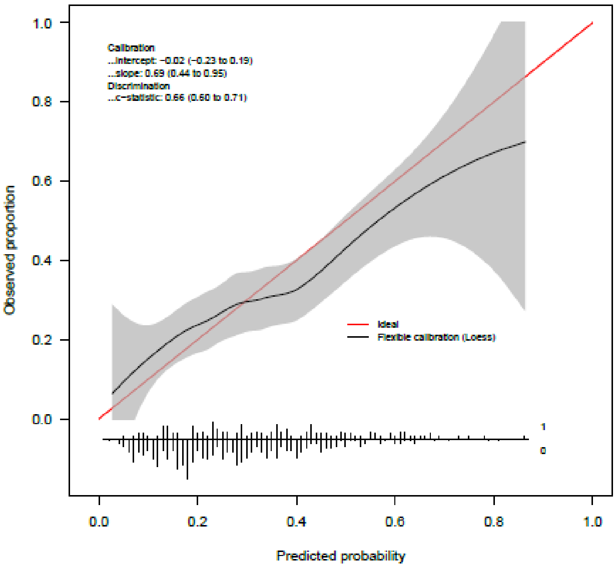
Table 4. Precision, sensitivity, and specificity for probability threshold for the primary model of the outcome measure, no improvement. Data based on temporal validation dataset with imputed missing data. No inclusion of peri-operative predictor variables.

Probability Threshold	Precision	Sensitivity	Specificity
0.1	0.333	0.686	0.289
0.2	0.836	0.137	0.922
0.3	0.888	0.039	0.993
0.4	0.89	0	1
0.5	0.89	0	1
0.6	0.89	0	1
0.7	0.89	0	1
0.8	0.89	0	1
0.9	0.89	0	1

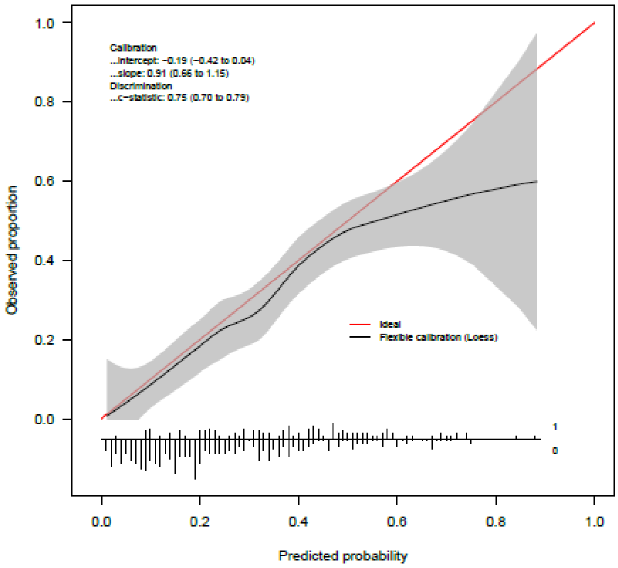
Appendix 4

CALIBRATION PLOTS AND ASSOCIATION STATISTICS FOR THE SUPPLEMENTARY PREDICTION MODELS (INCLUDING PERI-OPERATIVE VARIABLES) DERIVED BASED ON THE TEST SAMPLE WITH MISSING DATA IMPUTATION

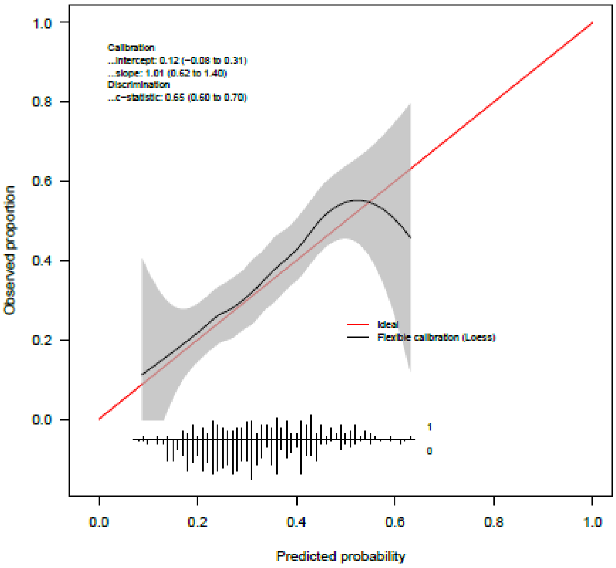
Successful outcome



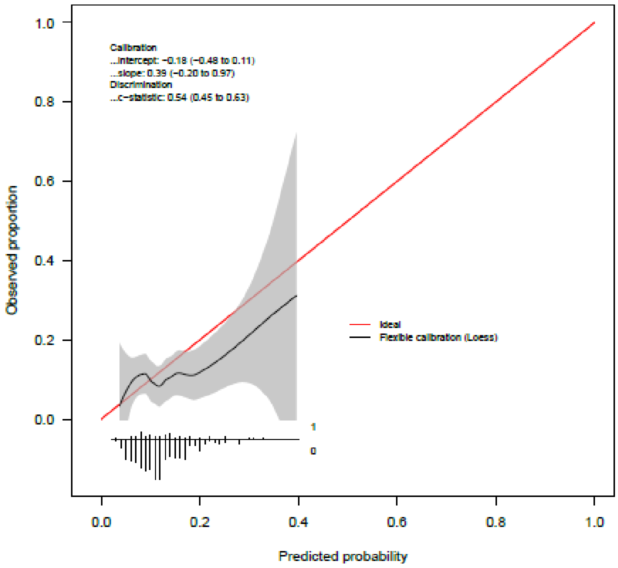
Unsuccessful outcome



Improvement



No improvement



PAPERS

Study I

Ishøi, L., Thorborg, K., Kraemer, O., Lund, B., Mygind-Klavsen, B., & Hölmich, P. (2019). Demographic and Radiographic Factors Associated With Intra-articular Hip Cartilage Injury: A Cross-sectional Study of 1511 Hip Arthroscopy Procedures. The American Journal of Sports Medicine, 47(11), 2617–2625.

Demographic and Radiographic Factors Associated With Intra-articular Hip Cartilage Injury

A Cross-sectional Study of 1511 Hip Arthroscopy Procedures

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Investigation performed at the Sports Orthopedic Research Center–Copenhagen, Department of Orthopaedic Surgery, Copenhagen University Hospital, Amager-Hvidovre, Denmark

Background: Moderate to severe (grade 3-4) hip joint cartilage injury seems to impair function in patients with femoroacetabular impingement syndrome.

Purpose: To investigate whether demographic and radiographic factors were associated with moderate to severe hip joint cartilage injury.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Patients were identified in the Danish Hip Arthroscopy Registry. The outcome variables were acetabular cartilage injury (modified Beck grade 0-2 vs 3-4) and femoral head cartilage injury (International Cartilage Repair Society grade 0-2 vs 3-4). Logistic regressions assessed the association with the following: age (<30 vs 30-50 years); sex; sport activity level (Hip Sports Activity Scale); alpha angle (AA) assessed as normal (AA <55°), cam (55° ≤ AA <78°), or severe cam (AA ≥78°); lateral center-edge angle (LCEA) assessed as normal (25° ≤ LCEA ≤ 39°), pincer (LCEA >39°), or borderline dysplasia (LCEA <25°); joint space width (JSW) assessed as normal (JSW >4.0 mm), mild reduction (3.1 mm ≤ JSW ≤ 4.0 mm), or severe reduction (2.1 mm ≤ JSW ≤ 3.0 mm).

Results: A total of 1511 patients were included (mean ± SD age: 34.9 ± 9.8 years). Male sex (odds ratio [OR], 4.42), higher age (OR, 1.70), increased AA (cam: OR, 2.23; severe cam: OR, 4.82), and reduced JSW (mild: OR, 2.04; severe: OR, 3.19) were associated ($P < .05$) with Beck grade 3-4. Higher age (OR, 1.92), increased Hip Sports Activity Scale (OR, 1.13), borderline dysplasia (OR, 3.08), and reduced JSW (mild: OR, 2.63; severe: OR, 3.04) were associated ($P < .05$) with International Cartilage Repair Society grade 3-4.

Conclusion: Several demographic and radiographic factors were associated with moderate to severe hip joint cartilage injury. Most notably, increased cam severity and borderline dysplasia substantially increased the risk of grade 3-4 acetabular and femoral head cartilage injury, respectively, indicating that specific deformity may drive specific cartilage injury patterns in the hip joint.

Keywords: femoroacetabular impingement syndrome; hip pain; cartilage degeneration; risk factors; osteoarthritis

Exercise-related long-standing groin pain can lead to considerable disability[25] and cessation of sport activities.[20] Femoroacetabular impingement syndrome (FAIS) is the most common diagnosis of exercise-related groin pain leading to surgical management,[10,15] and the condition may coexist with acetabular dysplasia.[32] FAIS is thought to be caused by cam and/or pincer deformity.[14,15] While the cause of pincer deformity is unknown, cam deformity seems to develop as an adaptation to repetitive hip loading during skeletal maturation.[2,42,45] Consequently, such bony deformities are frequently observed in asymptomatic individuals.[13] For example, in a cohort of 445 professional football players, bony deformities were found in up to 72% of players.[34] Moreover, inconclusive findings have been observed regarding the association between cam deformity and risk of subsequent groin pain,[24,35] and poor association exists between cam and/or pincer deformity and hip pain before[43] and after hip arthroscopy.[7] Collectively, this calls into question the role of bony deformity in FAIS. However, hip cartilage injury seems to be important for hip function before and after hip arthroscopy.[17,26,37] Thus, a systematic review with meta-analysis demonstrated a high prevalence (64%) of imaging-defined hip cartilage injury in symptomatic

The American Journal of Sports Medicine
2019;47(11):2617–2625
DOI: 10.1177/0363546519861088

patients as compared with a low prevalence (12%) in asymptomatic patients.[17] Furthermore, a high prevalence (>70%) of cartilage injury exists in patients undergoing hip arthroscopy for FAIS,[23,36] with the severity affecting the postoperative outcome.[9,12,30,37] Few studies have investigated the association between hip bony morphology and demographic factors with cartilage injury in FAIS[21,22,31,39] and between cam deformity and end-stage hip osteoarthritis.[1] However, lack of consistency in the definition of bony deformity characterizing FAIS and in the classification of cartilage severity makes interpretation of existing literature difficult.[1,21,22,31,39] Thus, using contemporary definitions of bony hip morphology[4,15] improves current clinical relevance and understanding of the role of bony hip deformity, including severity, for progression of cartilage injury in young to middle-aged patients with FAIS. Such information is particularly important in light of the number of arthroscopic procedures performed in patients with FAIS to correct bony deformity.[8,44] The purpose of this cross-sectional study was to investigate demographic and radiographic factors associated with acetabular and femoral head cartilage injury in young to middle-aged patients undergoing hip arthroscopy.

METHODS

Study Design

This cross-sectional study investigated the association of patient demographic factors (age, sex, and sport activity level) and radiographic factors (alpha angle [AA], lateral center-edge angle [LCEA], and joint space width [JSW]) with hip joint cartilage injury identified during hip arthroscopy. All data on patients undergoing hip arthroscopy procedures, including demographic, radiographic, and perioperative data, were extracted from the Danish Hip Arthroscopy Registry (DHAR).[36] The reporting adheres to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.[52] The study was deemed exempt from review by the Danish Ethics Committee of the Capital Region, as all data were extracted from a registry approved by the Danish Health Authorities.[36]

Study Setting

DHAR is a national registry initiated in 2012 with ongoing prospective registration of hip arthroscopies performed at 11 specialized centers in Denmark.[36] Operative and perioperative data registered in the DHAR between January 2012 and March 2018 were identified for the present study.

Participants

Data from 1923 eligible hip arthroscopy procedures were identified in the DHAR. Inclusion criteria were a male or female who had a hip arthroscopy at the age of 15 to 50 years. Exclusion criteria were a previous periacetabular osteotomy; revision hip arthroscopy (data from the initial hip arthroscopy procedure were included); previous hip pathology, such as Perthes disease, slipped capital femoral epiphysis, and/or avascular necrosis of the femoral head; any rheumatoid disease in the hip joint, such as synovial chondromatosis; and incompleteness of demographic, radiological, and perioperative data.

Outcome Measures

The outcomes of interest were the associations, measured as odds ratios (ORs), between the dependent variables related to intra-articular hip joint cartilage injury and the independent predictor variables related to demographic and radiographic factors. The dependent outcome variables were acetabular and femoral head cartilage injury documented during the hip arthroscopy procedure and assessed by the operating hip surgeon. Acetabular cartilage injury was measured with the modified Beck cartilage classification and graded as follows: normal cartilage (grade 0), fibrillation (grade 1), wave sign (grade 2), cleavage tear between acetabular bone and cartilage (grade 3), or exposed bone (grade 4).[5,27] Femoral head cartilage injury was measured with the International Cartilage Repair Society (ICRS) classification and graded as follows: normal cartilage (grade 0), nearly normal (grade 1), abnormal (grade 2), partial loss of cartilage (grade 3), or exposed bone (grade 4). Subsequently, for the statistical analyses, acetabular and femoral head cartilage status was dichotomized into no to minimal cartilage injury (grade 0-2) or moderate to severe cartilage injury (grade 3-4) in line with previous studies.[23,30,39]

Predictor Variables

The independent predictor variables included demographic and radiographic data obtained before surgery. Selection of predictor variables were performed a priori and based on availability from the DHAR and previous findings indicating that age, sex, sport activity, and bony deformity may

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The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

affect cartilage status in the hip.[1,31,39,53] Demographic data included age (15 to <30 years vs 30-50 years),[39] sex (male/female), and sport activity obtained with the Hip Sports Activity Scale (HSAS).[38] HSAS is a valid and reliable tool to determine sport activity level, with a scale from 0 (no recreational or competitive sport) to 8 (competitive sport at elite level).[38] Radiographic data were obtained with plain radiography and included the AA, the LCEA, and the JSW. The AA was obtained from a cross-table lateral, Dunn, or frog lateral view radiograph,[29] as recommended by the Warwick agreement[15] and measured as the angle between (1) the line from the center of the femoral head parallel to the axis of the femoral neck and (2) the line from the center of the femoral head to the point where the femoral head-neck junction extends beyond the margin of the circle along the periphery of the femoral head.[40] The AA was categorized into normal (AA <55°), cam deformity (55° ≤ AA < 78°), or severe cam deformity (AA ≥78°).[1,4,15,50] The LCEA was obtained from a weightbearing anterior-posterior pelvic view and measured as the angle between (1) the vertical line through the femoral head perpendicular to the line between the centers of the 2 femoral heads (or a similar horizontal line) and (2) the line between the center of the femoral head and the lateral end of the sourcil.[40] The LCEA was categorized into normal (25° ≤ LCEA ≤ 39°), pincer deformity (LCEA >39°), or borderline dysplasia (LCEA <25°).[16,18] The JSW was assessed on weightbearing radiographs at the lateral sourcil[29] as normal (JSW >4.0 mm), mild reduction (3.1 mm ≤ JSW ≤ 4.0 mm), or severe reduction (2.1 mm ≤ JSW ≤ 3.0 mm).

Bias

To minimize potential selection, the present study included hip arthroscopy procedures not only related to FAIS. Thus, a proportion of patients had normal hip joint morphology on radiographs, which allows us to determine the effect of bony deformity (cam, pincer, dysplasia) on acetabular and femoral head cartilage status in patients with abnormal hip morphology versus patients with normal hip morphology (Table 1).

Sample Size Consideration

In multivariate logistic regression analyses, attempts to lower the risk of overfitting—that is, too many independent predictor variables as compared with the lowest number of events of the dependent variable—should be prioritized to secure adequate validity and precision, with a suggested 5 to 10 events per variable.[33] In the present study, the number of events of the dependent variables is as follows: Beck (grade 0-2: n = 901 vs grade 3-4: n = 610) and ICRS (grade 0-2: n = 1439 vs grade 3-4: n = 72), indicating sufficient statistical power to include 10 predictor variables in both analyses.[33]

Statistical Methods

The association, calculated as OR, between the dependent outcome variables (Beck grade 0-2 vs 3-4 or ICRS grade 0-2 vs 3-4) and independent predictor variables was derived with multivariate logistic analysis, with all predictor variables entered in the model for each dependent outcome variable. The 10 predictor variables included were as follows: age 15 to <30 years (vs age >30 years; dichotomized variable), sex (dichotomized variable), HSAS score (continuous variable), cam deformity (vs normal AA; dichotomized variable), severe cam deformity (vs normal AA; dichotomized variable), pincer deformity (vs normal LCEA; dichotomized variable), borderline dysplasia (vs normal LCEA; dichotomized variable), mild reduction in JSW (vs normal JSW; dichotomized variable), and severe reduction in JSW (vs normal JSW; dichotomized variable). The statistical analyses were performed in SPSS (v 23; IBM) with a significance level set at .05.

TABLE 1
Overview of Demographic, Radiographic, and Operative Data on Included Patients[a]

	n (%) or Mean ± SD
Demographic data	
Sex: female	781 (51.7)
Age at surgery, y	34.9 ± 9.8
Hip Sports Activity Scale score at the time of surgery	2.62 ± 2.02
Radiographic data	
AA	
Mean AA, deg	68.7 ± 13.3
Normal (AA <55°)	222 (14.7)
Cam deformity (55° ≤ AA < 78°)	836 (55.3)
Severe cam deformity (AA ≥78°)	453 (30.0)
LCEA	
Mean LCEA, deg	31.4 ± 5.0
Normal (25° ≤ LCEA ≤ 39°)	1321 (87.4)
Pincer deformity (LCEA >39°)	111 (7.3)
Borderline dysplasia (LCEA <25°)	79 (5.2)
JSW, mm	
Normal (JSW >4.0)	987 (65.3)
Mild reduction (3.1 ≤ JSW ≤ 4.0)	472 (31.2)
Severe reduction (2.1 ≤ JSW ≤ 3.0)	52 (3.4)
Operative data	
Beck classification	
Grade 0-2	901 (59.6)
Grade 3-4	610 (40.4)
ICRS classification	
Grade 0-2	1439 (95.2)
Grade 3-4	72 (4.8)
Most common operative procedures	
Labral repair	1395 (92.3)
Reshaping of femoral head-neck junction	1372 (90.8)

[a]AA, alpha angle; ICRS, International Cartilage Repair Society; LCEA, lateral center-edge angle; JSW, joint space width.

RESULTS

Participants

Out of the eligible 1923 hip arthroscopy procedures, 1511 were included, owing to missing radiographic and/or operative data on 412 procedures (Table 1).

TABLE 2
Multivariate Logistic Analysis: Association Between Presurgery Demographic and Radiographic Findings and Moderate to Severe Acetabular Cartilage Injury Identified During Hip Arthroscopy[a]

	Odds Ratio (95% CI)[b]	P Value
Demographic data		
Higher age[c]	1.70 (1.30-2.22)	.001[d]
Increasing HSAS[e]	1.06 (1.00-1.13)	.0740
Male sex	4.42 (3.47-5.62)	.001[d]
Radiographic data		
AA		
Normal (AA < 55°)	Reference	
Cam deformity (55° ≤ AA < 78°)	2.23 (1.48-3.34)	.001[d]
Severe cam deformity (AA ≥ 78°)	4.82 (3.14-7.41)	.001[d]
LCEA		
Normal (25° ≤ LCEA ≤ 39°)	Reference	
Pincer deformity (LCEA >39°)	0.67 (0.42-1.07)	.091
Borderline dysplasia (LCEA <25°)	1.28 (0.77-2.14)	.340
JSW, mm		
Normal (JSW >4.0)	Reference	
Mild reduction (3.1 ≤ JSW ≤ 4.0)	2.04 (1.58-2.64)	.001[d]
Severe reduction (2.1 ≤ JSW ≤ 3.0)	3.19 (1.62-6.30)	.001[d]

[a]AA, alpha angle; HSAS, Hip Sports Activity Scale; LCEA, lateral center-edge angle; JSW, joint space width.
[b]For identifying moderate to severe (Beck grade 3-4) acetabular cartilage injury.
[c]Age: 15 to <30 years vs 30 to 50 years.
[d]$P < .05$.
[e]Per increase in score.

Acetabular Cartilage Status

Independent predictor variables associated with increased risk of moderate to severe acetabular cartilage injury (Beck grade 3-4) were as follows: higher age (OR, 1.70; $P < .001$), male sex (OR, 4.42; $P < .001$), cam deformity (OR, 2.23; $P < .001$), severe cam deformity (OR, 4.82; $P < .001$), mild reduction in JSW (OR, 2.04; $P < .001$), and severe reduction in JSW (OR, 3.19; $P = .001$). Conversely, pincer deformity (OR, 0.67; $P = .091$) showed a trend toward reduced risk of moderate to severe acetabular cartilage injury (Table 2, Figure 1). The model showed adequate goodness of fit (Hosmer and Lemeshow test, $\chi^2[8] = 6.944$; $P = .543$).

Femoral Head Cartilage Status

Independent predictor variables associated with increased risk of moderate to severe femoral head cartilage injury (ICRS grade 3-4) were as follows: higher age (OR, 1.92; $P = .041$), increasing HSAS (OR, 1.13 for every increase in HSAS level; $P = .047$), borderline dysplasia (OR, 3.08; $P = .004$), mild reduction in JSW (OR, 2.63; $P < .001$), and severe reduction in JSW (OR, 3.04; $P = .033$) (Table 3, Figure 2). The model showed adequate goodness of fit (Hosmer and Lemeshow test, $\chi^2[8] = 7.239$; $P = .511$).

DISCUSSION

This cross-sectional study showed that several demographic and radiographic findings were associated with grade 3-4 acetabular and femoral head cartilage injury in patients undergoing hip arthroscopy for hip-related groin pain. Notably, cam deformity (AA >55°) and severe cam deformity (AA >78°) substantially increased the odds of grade 3-4 acetabular cartilage damage. Furthermore, acetabular borderline dysplasia was associated with grade 3-4 femoral head cartilage injury. The present study is the first to adopt established and agreed-on cutoffs for defining bony hip deformities in line with contemporary literature on FAIS[15] and hip osteoarthritis[1,4] and to use a well-defined cartilage injury classification system in line with studies investigating predictors of postoperative outcomes.[30,37] Thus, these observations—that specific hip bony deformities are associated with specific hip joint cartilage injury patterns in young to middle-aged patients with FAIS—support what Ganz et al[14] proposed in 2003, by providing ORs for these associations.

Demographic Factors and Hip Cartilage Injury

Male sex and increasing age were associated with grade 3-4 acetabular cartilage injury, whereas increasing age and HSAS were associated with grade 3-4 femoral head cartilage injury. Consistent with the present findings, previous studies have identified male sex as a risk factor for acetabular cartilage injury in mixed[39] and adolescent[31] cohorts. The reason for this is unknown; however, it has been suggested that females have a lower pain threshold, leading to earlier presentation and/or surgery and, consequently, less osteoarthritic changes.[31] In line with the present study, increasing age has been linked to cartilage injury in previous research.[31,39] Thus, it can be speculated that age is positively related to the cumulative stress to the

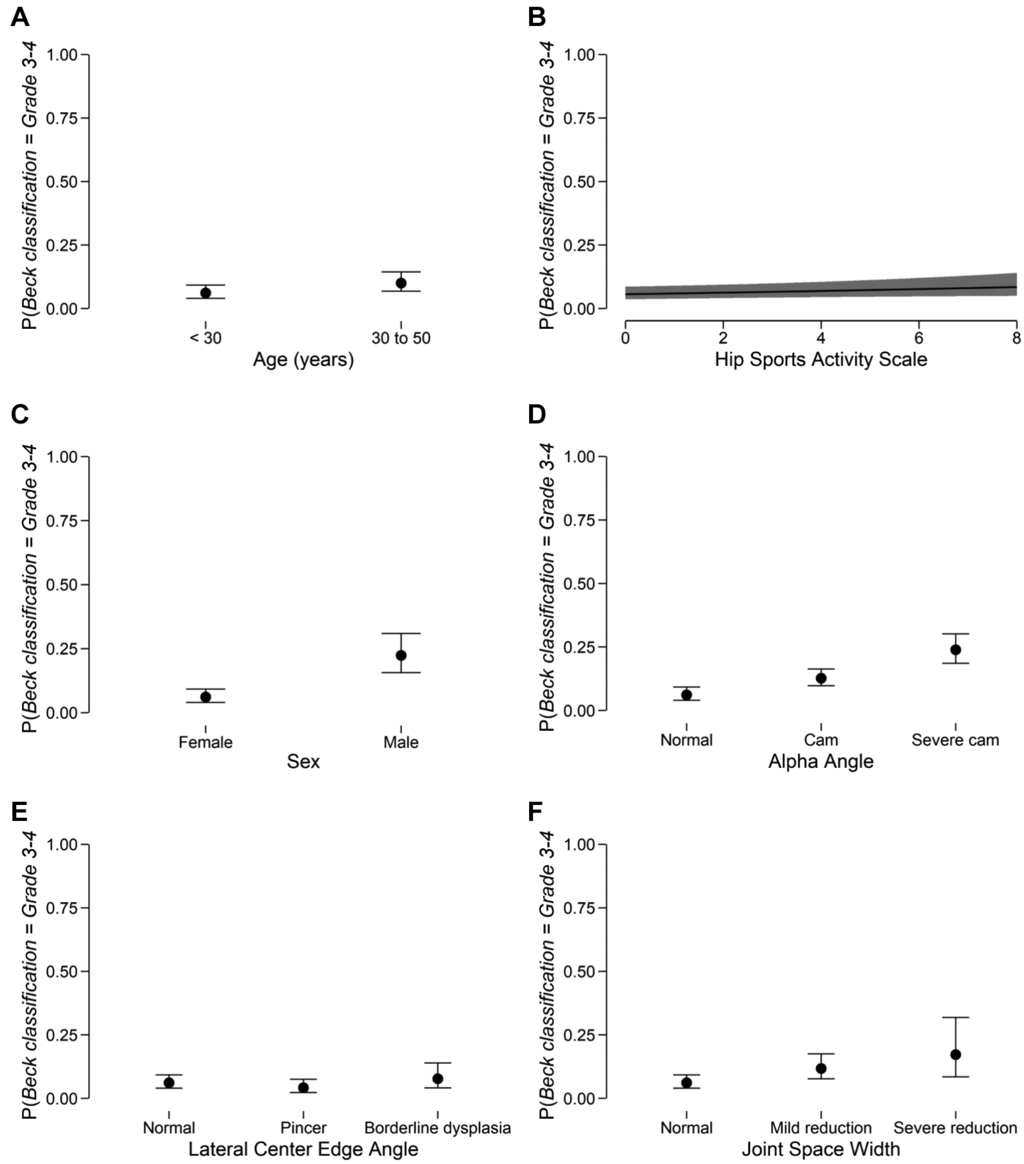

Figure 1. Conditional estimate plots depict the probability from 0 (0%) to 1 (100%) of moderate to severe (grade 3-4) acetabular cartilage injury as measured with the Beck classification based on each independent predictor variable of (A) age, (B) sport activity level, (C) sex, (D) alpha angle (AA), (E) lateral center-edge angle (LCEA), and (F) joint space width (JSW), given that all other predictor variables are held constant at their reference values. Error bars (categorical variables) and shaded area (continuous variables) show 95% CIs. AA is categorized as normal (AA $<55°$), cam deformity ($55° \leq$ AA $< 78°$), or severe cam deformity (AA $\geq 78°$). LCEA is categorized as normal ($25° \leq$ LCEA $\leq 39°$), pincer deformity (LCEA $>39°$), or borderline dysplasia (LCEA $<25°$). JSW is categorized as normal (JSW >4.0 mm), mild reduction (3.1 mm $\leq$ JSW $\leq$ 4.0 mm), or severe reduction (2.1 mm $\leq$ JSW $\leq$ 3.0 mm).

hip joint,[31] resulting in more degenerative changes over time owing to impaired mechanical properties of the cartilage often seen in patients with FAIS.[48] In the present study, increasing HSAS score was weakly (OR, 1.13) associated with grade 3-4 femoral head cartilage injury, whereas HSAS tended (P = .074) to be associated with grade 3-4 acetabular cartilage injury. It should, however, be noted that patients scheduled for hip arthroscopy often show a reduction in sport activity level before surgery as compared with that before onset of hip symptoms[46]; thus, the sport activity level obtained in the present study may likely be lower than that before onset of hip pain. Regardless, as higher HSAS scores reflect more demanding and high-impact sports,[38] this could expose the cartilage at a particular risk of injury even before onset of symptoms.[47] In support of this, participation in elite high-impact sports, such as football and handball, is associated with increased risk of hip osteoarthritis as compared with matched controls.[53]

TABLE 3
Multivariate Logistic Analysis: Association Between Presurgery Demographic and Radiographic Findings and Moderate to Severe Femoral Head Cartilage Injury Identified During Hip Arthroscopy[a]

	Odds Ratio (95% CI)[b]	*P* Value
Demographic data		
Higher age[c]	1.92 (1.03-3.57)	.041[d]
Increasing HSAS[e]	1.13 (1.00-1.27)	.047[d]
Male sex	1.22 (0.73-2.06)	.447
Radiographic data		
AA		
Normal (AA < 55°)	Reference	
Cam deformity (55° ≤ AA < 78°)	0.67 (0.33-1.34)	.259
Severe cam deformity (AA ≥ 78°)	0.82 (0.39-1.73)	.597
LCEA		
Normal (25° ≤ LCEA ≤ 39°)	Reference	
Pincer deformity (LCEA >39°)	0.97 (0.38-2.50)	.949
Borderline dysplasia (LCEA <25°)	3.08 (1.34-6.61)	.004[d]
JSW, mm		
Normal (JSW >4.0)	Reference	
Mild reduction (3.1 ≤ JSW ≤ 4.0)	2.63 (1.58-4.38)	<.001[d]
Severe reduction (2.1 ≤ JSW ≤ 3.0)	3.04 (1.07-8.45)	.033[d]

[a]AA, alpha angle; HSAS, Hip Sports Activity Scale; ICRS, International Cartilage Repair Society; LCEA, lateral center-edge angle; JSW, joint space width.
[b]For identifying moderate to severe (ICRS grade 3-4) femoral head cartilage injury.
[c]Age: 15 to <30 years vs 30 to 50 years.
[d]*P* < .05.
[e]Per increase in score.

Radiographic Factors and Hip Cartilage Injury

The present study observed increased odds of grade 3-4 acetabular cartilage injury in patients with cam deformity (increasing AA) and reduced JSW, whereas reduced JSW and borderline dysplasia (LCEA <25°) were associated with grade 3-4 femoral head cartilage injury. Regarding acetabular cartilage injury, previous studies have linked cam deformity to increased risk.[21,31,39] Nepple et al[39] evaluated 355 hips undergoing hip arthroscopy and observed increased odds (OR, 3.0) of severe (grade 3-4) acetabular cartilage injury in hips with an AA >50°. Nepple et al investigated the presence of cam deformity on a dichotomous scale; thus, our study extends their findings as we included 3 levels of cam severity. This allowed us to report a potential dose-association relationship between cam severity and cartilage injury in line with the established risk of end-stage osteoarthritis with increasing cam deformity.[1,51] We observed an OR of 2.23 for grade 3-4 acetabular cartilage in patients with cam deformity (55° ≤ AA < 78°) and an OR of 4.82 in the presence of severe cam deformity (AA ≥78°) as compared with a normal AA (<55°). This observation is in line with the findings of McClincy et al,[31] who observed an increased odds (OR, 1.77) in acetabular cartilage injury for each increase in AA of 10° starting from 45° in an adolescent cohort undergoing hip arthroscopy for FAIS. However, the degree of cartilage injury in that study was not reported.

Borderline dysplasia was associated with grade 3-4 femoral head cartilage injury corresponding to an OR of 3.08 as compared with a normal LCEA of 25° to 39°. In line with this, Bolia et al[6] found that patients undergoing hip arthroscopy for FAIS with an LCEA of 20° to 25° were 10 times more likely to have a grade 3-4 femoral head cartilage injury as compared with patients with an LCEA of 25° to 40°. Furthermore, they did not observe any difference regarding the prevalence of grade 3-4 acetabular cartilage injury between groups, indicating that dysplasia may primarily result in cartilage degeneration at the femoral head rather than at the acetabulum, as confirmed in the present study.

Although not statistically significant (*P* = .091), pincer deformity was associated with reduced odds (OR, 0.67) of grade 3-4 acetabular cartilage injury. In line with this, McClincy et al[31] observed an OR of 0.24 for acetabular cartilage injury in adolescents with a positive crossover sign indicative of pincer deformity who were undergoing hip arthroscopy for FAIS, suggesting that pincer deformity may be protective of intra-articular degenerative changes.

Reduced JSW was associated with grade 3-4 acetabular and grade 3-4 femoral head cartilage injury, corresponding to an increase in OR of 2.04 (mild reduction) to 3.19 (severe reduction) and 2.63 (mild reduction) to 3.04 (severe reduction), respectively. These findings are in line with those of Nepple et al,[39] who observed increased odds (OR, 3.7) of grade 3-4 acetabular cartilage injury in patients with Tönnis grade 1-2 (slight to moderate joint space narrowing) as compared with a Tönnis grade 0. In contrast, McClincy et al[31] observed no association between JSW and acetabular cartilage injury in an adolescent cohort. However, it should be noted that the interquartile range in their cohort was 5 to 6 mm, indicating that the majority of the patients had a normal JSW.

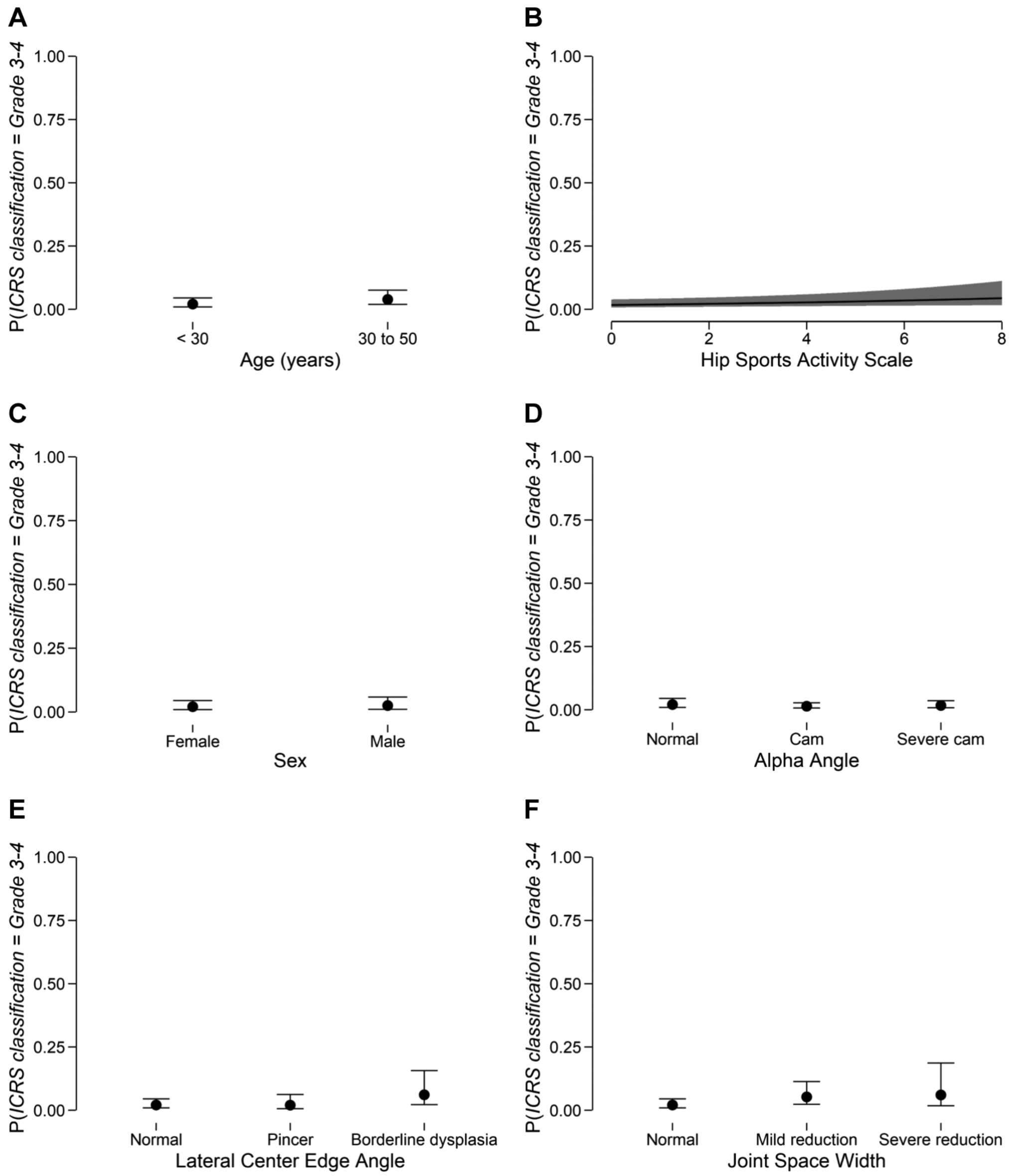

Figure 2. Conditional estimate plots depict the probability from 0 (0%) to 1 (100%) of moderate to severe (grade 3-4) femoral head cartilage injury measured with the International Cartilage Repair Society (ICRS) classification based on each independent predictor variable of (A) age, (B) sport activity level, (C) sex, (D) alpha angle (AA), (E) lateral center-edge angle (LCEA), and (F) joint space width (JSW), given that all other predictor variables are held constant at their reference values. Error bars and shaded area show 95% CIs. AA is categorized as normal (AA $<55°$), cam deformity ($55° \leq$ AA $< 78°$), or severe cam deformity (AA $\geq 78°$). LCEA is categorized as normal ($25° \leq$ LCEA $\leq 39°$), pincer deformity (LCEA $>39°$), or borderline dysplasia (LCEA $<25°$). JSW is categorized as normal (JSW >4.0 mm), mild reduction (3.1 mm $\leq$ JSW $\leq$ 4.0 mm), or severe reduction (2.1 mm $\leq$ JSW $\leq$ 3.0 mm).

Etiology of Hip Cartilage Injury

The present findings provide evidence for the proposed etiology of cartilage injury and progression of osteoarthritis in young to middle-aged symptomatic patients with cam deformity.[5,14] In the initial proposal, cam deformity was hypothesized to lead to shear forces driving degeneration of the acetabular cartilage.[14] Loss of proteoglycan content in the acetabular cartilage, including a 70% reduction in compressive stiffness of the cartilage, has been observed in patients with cam deformity.[48] This may be explained by increased contact forces acting at the acetabular subchondral bone, potentially increasing the load on the acetabular cartilage.[41,49] Furthermore, a dose-response relationship between AA and cartilage contact pressures has been suggested.[28] The present study findings extend on these laboratory observations by indicating a similar dose-response relationship between cam severity and grade

3-4 acetabular cartilage injury in young to middle-aged patients with FAIS. Thus, it is likely that continuously loading a hip joint with cam deformity may lead to increased risk of severe cartilage injury and hip osteoarthritis. Consequently, the present study strengthens the observation in middle-aged to elderly patients with cam deformity where a 3- to 10-fold increased risk of progressing from early symptomatic to end-stage osteoarthritis was found.[1] In contrast, pincer deformity was not associated with increased risk of grade 3-4 cartilage injury in the present study and may even reduce the risk of hip osteoarthritis.[3]

The association between borderline dysplasia and grade 3-4 femoral head cartilage injury observed in the present study is consistent with an increased risk of end-stage osteoarthritis in dysplastic hips.[3,51] Increased cartilage injury at the femoral head rather than at the acetabulum may be explained by the lateral shift of the femoral head increasing the loading on the acetabular labrum and cartilage of the femoral head, while only leading to limited changes in contact forces at the acetabulum.[19]

Limitations

Our cross-sectional study design means that we report associations among variables rather than causation. However, our findings are in line with those from experimental and laboratory studies suggesting a causal relationship between bony hip deformities and cartilage injury.[19,28] To minimize potential selection bias of surgical procedures, the present study included hip arthroscopies not only related to FAIS. However, the DHAR does not contain information on specific indications for surgery, which may be considered a limitation of the present study. Furthermore, although the present study included information on sport activity level, this was obtained immediately before surgery and thus likely does not represent sport activity before onset of symptoms or during maturation. Such information is a potentially important confounder, since high-impact sport activities are associated with hip osteoarthritis[53] and cam development.[2] Finally, hip morphology was based on plain radiographs only,[29] which may not accurately reflect morphology in some cases as compared with magnetic resonance imaging or computerized tomography.[40] However, a cross-table lateral view or similar was adopted,[15,29] which has shown high accuracy as compared with magnetic resonance imaging in assessing cam deformities at the anterosuperior aspect.[11]

CONCLUSION

Several demographic and radiographic factors were associated with grade 3-4 hip joint cartilage injury in patients undergoing hip arthroscopy. Particularly, increasing cam severity showed a dose-response association with grade 3-4 acetabular cartilage injury, whereas borderline dysplasia was associated with grade 3-4 femoral head cartilage injury. This indicates the potential role of these bony hip deformities in the progression of cartilage injury in FAIS among young to middle-aged patients.

ACKNOWLEDGMENT

The authors thank the Steering Committee of the DHAR for allowing access to registry data.

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Study II

Ishøi, L., Thorborg, K., Ørum, M. G., Kemp, J. L., Reiman, M. P., & Hölmich, P. (2021). How Many Patients Achieve an Acceptable Symptom State After Hip Arthroscopy for Femoroacetabular Impingement Syndrome? A Cross-sectional Study Including PASS Cutoff Values for the HAGOS and iHOT-33. Orthopaedic Journal of Sports Medicine, 9(4), 2325967121995267.

Original Research

How Many Patients Achieve an Acceptable Symptom State After Hip Arthroscopy for Femoroacetabular Impingement Syndrome?

A Cross-sectional Study Including PASS Cutoff Values for the HAGOS and iHOT-33

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Background: Hip arthroscopy is a viable treatment for femoroacetabular impingement syndrome (FAIS). Clinically relevant improvements in hip function and pain after surgery are often reported, but it is less clear how many patients achieve an acceptable symptom state (Patient Acceptable Symptom State [PASS]).

Purpose: To investigate the proportion of patients who achieved a PASS 12 to 24 months after hip arthroscopy and to determine the cutoff scores of the 2 recommended and valid patient-reported outcome measures (the subscales of the Copenhagen Hip and Groin Outcome Score [HAGOS] and the International Hip Outcome Tool—33 [iHOT-33]) for which patients are most likely to achieve PASS.

Study Design: Cohort study; Level of evidence, 3.

Methods: Eligible study patients were identified in the Danish Hip Arthroscopy Registry. An electronic questionnaire was used to collect data on PASS, HAGOS, and iHOT-33 12 to 24 months after surgery. PASS was measured using an anchor question. Receiver operating characteristic curve analyses were applied to identify the PASS cutoff values of HAGOS and iHOT-33 scores.

Results: A total of 137 individuals (mean age at surgery, 35.4 ± 9.4 years) were included in the study at a mean follow-up of 18.5 ± 3.2 months after surgery. At follow-up, 64 individuals (46.7%; 95% CI, 38.6-55.1) reported PASS. Higher HAGOS and iHOT-33 values were observed for participants who reported PASS compared with those who did not report PASS (Cohen $d \geq 1.06$; $P < .001$). Cutoff scores for HAGOS subscales (42.5-82.5) and iHOT-33 (67.00) showed excellent to outstanding discriminative ability in predicting PASS (area under the curve, 0.82-0.92).

Conclusion: In total, 46% of individuals having hip arthroscopy for FAIS achieved PASS at 12 to 24 months of follow-up. Patients who achieved PASS had statistically significant and substantially better self-reported hip function compared with those who did not achieve PASS. Cutoff values at HAGOS subscales and iHOT-33 showed excellent to outstanding discriminative ability in predicting patients with PASS.

Keywords: hip arthroscopy; Patient Acceptable Symptom State; PASS; patient-reported outcome measure; HAGOS; iHOT-33

Femoroacetabular impingement syndrome (FAIS) is a common cause of hip-related groin pain, mainly diagnosed in young and middle-aged physically active individuals.[33] FAIS is defined as a motion-related disorder of the hip joint,[11] predisposing to acetabular labral and cartilage injuries,[10,19] and end-stage osteoarthritis.[1]

FAIS is often treated surgically using hip arthroscopy.[8,34] A recent meta-analysis of 2 randomized controlled trials (RCTs) has found evidence for a small positive effect size (0.32; 95% CI, 0.07-0.57) of hip arthroscopy versus nonoperative treatment at 6 to 12 months of follow-up.[12,22,32] Additionally, many cohort studies suggest that hip arthroscopy for FAIS is associated with large and clinically relevant improvements in pain and function pre- to postoperatively.[17,23,24,30,39] Many patients, however, still present with persistent hip and groin pain and functional

The Orthopaedic Journal of Sports Medicine, 9(4), 2325967121995267
DOI: 10.1177/2325967121995267

limitations after surgery,[17,18,21,39] indicating that discrepancies may exist between "getting better" and "feeling good."[25] To better understand if patients consider their current state of health (eg, pain and function) to be at an acceptable level after hip arthroscopy for FAIS, the Patient Acceptable Symptom State (PASS) can be used.[5,25] A 2015 study determined the cutoff scores of the modified Harris Hip Score (mHHS) and the Hip Outcome Score (HOS) for patients to be considered to have achieved PASS. Based on cutoff scores, approximately 65% achieved PASS.[5] In addition, a recent systematic review showed that the majority of studies on hip arthroscopy did not achieve the PASS cutoff score for the HOS Sport subscale; however, this was measured across studies and not on an individual patient level.[21] Furthermore, recent consensus statements and systematic reviews do not recommend the use of mHHS and HOS to evaluate patients with FAIS due to lack of content validity.[11,15,40] The Copenhagen Hip and Groin Outcome Score (HAGOS)[38] and the International Hip Outcome Tool-33 (iHOT-33)[29] are recommended as the 2 preferred self-reported outcome measures to assess hip-related pain and function in young and middle-aged patients.[11,15,40] Thus, combining PASS with HAGOS and/or iHOT-33[15] could provide important information on the symptom state after hip arthroscopy for FAIS. This may help guide decision making before treatment,[27] which is particularly relevant given the rapid rise in the number of patients diagnosed with FAIS.[34]

Therefore, the primary aim was to investigate the proportion of patients who achieved a PASS at 12 to 24 months after hip arthroscopy with a secondary aim to determine the cutoff values of the HAGOS subscales and iHOT-33 scores that indicate PASS after hip arthroscopy.

METHODS

Study Design

This cross-sectional survey study investigated the proportion of individuals with PASS 12 to 24 months after hip arthroscopy for FAIS as the primary outcome measure, and the cutoff values of the HAGOS subscales[38] and iHOT-33 scores[29] for obtaining PASS as secondary outcomes. All eligible individuals and associated radiographic and operative data, were identified and extracted from the Danish Hip Arthroscopy Registry, initiated in 2012 with ongoing prospective registration of hip arthroscopies performed at 11 public and private hospitals in Denmark.[31] The reporting adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.[41] The study was deemed exempt from ethics review, as no intervention or testing of participants was conducted and all data were extracted from a registry approved by the Danish health authorities.[31] The study was approved by the data agency of the capital region (ID: P-2019-277).

Study Setting

Demographic, radiological, and operative data, including preoperative HAGOS subscale scores, were extracted retrospectively on eligible participants from the Danish Hip Arthroscopy Registry undergoing hip arthroscopy between September 26, 2017, to September 26, 2018. Subsequently, we sent out questionnaires (PASS,[5] HAGOS,[38] and iHOT-33[29]) to patients.

Participants

Data on 232 eligible patients who had undergone hip arthroscopy for FAIS during the preceding 12 to 24 months were extracted from the Danish Hip Arthroscopy Registry.[31] Radiological and operative data were registered by the operating surgeons. Inclusion criteria were men/women aged 18 to 50 years at the time of surgery; treated for FAIS (minimal surgical procedures: cam resection and labral surgery) in the preceding 12 to 24 months; and preoperative evidence of cam morphology defined as an alpha angle $\geq 55^\circ$.[11] Exclusion criteria were pure pincer morphology; a joint space width <3 mm; borderline hip dysplasia defined as a lateral center-edge angle $<25^\circ$; pure extra-articular surgical procedure; a previous periacetabular osteotomy; revision hip arthroscopy; total hip arthroplasty; previous hip pathology such as Perthes disease, slipped capital femoral epiphysis and/or avascular necrosis of the femoral head; or any rheumatoid disease in the hip joint such as synovial chondromatosis.

Data Collection

Postoperative patient-reported outcome measures (PROMs: PASS,[5] HAGOS,[38] and iHOT-33[29]) were collected using a web-based survey distributed to eligible participants 12 to 24 months after the hip arthroscopy. The survey was delivered using the Research Electronic Data Capture (REDCap) tools (V 7.1.1; Vanderbilt University) hosted at the capital region of Denmark.[13] Eligible individuals were contacted through a secure email system based on their civil

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Final revision submitted October 18, 2020; accepted November 23, 2020.

The authors declared that there are no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was waived by the Danish Ethics Committee of the Capital Region.

registration number and provided with a unique password-secured link to the survey. Reminder emails were sent once a week for 3 consecutive weeks to all nonresponders.

Outcome Measures

The primary outcome measure was the proportion of patients who achieved a PASS at 12 to 24 months after hip arthroscopy for FAIS. This was measured using the following question (yes/no response): "Taking into account your hip and groin function and pain and how it affects your daily life including your ability to participate in sport and social activities, do you consider that your current state is acceptable if it remained like that for the rest of your life?"[5,25] As secondary outcomes, we assessed the discriminative ability, measured as the area under the curve (AUC),[14] and the cutoff scores, based on the Youden index,[45] of the HAGOS subscales and iHOT-33 scores beyond which patients are more likely to achieve PASS.[25] The HAGOS consists of 37 items divided into 6 subscales for symptoms, pain, physical function in activities of daily living (ADL), function in sport and recreation, participation in physical activities, and quality of life (QOL). Each question is assessed on a 5-point Likert scale with a corresponding score of 0 to 4. Subsequently, a score ranging from 0 (extreme symptoms) to 100 (no symptoms) is calculated for each subscale.[38] The iHOT-33 consists of 33 items covering aspects of symptoms and functional limitation; sports and recreational activities; job-related concerns; and social, emotional, and lifestyle concerns. Each question is scored on a visual analog scale of 0 to 100 mm with higher values indicating better QOL. The overall score is calculated as the average score across items.[29]

Finally, we measured PASS in relation to sports function ($PASS_{Sport}$) and activities of daily living ($PASS_{ADL}$) separately, since patients with FAIS often seem be severely impaired in sports function, rather than daily activities.[17,39] This was done using the following question for $PASS_{Sport}$: "Taking into account your hip and groin function and pain, and how it affects your ability to participate in sport, do you consider that your current state is acceptable if it remained like that for the rest of your life?" And for $PASS_{ADL}$: "Taking into account your hip and groin function and pain, and how it affects your ADL, do you consider that your current state is acceptable if it remained like that for the rest of your life?" In addition, we analyzed the associations, measured as odds ratio, between $PASS_{Sport}$ and $PASS_{ADL}$ with the overall PASS.

Bias

To reduce potential selection bias associated with only including patients from a single hip arthroscopy center and surgeon, we identified eligible patients in the Danish Hip Arthroscopy Registry.[31] Additionally, we aimed for homogeneity of the study sample by including individuals who had been treated with both cam resection and acetabular labral surgery.[26] Thus, pincer FAIS alone was not included, as this condition is less likely to result in intra-articular pathology.[2,19] Furthermore, we used PROMs to evaluate the current state of health to avoid the potential that stakeholders, such as physiotherapists or surgeons, could bias the outcome.

Sample Size Considerations

The number of eligible individuals in the Danish Hip Arthroscopy Registry and responders determined the sample size of the study. With an expected proportion of patients who achieved PASS of approximately 50%,[32] a precision of 10%, and a 95% CI, 96 patients were needed.[42] This would also meet the minimum required sample size for detecting an AUC of $\geq$0.7 (acceptable discrimination) with an alpha and beta level of .05 and 0.2, respectively (V 19.2.1; MedCalc Software).

Statistical Analysis

Data derived from the PASS, $PASS_{Sport}$, and $PASS_{ADL}$ were calculated using percentages with corresponding 95% CIs. Logistic regression analyses were conducted to assess the associations, measured as odds ratios, between both $PASS_{Sport}$ and $PASS_{ADL}$ (independent variables) with overall PASS (dependent variable). HAGOS subscale and iHOT-33 scores at follow-up were compared between participants with and without PASS using independent *t* tests, whereas differences in pre- and postoperative HAGOS subscales scores were analyzed using independent *t* tests, as missing preoperative data precluded paired *t* test analyses. No preoperative iHOT-33 scores were available from the Danish Hip Arthroscopy Registry precluding pre- to postoperative analysis.

Effect sizes for differences were calculated as Cohen *d* and assessed as trivial ($<$0.2), small ($\geq$0.2), medium ($\geq$0.5), and large ($\geq$0.8).[7] The discriminative ability of HAGOS subscale and iHOT-33 scores to predict PASS was analyzed by constructing receiver operating characteristic (ROC) curves for all HAGOS subscale and iHOT-33 scores using the PASS as the dependent variable. Discriminative ability was assessed as the AUC and classified according to Hosmer and Lemeshow[14] as no discrimination (AUC = 0.5), poor discrimination ($0.5 < AUC < 0.7$), acceptable discrimination ($0.7 \leq AUC < 0.8$), excellent discrimination ($0.8 \leq AUC < 0.9$), and outstanding discrimination ($AUC \geq 0.9$). The optimal HAGOS subscales and iHOT-33 cutoff scores to best predict the PASS with highest combined sensitivity and specificity, was derived using the Youden index (J = sensitivity + specificity –1), with a higher index score yielding a better combined sensitivity and specificity.[45] The statistical analyses were performed in SPSS V 23 (SPSS Inc), with the significance level set at $P < .05$.

RESULTS

Participants

A total of 140 out of 232 eligible individuals responded to the survey between October 15, 2019, and November 11, 2019 (response rate, 60.3%), of which 137 patients were included; 1 patient declined to participate whereas 2

TABLE 1
Overview of Included Patients and Nonrespondents[a]

	Included (N = 137)	Nonrespondents (n = 92)
Male sex	63 (46)	68 (73.9)[b]
Mean age at surgery, y	35.4 ± 9.4	33.3 ± 9.7
Follow-up, mo	18.5 ± 3.2	
Radiological data		
Alpha angle, deg	72.3 ± 10.7	72.1 ± 10.2
Lateral center-edge angle, deg	31.1 ± 4.3	30.8 ± 4.6
Joint space width >4.0 mm	104 (75.9)	71 (77.2)
Presence of crossover sign	79 (57.7)	43 (46.7)
Cartilage damage	(n = 131)	(n = 86)
Beck classification (acetabulum)		
Normal cartilage	1 (0.7)	0 (0)
Fibrillation	6 (4.6)	10 (11.6)
Wave sign	62 (47.3)	32 (37.2)
Cleavage	45 (34.4)	38 (44.2)
Exposed bone	17 (13.0)	6 (7.0)
ICRS classification (caput femoris)		
Normal cartilage	103 (78.6)	56 (65.1)
Almost normal	10 (7.6)	7 (8.1)
Abnormal	10 (7.6)	13 (15.1)
Severely abnormal	7 (5.3)	7 (8.1)
Exposed bone	1 (0.7)	3 (3.5)
Preoperative HAGOS score	(n = 102)	(n = 59)
Pain	53.5 ± 19.0	50.8 ± 18.8
Symptoms	49.8 ± 18.2	44.9 ± 15.5
Function in activities of daily living	56.4 ± 25.4	50.0 ± 21.7
Function in sport and recreation	37.2 ± 23.9	33.6 ± 20.8
Participation in physical activities	22.7 ± 26.2	22.6 ± 20.2
Quality of life	30.5 ± 15.7	30.3 ± 16.5

[a]Data are reported as n (%) or mean ± SD. HAGOS, Copenhagen Hip and Groin Outcome Score; ICRS, *International Cartilage Regeneration* & Joint Preservation *Society*.

[b]Statistically significant between-group difference in proportion ($P < .001$).

patients were excluded due to not answering the overall PASS question. Of the 137 included patients, data were missing for the following outcomes due to not answering questions: $PASS_{Sport}$ (n = 1); $PASS_{ADL}$ (n = 2); HAGOS (n = 5); and iHOT-33 (n = 27). Detailed characteristics of the included patients and nonresponders are provided in Table 1. A significant difference in proportion was observed for sex between responders and nonresponders ($P < .001$). Significantly higher HAGOS Subscale scores were observed at follow-up compared with preoperatively (d = 0.51-0.94; $P \leq .001$) (Appendix Table A1).

Patient Acceptable Symptom State

At follow-up, 64 participants (46.7%; 95% CI, 38.6-55.1) achieved an overall PASS.

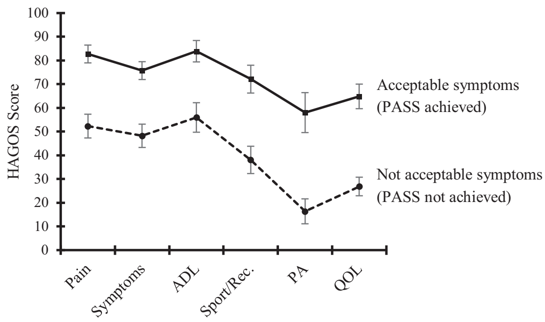

Figure 1. Self-reported hip and groin symptoms and function in individuals with (n = 64; solid line) and without (n = 68; dotted line) a Patient Acceptable Symptom State (PASS) at follow-up for subscales of the Copenhagen Hip and Groin Outcome Score (HAGOS). *X*-axis shows the 6 subscales of HAGOS. ADL, physical function in activities of daily living; PA, participation in physical activities; QOL, quality of life; Sport/Rec, function in sport and recreation. Error bars show 95% CIs.

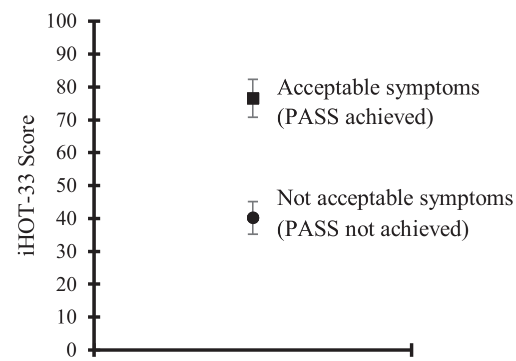

Figure 2. Self-reported hip symptoms in individuals with (n = 53; square) and without (n = 57; circle) a Patient Acceptable Symptom State (PASS) at follow-up for the International Hip Outcome Tool–33 (iHOT-33). Error bars show 95% CIs.

Patient-Reported Outcome Measures Between Participants With and Without PASS

At follow-up, higher HAGOS values were observed for individuals with an acceptable symptom state compared with those without an acceptable symptom state for all subscales corresponding to large effect sizes ($d \geq 1.06$; $P < .001$) (Figure 1 and Appendix Table A2).

Likewise, higher iHOT-33 values were observed for participants with an acceptable symptom state compared with those without an acceptable symptom state corresponding to a large effect size (d = 1.35; $P < .001$) (Figure 2 and Appendix Table A3).

TABLE 2
AUC Values Derived From ROC Curve Analyses and PASS Cutoff Values, and Their Respective Sensitivity and Specificity, for HAGOS Subscales and iHOT-33 Scores[a]

PROM	AUC (95% CI)	Cutoff Value[b,c]	Sensitivity	Specificity
HAGOS subscale				
Pain	0.89 (0.84-0.95)	68.75	0.84	0.79
Symptoms	0.86 (0.80-0.92)	62.50	0.84	0.74
ADL	0.82 (0.74-0.89)	82.50	0.66	0.85
Sport/Rec	0.84 (0.78-0.91)	60.94	0.75	0.81
Physical activity	0.83 (0.75-0.90)	43.75	0.69	0.90
Quality of life	0.92 (0.87-0.97)	42.50	0.84	0.90
iHOT-33	0.88 (0.82-0.95)	67.00	0.74	0.95

[a]ADL, physical function in daily living; AUC, area under the ROC curve; HAGOS, Copenhagen Hip and Groin Outcome Score; iHOT-33, International Hip Outcome Tool–33; PASS, Patient Acceptable Symptom State; PROM, patient-reported outcome measure; ROC, receiver operating characteristic; Sport/Rec, function in sport and recreation.

[b]The cutoff values were derived using the Youden index (J = sensitivity + specificity -1), which is based on the best combined sensitivity and specificity; a higher index score yields a better combined sensitivity and specificity.[45]

[c]The cutoff score represents the score beyond which an individual is more likely to have an acceptable symptom state.

ROC Curve Analyses

For all HAGOS subscales and iHOT-33, the AUC showed excellent to outstanding discriminative ability (AUC, 0.815-0.916) in predicting individuals with PASS (Table 2 and Appendix Figures A1 and A2). The cutoff values, including sensitivity and specificity, for each subscale of HAGOS and iHOT-33, are presented in Table 2.

PASS in Relation to Sport and ADL

At follow-up, 55 individuals (40.4%; 95% CI, 32.6-48.8) and 72 individuals (53.3%; 95% CI, 44.9-61.9) reported an acceptable symptom state in relation to $\text{PASS}_{\text{Sport}}$ and PASS_{ADL}, respectively. Having achieved $\text{PASS}_{\text{Sport}}$ or PASS_{ADL} was associated with overall PASS corresponding to an odds ratio of 168.6 (95% CI, 35.9-793.2) and 30.4 (95% CI, 11.5-80.2), respectively.

DISCUSSION

We found that less than half of patients (46.7%) who had undergone hip arthroscopy for FAIS in the previous 12 to 24 months reported an acceptable symptom state. Additionally, 40.4% and 53.3% had an acceptable symptom state related to $\text{PASS}_{\text{Sport}}$ and PASS_{ADL}, respectively. The cutoff scores, beyond which patients are more likely to achieve PASS,[25] ranged from 42.5 (HAGOS QOL subscale) to 82.5 (HAGOS ADL subscale), whereas the iHOT-33 score was 67. These findings can easily be applied in previous studies where HAGOS and/or iHOT-33 scores have been obtained, to retrospectively quantify the proportion of patients with PASS.

The proportion of patients with a PASS in the present study (46.7%) is similar to a recent multicenter RCT showing that 48% allocated to hip arthroscopy achieved the PASS cutoff score of HOS ADL (≥87 points) at the 8-month follow-up.[32] Similar to the study from Palmer et al,[32] our study included a general population with FAIS from multiple hip arthroscopy centers, indicating that the percentage of patients achieving PASS in a general population is likely about 50%. Of note, cohort studies from single high-volume hip arthroscopy centers and a single surgeon have reported that 60% to 73% of patients seem to achieve PASS based on cutoff scores from HOS Sport (≥72.1 points[35] and ≥75 points[5]), HOS ADL (≥87 points),[5] mHHS (≥74 points),[5,43] and iHOT-33 (≥58 points).[28] Such discrepancy may be explained by surgeon experience, criteria for surgery, and selection bias of patients undergoing surgery. Surprisingly, none of the above studies reported the proportion of patients that achieved PASS based on the question itself,[25] despite having obtained this information for calculation of the cutoff score.[5,28,35] Thus, we argue that the present study is the first to clearly report PASS in a general population after hip arthroscopy for FAIS.

PASS Cutoff Scores for HAGOS and iHOT-33

Our study showed a large difference in all HAGOS subscale and iHOT-33 scores between individuals who achieved PASS versus those who did not achieve PASS, indicating that the PASS question was effective in dichotomizing patients into good and poor outcomes. Consequently, ROC analyses showed excellent to outstanding discriminative ability in predicting PASS with sensitivity and specificity ranging from 0.66 to 0.84 (HAGOS subscales) and 0.74 to 0.95 (iHOT-33). This corresponds well with previous studies of HOS-Sport (cutoff score ≥72.1 points; AUC, 0.886[35] and ≥75 points; sensitivity, 79.6; specificity, 96.9),[5] HOS ADL (cutoff score ≥87 points; sensitivity, 82.7; specificity, 84.4),[5] mHHS (cutoff score ≥74 points; sensitivity, 89.7; specificity, 87.5),[5] and iHOT-33 (cutoff score ≥58 points; AUC, 0.870).[28] However, HOS and mHHS are not recommended as PROMs for patients with FAIS.[15]

To our knowledge, our study is the first to report PASS cutoff values for HAGOS, which is a recommended PROM in young and middle-aged individuals with FAIS.[11,15] The cutoff score for iHOT-33 in the present study is slightly higher than what has previously been reported by Maxwell et al,[28] with a cutoff score of ≥58 points compared with our cutoff score of ≥67 points. This may be due to a different setting (single surgeon vs national registry) or study population in Maxwell et al, which included different diagnoses in their study, with only 36% presenting with cam morphology versus 100% in the present study. Nonetheless, by using these cutoff scores for HAGOS and/or iHOT-33, it is possible to obtain a more detailed profile of the symptomatic state after hip arthroscopy for FAIS, not only relying on pre- to postsurgical improvements and/or achievement of a healthy reference score.[39] As an example, the UK FASHIoN trial, an RCT comparing the effect of hip arthroscopy with nonoperative treatment for FAIS, reported mean iHOT-33 values of 58.8 (hip arthroscopy group) and 49.7 points (nonoperative group) at 12-month follow-up.[12] Thus, based on the iHOT-33 cutoff scores for achieving PASS (approximately 58-67 points),[28] it is likely that approximately half of the patients allocated to hip arthroscopy in the UK FASHIoN trial did not achieve PASS[12]; findings that are similar to the present study, and the Femoroacetabular Impingement Treatment trial where 48% (hip arthroscopy group) achieved the PASS cutoff scores based on HOS ADL.[32]

Sport Function and ADL

To our knowledge, our study is the first to categorize PASS into different domains: $PASS_{Sport}$ and $PASS_{ADL}$. While the PASS is normally employed to investigate the acceptable state of health considering pain and symptoms in all aspects of life,[5,25] achieving or not achieving PASS may be driven by pain and/or symptoms in specific situations and contexts. This is further highlighted by the logistic regression analyses, showing that patients who achieved $PASS_{Sport}$ had the highest odds versus $PASS_{ADL}$ (168 vs 30) of achieving overall PASS. Our results suggest that an acceptable symptom state may be more difficult to achieve in relation to sport compared with ADL (40.4% vs 53.3%). The fact that 60% did not achieve PASS in relation to sport is in line with a recent systematic review reporting that 64% of studies failed to achieve the PASS cutoff score for the HOS Sport subscale.[21] Thus, in a general population, achieving PASS in relation to sports function seems less likely than achieving PASS in relation to ADL. Such information should be included as part of the shared decision-making process before surgery. The discrepancy between $PASS_{ADL}$ and $PASS_{Sport}$ in the present study corresponds well with the notion that the HAGOS ADL subscale has a higher ceiling effect compared with the HAGOS Sport/Rec subscale.[36,38] Therefore, a larger proportion of participants are more likely to report no problems in ADL compared with sport activities. We speculate that problems in sports activities may be the reason for not achieving overall PASS while still having acceptable symptoms during ADL in some patients.[17,18,39] This highlights that including sports function in the PASS question seems crucial to truly capture patient satisfaction.

Different Concepts of PROMs: Getting Better (Minimal Important Change), Feeling Good (PASS), or Getting Back to Normal (Normal Reference Values)

Previous hip arthroscopy studies have mainly used PROMs to deal with the concept of "change scores" over a specific time period.[12,23] While such information is important for establishing the effect of a treatment, a change score may be difficult to interpret for the patient who is about to decide whether to undergo hip arthroscopy (ie, "What does a 15-point improvement on iHOT-33 or HAGOS Sport/Rec actually mean?"). Such information can be obtained using the minimal important change score,[20,25] with data suggesting that most patients (>66%) exceed this and get better from before to 1-year after surgery.[39] While this is useful for the patient to know before treatment, "getting better" is not equivalent to "feeling good,"[39] which is normally measured with PASS.[25] While "feeling good" after hip arthroscopy is often considered a successful treatment outcome, achieving PASS may not reflect a normal state of function. Reference values for HAGOS subscales have previously been defined based on mixed healthy individuals[39] and hip and groin injury-free male soccer players.[37] These scores are generally higher (range, 64.3-100 points)[37,39] compared with the HAGOS subscale PASS cutoff values in the present study (range, 42.5-82.5 points).[39] This discrepancy highlights that patients with FAIS do not need to reach values comparable with healthy individuals in order to "feel good" after hip arthroscopy. We can only speculate why this seems to be the case; one reason may be that patients often have long periods of pain and functional limitations before receiving appropriate treatement.[4,6] Thus, it may be that improvements in pain and function after hip arthroscopy, although not reaching a pain-free level, are regarded as acceptable for many patients also considering their state before treatment. This is further highlighted by the large proportion of patients being satisfied with the treatment, without this necessarily reflecting pain-free function.[3]

Clinical Implications

We believe information based on these different concepts of PROMs (ie, "getting better," "feeling good," and "getting back to normal") is paramount to convey to surgical candidates as part of the shared treatment decision-making process. Such information may also help align preoperative expectations with actual postoperative outcomes.[27] This seems important, as patients with FAIS tend to be overly optimistic regarding the effect of hip arthroscopy, with 53% and 61% of patients not meeting their preoperative expectations for general and sport function, respectively, at the 12-month follow-up.[27] The current literature of postoperative FAIS patients suggests that 60% to 70% exceed the minimal important change and thus get better,[39] around 50% achieve PASS and thus feel good,[32] and 20% to 30% achieve healthy reference values and thus get back to normal function.[39]

Limitations

The present study is not without limitations. First, the response rate of 60% may result in selection bias; however, the responders and nonresponders are comparable in terms of demographic, radiographic, and surgical parameters, whereas our PASS results resemble those from a recent RCT.[32] Second, there are different methods to measure a patient's acceptable symptom state[25]: by using either a dichotomized yes-no question, as in the present study, or by using continuous scales[9] or Likert scales[16] with predefined cutoffs. In addition, the anchor question may be formulated differently, with no consensus on the most appropriate way.[25] Inspired by previous studies,[16,25] we used an anchor question related to acceptable symptoms and function, whereas other studies have used anchor questions related to treatment satisfaction.[9] It is, however, likely that satisfaction with the treatment measures a different construct than postoperative symptoms and function[3]; thus, our PASS question concerned symptoms and function, rather than treatment satisfaction. Additionally, we categorized the overall PASS question into $PASS_{Sport}$ and $PASS_{ADL}$; however, we appreciate that no psychometric properties have been established, and thus these results should be interpreted with caution.

A third limitation is that several ways exist to derive the PASS cutoff values: the Youden index[45]; the 80% specificity method; and the 75th percentile approach. In a study applying all methods, comparable cutoff values of the Harris Hip Score were found after hip arthroplasty.[45] Thus, we used the Youden index[45] in line with previous hip arthroscopy studies.[5,28,35] Fourth, the large dropout of patients not answering the full iHOT-33 questionnaire may have implications for the cutoff score. Finally, it should be acknowledged that PASS cutoff scores may be influenced by cross-cultural differences, age, the patient's own context of what constitutes an acceptable symptom state or not,[44] and the follow-up time point.[9] However, self-reported pain and function in patients with FAIS seems to plateau at 12 to 24 months after surgery.[23] Future studies with large sample sizes should seek to investigate whether PASS cutoff scores after hip arthroscopy are affected by age and sex.

CONCLUSION

In total, 46% of individuals having hip arthroscopy for FAIS achieved PASS at 12 to 24 months of follow-up. Patients who achieved PASS had statistically significant and substantially better self-reported hip function compared with those who did not achieve PASS. Cutoff values at HAGOS subscales and iHOT-33 showed excellent to outstanding discriminative ability in predicting individuals with an acceptable symptom state.

ACKNOWLEDGMENT

The authors thank the steering committee of the Danish Hip Arthroscopy Registry for allowing access to registry data.

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APPENDIX

TABLE A1
Differences in Self-reported Hip and Groin Function Measured With the HAGOS Preoperatively to Postoperatively[a]

HAGOS	Preoperative (n = 102)	Postoperative (n = 132)	Between-Group Difference (95% CI); Cohen d
Symptoms	49.8 ± 18.2	61.6 ± 22.6	11.7 (6.3-17.1); 0.64[b]
Pain	53.5 ± 19.0	67.1 ± 23.7	13.6 (8.0-19.3); 0.72[b]
ADL	56.6 ± 25.4	69.5 ± 26.3	12.9 (6.2-19.7); 0.51[b]
Sport/Rec	37.2 ± 23.9	54.6 ± 29.1	17.3 (10.3-24.3); 0.72[b]
PA	22.7 ± 26.2	36.6 ± 35.0	13.9 (5.7-22.1); 0.53[b]
QOL	30.5 ± 15.7	45.3 ± 26.5	14.7 (8.9-20.6); 0.94[b]

[a]Data are presented as mean ± SD. ADL, physical function in daily living; HAGOS, Copenhagen Hip and Groin Outcome Score; PA, participation in physical activities; QOL, quality of life; Sport/Rec, function in sport and recreation.

[b]Statistically significant difference between groups ($P < .05$).

TABLE A2
Differences in Self-reported Hip and Groin Function Measured With the HAGOS in Patients With and Without an Acceptable Symptom State at Follow-Up[a]

HAGOS	Postoperative (n = 132)	Acceptable Symptom State (n = 64)	Not Acceptable Symptom State (n = 68)	Between-Group Difference (95% CI); Cohen d
Symptoms	61.6 ± 22.6	75.7 ± 15.1	48.2 ± 20.3	27.5 (21.3-33.7); 1.22[b]
Pain	67.1 ± 23.7	82.7 ± 15.0	52.3 ± 20.7	30.4 (24.2-36.7); 1.28[b]
ADL	69.5 ± 26.3	83.9 ± 18.1	56.0 ± 25.7	28.0 (20.2-35.7); 1.06[b]
Sport/Rec	54.6 ± 29.1	72.1 ± 23.5	38.1 ± 23.8	34.1 (25.9-42.2); 1.17[b]
PA	36.6 ± 35.0	58.0 ± 33.7	16.4 ± 21.7	41.6 (31.9-51.4); 1.19[b]
QOL	45.3 ± 26.5	64.8 ± 20.7	26.8 ± 16.2	38.0 (31.6-44.4); 1.43[b]

[a]Data are presented as mean ± SD. ADL, function in activities of daily living; HAGOS, Copenhagen Hip and Groin Outcome Score; PA, function in physical activities; QOL, quality of life; Sport/Rec, function in sport and recreation.
[b]Statistically significant difference between groups ($P < .05$).

TABLE A3
Differences in Self-reported Hip and Groin Function Measured With the iHOT-33 in Patients With and Without an Acceptable Symptom State at Follow-up[a]

	Postoperative (n = 110)	Acceptable Symptom State (n = 53)	Not Acceptable Symptom State (n = 57)	Between-Group Difference (95% CI); Cohen d
iHOT-33	57.6 ± 26.8	76.5 ± 20.9	40.2 ± 16.6	36.2 (28.7-43.7); 1.35[b]

[a]Data are presented as mean ± SD. iHOT-33, International Hip Outcome Tool–33.
[b]Statistically significant difference between groups ($P < .05$).

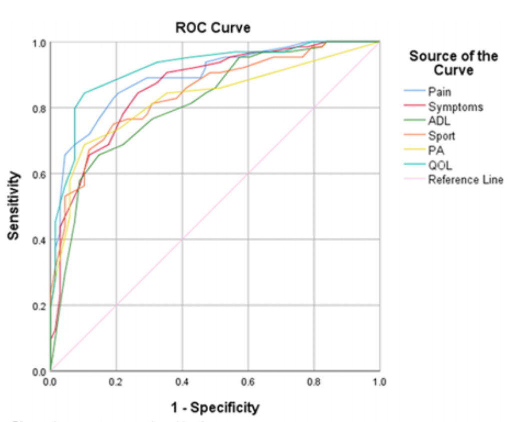

Figure A1. Receiver operating characteristic (ROC) curves for the subscales of the Copenhagen Hip and Groin Outcome Score. ADL, physical function in activities of daily living; PA, participation in physical activities; QOL, quality of life; Sport, function in sport and recreation.

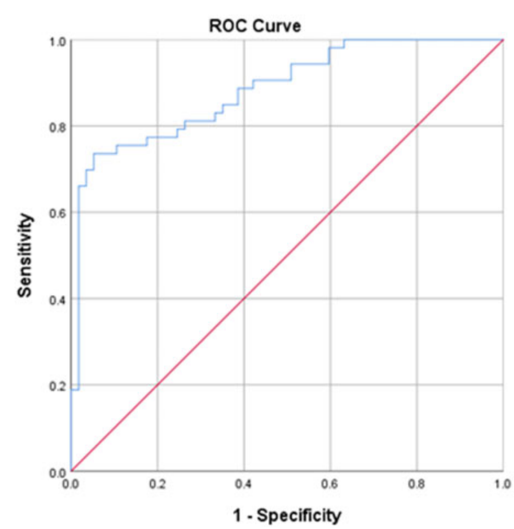

Figure A2. Receiver operating characteristic (ROC) curves for the International Hip Outcome Tool–33. Red line indicates reference line.

Study III

Ishøi, L., Thorborg, K., Kraemer, O., & Hölmich, P. (2018).
Return to Sport and Performance After Hip Arthroscopy for Femoroacetabular Impingement in 18- to 30-Year-Old Athletes: A Cross-sectional Cohort Study of 189 Athletes. The American Journal of Sports Medicine, 46(11), 2578–2587.

Return to Sport and Performance After Hip Arthroscopy for Femoroacetabular Impingement in 18- to 30-Year-Old Athletes

A Cross-sectional Cohort Study of 189 Athletes

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Background: A recent systematic review found that 87% of athletes return to sport after hip surgery for femoroacetabular impingement syndrome. However, the proportion of athletes returning to preinjury sport at their preinjury level of sport is less clear.

Purpose: The main purpose of this study was to determine the rate of athletes returning to preinjury sport at preinjury level including their associated sports performance after hip arthroscopy for femoroacetabular impingement syndrome. Furthermore, self-reported hip and groin function was investigated.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Eligible subjects were identified in the Danish Hip Arthroscopy Registry. A self-reported return to sport questionnaire was used to collect data after hip arthroscopy. If athletes reported they were engaged in preinjury sport at their preinjury level, the associated sports performance and participation were assessed as either (1) optimal sports performance including full sports participation; (2) impaired sports performance, but full sports participation; or (3) impaired sports performance including restricted sports participation. Self-reported hip and groin function was assessed for all athletes by use of the Copenhagen Hip and Groin Outcome Score.

Results: The study included 189 athletes (mean ± SD age at follow-up, 26.9 ± 3.4 years) at a mean ± SD follow-up of 33.1 ± 16.3 months after surgery. At follow-up, 108 athletes (57.1%) were playing preinjury sport at preinjury level, whereas the remaining 81 athletes (42.9%) failed to return to preinjury sport at preinjury level. Of the 108 athletes engaged in their preinjury sport at preinjury level at follow-up, 32 athletes (29.6%) reported optimal sports performance including full sports participation, corresponding to 16.9% of the study sample. Better self-reported hip and groin function was observed in athletes who were engaged in preinjury sport at preinjury level compared with athletes who were not.

Conclusion: Fifty-seven percent of athletes returned to preinjury sport at their preinjury level. This is considerably lower than a previously reported return to sport rate of 87% and may reflect that the present study used a clear and strict definition of return to sport. Of note, only one-third of athletes who returned to preinjury sport at preinjury level reported their sports performance to be optimal, corresponding to 16.9% of the study sample. Better self-reported hip and groin function was observed in athletes who were playing preinjury sport at preinjury level compared with athletes who were not.

Keywords: hip arthroscopy; return to sport; sports performance; patient-reported outcome; HAGOS

Femoroacetabular impingement syndrome (FAIS), a motion-related clinical disorder of the hip joint,[11] is the most common diagnosis leading to hip arthroscopy in athletes with long-standing hip and groin pain.[5] A systematic review with meta-analysis found improvements in self-reported hip function for pain, activity of daily living, sports function, and quality of life after hip arthroscopy for FAIS.[18] However, only a minority of patients seem to obtain normative values of self-reported hip and groin function when compared with healthy controls 12 months after hip arthroscopy.[38]

A systematic review reported a return to sport rate of 87% in professional and recreational athletes at a mean follow-up of 2.3 years after surgery for FAIS.[3] However, the majority of studies included in the systematic review

The American Journal of Sports Medicine
2018;46(11):2578–2587
DOI: 10.1177/0363546518789070

were conducted at single high-volume hip arthroscopy centers using a single surgeon and with varying criteria of return to sport.[3] Such factors are likely to influence the interpretation of the findings. First, using data from a single high-volume hip arthroscopy center including a single surgeon may likely result in selection bias of athletes and may limit extrapolation of findings to other centers and surgeons.[3] Second, because the definition of "return to sport" determines the treatment outcome, using varying and/or unclear definitions will likely affect the outcome.[1] For athletes, the ability to return to their preinjury sport at their preinjury level rather than just return to sport is often the single most important priority.[1] Furthermore, a recent consensus statement highlights the importance of evaluating the associated sports performance and participation.[1] This implies that an athlete can return to preinjury sport at preinjury level without performing at his or her optimal performance or even without participating fully in the sport.[1] However, despite being considered as highly relevant when evaluating return to sport, information on performance and participation has rarely been investigated in subjects returning to sport after hip arthroscopy for FAIS.[3]

Therefore, the primary aim of this cross-sectional survey study was to investigate the rate of return to preinjury sport at preinjury level in athletes who had undergone hip arthroscopy for FAIS and who were registered in a nationwide hip arthroscopy registry. Furthermore, for athletes engaged in their preinjury sport at their preinjury level at follow-up, the associated sports performance and participation were investigated. Finally, we aimed to investigate differences in self-reported hip and groin function between athletes who were playing preinjury sport at preinjury level and athletes who were not.

METHODS

Study Design

This is a cross-sectional survey study investigating rate of return to preinjury sport at preinjury level in athletes after hip arthroscopy for FAIS as the primary outcome measure. Subjects were identified in the Danish Hip Arthroscopy Registry at a follow-up of 6 months to 6 years. The reporting adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommedations.[40] Approval was obtained from the Danish Ethics Committee of the Capital Region (ID: H-17016762) and the Data Agency of the Capital Region (ID: AHH-2016-053).

Study Setting

The Danish Hip Arthroscopy Registry is a nationwide registry with ongoing prospective registration of all hip arthroscopies performed at 11 specialized centers in Denmark since 2012.[27] Participants were retrospectively recruited between September 6, 2017, and October 5, 2017.

Participants

Three-hundred and fifty eligible subjects who had undergone hip arthroscopy for FAIS during the preceding 6 months to 6 years were identified in the Danish Hip Arthroscopy Registry and invited to complete a web-based return to sport questionnaire. Inclusion criteria were male and female patients age 18 to 30 years at the time of surgery and age 35 years or younger at the time of follow-up; presurgery cam deformity on plain radiograph (alpha angle $\geq 55°$)[11]; and surgical procedure consisting of least cam resection and acetabular labral surgery.[10] Exclusion criteria were joint space width less than 3 mm[33]; grade 4 on the Beck cartilage classification (exposed bone in the acetabulum); grade 4 on the International Cartilage Repair Society (ICRS) cartilage classification (exposed bone of the femoral head)[23]; previous hip arthroscopy in the same hip joint; previous hip pathologic conditions such as Perthes disease, slipped capital femoral epiphysis, hip dysplasia (lateral center edge angle [Wiberg angle] $<25°$), and/or avascular necrosis of the femoral head; any rheumatoid disease in the hip joint such as synovial chondromatosis; and any of the following surgical procedures at any time: extra-articular surgery of the hip joint (except capsular closure), microfracture in the hip joint, periacetabular osteotomy, and surgery to the ligamentum teres. Furthermore, subjects were excluded from data analyses if they indicated in the return to sport questionnaire that they did not participate in sport before the initial onset of hip and groin pain (preinjury) or did not intend to return to their preinjury sport at their preinjury level after hip arthroscopy (Figure 1). Informed consent was provided by the participants by responding to the survey.

Data Collection

A web-based survey was used to collect data regarding preinjury and postsurgery sport activities using a custom-made return to sport questionnaire based on recent consensus definitions on return to sport.[1] The questionnaire was pilot-tested at our facility by patients who had undergone a hip arthroscopy for FAIS at 1-year follow-up. Upon completion of the questionnaire, patients were

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The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

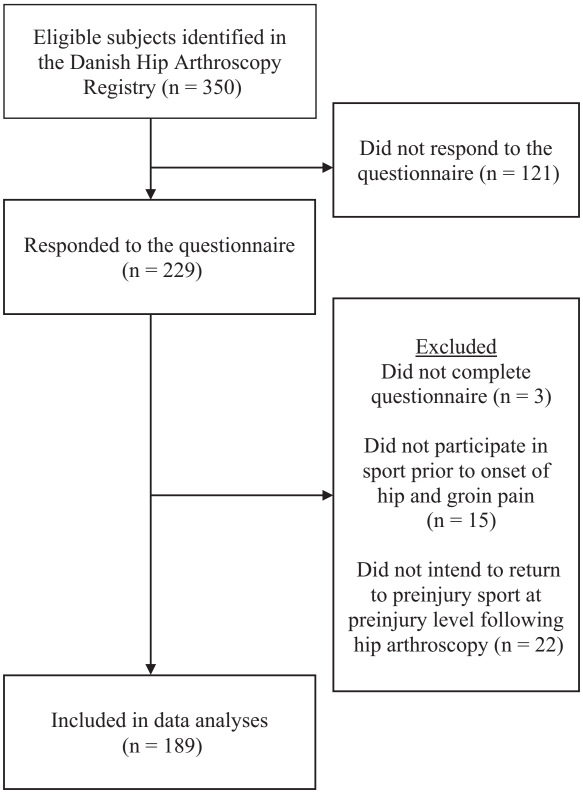

Figure 1. Flow of participants.

contacted by the corresponding author and interviewed on their return to sport status to validate the answers of the questionnaire. Based on this process, the questionnaire was adjusted accordingly. The postsurgical self-reported hip and groin function was assessed by use of the Copenhagen Hip and Groin Outcome Score (HAGOS).[37] The survey was delivered using the Research Electronic Data Capture (REDCap) tools (v. 7.1.1; Vanderbilt University) hosted at the Capital Region of Denmark.[13] Eligible subjects were contacted by email and provided with a unique password-secured link to the survey. Reminder emails were sent once every week for 4 consecutive weeks to all nonresponders.

Outcome Measures

The primary outcome measure was rate of return to sport, defined as the proportion of athletes who were engaged in their preinjury sport at preinjury level at follow-up. This definition was chosen in accordance with a recent consensus statement on return to sport in athletes.[1] Initially, subjects were instructed to indicate their preinjury sport and level of sport (elite, competitive, or recreational). “Preinjury” was defined as before the onset of initial hip and groin pain. If subjects were engaged in sport at the time of preinjury and intended to return to their preinjury sport at preinjury level after hip arthroscopy, they were instructed to indicate whether they were engaged in their preinjury sport at preinjury level. Athletes who were not engaged in their preinjury sport at preinjury level were asked whether this was due to hip and groin pain and whether they had attempted to perform their preinjury sport at preinjury level at any time since surgery. Moreover, they were instructed to indicate their current sports activity as (1) preinjury sport but lower level due to hip and groin pain, (2) different sport due to hip and groin pain, (3) no sport due to hip and groin pain, or (4) change in preinjury sport and/or level of sport unrelated to hip and groin pain.

Athletes who were engaged in their preinjury sport at preinjury level were instructed to indicate their sports performance and participation as either (1) optimal sports performance including full sports participation, defined as the same or better athletic performance compared with preinjury including unrestricted participation in all elements of the sport; (2) impaired sports performance but full sports participation, defined as a lower athletic performance compared with preinjury but unrestricted participation in all elements of the sport; or (3) impaired sports performance including restricted sports participation, defined as a lower athletic performance including restricted participation in at least one element of the sport (eg, match play).[1] Athletes who reported optimal sports performance including full sports participation were instructed to indicate the occurrence of sport-related hip and groin pain assessed on a 5-point Likert scale (always, often, once in a while, rare, never). Athletes who reported either “impaired sports performance but full sports participation” or “impaired sports performance including restricted sports participation” were instructed to indicate whether this was due to hip and groin pain.

Finally, self-reported hip and groin function was obtained by use of the HAGOS questionnaire.[37] HAGOS consists of 37 questions divided into 6 subscales for symptoms, pain, physical function in daily living, function in sport and recreation, participation in physical activities, and quality of life. Each question is assessed on a 5-point Likert scale with a corresponding score of 0 to 4. Subsequently, a score ranging from 0 (extreme symptoms) to 100 (no symptoms) was calculated for each subscale.[37]

Bias

To reduce potential selection bias of athletes from single hip arthroscopy centers,[3] eligible subjects were identified in the Danish Hip Arthroscopy Registry.[27] Furthermore, to increase the homogeneity of the study sample, subjects were included if at least cam resection and acetabular labral surgery were performed, as these are the most common FAIS procedures performed in Denmark.[22] Thus, FAIS caused by pure pincer deformity was not included. Finally, return to preinjury sport at preinjury level including performance and participation was defined in accordance with a recent consensus statement,[1] and the return to sport outcome was determined by the athlete so that stakeholders such as physical therapists, coaches, or surgeons could not bias the outcome.[1,3]

Sample Size

The number of eligible subjects in the Danish Hip Arthroscopy Registry and responders determined the sample size of the study.

TABLE 1
Demographic, Radiological, Operative, and Self-Reported Hip and Groin Data on Included Athletes and Nonresponders[a]

	Included in the Study (n = 189)	Did Not Respond to the Survey (n = 121)	*P* Value
Follow-up, mo (range)	33.1 ± 16.3 (6.3-67.8)	32.7 ± 15.1 (6.4-64.4)	.847
Male sex, n (%)	96 (50.8)	82 (68)	.003[b]
Age at surgery, y	23.6 ± 3.3	24.1 ± 3.5	.239
Age at follow-up, y	26.9 ± 3.4	27.4 ± 3.6	.224
Radiological data			
Alpha angle, deg	72.8 ± 10.8	74.5 ± 10.8	.183
Lateral center edge angle, deg	32.6 ± 5.6	32.9 ± 5.9	.644
Joint space width >4.0 mm, n (%)	159 (84.1)	95 (78.9)	.210
Operative data, n (%)			
Operation side, right	98 (51.9)	70 (57.9)	.301
Bilateral operation	24 (12.7)	13 (10.7)	.605
Beck classification			.373
Normal cartilage	3 (1.6)	2 (1.7)	
Fibrillation	46 (24.3)	22 (18.2)	
Wave sign	79 (41.8)	47 (38.9)	
Cleavage tear between labrum and articular cartilage	61 (32.3)	50 (41.3)	
Normal ICRS classification	140 (74.1)	98 (80.1)	.159
Preoperative HAGOS subscale scores	(n = 108)	(n = 57)	
Symptoms	53.8 ± 18.7	49.5 ± 19.0	.168
Pain	58.9 ± 18.6	51.2 ± 19.2	.015[b]
Physical function in daily living	63.9 ± 23.4	54.3 ± 24.7	.017[b]
Function in sport and recreation	42.5 ± 23.2	32.8 ± 20.9	.007[b]
Participation in physical activities	20.0 ± 23.3	21.6 ± 26.9	.695
Hip-related quality of life	31.8 ± 16.3	28.2 ± 16.1	.177

[a]Values are expressed as mean ± SD unless otherwise noted. HAGOS, Copenhagen Hip and Groin Outcome Score; ICRS, International Cartilage Repair Society.
[b]Denotes a statistically significant ($P < .05$) between-group difference.

Statistical Methods

Data derived from the return to sport questionnaire were calculated by use of percentages with a corresponding 95% confidence interval (95% CI). A binominal logistic regression was applied to investigate the likelihood of being engaged in preinjury sport at preinjury level at follow-up based on time to follow-up (0.5 to <1 year, 1 to <3 years, 3 to <6 years), level of sport (elite, competitive, recreational), and type of sport (contact; noncontact, pivoting; noncontact, nonpivoting) as predictor variables. For athletes who were engaged in their preinjury sport at preinjury level at follow-up, a chi-square test of independence was used to analyze the association between reporting optimal performance including full participation, impaired performance but full participation, or impaired performance including restricted participation with level of sport and type of sport. Due to a violation of the minimum expected counts per cell of 5, the chi-square test of independence was omitted for time to follow-up. For all HAGOS subscales, independent *t* tests were applied to investigate for presurgery and follow-up differences between subjects who were engaged in their preinjury sport at preinjury level and subjects who were not. Subsequently, for all HAGOS subscales, a 1-way analysis of variance (ANOVA) was applied to investigate differences at follow-up between athletes not engaged in their preinjury sport at preinjury level compared with athletes engaged in their preinjury sport at preinjury level grouped on performance and participation (optimal performance including full participation, impaired performance but full participation, impaired performance including restricted participation). Because homogeneity of variances was violated (Levene test of homogeneity of variance, $P < .05$), Games-Howell post hoc analyses were applied.

An analysis of covariance (ANCOVA) that used presurgery HAGOS values as the covariate[41] was applied to analyze between-group (engaged in preinjury sport at preinjury level vs not engaged in preinjury sport at preinjury level) differences in mean changes from presurgery to follow-up in all HAGOS subscales. Finally, paired *t* tests were applied to assess changes from presurgery to follow-up in all HAGOS subscales for each group (engaged in preinjury sport at preinjury level, not engaged in preinjury sport at preinjury level) and for the total sample. Statistical significance was set at $P < .05$ for all statistical analyses. Effect size was calculated as Cohen's d and assessed as trivial ($d < 0.2$), small ($d \geq 0.2$), medium ($d \geq 0.5$), and large ($d \geq 0.8$).[4] Continuous data are presented as mean ± standard deviation (SD).

RESULTS

Flow of Participants

A total of 229 of 350 subjects responded to the survey (response rate, 65.4%). Of the responders, data were missing

TABLE 2
Proportion of Athletes Engaged in Preinjury Sport at Preinjury Level Based on Time to Follow-up, Level of Sport, and Type of Sport[a]

	Engaged in Preinjury Sport at Preinjury Level at Follow-up	
	Yes	No
All subjects (n = 189)	108 (57.1)	81 (42.9)
Time to follow-up		
0.5 to <1 y (n = 24)	12 (50)	12 (50)
1 to <3 y (n = 88)	57 (64.8)	31 (35.2)
3 to <6 y (n = 77)	39 (50.6)	38 (49.4)
Level of sport		
Elite level (n = 34)	23 (67.6)	11 (32.4)
Competitive level (n = 77)	38 (49.4)	39 (50.6)
Recreational level (n = 78)	47 (60.3)	31 (39.7)
Type of sport		
Contact (n = 85)	44 (51.8)	41 (48.2)
Noncontact, pivoting (n = 37)	24 (64.9)	13 (35.1)
Noncontact, nonpivoting (n = 67)	40 (59.7)	27 (40.3)

[a]All results are expressed as n (%).

from 3 subjects who did not complete the survey. Furthermore, 37 subjects were excluded from the data analyses based on exclusion criteria (Figure 1).

Return to Preinjury Sport at Preinjury Level

One-hundred and eighty-nine athletes (mean ± SD age at surgery, 23.6 ± 3.3 years) were included in the analyses at a mean ± SD follow-up of 33.1 ± 16.3 months (range, 6.3-67.8 months). Detailed characteristics of the included athletes and nonresponders are provided in Table 1.

At follow-up, 108 athletes (57.1%; 95% CI, 50.0%-64.0%) were engaged in their preinjury sport at preinjury level (Table 2). Of the 81 athletes not engaged in their preinjury sport at preinjury level at follow-up, 5 athletes (6.2%; 95% CI, 2.7%-13.7%) were engaged in the same sport but at a lower level due to hip and groin pain; 26 athletes (32.1%; 95% CI, 22.9%-42.9%) were engaged in another sport due to hip and groin pain; 35 athletes (43.2%; 95% CI, 33.0%-54.1%) were not engaged in any sport due to hip and groin pain; and 15 athletes (18.5%; 95% CI, 11.6%-28.3%) reported their reasons to be unrelated to hip and groin pain. Additionally, of the 81 athletes, 23 athletes had attempted to perform their preinjury sport at preinjury level at any time since surgery; however, 16 athletes (69.6%; 95% CI, 49.1%-84.4%) discontinued preinjury sports participation due to hip and groin pain, whereas 7 athletes (30.4%; 95% CI, 15.6%-50.9%) ceased preinjury sports participation due to other reasons.

The effect of time to follow-up, level of sport, and type of sport on the likelihood of being engaged in preinjury sport at preinjury level was found to be nonsignificant (χ^2_6 = 8.459, P = .206) explaining 5.9% (Nagelkerke R^2) of the variance. None of the predictor variables were significant ($P \geq .129$) (see Appendix Table A1, available in the online version of this article.)

Sports Performance and Participation

Of the 108 athletes engaged in their preinjury sport at preinjury level at follow-up, 32 athletes (29.6%; 95% CI, 21.8%-38.8%) reported optimal sports performance including full sports participation, corresponding to 16.9% (95% CI, 12.3%-22.9%) of the study sample. The remaining 76 athletes reported either impaired sports performance but full sports participation (24.1%; 95% CI, 17.0%-32.9%) or impaired sports performance including restricted sports participation (46.3%; 95% CI, 37.2%-55.7%). Only 1 athlete (8.3%; 95% CI, 1.5%-35.4%) reported optimal performance and full participation at 0.5 to <1 year of follow-up, whereas 18 athletes (31.6%; 95% CI, 21.0%-44.5%) and 13 athletes (33.3%; 95% CI, 20.6%-49.0%) reported optimal performance at 1 to <3 years and 3 to <6 years, respectively. No significant association between sports performance and participation with level of sport (χ^2_4 = 6.732, P = .151) or type of sport (χ^2_4 = 2.609, P = .625) was observed (Table 3). Of the 32 athletes reporting optimal sports performance including full sports participation, 3 athletes (9.4%; 95% CI, 3.2%-24.2%) reported no groin pain, while 21 athletes (65.6%; 95% CI, 48.3%-79.6%) and 8 athletes (25%; 95% CI, 13.3%-42.1%) reported the occurrence of groin pain to be either "rare" or "once in a while," respectively. Of the remaining 76 athletes reporting impaired sports performance, 68 athletes (89.5%; 95% CI, 80.6%-94.6%) reported this to be due to persistent hip and/or groin pain.

Self-Reported Hip and Groin Symptoms and Function at Follow-up

At follow-up, higher values for all HAGOS subscales were observed for athletes engaged in their preinjury sport at preinjury level compared with athletes not engaged in their preinjury sport at preinjury level, corresponding to small-to-large effect sizes ($P \leq .001$) (Figure 2) (Appendix Table A2, available online).

When athletes not engaged in their preinjury sport at preinjury level were compared with athletes engaged in preinjury sport at preinjury level, based on performance and participation (optimal performance including full participation, impaired performance but full participation, impaired performance including restricted participation), significant differences at follow-up were observed between groups for all HAGOS subscales (Welch's $F_{3,\ 78.97\text{-}81.30}$ = 18.62-75.88, P < .001) (Figure 3). Athletes engaged in their preinjury sport at preinjury level with optimal performance including

TABLE 3
Proportion of Athletes Engaged in Preinjury Sport at Preinjury Level Reporting Different Level of Performance and Participation Based on Time to Follow-up, Level of Sport, and Type of Sport[a]

	Sports Performance and Participation		
Engaged in Preinjury Sport at Preinjury Level at Follow-up	Optimal Performance Including Full Participation	Impaired Performance but Full Participation	Impaired Performance Including Restricted Participation
All subjects (n = 108)	32 (29.6)	26 (24.1)	50 (46.3)
Time to follow-up			
0.5 to <1 y (n = 12)	1 (8.3)	2 (16.7)	9 (75)
1 to <3 y (n = 57)	18 (31.6)	16 (28.1)	23 (40.4)
3 to <6 y (n = 39)	13 (33.3)	8 (20.5)	18 (46.2)
Level of sport			
Elite level (n = 23)	11 (47.8)	5 (21.7)	7 (30.4)
Competitive level (n = 38)	8 (21.1)	12 (31.6)	18 (47.4)
Recreational level (n = 47)	13 (27.7)	9 (19.1)	25 (53.2)
Type of sport			
Contact (n = 44)	14 (31.8)	11 (25)	19 (43.2)
Noncontact, pivoting (n = 24)	5 (20.8)	8 (33.3)	11 (45.8)
Noncontact, nonpivoting (n = 40)	13 (32.5)	7 (17.5)	20 (50)

[a]All results are expressed as n (%).

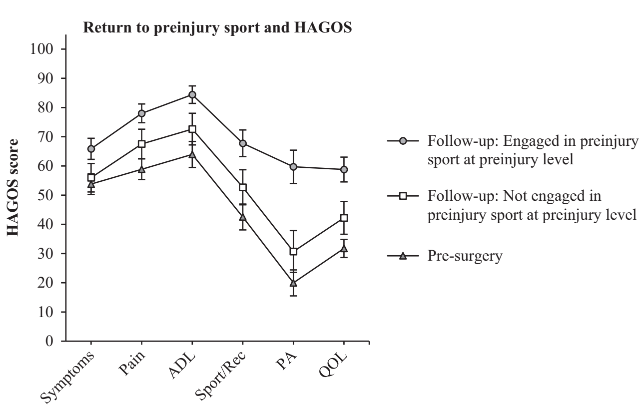

Figure 2. Self-reported hip and groin symptoms and function at presurgery (n = 108; gray triangles) and in athletes engaged in preinjury sport at preinjury level at follow-up (n = 108, gray circles) and athletes not engaged in preinjury sport at preinjury level at follow-up (n = 81, white squares) for subscales of the Copenhagen Hip and Groin Outcome Score (HAGOS). Due to missing data, presurgery HAGOS values were available for only 108 athletes. Error bars show 95% CI. ADL, physical function in daily living; Sport/Rec, function in sport and recreation; PA, participation in physical activities; QOL, quality of life.

full participation showed significantly higher HAGOS subscale scores compared with all groups ($P \leq .024$). A detailed overview of between-group differences is provided in Appendix Table A3 (available online).

Self-Reported Hip and Groin Symptoms and Function at Presurgery

Athletes engaged in their preinjury sport at preinjury level at follow-up showed significantly higher presurgery scores in physical function in daily living compared with athletes not engaged in their preinjury sport at preinjury level (mean difference, 16.6; d = 0.70; 95% CI, 7.4-25.7; P = .001) (Appendix Table A5, available online).

Changes in Self-Reported Hip and Groin Symptoms and Function From Presurgery to Follow-up

For the total sample, significant improvements were observed from presurgery to follow-up for all HAGOS subscales corresponding to small to large effect sizes ($P < .001$) (Appendix Table A4, available online). Significant differences in mean change from presurgery to follow-up were observed between athletes engaged in preinjury sport at

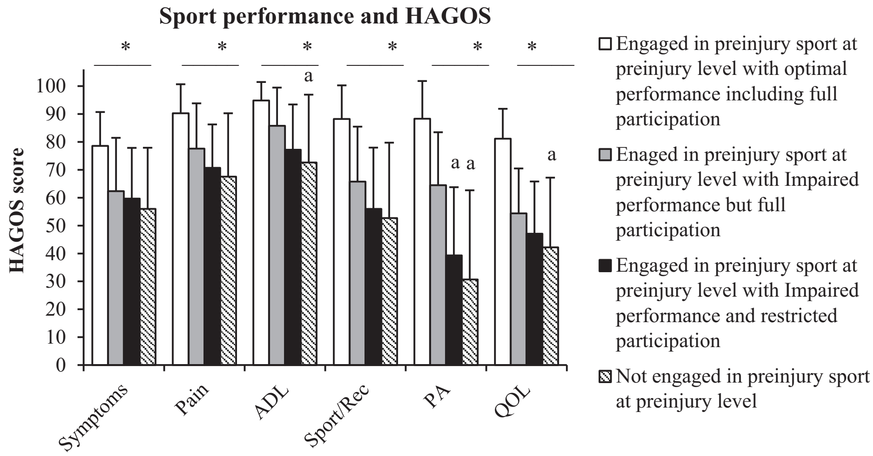

Figure 3. Differences at follow-up in self-reported hip and groin function between athletes engaged in preinjury sport at preinjury level with either (1) optimal performance including full participation (white bars), (2) impaired performance but full participation (gray bars), or (3) impaired performance including restricted participation (black bars), and athletes not engaged in preinjury sport at preinjury level (scattered bars) for subscales of the Copenhagen Hip and Groin Outcome Score (HAGOS). *Statistically significant ($P < .05$) difference between athletes with optimal performance including full participation (white bars) and all other groups. [a]Statistically significant ($P < .05$) difference from athletes with impaired performance but full participation (gray bars). Error bars show standard deviation. ADL, physical function in daily living; Sport/Rec, function in sport and recreation; PA, participation in physical activities; QOL, quality of life.

preinjury level and athletes not engaged in preinjury sport at preinjury level for all HAGOS subscales ($P < .05$). The differences corresponded to small to large effect sizes, with the largest effect size (d = 1.29) observed for the participation in physical activities subscale. A detailed overview of changes from presurgery to follow-up is provided in Appendix Table A6 (available online).

DISCUSSION

Rate of Return to Preinjury Sport at Preinjury Level

The main finding of this cross-sectional survey study was that only 108 of 189 athletes (57.1%) were engaged in their preinjury sport at preinjury level at a mean follow-up of 33.1 months after hip arthroscopy for FAIS. This is in line with a recent study indicating markedly reduced ability to participate in sport at 12 months after hip arthroscopy for FAIS,[38] indicating that hip arthroscopy for FAIS may not be a 1-way ticket back to preinjury sport and level as suggested previously.[15] The rate of return to sport in the present study is considerably lower than the previously reported rate of 87% after hip surgery in both elite and amateur athletes at a mean follow-up of 2.2 years.[3] This may be explained by our use of a clear and strict definition: that is, return to preinjury sport at preinjury level, rather than just return to sport.[1] Moreover, the present study used a nationwide hip arthroscopy registry with prospective registration from 11 specialized public and private hip arthroscopy centers in Denmark including several surgeons.[27] In contrast, previous research has used data mainly from single high-volume hip arthroscopy centers including single world-renowned surgeons,[20,21,30,31,42] potentially resulting in selection bias of athletes and limited generalizability.[3]

Contextual factors such as level of sport, type of sport, and time to follow-up are considered important when evaluating the rate of return to preinjury sport at preinjury level.[1] For athletes undergoing hip surgery for FAIS, these parameters have been suggested to influence the outcome.[3] However, level of sport, type of sport, and time to follow-up explained only 5.9% of the variance in the rate of return to preinjury sport at preinjury level, with no single predictor variable being significant. Nevertheless, the present study observed a higher return to preinjury sport at preinjury level for elite athletes compared with competitive athletes (67.6% vs 49.4%) and recreational athletes (67.6% vs 60.3%). This finding is comparable to the results of a previous study showing a tendency toward a higher return to sport rate in professional athletes at both 6 months (78% vs 65%) and 1 year (88% vs 73%) after hip arthroscopy for FAIS.[24] The higher rate of return to sport observed in elite athletes may be due to contextual factors such as more dedicated time to postoperative rehabilitation or financial interests and/or external pressure from the society, coaches, or teammates.[1,32] Although type of sport was found to be a nonsignificant predictor of returning to preinjury sport at preinjury level in the present study, a lower rate was observed for contact sports compared with noncontact, pivoting (51.8% vs 64.9%) or noncontact, nonpivoting sports (51.8% vs 59.7%). We speculate that contact sports, such as soccer and team handball, may result in high impact forces exceeding the load absorption capacity of the degenerative cartilage in the hip joint.[16,19,23] In line with this, Naal et al[28] observed a shift in sports participation from high-impact sports to low-impact sports after hip surgery for FAIS. On the basis of time to follow-up, more athletes were engaged in preinjury sport at preinjury level at 1 to <3 years compared with 0.5 to <1 year (64.8% vs 50.0%) and 3 to <6 years (64.8% vs 50.6%). In line with this tendency, Philippon et al[32] reported that 93% of athletes returned to sport, but only 78% remained active at a mean follow-up of 1.6 years. The lower return to sport rate over time has been suggested to be due to persistent hip and groin pain.[3,7,20,31] In line with this hypothesis, the present study observed that 69.6% of athletes who had attempted to perform their preinjury sport at preinjury level at any time since surgery discontinued sports participation due to hip and groin pain. Additionally, the main reason for not being engaged in preinjury sport at preinjury level at follow-up was persistent hip and groin pain for the majority of athletes (81%). Persistent hip and groin pain may be due to degenerative cartilage damage in the hip joint[16,23] or concomitant damage in the hip and groin area not addressed during the arthroscopic procedure or rehabilitation, such as soft tissue groin-related pain.[14,29,35,43]

Sports Performance and Participation

Only 29.6% of athletes who were engaged in their preinjury sport at preinjury level at follow-up reported optimal performance and full participation, corresponding to 16.9% of the study sample. To the authors' knowledge, this is the first study to adopt the consensus-based return to sport continuum assessing different levels of performance and participation[1] in athletes who have undergone hip arthroscopy for FAIS. Contrary to the present study findings, previous reports suggest that the majority of athletes return to a high level of performance and participation based on sport-specific statistics.[2,20,21,25,30] The discrepancy may reflect different methods of assessing sports performance and participation and underpins the importance of including an assessment of self-reported performance rather than exclusively focusing on sport-specific statistics when evaluating sports performance.[1] Of note, only 1 of 12 (8.3%) athletes who were engaged in preinjury sport at preinjury level at 0.5 to <1 year of follow-up reported optimal performance including full participation, whereas 9 athletes (75%) reported impaired performance including restricted participation. In relation to this, the time to return to sport has been recommended to be less than 12 months,[44] with surgeons from high-volume hip arthroscopy centers recommending 3 to 5 months.[8] Such recommendations may primarily rely on tissue healing and ability to perform pain-free movements[8] rather than restoration of hip muscle strength and functional performance.[44] These deficits are frequently observed in patients with FAIS both before and after hip arthroscopy and may affect athletic performance if not addressed adequately in the postoperative rehabilitation.[6,9,26]

Self-Reported Hip and Groin Symptoms and Function

Athletes engaged in their preinjury sport at preinjury level with optimal performance including full participation showed significantly better hip and groin function compared with all other subgroups, with HAGOS values approaching reference values for hip and groin injury–free football players.[36] Conversely, no follow-up difference in hip and groin function was observed between athletes reporting impaired performance, including restricted participation, and athletes not engaged in preinjury sport at preinjury level. This may suggest that the decision regarding return to sport, for a subgroup of athletes, is not based solely on hip and groin function but may include other factors, such as psychological readiness and coping strategies.[1,44] Interestingly, returning to impaired performance and restricted participation may reflect adaptive coping strategies, including self-efficacy and social support, or a desire to return to sport potentially overruling symptoms and poor hip and groin function.[39] However, symptoms and poor self-reported hip and groin function may also be associated with fear of reinjury and avoidance behavior complicating the ability to successfully return to preinjury sport.[39]

The improvements in HAGOS values from presurgery to follow-up for the whole study sample are in line with previous reports indicating that hip arthroscopy for FAIS is an effective treatment strategy to improve self-reported hip and groin pain.[18] Athletes engaged in their preinjury sport at preinjury level showed significantly better improvements from presurgery to follow-up, corresponding to small to large effect sizes, for all HAGOS subscales compared with athletes not engaged in preinjury sport at preinjury level. In line with this, Domb et al[7] reported better improvements in self-reported hip function in athletes who returned to sport compared with athletes who did not return to sport at 2-year follow-up. The present study findings may indicate that the ability to return to preinjury sport at the preinjury level may be driven in part by changes in self-reported hip and groin function. As hip muscle strength seems to be positively associated with self-reported hip function after surgery for FAIS,[17] emphasis on postoperative rehabilitation may increase the ability to return to preinjury sport at preinjury level. At present, however, no studies of level 1 evidence on postoperative rehabilitation exist.[11,12]

Methodological Considerations

The recruitment of athletes from a nationwide hip arthroscopy registry is considered an inherent strength of the present study, likely minimizing selection bias of athletes and hence increasing the generalizability of the findings. Furthermore, the present study used a clear and strict definition of return to sport based on a recent consensus statement on return to sport in athletes.[1] Finally, the study included only young subjects with an intention to return to preinjury sport at preinjury level after hip arthroscopy for FAIS.

The present study contains some limitations. First, given the response rate of 65%, it is possible that the nonresponders showed discrepancies in the rate of return to preinjury sport at preinjury level. However, the response rate in the present study is comparable with previous cross-sectional survey studies.[1,7] Second, due to the cross-sectional study design, the present findings represent return to sport status including sports performance and self-reported hip and groin function at a single time point after hip arthroscopy for FAIS. In relation to this, subjects were included retrospectively and thus may be prone to recall bias. However, as sport and level are 2 very discrete factors associated with sports participation, the influence of recall bias is expected to be minor. Third, because patients seem to improve in self-reported hip and groin function from 3 to 12 months after hip arthroscopy for FAIS,[38] evaluating the rate of return to preinjury sport at preinjury level, including sport performance at 0.5 to <1 year of follow-up, may underestimate the results. However, surgeons from high-volume hip arthroscopy centers recommend return to sport at 3 to 5 months after hip arthroscopy.[8] Fourth, sports performance and participation were assessed subjectively; hence, it can only be speculated whether these assessments correlate with deficits in objectively monitored athletic performance, such as sprint and jump performance. Nonetheless, the results provide valuable new information on the expected degree of return to preinjury sport at preinjury level, which clinicians should consider when advising athletes on return to sport after hip arthroscopy for FAIS. Fifth, factors that potentially modify the rate of return to preinjury sport at preinjury level, such as the timeframe from initial hip and groin pain to surgery[34] and preoperative cartilage status,[16] were not taken into consideration. However, subjects with severe cartilage damage were not included in the present study, and thus the potential influence is expected to be minor.

CONCLUSION

Fifty-seven percent of athletes returned to preinjury sport at preinjury level after hip arthroscopy with labral repair and cam resection. This is considerably lower than a previously reported return to sport rate of 87% and may reflect that the present study used a clear and strict definition of return to sport. Of note, only one-third of athletes who returned to preinjury sport at preinjury level reported their sports performance to be optimal, corresponding to 16.9% of the study sample. Better self-reported hip and groin function was observed in athletes who were engaged in their preinjury sport at preinjury level compared with athletes who were not.

ACKNOWLEDGMENT

The authors thank all patients at their facility involved in pilot testing of the return to sport questionnaire, the Steering Committee at the Danish Hip Arthroscopy Register for providing the patient records, and all the subjects who responded to the questionnaire.

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Study IV

Ishøi, L., Thorborg, K., Kemp, J. L., Reiman, M. P., & Hölmich, P. (2021). Maximal hip muscle strength and rate of torque development 6-30 months after hip arthroscopy for femoroacetabular impingement syndrome: A cross-sectional study. Journal of Science and Medicine in Sport. https://doi.org/10.1016/j.jsams.2021.05.006.

Journal of Science and Medicine in Sport xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Maximal hip muscle strength and rate of torque development 6–30 months after hip arthroscopy for femoroacetabular impingement syndrome: A cross-sectional study

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A R T I C L E I N F O

Article history:
Received 14 April 2020
Received in revised form 3 May 2021
Accepted 11 May 2021
Available online xxxx

Keywords:
Groin pain
Hip pain
Physical impairments
Rehabilitation
Surgery

A B S T R A C T

Objectives: Reduced sports function is often observed after hip arthroscopy for femoroacetabular impingement syndrome (FAIS). Impaired muscle strength could be reasons for this. We aimed to investigate hip muscle strength after hip arthroscopy for FAIS and its association with sports function and participation.
Design: Cross-sectional study.
Methods: We included 45 patients (34 males; mean age: 30.6 ± 5.9 years) after unilateral hip arthroscopy for FAIS (mean follow-up [range]: 19.3 [9.8–28.4] months). Maximal isometric hip muscle strength (Nm/kg) including early- (0–100 ms) and late-phase (0–200 ms) rate of torque development ($Nm{*}kg^{-1}{*}s^{-1}$) for adduction, abduction, flexion, and extension was measured with an externally fixated handheld dynamometer and compared between operated and non-operated hip. Associations between muscle strength and self-reported sports function and return to sport were investigated.
Results: For maximal hip muscle strength, no between-hip differences were observed for adduction, abduction, flexion, and extension ($p \geq 0.102$). For rate of torque development, significantly lower values were observed for the operated hip in flexion at both 0–100 ms (mean difference: 1.58 $Nm{*}kg^{-1}{*}s^{-1}$, 95% CI [0.39; 2.77], $p = 0.01$) and 0–200 ms (mean difference: 0.72 $Nm{*}kg^{-1}{*}s^{-1}$, 95% CI [0.09; 1.35], $p = 0.027$). Higher maximal hip extension strength was significantly associated with greater ability to participate fully in preinjury sport at preinjury level (odds ratio: 17.71 95% CI [1.77; 177.60]).
Conclusions: After hip arthroscopy for FAIS subjects show limited impairments in maximal and explosive hip muscle strength between operated and non-operated hip. Higher muscle strength was positively associated with higher sports function and ability to participate in sport.

Practical implications

- Patients with femoroacetabular impingement syndrome often have residual symptoms after surgery, yet they do not seem to present with substantial deficits in hip muscle strength in the operated compared to non-operated hip.
- Absolute hip muscle strength, which may reflect improved load-bearing capacity of the hip joint, was positively associated with sports function and the ability to participate in preinjury sport at preinjury level
- Clinicians should focus on improving absolute hip muscle strength and load-bearing capacity of the operated hip rather than focusing on leg-to-leg symmetry.

1. Introduction

Femoroacetabular impingement syndrome (FAIS) is a cause of hip and groin pain[1] and may drive hip joint cartilage injury.[2] Although hip arthroscopy is a viable treatment,[3,4] residual symptoms and impaired sports function often persist after surgery.[5–8] This could be linked to poor load-bearing capacity of the hip joint[9] and/or reduced maximal and explosive hip muscle strength.[10]

To improve self-reported post-operative outcomes it is recommended to follow a physical impairment-based approach focusing on muscular and functional deficits.[11] In patients undergoing hip arthroscopy due to chondrolabral pathology as the primary surgical indication and potential concomitant hip morphological abnormalities such as FAIS or hip dysplasia, lower maximal hip muscle strength and impairments in functional performance such as single-leg jump and squat have been observed 1–2 years after surgery compared to healthy controls.[12,13] However, in patients treated for FAIS (cam and/or pincer morphology) as the primary surgical indication, physical impairments seem be less pronounced.[14,15]

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https://doi.org/10.1016/j.jsams.2021.05.006
1440-2440/

In addition to maximal muscle strength, rate of torque development[16] could provide valuable clinical insight on the state of recovery after hip arthroscopy for FAIS. Patients with FAIS often report problems in vigorous sports activities that require rapid torque production across the hip joint such as running and kicking.[9] However, hip muscle rate of torque development has not been reported in patients after hip arthroscopy for FAIS.

Therefore, to guide post-operative rehabilitation strategies and return to sport after hip arthroscopy for FAIS, our primary aim was to investigate maximal hip muscle strength and rate of torque development between the operated and non-operated hip. As explorative analyses, we investigated association between muscle function and provoked pain during testing with sports function and participation.

2. Material and methods

This pre-registered (ClinicalTrials.gov ID: NCT03669471) cross-sectional study investigated hip muscle strength and rate of torque development between the operated and non-operated hip after arthroscopy for FAIS. Furthermore, we explored associations between hip and groin function (maximal strength, rate of torque development, and pain and hip adduction squeeze strength during the Copenhagen five-second squeeze test; 5SST)[17] with return to sport, the Copenhagen Hip And Groin Outcome Score (HAGOS) Sport subscale,[18] and self-reported difficulties in specific high-load sports activities.[9] The reporting adheres to the Strengthening the Reporting of Observational Studies in Epidemiology.[19] Approval was obtained from the Danish Ethics Committee of the Capital Region (Identifier: H-17019653). All participants gave their informed written consent according to the Declaration of Helsinki.

Participants who had underwent hip arthroscopy for FAIS in the Greater Copenhagen area during the preceding 6–30 months were identified in the Danish Hip Arthroscopy Registry.[20] This time frame is associated with stable patient reported outcome measures.[6,21] A secure email with written information and a web-based link to register interest in the study was distributed to eligible participants. Inclusion criteria were: men and women with pre-operative cam morphology (alpha angle ≥55°) and aged 18–40 years at the time of surgery; undergone hip arthroscopy during the previous 6–30 months (minimal surgical procedure: cam resection and labral surgery). Exclusion criteria were: pre-surgery joint space width < 3 mm; any of the following surgical procedures at any time: extra articular surgery of the hip joint (except capsular closure), microfracture, periacetabular osteotomy, and surgery of the ligamentum teres; previous hip arthroscopy; previous hip pathology such as Perthes' disease, slipped upper femoral epiphysis, hip dysplasia (Lateral Center Edge Angle <20°), and/or avascular necrosis; any rheumatoid disease in the hip joint such as synovial chondromatosis.

Outcomes evaluated included differences between the operated and non-operated hip regarding maximal isometric hip muscle strength ($Nm{*}kg^{-1}$) including early- (0–100 ms) and late-phase (0–200 ms) rate of torque development ($Nm{*}kg^{-1}{*}s^{-1}$) for hip adduction, abduction, flexion, and extension,[22] and single-leg Reactive Strength Index obtained during a drop jump test.[23] Furthermore, as exploratory analyses we investigated the associations, measured as explained variance (coefficient of determination: r^2) or odds ratios (OR), between independent variables of hip muscle function (maximal strength and early- and late-phase rate of torque development) of the operated hip and sports function (dependent variables).[9] Finally, we investigated the association between hip adduction squeeze strength ($Nm{*}kg^{-1}$) and hip and groin pain (0–10 Numeric Rating Scale [NRS]) during the 5SST with sports function (dependent variables). The dependent variables included: 1) Return to sport status dichotomized into full participation in preinjury sport at preinjury level with or without optimal performance versus restricted or no participation in preinjury sport at preinjury level,[5] 2) HAGOS Sport subscale, and 3) difficulties in specific sports activities ("running as fast as you can" and "kicking, skating etc.") derived from the HAGOS Sport subscale Items (SP5 and SP6, respectively) dichotomized as none-to-mild versus moderate-to-extreme problems.[9] Since sports function after hip arthroscopy may be influenced by several factors, we identified potential variables that could confound the association between the muscle function and pain with sports function. Potential confounding variables were based on previous research, clinical relevance, and data availability, and included: male sex,[2] older age,[2] severity of cartilage injury at surgery,[24] and symptom duration prior to surgery (Please see Supplementary File A for specific reasons).[25] After identification, we used a causal Directed Acyclic Graph (DAG) approach using a freely available software (DAGitty; http://www.dagitty.net/) to identify minimal sufficient adjustment sets for estimating the influence of muscle function and pain on sports function.[26] This resulted in adjustment for age at the time of surgery (years), severity of cartilage injury (grade 0–2 versus grade 3–4), and symptom duration prior to surgery (months) (Supplementary File A).

Maximal isometric hip muscle force including early- (0–100 ms) and late-phase (0–200 ms) rate of force development was assessed using an externally-fixated handheld dynamometer (Hoggan MicroFET2, Hoggan, Scientific L.L.C., Salt Lake City, USA) for hip flexion, adduction, abduction, and extension.[22] We decided pragmatically to include both early- (0–100 ms) and late-phase (0–200 ms) rate of force development since this is the first study to investigate if hip rate of force development could be a potential target for rehabilitation. Intra-tester reliability has previously been established; maximal isometric hip muscle force (ICC: 0.93–0.96, SEM %: 5.9–7.6); 0–100 ms rate of force development (ICC: 0.82–0.93, SEM %: 10.6–15.5); 0–200 ms rate of force development (ICC: 0.85–0.92, SEM %: 7.4–14.0).[22] A detailed description of each test is provided elsewhere.[22] Prior to each muscle test, two warm-up trials at 50% and 100% of maximal voluntary contraction (MVC) were performed, followed by 3 valid trials at 100% of MVC separated by 60 s of rest between trials. Participants were instructed to push as "fast and hard" as possible to emphasize rapid force development,[16] and to keep pushing for a duration of 3–4 s until instructed to relax.[16] Each leg was tested separately with the starting leg and sequence of tests randomized to minimize the risk of any intra-participant effect. Force measures were recorded in Newtons (N) and registered by a software program in wireless connection with the handheld dynamometer using a sampling rate of 100 Hz. Maximal muscle force was defined as the peak force of the three trials. Rate of force development was defined as $\frac{\Delta\text{force (Newton)}}{\Delta\text{time (seconds)}}$ and calculated from the trial with the highest rate of force development for the time intervals 0–100 ms and 0–200 ms. The onset of force, representing time point 0 ms was set at 6.67 N.[16] Maximal muscle force and rate of force development were normalized using lever arm (measured as the length from the anterior superior iliac spine to 5 cm proximal to the medial malleolus) and body mass ($Nm{*}kg^{-1}$and $Nm{*}kg^{-1}{*}s^{-1}$).

Single-leg Reactive Strength Index was obtained during a drop-jump test from a 20-cm box following a standardized procedure.[23] Participants were instructed to lean forward and "step out" from the box, and when landing on a single leg to "jump as high and as fast as possible".[23] Participants were given 3–5 practice trials followed by three valid trials separated by 60 s. Each jump was recorded using a high-speed camera (240 Hz; Iphone 6, Apple Inc. USA), and the Reactive Strength Index was calculated with the *MyJump* application as the flight time divided by the contact time.[27] Contact time was obtained as the difference between initial foot contact (initial landing) and take-off, while flight time was obtained as the difference between take-off and foot contact (second landing). We used the mean of the three trials for analysis.[23]

The 5SST was performed as a long-lever hip adduction squeeze test with maximal exertion for 5 s. Upon completion, participants rated their hip and groin pain during the squeeze on a 0–10 Numerical Rating Scale (NRS).[17] During the 5SST, we also measured maximal hip adduction squeeze torque ($Nm*kg^{-1}$), referred to as hip adduction squeeze strength, using a handheld dynamometer placed between the ankles, with the lever arm identical to the unilateral tests.[28]

Immediately prior to testing, participants answered an electronic questionnaire using the Research Electronic Data Capture (REDCap) tool (v. 7.1.1, Vanderbilt University). Self-reported hip and groin function was obtained with the HAGOS questionnaire,[18] and return to sport status was obtained using a self-report questionnaire described in detail elsewhere.[5] Satisfaction regarding post-operative rehabilitation was obtained using the question *"Beside the regular post-operative rehabilitation, have you felt a need for further rehabilitation?"* answered with a three-point Likert scale (No; Yes, somewhat needed; Yes, much needed).

The sample size was performed a-priori and based on a hypothesized difference in maximal hip muscle strength between the operated and non-operated hips of approximately 10–15% (expected effect size of 0.4).[22] With a power of 80% and an alpha-level of 5%, 45 participants were deemed adequate (G*power software version 3.1, Heinrich-Heine-Universität, Düsseldorf, Germany).

Mean differences in hip muscle strength, rate of torque development, and Reactive Strength Index between the operated and non-operated hips were analyzed using one-sample *t*-tests, with the mean values of the non-operated hips used as references. Prior to analyses, data were visually inspected for normal distribution using the Q-Q plot. The associations between hip muscle strength and rate of torque development of the operated hip (independent predictors) with HAGOS Sport subscale, return to sport status, and difficulties in specific sports activities (dependent variables) were analyzed using multivariate linear or logistic regression models as appropriate with stepwise selection of variables.[29] Age (years; continuous variable), cartilage injury (grade 0–2 vs. grade 3–4; dichotomous variable), and symptom duration (months; continuous variable) were included in the model as fixed co-variates. Multicollinearity was assessed prior to analyses using a correlation matrix. Maximal hip muscle strength measures were highly correlated (>0.7), thus only hip extension strength was included as this showed the highest torque production. Furthermore, measures of late-phase rate of torque development were highly correlated with maximal strength; likewise, was hip adduction and abduction rate of torque development. Thus, hip extension strength, and early-phase rate of torque development for hip extension, flexion, and adduction were included in the models. A similar procedure was used to assess the association between hip adduction squeeze strength and hip and groin pain during the 5SST with sports function. All statistical analyses were performed in SPSS (v. 23, IBM) with a significance level set at <0.05.

3. Results

Participants

Out of the 89 eligible participants, 45 participants agreed to participate (34 males; mean age (SD): 30.6 ± 5.9 years) at a mean (range) follow-up of 19.3 (9.8–28.4) months postoperatively (Table 1). Data was collected at the Department of Orthopedic Surgery at Hvidovre University Hospital in Copenhagen between the 18th of September 2018 and the 7th of October 2019. Self-reported hip and groin function and return-to-sport status at the time of inclusion, and satisfaction with post-operative rehabilitation are presented in Table 1. Thirty-one participants had an intention to return to preinjury sport at preinjury level and these were included in the regression analysis concerning return to sport.

Table 1
Demographic, radiological, operative, and post-operative self-reported hip and groin function on included participants and non-responders/subjects who declined participation.

	Included in the study ($n = 45$)	Non-responders/subjects who declined participation ($n = 44$)
Follow-up, months (SD), range	19.3 (5.4), (9.8–28.4)	–
Gender, no. males (%)	34 (75.6)	30 (68.2)
Mean age at surgery, years (SD)	29.4 (5.8)	30.6 (6.1)
Mean age at follow-up, years (SD)	30.6 (5.9)	–
Symptom duration prior to surgery, months (SD)	34.8 (37.3)	–
Radiological data		
Alpha angle, ° (SD)	69.0 (8.2)	69.2 (7.6)
Lateral center edge angle, ° (SD)	32.7 (8.6)	29.6 (4.7)
Joint space width, no. >4.0 mm (%)	32 (71.1)	28 (63.6)
Operative data		
Becks classification[a]		
Grade 0–2, no. (%)	25 (58.1)	22 (53.7)
Grade 3–4, no. (%)	18 (41.9)	19 (46.3)
ICRS classification[a]		
Grade 0–2, no. (%)	39 (90.7)	38 (92.7)
Grade 3–4, no. (%)	4 (9.3)	3 (7.3)
Post-operative HAGOS		
Pain (SD)	77.9 (15.3)	–
Symptoms (SD)	67.7 (17.8)	–
Physical function in daily living (SD)	84.2 (18.6)	–
Function in sport and recreation (SD)	69.7 (23.5)	–
Participation in physical activities (SD)	52.8 (32.8)	–
Hip related quality of life (SD)	54.4 (21.5)	–
Return-to-sport status[b]		
Pre-injury sport at preinjury level, no. (%)	18 (58.1)	–
Optimal sports performance, no. (%)	3 (9.7)	–
Reduced sports performance, no. (%)	8 (25.8)	–
Restricted participation, no. (%)	7 (22.6)	–
Satisfaction with post-operative rehabilitation		
No need for further rehabilitation, no. (%)	9 (20)	–
Some need for further rehabilitation, no. (%)	27 (60)	–
Much need for further rehabilitation, no. (%)	9 (20)	–

[a] Missing data on two included participants and three non-responders.
[b] Based on 31 participants who had intentions to return to preinjury sport at preinjury level after surgery.

Table 2
Overview of maximal hip muscle strength and rate of torque development for abduction, adduction, flexion, and extension between the operated and non-operated hip.

Isometric hip actions	Operated hip, Mean (SD)	Non-operated hip, Mean (SD)	Difference, Mean [95% CI]	One-sample t-test (*p*-value)
Peak torque ($Nm{*}kg^{-1}$)				
Abduction	1.79 (0.53)	1.83 (0.45)	−0.03 [−0.19; 0.13]	0.689
Adduction	2.10 (0.69)	2.21 (0.74)	−0.11 [−0.32; 0.96]	0.280
Flexion	1.81 (0.48)	1.93 (0.56)	−0.12 [−0.27; 0.03]	0.102
Extension	2.97 (0.83)	2.96 (0.79)	0.01 [−0.24; 0.26]	0.944
RTD 0–100 ms ($Nm{*}kg^{-1}{*}s^{-1}$)				
Abduction	9.34 (3.53)	9.02 (3.52)	0.32 [−0.74; 1.38]	0.550
Adduction	9.72 (5.07)	10.09 (4.67)	0.38 [−1.92; 1.17]	0.625
Flexion	10.95 (3.92)	12.53 (4.14)	−1.58 [−2.78; −0.39]	**0.010***
Extension	11.99 (4.73)	12.97 (5.41)	−0.98 [−2.42; 0.46]	0.178
RTD 0–200 ms ($Nm{*}kg^{-1}{*}s^{-1}$)				
Abduction	6.41 (2.20)	6.18 (1.84)	0.23 [−0.43; 0.89]	0.492
Adduction	6.40 (2.61)	6.67 (2.56)	−0.27 [−1.06; 0.52]	0.497
Flexion	6.72 (2.07)	7.43 (2.37)	−0.72 [−1.35; −0.09]	**0.027***
Extension	8.90 (2.94)	9.35 (3.15)	−0.44 [−1.34; 0.45]	0.322

$Nm{*}kg^{-1}$, Newton meter per body mass; $Nm{*}kg^{-1}{*}s^{-1}$, Newton meter per body mass per second; RTD, rate of torque development; SD, standard deviation; 95% CI, 95% confidence interval.
* p-value <0.05.

Maximal hip muscle strength and rate of torque development

No differences in maximal hip muscle strength were observed between the operated and non-operated hips ($p \geq 0.102$) (Table 2).

Lower hip flexion rate of torque development was observed in the operated hip at both 0–100 ms (mean difference: -1.58 $Nm{*}kg^{-1}{*}s^{-1}$, 95% CI [−2.78; 0.39], $p = 0.01$) and 0–200 ms (mean difference: -0.72 $Nm{*}kg^{-1}s^{-1}$, 95% CI [−1.35; −0.09], $p = 0.027$). No other differences were observed ($p \geq 0.178$) (Table 2).

Reactive strength index

No difference between the operated (RSI: 0.716 ± 0.244) and non-operated leg (RSI: 0.776 ± 0.255) was observed for Reactive Strength Index (mean difference: -0.06, 95% CI [−0.14; 0.017], $p = 0.123$).

Associations between hip muscle strength and levels of sports function and participation

In the multivariate linear regression model, hip extension strength was retained in the model (Adjusted $R^2 = 0.265$, $p < 0.001$), with higher strength associated with better HAGOS Sport subscale scores (unstandardized $\beta = 18.07$, 95% CI [8.31; 27.40], $p < 0.001$) (Supplementary File B, Tables 1–2).

In the three multivariate logistic regression models, hip extension strength was retained in the models, with higher strength associated with greater odds of full participation in preinjury sport at preinjury level (OR = 17.71, 95% CI [1.77; 177.60], $p = 0.015$), and none-to-mild difficulties in SP5 ("running as fast as you can") (OR = 14.42, 95% CI [1.98; 104.87], $p = 0.008$) and SP6 ("kicking, skating etc.") (OR = 58.18, 95% CI [2.34; 1444.10], $p = 0.013$) (Supplementary File B, Tables 3–8). Hip extension strength between groups are provided in Table 3.

Associations between Copenhagen five-second squeeze test and sports function

In the multivariate regression model, hip adduction squeeze strength and pain scores, obtained from the 5SST, were retained in the model (Adjusted $R^2 = 0.570$, $p < 0.001$), with higher strength and pain scores associated with better (unstandardized $\beta = 14.22$, 95% CI [5.94; 22.50], $p = 0.001$) and worse (unstandardized $\beta = -6.67$, 95% CI [−9.78; −3.56], $p < 0.001$) HAGOS Sport subscale scores, respectively (Supplementary File B, Tables 9–10).

In the three multivariate logistic regression models, hip adduction squeeze strength, obtained from the 5SST, was retained in all models whereas pain, obtained from the 5SST, was retained in models concerning difficulties in specific sports activities. Higher hip adduction squeeze strength was associated with increased odds of full participation in preinjury sport at preinjury level (OR = 16.43, 95% CI [2.29; 117.76], $p = 0.005$), and none-to-mild difficulties in SP5 ("running as fast as you can") (OR = 8.33, 95% CI [1.72; 40.23], $p = 0.008$) and SP6 ("kicking, skating etc.") (OR = 15.67, 95% CI [1.76; 139.25], $p = 0.014$) (Supplementary File B, Tables 11–16). Higher pain scores were associated with lower odds of none-to-mild difficulties in SP5 ("running as fast as you can") (OR = 0.67, 95% CI [0.41; 1.10], $p = 0.114$) and SP6 ("kicking, skating etc.") (OR = 0.32, 95% CI [0.12; 0.81], $p = 0.017$) (Supplementary File B, Tables 13–16). Hip adduction squeeze strength and pain scores between groups are provided in Table 3.

4. Discussion

Despite substantial self-reported impairments as indicated by HAGOS scores ranging 52–84 points across subscales (Table 1), our primary findings suggest that limited leg-to-leg differences in hip muscle function exist between the operated and non-operated hip. In fact, we only observed lower muscle function in form of lower early- and late-phase hip flexion rate of torque development corresponding to 12.6% and 9.6%, respectively, in the operated versus non-operated hip. These observations are supported by previous findings of minimal between-hip differences in hip muscle strength after arthroscopy for FAIS,[14,15] although these studies reported small deficits in hip flexion and extension strength in the operated hip compared to healthy controls.[14,15] Thus, comparison with the non-operated hip may not capture subtle physical impairments in hip strength, questioning the clinical use of leg-to-leg comparison during rehabilitation. The lack of difference could be explained by potential deconditioning of both legs due to hip and groin symptoms both prior to and after surgery limiting participation in physical activity; in the present study participants reported a mean symptom duration of 34.8 months prior to surgery.

The current study is the first to report on rate of torque development measures after hip arthroscopy for FAIS. While we did observe both lower early- and late-phase rate of torque development for hip flexion in the operated versus non-operated leg, we do appreciate that the lower late-phase rate of torque development may be driven by a lower early-phase rate of torque development.[16] Nonetheless, a lower early-phase rate of torque development may suggest an impaired neural drive.[16] Interestingly, this was not associated with lower self-reported sports function and participation in the regression models, questioning the clinical relevance of specifically targeting this muscle parameter per se during rehabilitation. These findings could indicate that even though rate of torque development is considered important for objectively measured sports

Table 3
Overview of hip extension strength, and bilateral hip adduction and hip and groin pain scores obtained during the Copenhagen five-second squeeze test in relation to return to sport and difficulties in specific sports activities.

	Full participation in preinjury sport at preinjury level	
	Yes ($n = 11$)	No ($n = 20$)
Hip extension strength (Nm*kg^{-1}), Mean [95% CI]	3.45 [3.12; 3.77]	2.61 [2.31; 2.91]
Hip adduction squeeze strength (Nm*kg^{-1}), Mean [95% CI]	3.15 [2.67; 3.64]	2.14 [1.85; 2.42]
Hip and groin pain during squeeze (0–10 NRS), Median (25-75th IQR)	2 (1–2)	2 (0–4)
	Self-reported difficulties in “running as fast as you can”	
	None-to-mild ($n = 29$)	Moderate-to-extreme ($n = 16$)
Hip extension strength (Nm*kg^{-1}), Mean [95% CI]	3.25 [2.97; 3.52]	2.48 [2.13; 2.82]
Hip adduction squeeze strength (Nm*kg^{-1}), Mean [95% CI]	2.76 [2.47; 3.05]	2.02 [1.74; 2.31]
Hip and groin pain during squeeze (0–10 NRS), (0–10 NRS), Median (25-75th IQR)	1 (0–3)	3 (0.75–4.25)
	Self-reported difficulties in “kicking, skating, etc.”	
	None-to-mild ($n = 26$)	Moderate-to-extreme ($n = 19$)
Hip extension strength (Nm*kg^{-1}), Mean [95% CI]	3.27 [2.95; 3.58]	2.57 [2.28; 2.86]
Hip adduction squeeze strength (Nm*kg^{-1}), Mean [95% CI]	2.82 [2.52; 3.13]	2.05 [1.77; 2.33]
Hip and groin pain during squeeze (0–10 NRS), Median (25-75th IQR)	1 (0–2)	3 (1.5–4)

Nm/kg, Newton meter per body mass; SD, standard deviation; IQR, Interquartile range.

performance in athletes,[10] it may not reflect the individual's ability to tolerate large hip joint moments across the hip without pain and difficulties.

Interestingly, despite negligible limb-to-limb differences in maximal muscle strength, higher muscle strength was positively associated with the ability to both participate fully in preinjury sport at preinjury level and to perform high-load sports activities without difficulties. These novel findings indicate that absolute torque production rather than differences between the operated and non-operated hip may be crucial for engaging in high-load activities. Since we excluded maximal hip strength measures of adduction, abduction, and flexion in the regression analyses due to multicollinearity, it is likely that these measures would also have associated with higher levels of sports function and participation. Therefore, we speculate that the associations are unlikely to be movement/muscle specific, but rather an indication of the load-bearing capacity of the hip and groin structures. Since muscle torque production is the primary driver of joint contact forces,[30] the ability to produce more torque across the hip joint may reflect a better capacity to tolerate higher hip joint contact forces,[9] increasing the likelihood of participating fully in sport without severe difficulties. In support of this, greater hip adduction squeeze strength during the 5SST was also associated with greater ability to perform high load sports activities and return to sport levels, while hip and groin pain during the 5SST was associated with HAGOS Sport and specifically the ability to perform “kicking, skating, etc.” These findings add to existing literature regarding usefulness of the 5SST as a valid indicator of sports function in subjects with hip and groin pain. Collectively, clinicians may use these data to guide and monitor the rehabilitation and/or return to play process, by aiming at a minimum torque production of ≈3.0 Nm/kg and/or 2.5 Nm/kg during hip extension and 5SST, respectively, and pain ≤2 during 5SST (Table 3). This can be easily and reliably done using a handheld dynamometer with external fixation.[22]

The present study is not without limitations; first due to the cross-sectional design, no inference can be made regarding change in muscle strength from pre-to-post surgery or causality in the regression models. Second, no information was obtained regarding the specific content of the post-operative rehabilitation program, however, in accordance with the Danish Health Act all participants were offered a semi-standardized post-operative rehabilitation program. Third, as no healthy control group was included, we may not have been able to detect subtle deficits as shown in previous studies,[14,15] however, in clinical practice comparison between the operated and non-operated side is often the preferred method of assessment. Fourth, we did not perform a clinical or radiological examination of the non-operated hip, and thus we cannot exclude that some patients may have had morphological deviations, such as cam and/or pincer. However, as all patients reported no hip and groin pain in the non-operated hip, and morphological changes does not seem to influence athletic performance,[31] we consider this as a minor factor. Finally, the review process pointed out the potential influence of the large time span (6–30 months) on the results. To test this, we conducted post-hoc analyses of the associations between time to follow-up with muscle strength and HAGOS which showed negligible associations ($R^2 < 0.05$) for all outcomes, suggesting limited influence of the time to follow-up.

5. Conclusion

Patients who have undergone hip arthroscopy for femoroacetabular impingement syndrome show comparable maximal hip muscle strength and single-leg jump performance between operated and non-operated hip at a mean of 19 months post-surgery, whereas rate of torque development for hip flexion is approximately 10% lower in the operated leg. Additionally, as explorative findings, we observed higher maximal muscle strength – but not rate of torque – to be positively associated with higher sports function and levels of participation in sport.

Funding information

No funding received for this project.

Declaration of interest

None declared.

Confirmation of ethical compliance

Approval was obtained from the Danish Ethics Committee of the Capital Region (Identifier: H-17019653).

Acknowledgements

We would like to thank all the participants and the Danish Hip Arthroscopy Registry.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2021.05.006.

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Study V

Ishøi, L., Thorborg, K., Kallemose, T., Kemp, J.L., Reiman, M.P., Nielsen M.F., Hölmich, P.
Stratified care in hip arthroscopy – can we predict successful and unsuccessful outcomes?
Development and external temporal validation of multivariable prediction models
(*Submitted*)

TITLE PAGE

Stratified care in hip arthroscopy – can we predict successful and unsuccessful outcomes? Development and external temporal validation of multivariable prediction models

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Word count: 3825

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ABSTRACT

Background

Approximately 50 % of patients do not have acceptable symptoms (PASS) 1 year post hip arthroscopy. It is unknown whether pre-operative clinical information can be used to assist with surgical decision-making to avoid offering surgery to patients with limited potential for a successful outcome. We aimed to develop and validate clinical prediction models to identify patients with an unsuccessful or successful outcome 1-year post hip arthroscopy.

Materials and Methods

Patient records were extracted from the Danish Hip Arthroscopy Registry (DHAR). A-priori, 26 common clinical variables from DHAR were selected as prognostic factors, including demographics, radiographic parameters of hip morphology, and self-reported measures. We used 1082 hip arthroscopy patients (surgery performed 25th April 2012 to 4th October 2017) to develop the clinical prediction models based on logistic regression analyses. Temporal external validation was performed using 464 hip arthroscopy patients (surgery performed 5th October 2017 to 13th May 2019).

Results

For unsuccessful outcomes, predictive performance on the external validation dataset showed adequate calibration and acceptable discrimination (AUC: 0.75, 95 % CI [0.70-0.80]). For successful outcomes, predictive performance showed adequate calibration, but poor discrimination (AUC: 0.65, 95 % CI [0.59-0.70]).

Conclusion

Common clinical variables including demographics, radiographic parameters of hip morphology, and self-reported measures were able to predict the probability of having an unsuccessful outcome 1-year after hip arthroscopy. This externally validated prediction model can be used to support

clinical evaluation and shared decision making by informing the orthopedic surgeon and patient about the risk of an unsuccessful outcome, and thus when surgery may not be appropriate.

INTRODUCTION

Hip-related pain causes disability and low quality of life in young to middle-aged individuals.[1–3] Since the conceptualization of femoroacetabular impingement in the early 2000s by Ganz et al.,[4] large advances have been made in relation to definitions, diagnosis, classifications, and treatment of hip-related pain.[1,2,5] This has led to an exponential rise in the number of hip arthroscopies performed globally.[3,6] Several studies have investigated outcomes after hip arthroscopy, showing favorable short- to long-term results.[7–9] However, residual symptoms and activity limitations are common, [10] and up to 50 % of patients seem to have unacceptable symptoms [11–13] or are unable to return to pre-injury sports activities after hip arthroscopy.[14–16]. These results suggest that, although considered effective at a group level, not all patients are suited for hip arthroscopy. Consequently, there has been recent focus on identifying prognostic factors (such as age and sex) associated with good and poor outcomes after hip arthroscopy to aid surgical candidate selection and improve surgical outcomes.[17] While identification of prognostic factors can be used to guide preliminary decision-making at a group level, development and external validation of clinical prediction models are needed for individual outcome prediction.[18] Several prediction models have been published recently for hip arthroscopy patients,[19–27] yet, only one model, predicting conversion to hip arthroplasty, has been externally validated.[20] However, this study included intra-articular findings identified during hip arthroscopy as predictor variables, limiting the utility of the model prior to surgery.[20] In addition, most existing prediction models attempted to predict achievement of the minimal clinically important difference (MCID),[19,21,22,24–26] although achieving an acceptable symptom state or not matters more to patients than an improvement.[28]

To advance the field of individual prognosis in patients undergoing hip arthroscopy, we aimed to develop and validate prediction models to preoperatively determine the probability of achieving an unsuccessful or successful outcome defined by the patient’s acceptable symptom state, as a primary aim, and improvement or not, based on MCID, as a secondary aim, at 1-year post hip arthroscopy. In addition, all models were also constructed using intra-articular findings from the arthroscopic procedure as explorative analyses to investigate the potential added benefit of such information.

METHODS

For the current study, we followed the initial 3-steps of The PROGnosis RESearch Strategy (PROGRESS) framework (Figure 1).[29] The PROGRESS [29] is a 4-step framework for prognostic research; (Step 1) description of outcomes of current care (fundamental prognosis research), (Step 2) identification of factors associated with outcomes (prognostic factor research), (Step 3) development and validation of prediction models (prognostic model research), and (Step 4) utilization of the information to tailor treatment (stratified care research). The final step in the PROGRESS framework (Step 4: stratified care research) is beyond the scope of the present study.

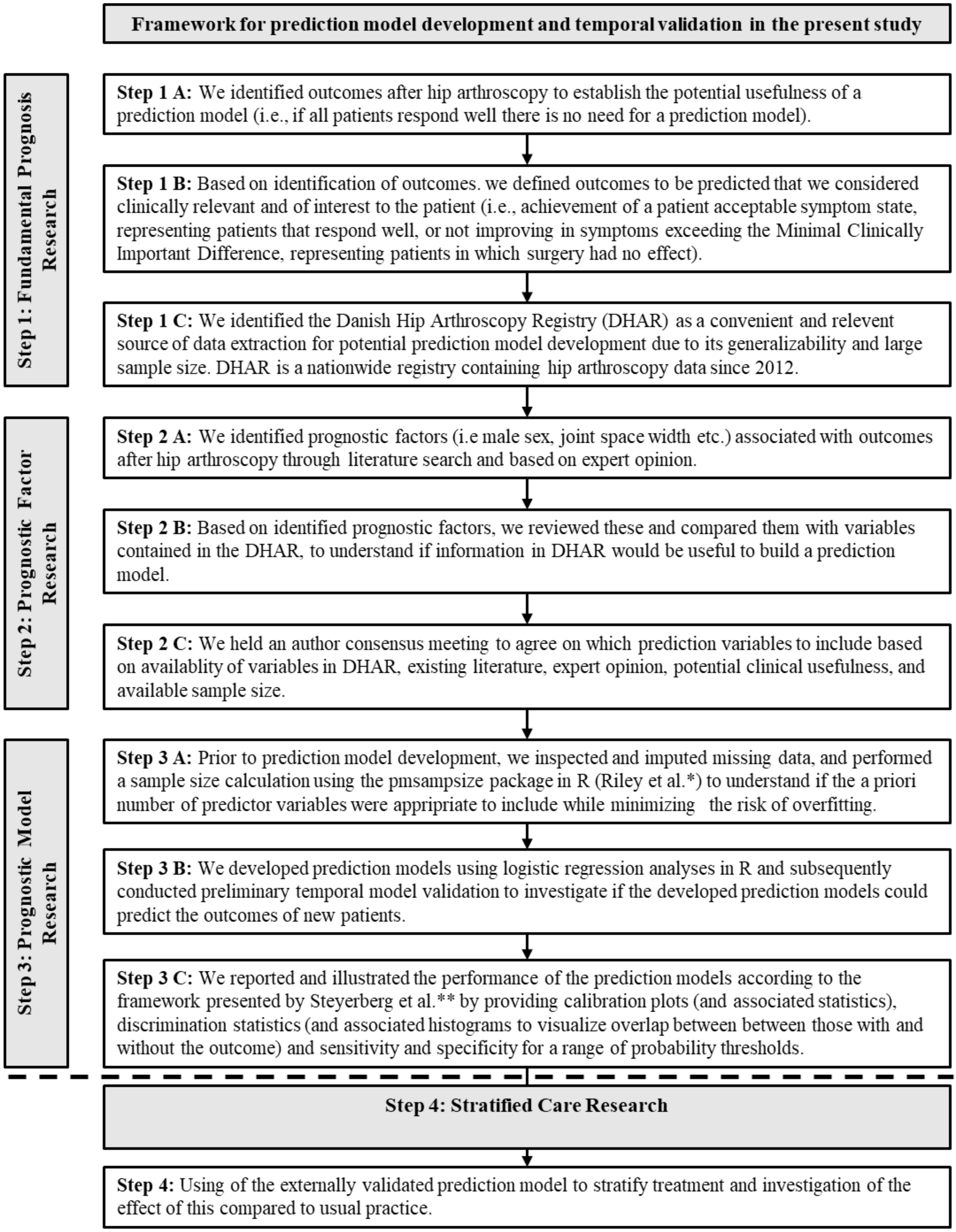

Figure 1. Study process from initial idea to prediction model development inspired by The PROGnosis RESearch Strategy (PROGRESS) Framework.[5] * and ** refers to reference [35] and [36], respectively.

The reporting of the present study adheres to the *Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis (TRIPOD)* guidelines,[37,38] supplemented with recommendations from *Prediction model Risk Of Bias Assessment Tool (PROBAST).*[39] Data handling approval was granted by the Data Protection Agency of the Capital Region, Denmark (Review number: 2012-58-0004). The study was deemed exempt from review of the Danish Ethics Committee of the Capital Region as all data were extracted from a registry approved by the Danish Health Authorities.[40] We developed and validated four multivariable prediction models to determine one-year outcomes of patients with hip-related pain undergoing hip arthroscopy in Denmark using predictor variables available before undergoing hip arthroscopy (demographic data, radiological data, patient-reported outcome measures) to reflect the intended use of the models.[37–39] As supplementary examinations, all models were also constructed with peri-operative predictor variables (information in hip-joint cartilage and labral injury identified during surgery). These models were considered supplementary since the additional predictor variables were not available at the time the models are intended to be used; that is before undergoing surgery,[39] and thus merely serve as explorative analyses to understand the potential added benefit of adding peri-operative variables.

Source of data

Data was collected retrospectively from the Danish Hip Arthroscopy Registry (DHAR) for both development and temporal validation (Step 1C, 2B, 2C; Figure 1).[40] DHAR is a national database initiated in 2012 with ongoing web-based prospective registration of hip arthroscopies performed at 11 specialized public and private hospitals/clinics, including 21 orthopedic surgeons, in Denmark (detailed information on DHAR is provided in references [40–42]). Hip arthroscopies included in the present study were performed between 25th April 2012 to 4th October 2017 (development sample) and 5th October 2017 to 13th May 2019 (validation sample).

Participants

All participants for the development and validation models were included from DHAR database.[40,42] Inclusion criteria were: Male/female who had a hip arthroscopy at the age of 15-50 years. Exclusion criteria were: A previous periacetabular osteotomy; revision hip arthroscopy within one year (mean time to revision in DHAR: 17 months)[41]; previous hip pathology such as Perthes' disease, slipped capital femoral epiphysis and/or avascular necrosis of the femoral head; any rheumatoid disease in the hip joint such as synovial chondromatosis, incompleteness of data regarding pre- and post-operative self-reported hip and groin function and pain (see Table 1 for key characteristics related to the development and validation sample).

Table 1. Summary of key study characteristics for the development and temporal validation samples (n=1546)

Characteristics	Development sample (n=1082)	Temporal validation sample (n=464)
Study setting		
Data collection period	25th April 2012 to 4th October 2017	5th October 2017 to 13th May 2019
Study design	Retrospective	
Setting	Secondary care (public and private hospitals in Denmark)	
Inclusion criteria	Male/female undergoing a hip arthroscopy at the age of 15-50 years	
Demographic data		
Sex, female, no. (%)	640 (59.1 %)	283 (61.0 %)
Age at surgery	34.8 (10.0)	34.6 (10.2)
Hip Sports Activity Scale[&]	2.5 [IQR: 1-4]	2.6 [IQR: 1-4]
Radiographic data		
Alpha Angle	68.0 (13.4)	66.2 (14.2)
Lateral Center Edge Angle	31.6 (5.1)	29.8 (5.3)
Joint Space Width >4.0 mm, no. (%)	713 (65.9 %)	326 (70.3 %)
Acetabular Index Angle	5.2 (3.8)	4.7 (4.0)
Peri-operative data		
Becks classification, grade 0-1, no. (%)	811 (84.3 %)	296 (72.4 %)
ICRS Classification, grade 0-1, no. (%)	150 (15.6 %)	67 (16.3 %)
Labral injury, no. (%)	994 (91.9 %)	428 (92.2 %)
Diagnostic entity based on bony morphology*		
Normal, no. (%)	134 (13.7 %)	86 (22.4 %)
Isolated cam, no. (%)	717 (73.4 %)	233 (60.7 %)
Cam and pincer, no. (%)	64 (6.6 %)	9 (2.3 %)
Cam and dysplasia, no. (%)	39 (4.0 %)	39 (10.2 %)
Isolated pincer, no. (%)	16 (1.6 %)	7 (1.8 %)
Isolated dysplasia, no. (%)	7 (0.7 %)	10 (2.6 %)
Pre-operative self-reported hip and groin function		
HAGOS Pain	52.2 [IQR: 37.5-65.0]	50.3 [IQR: 35.0-65.0]
HAGOS Symptoms	49.8 [IQR: 35.7-64.3]	47.1 [IQR: 35.7-60.7]
HAGOS Activities of Daily Living	55.0 [IQR: 40.0-75.0]	52.6 [IQR: 35.0-70.0]
HAGOS Sport and Recreational activities	37.1 [IQR: 18.8-53.1]	35.3 [IQR: 15.6-53.1]
HAGOS Physical Activities	20.3 [IQR: 0.00-37.5]	21.1 [IQR: 0.00-37.5]
HAGOS Quality of Life	30.3 [IQR: 20.0-40.0]	29.0 [IQR: 20.0-40.0]

HAGOS: Copenhagen Hip And Groin Outcome Score; ICRS: International Cartilage Repair Society. * Only based on patients with full data on alpha angle and lateral center edge angle. [&] Hip Sports Activity scale is measured on a 1-9 scale.

All included patients were treated arthroscopically for various causes of hip-related pain.[1] The DHAR contains data from several surgeons and the specific surgical techniques and indications for surgery may vary; and are not captured in DHAR.[40] Commonly, surgeries were performed under general anesthesia in supine position using a standard 2-portal technique (anterolateral and inferior mid-anterior),[10,43] with surgical procedures (e.g. rim trimming, labral repair, chondral debridement, and capsular closure) performed as indicated by the surgeon. Information on post-operative management is not contained in DHAR,[40] however, all patients were offered physiotherapist-led rehabilitation, either at the surgical facility or at a local community/private physical therapy center for a period of 3-5 months.[10,43–45]

Outcomes predicted by the models

Successful and unsuccessful outcome (PASS or not)

The primary outcomes of interest to be predicted were defined a-priori (Step 1A and 1B; Figure 1) and included patients who, at one-year after surgery, had: 1) a successful or 2) an unsuccessful outcome. To determine a successful and unsuccessful outcome, we used previously established cut-off scores of the Patient Acceptable Symptom State (Supplementary File 1, Table 1) [13] based on the Copenhagen Hip and Groin Outcome Score (HAGOS) [50]. Patients were categorized as having a successful outcome if all HAGOS subscale scores at one-year, extracted from DHAR, surpassed the individual subscale PASS cut-off scores. In contrast, patients were categorized as having an unsuccessful outcome if none of the HAGOS subscale scores surpassed the PASS cut-off scores. This means that patients who only had achieved PASS cut-off scores for some HAGOS subscales were included as comparator group in both prediction models.

The primary endpoint of one-year post-hip arthroscopy was decided upon based on previous literature indicating that patient-reported outcomes seem to plateau from 1-5 year post-operatively,[46] and one-year outcomes being associated with both revision surgery [47,48] and 5-year outcomes.[49] The authors agreed on the definitions of outcomes a-priori.

Clinical improvement (MCID or not)

The secondary outcomes to be predicted were patients who had 1) an improvement or 2) not an improvement in self-reported hip and groin function and pain from before to 1-year after hip arthroscopy. To determine an improvement or not an improvement, we used the Minimal Clinically Important Difference (MCID) [51] of the HAGOS questionnaire. We calculated MCID for each HAGOS subscale as 0.5 standard deviation of the pre-operative HAGOS subscale values (Supplementary File 1, Table 1).[10] Patients were categorized as having an improvement if the change from pre- to- one-year post-operation on all HAGOS subscales surpassed the MCID scores, whereas patients were categorized as not having an improvement if no change above the MCID scores in any HAGOS subscale were observed from pre- to- one-year post-operation.

Predictor variables

All predictor variables were extracted from DHAR a-priori.[40] Based on availability of predictor variables, we decided upon 26 predictor variables for the primary prediction models (and 5 additional variables for the supplementary models). Selection of variables were based on previous studies regarding prognostic factors for outcomes after hip arthroscopy [17] combined with consensus among the authors (hip arthroscopy surgeon (n=1), physiotherapist (n=5), Step 2 A-C, Figure 1). This was done by listing all the potential predictor variables contained in DHAR including items from HAGOS, and subsequently relating them to existing literature on risk factors for a poor or good outcome (Table 2) combined with clinical experience of the authors (LI, 5 years; KT, 23 years; JK, 28 years; MR, 30 years; MFN, 3 years, PH, 40 years). A full list of predictor variables and reasons for selection is presented in Table 2. Pre-operative radiographies were assessed by the operating surgeon and included Lateral Center Edge Angle, Ischial Spine Sign, Alpha Angle, Joint Space Width, and Acetabular Index Angle as these represent common radiological measures to determine femoral head-neck and acetabular morphology.[2,52] For a description of each measure, we refer to Supplementary File 2. Pre-operative self-reported variables related to hip function, pain severity, psychosocial state was obtained using patient-reported outcome measures (Table 3). We prioritized to include specific items as predictors rather than composite scores, as single items can represent specific constructs and be easily implemented in the history-taking process (Table 3). Finally, peri-operative findings of cartilage and labral injury were assessed during hip arthroscopy (Supplementary File 2), but these variables were only included in the supplementary prediction models (Table 3).

Table 2. Overview of a-priori defined predictor variables included in the prediction models.

Predictor variables	Scale	Reasons for selection of predictor variable
Demography		
Age	Continuous (years)	Younger age is associated with improved self-reported outcome and lower revision rates.[17]
Sex	Dichotomous	Male sex is associated with improved self-reported outcome.[17]
Hip Sports Activity Scale	Ordinal (9-point scale)	Sports participation reflects overall hip function, which is associated with self-reported outcomes.[17]
Context		
Hospital setting	Dichotomous (Private vs. public)	Patients in a private setting seems to have better pre-operative symptoms, which may reflect a specific subgroup of patients.[53]
Pre-operative radiography		
Lateral Center Edge Angle	Continuous (angle)	Higher angle is associated with lower failure rates.[17]
Ischial Spine Sign	Dichotomous	Acetabular version is associated with outcome.[17]
Alpha Angle	Continuous (angle)	Larger cam morphology is associated with revision surgery [17] and severe acetabular cartilage injuries.[54]
Joint Space Width	Ordinal (5-point scale)	Narrow joint space width is associated with severe cartilage injury, [54] worse self-reported outcomes, and conversion to total hip replacement,[17]
Acetabular Index Angle	Continuous (angle)	Less than 3 degrees is associated with revision surgery.[17]
Pre-operative self-reported hip function		
Overall rating of hip function	Continuous (0-100 VAS)	Better overall hip function pre-operatively is generally associated with better post-operative outcome.[17]
Problems during running*	Ordinal (5-point scale)	Activities that reflects overall hip function and load bearing capacity,[55] and thus may be associated with self-reported outcome.[17] The ability to walk, run, participate in sport and get in or out of a car represent everyday activities which is often part of the history-taking process.
Problems during walking*	Ordinal (5-point scale)	
Problems get in/out of car*	Ordinal (5-point scale)	
Sports participation*	Ordinal (5-point scale)	
Pre-operative self-reported pain severity		
Pain frequency*	Ordinal (5-point scale)	Having less pain pre-operatively, indicative of better pre-operative status may be associated with better post-operative outcome.[17] Pain characteristics, such as stabbing and stiffness, as well as pain intensity during specific activities is considered important for the diagnosis of hip pain,[5] and is often part of the history-taking process.
Pain in other areas*	Ordinal (5-point scale)	
Stabbing sensation*	Ordinal (5-point scale)	
Morning stiffness*	Ordinal (5-point scale)	
Stiffness after sitting*	Ordinal (5-point scale)	
Night pain*	Ordinal (5-point scale)	
Pain during rest	Continuous (0-100 NRS)	
Pain during walking	Continuous (0-100 NRS)	
Pre-operative self-reported psychosocial factors		
Anxiety or depression#	Ordinal (3-point scale)	Pre-operative mental status and depression state are associated with worse self-reported outcomes.[17]
Awareness of hip*	Ordinal (5-point scale)	
Lifestyle changes*	Ordinal (5-point scale)	
Mood changes*	Ordinal (5-point scale)	
Peri-operative findings&		
ICRS Femoral head	Ordinal (5-point grading)	Degeneration of intra-articular structures, such as severe cartilage and/or labral injury, is associated with worse self-reported outcomes and conversion to total hip replacement.[17]
Femoral size lesion	Ordinal (4-point grading)	
BECKS acetabulum	Ordinal (5-point grading)	
Acetabulum size lesion	Ordinal (4-point grading)	
Labral injury	Dichotomous	

*Represent single Items from the Copenhagen Hip And Groin Outcome Score (HAGOS). Items are scored on a 5-point Likert scale ranging from extreme problems/pain to no problems/pain.[50] #Represent the anxiety and depression Item from the EQ-5D-3L Health questionnaire, which is scored on a 3-point Likert scale ranging from no anxiety/depression to extreme anxiety/depression.[56] &Predictor variables representing intra-articular findings identified during hip arthroscopy. These variables are only included in the supplementary prediction models.

Sample size considerations

An a-priori sample size calculation was not performed as the sample size was determined by eligible patients in DHAR (n=1546). However, to minimize the risk of overfitting and ensure precise estimations, we performed the 4-step sample size calculation approach suggested by Riley et al. [35] using the "pmsampsize" (ver.1.1.0) package in R. This helped us to identify if the number of a-priori defined predictor variables were reasonable to include in the development of the models before overfitting becomes a concern.[35] With an outcome proportion of 0.3 for the primary outcome measures, 26 predictor variables, an expected shrinkage factor of $\leq$10 %, and a C-statistics of 0.78 based on previous models,[21,22,25,26] 1043 patients were deemed adequate for model development, corresponding to 313 events and 12.03 events per predictor; we included 1082 patients in the development sample.[35] The remaining 464 patients were used in the temporal external validation sample, which secured at least 100 events as recommended for the primary outcome measures.[57] However, larger sample sizes may be needed for precise estimates of calibration.[58]

Missing data

Missing data for predictor variables was imputed by single imputation on both development and validation sample. Two radiological variables (alpha angle and acetabular index angle) had ~ 10 % missing data (Supplementary File 1, Table 2). Imputations models were based on all available data from the 26 predictor variables. Continuous variables were imputed by predictive mean matching and categorical variables by polytomous logistic regression. Prediction models were fitted by both imputed data as well as complete case to evaluate impact of the missing values.[37]

Statistical methods

Development and temporal validation of prediction models were analyzed using logistic regression models including all 26 prediction variables as single term with no interactions to minimize risk of overfitting.[37] The supplementary prediction models included 5 additional predictors related to peri-operative findings (Table 2). We chose a logistic regression model approach over machine learning, although machine learning is popular in hip arthroscopy research,[19,21,24–26] since a recent systematic review found similar predictive performance between the two approaches for clinical prediction models.[59] In addition, logistic regression requires far less events per variable compared to machine learning strategies.[60] All continuous variables were kept continuous [37] and ordinal scales were treated as continuous; both were linearly modelled (Table 3). All analyses were performed in R (*R Foundation for Statistical Computing, Vienna, Austria, version 3.6.3*).

External temporal validation

To evaluate the performance of the prediction models on the temporal external validation set, we obtained the predicted probability for each patient in the validation data set using the intercept and regression coefficients derived from the development data set after applying uniform shrinkage by bootstrapping, with 1000 replication bootstrapping and shrinkage.[37] Model performance was investigated in line with the TRIPOD recommendations [37] using the framework presented by Steyerberg et al.[36]. We report the explained variance (Nagelkerke R^2), calibration plots (and associated statistics), and [61] discrimination statistics (Area Under the receiver operating characteristics Curve (AUC).[62] In addition, we report histograms to visualize the distribution of predicted probability between patients with and without the outcome [36] and sensitivity and specificity for a range of probability thresholds.[62]

Calibration refers to the agreement between observed outcomes and outcome predictions, and thus is a measure of the model's ability to provide unbiased estimates.[37] We assessed calibration as defined by Van Calster et al.[61] as: 1) Mean calibration (calibration-in-the-large) reflecting if the observed outcome rate equals the average predicted risk, 2) weak calibration reflecting if the model, on average, over- or underestimates the risk assessed by calibration intercept and slope, with a target value of 0 and 1, respectively, and 3) moderate calibration, reflecting if the estimated risks corresponds to the observed proportions, assessed graphically using a calibration plot, with the target being a smoothed calibration curve lying closely around the 45° line.[61] Calibration plots and associated parameters were produced using "*val.prob.ci.2*" package in R.[63] Discrimination was assessed using AUC (c-statistics), which quantifies the model's discriminative ability, that is the probability that the model estimates higher risks for patients with the outcome than patients without the outcome.[62] AUC ranges from 0.5 to 1, representing no and perfect discriminative ability, respectively.[62]

RESULTS

Of 2550 eligible patients, we included 1546 patients with complete outcome data at 1-year follow-up (Figure 2). In general, very small differences were observed between included and patients with missing outcome data for demographics, radiology, operative findings, and pre-operative symptoms (Supplementary File 1, Table 3)

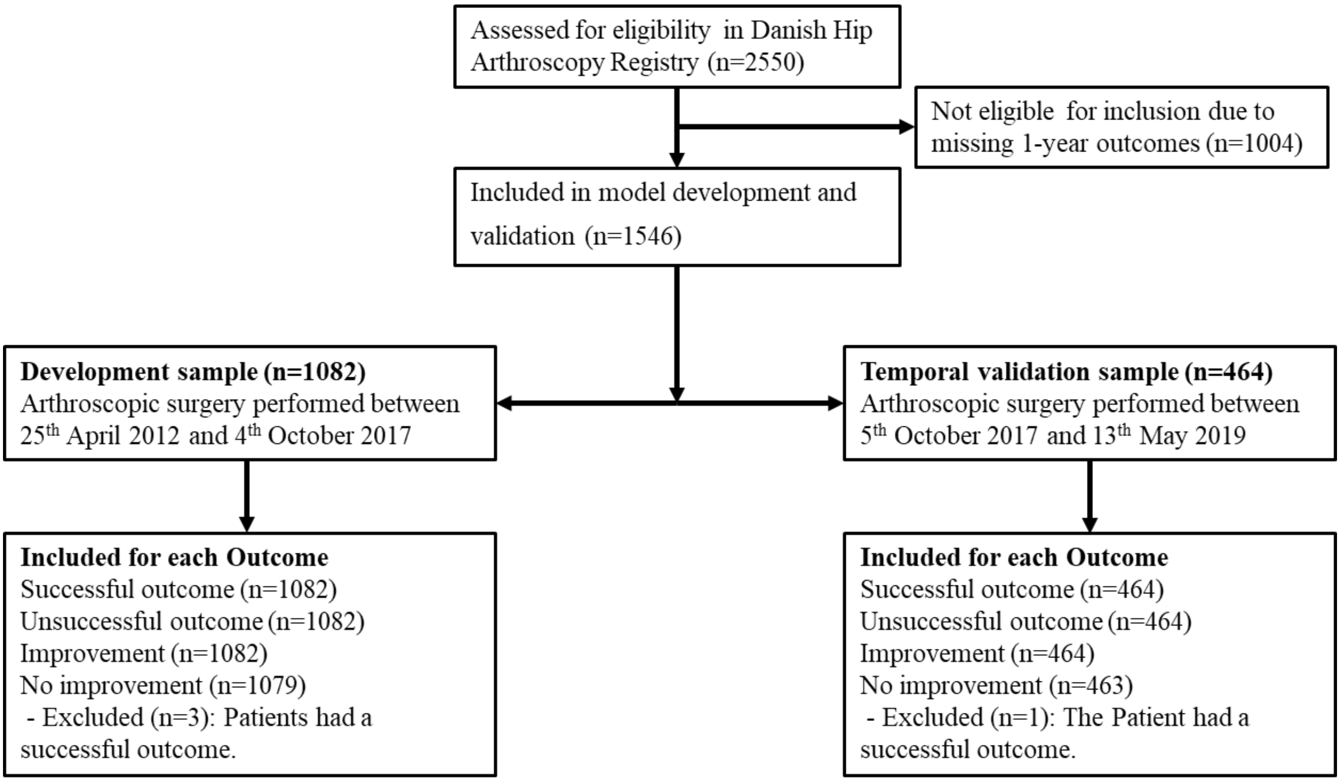

Figure 2. Flow of patients.

Participants

In total, 1082 patients were used for developing the models, whereas 464 patients were used for validation, with samples being comparable in terms of demographics, radiology, operative findings, pre-operative symptoms, and outcomes (Table 1; See Supplementary File 1, Table 4 for a summary of the distribution of predictor variables in the development and validation sample).

Model development

Calibration plots and associated statistics for the development sample are presented in Supplementary File 3. Since missing data in predictor variables were imputed, all patients with complete HAGOS at baseline and 1-year follow-up were included. The proportion of events were similar between the development and validation samples; successful outcome (Development: 339 events [31.3 %], Validation: 137 events [29.5 %]), unsuccessful outcome (Development: 294 events [27.2 %], Validation: 117 events [25.2 %]), improvement (Development: 333 events [30.8 %], Validation: 161 events [34.7 %]), and no improvement (Development: 140 events [13.0 %], Validation: 51 events [11.0 %]). When stratified by outcome, clear differences were found between groups in post-operative HAGOS scores and change in HAGOS score from pre-to-post-surgery (Figure 3 and 4; Similar findings were observed in the development sample; Supplementary File 4).

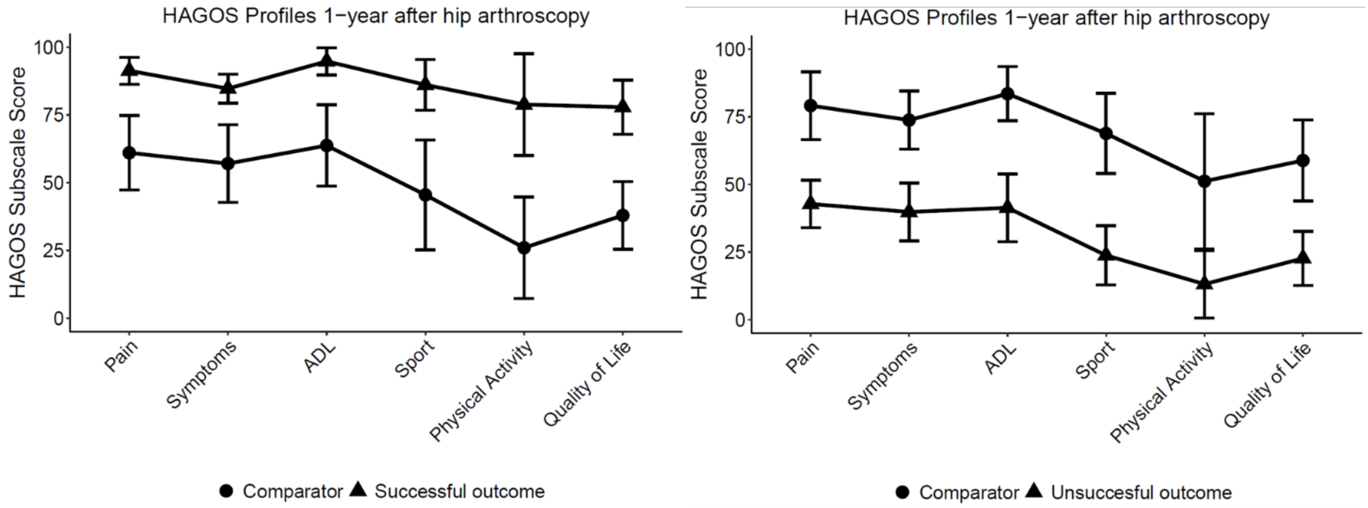

Figure 3. Self-reported hip and groin pain and function measured using the Copenhagen Hip and Groin Outcome Score (HAGOS) in patients with a successful outcome defined as having a patients Acceptable Symptom State (PASS) in all HAGOS subscales versus in some/no subscales (Left figure), and patients with an unsuccessful outcome defined as having PASS in no HAGOS subscales versus in some/all subscales (Right figure). Error bars show interquartile range.

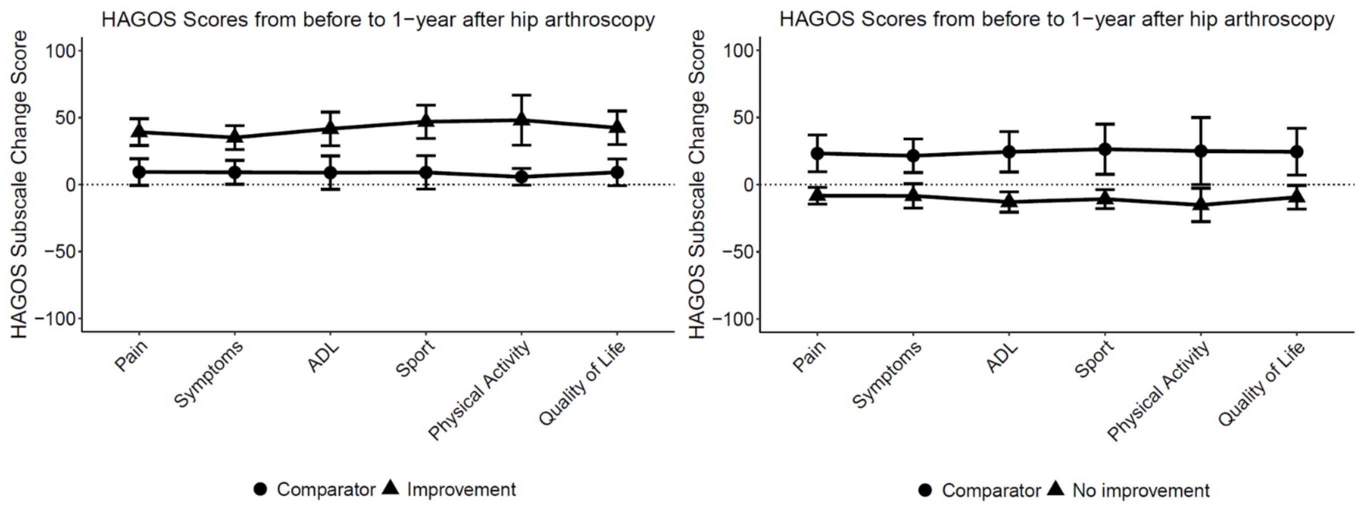

Figure 4. Changes in Self-reported hip and groin pain and function measured using the Copenhagen Hip and Groin Outcome Score (HAGOS) in patients who have achieved an improvement defined as exceeding the Minimal Clinically Important Difference (MCID) in all HAGOS subscales versus in some/no subscales (Left figure), and patients who have not achieved an improvement defined as not exceeding MCID in any HAGOS subscale versus in some/all subscales (Right figure). Error bars show interquartile range.

Model specification and performance

The best model performance was found for the primary outcome measure, an unsuccessful outcome (Nagelkerke R^2: 0.27), which also showed adequate calibration (predicted mean probability vs.

actual mean probability: 28.2 % vs. 25.2 %; intercept: -0.18, 95% CI [-0.41; 0.05]; slope: 0.99, 95% CI [0.75; 1.25]) and discrimination (AUC: 0.75, 95% CI [0.70; 0.80]) (Figure 5).

Calibration plots and histograms for prediction models based on the temporal validation sample

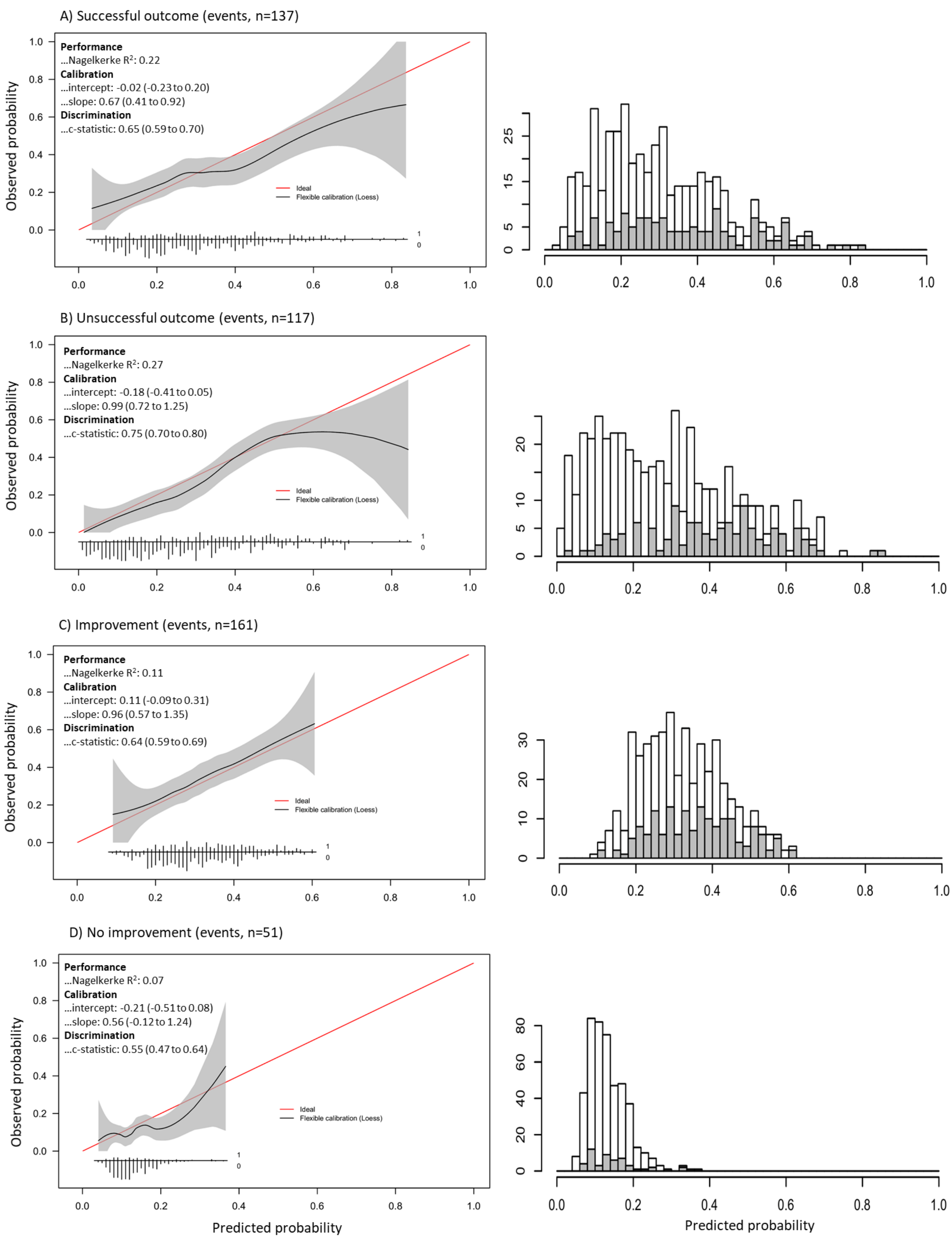

Figure 5. Calibration plots and histograms for predicting patients who have achieved a successful outcome (Patient Acceptable Symptom State [PASS] in all HAGOS subscales) (A) or an unsuccessful outcome (PASS in no HAGOS subscale) (B), achieved an improvement (Minimal Clinically Important Difference [MCID] in all HAGOS subscales) (C), and no improvement (not achieved MCID in any HAGOS subscale) (D). Grey bars in histograms represent frequency of patients with the outcome of interest for each predicted probability, whereas white bars represent control patients. Shaded area in calibration plots depicts 95 % Confidence Intervals. HAGOS; Copenhagen Hip and Groin Outcome Score.

A complete summary of model performance for all four models are available in Supplementary File 1; Table 5, while sensitivity and specificity for probability thresholds (from 0.1 to 0.9) are presented in Supplementary File 5.

For usage of the prediction models, the full models with estimates are presented in Supplementary File 6 while an excel calculator is provided online https://bit.ly/3avOcjJ. The complete case analyses showed similar model performance for all outcomes (see calibration plots, Supplementary File 7). For the supplementary models, the addition of peri-operative findings (information on cartilage and labrum injuries) did not improve model performance (see calibration plots, Supplementary File 8).

DISCUSSION

The present study is the first to develop and externally temporal validate clinical prediction models to identify hip arthroscopy patients who at 1-year after surgery can be considered as having a successful (having achieved PASS) or unsuccessful (not having achieved PASS) outcome. Our findings indicate that by using 26 common clinical variables, including demographics, radiographic parameters of hip morphology, and self-reported measures, the probability of patients with an unsuccessful outcome (1-year mean HAGOS Subscales scores ranging 13-43 points; Figure 2) can be predicted with acceptable discrimination and adequate calibration, although calibration becomes imprecise towards higher predicted probability due to few events (Figure 3).

The present study extends on the existing literature regarding prediction modelling for hip arthroscopy. Although several models have been published, these are associated with important methodological shortcomings, which may result in too optimistic and/or unstable predictive performance.[20–22,24–27] First, only one of eight existing prediction models has been attempted externally validated,[20] however, this was only based on 13 patients with the outcome of interest (a minimum of 100 events are recommended for external validation).[57,58] Since prediction models show best performance on the development sample, external validation is needed to adjust optimism and improve application to future patients.[37] In the present study, this is illustrated by c-statistics for all models being lower in the validation sample than the development sample. Second, as opposed to the present study, no sample size consideration has been made in any previous study, resulting in events per predictor ranging between 3-8.[21,22,24–26] While this may not seem very different from the present study (events per predictor for the primary outcome: 11-13), the majority of published prediction models has been developed using machine learning strategies,[21,24–26] which require >200 events per predictor before low optimism and stable performance measures are reached.[60] Thus, the existing previous prediction models for hip arthroscopy patients are associated with a high risk of overfitting, and thus potentially unreliable predictions when applied on future patients.[35]

Clinical usefulness of the prediction models

The present study suggests that the probability of having an unsuccessful outcome, defined as not having PASS in any of the HAGOS subscales, can be predicted. While hip arthroscopy is considered an effective procedure for treatment of hip joint-related pain,[8] up to 50 % of patients have unacceptable symptoms (unsuccessful outcome) at 1-2-year follow-up [13] highlighting the clinical relevance of identifying patients for whom surgery may not be helpful. The proportion of patients with residual symptoms may thereby decrease and the overall outcome of hip arthroscopy improve. Thus, the prediction model is an initial step towards stratified care for patients with hip joint-related pain,[30] however, the effectiveness of the model needs further testing in a randomized controlled trial before stratified care can be implemented (Step 4 of the PROGRESS Framework).[30]

How should the prediction models be used

The prediction model can support clinical evaluation and shared decision making by informing the orthopedic surgeon and patient about the risk of an unsuccessful outcome. In practice, the probability is derived using the prediction formula (presented in Supplementary File 6, Table 2) available as a free Excel calculator (https://bit.ly/3avOcjJ), which combines the odds ratios for all 26 predictors into a single probability from 0 to 100 %. This means that single predictors, although statistically significant, should not be used in isolation, as the performance of the prediction model relies on all predictors regardless of p-values for individual predictors. Since the prediction model is developed and validated on patients who underwent surgery, the prediction model is best used once the orthopedic surgeon has decided for surgery. In such instance, the model can be used as a data-driven "second opinion" to estimate the risk of an unsuccessful outcome and indicate if surgery is still beneficial or not. In clinical practice, this means that the prediction model is suited to be used in the final stages of a stepped-care approach [64] starting with targeted exercise-based treatment and followed by potential surgery if symptoms have not resolved.[2,65] If used for dichotomous decisions in clinical practice (surgery vs. no surgery), we advise that the predicted probability is combined with the sensitivity and specificity measures presented in Supplementary File 5, to understand the false positive and negative rates of the specific probability threshold, that is misclassification of patients.

Limitations

The present study is associated with some limitations. First, we appreciate that our categorization of PASS-achieved and PASS-not achieved may underestimate the proportion of patients with PASS, compared to a single question approach,[13] but we chose these definitions to minimize the risk of categorizing patients in a wrong group and to improve clinical applicability. Thus, we believe that patients who have exceeded the cut-off scores of all HAGOS subscales at one-year follow-up are likely to represent a subgroup of patients that feel very well after surgery (a successful outcome) and vice-versa for patients who do not surpass a single subscale score (an unsuccessful outcome).[28] Second, since the prediction models were developed based on data from the DHAR, predictor variables were limited to those contained in the registry.[40] However, these were included based on their potential association with hip arthroscopy outcomes [17] and represent common, currently used, and easily collectable clinical variables, although we cannot exclude the potential added value of additional variables. Third, although we included at least 100 events in the external validation models for the primary outcome based on rule-of-thumb,[57] we appreciate that this rule may be imprecise.[58] Fourth, we appreciate that model development and validation was performed using all hospitals combined and that site-specific differences may exist that could impact on the predictive performance when applied in a specific setting. Therefore, further external validation is needed to confirm the present findings at each site. Fifth, while DHAR captures 1-year outcomes, the specific time for follow-up is not reported, thus there may be some slight variations in the follow-up time. Finally, while we have no specific information on the post-operative rehabilitation received, we acknowledge that this is considered an integral part of the hip arthroscopy procedure [65] with potential to affect post-operative outcomes,[66–68] and thus the predictive performance.

Conclusion

Common clinical variables including demographics, radiographic parameters of hip morphology, and self-reported measures were able to predict the probability of having an unsuccessful outcome 1-year after hip arthroscopy. It is important to state that the models were developed and validated using all clinical variables, and thus the use of single variables, although statistically significant, for prediction should be avoided. This temporal externally validated prediction model can be used to support clinical evaluation and shared decision making by informing the orthopedic surgeon and patient about the risk of an unsuccessful outcome, and thus when surgery may not be appropriate. This may reduce unsuccessful outcomes and could therefore improve the overall outcome of hip arthroscopy in the future.

Contributors:

Authors contributed to the concept and design (LI, KT, MR, JK, MN, PH), acquisition of the data (LI. KT. PH), analysis (LI and TK) and interpretation (all authors), drafting and revision (all authors), final approval (all authors), and agreement to be accountable (all authors). The guarantor (PH) accepts full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Funding:

This project was funded by a research grant from Hvidovre Hospital, Copenhagen, Denmark. The funder had no role in considering the study design or in the collection, analysis, interpretation of data, writing of the report, or decision to submit the article for publication.

Competing interests:

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/disclosure-of-interest and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work.

Ethical approval:

Data handling approval was granted by the Data Protection Agency of the Capital Region, Denmark (Review number: 2012-58-0004). The study was deemed exempt from review of the Danish Ethics Committee of the Capital Region as all data were extracted from a registry approved by the Danish Health Authorities

Data sharing:

Relevant anonymised patient level data available on reasonable request.

The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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