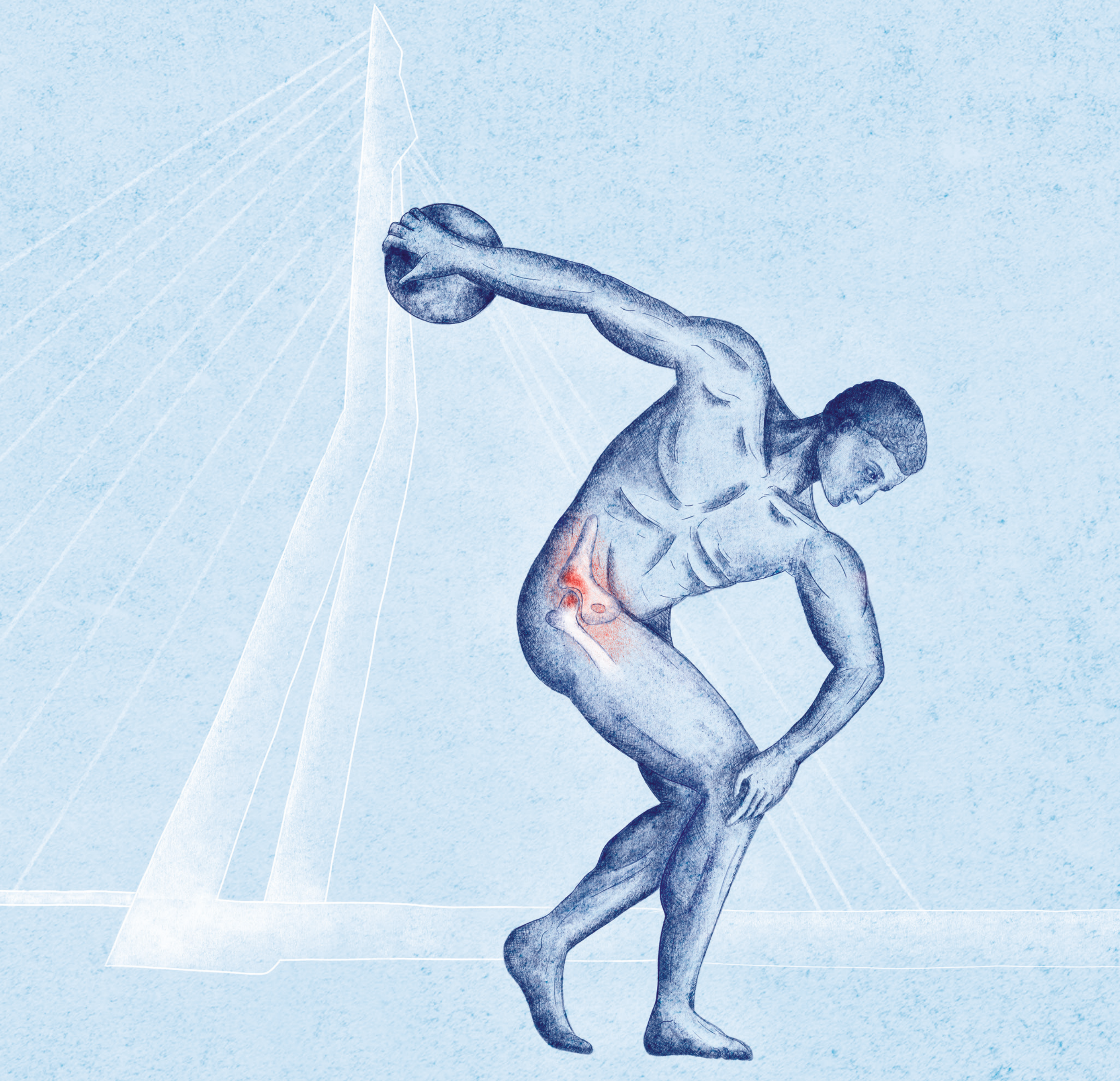
IDENTIFYING AND MODIFYING THE IMPINGING HIP

Maarten A. Röling



Identifying and modifying the impinging hip

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Voor mijn lieve gezin

Laat me je de stad tonen, waarvan ik ben gaan houden
Zwier mee over het Weena, met zijn hoge flatgebouwen
Zie je daar aan het einde al het prachtige Hofplein
Als Feyenoord heeft gewonnen, duik je zo in de fontein
Van hier naar rechts dan kom je langs het statige Stadhuis
En dit hier is de Meent, de straat die de Coolsingel kruist
Geef je geld uit in de Koopgoot, daar is 'ie voor gegraven
En loop wat verder door, dan kom je bij de Leuvehaven
En daar staat Rotterdam dan door de ogen van Zadkine
De stad raast door, maar jij bent even stil om het te zien
Schei toch uit over die moffen, hou toch op over die bommen
Rotterdam stad zonder hart, mijn hart ligt er wel verdomme!
Wat een ander ook mag zeggen, die slaat de plank maar mis
Rotterdam, de mooiste Rotstad die er is.

(Hermes House Band)

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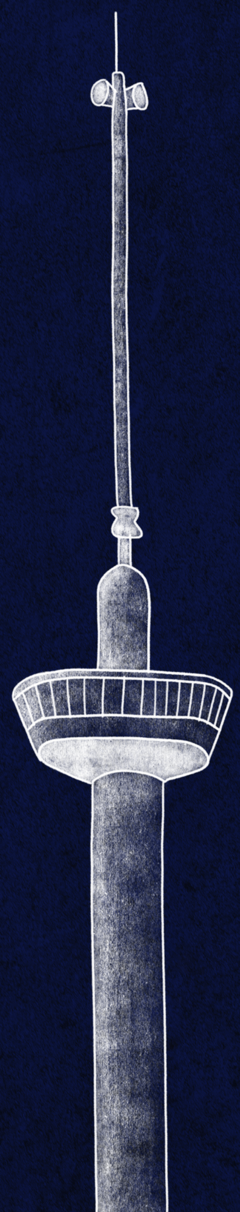


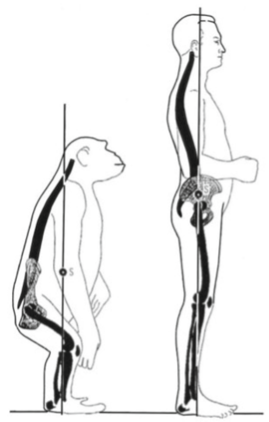
CHAPTER 1

GENERAL INTRODUCTION

Leonardo da Vinci described the human skeleton as a framework supporting the human machine. This framework can move because of several large joints. One of the most important joints to carry and move this human machine is the hip joint. Hip joints consist of the femoral head, which has the shape of a ball, and the acetabulum, which forms a partially covered socket. This ball-in-socket joint is perfectly adapted for our human upright and bipedal gait. In upright position, the hip joint is fully extended. As described by Hogervorst (1), other mammals have a more flexed hip position, even those who are bipedal like us humans, figure 1.

An upright and extended position of the hip joint requires osseous and muscular adaptations in the development of the human skeleton, considering that our skeleton developed from a more horizontal gait to an almost vertical gait. This adaptation led to a hip joint with a high concavity and osseous coverage on the posterior part of the femoral head (1). However, the anterior side of the femoral head is osseous uncovered but is partially consolidated by the labrum, a fibrocartilage ring that improves the surface area and thereby increases the acetabular coverage and concavity and possibly adds stability to the anterior side of the joint (2). Stability is mainly provided by the ligamentous structures that embrace the hip joint, the so-called iliofemoral and pubofemoral ligaments. The hip is also stabilized by the teres ligament and by the resultant force of the muscular structures around the hip; the abductors, the adductors, the flexing muscles, and the extending muscles.

Figure 1: The upright and bipedal human gait



Femoroacetabular impingement (FAI): the anatomic properties of an impinging hip

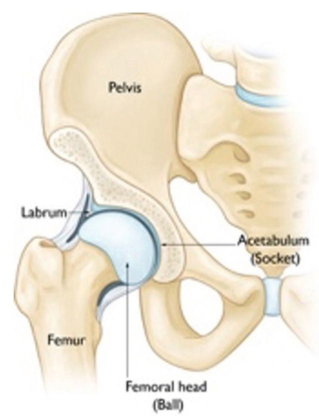
The ideal design of the hip joint is a perfectly spherical ball, the femoral head, which spins freely in the perfectly spherical fitted socket of the acetabulum. This results in a large free range of motion of the joint, with flexion up to 120 degrees and rotations up to 75 degrees range of freedom (3). However, this range of motion may be changed due to several morphological variations and anomalies of the hip joints. Morphological variations have been described in acetabular shape with more or with less coverage: a protruding acetabulum might decrease the range of motion due to increased coverage, and a dysplastic shape of the acetabulum could cause instability and an enlarged range of motion due to diminished osseous coverage. Another morphological variant is a partial overhang or over-coverage on the anterior superior side of the acetabulum, which is called a pincer morphology. The shape of

the femoral head can also differ among individuals. For example, deformities after slipped capital femoral epiphysis (SCFE) (4) and post-traumatic shape deformities can lead to an a-sphericity of the femoral head. This change in morphological relation between femoral head and neck can cause premature collision with the acetabular edge during movement, which we call impingement. Another example of morphological variation is an enlarged amount of bone on the femoral head-neck region. This phenomenon is called a cam morphology, named after the camshaft in a mechanical linkage system, which is explained further on. Cam morphology is a well-recognized cause of premature contact between the proximal femur and the acetabulum, i.e., femoroacetabular impingement (FAI). The FAI syndrome is defined as a motion-related clinical disorder of the hip with a triad of symptoms, clinical signs, and imaging findings.

Illustration of differences in hip morphology are presented in figures 2-13.

Whenever premature contact of the femoral head and the acetabular socket occurs and this repetitive trauma continues, microdamage of structures and tissues may be caused, resulting in an inflammatory response and repair reaction. Repetitive impingement moments can cause damage to the labrum, the cartilage, and the synovial membrane. Ganz et al. (5) described this specific damage of the acetabular chondro-labral junction in co-existence with the non-spherical and impinging head. Repetitive trauma leads to injury at the chondro-labral junction and could over time lead to cartilage delamination and joint degeneration (6). The degree of injury depends on the activity level and on the amount and repetitive nature of forced impingement. Besides this theory, a genetic factor has been described to play a role in cartilage injury and degeneration (7, 8).

Figure 2 and 3: Hip joint with a normal shape of the acetabulum and a normal coverage of the femoral head



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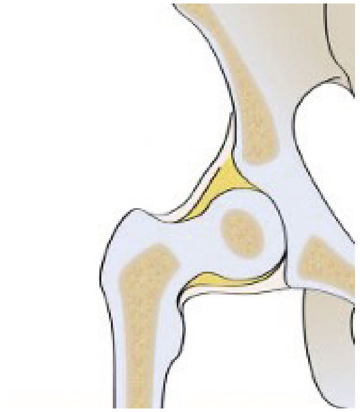

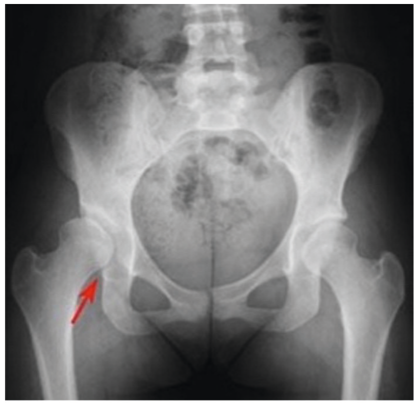

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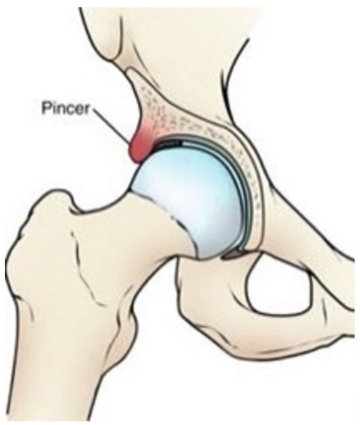

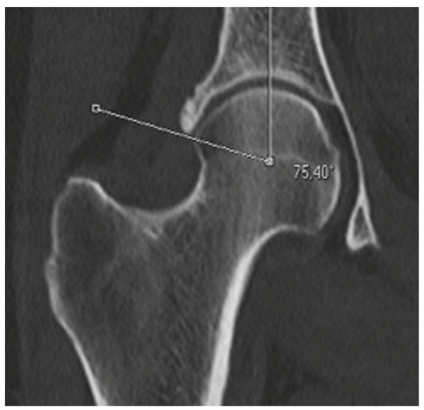

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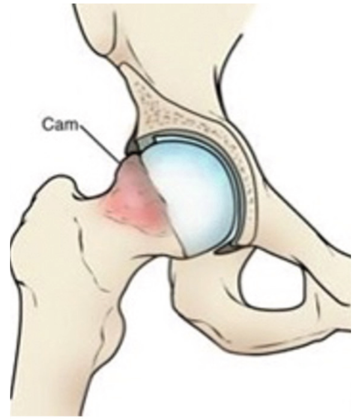

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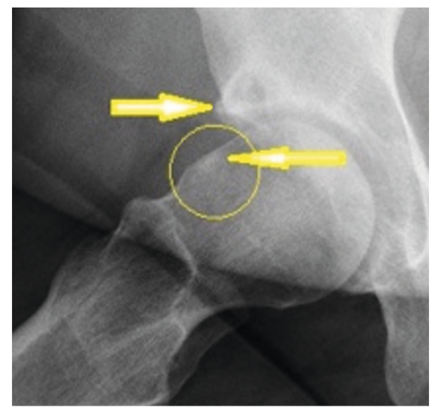

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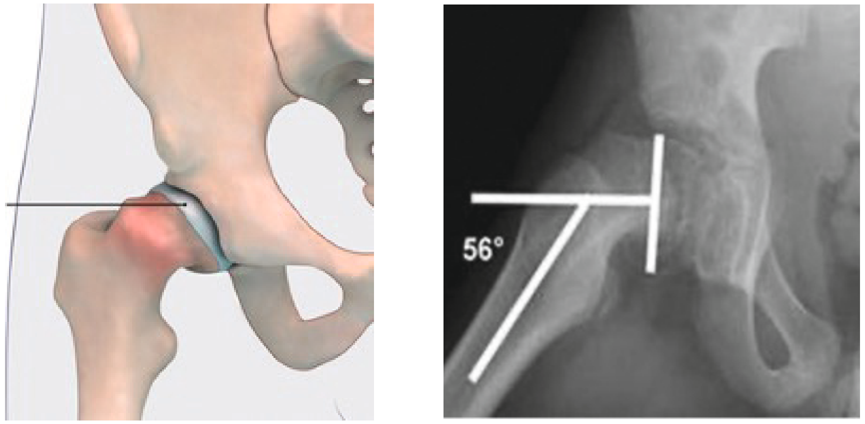


Recognition of FAI

The FAI syndrome is a relatively new concept in the differential diagnosis of groin pain. However, already in 1936, Smith-Peterson et al. (9) described the impingement of the hip joint in a study of intrapelvic protrusion of the acetabulum, saying that impingement of the femoral neck on the anterior acetabular margin would result in traumatic arthritis with characteristic changes of the joint surfaces as well as of the synovium. “If we could eliminate this impingement, we should be able to eliminate the result in reactions and pain.” This is the earliest notice of the phenomenon which we now call the femoroacetabular impingement syndrome.

The key publication which led to increased attention to this topic was written by Ganz et al. (10), who described it as an abnormal contact that may arise because of either abnormal morphological features or because of increased range of motion. The deformity of the junction between femoral head and neck was named cam deformity. This morphology is named after shape of the femoral head’s neck, which resembles the mechanical camshaft shape. A cam is a rotating or sliding piece in a mechanical linkage system, used in transforming a rotatory motion into a linear motion. It is often part of a rotating wheel or shaft that strikes a lever at one or more points on its circular path. The femoral shape of a cam morphology can cause impingement with the acetabular edge.

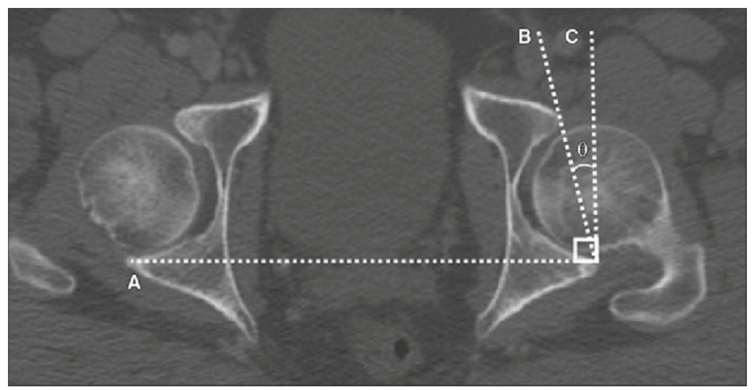
In 1971, Murray, a radiologist, already suggested that *“a tilt deformity”* of the femoral head-neck junction, now called cam morphology, might be the result of chronic stress on the hip during adolescence (7) and could lead to osteoarthritis. Agricola et al., who analysed the role of stress during skeletal maturation and the development of cam type deformities (11), hypothesized that a cam deformity may be a result of structural adaptation to high-impact sporting activities during growth, as the

developing skeleton has a high sensitivity for mechanical loading (12). Specific loading patterns with external rotation and flexion might stimulate the development of cam-type deformities (13). This mechanism is thought to develop in patients when growth plates are not closed yet, for example during adolescence when participating in high impact sports such as soccer (14). None of these hypotheses have been scientifically proven, but they are all plausible.

We also have the suggestion of another hypothesis, which is based on the concept that axial loading on the growing hip creates a downforce on the femoral head that is orientated in posterior direction. It seems likely that this downforce automatically creates a reaction force on the proximal femur to the anterior side. As an epiphysis adapts to structural pressure during growth, the vector of reaction forces will cause the epiphysis of the femoral head to decentralize its central position on the collum femoris. After closure of the epiphysis, the cam morphology is formed on the anterolateral side of the hip. This hypothesis was developed by us but has not been confirmed by other authors or by diagnostic studies, for example with MRI images, during growth and closure of proximal femoral epiphysis.

At the acetabular side, the pincer deformity has been described as an over-coverage and has been referred to as a deep or retroverted acetabular socket. Acetabular version explains the orientation of the acetabulum in the horizontal plane (15). An average orientation is around 20 degrees in anterior direction, anteversion. If the acetabular orientation is posterior to the horizontal plane, it is called retroversion: see figure 14. Because of the deep position of the femoral head in the acetabulum, movement is limited and painful due to premature impingement. This phenomenon is called acetabular protrusion (16). No clear cause has been identified yet, but some authors suggested a genetic morphological background (17). Limited motion of the hip joint can also be caused by Coxa profunda, which is characterized by a deep acetabular socket, identified as the acetabular fossa being medial to the ilio-ischial line.

Figure 14: An anteriorly orientated acetabulum compared to the horizontal plane



The morphological abnormalities of FAI can also be present in a non-symptomatic population (18). For example, Khanna et al. discovered a prevalence of 14% of cam morphologies in non-symptomatic volunteers, and a Japanese study showed a prevalence of 23.7% of radiographic pincer morphologies. This illustrates that actual impingement with complaints might only be caused by specific movements of the hip joint, mostly flexion combined with rotation (19, 20). The symptomatic population is mostly relatively young and is physically active or even athletic. Patients present with groin pain during or after sports activities. Incidence numbers of groin pain in athletes teach us that 2 to 5% of all athletes will experience groin pain during their sports-career. Of all soccer players, 10 to 18% have had groin complaints and 10% of consultations with sports physicians are due to groin complaints. The differential diagnosis of groin pain in athletes is wide and broad. Hip-related diagnoses might be delayed because other diagnoses were excluded first, such as adductor-related pain, tendinitis and sportsmen hernia (21-23).

Diagnostics in FAI syndrome

In 2016, the Warwick international research panel (24) reached consent about the definition of FAI. The diagnosis of FAI syndrome is based on two main criteria: 1) a triad of symptoms and clinical signs and 2) imaging findings. The triad of symptoms mainly comprises groin pain during exercise and during hip motions such as flection and rotations. Clinical findings during physical examination of the hip joint have been described extensively. However, the value of such a physical examination is low in terms of the sensitivity and specificity of the most used tests. Impinging hip pathology can be identified with several well-known specific hip examination tests (25, 26). For example, the FADIR test is used to examine range of motion of the hip and combined movements, such as flexion, adduction, and internal rotation, while the FABER test is used to examine flexion of the hip, abduction, and external rotation. In 2012, Tijsen et al. (27) evaluated data regarding the accuracy of these tests and concluded that a wide range of physical diagnostic tests have been described, but with low diagnostic accuracy and validity. The authors could not make a definite recommendation regarding the use of specific tests due to the low quality of the available studies. Most recently, a large review by Caliesch et al. (26) also showed a low specificity for all clinical tests, with specificity ranging from 0.11 to 0.56. Sensitivity ranged from 0.11 to 1.00, with high sensitivities for the widely used FADIR test. The authors concluded that all the available studies provided low-quality evidence.

Radiographs of the hip joint can visualize the shape of the acetabulum and the femoral head in two dimensions: anteroposterior (AP) and axial. Patients are placed in supine position with the legs 15 degrees internally rotated and the beam centred between the superior anterior iliac spine and the symphysis pubis. However, cam morphologies are mainly present in the anterolateral plane on the head-neck junction. This morphology is not visible in the true coronal and axial plane. Additional

imaging with the Dunn view or the Lauenstein/frog leg images provides another view for identifying cam morphologies (figure 15). A Lauenstein view is made with the hip in 30 to 40 degrees of flexion and 45 degrees of abduction with the heel at rest against the contralateral medial side of the knee. Standardization of imaging is important to compare measurements made between individuals.

The shape of the femoral head should fit into a circle which can be drawn on the femoral head. In patients with a cam morphology, the cam exceeds this circular shape (see figure 15). Identification of a cam morphology is made by measuring the so-called alpha angle (28) on the Lauenstein image. The alpha angle is measured between two lines: one line drawn from the centre of the femoral head to the point where the radius of the femoral head exceeds a perfect circle drawn around the femoral head to the centre of the femoral neck. The second line is drawn from the collum to the centre of the femoral had. The angle between those lines defines the alpha angle. An alpha angle >60 degrees indicate a non-spherical shape of the femoral head, which defines a cam morphology. Normal values differ in literature between 60 and 65 degrees (29, 30). The sensitivity for alpha angles is described to be as high as 91%, with medium intra-observer reliability (ICC 0.43) (31).

Figure 15: Alpha angle measurement on a Lauenstein image

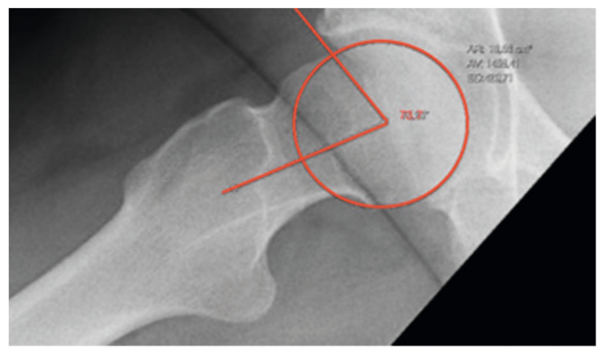
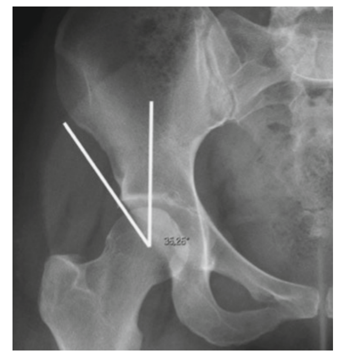
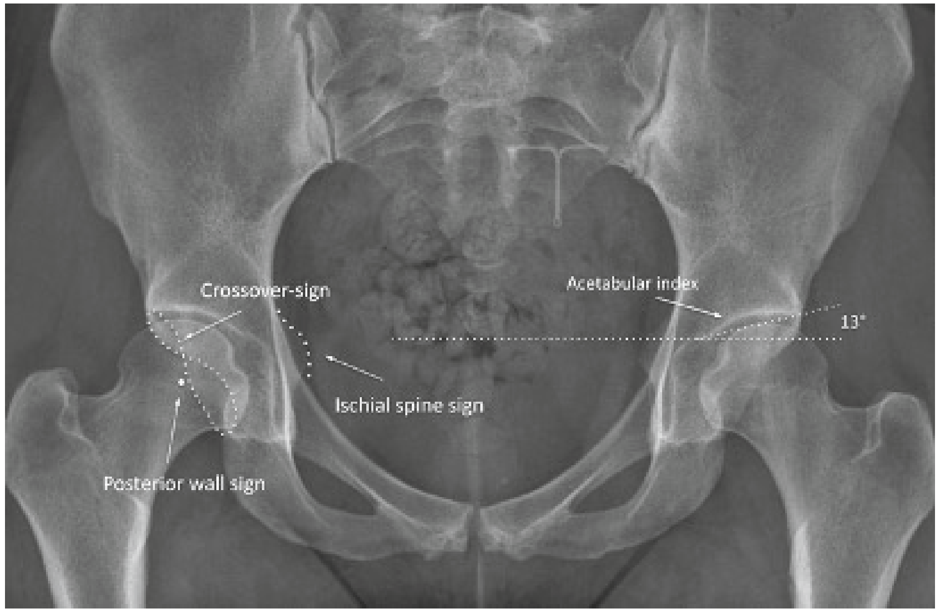


Figure 16: LCE angle



Pincer morphologies are recognized on frontal radiographs on which the lateral side of the acetabulum is clearly visible. The amount of overhanging acetabular rim is detected by measuring the lateral centre edge (LCE) angle. This is the angle between a line vertical to the centre of rotation of the femoral head and the lateral edge of the acetabulum (figure 16). Increased angles of the LCE imply an overhanging acetabular rim. Angles varying from 25 to 40 degrees have been reported to imply pincer morphology, (32), with a sensitivity of up to 84%. Possible pincer morphology can also be identified with several other measurements on radiographs. The most frequently used methods were described in 2017 in a review by Rhee et al. (33). Other measurements include the crossover sign, the posterior wall sign, the ischial spine sign, and the acetabular index (figure 17), as well as identification of a herniation pit. All these methods have been used in level-4 studies, but no comparative studies have shown any method's superiority in use. All methods were developed to identify overhang of the acetabular wall as opposed to "normal" and non-impinging acetabular shape. Evaluation of radiographs is limited by the quality of the image. Frontal radiographic images are made in supine position with lower limbs internally rotated 15 degrees.

Figure 17: Acetabular crossover-sign, posterior wall sign, ischial spine sign and acetabular index



More recently, an addition to this imaging was made using 3D CT scanning (34). In combination with specific software, these CT images can be used to develop three-dimensional images, which can also be used dynamically. The software creates a dynamic model of the hip joint. This three-dimensional model of the hip joint can be rotated and flexed within the normal range of motion (35). The development of this software was described in 2010 (36).

If FAI syndrome is identified, patients should be informed about the treatment options, which are conservative treatment (37) or surgical treatment (38), and the expected results.

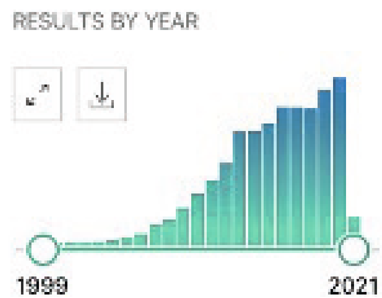
Treatment with hip arthroscopy

A relatively modern type of surgery of the hip joint is arthroscopic surgery. However, this type of surgery was first mentioned 90 years ago. The first surgeon to develop

and perform this type of surgery was Burman (Figure 18) (1901-1976), an orthopaedic surgeon from New York. Already in 1931, he arthroscopically investigated all large joints in a cadaver laboratory in Dresden, Germany. Burman and his team performed over 20 arthroscopic procedures of the hip joint, 40 of knee joints, 25 of the shoulder joints and two or three of the ankle and elbow joints. They stated: "We believe arthroscopy to be a key procedure in the study of joint physiology and pathology." (39).

Figure 18: dr Burman

Figure 19: Publications on FAIs



After these pioneers in the beginning of the 20th century, it took a long time for others to follow their example. From 1980 till 2000, 190 publications on arthroscopy can be identified on the online PubMed database. From 2000 until 2020, this number has increased to 3188 publications (figure 19). Arthroscopic surgery of the hip joint is much more complex than arthroscopic surgery of other joints, such as the shoulder or the knee. The hip is a more contained and tighter joint than other joints, hence it is more challenging to gain access and vision inside the joint. Developments in hip arthroscopy took place many years after advances in knee arthroscopy. For example, in 1976, when modifications in technique for knee arthroscopy were described (40), there were no publications at all discussing hip arthroscopy. The popularity of this type of surgery increased due to improvements of quality and safety, such as the safe distraction of the joint by using a distraction table in the operating theatre.

At first, the main indication for arthroscopic hip surgery was providing direct visualization to improve diagnostics in patients with hip pain. The first therapeutic options with hip arthroscopy were removal of free bodies and resection of impinging osteophytes, partial resection of labral tears and partial synovectomy. Byrd (1) describes the importance of a proper selection of surgical indications in patients and the paramount importance of a proper surgical technique to obtain good results from the surgery. He states that "due to [the hip's] constrained architecture and dense soft tissue envelope, the potential for inadvertent iatrogenic scope trauma is significant and perhaps unavoidable to some extent" (42). Due to these difficulties, the learning curve in hip arthroscopy is long. The number of surgical procedures described in this learning curve varies widely, from 30 up to 519 (43). The widely used techniques include intra-articular inspection of the cartilage of the femoral head and acetabulum, teres ligament, acetabular rim with or without pincer morphology, labrum, and possible free bodies intra-articular. The extra-articular compartment, the peripheral compartment, allows inspection of the impinging area at the cam morphology site. With the use of hip arthroscopy, labral tears can be sutured or removed, free bodies can be removed, focal chondral pathology can be repaired, ligamentum teres pathology can be treated, septic arthritis can be drained, synovial disorders can be removed, impinging psoas tendon can be released and pincer and cam morphologies can be resected (44).

Complications in hip arthroscopy are rare, around 3.3% (45), and most are due to traction force during surgery. This traction is needed to safely dislocate the femoral head out of the acetabulum (10), to gain access to the intra-articular compartment. Counter force is obtained by using a padded post in between the legs. The most frequently described complications after surgery are caused by this traction: neuropraxia of the pudendal nerve and of the femoral cutaneous nerve, temporary erectile disfunction and numbness of the perineal area (46). The complication rate is associated with total traction force and the total amount of time during which the force is applied (47). However, the main complication and the main reason for revision arthroscopy is persistence of symptoms due to incomplete cam or pincer resection (48).

Functional outcome results after surgery and the importance of patient-reported outcome measures

A first large multi-centre trial comparing the surgical treatment for FAI syndrome to best conservative care was published in 2018 in the Lancet (49). This study concluded that hip arthroscopy led to a greater improvement than non-surgical treatment. This difference in outcome was clinically significant and was measured by means of specialized patient-reported outcome measures (PROM) for hip arthroscopy. Also, another recent randomized controlled trial confirmed that surgical intervention has superior outcomes compared to conservative treatment (50).

Much research has been done on the femoroacetabular impingement syndrome, but many questions remain. We started our research projects around 2012 and formulated several research questions. The different studies will be discussed in different chapters of the thesis.

Research questions and thesis outline

1. What is the incidence of symptomatic FAI syndrome in the general population? There is limited knowledge about the incidence of FAI syndrome. In chapter 2, we describe a study performed in cooperation with general practitioners who registered all the diagnoses related to groin pain in their practice for one year.

2. Is three-dimensional CT-based motion simulation software a reliable measurement tool to detect reduction in range of motion caused by cam type FAI syndrome? The aim of chapter 3 was to validate software in the context of diagnosing the FAI syndrome. We determined the accuracy of this software in a study assessing range of motion in five human cadavers. We assessed the CT-based software in comparison with an electromagnetic tracking system (EMTS), the gold standard for measuring range of motion. Our hypothesis was that the software is a reliable measurement tool to detect a reduction in achievable range of motion caused by a cam-type morphology.

3. What is the sensitivity and specificity of three-dimensional CT analysis in detecting cam- and pincer-type morphologies? Cam- and pincer-type morphologies can be measured on plain radiographs using the alpha angle and the lateral centre edge angle. Dynamic three-dimensional CT simulation is validated to visualize the interplay between the acetabular and femoral morphology. This technique is used as an additional tool for the identification of impinging morphologies. The objective of chapter 4 was to compare alpha angles and LCE angles on plain radiographs with the angles measured on dynamic CT analysis. We hypothesized that dynamic CT analysis had a higher sensitivity and specificity in representing the impinging cam- and pincer-type morphologies than the radiographs.

4. How much traction force is needed for hip dislocation in hip arthroscopy, and can a relation be established between traction force and joint space widening? To perform a hip arthroscopy, the joint must be subluxated to create enough joint space widening to enter the joint with arthroscopic equipment. The amount of traction force needed for this intra-articular access has not been studied in vivo before. It has not yet been determined what the relation is between traction force and the obtained joint space widening and whether the required traction force is influenced by several physical parameters, such as age, body mass index (BMI) and joint arthritis. For chapter 5, we developed a method to measure traction force and joint space widening.

5. Can the Hip Outcome Score be translated into Dutch and validated in the Dutch language? Functional outcome and recovery after surgery are often measured using specially developed questionnaires, so-called patient-reported outcome measures (PROMs). Several PROMs have been developed for pathologies related

to the hip joint, such as the Hip Outcome Score (HOS). Most questionnaires were developed for English-speaking patients. For optimal usage of this questionnaire, we translated it into Dutch and evaluated the Dutch version of the HOS (HOS-NL) in terms of its reliability, internal consistency, construct validity and content validity. In chapter 6, we hypothesized that the HOS-NL is a reliable patient-reported outcome measure for assessing physical function and health-related quality of live in active and young patients with FAI syndrome.

6. What is the short-term functional outcome after hip arthroscopic treatment? We started a prospective cohort registration of all patients operated for FAI syndrome. The prospective registration from 2012 to 2014 was used to describe the short-term functional outcome in a cohort of 80 patients in chapter 7. Primary outcomes were pain measured with the visual analogue scale (VAS) and functional outcomes measured with the HOS and modified Harris Hip Score (mHHS). Secondary outcomes were sports (HOS-Sports domain), time to resume work, and complications. We compared pre- and postoperative functional outcome scores.

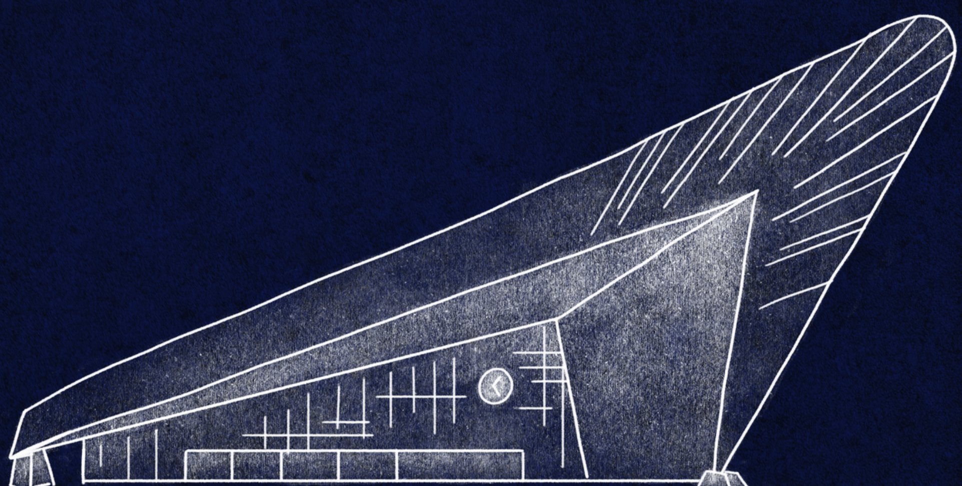
7. Can a model be developed to predict outcomes after hip arthroscopy? It is known that not all patients benefit and recover equally after arthroscopic surgery for FAI syndrome. Functional recovery in terms of functional outcome score is known to be influenced by several risk factors, such as progressive arthritis, age, gender, BMI, duration of symptoms and low pre-operative functional outcome scores (51, 52). To predict the outcome scores of individual patients, it would be a great asset to have a clinical prediction model. Such as model could also be used to support doctors and patients in shared decision-making regarding treatment and expectations. For chapter 8, we developed, and tested a clinical prediction model that can be used to predict functional outcome 1 year after hip arthroscopy.

8. Can subgroups be distinguished with different functional recovery trajectories after hip arthroscopy for FAI syndrome? Since differences in functional recovery after hip arthroscopy are evident, we analysed for chapter 9 whether subgroups with different recovery trajectories can be identified, if predictors exist for group membership and if differences between those subgroups can be identified. Our hypothesis was that at least two subgroups with different functional recovery trajectories could be identified and that several parameters could be identified as predictors for group membership.

9. Finally, chapter 10 comprises the discussion of our main findings, addresses the current literature, and provides recommendations and future perspectives. Chapter 11 presents a summary of this thesis.

PART I

RECOGNIZING FAI SYNDROME



CHAPTER 2

INCIDENCE OF SYMPTOMATIC FEMOROACETABULAR IMPINGEMENT IN DE THE GENERAL POPULATION: A PROSPECTIVE REGISTRATION STUDY

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ABSTRACT

Introduction
Groin pain is a frequent cause of discomfort in patients and highly prevalent in active patients. One of the diagnoses causing groin pain is Femoroacetabular impingement (FAI). However, the incidence of FAI in the general population is unknown. This study aimed to identify the incidence of groin pain suggestive of FAI in a cohort of 31.451 patients in the Netherlands during one year.

Materials and methods
A cooperation of sixteen general practitioners (GPs) participated in this prospective registry. All GPs were educated in the clinical manifestation of FAI and the physical examination for FAI. Patients of all ages were registered when presenting with "groin pain".

Results
Between July 2013 and July 2014, 84 patients aged between 15 and 60 years of age presented with groin pain, reflecting an incidence of 0.44%. Of these patients, 17% (14 patients) were radiologically diagnosed with FAI. Another 30% of these patients had a high clinical suspicion for FAI.

Discussion
This is the first report on the incidence of groin pain suggestive of FAI in a general population diagnosed by GPs. Of all 84 patients presenting with groin pain, 17% were diagnosed with FAI. Creating awareness of FAI in GPs helps identifying patients that might benefit from FAI treatment.

Keywords:
Femoroacetabular impingement, Incidence.

INTRODUCTION

Groin pain is a frequent cause of discomfort in young and active patients. In sports, incidence rates of groin pain vary from 0.5 to 18%, depending on level and type of sport [1-5]. The pathologies explaining groin pain are in many cases self-limiting. However, 13.5% of all complaints last longer than three weeks, and treatment of the underlying pathology is often required [6]. The differential diagnosis of groin pain is broad and contains both sports-related and non-sports-related conditions. Frequently diagnosed conditions are adductor-related tendinitis, snapping hip, inguinal hernia, sportsmen hernia and other ligament-related pain and several bony conditions, such as juvenile osteoarthritis, avascular necrosis of the femoral head or referred back-pain [3,7].

As recently described by the Cochrane Bone, Joint and Muscle trauma group, groin pain in general can be difficult to treat [6]. However, surgical treatment with a good short-term outcome is possible if the groin pain is caused by Femoroacetabular impingement (FAI) [8-10]. FAI is caused by a bony anatomical deformity that causes the hip joint to impinge, which can lead to subchondral or intra-articular damage and pain. Ganz identified two types of deformities: the cam deformity, in which impingement is caused by an osseous deformity of the femoral head-neck contour, and a focal over-coverage of the femoral head by the acetabulum, which is known as pincer deformity [11]. Both deformities rarely occur in isolation and are often combined. Patients with FAI might have a high risk of developing osteoarthritis of the hip [11]. Therefore, it is important to identify patients with groin pain due to FAI in an early stage, in order to delay or even prevent the development of osteoarthritis.

While the treatment of FAI has a good short-term outcome [8-10], patients in the Netherlands can only receive the required treatment from an orthopaedic surgeon after referral from a general practitioner (GP). This means that GPs need to be able to diagnose FAI in patients presenting with groin pain. Whether GPs succeed in recognizing FAI is difficult to assess since the incidence of groin pain caused by FAI in the general population is unknown. Several authors have presented prevalence rates of the radiological characteristics of FAI in asymptomatic volunteers as well as in young athletes [12-16]. These prevalence rates ranged from seven percent to 14 percent and 23 percent. While these studies confirm that FAI is present in the general population, no data exists about the incidence of groin pain caused by FAI. Our hypothesis is that FAI represents a significant group of patients in all patients with groin pain in the general population of GPs. Based on the described prevalence numbers of FAI in asymptomatic volunteers (seven till 23 percent) [13, 15], we estimated that the incidence of FAI in symptomatic patients with groin pain, will be similar to these numbers, e.g. approximately 15 percent.

The objective of this study was to identify the incidence of patients with groin pain caused by FAI in a cohort of patients visiting GPs in the Netherlands during one year. Creating awareness of FAI among GPs may help identify more patients with long lasting groin pain who might benefit from treatment of FAI.

METHODS

A cooperation of 16 general practitioners were invited to participate in this study. The cooperation is located in the province of Noord-Holland (Haarlemmermeer), the Netherlands. According to the data of the local authorities, this area has a population of 31.451 patients [17]. More specifically, the 16 GPs are responsible for the general medical care of 19,185 patients between 15 and 60 years old.

The GPs were asked to register all patients aged between 15 and 60 who presented with groin or hip pain during one year, from 1 July 2013 to 31 June 31 2014. The only exclusion criterion was if the groin pain had already been diagnosed and successfully treated in the past.

Before the start of the study, the participating GPs attended an educational symposium on the pathophysiology of FAI, the clinical presentation of patients and the specific physical examination for FAI. The physical examination included specific FAI tests: the FADDIR test (flexion, adduction, and internal rotation of the hip) and FABER test (flexion, abduction, and external rotation of the hip), both performed in supine position as described by Martin et al [18] Also, participants were educated to suspect FAI in case of impaired range of motion of the joint with specific limitation of internal rotation. Whenever patients experienced recognizable pain with these physical tests, the tests were to be considered positive. These physical examination tests are highly reproducible but with limited specificity [18, 20] For example, positive testing of the groin with limited internal rotation can also be present in osteoarthritis (OA) of the hip.

Patients were clinically suspected of FAI if they presented with groin pain for the first time or if the groin pain recurred after an inactivity period or after referral to a physical/manual therapist or chiropractor. Groin pain was defined as a painful sensation in the area on either side of the body where the thighs meet the abdomen. Furthermore, if patients described the pain to be present after sports or during bending or twisting of the hip during sports or daily activities, the pain in the groin was suspect for FAI.

All GPs received guidelines for additional diagnostics in case the diagnosis FAI was made after a positive clinical presentation and physical examination. Additional diagnostics included plain radiographs of the hip in anteroposterior (AP) view and

frog-leg view (commonly known as Lauenstein view), which were obtained in the nearest hospital (Spaarne Hospital, Hoofddorp) with standardized views. All GPs were asked to specifically enquire information about signs of cam or pincer deformity. If the diagnosis of FAI was sustained by the report of the musculoskeletal radiologist (describing cam deformity, pincer deformity, enlarged alpha angle or a cross-over sign as described by Macfarlane [19]), participants were advised to refer the patient to an orthopaedic surgeon. The GPs could contact the senior author for advice whenever they were in doubt about the diagnosis. In order to avoid interference with common practice, it was emphasized to all GPs that they were not obliged to refer the patient to any specialist or physical therapist, so all the GPs were free to decide what treatment to start.

A new registry-code was created in the electronic patient files (Medicom Pharmapartners Healthcare and HIS Zorgdossier). During this observational year, all patients who presented with groin pain were categorized under this code. All types of diagnoses causing groin pain were registered.

Once every month, an email was sent to all participating GPs to remind them of the registration. At three months, six months, and 12 months, we visited all the participating practices to collect the data.

No compensation was provided for participation.

RESULTS

All general practitioners agreed to participate. For all the participating GPs, the symposium was the first introduction to FAI. After the symposium, all GPs were familiar with the physical examination for FAI.

Of a total of 19,185 patients in the age range 15 to 60 years, 84 patients were registered with groin or hip pain, which resulted in an incidence of 0.44%. The male / female ratio of these patients with groin pain was 44/40, and the average age of the entire population with groin pain was 41.2 (16.8-59.5, ffl SD 12.7) years.

The most frequently diagnosed conditions were tendinitis (mostly adductor related), osteoarthritis of the hip, skin conditions such as Herpes or dermatomycosis, inguinal hernia, FAI, and several other conditions, such as herniated discs or lymphadenitis (table I).

Table I: Diagnoses made by the GPs

Differential diagnosis	N	Percentage
Tendinitis, adductor related	29	34
Osteoarthritis of the hip	4	5
Skin abnormalities (dermatomycosis, herpes zoster)	15	18
Inguinal hernia	9	11
FAI (clinical, PE* and radiological)	14	17
Clinical FAI	25	30
Other (herniated discs, coxitis fugax, testis torsion, lymphadenitis)	13	15

*PE: physical examination

Of the 84 patients with pain in the groin, clinically, physically, and radiologically confirmed FAI was present in 17% (14 patients, nine of whom were female). These patients were therefore diagnosed with FAI (table I). The average age of these patients was 40.5 (21.6 – 51.6, ffl SD 8.1) years. Of these patients, two had hip dysplasia in their medical history, but they had not presented with groin pain before. All patients diagnosed with FAI were referred to an orthopaedic surgeon in a nearby hospital. At the time of this data analysis, two of the referred patients were diagnosed with labral tears with the use of a MRI scan.

Another 25 patients (30%) were clinically diagnosed with groin pain caused by FAI because of the clinical presentation and positive physical exam tests (table I). In 12 of these patients, additional radiograph imaging did not reveal large bony deformities. The other 13 patients had not yet received additional imaging at the time of this analysis. All were referred to a physical therapist to exclude adductor muscle related tendinitis. Two additional MRI scans showed oedema in the adductor tendons. In two patients, additional sonograms were made, but they could not confirm adductor-related tendinitis. In one patient, a CT scan was made, which did not confirm any deformity of the hip.

No further follow-up of these patients has been registered yet.

DISCUSSION

The incidence of groin pain in the study cohort was 0.6%. Of all registered patients with groin pain, 17% were diagnosed with FAI. Moreover, another 30% were clinically diagnosed FAI but were referred to the physiotherapist first. Our data confirms our hypothesis that FAI is a substantial cause of groin pain in a general population. Our estimation that at least 15% of all groin pain might be caused by FAI even proved to be a small underestimation.

In the present study, patients were registered with “groin pain” during their first presentation at the GPs practice. As we set no limitation on further specific information for inclusion, we also registered patients with diagnoses other than FAI. In this way we ensured that the registration resembled the differential diagnoses of groin pain in the general population.

With an incidence of almost three patients a year for each GP and with one confirmed diagnosis a year, FAI is a likely cause of groin pain in the practice of GPs in the Netherlands. Nevertheless, the general practitioners who participated in our study did not have any knowledge about FAI before the start of the study. Moreover, they all were quite convinced that they had never seen patients with such a condition. Before the start of the registration, we tried to optimize the GPs’ knowledge of FAI by means of an educational symposium on the clinical presentation and physical examination for FAI. Nevertheless, possible failures in the registration may have occurred if patients were seen by residents of the GPs, physician assistants or temporary replacement GPs, all of whom might have had less or even no knowledge of FAI.

Recognition of clinical presentation and thorough physical examination is important in the identification of FAI. As stated, the physical examination tests have a rather limited specificity, but they are highly reproducible [18, 20] Positive testing of the groin with limited internal rotation can also be present in osteoarthritis (OA) of the hip. That is the reason why patients with OA of the hip were also identified and registered by the GPs.

Several authors have presented incidences of groin pain in athletes. It has been estimated that over 10% of the consultations in sports medicine centres involve groin pain [1]. These injuries occur most frequently in soccer, field hockey and field-based sports [1,2]. The incidence of groin injuries among professional athletes is 0.5-6.2 % [5], but it is much higher among soccer players, around 10-18% yearly [4]. The cause of this groin pain in athletes is not FAI based. Our study is the first to describe groin pain in the general population due to FAI.

Other authors have presented incidence rates of cam or pincer deformities that might cause FAI in asymptomatic patients. Hack described an incidence of 14% in non-symptomatic volunteers [15]. Moreover, Fukushima presented the same rate in the Japanese population, also in non-symptomatic volunteers [13]. Most recently, Frank et al. reviewed all the literature about the prevalence of FAI in asymptomatic volunteers and identified a prevalence of 23% FAI in the general population [21]. Khanna et al. [14] presented a prevalence of seven% in asymptomatic patients with painful hips during examination and radiological FAI. However, not all patients with a cam or pincer deformity on radiographic images will develop FAI. Bony deformities in asymptomatic patients do not necessarily lead to FAI of the joint, while FAI is the result of impingement caused by a combined movement of the hip joint, which cannot be simulated with plain radiographs [22]. We think that our incidence of 17% of FAI in symptomatic patients is of additional value to these recent publications. Our study adds the valuable information that groin pain is proportionally caused by FAI in our general population.

The average age of our patients seems high but is similar to what other authors have described in their studies about outcomes after treatment for FAI [8-10]. FAI deformities might be present at a younger age, as was described by Agricola, but the age of onset of groin pain caused by FAI is rather diverse [12]. Therefore, it is not surprising that our population does not only contain young athletes but also middle-aged persons.

The total number of groin pain complaints is almost certainly an underestimation, since not all patients with groin pain present themselves to the GP. A limitation of our study is that we did not register patients who directly visited their physical or manual therapist or any other health care professional without needing any further referral to specialist care. The electronic file system of the GPs has no registration for those types of consultations if there was no prior consultation of the GP. However, we did register all the patients who needed any further consultation of the orthopaedic surgeon, since all those patients needed a referral from the GP. In the Netherlands, the health insurance does not cover specialist care without a referral from a GP.

Some patients with clinical signs of FAI were first referred to a physical therapist in order to maintain conservative treatment or to exclude symptoms of adductor muscle related tendinitis. We did not receive information about the follow-up of these patients, so no information can be given about the recovery or continuation of the groin pain in these patients. It is to be expected that in some of these patients the groin pain has persisted, and that the diagnosis FAI might be made at another moment. The lack of follow-up of patients referred to the physical therapist is another limitation of our study.

The diagnoses made by the GPs also included other diagnoses than orthopaedic differential diagnoses for groin pain. Groin pain is a very complex condition. A skin abnormality of lymphadenitis is not a cause for groin pain in orthopaedic practice. However, we invited the GPs to include all patients who presented with anamnestic groin pain. Groin pain was a frequent cause of complaints in these GPs' general practice, and we decided to present all these conditions, since we present the results collected by the GPs. They have no further value for the diagnoses of FAI or related groin complaints.

Other limitations of our study must be pointed out. The radiographs were made in the hospital nearest to each general practitioner. Since we did not want to interfere with the local guidelines, we had no influence on the standardization of the radiographic images. The reports of the images were made by a musculoskeletal radiologist, but they were not available for the authors. We therefore had to rely on the expertise of the local radiologic department and on the report of the radiologist, since we were not able to measure the alpha angle or the centre-edge angle [19, 23].

Groin pain is a very complex diagnosis with a large grey area of conditions. The GP is widely educated in order to be able to make many diagnoses. Depending on anamnestic information, physical examination and additional x-ray and referral, some diagnoses made by the GPs might have changed after inclusion. We had no information on the development of the groin pain (diminishing, progressing) or on the change of diagnoses over time. In order to verify the diagnoses made initially, all patients might have been seen again by the GPs in order to confirm the diagnoses made initially. Since this was not done, we consider this to be a limitation in our registration.

On average, each general practitioner yearly has one patient with FAI and two more who are clinically highly suspected of FAI. In order to present a more reliable incidence and prevalence number for the entire Dutch population, the registration of groin pain and its causes should be managed in a larger cohort from, for example, the entire province.

Since FAI might be a cause of osteoarthritis of the hip, it is important to identify those patients who develop complaints of groin pain at an early stage, so that osteoarthritis might be delayed or possibly even prevented [11]. Further research is essential in order to investigate whether osteoarthritis of the hip can be prevented by early identification and therapy for FAI.

CONCLUSION

The incidence of FAI in patients with groin pain in the general population is 17%, with an incidence of 0.44% in the entire population. Creating awareness of FAI by educating GPs helps to identify patients who might benefit from treatment for FAI.

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The authors would like to give special attention to the cooperation of GPs who took the effort to participate in this registration study. All GPs contributed to this study and this study would not have succeeded without their effort.

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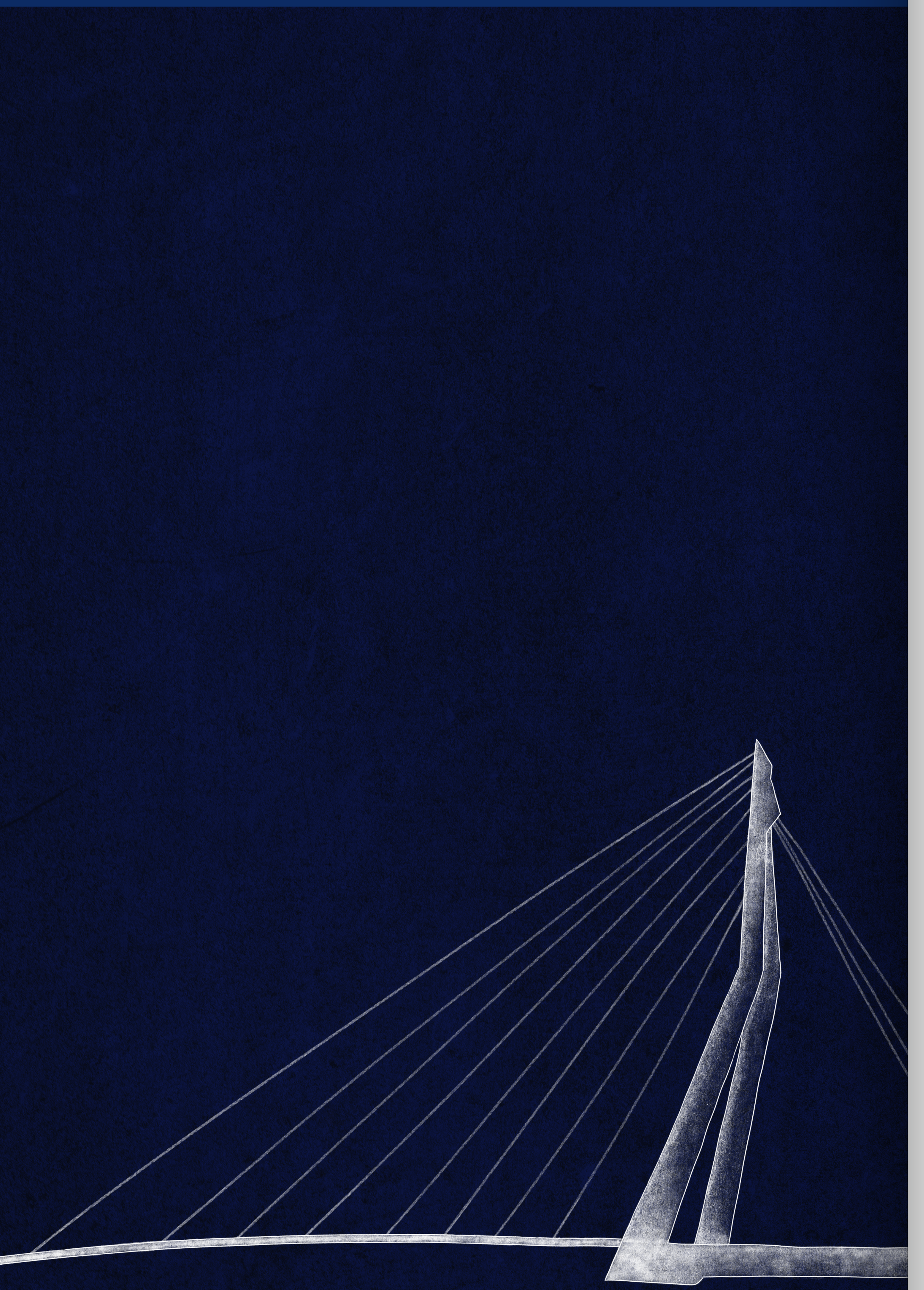
Conflict of interest and funding

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

PART II

IDENTIFYING THE IMPINGING HIP



CHAPTER 3

A QUANTITAVE NON-INVASIVE ASSESSMENT OF FEMOROACETABULAR IMPINGEMENT WITH CT-BASED DYNAMIC SIMULATION – CADAVERIC VALIDATION STUDY

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ABSTRACT

Background
Femoroacetabular impingement (FAI) is caused by an anatomic deviation of the acetabular rim or proximal femur, which causes chronic groin pain. Radiological identification of FAI can be challenging. Advances in imaging techniques with the use of computed tomography (CT) scan enable 3D simulation of FAI. We made an experimental cadaveric validation study to validate the 3D simulation imaging software.

Methods
The range of motion (ROM) of five cadaveric hips was measured using an electromagnetic tracking system (EMTS). Specific marked spots in the femur and pelvis were created as reproducible EMTS registration points. Reproducible motions were measured. Hips were subsequently imaged using high-resolution CT after introduction of artificial cam deformities. A proprietary software tool was used, Articulis (Clinical Graphics) to simulate the ROM during the presence and absence of the induced cam deformities.

Results
According to the EMTS, 13 of the 30 measured ROM endpoints were restricted by > 5° due to the induced cam deformities. Using Articulis, with the same 5° threshold, we correctly detected 12 of these 13 end point limitations and detected no false positives. The median error of the measured limitations was 1.9° (interquartile range 1.1° - 4.4°). The maximum absolute error was 5.4°.

Conclusions
The use of this dynamic simulation software to determine the presence of motion limiting deformities of the femoroacetabular is validated. The simulation software is able to non-invasively detect a reduction in achievable ROM, caused by a cam type deformity.

List of abbreviations

FAI:	femoroacetabular impingement
CT:	computed tomography
ROM:	range of motion
EMTS:	electromagnetic tracking system
MRI:	magnetic resonance imaging

Keywords
Femoroacetabular impingement, diagnostics, CT, dynamic

BACKGROUND

Femoroacetabular impingement (FAI) is an accepted aetiology of premature osteoarthritis of the non-dysplastic hip (1). It has predominance for males, with a prevalence of 17% in men and 4% in women (2, 3). FAI caused by a cam or pincer deformity can be treated by open dislocation and osteotomy, mini-open procedure or by an arthroscopic resection of the bony deformity. All methods are effective at reducing pain, improving function and are relatively save. The arthroscopic method has a lower complication rate and functional results of this procedure have been described as good (4-7). Also, a high return to pre-injury levels of sports performance in athletes has been described (8). However, not all patients recover as to be expected, and revision of the arthroscopy may be needed in these cases. Persistent bony impingement due to residual or untreated bone deformity of the hip and underlying osteoarthritis have been described as the most frequent causes of revision arthroscopy, up to 95% (9-11) It is, therefore, of paramount importance to diagnose the exact position of the deformity causing the impingement. Plain radiography, computed tomography (CT) and magnetic resonance imaging (MRI) are commonly used in the common diagnostic work-up of FAI. Despite this variety of radiological modalities, it remains a challenge to comprehensively evaluate the FAI associated deformities and, thus, to create a complete resection of the FAI. Several authors have pointed out the inefficacy of the current morphological parameters on plain radiographs. (12-15. We still lack methods to determine whether a deformity impinges during movements of a patient. Evaluation by clinicians remains an important part of diagnosing FAI (16). Dynamic evaluation can be helpful in determining whether impingement occurs.

Recent advances in 3D imaging enable simulation of range of motion (ROM) of joints in patients (17). By converting image data to virtual 3D models of the femur and the pelvis, it is possible so simulate the dynamic function of a hip joint. Used in conjunction with the clinical examination of the hip joint, these motion simulations may confirm whether groin pain is attributable to morphological characteristics of the joint (18).

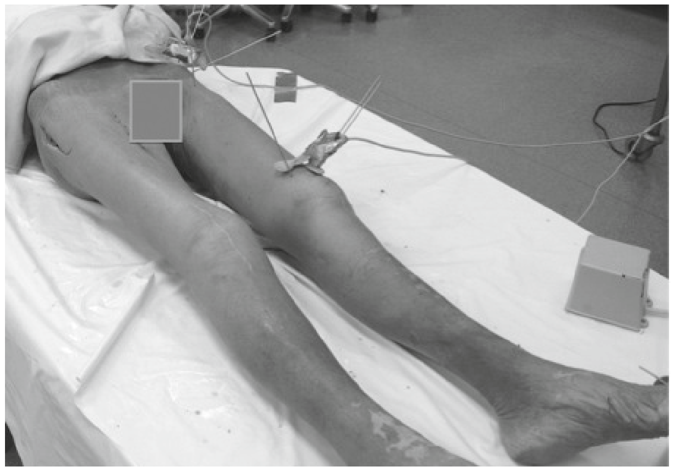
The aim of this study was to validate a CT-based motion simulation software method that has already been validated for other joints (16,19), in the context of FAI, and to evaluate the method's applicability for the diagnostic work-up of FAI in a prospective cohort follow-up study of FAI patients. Although this software has perfect repeatability, it is no golden standard for measurement of range of motion. For this purpose, we determined its accuracy in a range of motion assessment study of five human cadavers. We hypothesized that the software is a reliable measurement tool to detect a reduction in achievable ROM caused by a cam type deformity.

METHODS

Five human cadaveric hip joints from three individuals who had donated their bodies to science (two female, one male) were available from the Department of Anatomy (institution blinded). All anatomic specimens were prepared with Anubifix™ (city blinded, the Netherlands) for optimal preservation (20) and selected for absence of obesity, lack of a total hip arthroplasty and an optimal flexibility of the hip joint of at least 90° of flexion. Gender or age was no selection criteria.

In order to expose the hip joint and to maintain stability and flexibility all the cadaveric hip joints were prepared with the anterolateral approach according to Hueter (21) (Figure 1).

Figure 1: The positioning of the cadaver in supine position with the Kirschner-wires in position. Next to the left foot is the main device of the EMTS.

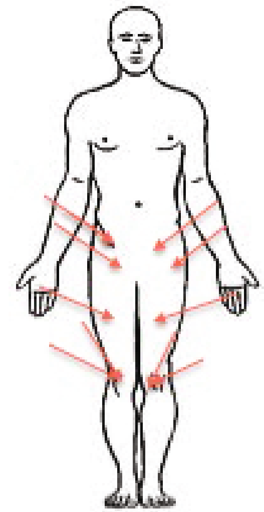


Measurements of the range of motion of the hips were acquired using the electromagnetic tracking system (22) (EMTS), (Flock of Birds, Ascension Technology, United States). This system uses a magnetic field to determine the position and orientation of the sensors to its transmitter. The system requires reproducible registration points on the hip and the femur, according to the ISB recommendations coordinate system. Kirchner-wires were attached into every specimen on marked locations: two K-wires, three centimetres apart, were positioned into the superior anterior iliac spine as registration points for the pelvis. One K-wire was attached into the greater trochanter and one in each epicondyle of the knee as the registration points of the femur (Figure 2). The sensors were attached to the K-wires, as close to the skin as possible. A final sensor was attached to a pointer that registered the other sensors. As per the guidelines of Milne (23), optimal range between the transmitter

and the sensors should be between 22.5 and 64.0 cm. All specimens were prepared and measured on a plastic table and all metal objects within a range of one meter were removed to prevent interference with the magnetic signal.

We registered the maximum flexion, abduction, internal rotation at 0°, 30°, 60° and 90° of flexion. Any positional and rotational changes of respectively 0.25 mm and 0.1° were determined. We measured all end points twice and all differences were < 2%.

Figure 2: The position of the K-wires in the specimen.



An artificial cam deformity was created using nylon screws with a diameter of 1 cm and a thickness of 3.5 mm (Figure 3). Nylon was used because it is known not to interfere with the EMTS while it provides sufficient contrast on the CT images. The density of nylon is less than human bone: 1.15 g/cm³ vs. 1.9 g/cm³ respectively and can be distinguished from bone and surrounding soft tissues. Two screws were inserted on the anterio-superior position of the femoral head, between the 11 and 2 ‘o clock-position in full extension and neutral position of the hip (24,25). After insertion of the screws, the exact same measurements were taken as before. As the simulation software does not take into account the soft tissues of the joint and thus over-estimated the range of motion of each hip joint by default, we chose not to assess the absolute range of motion but the relative change in range of motion as a result of an introduced cam deformity.

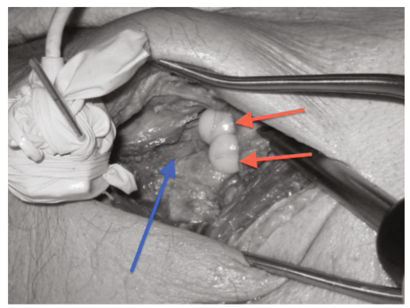


Figure 3: Artificial cam deformity created by nylon screws (red arrow pointing at the screws) inserted at the anterio-superior position of the head-neck junction, after preparation with the Hueter approach. The blue arrow points at the collum of the femur.

The specimens were subsequently imaged by means of non-contrast CT scan. CT scan was performed in the Department of Radiology, (institution blinded), using a second-generation dual source multidetector spiral CT scanner (SOMATOM Definition Flash, Siemens Healthcare AG, Erlangen, Germany) with a tube voltage of 80 kV and an effective mAs-value of 3,140. Scan time per CT scan was approximately 30 seconds. All specimens were scanned in the standard anatomic axial plane orientation and were reconstructed with an effective slice thickness of 1.0 mm and a sharp reconstruction kernel (B75s). Multi-planar reconstruction was performed (image pixel size 0.265 mm).

We used the software package Articulis (institution blinded, city blinded, the Netherlands) to simulate the ROM of the hip joints. The software used the introduced k-wires as registration points, so that the measurements were exactly reproducible between the CT-model and the specimens. The software then automatically converts the CT scans to 3-Dimensional models of the femur and the pelvises. For each hip joint, two different versions of the femur were created: one with and one without the artificially induced cam deformities. The software identifies the impinging area by 0.1 mm and calculates the amount of bone necessary to resect and dissolve the impingement.

Figure 4: A simulation of the artificial cam deformity by the software with the hip in extension: the cam deformity is clearly visible at the anterio-superior position at the head-neck edge.

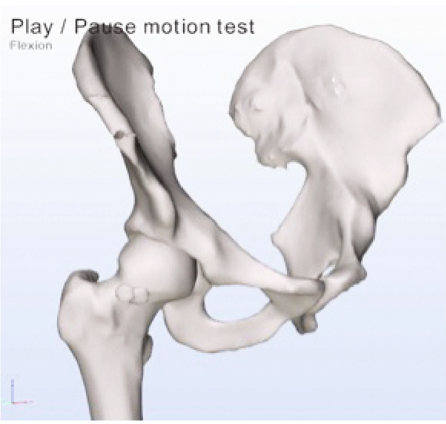
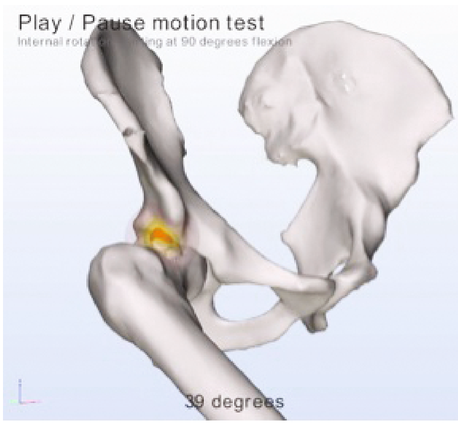


Figure 5: A simulation of internal rotation made by the software, which detects an impingement of the cam deformity with the acetabulum and therefor limiting the internal rotation.



Articulis uses the coordinate systems as described in the Recommendations of the International Society of Biomechanics (26) and the equidistant method described by Puls et al. in 2010. (27) Flexion refers to elevation parallel to the sagittal plane along the Z-axis of the pelvis. Abduction refers to elevation in the coronal plane along the X-axis of the pelvis and internal rotations refer to axial rotation along the femur shaft of Y-axis of the femur. The software systematically simulates different motions, for example flexion, abduction, internal rotations with 90° flexion. While reorienting the femur model the software checks for collisions of the bone models. Up to 3 mm of translation of the femoral head is allowed, applied when reorienting the femur leads to collisions. When more than 3 mm of translation is required to reach a collision free state, simulation is halted and the angle at which impingement

occurred is registered. Figures 4 and 5 are simulations as provided by the software of a cam deformity causing impingement during simulated internal rotation.

No ethics approval was obliged for this cadaveric validation study.

Statistical analysis
We compared the motion limitations observed with the EMTS to the motion limitations determined by the Articulis ROM simulation software. The median deviation, interquartile range and the maximum absolute deviation of the differences were calculated. For these calculations the measurements of the five cadaveric hip joints were combined. Statistical analysis was performed using IBM SPSS Statistic 20 (SPSS, Chicago, Illinois).

RESULTS

According to the EMTS, 13 of the 30 measured ROM end points were restricted by more than 5° due to the induced cam deformities. Using Articulis and with the same 5° threshold, we correctly detected 12 of these 13 end point limitations and detected no false positives. The median error of the simulated ROM limitations compared to the EMTS measured limitations was 1.9° (interquartile range 1.1° - 4.4°). The maximum absolute error was 5.4°.

Table 1 is an example of our measurements of a cadaveric hip joint. Table 2 summarized all measurements.

Table 1: Example of comparison measurements software vs. EMTS of hip joint 5.

	Simulations			EMTS			
	No Cam	Cam	Difference	No Cam	Cam	Difference	Difference of the difference
Max flexion	105	93	12	110	93	16	-4
Max abduction	29	31	0	35	34	1	-1
Max internal rotation	60	60	0	38	37	1	-1
Max internal rotation at 30°	34	34	0	32	34	-2	2
Max internal rotation at 60°	27	26	0	37	31	6	-5
Max internal rotation at 90°	20	1	19	32	18	14	5

Table 2: Difference in degrees between the true limitation (measured with EMTS) and the limitation detected by the simulation software

Hip Joint	1	2	3	4	5	
	R	R	L	R	L	Median
Max flexion	-2	-1	-2	-2	-4	-1.7
Max abduction	-1	0	1	-1	-1	-0.5
Max internal rotation	0	3	-7	-2	-1	-0.8
Max internal rotation at 30°	0	-1	2	-1	1	0.1
Max internal rotation at 60°	-1	-1	5	-2	-5	-1.3
Max internal rotation at 90°	02	1	0	-3	5	0.0

DISCUSSION

In this cadaveric study we evaluated the presence of motion limiting deformities of the femoroacetabular joint by non-invasive modelling software, using 3D radiological imaging. We correctly detected 12 of the 13 end point limitations compared to the EMTS as the gold standard for measurements of ROM. The one hip that we could not correctly detect was mainly limited by soft tissue problems of the hip, which totally limited the internal rotation in neutral position. With a median error of only 1.9°, we can consider the software a highly reliable measuring tool.

Based on our study, we consider this CT-based motion simulation software as validated in the context of measuring the ROM of a hip joint that are limited by FAI deformities.

We chose a 5° threshold to evaluate if the software could detect such a limitation. A 5° threshold is fare above the measurement error (1,9°) of the software. We don't state that this 5° limitation also is a significant limitation of the motion of the hip. This amount is only set to evaluate the accurateness of the software in detecting changes in the range of motion caused by an impinging deformity.

The use of cadaveric hip joints has its limitations and disadvantages. All specimens were prepared with Anubifix™ for optimal preservation (20). Despite being optimally preserved, joints' flexibility or ROM is not identical as in a living human. The use of specimens was inevitable to be able to prepare a standardized artificial cam deformity in the hip joint. By creating the cam deformity, we had exact information about the size and position of the deformity. This knowledge provided us with an accurate ground truth to compare our simulations against. We consider our method of comparing our standardized measurements of the deformities to their exact parameters as very accurate. The expected limited ROM of the cadavers did not

influence our measurements, as the movements of the hips during our measurements were not limited by stiffness of the soft tissues of the cadavers.

Our purpose was to determine whether the simulations of the software could accurately determine ROM as encountered in physical examinations. We used the EMTS "Flock of Birds" system as a gold standard for the measurement of movement and angulation. This system has been calibrated and validated for many applications in motion measurements. Comparing the angles of the ROM with and without an impinging cam-type deformity of both methods demonstrates that the software correctly assesses ROM.

To compare the measurements of the software to the movements of the hip in real life, during sports-activities for example, was not the goal of this study. Our goal was to determine whether the measurements were reliable and valid. The software is able to determine every kind of range of motion possible in the joint. We didn't measure complicated combined angles, which are needed in real life sports like field hockey or soccer, because our specimen wasn't able to provide such range of motion. This is a limitation of our study and due to the specimen, we used. If we had determined what kind of combined movements the hip joint makes during sports, then the software should be able to reproduce these combined movements. However, if the hip joint is limited at the ranges we measured, then it would probably also be limited during sports which requires a larger free range of motion.

Visualization of the cam deformity causing a FAI is challenging. Plain radiography with measurement of alpha angles as well as high resolution and multiplanar CT are widely used. Because of the dynamic aspect of FAI, it is nearly impossible to detect the exact impinging location on a two-dimensional image. Although Barton et al (28) and Nepple et al. (29) state that the use of the alpha angle in the evaluation of cam-type FAI is validated, the use of CT scans adds an essential third dimension. But even in this gold standard for diagnostics, the dynamic aspect remains neglected. Several authors support this flaw of the alpha angle measurement (12-15). Also, a recent study by de Bruin et al. (30) describes a very high prevalence of radiographic signs of FAI at all ages in an asymptomatic population (up to 86.59%). This emphasizes the importance of a simulated analysis based on these radiographic images or direct kinematics analysis.

CT scans have the disadvantage of ionizing radiation. The appropriateness of the use of CT scans should therefore always be evaluated. Accurate diagnosing could, however, limit the amount of unsuccessful operations and revision arthroscopies of the hip joint for FAI. We believe that the use of non-contrast-based CT scans for diagnosing FAI is acceptable because there is currently no true alternative. Low dose reduction techniques and, as described by Gervaise in 2013 (31) and low dose protocols as described by Becce et al. in 2013 (32), might be solutions for these radiation problems. Further research in this area must point out if these alterations compromise the quality of possible dynamic analyses. Magnetic resonance imaging (MRI) has the potential to be a good alternative, as it does not involve radiation. MRI is, however, more challenging for three-dimensional simulation of the joints due to a lower spatial resolution and less accurate delineation of bone compared to CT with most MRI pulse sequences. Besides image acquisition with MRI requires more time than for CT.

The validation of this software opens the possibility to use dynamic motion simulation based on CT scans in the diagnostic pathway or FAI. We hypothesize that creating a dynamic model will result in better functional outcomes in patients with FAI compared to those in previous studies. Described functional outcome results of FAI treated by hip arthroscopy are good (4,7). The rate of unsuccessful surgeries and revision-surgeries could be diminished due to better visualization of the deformity causing the impingement. This hypothesis is currently under investigation by adding the CT movement analysis to our diagnostic work-up for FAI in the off-setting of our prospective cohort, which is currently under analysis.

CONCLUSIONS

This cadaveric study evaluated the use of software to determine the presence of motion limiting deformities of the femoroacetabular joint using radiological imaging with CT. To our knowledge, this is the first study to validate a non-invasive dynamic simulation on pre- and post-operative scenarios representing cam type deformities. The simulation software is able to non-invasively detect a reduction in achievable ROM, caused by a cam type deformity. This technique shows promise as a clinically diagnostic tool for FAI diagnostics and for preoperative planning.

Competing interests
None to declare

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Peter Krekel, TU Delft, the Netherlands, for providing the software and hardware of Flock of Birds.

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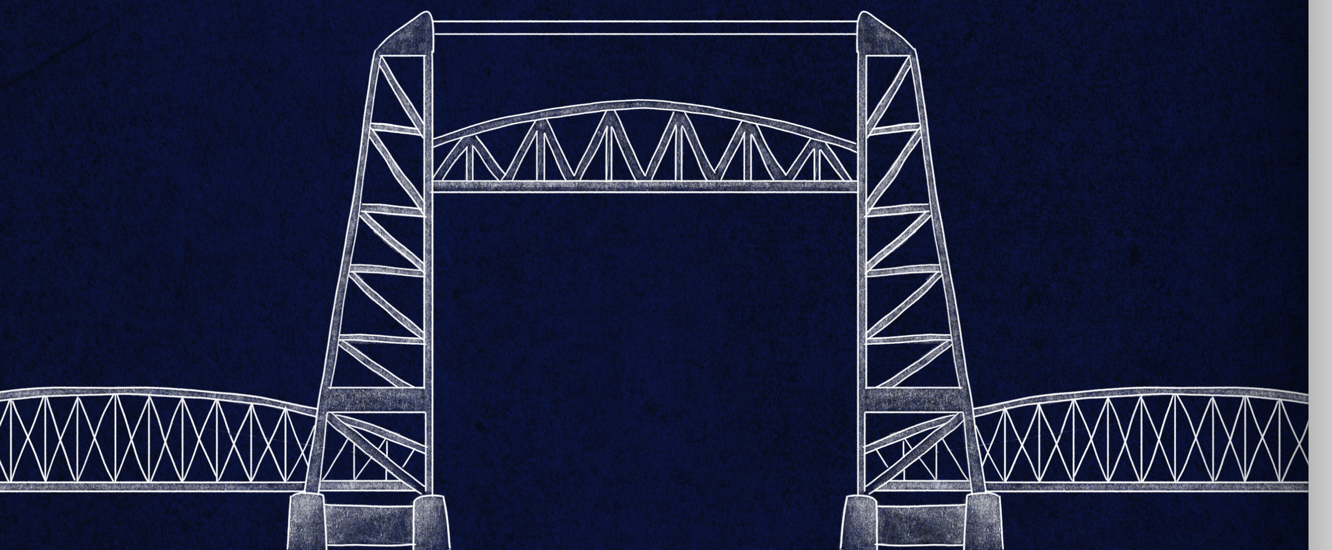

CHAPTER 4

DIAGNOSTIC SENSITIVITY AND SPECIFICITY OF DYNAMIC THREE-DIMENSIONAL CT ANALYSIS IN DETECTION OF CAM AND PINCER TYPE FEMOROACETABULAR IMPINGEMENT

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R.M. Bloem

BMC Musculoskeletal Disorders 2020 Jan 16;21(1):37-5.

ABSTRACT

Background
Cam and pincer-type morphologies can cause femoroacetabular impingement syndrome (FAI) and can be measured on plain radiographs using the alpha angle and the centre edge angle. As an addition to plain radiographs and to assess femoroacetabular impingement, it is possible to visualize the interplay of the acetabular and femoral morphology by means of dynamic three-dimensional simulation of hip joint. Therefore, the objective of this study is to compare alpha angles and centre edge angles on plain radiographs with the dynamic computerized tomography (CT) analysis in patients with complaints of femoroacetabular impingement.

Methods
All patients from our prospective cohort from 2012-2015 who underwent radiographs and a dynamic CT analysis for FAI were selected. Cam type morphologies were measured with the alpha angle and pincer type morphologies with lateral centre-edge angle on radiographs and with CT analysis. The dynamic CT analysis also calculated position and size of impingement of femur and acetabulum. Intra-operative assessment was used to confirm impingement. Sensitivity, specificity, and predictive values were calculated compared with respect to the intra-operative assessment.

Results
A total of 127 patients were included. 90 cam morphologies and 45 pincer morphologies were identified intra-operatively. The sensitivity and specificity for cam morphology measured with radiographs was 84% and 72% compared to 90% and 43% with three dimensional dynamic analyses. The sensitivity and specificity for pincer morphology measured with radiographs was 82% and 39% compared to 84% and 51% with three dimensional dynamic analyses.

Conclusions
Diagnostic accuracy is comparable in three-dimensional dynamic analysis of CT scans and radiographs representing FAI caused by cam or pincer type morphology.

Level of evidence
IV

Keywords
Femoroacetabular impingement, Diagnostics, CT, Radiograph.

BACKGROUND

Femoroacetabular impingement (FAI) syndrome is a well-known cause of hip related pain in athletes and active persons (1). FAI syndrome can be caused by cam and pincer type morphologies. (2). A cam type morphology is caused by an osseous deformity of the femoral head-neck contour, an overgrowth of bone, which can impinge with the acetabular rim during flexion and rotation of the hip. A pincer type morphology is an over-coverage of the acetabulum, which can be focal, and can also cause impingement of the joint. Both morphologies can cause damage in the hip joint, which might result in pain and possible degeneration of the hip joint. Resection of these bony morphologies with hip arthroscopy can relieve the impingement and the pain caused by it (3). It might also prevent further degeneration of the hip joint (4). Identification of the exact location of these morphologies is essential in order to be able to adequately treat the impingement. Intra-operative assessment of typical labral and cartilage lesions associated with cam or pincer type lesions seems the optimal diagnostic method. For cam type impingement damage to the anterosuperior acetabular cartilage with separation between the labrum and cartilage was identified. During flexion, the cartilage is sheared off the bone by the non-spherical femoral head while the labrum remains untouched. This typical damage caused by a cam morphology is a chondro-labral disruption and a progressive chondral delamination: a so-called wave sign. A cam type morphology, the asphericity of the femoral head, was identified in the peripheral compartment after release of the traction.

Damage from a pincer morphology causes an extensive degeneration of the labrum and the adjacent chondral surface. The cartilage damage is located circumferentially and includes only a narrow strip. During movement the labrum is crushed between the acetabular rim and the femoral neck causing degeneration and ossification of the labrum.

The intra-operative assessment, however, should not be used as a diagnostic tool alone, because of its invasive nature. Initial clinical evaluation is mainly done with plain radiographs (5) using the alpha angle (6) to detect cam morphology and lateral centre-edge (LCE) angles, crossover signs and other modalities to detect pincer morphology (7). However, plain radiographs have limitations due to their two-dimensional visualization of this three-dimensional process. The sensitivity for alpha angles varies widely but is described as high, up to 91% on Dunn views. Described inter and intra observer reliability varies also, with intraclass correlation coefficient (ICC) 0.43 for the alpha angle (8) and ICC 0.88 for LCE angles (9) The sensitivity for LCE angles is 84%. (10) These measurements seem quite reliable, but still lack information about the actual impinging moment of the morphologies. The presence of a cam or pincer morphology does not define an impinging hip, it only defines a deviating morphology. Imaging modalities like computed tomography (CT) or magnetic resonance imaging (MRI) might be a better diagnostic option for this three-dimensional process, compared to radiographs.

Dynamic CT analysis was validated for use in FAI analysis in a cadaver model (11). With dynamic CT analysis, a three-dimensional model of the hip is made to detect the area of femoroacetabular impingement. The software calculates the angles defining cam or pincer type morphologies and it also creates a dynamic analysis to identify impingement of hip and acetabulum within a pre-defined range of motion (12-14) of the hip joint.

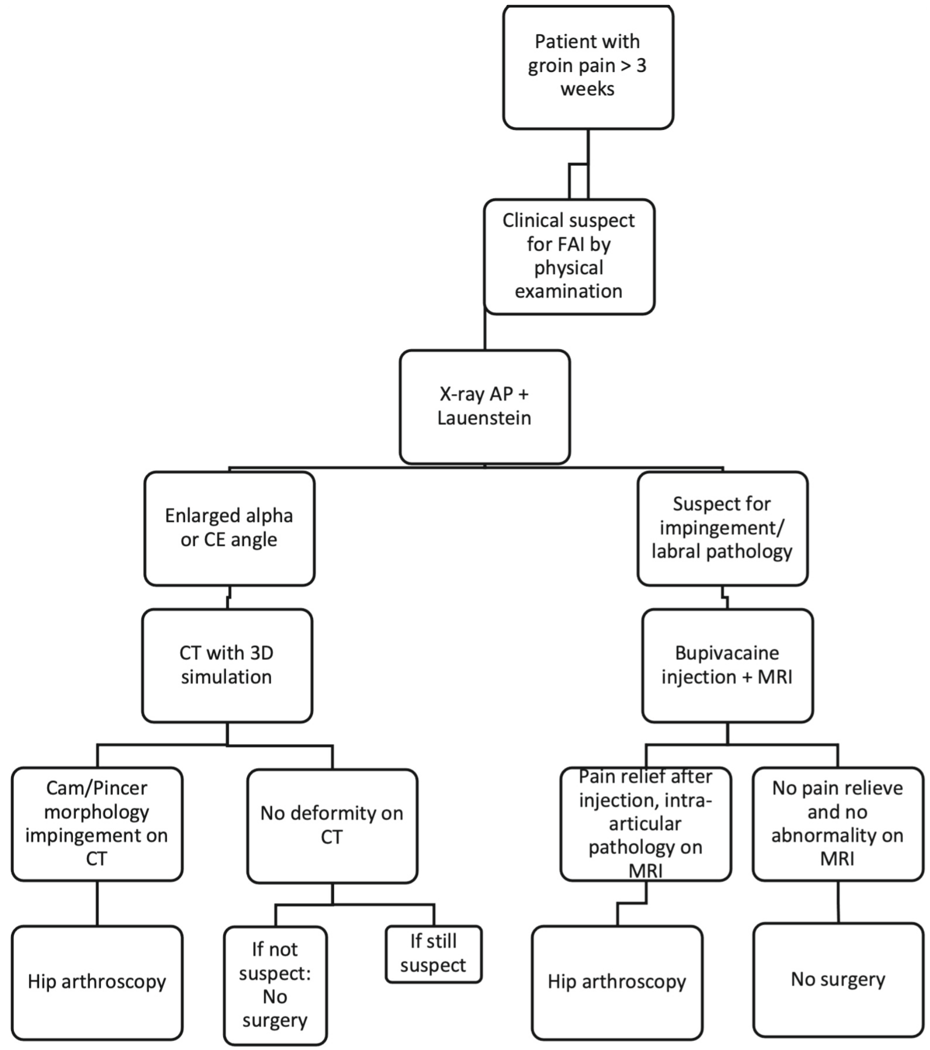
However, no clinical studies regarding dynamic CT analysis in patients suspect of FAI syndrome have been performed. Therefore, the objective of this study is to compare alpha angles and lateral centre edge angles on plain radiographs with the angles measured on dynamic CT analysis in patients with complaints of FAI syndrome. We compared the sensitivity, specificity, and predictive values of radiographs with dynamic CT-analyses with respect to the intra-operative assessment.

It was hypothesized that dynamic CT analysis has a higher sensitivity and specificity in representing the impinging cam and pincer type morphology compared to the radiographs.

METHODS

The present study used data from an ongoing prospective registry in our hospital. We selected all patients who underwent radiographs and dynamic CT analysis for FAI diagnostics and who were operated on between 2012 and 2015. Inclusion criteria for the prospective registry were: diagnosed with FAI syndrome (i.e. evident clinical signs of femoroacetabular impingement (15), positive clinical assessment with positive tests specific for FAI (15) flowchart figure 1), age 18-65, managed conservatively first (with strengthening physiotherapy for at least three months, lifestyle changes and non-steroid anti-inflammatory drugs), suitable for surgery (after consultation of the anaesthesiologist for any contra-indications for surgery) and patients have to be willing to participate. Exclusion criteria are age <18 or >65, prior hip arthroscopic surgery patient history and/or pathological fractures due to metastatic disease.

Figure 1: Diagnostic flowchart femoroacetabular impingement



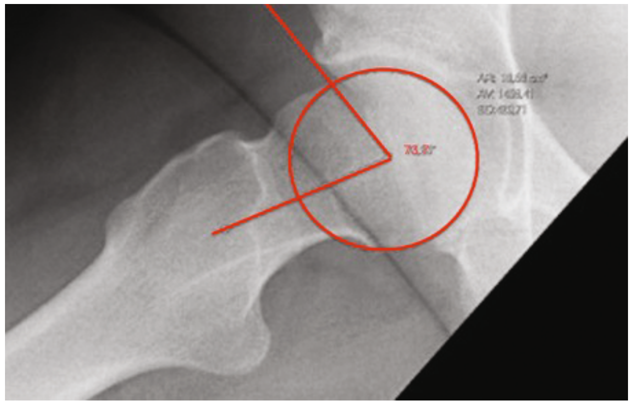
All patients were operated in our peripheral teaching hospital (location blinded). All patients signed informed consent to participate and to publish. The local Medical Ethics Committee decided that the study did not fall under the scope of the Medical Research Involving Human Subject Act because of the minimal burden for patients in comparison to regular care (METC nr 12-083). The data were retrospectively analysed.

Radiographic measurements

Radiographic antero-posterior (AP) and Lauenstein images were made when patients were included. Radiographs were performed using standardized techniques in the supine position as described by Clohisy et al (16). AP pelvis radiographs were performed with the legs 15° internally rotated with the beam centred between the superior anterior iliac spine and symphysis pubis. The Lauenstein views were performed the hip in 30-40° of flexion and 45° of abduction with the heel a rest against to contralateral medial side of the knee.

A cam type morphology was measured on a Lauenstein radiograph by measuring the alpha angle. The angle is measured between two lines: a line from the centre of the femoral head to the point where the radius of the femoral head exceeds a perfect circle drawn around the femoral head, and the line drawn from the centre of the femoral head to the centre of the femoral neck. An angle larger than 60° was considered an enlarged alpha angle and an indicator of cam morphology indicating FAI (6, 17, 18). Figure 2.

Figure 2: Example of an alpha angle measured on a Lauenstein radiograph



A pincer type morphology is measured on an AP pelvic radiograph with the lateral centre edge (LCE) angle. This is the angle between a line vertical to the centre of rotation of the femoral head and the lateral edge of the acetabulum. Figure 4a. An LCE angle larger than 33° was considered enlarged and an indicator of pincer morphology indicating FAI (10,19). All x-rays were interpreted by an independent radiologist who made a report in the patient file and by one of the researchers (MAR).

Dynamic CT analysis

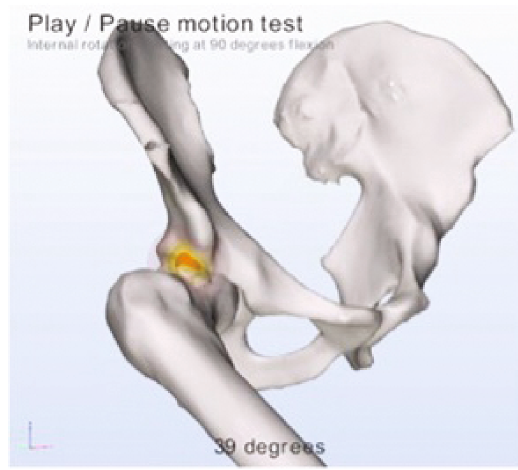
The CT scans of the pelvis were performed with a standardized protocol. CT scans were performed at the department of Radiology using a second-generation dual source multi-detector spiral CT scanner (SOMATOM Definition Flash, Siemens Healthcare) AG, Erlange, Germany) with a tube voltage of 80 Kv and an effective mAs-value of 3,140. Scan timer per CT scan was approximately 30 seconds. All patients were scanned in the standard anatomic axial plan orientation and were reconstructed

with an effective slice thickness of 1.0 mm and a sharp reconstruction kernel (B75s). Multi-planar reconstruction was performed (image pixel size 0.265).

The dynamic analysis of the hip joints was made with proprietary software of Clinical Graphics® (20) which uses the coordinate systems as described in the recommendations of the International Society of Biomechanics and the equidistant method described by Puls et al. to simulate translation of the femoral head (21). The software was previously validated in 2015 (11). Figure 3 is an example of a cam type morphology causing impingement during simulated internal rotation as provided by the software. If kinematic motion is limited, the software reports the depth and location of the impingement and exact location of the type of morphology, a dynamic movement analysis with exact impinging locations, an alpha angle (at seven positions from nine till three o'clock), a centre edge angle (at three positions; 11, 12 and one o'clock positions) and a reproduction of the unlimited range of motion (11, 20). An impingement is only detected within normal range of motion of the hip joint, according to relevant literature, which is discussed in the validation study (9).

The Dynamic CTs were interpreted by the software company who provides the software and dynamic analyses (Clinical Graphics), for which a detailed report of the analysis was made. Their reports and scans were also interpreted by one of the researchers (MAR).

Figure 3: A simulated internal rotation and flexion of the right hip joint with simulated impingement as represented by the software



Surgery

All patients underwent hip arthroscopy for treatment of the FAI. Intra-operative images with fluoroscopy were used to determine if the hip joint was adequately widened with traction and whether the impinging areas were adequately resected.

Examination of the joint and operative technique was performed in accordance with Bond et al. (22). The intra-operative assessment contained documentation of intra-articular damage to cartilage or labrum, caused by impingement, as described by Beck et al (23). This contained inspection of the central and the peripheral compartment. Damage to the anterosuperior cartilage of the acetabulum, a chondral delamination, separation of the labrum and cartilage, degeneration of the labrum and chondral surface on the femoral head, pincer morphologies caused by a bony edge of the acetabulum, cam morphologies on the femoral head neck junction or signs of herniation pits on the femoral head neck junction were identified and recorded in the patient file. Locations and types of lesions were recorded in the patient file.

Impingement can be proven by identifying and recording such typical lesions to the hip joint.

These intra-operative signs of impingement were afterward used as the golden standard for impingement, to compare with the pre-operative diagnostics methods of x-rays and dynamic analyses.

Statistics

A cam type morphology suspect for FAI was defined as an alpha angle > 60° measured on Lauenstein radiographs.

The presence of a cam type morphology on dynamic CT analysis was defined as an osseous impinging area on the anterolateral side of the collum, due to the asphericity of the femoral head. This was highlighted by the software during the simulated range of motion within values of normal hip motion. Example figure 3.

A pincer type morphology was defined as an LCE angle >33° measured on AP radiographs.

The presence of a pincer type morphology on the dynamic CT analysis was defined as an osseous impinging area on the anterior, lateral, or posterior wall of the acetabulum, highlighted by the software during the simulated range of motion within values of normal hip motion.

The intra-operative assessments with identification of impinging cam and/or pincer type morphologies, were considered as the gold standard for impingement.

Sensitivity, specificity, positive-predictive-values (PPV) and negative-predictive-values (NPV) were calculated.

Software of Microsoft Excel for MAC 2011, version 14.7.7. was used for the calculations.

RESULTS

A total of 127 patients were selected for analysis. Table 1 presents demographic data and intra-operatively registered morphologies of this cohort.

Table 1 Demographic characteristics of the patient population

Patients	N = 127
Male/Female	78/49
Age	37.5 (18-65)
Years of complaints	3.6 (1.0-30)
Alpha angle on X-ray	66° (39°-96°)
Lateral centre edge angle on X-ray	38° (25°-75°)
Deformities intra-operative	
Cam	90 (71%)
Pincer	45 (35%)
Combined cam and pincer	29 (23%)
Labral tears	83 (65%)

4

A total of 90 cam morphologies and 45 pincer morphologies were diagnosed intra-operatively. In 29 patients, a mixed-type morphology was present. The average alpha angle measured on a Lauenstein radiographs was 66°. The average LCE angle measured on an AP radiograph was 38°.

The alpha angle on radiographs indicated FAI due to a cam morphology in 86 patients (alpha >60°), of whom 76 showed signs of an impinging cam morphology with the intra-operative assessment.

The dynamic CT analyses showed impinging cam morphologies in 102 patients, of whom 81 showed signs of impinging cam morphology with the intra-operative assessment.

The LCE angle on radiographs was >33° in 87 patients, of whom 37 showed signs of an impinging pincer morphology with the intra-operative assessment.

The dynamic CT analyses showed impinging pincer morphologies in 78 patients, of whom 38 showed signs of impinging pincer morphology with the intra-operative assessment.

The sensitivity, specificity, PPV and NPV are reported in table 2 and 3.

Table 2 Sensitivity, specificity, PPV* and NPV** for cam type morphology comparing radiographs and dynamic CT scans with the per-operative assessment

	Sensitivity	Specificity	PPV*	NPV**
Alpha angle on X-ray	84%	72%	88%	63%
Dynamic CT impingement	90%	43%	79%	64%

*Positive predictive value
**Negative predictive value

Table 3 Sensitivity, specificity, PPV* and NPV** for pincer type morphology comparing radiographs and dynamic CT scans with the per-operative assessment

	Sensitivity	Specificity	PPV*	NPV**
LCE angle on X-ray	82%	39%	43%	80%
Dynamic CT impingement	84%	51%	49%	85%

*Positive predictive value
**Negative predictive value

DISCUSSION

The objective of this study was to compare sensitivity, specificity, and predictive values of radiographs with dynamic CT-analyses, with respect to the intra-operative assessment. For cam type morphology, the dynamic CT-analyses has higher sensitivity and NPV, but a lower specificity and PPV compared to radiographs. For pincer type morphology, only small differences could be observed in favour of the dynamic analysis. The use of a three-dimensional dynamic analysis of CT scans could be a useful tool for surgeons in their preoperative assessment, but the diagnostic value is comparable with the sensitivity and specificity of radiographs.

The use of an alpha angle to define cam type morphology (17, 24) is debatable. Some authors have described sensitivity up to 91% for an alpha angle on Dunn views (7, 10, 17, 25). Our results show sensitivity for an alpha angle >60° of 84%. Variations in diagnostic accuracy might be due to variations in the used alpha angles, different sizes of patient cohorts and differences in intra-operatively used assessment of impingement damage to the joint. However, the use of radiographs gives no

information of the position of the impinging area and the amount of bone needed to resect, to resolve the impingement.

A cam type morphology causes asphericity of the femoral head. Whether this asphericity causes FAI syndrome is defined by several factors, for example the version of the femoral neck, the shape of the acetabulum and the actual size and depth of the morphology. A relatively deepened acetabulum, protrusio acetabuli or retroversion of the collum and/or acetabulum, combined with a minor enlarged alpha angle cam type morphology might cause FAI syndrome. Representing the cam morphology only by the alpha angle gives no information about the shape of the acetabulum and the movement of the hip joint causing the impingement. We identified several morphologies outside the coronal plain (by the use of the dynamic CT scans), which could therefore not be identified on a plain radiograph (see figures 4a and 4b). A dynamic analysis of a CT scan might improve the visualization of this process because it includes the femoral offset, rotation, version, acetabular coverage, and tilt. The calculated sensitivity and specificity however do not highlight these theoretical improvements.

Figure 4a: Example LCE angle within normal limits, no detection of a pincer type morphology

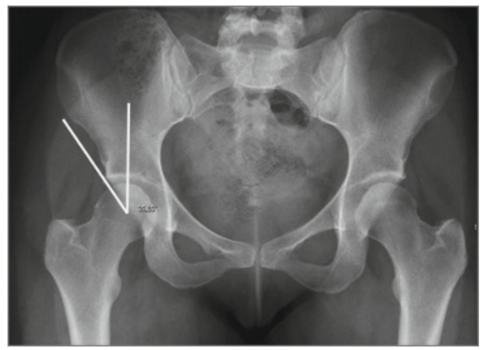


Figure 4b: The same right hip joint seen from sagittal plain: a single osteophyte causing a pincer type morphology outside the coronal plain and impinges in abduction and flexion

We used the alpha angle and LCE-angle measured on the radiographs. Other radiographic measurements might alternatively be used, e.g. the cross over sign, the posterior wall sign, the version of the hip and more (6). Using different measurements have advantages and disadvantages. The cross-over sign is mostly used (6) but also no strong evidence exists to support a single best set of radiographic markers for the diagnose of pincer type morphologies (26). To possibly improve diagnostics, maybe all should be used. Daily practice however still starts with the use of an AP radiograph, for the first impression of a possible pincer morphology/enlarged coverage. An AP radiograph in supine position does also not incorporate the tilt and inclination of the pelvis. In future measurement this could be adjusted by false profile pelvis radiographs and close attention for the pelvic tilt, as very recently stated by Putnam (27).

To use the LCE angle for pincer measurement is debatable. Several diagnostic tests are available for pincer-type FAI. According to Rhee et al. (6), no strong evidence exists to support a single best set of current radiographic markers for the diagnosis of pincer-type FAI. Furthermore, the definition of an enlarged LCE angle is debated and differs from 25-40° (28-30). Rhee et al. (7) describe that most authors use LCE angle greater that 35-40° for acetabular over-coverage, thus pincer morphology. Kutty et al. (10) describes a sensitivity and specificity rate of 84.2% and 100% for an LCE angle of <40°. These sensitivity and specificity measurements differ with our measurements, which are respectively 82% and 39% for plain radiographs and 84% and 53% for the dynamic CT analyses. A specificity rate of 100% is ideal and might be utopic. These authors have conducted a retrospective study, on a relatively small cohort (55 patients) who were already operated on. This might bias their results and partially explains the differences in our results. Furthermore, these differences could be explained by the use of a different LCE angle.

To compare radiographs with three-dimensional analysis, we used the intra-operative assessment as the golden standard, as stated by Rhee et al. (7). Specific damage caused to labrum and cartilage could be identified intra-operatively. Beck et al. (23) described how the labrum and cartilage is damaged by cam impingement and by pincer impingement in 244 hips. They described a pattern of damage to the acetabular cartilage and labrum depending on the shape of the hip, induced by repeated microtrauma. Anderson et al. also describes the delamination of acetabular articular cartilage due to femoroacetabular impingement (31). However, as several patients were diagnosed with only small morphologies, this intra-operative view might be biased by the judgment of the operating surgeon. The surgeon has all pre-operative imaging information. Therefore, if the patient had clinical symptoms of FAI and the imaging revealed a small cam/pincer type morphology, the surgeon might be biased to diagnose an actual morphology if any damage to labrum or cartilage can be identified. It is therefore debatable what gold standard should be used. Other authors have however also used the intra-operative findings as reference standard (25, 32-34).

Positive predictive value for cam type morphology is high for both modalities, but low for pincer type morphology. The negative predictive value is low for cam type morphology but high for pincer type morphology in both modalities. These predictive values seem not very high. As described by Vecchio et al (35), the predictive values are strongly related to the actual prevalence of the disease (cam/pincer morphology) in the total population. The prevalence of cam morphology in our

population was 71% and the prevalence of pincer morphology was 35%. When the prevalence rises, the predictive values grow and are more reliable.

This study has several limitations. Our analysis is retrospective, in a large prospectively registered cohort. Moreover, the analysed patient population is relatively small. A larger cohort could add more reliable information. Furthermore, we included patients up to 65 years of age, which is relatively high. This however should not influence our diagnostic study design.

The theoretical advantage of the 3D dynamic analysis, the three-dimensional orientation and information about the location and size of the impinging area between acetabulum and femur, could not be highlighted by defining the sensitivity and specificity. These theoretical advantages might improve functional outcome or revision rate, but this is beyond the scope of this article. The extra costs and radiation exposure due to pre-operative CT scans is therefore debatable if it is not improving pre-operative sensitivity and specificity of the diagnostics. The radiation exposure can be bypassed by the use of MRI (36).

CONCLUSION

Diagnostic sensitivity, specificity and predictive values are comparable in three-dimensional dynamic analysis of CT scans and radiographs representing FAI caused by cam or pincer type morphology. No clear improvement in diagnostics could be identified with the use of the dynamic analyses, despite that it could assist surgeons in pre-operative planning.

Declarations
Ethics approval and consent to participate

All patients signed informed consent to participate and to publish. The local Medical Ethics Committee (METC Zuidwest Holland, P/a LUMC, Secr CME, metc-ldd@lumcl.nl, Postbus 9600, 2300 RC Leiden) decided that the study did not fall under the scope of the Medical Research Involving Human Subject Act because of the minimal burden for patients in comparison to regular care (METC nr 12-083). After informed consent, no other specific administrative permission was required to access raw data.

Consent to publish
All patients signed informed consent to participate and to publish data obtained by this study.

Availability of data and materials
The datasets used and analysed during the current study are pubic available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

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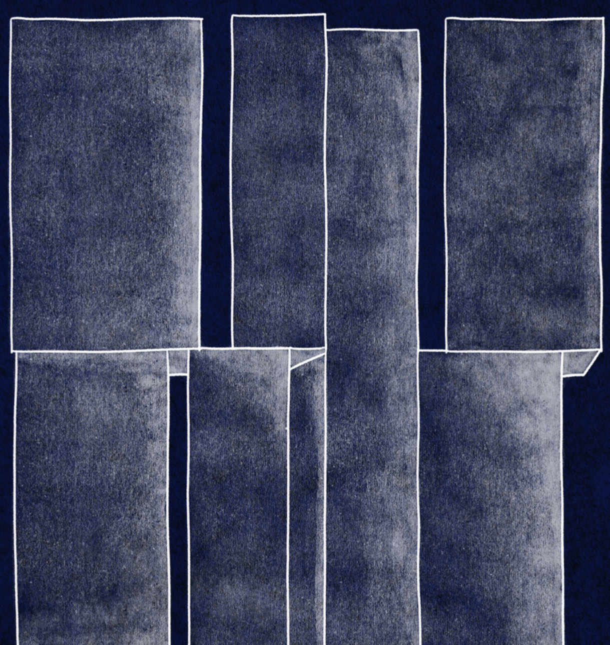
PART III

MODIFYING THE IMPINGING HIP



CHAPTER 5

TRACTION FORCE FOR PERIOPERATIVE HIP DISLOCATION IN HIP ARTHROSCOPY

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ABSTRACT

Introduction
Traction force widens the joint space during hip arthroscopy. It is unclear how much the traction force varies and if it is related to the joint space widening. Main goal of our study was to measure the amount of force needed to widen the hip joint. Second goal was to study the relation between this force and the amount of joint space widening.

Methods
Traction force was measured in 27 patients (of whom 24 female, mean age 41) during arthroscopy. Measurements were performed before the procedure, after vacuum seal release and after capsulotomy. Joint space widening was measured with fluoroscopy and was calibrated. Friedman and Wilcoxon tests were used to measure differences in traction. The Spearman's rho correlation coefficient was used to identify a correlation in traction force and joint space widening. Regression analyses were used to identify relations between age, BMI and hip degeneration and traction force.

Results
The median traction force before arthroscopy was 714N, lowered to 520N after vacuum seal release and to 473N after capsulotomy ($p<0.001$). Median joint space widening was 8.8mm. Spearmans' rho correlation between traction force and joint space widening was -0.13.

Discussion
Median traction force of 714N resulted in 8.8mm of joint space widening. This traction force was significantly lowered by 200N after release of the vacuum seal of the hip and 250N after additional capsulotomy without loss of joint space narrowing. No significant relation was identified for age, BMI, or progression of the Kellgren-Lawrence classification for hip degeneration and traction force.

Netherlands Trial Registry number 8610

Keywords
Arthroscopy Dislocation Hip Traction

INTRODUCTION

Hip arthroscopy is a widely used operation for treatment of intra-articular pathology of the hip joint.

The complication rate after a hip arthroscopy is approximately 3.3% (1-4). Nerve damage (pudendal nerve, cutaneous-femoral nerve, sciatic nerve), skin lacerations and avascular necrosis of the femoral head (5) are described complications with great impact on patient's life and recovery after surgery. Nerve damage to the perineal area causes large inconvenience for patients causing numbness or temporary erectile dysfunction. Most complications of hip arthroscopy occur due to traction on the leg needed for hip dislocation (6). Most of these complications recover over time, but not all recover completely. Despite this risk for possible complications, traction force on the leg is needed to dislocate the hip joint in order to have intra-articular access during hip arthroscopy. Ellenrieder et al (7) described that more than 400N traction force might cause traction-related complications. However, it was concluded by Telleria et al. that not only the amount of traction force, but also the time during which the force is applied is related to the occurrence of complications (8). Dienst et al (9) analysed the amount of traction force for optimal dislocation and concluded that 200-250N was needed for dislocation. Their study, however, was conducted in a cadaveric study design. The amount of traction force needed for intra-articular access with optimal joint space widening has not been studied in vivo.

Furthermore, it is unclear what the relation is between the used force and the obtained joint space widening.

Main goal of our study was to measure the amount of traction force needed to dislocate the hip joint during hip arthroscopy. Furthermore, we wanted to study the relation between traction force and the amount of joint space widening, and to analyse whether an association could be identified between age, BMI, and progressive degeneration of the joint and traction force for hip dislocation.

METHODS

This study was performed at the Reinier de Graaf Hospital, Delft, the Netherlands, between April 2016 and April 2017.

All consecutive patients who were selected for hip arthroscopy during this period were asked to participate. Inclusion criteria were age 15-65 years of age, diagnosed with femoroacetabular impingement (FAI) with/without labral damage, free bodies or chondral lesions which would be treated with microfracture. Exclusion criteria were:

<15 or >65 years of age, hip arthroscopic treatment in patient history, pathological fractures of metastatic hip disease, body length exceeding 1.74 meters.

The local Medical Ethics Committee decided that the study did not fall under the scope of the Medical Research Involving Human Subjects Act because of the minimal burden for patients in comparison to regular care (METC nr 16-042). However, written informed consent was obtained from all patients. The study was registered in the Netherlands Trial Registry (6810).

Force measurements

During hip arthroscopy, a traction table is used (Smith and Nephew Hip Distractor system). This system uses 2 leg-supports with a wadded post between the legs to protect the perineal region. In order to measure traction-force, a force gauge was used (Sauter FL2K, figure 1). This force gauge was incorporated in the traction table by an S-beam (figure 2), made with Solid Works (Dassault Systems SolidWorks Corporation Waltham, MA, USA) and created by MetaTech (Delft, The Netherlands). The S-beam was connected between the shoe of the traction table and the force gauge. That way, software from the force gauge (Sauter AFH FAST) was able to visualize continuous force measurements. Because the S-beam and the force gauge were incorporated in the traction table system, the maximum patient's length was set on 1.74 meters. Whenever patients exceed this length, the traction table of the leg will not be able to reach its full length and therefore it is not possible to reach maximum traction force.

Figure 1: Force gauge, Sauter FL2K

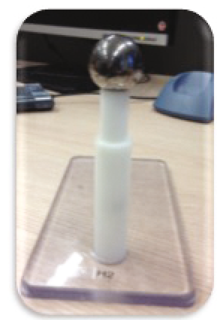
During arthroscopy, a fluoroscopy from Pulsera (Phillips Best, the Netherlands) is positioned perpendicular to the hip joint. The fluoroscopy uses 67 KV (65-68 kV), 8 mA and creates images with 25 pulses per second, which is saved as a secondary screen capture (Last Image Hold). The radiation is kept to a minimum this way with an absorbed dose of 3.6 cGy x cm^2.

Figure 2: S-beam with connection parts for the shoe and traction system

To be able to measure the joint space, we had to calibrate the size of the fluoroscopy images. Therefore, a calibration bullet (20mm diameter) was used, which is normally used for pre-planning in total hip arthroplasty. The bullet is placed between the legs of patients in pre-planning for total hip arthroplasty surgery. However, in the traction table position, the wadded perineal post is at this position. We therefore made a connection of the bullet to a plastic stick (figure 3) and kept the bullet just proximal and lateral of the greater trochanter during fluoroscopy.

After general anaesthesia with muscle relaxant, antibiotic prophylaxis and positioning in supine position, the procedure started. Both legs are positioned in the wadded boots and the wadded perineal pole was positioned. The force gauge was attached to the boot of the affected leg. The procedure contained 2 joint space images with fluoroscopy and 4 traction-force measurements.

Figure 3: Calibration bullet



A first image was made without traction to the hip joint, with the calibration bullet to the major trochanter side. This image is saved to measure the joint space without traction-force on the leg. After the first image, traction-force was given. At the moment optimal joint space widening is achieved according to the orthopaedic surgeon (which is an estimated 10mm widening of the joint space), the force was measured (measurement 1), and the image was saved, with the calibration bullet at the trochanteric side. The traction was released when the surgeon prepared for surgery. Traction was given to create the same amount of joint space widening, which is measurement 2. Now the hip is punctured with a large needle, relieving the vacuum on the hip joint. At this moment, measurement 3 is made. A first portal is made, and the trocar is introduced with the scope afterwards. After inspection of the hip joint, a second portal is made. Now a capsulotomy is performed, to create manoeuvring space for the instruments. At this moment, measurement 4 was made.

2 Researchers (blinded) measured the joint space and the widening of the joint space, independently from each other The software was used from JiveX (VISUS, Technology Transfer GmbH, Bochum, Germany). The scale was calculated with the dimension of the calibration bullet, 20mm. The joint space is defined as the central point of the femoral head to the central point of the acetabulum (figure 4). The joint space widening was calculated in mm (figure 5).

Figure 4: Joints space measurement and joint space widening measurement, with the calibration bullet as a scale

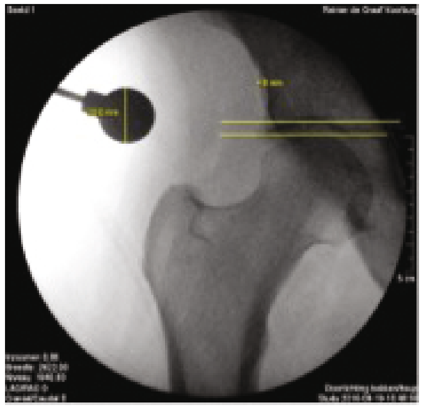
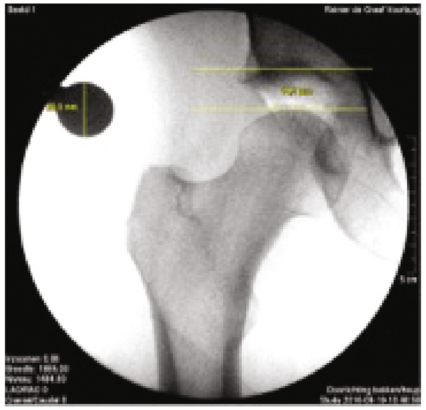


Figure 5: Joint space measurement with relative joint space widening, with the calibration bullet as a scale



All patients received standard medical care postoperative, according to our local treatment protocol. Complications were registered during follow-up, with meticulous anamnestic information and physical examination for neuropraxia of the foot, lateral side of the proximal femur and the groin area (respectively the lateral personal nerve, lateral cutaneal femoral nerve, pudendal nerve). Recovery of neuropraxia was registered during follow-up.

Statistical analyses

Mean traction forces off all 4 measurements were presented as well as the standard deviation. Since the data were not normally distributed, Friedman tests were executed with a significance level set at p=0.05 to determine differences between the 4 measurements. A Wilcoxon test was executed as post hoc analysis, with a significance level set at p=0.01 after a Bonferroni correction.

Reliability of the joint space widening measurements was determined with an intraclass correlation coefficient (ICC), two-way random.

Correlation between the traction force and the joint space widening was tested using spearman correlation test. We also tested for a correlation between traction force and complications/nerve damage. Binary logistic regression was performed to determine the relation between traction force (first measurement) and the occurrence of neuropraxia.

We performed a linear regression analysis to determine the relation between age, BMI and Kellgren-Lawrence radiographic classification and traction force. Factors that were associated with the outcome in univariable analyses (p<0.20) were included in a multivariable linear model. In the multivariable model p-values <0.05 were considered significant.

Data was analysed using SPSS, version 21.0 (Chicago, Il, USA).

RESULTS

From April 2016 until April 2017 a total of 105 patients were diagnosed with FAI and planned for hip arthroscopy. 72 Patients were excluded because of a too large body length and 4 patients declined participation and in 2 patients no measurements were made.

A total of 3 male and 24 female patients were included. Demographic characteristics are demonstrated in table 1. Median traction force was 714 Newton (390-1362) and median joint space widening was 8.8 mm (5.6-13.8) (tables 2 and 3).

Table 1: Patient characteristics

	Mean	Spread	IQR
Left/Right	12/15		
Age (yr.)	42	16-57	16.95
Height (m)	1.70	1.60-1.74	0.05
Weight (kg)	77	57-95	17
BMI	26.5	19.1-34.5	5.66
Kellgren-Lawrance scale	0.80	0-2	2

ICC of the joint space widening was 0.939 (p<0.001).

The joint space widening at the 4 different moments is presented in table 2. Spearmans' rho for the correlation between traction force and joint space widening was -0.13 (p=0.335).

Table 2: Traction forces during hip arthroscopy

	Measurement 1	Measurement 2	Measurement 3	Measurement 4	Sign
Traction force (Newton)	714	624	520	473	P=<0.001
Range	390-1362	185-1372	119-780	63-750	
IQR	315	173	172	152	

Values are presented as median

In total, 12 cases of neuropraxia were registered (44%): 5 cases of neuropraxia of the peroneal nerve, 5 cases of the lateral cutaneal femoral nerve and 2 cases of neuropraxia of the pudendal nerve: all were sensory neuropraxia, no motoric weakness was identified. All neuropraxia recovered within 3 months of follow-up. Binary logistic regression showed no relation between neuropraxia and traction force (OR 1.000 (95%CI 0.998-1.002)).

BMI and Kellgren-Lawrence radiographic stage had p-values below 0.20 in univariable analyses, however in the were multivariable model no associations were found with the traction force of measurement 1.

Table 3: Joint space widening

	Before traction	With traction	Total Widening	
Joint space (mm)	4.5 mm	13.1 mm	8.8 mm	P=0.001
Range	2.4-6.4 mm	9.4-19.4 mm	5.6-13.8 mm	
IQR	135	3.33	2.82	

Values are presented as median.

DISCUSSION

Main goal of our study was to describe the amount of traction force needed to dislocate the hip joint during hip arthroscopy and to determine whether there is a relation between this force and the amount of joint space widening. The median amount of traction force needed for dislocation of the joint was 714N. Furthermore, the median joint space widening was 8.8mm. No correlation could be found for the used traction force and the accompanied joint space widening. In other words, the traction force needed to obtain a median joint space widening of 8.8mm, varies greatly between individuals.

The traction forces measured in our study were higher compared to the traction forces measured in the study of Ellenrieder et al. (7), who measured an initial force of 477N. This might be caused by patient specific factors like more coverage of the femoral head, stronger joint capsule of more muscular patients. Statistical analyses showed no relation with high traction force and age, high body weight / body length ratio or with the Kellgren-Lawrence radiographic stage for a higher traction force. Furthermore, our results of obtained traction forces are higher compared to the traction forces in the study of Dienst et al. (9) However, they performed their study in anatomic specimen, which might be the reason for other results. Cadaveric studies do certainly not resemble the real-life reactive forces of the joint capsule and ligaments. From their study, it is unclear how the vacuum seal was released and at what moment during distraction this was done. Furthermore, the absolute joint space widening is not mentioned in both studies, making it difficult to compare our results.

The traction force we measured, gradually lowered during the procedure. This means that the traction force does not have to be constant during the entire intra-articular procedure. We should be aware of this reduction of force needed for joint space widening.

We could not identify any relation between the traction and the joint space widening for the entire cohort. In other words, the forces needed to obtain optimal joint space widening vary greatly between individuals. Traction of the hip joint is necessary to gain access to the hip joint. Traction on the leg provokes reactive force of the capsule, the iliofemoral, pubofemoral and ischiofemoral ligaments. More traction force creates more reaction force. The vacuum of the hip joint, maintained by the labrum, has a negative pressure and suction force. To overcome these forces, large amount of traction to the leg is essential to create a joint space narrowing. These items can all differ in individual patients.

Ellenrieder et al (7) have correlated male gender, a higher body weight and high Kellgren and Lawrence radiographic stage with a higher traction force. Due to our inclusion criterion for body length, almost no male patients were included. This biases our inclusion, since man have supposedly stronger muscles and possibly thicker capsules. We could also not identify this relation for BMI. A logic explanation could be that our patients do not have large differences in BMI as other patient cohort. Therefor we cannot completely relate our results to the results of Ellenrieder et al. (7).

We did also not measure any significant relation for progressive osteoarthritis of the hip and traction force. In theory, the progressive stiffness of the more degenerative hip joint might influence traction force. In our institution patients with radiological progressive hip degeneration are not suitable for hip arthroscopy and are therefore not included.

The reactive force caused by the capsule is lowered after release of the vacuum seal by puncture of the hip and after capsulotomy, (with another 47 Newton). Several operation alterations might be made. It might be a little adjustment to the operation technique to puncture the hip joint before the traction is applied, thereby theoretically lowering the maximum traction force for hip space widening. In our institution, the first distraction is made before puncture of the hip joint, to ascertain the distraction can be made and the traction table adjustments are adequate. Larger capsulotomies might also help to lower the total traction force during surgery. Large capsulotomies could be made to test this hypothesis, but these large incisions in the capsule should also be repaired afterwards, which could lead to a prolonged operating time, which could also have a negative influence on complications (8).

We registered a large amount of temporarily nerve related complications in this cohort (44%). All nerve damage was temporarily and recovered during follow-up without intervention. In other cohorts and our prospective cohort, complication rate is much lower, ranging from 1.5-2% (2,10-12). Much higher traction related problems were described by Frandsen et al. (1), who reported 74% of patients with some sort of traction related problems. These differences might be explained by the definition of a complication, the focus on the registration of complications and the accuracy of the physical examinations. We conducted a meticulous physical examination in an early stage after surgery (2 and 6 weeks). All traction related complications of neuropraxia were examined and registered. All registered complications however were temporarily and resolved within 3 months. If we only registered the neurogenic complications that sustained 3 months after surgery, our complication rate would also be comparable with Nakano et al. who reviewed over 36,000 cases. They described a complication ratio of 3.3% in total, with 0.9% of nerve injury (4). The examination used for complication registration can also be of influence. Telleria et al (8) described that damage to nerves is easily caused with the traction of the hip, however they measured the occurrence of nerve damage with SSEP (somatosensory evoked potential) and MEP (motor evoked potential). This is much more accurate and more sensitive compared to registration by a questionnaire, which often is used to register complications.

Telleria et al. also concluded that an increase of traction time did not increase the odds of a nerve event. We could not verify this conclusion since we did not measure total traction time.

Ellenrieder et al. (3) concluded that a traction force of more than 400N might cause nerve damage after hip arthroscopy. We could not relate the amount of traction force to the occurrence of neuropraxia in the current study. Other causes than the amount of traction force might be of importance, as the position and the shape of the perineal post, anatomical differences, and the position of the joint (13).

Hip arthroscopy performed without a perineal post might be promising in preventing the occurrence of nerve damage (14), as described by Mei-ho et al. (15)

A major limitation of our study is that only patients with a body length up to 1.74m could be included. The average length of the Dutch population of 20 years of age in 2016 was 1.74 meters for women and 1.81 meters for men (16). Therefore, most patients could not be included and of all patients, only 4 men were included. While men generally are stronger and have a larger amount of muscles, the traction force needed for male patients could be higher than presented in this study.

CONCLUSION

A median traction force of 714N is necessary to obtain a median 8.8mm of joint space widening. The acquired traction force decreases significantly after sub-luxation, release of the vacuum seal of the joint and after capsulotomy. No correlation was found between traction force and amount of joint space widening for this cohort. No significant relation was identified between Kellgren-Lawrence classification for hip degeneration, BMI or age and traction force during hip arthroscopy.

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CHAPTER 6

VALIDATION OF THE DUTCH VERSION OF THE HIP OUTCOME SCORE: VALIDITY, RELIABILITY, AND RESPONSIVENESS IN PATIENTS WITH FEMOROACETABULAR IMPINGEMENT SYNDROME

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ABSTRACT

Introduction

Due to a lack of a validated Dutch version of the Hip Outcome Score (HOS) considering functional outcome after hip arthroscopy for femoroacetabular impingement syndrome, we validated the Dutch version of the HOS (HOS-NL) in patients with femoroacetabular impingement syndrome for reliability, internal consistency, construct- and content validity. Furthermore, the smallest detectable change (SDC) and minimal clinically important difference (MCID) were determined.

Methods

All consecutive patients scheduled for an arthroscopic procedure for FAIS were selected. Five questionnaires covering groin and hip pain were filled in at three moments in time (two pre-operatively with a maximum two-week interval and 6 months postoperatively). Main endpoints were reliability (test re-test, SDC), internal consistency (Cronbach alpha), construct validity (construct validity was considered sufficient if a least 75% of a-priori made hypotheses were confirmed), content validity (floor and ceiling effects) and responsiveness (MCID).

Results

The intraclass correlation coefficient (ICC) was 0.86 for the HOS ADL-NL and 0.81 for the HOS Sports-NL. SDC for the HOS ADL-NL was 21 and for the HOS Sports-NL 29Cronbach alpha score was 0.882 for HOS ADL-NL and 0.792 for HOS Sports-NL. Construct validity was considered sufficient since 91% of the hypotheses were confirmed. No floor effects were determined. A small ceiling effect was determined for the HOS AD-NL postoperatively. The MCID for HOS ADL-NL and HOS Sports-NL were 14 and 11.0, respectively.

Discussion

The HOS-NL is a reliable and valid patient reported outcome measure for measuring physical function and outcome in active and young patients with femoroacetabular impingement syndrome.

Key words

HOS validation FAIS arthroscopy

Level of evidence: III: retrospective analysis prospective cohort study
Conflict of interest: none

INTRODUCTION

Patient Reported Outcome Measures (PROMs) are increasingly being used to evaluate clinical outcome in orthopaedics (1). More orthopaedic assessment tools are used, and many are predominantly developed for elderly patients (2-3) who were supposed to suffer more from orthopaedic related functional limitations like osteoarthritis. However, young, and active patients with hip or groin pain can suffer from femoroacetabular impingement syndrome (FAIS) (4-5). Over the last decade, hip arthroscopy has become a popular and successful procedure for the treatment of FAIS in adults and adolescents, both male and female population (6-12). To measure outcome and results of arthroscopic surgery for FAIS, questionnaires should focus on activities of these patients, since most of these patients are physically more active compared to patients suffering from osteoarthritis (13-15). The Hip Outcome Score (HOS) is an example of an English-language questionnaire focused on activities and sports and is considered a valid tool for measuring function in individuals who have undergone hip arthroscopy (16-18). The HOS was intended to measure self-reported functional status, i.e. items that related to activity and participation were included. Tijssen (1) recommended the HOS for evaluating patients after hip arthroscopy for FAIS in a review in 2011 and many authors have used the HOS to describe post-operative results after hip arthroscopy for FAIS (15-19). The HOS is especially designed for FAIS since it has a Sports domain covering a unique type of questions considering sports activities in patients. The HOS scored very high on observer-agreement, internal consistency, test re-test reliability, construct validity, interpretability, and measurement error (16-17). In concordance with the international growth in number of hip arthroscopies performed for FAIS, also an increasing amount of hip arthroscopies is performed in the Netherlands. To measure functional outcomes after arthroscopy for FAIS, several Dutch PROMs are available, like the iHOT-12 NL and the HAGOS, but also a validated Dutch translation of the HOS is desirable. If several PROMs can be combined to measure functional outcome after hip arthroscopy for FAIS, this is more accurate and less influenced by the flaws of just that one PROM. As stated by Kluzek et al (20) collecting multiple PROMS over time may help to overcome the single measure variability. The Hip Outcome Score is not yet translated into the Dutch language, nor is it validated for the Dutch language. We therefore translated the HOS questionnaire into the Dutch language (HOS-NL), in concordance with other translation studies into Spanish, Korean, Portuguese and German (21-24). The quality of a PROM can be determined by several measurement properties, as stated by the COSMIN taxonomy (25,26). These properties are the reliability (internal consistency, test-retest reliability), validity (content validity, construct validity) and responsiveness. The objective of this study was therefore to evaluate these properties of the Dutch version of the HOS questionnaire in patients with FAIS. The smallest detectable change (SDC) and minimal clinically important difference (MCID) were determined. Our hypothesis was that the HOS-NL is a reliable and valid patient reported outcome measure for measuring physical function outcomes in ADL and sports related activities in active and young patients with FAIS.

METHODS

The study was performed in the orthopaedic surgery department of two large peripheral hospitals in (Blinded), (hospitals blinded) and contained two phases: translation, and investigation of reliability and validity.

The local medical ethical committee approved the study (blinded).

All participating patients signed a written informed consent after being informed about the study. The preoperative assessment, operative treatment, and postoperative rehabilitation for FAIS were according to the local protocol and did not interfere with study participation.

Study population consisted of all consecutive patients with FAIS, derived from the orthopaedic outpatient department from the two participating hospitals. Inclusion criteria were age between 18-65 years, a physical and radiological examination that confirms FAIS without severe osteoarthritis (^{3} Tönnis grade 3) (9), conservative treatment of FAIS of at least 6 months and physical activity. Exclusion criteria were patients with prior surgery to the hip for FAIS, a pathological fracture of the hip or other metastatic pathology, patients not speaking the Dutch language or refusing to participate.

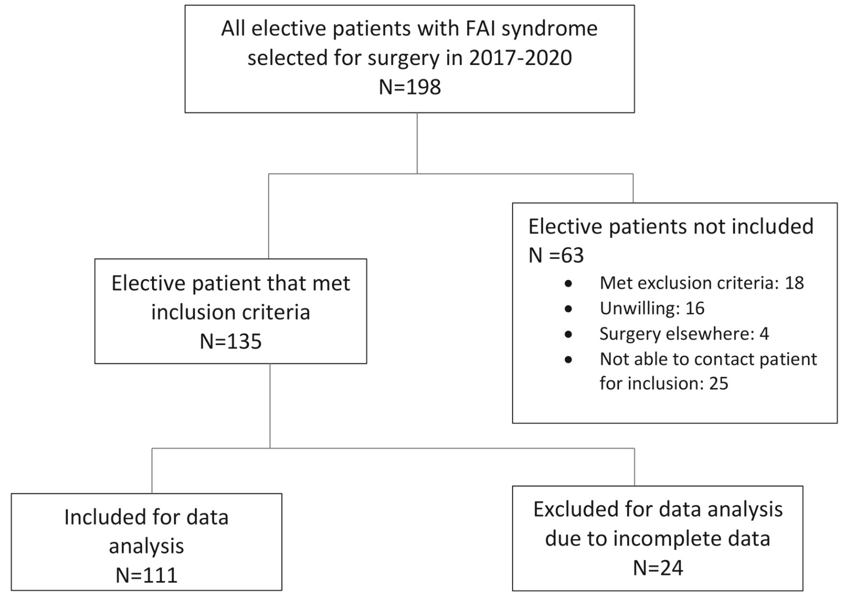
We aimed to include at least 100 patients, based on recommendations of the COSMIN guidelines and other authors (25-29).

Translation procedure

A Dutch translation was made using a forward/backward translation protocol according to the guidelines of cross-cultural adaptations (30). Since no major cultural differences in lifestyle exists between the Dutch and English/American population, we assumed that large cultural adaptation of the questionnaire was not required. For this first phase, the English version was translated into a Dutch version by two Dutch native speakers who speak the English language fluently, one with medical knowledge and one without. Both translations were combined by the translators and a team of experts (consisting of an orthopaedic surgeon, a resident orthopaedic surgery, and a researcher). Two persons translated the Dutch version back into an English version: both English speaking (native) as well as Dutch fluently. The final version was made by the research team. This version was tested in 20 patients with various hip pathologies (mainly FAIS) in the correct age category, to determine whether the questions were

understandable and whether patients were able to complete the questions. With these amendments, the final version was created as the HOS-NL.

Figure 1 Flowchart for inclusion



Validation study

All participating patients completed several PROMs at three moments in time, twice before surgery with a maximum interval of two weeks, and once at six months postoperatively. Patients completed the HOS-NL and translated versions of the modified Harris Hip Score (mHHS), the Hip and Groin Outcome Score (HAGOS)-NL, the international Hip Outcome Tool (iHOT-12 NL) and the numeric rating scale (NRS) for pain. Patients were asked to rate their own level of functioning due to their hip problems (“normal”, “almost normal”, “abnormal” or “severely abnormal”), as well as the change in functioning after surgery (“much improved”, “somewhat improved”, “slightly improved”, “unchanged”, “slightly worse”, “somewhat worse” or “much worse”).

Reliability is defined as the ability of a test to yield the same results on repeated moments under the same conditions (31). We used a two-week interval pre-operatively to define this. The test re-test reliability was assessed using the intraclass correlation coefficient (ICC) between the first and second applications of the HOS-NL. Values <0.5, between 0.5-0.75, between 0.75-0.90 and >0.90 were considered poor, moderate, good, and excellent, respectively (32).

The measurement error is a combination of systematic and random error of scores in the HOS-NL, that is not determined by true change in the measured construct. To quantify the measurement error, we calculated the smallest detectable change (SDC). Data from T1 and T2 were used to determine the measurement error. We assumed that there would be no real change in patient's functioning within a 2-week interval, pre-operatively.

Internal consistency is a measure based on the correlations between different items on the same test (26). We used Cronbach's alpha (33). A value exceeding 0.7 would indicate that the HOS-NL has good internal consistency in measuring functional outcome scores after surgery for FAIS (29).

Construct validity is the degree to which a test measures what it claims to be measuring (34). The HOS-NL was therefore compared with the Dutch version of the HAGOS, the HAGOS-NL (35), the mHHS (36), and the Dutch version of the iHOT-12, the iHOT 12-NL (37-39) and the NRS for pain (40). The association was determined by Pearson's correlation coefficients. Correlation coefficients can be considered small (r<0.30), moderate (r=0.31-0.50) or large (r>0.50), or reversed (r<-0.3, r=-0.3- -0.5, r>-0.5) when a maximum achievable score of one scale correlates with a minimum achievable score on the comparative scale (41). If the instruments are measuring the same/similar attributes, the correlation coefficients should be between 0.4 and 0.8 (42). A-priori hypotheses were made concerning the correlations between the subscales. Construct validity was considered sufficient if a least 75% of the hypotheses were confirmed (43). All hypotheses are summarized in table 4.

Content validity addresses whether a questionnaire has enough items and adequately covers the domain of interest (53). Content validity was evaluated by assessing floor and ceiling effects of the questionnaire. Floor and ceiling effects were considered present if more than 15% of the respondents achieved the highest (95-100%) or lowest (0-5%) possible score (18).

Responsiveness is the ability of a measure to detect a change when an actual change has occurred, a change in response to a (surgical) intervention. To determine which change in HOS-NL scores can be interpreted as meaningful change, we calculated the minimal clinically important difference (MCID) at six months postoperatively.

Statistics

Data was collected in Castor electronic database (44). Statistical analyses were performed using IBM SPSS Version 22.0 for windows and Mac and in R using RStudio (45). Patient characteristics were analysed by means of descriptive statistics. P-values less than 0.05 were considered to indicate statistical significance.

The test-retest reliability was assessed using the intraclass correlation coefficient two-way mixed model (ICC (3,1), 95% CI) between the first and second applications of the HOS-NL. Paired t-tests were performed to determine the systematic difference between first and second tests. R package 'psych' was used to calculate the ICC (46).

To calculate the SDC, we used the following formula: SDC = 1.96 * standard error of measurement (SEM) * √2. SEM was calculated using the formula SEM = $\sqrt{\sigma^2_{error}}$, where σ^2_{error} is a variance component of the ICC (47).

To calculate the MCID, we used an anchor-based approach. The anchor question/criterion used to determine the MCID was whether patients reported being "much improved", "somewhat improved" or "slightly improved" versus "unchanged", "slightly worse", "somewhat worse" or "much worse". Based on sensitivity and specificity values, receiver operating characteristic (ROC) curves were constructed for possible HOS change scores, using R package 'pROC' (48). Youden's cut-off was used to determine the MCID.

RESULTS

Patients were included from August 2017 – August 2020.

Pre-testing of the translated version of the HOS did not reveal any obstacles or any major difficulties for implementing and using the questionnaire. The HOS-NL version is added to the manuscript as a supplement.

A total of 135 patients were included for this study. A total of 111 patients had complete data (figure 1). Demographic characteristics are presented in table 1 and the baseline and outcome scores of all PROMs are displayed in table 2.

Table 1: Demographic characteristics

	N = 111
Gender	M=41 (37%) F=70 (63%)
Mean Age (range)	37.6 (18-59) SD 9.9
(American Society of Anaesthesiologist physical status classification) ASA 1	83 (75%)
ASA 2	25 (22.5%)
ASA 3	3 (2.7%)
Affected side	Left 45 (40.5%) Right 66 (59.5%)
Diagnosis pre-operative	
Cam	24 (22%)
Pincer	8 (7%)
Combined cam & pincer	5 (5%)
Labral tear	85 (77%)
Labral tear & FAI	15 (14%)
Other	3 (3%)

Table 2: PROM scores of HOS ADL-NL, HOS Sports-NL, iHOT 12-NL, HAGOS ADL-NL, mHHS, NRS for pain

	Preoperative score (SD)	Postoperative score (SD) at 6 months	P-value ··
HOS ADL-NL	60.0 (19.0)	76.5 (20.8)	<0.001
HOS Sport-NL	41.2 (23.1)	61.6 (27.7)	<0.001
mHHS	39.1 (7.8)	43.7 (8.1)	<0.001
iHOT 12-NL	37.0 (17.6)	59.6 (25.6)	0.01
HAGOS ADL-NL	48.8 (24.9)	31.9 (27.3)	<0.001
NRS pain rest ·	50.8 (25.4)	30.1 (29.1)	<0.001
NRS pain active ·	68.4 (21.9)	44.1 (29.7)	<0.001

· NRS for pain on a visual analogue scale from 0-100
··Differences between preoperative and postoperative PROM means were analysed by independent student t-test

The test re-test reliability of the HOS-NL subdomains based on calculated ICC values was good. The ICC values for the test re-test reliability are presented in table 3. SDC was 21 for the HOS ADL-NL and 29 for the HOS Sports-NL. Internal consistency was determined by Cronbach's alpha which was 0.882 for the HOS ADL-NL and 0.792 for the HOS Sports-NL, which indicates a high level of internal consistency.

The construct validity is considered sufficient because 91% of the hypotheses were confirmed. Table 4 contains all correlations for this construct validity.

Table 3: Test-retest reliability measures of HOS-ADL NL

	First measurement mean score (SD) T1	Second measurement · mean score (SD) T2	ICC (R) ··	Mean difference T1-T2 (95% CI)
HOS ADL-NL	60.1 (19.6)	57.5 (21.0)	0.86	3.12 (0.94-5.29)
HOS Sports-NL	41.2 (24.0)	38.3 (24.5)	0.81	3.11 (0.12-6.10)

·<2 weeks after first measurement: mean time 11 days, SD 6.3, 95% CI (9.36-11.75).
·· Intraclass correlation coefficient

Table 4: Construct validity for HOS NL

Subscale	Questionnaire	Hypothesized correlation··	Calculated correlation T1···	Calculated correlation T3····
HOS ADL-NL	HAGOS-NL ADL·	r>0.5	r=0.826	r=0.911
HOS ADL-NL	HAGOS-NL QOL·	r>0.5	r=0.589	r=0.722
HOS ADL-NL	HAGOS-NL S·	r>0.5	r=0.670	r=0.824
HOS ADL-NL	iHOT 12-NL	r>0.5	r=0.703	r=0.839
HOS ADL-NL	NRS pain	r>-0.5	r=-0.486	r=-0.550
HOS Sports-NL	HAGOS-NL SR·	r>0.5	r=0.797	r=0.876
HOS Sports-NL	NRS pain	r>-0.5	r=-0.423	r=-0.589
HOS Sports-NL	HAGOS-NL QOL·	r>0.4	r=0.597	r=0.768
HOS Sports-NL	HAGOS-NL S·	r>0.4	r=0.600	r=0.744
HOS Sports-NL	iHOT 12-NL	r>0.3	r=0.711	r=0.819
HOS Sports-NL	mHHS	r>0.3	r=0.607	r=0.718

·Subdomains ADL, Quality of Life, Symptoms, Sports, and Recreation
··Determined with Pearson's correlation coefficient
···T1: preoperatively
····T3: 6 months postoperatively
The incorrect hypothesized correlations are highlighted

6

Table 5 contains the content validity with the percentage of patients that scored the 5% lowest (floor effect) and 5% highest (ceiling effect) possible scores. No floor effect could be identified. A small ceiling effect was identified for the HOS-ADL NL postoperatively.

The responsiveness was determined by the MCID. For HOS ADL-NL the MCID was 14 and for the HOS Sports-NL 11. Presented in table 6. The MCID is smaller than the SDC for both domains. Area under the curve is presented in figure 2.

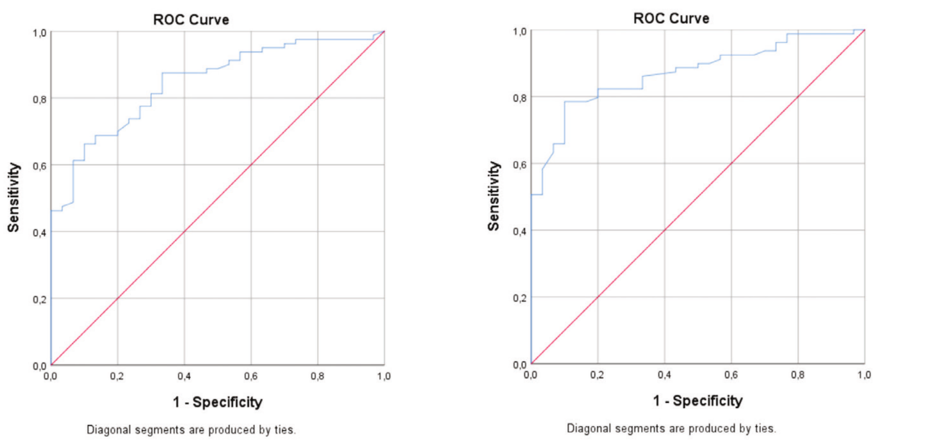
Table 5: Content validity of HOS ADL-NL and HOS Sports-NL

	Preoperative (T1) floor effect N (%)	Preoperative (T1) ceiling effect N (%)	6 Months post-operative (T3) floor effect (%)	6 Months post-operative (T3) ceiling effect (%)
HOS ADL-NL	N=0 (0%)	N=2 (1%)	N=0 (0%)	N=21 (19%)
HOS Sports-NL	N=6 (4%)	N=0 (0%)	N=2 (2%)	N=8 (7%)

Table 6: Smallest detectable change and MCID calculations for the HOS ADL-NL and HOS Sports-NL

	SEM	SDC	MCID
HOS ADL-NL	7.54	21	14
HOS Sports-NL	10.34	29	11

Figure 2 ROC curves HOS ADL-NL and HOS Sports-NL



DISCUSSION

The results of this study offer evidence for test re-test reliability, validity, and responsiveness of the HOS NL in young active individuals undergoing hip arthroscopic surgery for FAIS. This study also presents values to interpret change in scores over time, with SDC values of 21 and 29 over a two-week pre-operative period, and MCID values of 14 and 11 over a 6-month post-operative period for the HOS ADL-NL and Sport-NL, respectively.

The HOS is an important functional outcome tool that is used internationally to measure functional outcome after hip surgery (1). Such a PROM must be validated for its purpose: i.e testing functional outcome and changes in outcome (30). It is

therefore important to have validated this PROMs in patients' native language, in this case the Dutch language.

Construct validity was determined by predefined hypotheses between the HOS-NL and other questionnaires. A minimum of 75% had to be confirmed to become good construct validity (43). Our hypotheses were confirmed in 91%. These correlations with other PROMs such as the iHOT-12 and the NRS for pain are comparable to other validation studies of the HOS (21-24). The HOS-Brazil was validated in 2018 and showed high correlations with the SF-12 (Short-Form 12) and the Non-Arthritic Hip Score (NAHS) (23). A Spanish version of the HOS was translated and validated in 2014 and showed equal correlation scores to the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (21). All validation studies showed good validity and internal consistency, comparable with our results. Expected weaker correlations were found with HOS Sports-NL subscale and the HAGOS-NL and NRS. This weak correlation can be explained by the lack of specific sports related scales in the HAGOS-NL or the NRS for pain. It is therefore difficult to compare the HOS Sports-NL to other questionnaires. This lack of specific sports PROMs is highlighted by a review of available PROMs in sports in 2019 (49), that concludes that there is a void in PROMs to evaluate the postoperative outcomes regarding the physical and psychological demands of athletes and sports practitioners. We think that the sports related domain of the HOS is of additional value in this young and active patient population.

We determined a small ceiling effect in the HOS-ADL in 2% of all patients before surgery, which increased to 19% 6 months postoperatively. A ceiling effect in the HOS-Sports also developed during follow-up in 7.3%. Floor and ceiling effects might influence the reliability and validity if these effects occur in >15% of patients (18). Thus, we can conclude that the ceiling effect in our analyses for the HOS ADL-NL postoperatively might influence the validity negatively.

The MCID is defined as the smallest measured change score that patients feel is important. If the MCID is smaller than the SDC, that clinically relevant change in score could not be safely detected above measurement error (50). The MCID for the HOS is described by several authors. Nwachukwu (51), for example, calculated a MCID of 8.8 at one year for the HOS ADL and 13.9 for the HOS Sports. Martin (16) has a different MCID for ADL and for Sports, 9 and 6, respectively. Ueland et al. (52) summarized these differences in a recent review in 2021. We determined a MCID of 14 for the HOS ADL-NL and 11 for HOS Sports-NL, which differed from the results of Martin (16) and Nwachukwu (51). Differences in MCID between studies, can be explained by methodology (distribution based and anchor-based methods), differences in patient cohort and follow-up time. Difference in age at baseline, differences in sports/physical activities, or differences in baseline PROM scores, value relevant improvements in scores differently (50, 53). Duration of follow-up can influence the MCID also as highlighted by Nwachukwu who determined different MCIDs at one-, two- and 5-year follow-up. The SDC we determined was 21 and 29 for the HOS ADL-NL and Sport-NL respectively, which is high. The MCID we determined was smaller than the SDC. It is however important to note that in our study a change in scores large enough to represent a clinically relevant change could not be safely detected above measurement error.

Another way of defining success of hip arthroscopy, is through the patient acceptable symptom state (PASS) and by substantial clinical benefit (SCB) (52). All together known as clinically important outcomes values (CIOVs), which all provide important parameters for determining meaningful improvement after surgery. We have only determined the MCID, and not the PASS nor SCB, which might have added more evidence for clinical improvement after surgery in our study.

Other limitations must be mentioned. Our cohort has some heterogeneity regarding level of activity in patients pre-operatively and in surgical procedures performed in patients. Also, we stated that no large cultural adaptation was assumed, considering no large differences in Dutch and American culture. This is an assumption, and differences in patient population due to cultural difference might be present and therefore also might slightly influences differences in outcomes of this study compared to other studies. Only 111 out of 135 included patients could be analysed. It has been described that <5% loss to follow-up could already lead to small bias (54). We think this is due to the large number of questionnaires patients were asked to fill in, with overlap in type of questions. Many patients commented on this. Despite considerable effort to contact all patients, the use of an electronic database instead of papers and to help patients with the questionnaires, loss to follow-up could not be prevented entirely.

CONCLUSION

The HOS-NL is a reliable and valid patient reported outcome measure for measuring physical function and outcomes in active and young patients with femoroacetabular impingement syndrome.

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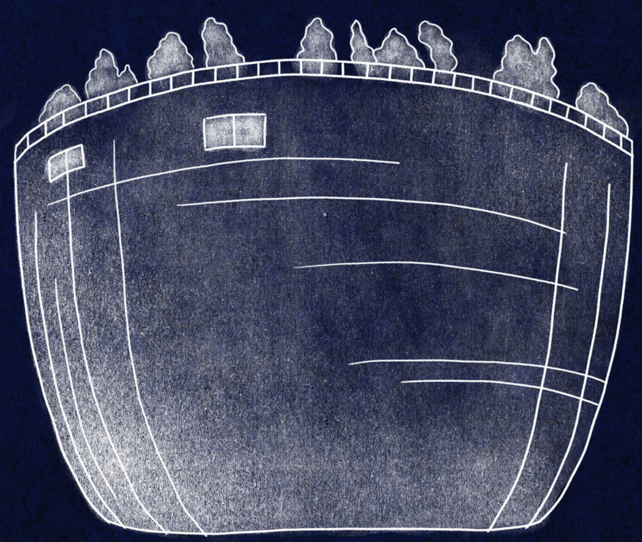

CHAPTER 7

CLINICAL OUTCOME AFTER HIP ARTHROSCOPY IN PATIENTS WITH FEMOROACETABULAR IMPINGEMENT

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ABSTRACT

Introduction
Femoroacetabular impingement (FAI) is an increasingly recognized condition in young and active patients with pain in the groin. Short-term follow-up results after arthroscopic surgery for FAI show promising results with increasing clinical evidence that surgical correction of FAI relieves pain and improves function outcome.

Purpose
The primary purpose of this study is to examine the short-term clinical outcome results and pain relief of patients with arthroscopic surgery for FAI.

Methods
We included patients from January 2012 to September 2013 in a prospective cohort study. Patients completed PROMs prior to surgery and a set time post-operatively. The used PROMs were the mHHS, HOS score and VAS score for pain.

Results
A total of 80 patients were included with a main age of 39.2 years. The VAS score improved significantly from 6.5 (IQR 2.8) pre-operatively to 1.0 (IQR 4.3) 12 months post-operatively. The modified Harris Hip Score improved significantly from 59.0 (IQR 15.0) pre-operatively to 85.0 (IQR 22.0) 12 months post-operatively. The HOS ADL improved significantly from 57.5% (IQR 35.9) to 87.5% (IQR 24.0). The HOS Sport improved from 44.4% (IQR 36.2) to 79.8% (IQR 40.3). We registered complications in approximately 5.5% of all cases.

Conclusion
Patients improved significantly in function and pain one year after hip arthroscopy for FAI.

INTRODUCTION

Femoroacetabular impingement (FAI) is an increasingly recognized condition in young and active patients with pain in the groin.[1] FAI is caused by abnormal contact between the femoral head-neck offset and the acetabulum and can be divided into pincer- and cam-impingement. A pincer impingement arises from increased coverage of the femoral head due to a deepened socket of the acetabulum, whereas a cam-impingement is characterized by a decreased femoral head-neck offset.[2,3,4]

The aetiology of FAI is probably caused by a combination of genetic, developmental and environmental factors and is associated with disorders such as slipped capital femoral epiphysis, Legg-Calve-Perthes, and coxa profunda.[2,5] The prevalence of FAI is estimated to be 15-25% in asymptomatic patients, but is still unknown.[6] Moreover, it is suggested that FAI may be a risk factor for the development of osteoarthritis.[2,5,6,7,8,9,10]

Arthroscopic treatment of these hip deformities is gaining popularity.[11] Short-term follow-up results show promising results and there is increasing clinical evidence that surgical correction of FAI relieves pain and improves function.[12,13]

This single-surgeon prospective cohort study presents the functional outcome results of arthroscopic treatment of FAI and labral tears, 1 year after surgery. We considered pain and functional outcomes to be primary outcomes, and sports, work, and complications to be secondary outcomes. Moreover, per-operative results are compared to the results of the pre-operative assessment.

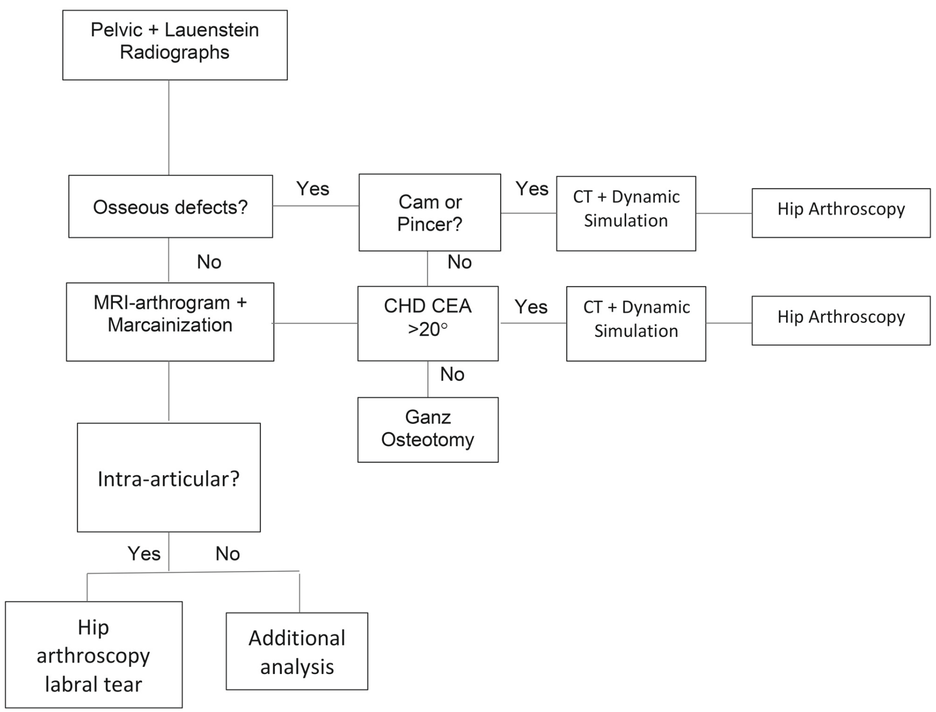
METHODS

In this prospective cohort study, consecutive patients were included from January 2012 to September 2013 in the Reinier de Graaf Groep, Delft, the Netherlands. The local Medical Ethics Committee decided that the study did not fall under the scope of the Medical Research Involving Human Subjects Act because of the minimal burden for patients in addition to regular care. Still, written informed consent was obtained from all patients. Patients were included were 15 to 65 years of age with a physical examination suspect for FAI, a labral tear or lesion, or suspect for loose bodies in the hip joint, chondral lesions or osteophyte impingement. Patients had to speak the Dutch language. The arthroscopic surgery was performed by a highly experienced orthopaedic surgeon, with an average of around 80 surgeries yearly since 2007. Exclusion criteria were patients who had prior surgery (open or arthroscopic) for FAI, pathological fractures, or other metastatic pathology as a cause of the hip/groin pain. Moreover, patients unwilling to participate were excluded.

Patients were analysed with either CT or MRI arthrogram and intra-articular bupivacaine injection according to the protocol depicted in Figure 1. Patients were included in the study when surgery was scheduled after these examinations.

A preoperative assessment of the deformity was made with x-ray and additional dynamic analysis. Alpha angles were measured according to the method described by Barton et al. [14] The results of this pre-operative assessment were compared to the per-operative results.

Figure 1: Protocol for analysing patients



A standardized operation protocol was used for all patients: general anaesthesia, supine positioning, traction table for subluxation of the hip joint, fluoroscopy and two to three portals were used in order to visualize the joint. The central and peripheral compartments were inspected for abnormalities. Labral tears, focal chondropathy, loose bodies, pincer- and/or cam deformities were identified and treated.

Physical examination was performed pre-operatively and 6 weeks, 3 and 12 months after surgery. Patients also completed the Hip Outcome Score (HOS) preoperatively and 12 months after surgery, and the VAS score for pain preoperatively, and 6 weeks, 3 and 12 months postoperatively. Patients were also asked to indicate when their work

was resumed and how long complaints of the hip persisted. The modified Harris Hip Score (mHHS) was scored preoperatively and 3 and 12 months after surgery.

Statistics

Missing data were handled according to the rules of the questionnaire or ignored using statistical software and tests. Since data did not show a near-Gaussian distribution, the non-parametric one-way repeated measures analysis of variance by rank was performed using Friedman's test to analyse differences in medians between the follow-up moments. Where applicable, Wilcoxon's signed rank test was performed as post-hoc test with Bonferroni correction to localize significant differences. P-values less than 0.05 were considered significant. Data are presented as median and interquartile range. Data analysis was conducted with IBM SPSS Statistics, version 21.

RESULTS

A total of 80 patients (80 hips) was included, 32 men and 48 women. (Figure 2) Mean age was 39.2 (range 16.9-64.3) years and 90 % of all patients had ASA class 1 (range 1-3). One patient had a history of Legg-Calve-Perthes disease (1.3%), two patients (2.5%) had a history of Slipped capital femoral epiphysis *(*SCFE). Patients had a mean alpha-angle of 64.5 (ﬀl15.3) degrees. On average, patients experienced hip pain for 3.7 years (range 1-25 years).

Preoperatively, 56 patients (70.0 %) were diagnosed with a cam impingement, 20 (25 %) with a pincer impingement, and 13 patients (16.3 %) had a cam as well as a pincer impingement. Per-operatively, 59 patients (73.8 %) appeared to have a cam impingement and 22 (27.5 %) a pincer impingement (Table 1).

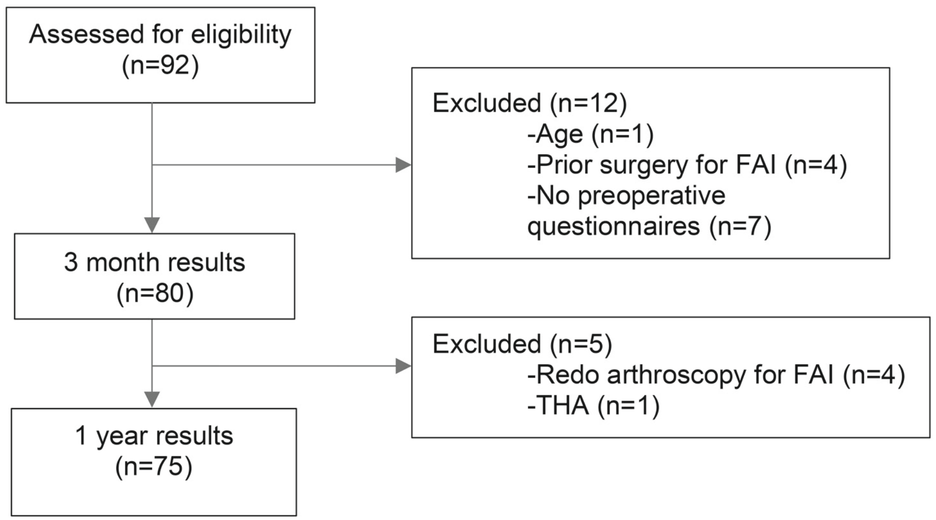
Table 1: Pre- and per-operative diagnosis

	Pre-operative diagnosis N (%)	**Per-operative diagnosis N (%)**
Cam impingement	43 (53.8)	44 (55.0)
Pincer impingement	7 (8.8)	7 (8.8)
Cam and pincer	13 (16.3)	15 (18.8)
Labral tear	43 (53.8)	67 (83.3)
Corpus liberum	2 (2.5)	2 (2.5)
Chondropathy	0 (0)	21 (26.3)
No deformities	0 (0)	4 (5)

4 Patients (5.5%) had a complication after surgery. Three patients had neuropraxia of the lateral femoral cutaneous nerve, one patient suffered from a small skin abrasion in the perineum due to traction during surgery.

Five patients were excluded from follow-up analyses. Four of these patients had a re-arthroscopy due to persisting pain before the one-year follow-up visit. One patient underwent a total hip arthroplasty before the one-year follow-up. (Figure 2)

Figure 2: Inclusion of patients



Not all patients completed all questionnaires; 69 patients completed the VAS and mHHS at all follow up moments, and 65 patients completed the HOS. The remaining patients were considered lost to follow-up.

VAS

A total of 69 patients (86.3%) completed a VAS score pre-operatively, and 6 weeks, 3 months, and 12 months postoperatively. VAS scores were 2.0 (IQR 3.0) and 1.0 (IQR 4.3) 3 and 12 months after surgery, respectively. Post-hoc analysis with a Mann-Witney test showed a significant decrease ($P < .001$) in VAS score from 6.5 (IQR 2.8) pre-operatively to 3.0 (IQR 3.3) 6 weeks postoperatively. The decrease in VAS between 6 weeks and 3 months was not significant ($P = .49$, a P-value $< .017$ was considered significant due to a Bonferroni correction). A comparison of these results with all cases, including incomplete data revealed no other results (VAS scores were 7.0 (IQR 3.0), 3.0 (IQR 3.5), 2.0 (IQR 3.0) and 1.3 (IQR 4.4), respectively).

Modified Harris Hip Score (mHHS)

A total of 69 (86.3%) patients had a complete mHHS preoperatively, and 3 and 12 months postoperatively. Post-hoc analysis with a Mann-Witney test showed that the mHHS improved significantly from 59.0 (IQR 15) preoperatively to 77.0 (IQR 19.0) 3 months after surgery ($P < .001$) to 85.0 (IQR 22.0) 12 months postoperatively ($P = .005$). (a P-value <.017 was considered significant after Bonferroni correction). A comparison of these results with all cases, including incomplete data, revealed no other results (mHHS scores were 57.0 (IQR 15.0), 77.0 (IQR 21.0) and 85.0 (IQR 22.0), respectively).

HOS

65 patients (81.3%) completed the HOS questionnaires preoperatively and 12 months after surgery. The HOS ADL improved significantly ($P < .001$) from 57.5% (IQR 35.9) to 87.5% (IQR 24.0) ($P < .001$). The HOS Sport improved from 44.4% (IQR 36.2) to 79.8 % (IQR 40.3) ($P < .001$).

Work

Patients indicated that they went back to work after a median of 8.0 weeks (min-max: 1-54 weeks). However, 33 (48.5%) patients were not symptom free until 12.0 weeks (min-max: 0-48 weeks) postoperatively. 24 (28.6%) patients still had complaints during working activities 12 months postoperatively. A total of 5 (6%) patients did not resume there working activities because of persistent hip pain.

DISCUSSION

This single-surgeon prospective cohort study presents the functional outcome results of arthroscopic treatment of FAI and labral tears, 1 year after surgery.

Function and pain were measured with the mHHS, the HOS and the VAS score for pain. Post-operatively, all scores improved statistically significant compared to the pre-operative status. However, the minimal clinical important difference (MCID) is a value which defines a meaningful improvement in the patient's status from before surgery to follow-up and is therefore of more importance than a statistically significant difference. The MCID of the mHHS, as described by Chahal et al. in 2014, at 3 months and one year after surgery is 13.0 and 20.0 points, respectively.[15] Our results show an increase of 18.0 points three months after surgery and 26 points one year postoperatively. The MCID for the HOS ADL and the HOS Sports, is 23.0 and 47.0 points one year after surgery. HOS ADL in our cohort improved with 30 points and 35.4 points for the HOS Sports. Lastly, the VAS for pain is described to have a MCID of 3.0, as stated by Lee et al.[16] The VAS score for pain declined from 6.5 to 1.0 after one year in our study, which is a difference of 5.5 and therefore clinically important. Thus, despite the HOS Sports, all functional outcomes improved more than the

MCID. Several other authors reported significant improvements after surgery, in VAS and mHHS but did not relate their findings to the MCID.[4,12,17-21]

Nho et al. found a significant improvement in the HOS score of 12.6 points but did not specify this any further.[18] Philippon et al. found a significant improvement in 2009 and 2012 in the HOS ADL (17 and 21 respectively) as well as in the HOS Sports (24 and 30 points, respectively).[12,22] In accordance with the results of our study, they also did not find an improvement of the HOS sports beyond the MCID.

Although the mHHS is most frequently used to determine clinical outcome after hip surgery, it suffers from a potential floor and ceiling effect. The HOS score is suggested to be more appropriate after hip arthroscopy; therefore, we used both scores to measure possible recovery after hip arthroscopy.[1]

Conspicuous is that the mHHS and VAS score for pain did not improve further 6 weeks to one year post-operatively. Several other studies found an increase of the mHHS, ranging 15.3-24 points.[4,12,17-21] However, only Dipmann et al. [17] described the improvement to be in the first 3 months postoperatively. Based upon their findings combined with the results of Larson et al.[4], they concluded that the effect of a hip arthroscopy mainly occurs during the first 3 months postoperatively. They therefore question whether revision should not already be considered 3 months after surgery. Our results support this question. Other articles only focus on the one-year postoperative outcome and do not mention the outcome in the first months postoperatively.

Several limitations should be mentioned. We examined the outcome of hip arthroscopy in FAI in general and did not differentiate between fixations of labral tears or FAI caused by bony deformities. Philippon et al.[23] described that labral repair is an independent predictor for better functional outcome after arthroscopic treatment. We consider our cohort to be too small to analyse fixation of the labral tears and resection of the bony deformities independently.[12]

Another limitation of our study is that we could not analyse five patients one year after surgery because of a prior revision arthroscopy or because of a total hip arthroplasty. We considered these 5 patients missing values. We analysed the results with and without the missing values and did not find any new results. These failures were possibly caused by poor indications, mainly a higher grade of osteoarthritis then accessed pre-operatively. Ultimately, not all questionnaires were fully completed by the patients and these patients were therefore considered lost to follow-up.

We registered a complication rate of 5.5% in our cases which is comparable to recent literature. A complication rate varies from 0% to 7% according to other

authors.[3,4,11,12,20,21,23,25-27] Our main complication is neuropraxia of the pudendal nerve. Other complications described in literature are fluid extravasation and abdominal compartment syndrome, instability or dislocation and femoral neck fracture and heterotopic ossification. We found none of these complications. The majority of our patients improved after surgery on short-term outcome.

Our study presents short-term follow-up results, which are similar to previous reports. This study presents the first cohort in the Netherlands of patients operated for FAI. Further research should point out whether we can improve our results by optimizing the treatment of FAI and patients' selection.

CONCLUSION

Significant improvements of the mHHS, VAS, and HOS ADL were found one year after hip arthroscopy in patients with FAI, compared to the preoperative level. These improvements exceeded the minimal clinical important difference (MCID) for these outcome measures.

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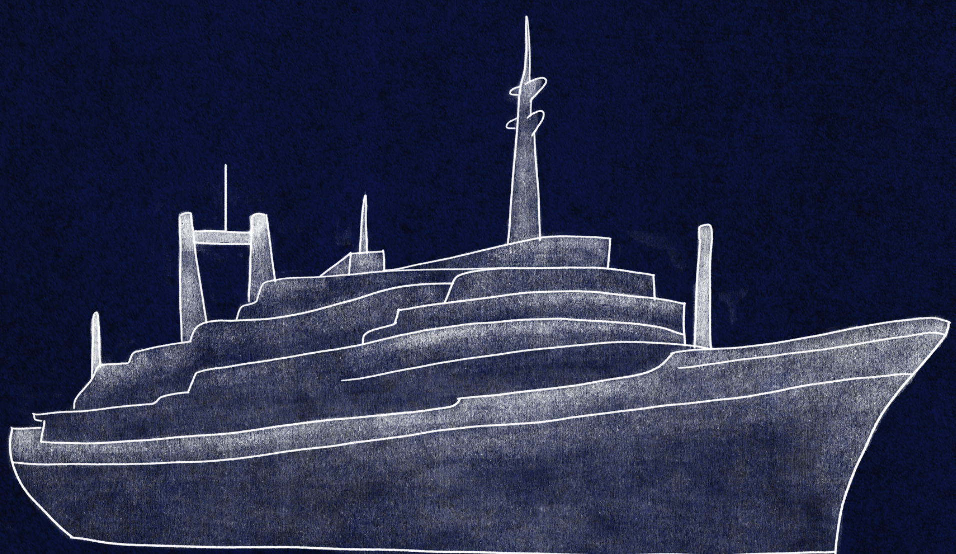

CHAPTER 8

RISK FACTOR MODEL FOR FUNCTIONAL RECOVERY AFTER ARTHROSCOPIC TREATMENT OF FEMOROACETABULAR IMPINGEMENT — A PROSPECTIVE COHORT STUDY

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ABSTRACT

Introduction
Hip arthroscopic treatment is not equally beneficial for every patient undergoing this procedure. Therefore, the purpose of this study was to develop a clinical prediction model for functional outcome after surgery based on preoperative factors.

Methods
Prospective data was collected on a cohort of 205 patients having undergone hip arthroscopy between 2011 and 2015. Demographic and clinical variables and patient reported outcome (PRO) scores were collected and considered as potential predictors. Successful outcome was defined as either a Hip Outcome Score (HOS)-ADL score of over 80% or improvement of 23%, defined by the minimal clinical important difference, 1 year after surgery. The prediction model was developed using backward logistic regression. Regression coefficients were converted into an easy-to-use prediction rule.

Results
The analysis included 203 patients, of which 74% had a successful outcome. Female gender (OR: 0.37 (95%CI 0.17 - 0.83); p=0.02), pincer impingement (OR: 0.47 (95%CI 0.21 - 1.09); p= 0.08), labral tear (OR: 0.46 (95%CI 0.20 - 1.06); p=0.07), HOS-ADL score (IQR OR: 2.01 (95%CI 0.99 - 4.08); p= 0.05), WHOQOL physical (IQR OR: 0.43 (95%CI 0.22 - 0.87); p=0.02) and WHOQOL psychological (IQR OR: 2.40 (95%CI 1.38 - 4.18); p=<0.01) were factors in the final prediction model of successful functional outcome 1 year after hip arthroscopy. The model's discriminating accuracy turned out to be fair, as 71% (95%CI: 64-80%) of the patients were classified correctly.

Conclusions
The developed prediction model can predict the functional outcome of patients that are considered for a hip arthroscopic intervention, containing six easily accessible preoperative risk factors. The model can be further improved trough external validation and/or adding additional potential predictors.

Keywords
Hip arthroscopy, Risk prediction, Clinical prediction rule, Functional outcome, Hip Outcome Score, Preoperative decision-making

INTRODUCTION

Arthroscopic intervention in the hip joint has evolved as a successful therapeutic procedure over the last decades for treating various causes of hip complaints. As diagnostic skills and surgical techniques continue to improve in managing these hip disorders, the indications for hip arthroscopy are also expanding.[1, 2] Hip arthroscopy is primarily used in the treatment of femoroacetabular impingement (FAI) caused by cam and/or pincer morphology, labral tears, focal articular cartilage injuries or the removal of loose bodies in the joint.[3] Treatment of these conditions can lead to pain relief, improvement of hip function[2] and might delay the onset of osteoarthritis and the progression to total hip arthroplasty (THA).[4, 5]

Despite that an arthroscopic treatment for FAI in general is successful, not all patients equally benefit from this procedure.[6] As with any operative procedure, multiple studies emphasize the importance of proper patient selection in achieving favourable results.[7-12] Unsuccessful treatment, e.g. insufficient reduction of complaints, requiring revision surgery or even short term progression to total hip arthroplasty caused by progressive osteoarthritis, has been associated with different preoperative factors. Progressive osteoarthritis has proven to have a negative effect on outcome results of patients treated for FAI.[7-13] A high Tönnis classification (grade ≥2) and a reduced joint space (<2mm) have been described as exclusion criteria for hip arthroscopy.[7] Literature suggests that age, gender, BMI, duration of symptoms, preoperative outcome scores, preoperative alpha-angle and hip dysplasia could be predictive for the outcome after hip arthroscopic surgery.[7-11, 13-17]

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A clinical prediction model would be a great asset in making it easier to predict the outcome of individual patients that are considered for a hip arthroscopic intervention, and could be used to guide doctors and patients in shared decision making regarding treatment and expectations.[18, 19] Therefore, the purpose of this study was to develop a clinical prediction model that can be used to predict the functional outcome 1 year after hip arthroscopy.

METHODS

Study population
This study is a retrospective analysis of routinely collected data on all patients who underwent a hip arthroscopic intervention in our hospital between April 2011 and March 2015. All data were collected prospectively. Two hundred five consecutive patients underwent a hip arthroscopic intervention and surgery was performed by an experienced single orthopaedic surgeon (RMB). Inclusion criteria for hip arthroscopy were a cam and/or a pincer deformity or a suspicion of a labral tear. The diagnosis was made based on clinical examination with a combination of complaints (hip/

groin pain or functional disability), physical examination (FADIR and FABER tests as described by Phillippon et al.[20]) and the presence of radiographic findings that correlate with FAI hip pathology. Patients with severe signs of hip osteoarthritis (Tönnis grade 3) were not offered hip arthroscopy and were therefore excluded from the study. Also, patients unwilling to participate were excluded. All included patients were asked to fill out patient reported outcome (PRO) questionnaires preoperative and at postoperative follow up at 3 months and 1 year. Patient assessment did not differ from normal clinical practice.

The questionnaires used to assess improvement in patient outcome were the Visual Analogue Scale (VAS) for pain, modified Harris Hip Score (mHHS), Hip Outcome Score (HOS)-ADL and HOS-Sport and the physical and psychological domains of the WHOQOL. The mHHS, HOS-ADL and HOS-Sport were used to assess hip related improvement in patient outcome, which are scored percentage based on 8, 17 and 9 questions respectively. The WHOQOL-BREF[21] score was used to measure the general (non hip related) quality of life (QOL). The WHOQOL score is a generic measure designed for use in a wide spectrum of psychological and physical disorders. It is a multidimensional measure for subjective assessment of QOL. The WHOQOL-BREF has a good to excellent validity and reliability.[22] High scores indicate a good QOL. Patients in the study were scored on both the physical and psychological domains. The study protocol was assessed by the regional Medical Ethical Committee (Medisch Ethische Toetsings Commissie Zuidwest Holland (METCZH); no. METCZWH 12-083). Ethical approval was waived by the METCZH on basis of the Dutch Medical Research Involving Human Subjects Act (WMO). However, all the patients who were included gave their written informed consent. Our study was reported according to the TRIPOD [23].

Surgical technique

Patients were operated in supine position under general anaesthesia. A traction table was used for subluxation of the hip joint. Fluoroscopy guided, two to three portals were inserted into the hip joint in order to adequately visualize the acetabulum, acetabular labrum, cartilage, transverse ligament and the anterior, superior and posterior aspects of the femoral head. The central and peripheral compartments were inspected for abnormalities (as described by Bond 2009).[24] Labral tears, focal chondropathy, loose bodies, cam- and/or pincer morphologies were identified and treated accordingly: tears were repaired if possible, otherwise debrided, cam/pincer morphologies resected, loose bodies extracted and focal chondropathy > grade II were treated with microfracture.

Outcome measure

To be able to predict the risk of a successful outcome it was required to define a cut-off in the HOS-ADL, which is used as the main outcome score. To do this the

Minimal Clinically Important Difference (MCID) for the HOS-ADL was used. The MCID is a common tool used to determine the smallest change in a treatment outcome that a patient would identify as important. In a recent study Chahal et al. reported a MCID of 23 for the HOS-ADL.[25] Also patients scoring above 80% in HOS-ADL score were classified as having an successful outcome.[14]

Ultimately, a successful outcome was defined as either a 23% improvement in HOS-ADL from preoperative to 1 year postoperative, or a HOS-ADL score of over 80% at 1 year postoperative.

Potential predictive factors

Based on literature,[7-17] the following potential predictors were considered: age, gender, years of complaints, BMI, operation indication (cam, pincer, labral tear), preoperative radiographic findings (Tönnis classification, alpha angle) and PRO scores (VAS for pain, mHHS, HOS-ADL, HOS-Sport, WHOQOL physical and psychological domains). The predictors were either continuous (age, years of complaints, BMI, alpha angle, and all outcome scores), dichotomous (gender) or categorical (indication, Tönnis classification) and used as such.

Statistical analysis

Descriptive statistics were used to summarize the data. For 12 of the 21 variables, data were missing ranging between 1% to 18% (Table 1). These missing data were imputed using multiple imputation by chained equations procedure (predictive mean matching). [26, 27] Missing data were assumed to be missing at random (MAR), five imputed datasets were created.

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Logistic regression was used to evaluate the association between each prognostic factor and outcome. Potential prognostic variables were entered into a logistic regression model, taking into account the multiple imputed datasets. The univariable odds ratios of the variables were calculated using univariable logistic regression analyses to evaluate their individual contribution. Multivariable logistic regression with a backward stepwise selection procedure was used to achieve the most informative and parsimonious combination of predictors. Akaike's information criterion ($p < 0.157$) was used as a selection criterion.[28, 29] The probability of having an successful functional outcome can be calculated by using the following formula: $P_{successful\ outcome} = e^{(\beta^{0+}\beta^{1*x1+}\beta^{2*x2+\ldots+}\beta^{n*xn)}} / 1 + e^{(\beta^{0+}\beta^{1*x1+}\beta^{2*x2+\ldots+}\beta^{n*xn)}}$.

In this formula, $P_{successful\ outcome}$ is the probability of having a successful functional outcome, β0 represents the constant and β_1, β_2 and β_n are the regression coefficients of the predictors x_1, x_2, and x_n, respectively, after having been pooled.

The model performance was assessed on calibration with the Hosmer-Lemeshow goodness-of-fit test and a calibration plot to estimate its reliability.[29, 30] The model's ability to discriminate between patients with successful or unsuccessful outcomes was estimated as the area under the curve (AUC) of the receiver operating characteristic (ROC) curve of the model.[31] Prediction models derived with multivariable regression analyses are known for over fitting, which results in too extreme predictions when applied in new cases. Therefore, the model was validated internally using bootstrapping techniques. Five hundred samples were drawn with replacement from the development sample. Bootstrapping techniques provide information on the performance of the model in comparable datasets and generate a shrinkage factor to adjust the regression coefficients.[31, 32] After this adjustment, the model performance was re-evaluated. A nomogram was created to easily calculate the risk of a successful outcome after hip arthroscopy for a given patient.

All statistical analyses were performed using SPSS version 22 (IBM, New Jersey, US) and R version 3.3.1 (R Foundation, Vienna, Austria) with package 'rms'.[33]

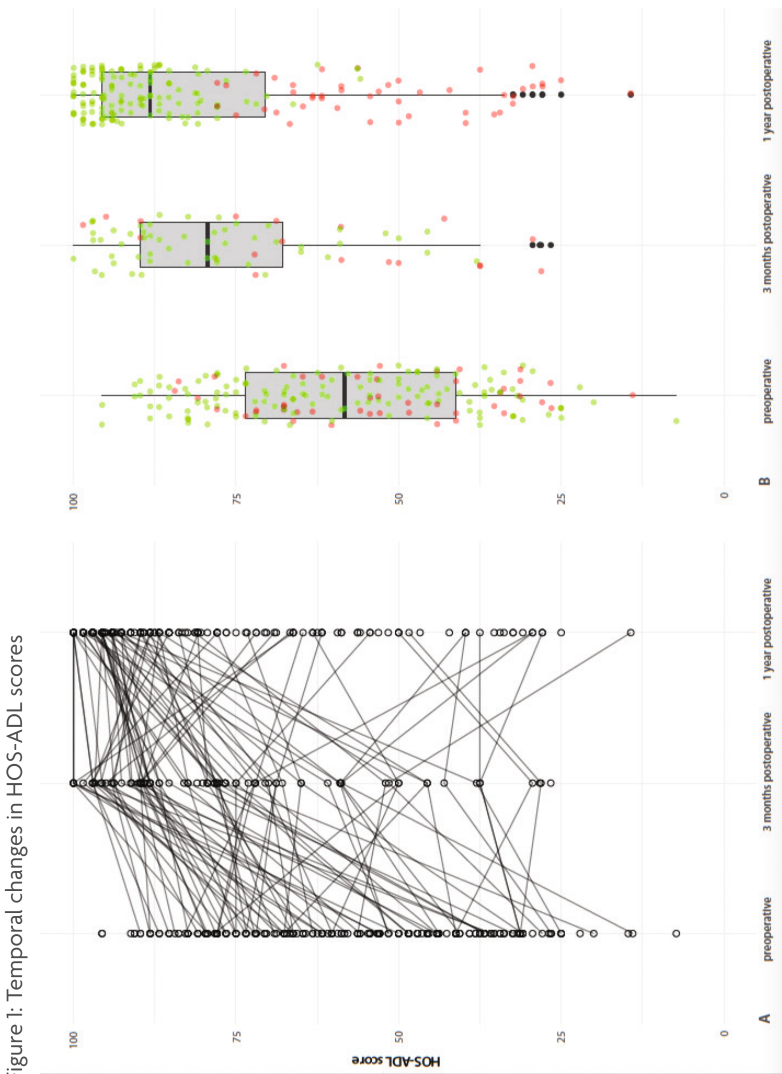
RESULTS

Our database yielded 205 patients, 203 were eligible for statistical analysis. Two patients were excluded: one because of a different indication (free body), and the other because at the start of surgery it was not possible to reach the joint space as the capsule was too tight. The latter patient was afterwards referred for a Ganz osteotomy. Out of the 203 participating patients 74% had a successful outcome 1 year after hip arthroscopy according to our composite outcome. Temporal changes (pre-operative, 3 months and 1 year) in HOS-ADL scores are shown in Fig 1. Additional information on the two components of our composite outcome (i.e., > 23 points improvement in preoperative HOS-ADL at 1 year postoperative, or a HOS-ADL > 80 at 1 year postoperative) is presented in Table 1.

Of the 203 eligible patients 114 (56%) were female. The patients had a mean age of 40 years (SDffl11), a mean BMI of 26 (SDffl4), and the mean time of complaints prior to surgery was 4 years (SDffl4). The indications for surgery were cam morphology (121 (60%)), pincer morphology (46 (22%)) (both causing FAI) and labral tear (138 (67%)). Patients had a mean alpha angle of 65° (SDffl14). Table 1 presents the demographic and clinical characteristics of the study population.

Gender, cam, preoperative PRO scores of the HOS-ADL and WHOQOL psychological showed to be significantly ($p < 0.05$) associated with outcome in univariable analysis (Table 2).

Figure 1: Temporal changes in HOS-ADL scores



A. Graphical representation of temporal changes in HOS-ADL scores for each patient. Please note that due to missing values for some patients scores at certain time points are not available and connecting lines not drawn.
B. Boxplots showing distribution of preoperative HOS-ADL scores and scores at 3 months and 1 year postoperative. Green dots represent patients with successful outcome after hip arthroscopy at 1 year follow-up. Red dots represent patient without successful outcome.

Table 1. Demographic and clinical characteristics of study participants.

Characteristic	Total sample (n = 203)		Patients with successful outcome* (n = 133)		Patients with unsuccessful outcome* (n = 46)		Patients with missing outcome (n = 24)	
	Value	Missing	Value	Missing	Value	Missing	Value	Missing
Gender (female)	114 (56%)	-	64 (48%)	-	33 (72%)	-	17(71%)	-
Age (yr.)	40 (11, 15-67)	-	40 (11, 17-67)	-	40 (10, 18-55)	-	39(13, 15 – 64)	-
BMI (kg/m2)	26 (4, 18-42)	-	25 (4, 18-35)	-	26 (5, 20-42)	-	27(6, 20 – 40)	-
Duration of complaints (yr.)	4 (4, 1-30)	-	4 (4, 1-25)	-	3 (2, 1-10)	-	5(6, 1-30)	-
Tönnis classification	193	10 (5%)	128	5 (4%)	45	1 (2%)	20	4 (17%)
Grade 0	142 (74%)	-	94 (73%)	-	35 (78%)	-	13(65%)	-
Grade 1	46 (23%)	-	32 (25%)	-	9 (20%)	-	5(25%)	-
Grade 2	5 (3%)	-	2 (2%)	-	1 (2%)	-	2(10%)	-
Alpha angle (o)	64 (14, 39-99)	-	66 (14, 39-99)	-	62 (13, 39-91)	-	62 (14, 43 – 89)	-
Cam	120 (59%)	-	87 (65%)	-	20 (44%)	-	13(54%)	-
Pincer	45 (22%)	-	26 (20%)	-	12 (26%)	-	7(29%)	-
Labral tear	138 (68%)	-	87 (65%)	-	37 (80%)	-	14(58%)	-
Preoperative PRO scores								
VAS pain, mean	6 (2, 1-10)	-	6 (2, 1-10)	-	6 (2, 2-9)	-	7 (1,3 – 9)	-
mHHS, mean (SD, range)	55 (12, 22-90)	-	57 (12, 26-90)	-	53 (11, 23-80)	-	50 (14, 22 – 72)	-
HOS-ADL, mean (SD, range)	58 (20, 7-96)	2 (1%)	60 (20, 7-96)	-	53 (18, 14-84)	-	55 (22, 15 – 91)	2 (8%)
HOS-Sport, mean (SD, range)	40 (22, 0-94)	11 (5%)	42 (23, 0-94)	3 (2%)	38 (19, 3-78)	3 (7%)	34 (22, 0 – 72)	5 (21%)
WHOQOL physical, mean (SD, range)	49 (16, 7-86)	30 (15%)	50 (16, 7-86)	17 (13%)	48 (14, 21-82)	6 (13%)	45 (19, 7 – 75)	7 (29%)
WHOQOL psychological, mean (SD, range)	71 (15, 13-100)	29 (14%)	72 (15, 13-100)	16 (12%)	67 (16, 25-95)	6 (13%)	69 (16, 38 – 96)	7 (29%)

Table 1. Demographic and clinical characteristics of study participants. (continued)

Characteristic	Total sample (n = 203)		Patients with successful outcome* (n = 133)		Patients with unsuccessful outcome* (n = 46)		Patients with missing outcome (n = 24)	
	Value	Missing	Value	Missing	Value	Missing	Value	Missing
PRO scores at 3 months postoperative								
VAS pain	3 (2, 0 – 9)	12 (6%)	2 (2, 0 – 9)	6 (5%)	4 (3, 0 – 8)	1 (2%)	2 (2, 0 – 6)	5 (21%)
mHHS	73 (15, 17 – 91)	12 (6%)	77 (12, 41 – 91)	5 (4%)	63 (18, 17 – 91)	1 (2%)	69 (15, 41 – 87)	6 (25%)
HOS-ADL	76 (20, 27 – 100)	118 (58%)	81 (15, 38 – 100)	77 (58%)	64 (23, 28 – 100)	27 (59%)	73 (25, 27 – 100)	14 (58%)
HOS-Sport	62 (27, 6 – 100)	129 (64%)	65 (24, 6 – 100)	83 (62%)	51 (32, 6 – 100)	29 (63%)	63 (26, 33 – 97)	17 (71%)
WHOQOL physical								
WHOQOL psychological								
PRO scores at 1 year postoperative								
VAS pain	3 (3, 0-9)	20 (10%)	1 (2, 0-9)	-	5 (2, 0-9)	-	6 (4, 1 – 9)	20 (83%)
mHHS	77 (16, 27-91)	25 (12%)	84 (9, 47-91)	1 (1%)	57 (15, 27-91)	3 (7%)	60 (31, 29 – 91)	21 (88%)
HOS-ADL	81 (21, 14-100)	24 (12%)	91 (9, 56-100)	-	51 (17, 14-78)	-	-	24 (100%)
HOS-Sport	71 (26, 11-100)	36 (18%)	83 (16, 28-100)	7 (5%)	36 (18, 11-81)	6 (13%)	38 (38, 38 – 38)	23 (96%)
WHOQOL physical	70 (20, 7-100)	26 (13%)	77 (15, 7-100)	3 (2%)	48 (17, 14-79)	1 (2%)	50 (25, 32 – 68)	22 (92%)
WHOQOL psychological	76 (14, 29-100)	26 (13%)	79 (13, 29-100)	3 (2%)	68 (13, 38-92)	1 (2%)	52 (9, 46 – 58)	22 (92%)
Components of composite outcome								
Increase in HOS-ADL >23	85 (47%)	24 (12%)	85 (64%)	-	0 (0%)	-	-	24 (100%)
Postoperative HOS-ADL >80	120 (67%)	24 (12%)	120 (90%)	-	0 (0%)	-	-	24 (100%)

*Successful outcome is defined as an HOS ADL >80 or HOS ADL increase >23 1 year postoperative.
Unless otherwise indicated values between parentheses are (sd, range).

Table 2 Logistic regression analysis of predictor variables for successful outcome 1 year after hip arthroscopy.

Predictors	Univariable analysis		Multivariable analysis		
	Odds ratio (95%CI)	**P value**	**Odds ratio (95%CI)**	**Regression coefficient**	**P value**
Constant				- 0.19	
Gender female vs male	0.38 (0.19 - 0.76)	0.01	0.37 (0.17 - 0.83)	- 0.97	0.02
Age (IQR 31-48)	1.07 (0.67 - 1.72)	0.77	-	-	-
BMI (IQR 23-28)	0.75 (0.48 - 1.16)	0.20	-	-	-
Years of complaints (IQR 2-4)	0.95 (0.81 - 1.13)	0.59	-	-	-
Tönnis classification grade ≥1 vs grade 0	1.30 (0.36 - 4.66)	0.69	-	-	-
Alpha angle (IQR 52-75)	1.66 (0.97 - 2.83)	0.06	-	-	-
CAM yes vs no	2.38 (1.25 - 4.55)	0.01	-	-	-
Pincer yes vs no	0.58 (0.28 - 1.21)	0.15	0.47 (0.21 - 1.09)	- 0.74	0.08
Labral tear yes vs no	0.55 (0.27 - 1.15)	0.11	0.46 (0.20 - 1.06)	- 0.77	0.07
Preoperative VAS pain (IQR 5-8)	0.91 (0.50 - 1.63)	0.75	-	-	-
Preoperative mHHS (IQR 48-64)	1.44 (0.95 - 2.18)	0.09	-	-	-
Preoperative HOS-ADL (IQR 41-74)	1.84 (1.08 - 3.15)	0.02	2.01 (0.99 - 4.08)	0.02	0.05
Preoperative HOS-Sport (IQR 48-64)	1.38 (0.83 - 2.29)	0.21	-	-	-
Preoperative WHOQOL physical (IQR 48-64)	1.35 (0.88 - 2.06)	0.16	0.43 (0.22 - 0.87)	- 0.04	0.02
Preoperative WHOQOL psychological (IQR 60-79)	1.69 (1.12 - 2.57)	0.01	2.40 (1.38 - 4.18)	0.05	0.002

After backward selection, the following variables remained in the multivariable model: gender, pincer, labral tear, HOS-ADL, WHOQOL physical, and WHOQOL psychological (table 2). The reduced model's AUC of the ROC curve was 0.72 (95%CI: 0.65-0.80) and the Hosmer-Lemeshow goodness-of-fit test was not statistically significant, indicating that the model fits the data well.

Through bootstrapping the maximum absolute difference in predicted and calibrated probabilities (E_{max}) and a shrinkage factor were determined, 0.15 and 0.61, respectively. After multiplying the regression coefficients with the shrinkage factor the models' performance was re-evaluated. The mean probability of having a successful functional outcome was 67% (SDffl12%). Female patients in our population had a lower chance on a successful outcome one year after hip arthroplasty compared to men (OR: 0.37 (95% CI 0.17 - 0.83); p = 0.02). Patients with indications pincer morphology (OR: 0.47 (95%CI 0.21 - 1.09); p = 0.08) or labral tear (OR: 0.46 (95% CI 0.20 - 1.06); p = 0.07) had a lower chance on a successful outcome. Patients with a higher preoperative HOS-ADL had a higher chance on a successful outcome (IQR OR: 2.01 (95% CI 0.99 - 4.08); p = 0.05). A lower score on the WHOQOL physical domain (IQR OR: 0.43 (95%CI 0.22 - 0.87); p = 0.02) and a higher psychological score (IQR OR: 2.40 (95% CI 1.38 - 4.18); p = <0.01) gave a higher chance on a successful outcome. The final model's discrimination yielded an AUC of the ROC curve of 0.71 (95% CI: 0.64-0.80). The model's calibration was visualized with a calibration plot (Fig. 2). The Hosmer-Lemeshow goodness-of-fit test was not significant (p=0.48), indicating that the model fits the data well.

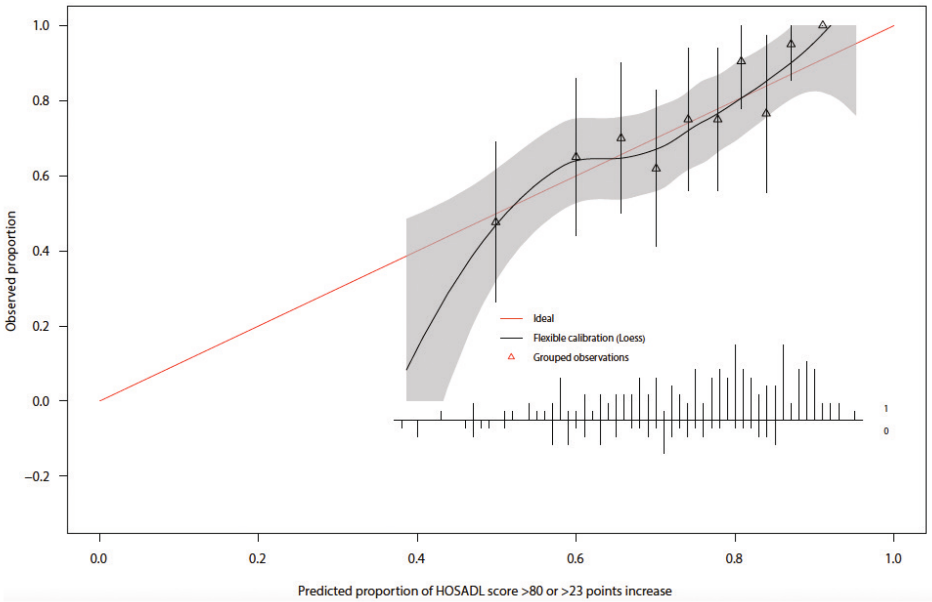
The risk of a successful functional outcome after hip arthroscopy for a given patient can be calculated as follows:

$$P_{successful\ outcome} = e^{(lp)} / 1 + e^{(lp)},$$

where
lp = - 0.19 + (- 0.97 * female) + (- 0.74 * pincer) + (- 0.77 * labral tear) + (0.02 * HOS-ADL score) + (- 0.04 * WHOQOL physical score) + (0.05 * WHOQOL psychological score).

The nomogram created as a tool to easily calculate the risk of a successful outcome after hip arthroscopy for a given patient is shown in Fig. 3.

Figure 2: Calibration plot. Distribution of predicted probabilities shown separately for patients with and without a successful outcome after hip arthroscopy. Triangles indicate observed proportions of successful outcome after hip arthroscopy, by tenths of predicted probability.



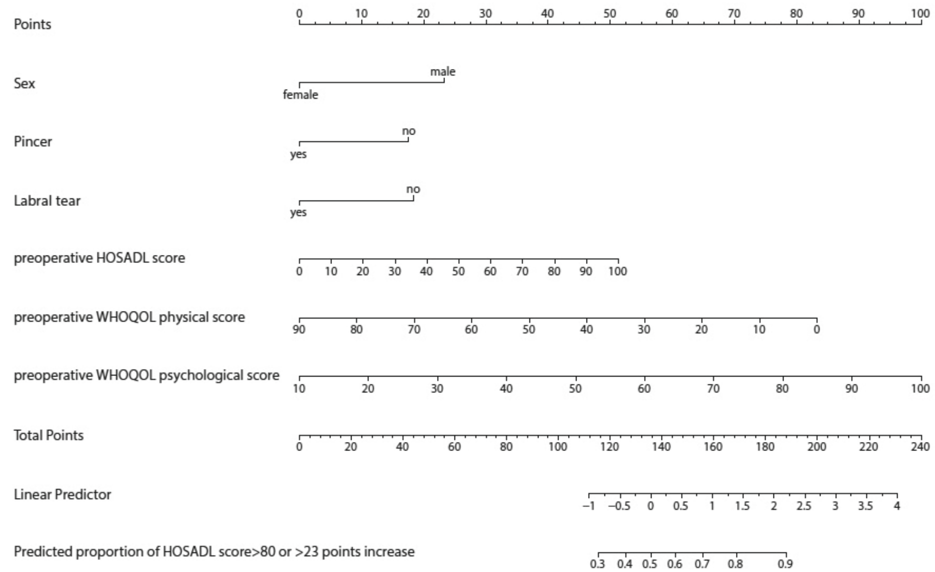
DISCUSSION

Arthroscopic procedures for FAI caused by cam/pincer morphologies or labral tears, can significantly resolve complaints and impairment in patients. However, not all patients equally benefit from this procedure. Careful patient selection is of great importance for success of this procedure. In this study a clinical prediction model was developed using logistic regression for functional outcome 1 year after hip arthroscopy, containing six easily accessible preoperative risk factors: gender, indication: pincer and labral tear, and the preoperative PRO scores: HOS-ADL and WHOQOL physical and psychological domains. Based on this model, a nomogram was created that can be used to easily calculate the risk of a successful outcome after hip arthroscopy for a given patient.

The discriminating accuracy of this model as assessed by the AUC of the ROC curve turned out to be fair, 71% (95%CI: 64-80%) of the patients were classified correctly. The model has a relatively high predictive probability (67%) for successful outcome after hip arthroscopy, as most patients in the cohort had a successful outcome after surgery. The developed model is a first step to predict the course of functional outcome of patients that are considered for a hip arthroscopic intervention, as its accuracy can still be improved through external validation to examine the

generalizability for other hip arthroscopic populations.[30] However, the model can be used as a guidance tool to optimize preoperative decision-making.

Figure 3: Nomogram for prediction of a successful outcome after hip arthroscopy in a given patient. To calculate the probability of a successful outcome, first obtain the value for each predictor by drawing a vertical line straight upward from that predictor to the points' axis, then sum the points obtained for each predictor, and locate this sum on the total points' axis of the nomogram, where the probability of a successful outcome after hip arthroscopy can be located by drawing a vertical line downward.



Female gender was identified as a predictor in the final model. Findings out of previous studies on gender as a predictor showed to be inconsistent.[34, 35] The study of McCarthy et al. [34] identified predictors for long term survivorship after hip arthroscopy and analysed that gender had no predictive value. The study of Frank et al. [35] compared clinical outcomes (HOS and mHHS) before and after hip arthroscopy and pointed out that gender was predictive for both HOS-Sport and mHHS. Women presenting with hip pain have different hip morphology compared to men (smaller alpha angles, increased acetabular version, and increased femoral anteversion), and speculations are made that this difference is caused by a greater component of soft-tissue laxity and difference in muscle mass, as it results in less protective dynamic stabilization of the painful hip joint.[36] Also hip dysplasia is known to have a higher occurrence in women and can lead to inferior results and higher failure rates after arthroscopic treatment of FAI.[16]

Our model identified pincer morphologies and labral tear indications as predictors that have a negative effect on a successful outcome. Multiple studies demonstrate that cam and pincer morphologies and labral tears induced FAI, in the absence of significant degenerative changes, are appropriate indications for arthroscopic hip surgery resulting in improvements in functional outcome.[37, 38] In our population patients with these indications had a lower chance to get the desired improvement in functional outcome. Therefore, more cautious consideration is advised compared to patients with cam impingement.

The other predictors in our model were based on preoperative PRO scores. Preoperative HOS-ADL showed to be a predictor in the prediction model. That a preoperative outcome score can have predictive value in predicting postoperative outcome seems logical, but there is still limited evidence on this subject, as only Philippon et al.[11] identified the preoperative mHHS as predictor for postoperative outcome. The physical and psychological domains of quality of life, based on the WHOQOL-BREF, were also identified as predictors in the final model. There have been no studies known by the authors to use this quality-of-life score as a predictor for functional outcome. Yet, there are studies that describe a strong correlation between psychological factors and post-operative outcome in other fields of orthopaedic surgery (including total joint arthroplasty, anterior cruciate ligament reconstruction, and spine surgery for degenerative disease).[39] Several intervention strategies exist to address these psychological factors when they appear to contribute suboptimal postoperative rehabilitation or recovery.[39]

Previous studies show there is evidence that demographic factors such as age, BMI and duration of symptoms can be predictors of outcome after hip arthroscopy but are inconsistent.[7, 9-11, 13-15, 34, 35] Our model does not show this predictive relationship either. However, some of the risk factors (the cam type FAI (IQR OR: 2.38 (95% CI 1.25 - 4.55); p = 0.01) and preoperative alpha angle (IQR OR: 1.66 (95% CI 0.97 - 2.83); p = 0.06)) that did not make it into the final predictive model, showed to have a correlation with successful outcome in univariable analysis.

In addition to assisting clinicians in patient selection for hip arthroscopic interventions, the model can be used for consulting patients on their expectations of successful surgery. A study examining satisfaction in total knee arthroplasty patients found that preoperative expectations affect satisfaction.[19] As patients with a lower risk score have a lower chance on a successful outcome, patients and clinicians should adjust their expectations accordingly.

Some potential limitations of our study must be discussed. We had to define improved functional outcome after hip arthroscopy (composite of HOS-ADL score above 80 or increase of 23 points). Despite the limitations related to the use

of composite outcomes, the impossibility for patients with preoperative HOS-ADL scores of >80 points to increase 20 points or more necessitated the use of a composite outcome (as these patients otherwise would have been considered unsuccessful irrespective of their score at 1 year postoperative). The HOS-ADL was chosen as the main outcome score because it is a validated, self-administered score and is designed for younger patients with hip pathology without relevant arthritic degeneration [40-42]. The cut-off value for improved outcome was based on the MCID of 23 determined in a recent study done by Chahal et al.[25] Other studies show different MCID values, e.g. Martin et al.[43] found an MCID of 9 (which we considered to be too low to be of clinical importance). Repeating the analysis with a cut-off based on this MCID (HOS-ADL score above 80 or increase of 9 points) resulted in a very similar model, yielding the same predictive factors as our current prediction model. Furthermore, in order to use this prediction model, the suggested PROs have to be used.

There are also limitations in our follow-up duration, population size and missing values in the outcome scores. Our study has a relatively short follow-up time (1 year) and a small study group size (205), although it is larger than presented by most previous authors. Models developed from datasets with too few outcome events relative to the number of candidate predictors are likely to yield biased estimates of regression coefficients. They lead to unstable prediction models that are overfit to the development sample and perform poorly on new data. It has been suggested that an EPV of 10 or more is needed to avoid the problem of overfitting. [44-46] To make sure that the model would not overfit the data, the number of variables included in the model was kept within the limit of 10 events per predictive variable. Another limitation is the influence of pre-, peri-, and postoperative factors on functional outcome. All patients had a standardized preoperative selection process, based on known indications, contraindications, and the surgeon's clinical expertise. Outcome can also be affected by factors as perioperative findings or treatment, complications during surgery or injuries after surgery. Examples are, e.g. unexpected chondral damage based on the Outerbridge classification [7, 10, 11, 13, 34], labral repair versus debridement [11], and residual FAI after surgery.[47] These factors are not in the prediction model but still influence the outcome of hip arthroscopic interventions.

Finally, this study included a relatively diverse range of preoperative risk factors, as the addition of preoperative PRO scores as potential risk factors, which is unique in this research field. However, not all possible preoperative risk factors were included in the study. For example, risk factors based on physical examination [48] or radiographic measurements (CT/MRI) [9, 49] can still be added to the model, as every predictor adds to a more accurate identification of patients at risk for an successful outcome.

CONCLUSION

This study identified six easily accessible preoperative risk factors that can be used to predict functional outcome 1 year after a hip arthroscopic intervention, i.e., gender (female), indication (pincer and labral tear), HOS-ADL (low), WHOQOL physical (high) and WHOQOL psychological (low) score. The proposed clinical prediction model is a first step to predict the functional outcome of patients that are considered for a hip arthroscopic intervention, as it can still be improved through external validation and/or adding additional potential predictors.

Declarations

Ethics approval and consent to participate

The study protocol was assessed by the regional Medical Ethical Committee (Medisch Ethische Toetsings Commissie Zuidwest Holland (METCZH); no. METCZWH 12-083). Ethical approval was waived by the METCZH on basis of the Dutch Medical Research Involving Human Subjects Act (WMO). Written informed consent was obtained from all study participants.

Consent to publish

Written consent for publication of the results was obtained from all study participants.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author (GH) on reasonable request.

Competing interests

The authors declare that they have no conflict of interest.

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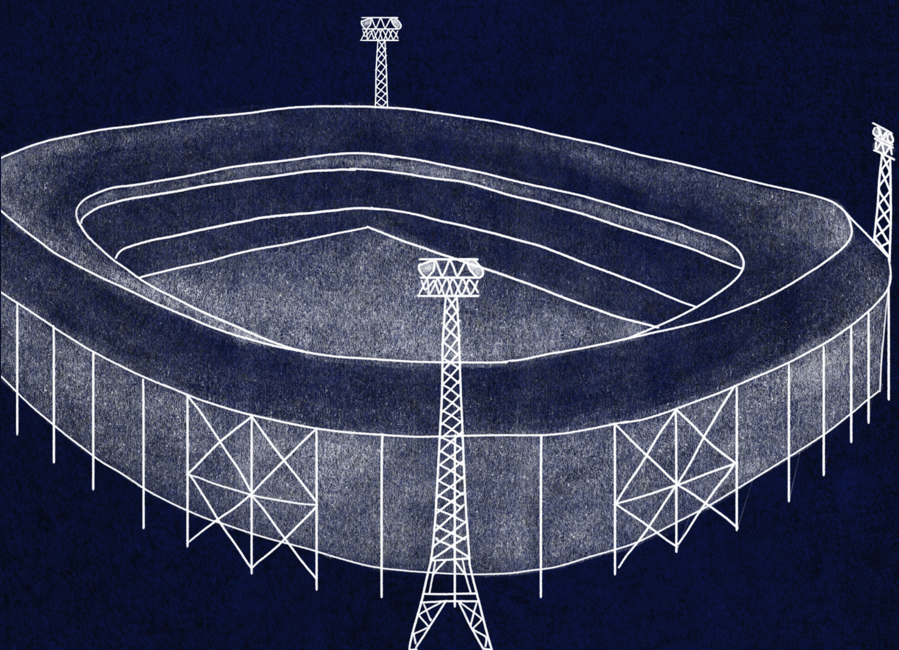

CHAPTER 9

HIP ARTHROSCOPY FOR FEMOROACETABULAR IMPINGEMENT SYNDROME RESULTS IN TWO TYPE RECOVERY PATTERNS BASED ON PRE-OPERATIVE PAIN AND ON ARTHRITIS: IMPROVERS AND NON-IMPROVERS

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ABSTRACT

Introduction

The purposes of this study were to analyse whether subgroups of patients could be distinguished with different functional recovery trajectories after hip arthroscopy for femoroacetabular impingement (FAI) syndrome and to identify differences between those subgroups using data from our prospective cohort registration.

Methods

We retrospectively reviewed prospectively registered data of patients who had undergone hip arthroscopy for FAI syndrome in our clinic from 2015-2018. Latent class growth modelling (LCGM) and growth mixture modelling (GMM) was used to identify and classify groups of patients according to trajectory of functional recovery using the Hip Outcome Score (HOS)-ADL. We used univariable analysis and descriptive statistics to explore whether differences in group membership could be identified.

Results

A total of 100 patients were analysed. GMM identified two main types of recovery patterns after surgery: patients who improved significantly after surgery in HOS to 90, which we called “the improvers” (with fast initial improvement within 3 months which is maintained during follow-up) and “the non-improvers” who did not significantly benefit from surgery (with only mild improvement in HOS-ADL at three months and no further change during follow-up).

Univariable analysis and comparing differences between subgroups, showed higher pre-operative visual analogue scales (VAS) for pain and more intra-operative arthrosis of the femoral head for “the non- improvers”.

Conclusions

We identified two main types of recovery patterns after arthroscopic treatment of FAI syndrome: “the improvers” and “the non-improvers”. Both recover in a different manner post-operatively. The non-improvers differed in pre-operative pain and intra-operative arthrosis of the femoral head compared to the improvers.

Level of evidence: III: retrospective cohort study.

INTRODUCTION

Arthroscopic surgery to resolve cam and pincer type morphology causing femoroacetabular impingement (FAI) syndrome has been recognized as an effective treatment with good to excellent results [1]. Most patients recover well in regaining prior sports level, reduction in pain and in terms of functional outcome [2-5]. As with any operative procedure, multiple studies emphasize proper patient selection for achieving good operative results, since not all patients experience optimal recovery which can lead to poor outcome or even revision of the procedure [6-8]. It is important to better understand differences between patients in how they respond to and recover from hip arthroscopy to further improve functional outcomes. A statistical technique that is increasingly being used for this matter, is Latent Class Growth Modelling (LCGM) and Growth Mixture Modelling (GMM) [9]. This is an extension to latent growth curve modelling, or the mathematical equivalent, which is the mixed or multilevel model [10]. A mixed model applied to longitudinal data allows for estimating the degree of heterogeneity between patients in recovery trajectories by estimating the random slope variance [11]. This is a suitable method to investigate heterogeneity in a patient cohort in change patterns for outcome results and performs subgrouping based on pattern recognition with high accuracy. This statistical method enables us to identify different types of recovery patterns in subgroups in a cohort of patients [12-14]. Previous and recent applications have for instance analysed subgroups of patients according to their hip function trajectory during the first six weeks after total hip arthroplasty (THA [15]. Other applications have addressed the wide variety in patients’ responses to total knee arthroplasty or cardiac rehabilitation [16,17]. To our knowledge, no other study used such a model to examine change in patient reported outcomes after hip arthroscopy for FAI syndrome.

We applied LCGM and GMM to prospectively collected data of patients operated for FAI syndrome using hip arthroscopy, to determine subgroups of patients according to their functional outcome results, as measured with the Hip Outcome Score for Activities of Daily Life (HOS)-ADL. Furthermore, we set out to determine associations of group membership with pre-operative and intra-operative parameters.

The purposes of this study were to analyse whether subgroups of patients could be distinguished with different functional recovery trajectories after hip arthroscopy for femoroacetabular impingement (FAI) syndrome and to identify differences between those subgroups using data from our prospective cohort registration. Our hypothesis was that at least two subgroups with different functional recovery trajectories could be identified and that several differences could be identified by comparing groups.

METHODS

Data collection

We retrospectively reviewed prospectively registered data of patients who had undergone hip arthroscopy for FAI syndrome in our clinic from 2015-2018. Lost to follow-up was reported. Patients were selected for elective hip arthroscopy for FAI syndrome according to our local protocol. Inclusion criteria in this protocol are: diagnosed with FAI syndrome (according to the Warwick agreement) [5]; i.e. positive clinical assessment with positive tests for FAI, (18) radiological assessment conclusive for FAI (with cam- and or pincer morphology on x-ray and/or labral tear on MRI scanning), age 18-65, managed conservatively first (with strengthening physiotherapy for at least three months, lifestyle changes and non-steroid anti-inflammatory drugs), suitable for surgery (after consultation of the anaesthesiologist for any contra-indications for surgery) and patients had to be willing to participate and sign informed consent. Exclusion criteria were signs of progressive osteoarthritis (Tönnis > grade 2), revision hip arthroscopy or metastatic pathological disease.

The study protocol (METCZWK 12-083) has been assessed by our regional Medical Ethical Committee, who decided that the study did not fall under the scope of the Medical Research Involving Human Subject Act because of the minimal burden for patients in comparison to regular care. The trial was registered in the Netherlands Trial register (NTR6792).

Arthroscopic surgery was performed by an experience orthopaedic surgeon (RMB), in a large educational hospital in Delft, the Netherlands.

After informed consent, all patients were asked to fill in patient reported outcome (PRO) questionnaires pre-operatively and post-operatively at 3 months, 12 months, and 24 months. Patients' assessment did not differ from normal clinical practice according to our local protocol.

Patient data was included with a post-operative follow-up and data registration of 24 months. Obtained data comprised patient characteristics (age, sex, BMI, ASA score, years of complaints, pre-operative diagnoses (cam, pincer, labral tear) and signs of osteoarthritis (Tönnis grading), pre-operative range of motion of the hip joint, intraoperative identified pathologies to central and peripheral compartment and several pre- and post-operative questionnaires. Postoperatively, all patients were physically examined for complications, as well as at 6 weeks, 3 months, and 12 months. The PRO questionnaires included Visual Analogue Scale (VAS) for pain, Hip Outcome Score (HOS)-ADL, and HOS-Sport and the EuroQoL-5D (EQ5D-5L) for mobility for pre- and postoperative assessment and the 4-Dimensional Symptom Questionnaire (4-DSQ) only at the post-operative assessment.

VAS for pain is a visual analogue scale on a 10 cm wide range, ranging from 0-100, on which patients point out the amount of pain they suffer, with 0 indicating no pain and 100 indicating the worst possible pain.

The EQ5D-5L is a standardized instrument developed by the EuroQol Group [19] as a measure of health-related quality of life that can be used in a wide range of health conditions. It contains five domains, with one VAS for overall health outcome.

The Hip Outcome Score (HOS) is subdivided into two domains, the HOS-ADL, and the HOS-Sports. The HOS-ADL is based on 17 questions, graded from 1-4 points with a minimum of 17 points and a maximum of 68 points. The HOS-ADL is calculated as a percentage of the maximum of 68 points. The higher the score, the better the outcome. The minimal clinical important difference (MCID) is a common tool used to determine the smallest change in a treatment outcome that a patient would benefit of and identify as important. The MCID of the and HOS-ADL at 12 months is 23, as reported by Chahal et al. [20] They also concluded that a HOS-ADL score of 80 and upward can be considered as a good outcome score.

Surgical technique

Patients were operated in supine position under general anaesthesia. A traction table was used for subluxation of the hip joint, fluoroscopy guided. Two to three portals were inserted into the hip joint to adequately visualize and inspect the central compartment and the peripheral compartment for pathology, as described by Bond et al [21]. Labral tears, focal chondropathy, loose bodies, pincer morphology and peripheral cam morphologies were identified and treated accordingly. Labral tears were repaired if possible or otherwise debrided. Cam and/or pincer morphologies were resected until impingement seemed resolved in flexion and rotation of the hip joint using fluoroscopy. Focal chondropathy was treated with microfracture if suitable.

Statistical analyses

We used IBM SPSS Statistics version 21.0 for the descriptive statistics of our overall sample, for data cleaning and analysis and for analysing differences between the final subgroups. To analyse if subgroups could be distinguished in our cohort, based on the trajectories of HOS-ADL outcome scores, we used Mplus Version 8.1 (Los Angeles, CA: Muthén&Muthén, [22]) to perform 1-class to 6-class LCGM (latent class growth modelling) analyses in the form of LCGA (latent class growth analysis) and GMM (growth mixture modelling). For all models, we specified a latent basis model for the growth pattern; first (pre-operative) and the last (24-months post-operative) measurements were fixed to 0 and 1, respectively, and the second and third measurements (3- and 12-months post-operative) were estimated freely. These estimated average slopes in our models represent the amount of change between the first and last measurement. Also, the estimated factor loading of the second measurement explains how much of that change occurred at the three months and 12 months (thus the second and third) measurements. The latent class models were independent from other variables. We based our models on a combination of visual inspection of the plots, interpretability and clinical meaningfulness of the model, the relative fit statistics Bayesian Information Criteria (BIC), Akaike Information Criteria (AIC) and Adjusted BIC (where lower values indicate a better fit) and entropy (where higher entropy indicates a higher confidence in the correct classification of individuals, [23].

A univariable analysis was performed with the r3step procedure in Mplus. We chose the largest subgroup of patients a priori as the reference category.

Differences between both groups were compared for several factors using descriptive statistics (independent T-test, student's T-test and Chi^2 tests). The tested factors were based on literature [6-8].

Predictors

Based on aforementioned literature [6-8] regarding risk factors, the following potential predictors were considered: age (subdivided in <30, 30-50 and >50 years), gender, BMI (subdivided in 25-30 and >30), ASA classification (American Society of Anaesthesiologists classification), years of pain, pre-operative Tönnis grading (radiographic findings of osteoarthritis), baseline PRO scores (VAS for pain in rest and activities, HOS) and intra-operative hip pathology (cartilage damage acetabulum or femoral head, labral tear, pincer morphology, cam morphology). The predictors were either continuous (age, years of pain, BMI, PRO outcomes), dichotomous (gender) or categorical (operation indication, Tönnis grading, intra-operative pathology) and were used as such.

RESULTS

Patient characteristics

From 2015-2018, 190 patients were diagnosed with FAIs and were selected for surgery. 22 Patients got a revision arthroscopy and therefore were excluded. A total of 168 patients were eligible for participation. 14 Patients were lost to follow-up, which made a total of 154 patients that were included in this study. Patient characteristics are presented in table 1. Due to missing data on one or more HOS measurement questions for several patients, data for analysis in Mplus was complete for 100 patients in total. Descriptive statistics for the PRO scores VAS for pain and HOS-Sports and HOS-ADL outcome scores are presented in table 2.

Table 1: Patient characteristics

Patients	N=100 (%)
Gender no. (%)	
F	60 (60%)
M	40 (40%)
Age, mean, (SD) [range]	39.2 (10.9) [17-63]
BMI, mean, (SD) [range]	25.5 (3.5) [18-35]
ASA 1 (%)	71 (71%)
ASA 2 (%)	29 (29%)
Years of pain, mean, (SD) [range]	3.0 (3.4) [0-19]
Pre-operative Tönnis gr	
0	44 (44%)
1	45 (45%)
2	11 (11%)
Intra-operative hip pathology	
Cam	52 (52%)
Pincer	22 (22%)
Labral tear	83 (83%)
Cartilage damage head	30 (30%)
Cartilage damage acetabulum	42 (42%)

Table 2: VAS for pain, HOS-Sports, and HOS-ADL at baseline and during follow-up

	Baseline	1-yr Follow-up	2-year Follow-up	P value*
VAS pain score (0-100)	63.1 (23.8)	13.2 (1.6)	n.a.**	<.001
HOS-Sports	51.1 (24.4)	76.6 (24.11)	73.7 (24.05)	<.006
HOS-ADL	65.7 (20.1)	88.2 (13.8)	86.0 (14.3)	<.001

*Significance level set at P<0.05 using paired T-tests
**n.a.: not asked

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Best model selection

We based our models on several model fit statistics, presented in table 3. Based on these criteria, we chose the 2-class GMM model as our final model in recovery trajectory. Despite that the fit statistics continued to decrease up to the 6-class model, this decrease started to flatten out already from the 2-class model upward (figure 1). This indicates that from the 3-class model and further upward, the new classes did not increase the clinical meaningfulness of the model since they were mostly slight variations of the classes from the 2-class model. All GMM models showed the same type of trajectories: one homogeneous class with a good improving model for functional recovery, and one or more other models with only minor improvement, no improvement or even minor decrease in functional outcome with a wide range of outcome results. These minor improvements or decreases in outcome score HOS-ADL, were all small and below the minimal clinical important difference (MCID) of 23 points [20]. The smaller classes became smaller and more heterogeneous from the 3-class models upward, thereby limiting its clinical meaningfulness. Also, from the 4 class-model upward, errors occurred in analysis due to local maxima, indicating the possibility that the results from those models may not be trustworthy. The estimation of the factor loadings (i.e., the percentage at three and 12 months of the total change) are therefore unreliable; these models were not suitable for our data (table 4). Adding more classes to the 2-classes model does not improve the model and it is therefore that we chose the 2-class model, as shown in figure 1.

Figure 1: Estimated means and sample means of the selected 2-class model for the recovery trajectory: 1good recovering class and 1 fairly poor recovering class. (HOS-ADL, Hip Outcomes Score – activities of daily life)

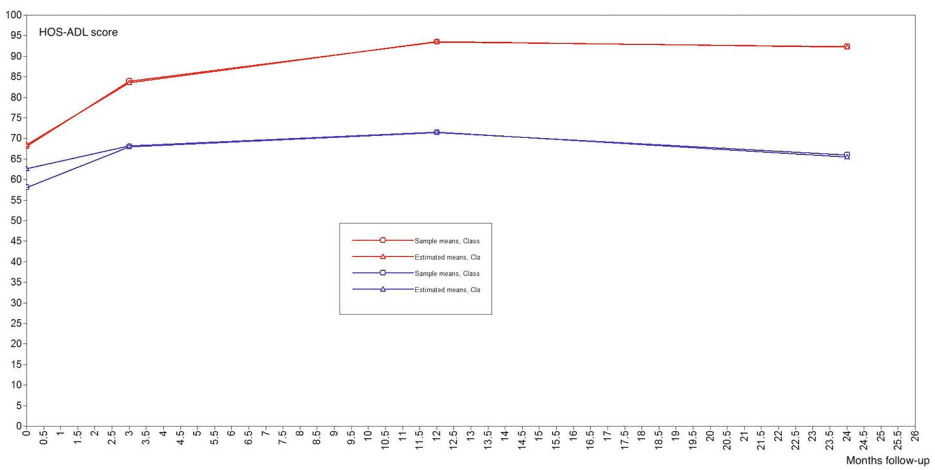


Table 3: Summary of model fit statistics.

Model	LL*	BIC*	AIC ***	Adjusted BIC ****	BLRT *****	Entropy	No. of Free Parameters
GMM							
1 Class	-1599.779	3250.215	3221.558	3215.474	-	-	11
2 Classes	-1567.497	3208.677	3166.994	3158.145	-	0.87	16
3 Classes	-1546.976	3190.66	3135.951	3124.336	-	0.878	21
4 Classes	-1536.912	3193.558	3125.824	3111.444	-	0.875	26
5 Classes	-1532.085	3206.93	3126.17	3109.025	-	0.867	31
6 Classes	-1519.216	3204.218	3110.432	3090.521	-	0.914	36

*LL: log likelihood
**BIC: Bayesian Information Criterion
***AIC: Akaike Information Criterion
****Adjusted BIC: Adjusted Bayesian Information Criterion
*****BLRT: Bootstrapped Likelihood Ratio Test

Table 4: Model Parameter Factor Loading at 3, and 12 Months, Intercept, Slope and Class Size.

Model and Class	**Factor loading HOS 3 months**	**Factor loading HOS 12 months**	**Intercept (S.E)**	**Slope (S.E.)**	**Patients per Class**
GMM 1 class	0.719 (0.062)	1.115 (0.055)	65.642 (1.998)	20.263 (2.028)	100
GMM 2 classes					
Class 1	0.635 (0.063)	1.060 (0.049)	68.496 (2.387)	23.665 (2.864)	78
Class 2	1.917 (1.099)	3.092 (1,754)	62.575 (7.005)	2.902 (2,977)	22
GMM 3 classes					
Class 1	0.740 (0.078)	1.43 (0.032)	71.599 (3,143)	25,147 (3,236)	46
Class 2	1,739 (0.461)	2.662 (0.520)	59.323 (4.048)	3.431 (2,333)	20
Class 3	0.246 (0.214)	1.477 (0.158)	72.287 (4.634)	9.828 (4.358)	34
GMM 4 classes					
Class 1	0.815 (0.182)	0.986 (0.032)	71.910 (2.886)	26.604 (3.047)	49
Class 2	1.962 (0.643)	2.250 (0.457)	38.212 (5.277)	10.934 (6.483)	5
Class 3	0.393 (0.182)	1.238 (0.114)	62.510 (5.945)	20.506 (6.995)	33
Class 4	0.472 (0.247)	-0.051 (0.167)	68.485 (3.452)	0.003 (5.064)	13
GMM 5 classes					
Class 1	0.865 (0.048)	1.103 (0.027)	72.039 (2.934)	23.785 (3.113)	47
Class 2	1.181 (0.234)	2.486 (0.440)	54.253 (4.432)	6.054 (3.463)	14
Class 3	0.276 (0.094)	1.190 (0.069)	58.670 (4.613)	27.481 (4.738)	27
Class 4	-0.571 (0.940)	0.614 (0.750)	77.634 (17.115)	-23.264 (12.863)	2
Class 5	0.723 (0.256)	-0.063 (0.261)	73.543 (4.533)	9.334 (4.461)	10
GMM 6 classes					
Class 1	2.261 (0.690)	2.939 (0.567)	39.598 (4.819)	8.797 (6.075)	5
Class 2	0.699 (0.106)	1.038 (0.031)	70.703 (2.781)	26.178 (2.763)	47
Class 3	0.516 (0.231)	1.419 (0.231)	63.812 (7.139)	16.561 (6.695)	22
Class 4	*** (***)	*** (***)	***	***	0
Class 5	0.506 (0.318)	-0.263 (0.212)	68.626 (2.535)	-2.125 (3.275)	13
Class 6	0.535 (0.208)	0.307 (0.240)	79.895 (3.097)	11.010 (4.346)	13

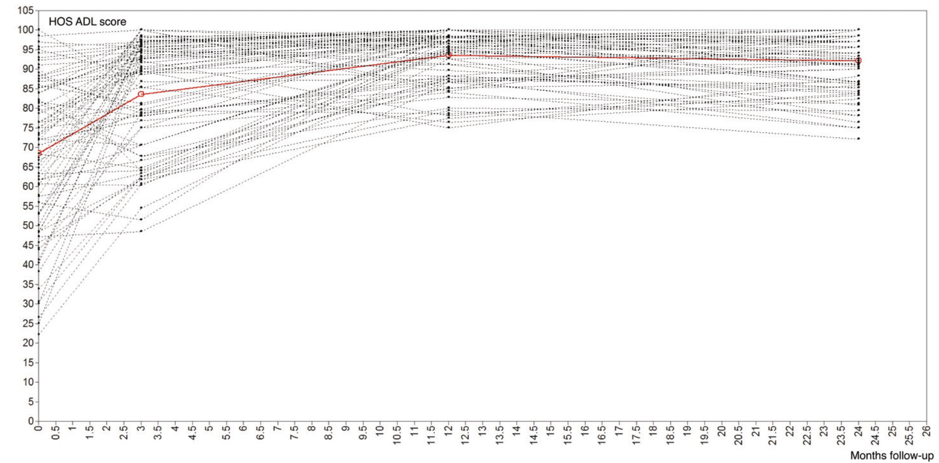
*** error in the calculations: the best loglikelihood value was not replicated. The solution may not be trustworthy due to local maxima and one or more parameters were fixed to avoid singularity of the information matrix.

Trajectory patterns

We labelled the first class as "the improvers" since this class, the largest (78 patients), is portrayed by a steep improvement in HOS-ADL scores during the first three months starting at a baseline score of 68.5, after which the HOS-ADL values subsequently levelled out after 1-year follow-up. At 24 months, the "improvers" reached 92.2 on the HOS-ADL, which is defined a good result. [20]

A more detailed figure of the first class shows a wide range in mainly the start at baseline. All patterns show the same type of positive recovery during follow-up, figure 2.

Figure 2: Observed individual values and estimated means for class 1: the improvers (HOS-ADL, Hip Outcome Score – activities of daily life).



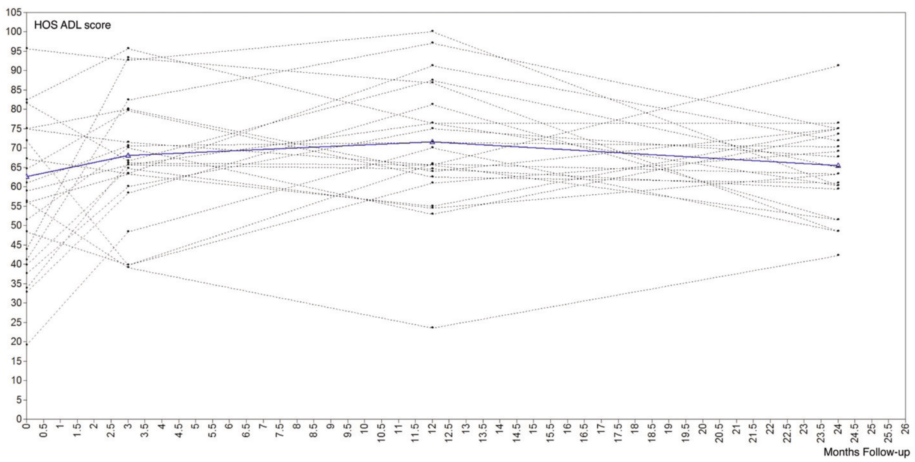
The second class consisted of 22 patients and was labelled as "the non-improvers". This class demonstrated a minor improvement in HOS-ADL score, lower than the MCID of 23, starting from a mean estimated baseline score of 62.6 and ending with a mean estimated score of 65.5. The largest part of this improvement occurred during the first three months after surgery. During follow-up, there is only minor improvement at two years compared to pre-operative scores in HOS-ADL: 3points improvement to a score of 62 which is non-clinically relevant difference (below the MCID) and <80% of total HOS-ADL score, which was defined by Chahal et al [20].

The second class shows a wider range in recovery patterns, which is projected in figure 3.

Figures 2 and 3 demonstrate that some observed individual values are not a perfect fit to the estimated trajectory within its class. However, homogeneity within the classes did not improve when adding classes to the model, as described in the 'Methods' section.

Class membership based on patient characteristics.

Figure 3: Observed individual values and estimated means for class 2: non-improvers (HOS-ADL, Hip Outcome Score - activities of daily life)



The overall patient characteristics are presented in table 1. Univariable analysis and comparing means and differences in several factors were used to identify differences between classes. The "improvers" class was chosen as the reference category.

In the univariable analysis, table 5, the following variables were statistically significant for membership to class "the non-improvers": high visual analogue scale (VAS) for pain pre-operatively (p=0.007), intra-operative arthrosis of the femoral head (p=0.025).

Table 5: Outcomes of the univariable analysis with "non-improvers" class membership as the dependent variable

Predictor	OR (95% CI)	P-value
Gender (F=1, M=0)	1.634 (0.547 – 4.878)	0.378
Age (>50 compared to <30 yrs)	1.274 (0.250 – 6.481)	0.770
Age (30-50 compared to <30 yrs)	1.017 (0.258 – 4.003)	0.981
BMI obesity (>30 compared to <25)	0.529 (0.044 – 6.380)	0.616
BMI overweight (25-30 compared to <25)	1.804 (0.608 – 5.354)	0.288
ASA 2 (compared to ASA 1)	2.134 (0.723 – 6.296)	0.169
Years of pain	0.963 (0.843 – 1.101)	0.587
Tönnis grade 1, pre-operative (compared to grade 0)	2.298 (0.742 – 7.120)	0.149
Tönnis grade 2, pre-operative (compared to grade 0)	1.192 (0.180 – 7.904)	0.855
Arthrosis of femoral head intra-operative diagnosed	3.442 (1.164 – 10.174)	0.025
Arthrosis of acetabulum intra-operative diagnosed	1.217 (0.432 – 3.424)	0.710
Labral tear intra-operative diagnosed	0.892 (0.233 – 3.416)	0.867
Pincer morphology intra-operative diagnosed	1.061 (0.310 – 3.625)	0.926
Cam morphology intra-operative diagnosed	0.694 (0.247 – 1.950)	0.488
VAS for pain in rest	1.025 (1.007 – 1.044)	0.007

We compared means and differences of several factors of both groups as mentioned in methods using descriptive statistics. Results are presented in table 6.

DISCUSSION

We identified two main subgroups with different functional recovery trajectories in our sample of 154 patients operated for FAI syndrome with hip arthroscopy.

We named the subgroups: "the improvers" and "the non-improvers". Based on ours results using the HOS-ADL as outcome measure, "the improvers" can be seen as an ideal recovery trajectory for FAI syndrome patients. "The non-improvers" can be seen as a less favourable trajectory since there is lower post-operative recovery in this class. Using univariable analysis and descriptive statistics, differences between the improvers and non-improvers were found in pre-operative VAS for pain in rest and for intra-operative cartilage damage of the femoral head. Multivariable analysis cannot be made, since our cohort is too small to be able to draw definite conclusion by such an analysis.

Table 6: Differences between subgroups "improvers" and "non-improvers"

Characteristic	Improvers N=78	Non-improvers N=22	Sig (p=)*
Gender (female)	N=45 (58%)	N=15 (68%)	0.375
Age (<30 yrs)	N=15 (19%)	N=4 (18%)	0.912
Age (30-50 yrs)	N=48 (62%)	N=13 (59%)	0.835
Age (>50 yrs)	N=15 (19%)	N=5 (23%)	0.717
Age mean (SD)	38.59 (11.00)	41.27 (10.57)	0.311
BMI (<25)	N=36 (46%)	N=8 (36%)	0.392
BMI (25-30)	N=34 (44%)	N=13 (59%)	0.392
BMI (>30)	N=8 (10%)	N=1 (5%)	0.392
BMI mean (SD)	25.47 (3.6)	25.69 (3.26)	0.799
ASA 1	N=58 (74%)	N=13 (59%)	0.163
ASA 2	N=20 (26%)	N=9 (41%)	0.163
Tönnis grade 0 intra-operative	N=37 (47%)	N=7 (32%)	0.192
Tönnis grade 1 intra-operative	N=32 (41%)	N=13 (49%)	0.133
Tönnis grade 2 intra-operative	N=9 (12%)	N=2 (9%)	0.746
Years of pain mean (SD)	3.07 (3.60)	2.72 (2.39)	0.666
VAS for pain rest pre-operative mean (SD)	36.64 (27.20)	53.82 (25.64)	0.009
VAS for pain active pre-operative mean (SD)	62.03 (24.78)	66.91 (20.20)	0.399
Intra-operative diagnosis			
Cam	N=42 (54%)	N=10 (45%)	0.487
Pincer	N=17 (22%)	N=5 (23%)	0.926
Labral tear	N=65 (83%)	N=18 (82%)	0.867
Cartilage damage head	N=19 (24%)	N=11 (50%)	0.020
Cartilage damage acetabulum	N=32 (41%)	N=10 (45%)	0.710

ASA, American Society of Anaesthesiologists: BMI, body mass index, CI, confidence interval, F, female; M, male, OR odds ratio; VAS, visual analogue score.
*Statistically significant (P<.05)

Other studies have found certain variables with varying effects on functional outcomes after FAI syndrome surgery, like female gender, higher age, labral tears, pincer morphology presence, cartilage degeneration, chondral defects, acetabular coverage (high lateral centre edge angle) and a femoral pistol grip deformity [24-28]. We could not define the true influence of any of these variables to class membership since multivariable analysis was not feasible. In a larger cohort, such analysis will be feasible. For example, Hesseling et al. [9] used LCGM to study a cohort of over six

thousand patients and found multiple predictors for functional recovery trajectories after THA.

An important finding of our study is that the GMM model identifies subgroups of patient recovery patterns after arthroscopic surgery for FAIs. This is a type of postoperative functional outcome analyses, which identifies subgroups in their recovery. This study identified one clearly superior recovery model. Unfortunately, this dataset did not include enough patients to properly identify risk factors for group membership with a multivariable regression analysis. Larger cohort studies must be analysed with LCGM or GMM to identify covariates for class membership. This future research might be able to improve the understanding of how class membership differs and if patients can pre-operatively be "upgraded" to be able to join the favourable class.

Arthroscopic surgery for FAI syndrome can significantly resolve pain and impairment in patients [1, 29, 30] However, not all patients benefit equally from surgery. A careful patient selection for surgery is important to obtain good results for patients in terms of functional recovery and pain relief. We identified differences for intra-operative cartilage damage of the femoral head and pre-operative pain sore between the groups. This is understandable: more cartilage damage of the femoral head causes higher pre-operative pain in patients and cannot be repaired with surgery, therefore causing more pain afterwards with poorer outcome in functional results. This GMM model study confirms that cartilage damage is a risk factor for poor recovery and shows the difference in recovery pattern.

Our study can be seen as an exploratory study and is an important step into a better understanding of the amount of heterogeneity in FAIs patents' recovery after hip arthroscopy. The outcome can be used a guidance tool in patient selection and patient counselling for their expectation management for recovery after surgery. It is known that pre-operative expectations can affect satisfaction after surgery [31]. Parameters that can help to predict outcome of surgery are helpful in the pre-operative expectation management. This, in turn, might help to improve outcome of surgery. For example, when patients suffer severe pre-operative pain, presented in a high VAS for pain in rest pre-operatively, it can be helpful to counsel patients that persisting symptoms of pain can maintain postoperatively.

We identified two different subgroups based on different trajectory outcomes, which were based on the functional improvement post-operatively measured with the HOS-ADL score. A significant improvement in HOS-ADL is defined as total score in HOS-ADL of larger than 80, or when improvement exceeds the MCID defined by Chahal et al [20], which is 23 at 12 months. The MCID is a common tool used to determine the smallest change in a treatment outcome that a patient would benefit of and identify as important. The MCID of the HOS-ADL was calculated at 23, as reported by Chahal et al [20]. Other authors however use a MCID for the HOS-ADL of 8.3 and 9 points, on a total of 68 points) [32]. It is not entirely clear to us how these different values of MCID can be explained, besides pointing out the differences in cohort size (Chahal's cohort of 130 patients, Nwachukwu's cohort contained 364) and moment in time of MCID calculation (Chahal calculated for 3, 6 and 12 months, Nwachukwu for 12 months).

The favourable recovery pattern, "the improvers" has a recovery of HOS-ADL scores of over 90. The improvement from 68.5 tot 92.2 is slightly higher than the MCID of 23 for HOS-ADL as defined by Chahal et al. and it is much larger than 8.3 and 9 points as defined by Nwachukwu et al [32] and Martin et al [33].

Another parameter for measuring successful recovery is the VAS for pain. Overall improvement in VAS for pain in our cohort was from 4.1 to 1.7, which is a 2.4 decrease. The MCID for the VAS for pain was calculated 1.48 [34].

Overall, "the improvers" trajectory can be considered as a successful recovery.

Another point is discussion in our study is that we used the HOS-ADL as primary outcome. Several PRO questionnaires are available and can be used to measure functional outcome after hip arthroscopy. These PRO questionnaires were designed and used to measure end-scores for recovery after surgery. We tried to identify trajectories of recovery and not only the endpoints. In this study we had to choose one specific questionnaire. Another questionnaire that could be used is the iHOT-12. We did not include the iHOT-12 questionnaire from the beginning of our registration; therefore, we did not have complete data on this questionnaire. This questionnaire is now however included into our daily practice.

A strength of this study is the unique analysis of recovery trajectories, thereby providing a more detailed understanding of the degree of variation between patients in the recovery after hip arthroscopy for FAI syndrome. We used data from all patients, including those with poor outcome after surgery.

Limitations

Our study is not without limitations. A limitation to our study is our lost to follow-up, which was 14 patients out of 168 initial suitable patients for study participation. This is an acceptable percentage but giving that a less of 5% rate of loss to follow-up can lead to a small amount of bias [35], this must be taken into account from our study. We also had many patients with incomplete questionnaires during follow-up. A total of 54 patients had incomplete questionnaires, which could not be handled other than

by exclusion out of our data analysis. Due to this incompleteness or our data, a total of 100 patients were analysed. We consider this to be a clear limitation in our data.

Another limitation is that our sample size was not large enough to perform a multivariable regression analysis to truly identify risk factors for group membership.

CONCLUSIONS

We identified two main types of recovery patterns after arthroscopic treatment of FAI syndrome: improvers non-improvers. Both groups recover in a different manner postoperatively. Preoperative pain and intraoperative arthrosis of the femoral head differed in the non-improvers compared with the improvers. This study is an exploratory study; these results and future research can help surgeons in providing better preoperative consultations and expectation management.

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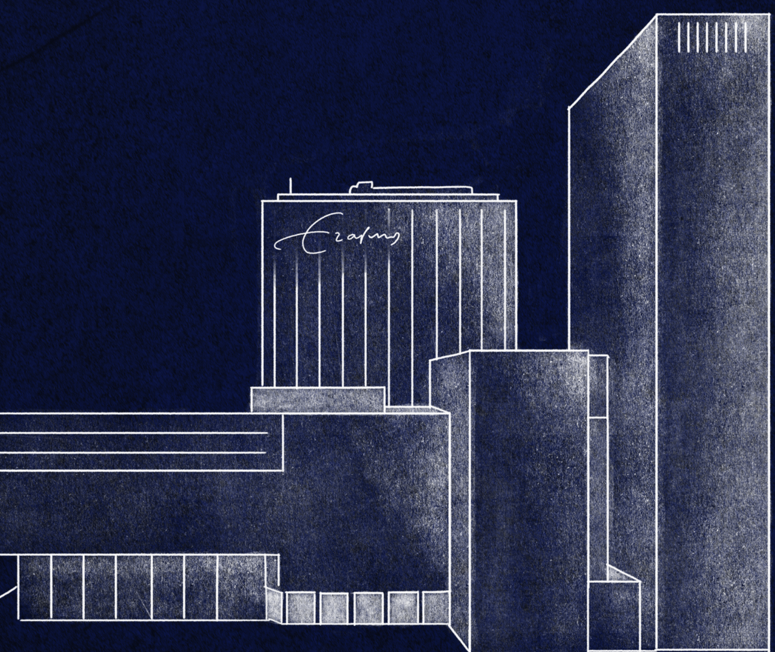

CHAPTER 10

GENERAL DISCUSSION AND FUTURE PERSPECTIVE

In this thesis, we focused on the identification and modification of the impinging hip. In the first part of the thesis, we studied the identification and the incidence of hip impingement. In the second part we analysed the radiographic identification of the morphology that leads to hip impingement and in the third part we analysed the outcome of surgical versus non-surgical treatment of hip impingement. Despite as well as due to our research, more questions remain to be answered by future research. We would like to discuss several of these questions and present future perspectives.

FAI syndrome incidence

We discovered that the overall incidence of groin pain is 0.44% in the general population, and that 17% of patients suffering from groin pain were diagnosed with FAI syndrome. This means that every general practitioner (GP) may see on average three patients per year with FAI syndrome in the differential diagnosis. However, this estimated incidence might constitute un underestimation. None of the participating general practitioners had ever diagnosed FAI syndrome before the start of this study. Therefore, even though we registered all types of groin pain, we may still have underreported FAI syndrome. A large population-based cohort study by Hale et al. (53) recently found a much higher incidence of FAI syndrome. They included and evaluated 1893 patients with hip pain from a population of 144,260 individuals, and 38% of all the evaluated hip pain patients were diagnosed with FAI syndrome, resulting in an overall incidence of FAI syndrome of 54.4 per 100,000 person-years. This much higher incidence may have been due to the fact that their inclusion criteria were more specific for FAI syndrome, and they defined FAI syndrome more specifically in their cohort. Patients included in the study of Hale et al. were selected on the basis of a triad of clinical symptoms, physical examination signs and imaging findings. This cohort differs from our cohort since we registered all types of groin pain. On the other hand, our data provided more information on the differential diagnoses that GPs make for groin pain, and they do not generally apply the selection criteria used by Hale et al. Since all the participating GPs reported that they had never heard of FAI syndrome before our educative symposium, our study underlines the need to provide more information about this syndrome.

Diagnostics

With 3D dynamic CT-based models, the identification of cam morphologies might be improved. We validated 3D CT-based dynamic motion simulation. For this purpose, we created an artificial cam morphology in anatomic specimen and tested to what extent this morphology resulted in limitations in the range of motion of the hip joint. We concluded that the simulation software can detect a reduction in ROM caused by a cam morphology. CT-based models are superior in representing the contrast between bone and soft tissue which makes CT scanning optimal for detecting hip impingement, since this involves an osseous mechanism (54). A disadvantage of

this technique is that it is based on CT images, which implies radiation exposure of patients, although the amount of radiation can be limited by using dose reduction techniques and protocols. Recently, Zeng et al. (55) and Guiguis et al. (56) introduced MRI-based 3D models. The use of MRI scanning can overcome the disadvantage of CT-based radiation. While this technique has not yet been validated like the CT-based models, it has the potential to eliminate the need for CT-based models (57, 58). MRI also has the additional advantage of superior accuracy in detecting acetabular cartilage damage (59), which is a well-known risk factor for poor recovery after surgery.

All patients in our prospective cohort study underwent the 3D CT dynamic analysis. We concluded that the specificity and sensitivity of the 3D CT analysis was not superior to radiographic measurement of the alpha angle and the LCE angle on standard AP and Lauenstein radiographs. However, it is difficult to measure the theoretical advantage for the surgeon of a better pre-operative assessment. This might theoretically improve outcome after surgery, but this assumption could not be evaluated in the present study since outcomes and possible revision rates depend on multiple factors.

The most common reason for revision hip arthroscopy is residual deformity due to incomplete resection (60). Insufficient resection of the impinging part of the hip might be prevented by combining the 3D models with intra-operative navigation (61-63). This combination has not been implemented yet, but if the impinging area of the hip can be highlighted intra-operatively, this would be of great assistance for the surgeon. Computer navigation is already being used in total knee arthroplasty (64). Mathew described (64) that these navigation systems improve the accuracy and precision of component alignment. This precision and intra-operative guidance is what is also needed in hip arthroscopy. Optimal correlation of intra-operative landmarks to the pre-operatively determined osseous morphology would ensure that enough bone is resected to resolve the impingement. Several studies in this area have been published and the used techniques all are still in development. For example, a small randomized controlled (65) trial showed a significantly improved alpha angle in a group operated with the help of computer navigation compared to the group that underwent conventional surgery. However, positioning time was significantly longer and radiation exposure was significantly higher in the navigation group. Kobayashi (66) described a pre-operative planning with virtual osteo-chondroplasty (resection of the deformity) and intraoperative computer navigation assistance. The navigation assistance was based on computer simulation analysis identifying the impingement point. A virtual resection was performed to determine range of motion improvement and with that information, a planning report was transported into a computed tomography-based computer navigation system for intra-operative assistance. Future research should use these techniques in larger comparative cohorts with long follow-up time.

Traction force

We developed a method to measure traction force and joint space widening. Major limitation of our study was the inclusion criterium of a maximum body length of up to 1.74m, due to the implementation of our traction force measuring device on the operating table. With this device, we could measure a traction force of 714 N (390-1362, IQR 315) that resulted in 8.8mm (5.6-13.8, IQR 2,82) of joint space widening. This force was reduced after vacuum seal release of the hip and was further reduced after capsulotomy, without joint space narrowing. We could not identify any factors that influenced the relation between the required traction force and the joint space widening. Ellenrieder et al. (67) have correlated male gender, higher body weight and radiographic signs of osteoarthritis to a higher needed amount of traction force for hip dislocation.

Neurological complications related to the traction have also been reported, such as neuropraxia of the pudendal area, of the lateral femoral cutaneous nerve or of the peroneal nerve. The incidence of such complications is low (68, 69) and most are transient. No persisting neurological complications occurred in the patients included in our study.

A peroneal post is used in most supine positioned traction table. This post is essential to distract the hip adequately. The size and material of the peroneal post is important in preventing possible pudendal neuropraxia. We padded and cushioned the post intensively to prevent high pudendal pressure. Recently, newer techniques have been described without the use of a perineal post but with a friction table and the contralateral leg in a leg-strap (70), which do not lead to any peroneal or pudendal pressure at all. Mei-dan et al. (71) used Trendelenburg positioning in addition to gravity and friction and found that this was sufficient to subluxate the hip joint. These techniques still require traction force on the hip joint, but because no perineal post is used, they prevent pressure-related complications such as neuropraxia of the pudendal area. A clear disadvantage of this technique is that is lacks the lateral vector of the traction: the force is not only caudally orientated, it also gives a lateral direction to the femoral head, which improves visibility of the joint during traction. Another described technique is the use of external fixators to create traction on the hip joint (72). This technique was described for patients with lower extremity amputations but could be used in all patients. There is a clear disadvantage of the penetrating rods true the femoral bone. The use of a hip-specific distractor is recently described (73). This distractor is used in lateral positioning and lacks the use of a peroneal post. No peroneal neuropraxia occurred in this study. This technique

has the disadvantages of penetration rods in the iliac crest and the femur. However, it creates a good dislocation and lateral translation of the femoral head.

Traction time and traction force will also be reduced using quick vacuum seal release and capsulotomy and by the reduction of operating time. No technique has been developed yet that fully prevents traction on the foot of penetration rods into the femur and iliac crest. Dislocation or partial dislocation of the hip joint is always necessary to be able to inspect the central compartment and therefore traction on the foot cannot be fully prevented with use of the current techniques. To create a technique without any traction on the foot or peroneal area is a challenge for future research.

PROMS

We translated the HOS into the Dutch language and we analysed the Dutch version's reliability, internal consistency, and construct and content validity. We concluded that the HOS-NL is a reliable and valid PROM for its purpose, with only a mild ceiling effect post-operatively. We found validation studies of the HOS for the Spanish, Korean, Brazilian, and German populations (74-77). All studies had results that were similar to the results found in our cohort. Other PROMs validated for the Dutch language are available for the same purpose, such as the iHOT-12 NL and the HAGOS. The iHOT-12 NL is a short questionnaire using a Likert-scale 0-100 to score the questions (78). The HAGOS was developed to measure symptoms, activity limitations and quality of life (79). Both questionnaires are valid and reliable, but they lack a good section on rating physical activities. Also, the HAGOS is not often used internationally. We selected the HOS because of its sports sub-domain and because it is widely used internationally. Since several PROMs are available in the Dutch language, they can be combined to measure functional outcome after hip arthroscopy for FAI syndrome. This combination may help overcome single measurement variability and thus improve the reliability of the measured outcome (80).

The use of PROMs creates the opportunity to register outcomes of surgery in large patient cohorts. An example is the national registry of orthopaedic implants in the Netherlands, the LROI, which provides digital registration of pre- and postoperative PROMs for various orthopaedic implant procedures. We recommend registration of PROMs for hip arthroscopy for FAI syndrome in a national register, since this could provide more and better data for detailed analyses of risk factors for failure or success of this type of surgery. Useful PROMs to include in the registration are the iHOT12-NL, the HOS-NL and the VAS for pain.

Functional outcome

Assessment of surgical procedures can be complex and prospective research databases are essential to analyse outcome, to identify outliers and rare events after surgery, as stated by McCulloch et al. in 2009 in the Lancet (81). We started such a prospective registration cohort and were able to conduct several analyses by this cohort. The functional outcomes of our prospective cohort study of hip arthroscopy for FAI syndrome were excellent at one year of follow-up. Patients reported significant improvements after surgery in VAS for pain, modified HHS and HOS. These improvements in pain and functional outcomes are in line with the findings of other authors (82, 83). The functional outcome scores after hip arthroscopy for FAI syndrome using PROMs were described in several other studies, including some studies with longer follow-up periods. In most of these studies, many patients recovered to good levels of functioning with high scores in PROMs. In 2020, Melugin et al. (84) presented their case-control study of almost 1000 patients who had been arthroscopically treated for hip pain. Mean follow-up was 24.7 years after occurrence of the hip pain, with generally good results. Kyin et al. (85) conducted a large systematic review of studies on hip arthroscopy in patients with FAI syndrome and long-term follow-up. They included 13 articles, with follow-up ranging from 5 to 20 years. Patient-reported functional outcomes were scored in several PROMs, the mHHS, HHS and HOS-Sports. Conversion rate to THA was considered a marker for end-stage osteoarthritis development during follow-up. Conversion rates ranged from 17.9 to 32.5%, and in one study with a 20-year follow-up, the conversion rate to THA was 41.0%. However, all the included studies with long-term follow-up were non-comparative studies, and therefore no conclusions could be drawn about the development of osteoarthritis after conservative treatment compared to the development of osteoarthritis after arthroscopic treatment. Several studies discussed conservative treatment (86,87); they concluded that conservative treatment is effective in reducing pain and improving function for short-term periods (3 months), and three level-1 RCT studies showed superior hip-related outcomes in the short term (10 months) for operative treatment compared to conservative treatment consisting of physical therapy alone. Differences in possible osteoarthritis development were not discussed. Future comparative studies should use a much longer follow-up than the studies published so far.

There is a clear need for further research on the options for conservative treatment with physiotherapy, life-style changes, sports activity modifications and the indications for surgical treatment of FAI syndrome. We need large and long-time follow-up cohort studies that also include patients that were treated conservatively, either because they did not fulfil the criteria for surgery or because they did not wish to undergo a surgical procedure. Another type of research that might be useful is a sham procedure, as it could inform us about the true effect of surgical treatment versus a possible placebo effect. In such a study, an arthroscopic treatment of FAI syndrome is compared to a sham surgery. To our knowledge, no such studies have been published, only one study protocol (89).

It is intended to continue our follow-up for a longer period and to present our long-term follow-up in future studies. With the use of electronical databases and electronical questionnaires, patients can be contacted more easily and followed for many years after surgery. If we could register PROMs at 10 and even at 20 years after surgery, long-term follow-up could be assessed, and we could determine whether postoperative functional improvement is sustained.

We developed a model that predicts successful outcome, based on six preoperative risk factors: female gender, pincer impingement, labral tear, low preoperative HOS-ADL score, low WHOQOL physical score and low WHOQOL phycological score. This prediction model might be useful in shared decision making. Other studies have found several risk factors for poor recovery. Wolfson et al. (90) described female gender, older age, obesity or labral debridement as risk factors for poor outcome of surgical treatment. Vahedi et al. (91) found that patients with acetabular retroversion often have inferior treatment results and very recently it was reported that an age over 40 years is a clear risk factor for conversion to THA (92). Also, outcome of treatment is influenced by the hip surgeon's experience, with fewer failures occurring after more years of surgical experience (93).

Another way of analysing postoperative recovery and differences in recovery is to use latent growth class modelling (LGCM). We used LGCM statistical shape modelling to define different recovery patterns, focussing on two major recovery patterns: *improvers* and *non-improvers*. Improvers increased in HOS directly after the operation and the improvement was maintained during a two-year follow-up period. The non-improvers showed no significant improvement post-operatively. A multivariable analysis for risk factors would be a better tool for group membership prediction, but our cohort was too small for such an analysis. Hence, future studies should include large cohorts to enable reliable multivariable analyses of possible risk factors for group membership. Identifying these risk factors can help in patient counselling to manage the patients' expectations regarding recovery after surgery, which can help to improve satisfaction after surgery and support the shared-decision process. Surgeons should be able to select improvers pre-operatively instead of doing so postoperatively. Mancuso et al. (94) described patients' expectations of hip arthroscopy and concluded that patients' expectations are influenced by correct preoperative information regarding recovery and long-term outcome. Such counselling can be optimized by identifying possible risk factors for specific recovery patterns. Another important parameter that is known to influence outcome after surgery is the psychological status of the patient. Sochacki et al. (95) described a negative association between preoperative depression and outcome after hip arthroscopy. In 2020, a review by Dick et al. (96) also concluded that patients with mental health disorders had inferior outcomes after hip arthroscopy but did still benefit from surgery in general. For patients with such specific risk factors, shared decision making about surgical or conservative treatment is essential and can only be done properly if risk factors are known and reliable prediction models are available. In our cohort study, the 4-DKL questionnaire for psychological status was included, but the univariable analysis showed no correlation with the outcome after hip arthroscopy for FAI syndrome.

Future perspectives

We conducted several studies to improve our knowledge on identifying and treating FAI syndrome. The main objective of treatment of FAI syndrome is to relieve patients' complaints and to maintain such relief during a significant period. Several authors have also suggested that FAI syndrome, if left untreated, could develop into osteoarthritis of the hip. In 2003, Ganz (5) proposed the theory that surgical treatment of FAI syndrome could delay the progression of the degenerative process. His study, however, was based on clinical experience and not on comparative research or on a long-term structural follow-up of the treated patients. In hip impingement, impinging areas of the femoral head-neck and acetabulum cause collision and damage the cartilage, which may initiate osteoarthritis. Treatment of the impingement should prevent the occurrence of further damage and thus prevent or postpone the development or the progression of osteoarthritis of the hip.

However, this leads to the question whether surgical treatment of FAI syndrome by means of resection of the impinging area is able to prevent further development of osteoarthritis or whether early treatment of FAI syndrome would prevent osteoarthritis altogether. Osteoarthritis of the hip is a major burden for western society and one of the leading causes of global disability (96). Prevalence numbers are up to 15 to 20% in patients older than 70. The impact can be measured in years lived with disability (YLD) and in disability-adjusted life-years (DALYs) and in 2015, osteoarthritis was the 8th leading cause of YLD in patients aged 65 to 75 in the Nordic region of Europe (98).

To answer such relevant questions, a national registry for all FAI syndrome treatment patients is necessary. Both surgical as well as conservatively treated patients could be included, and parameters that could influence outcome should be registered, such as the PROMS and physical and psychological parameters. The research question whether osteoarthritis of the hip joint is prevented by treatment of FAI syndrome can only be assessed with large cohort sizes and comparative studies. The follow-up time of such studies should be long, much longer than the follow-up times of most studies until now. Hip osteoarthritis occurs mostly in people who are older than 70, whereas in most studies, the average age of the FAI patients is around 40 years. For an adequate analysis, long-term follow-up results must include periods of 20 to 30 years. Even for a country as small as the Netherlands, large cohort sizes and long-time follow-up periods can be achieved if registration of preoperative and especially postoperatively PROMs is nationally managed in the Dutch national registry, the LROI.

Conclusions

We analysed the incidence of FAI syndrome in a cohort of patients of general practitioners. The identification of the impinging hip is challenging and correct visualization of the impingement is very complex. Imaging modalities are helpful, and 3D dynamic models support surgeons in the pre-operative work-up, although they did not prove superior to plain radiographs. Functional outcome scores after arthroscopic surgery of FAI syndrome measured in validated PROMs are good, and so are the short-term functional outcomes. Risk factors for a poor recovery pattern are a higher pre-operative pain score (VAS score) and intra-operative arthrosis of the femoral head. In the future, long-term comparative studies must point out if hip osteoarthritis can be postponed or even prevented by means of hip arthroscopy for FAI syndrome.

CHAPTER 11

SUMMARY

Femoroacetabular impingement syndrome (FAI syndrome) is a well-known cause of hip and groin pain in young and active patients. This thesis covers the recognition, the identification and the treatment of the impinging hip joint. We described how to recognize FAI syndrome by means of anamnestic and physical examination and how often it is present in the general population. After recognition of a possible FAI syndrome, it is essential to objectify the impinging areas of the hip joint. 3D dynamic CT scanning can be used to localize the morphologies which are likely to cause impingement of the hip joint. Treatment can be accomplished by surgical resection of the impinging structures of the hip; the modification of the hip. Patient-reported outcomes can be used to measure functional outcome in patients treated for FAI syndrome.

Recognizing FAI syndrome
To measure the true impact of a pathology or a disease, it is essential to know how often it is present in the population. In chapter 2 we outline the incidence of FAI syndrome in the general population in the Netherlands. We performed a study in which we registered all groin pain diagnoses in a large population in general practices for one year. In preparation for this study, we organized an educational symposium for participating general practitioners (GPs) to train them to perform the anamnestic recognition, the physical examination and the differential diagnosis of FAI syndrome. This study provides a unique insight into the incidence of FAI syndrome in the general population, showing that FAI syndrome is common: 17% of patients suffering from groin pain were diagnosed with FAI syndrome. We estimated that the incidence of FAI syndrome is at least three patients in every GP practice every year.

Identifying the impinging hip
After recognition of FAI syndrome as part of the differential diagnosis in patients with groin pain, several imaging modalities can be used to objectify the possible impinging cam or pincer morphologies. Many authors have described the use of radiographs for FAI recognition. Limitations of plain radiographs are mainly twofold: their two-dimensional character and the static visualization of a three-dimensional and dynamic phenomenon. In chapter 3 we described the use of a three-dimensional software model using a CT imaging modality. The software creates a dynamic three-dimensional model that detects limitation in range of motion of the hip due to impingement of the femoral head and the acetabular edge. We used cadaveric models in which we created an artificial cam morphology. To measure the range of motion of the cadaveric models before and after cam introduction, we used flock of birds measuring methods as a golden standard and compared this with the measurements of the CT-based software. In this way we were able to validate the software for this purpose.

In daily practice, the validated software was used in a prospective cohort. We hypothesized that the sensitivity and specificity of this 3D software is superior to Lauenstein radiographs in the detection of cam and pincer morphology. However, in chapter 4 we concluded that the 3D CT analysis showed no significant difference in sensitivity and specificity on detection of cam or pincer morphology compared to Lauenstein radiographs. As the golden standard we used the intra-operative identification of a cam or pincer morphology.

Modifying the impinging hip
In chapter 5, we describe the traction forces needed to dislocate the hip joint as part of the surgical procedure of hip arthroscopy. The main goal of this study was to measure the amount of force needed to adequately widen the hip joint for the arthroscopic procedure. The second goal was to analyse the relation between this traction force and the amount of joint space widening and to determine whether correlations could be identified that influenced this traction force. For this study, we designed a special traction force measuring device and connected it to the traction force surgical table. We measured a traction force of 714 N (390-1362, IQR 315), which significantly lowered to 520 N (119-780, IQR 172) after vacuum seal release during surgery and to 473 N (63-750, IQR 152) after capsulotomy. This force led to a median joint space widening of 8.8mm (5.6-13.8, IQR 2.82). No relation could be identified between the required traction force and parameters such as age, BMI, gender or osteoarthritis of the joint.

The outcome of surgical treatment can be measured in different ways. One way to analyse the effectiveness of a treatment is to evaluate functional outcome scores postoperatively and compare them to pre-operative functional scores. Such measurements are made with patient-reported outcome measures (PROMs). A PROM functions optimally if it is used for the specific population that it was designed for. The Hip Outcome Score (HOS) is a well-known and frequently used PROM in hip arthroscopy. Therefore, we performed a translation and validation study and described the results of this study in chapter 6. We concluded that the Dutch version of the HOS, the HOS NL, is a valid questionnaire to analyse functional outcome scores in young and active patients with FAI syndrome.

In chapter 7, we describe the short-term functional outcome scores of 80 arthroscopic hip-surgery patients, which were registered and operated in 2012 and 2013. The amount of groin pain, measured with the visual analogue scale (VAS), improved from 6.5 preoperatively to 1.0 post-operatively. The mHHS improved from 59.0 to 85.0 ($p<0.001$), the HOS-ADL improved from 57.5 to 87.5 ($p<0.001$) and the HOS-Sports improved from 44.4 to 79.8 ($p<0.001$). This study shows that patients improve after arthroscopic treatment for FAI in terms of functional outcome scores measured with PROMs. However, we know that not all patients improve equally. It is important to know which FAI syndrome patients have a high change to improve after arthroscopic surgery and which patients do not. For this purpose, we analysed 203 patients from the same prospective cohort, registered and operated in 2011 to 2015, to create a prediction model for successful outcome after hip arthroscopy (Chapter 8). A successful outcome was defined as either a HOS-ADL score of >80 or an improvement of the HOS-ADL score of at least 23 points, which is the minimal clinically important difference. The parameters included in this model were female gender, presence of pincer morphology, presence of a labral tear, a high pre-operative HOS-ADL score, a high pre-operative WHOQOL physical domain score and a high pre-operative WHOQOL psychological score. The final model included six parameters, and its discriminating accuracy was 71%, which can be considered a fair discriminating power for predicting success after hip arthroscopy. Such a prediction model should be used in the pre-operative phase to inform patients on their chances for a good or poor outcome of hip arthroscopy for FAI syndrome.

In chapter 9 we used a statistical method, Latent Class Growth Modelling, to analyse 100 patients which were registered and operated in our prospective cohort in 2015 until 2018. Minimal follow-up after surgery was two years. We used this statistical method to identify two main types of patterns in functional outcome after surgery, measured with the HOS, which we labelled the Improvers and the non-Improvers. The Improvers can be described as patients with an initial fast improvement within three months which is maintained during the two-year follow-up. Most patients were in this group: 78% of the cohort were Improvers. The Non-Improvers did not significantly benefit from surgery, with only a mild improvement in HOS-ADL at three months and no further change during follow-up. A univariable analysis showed significant risk for membership of the non-Improvers group in case of a higher pre-operative pain score (VAS score) and in case of intra-operative arthrosis of the femoral head. Risk factors for membership of the non-Improvers group should be taken into consideration in counselling patients about choosing the most suitable therapy: surgery or conservative treatment.

Several questions remain and many more research projects can be realized in the future. In chapter 10, some important questions on FAI syndrome are discussed, followed by my future perspective on some research questions that are important for the coming years.

APPENDIX

DUTCH SUMMARY/NEDERLANDSE SAMENVATTING

Femoroacetabulair impingement syndroom (FAI-syndroom), ook wel inklemming van de heup, is een bekende oorzaak van heupklachten bij jonge en actieve patiënten. Dit proefschrift bespreekt de herkenning van het FAI-syndroom, de beschikbare diagnostische modaliteiten én de behandeling van de inklemmende heup middels een kijkoperatie, arthroscopie. We beschrijven hoe het FAI-syndroom herkend kan worden en hoe vaak het voorkomt in de algemene populatie. Na herkenning van een FAI-syndroom is het belangrijk om de inklemmende gebieden van de heup te identificeren. CT-scans omgezet in 3D dynamische modellen kunnen gebruikt worden om deze specifieke afwijkingen te herkennen. Behandeling van FAI-syndroom kan worden bewerkstelligd door chirurgische resectie van de inklemmende structuren: het modificeren van de heup. Uitkomsten van de behandeling kunnen gemeten worden door gebruik te maken van hiervoor specifiek ontwikkelde vragenlijsten, de PROM; patiënt reported outcome measures.

Herkenning van het FAI-syndroom.

Om de impact van een ziektebeeld te kennen, is het van belang te weten wat de incidentie hiervan is. In hoofdstuk 2 beschrijven we de incidentie van het FAI-syndroom in een algemene patiëntenpopulatie onderzocht door huisartsen. Hiervoor hebben we een studie opgezet waarin een grote groep huisartsen gedurende een heel jaar alle patiënten met pijnklachten in de liesregio registreerden. Voor de start van de registratie werd een educatief symposium voor de deelnemende huisartsen gehouden, om uitleg te geven over het FAI-syndroom. Anamnestische herkenning, specifiek lichamelijk onderzoek en de uitgebreide differentiaaldiagnose van FAI-syndroom kwamen hierbij aan bod. Deze studie bood een uniek inzicht in de incidentie van FAI-syndroom in de algemene bevolking en toonde aan dat het relatief frequent voorkomt. 17% van alle patiënten bij de huisarts met liesklachten werden gediagnostiseerd met FAI-syndroom. We concludeerden ook dat elke huisarts gemiddeld driemaal per jaar een patiënt met klachten van het FAI-syndroom zou moeten diagnosticeren.

Identificatie van de inklemmende heup.

Na het klinisch herkennen van het FAI-syndroom zijn er meerdere beeldvormende mogelijkheden om de inklemmende structuren in beeld te brengen. De cam en pincer morfologie kunnen met röntgendiagnostiek in beeld worden gebracht. Beperkingen van röntgenfoto's zijn tweeledig: ze zijn tweedimensionaal en het betreft een statische weergave. Dit terwijl inklemming van het heupgewricht een dynamisch proces is en ook driedimensionaal. In hoofdstuk 3 beschrijven we het gebruik van een 3D software-model dat CT-scan beelden gebruikte om een dynamisch model te creëren. Hierdoor herkende de software beperkingen in rotatiemogelijkheden van het heupgewricht. Door eerdere inklemming van de

femurkop tegen de acetabulumrand zijn de bewegingsuitslagen bij het FAI-syndroom beperkt ten opzichte van normaalwaardes. Hiervoor hebben we kadaverheupen gebruikt waarin we een artificiële cam morfologie maakten. Om de beperkingen van de bewegingsuitslag te meten vóór en na cam introductie, gebruikten we een gouden standaard meetmethode: flock-of-birds. Deze metingen vergeleken we met de metingen van de software. Hierdoor konden we de software valideren voor het meten van bewegingsuitslagen van de heup met of zonder cam morfologie.

In onze dagelijks praktijk hadden we deze software bij patiënten gebruikt in ons prospectief cohort registratiestudie. We hadden als hypothese dat de sensitiviteit en de specificiteit van de 3D software beter zou zijn voor cam en pincer herkenning ten opzichte van röntgenfoto's. Echter, in hoofdstuk 4 concludeerden we dat de 3D CT-software analyses geen significant verschil vertoonden in sensitiviteit en specificiteit in de herkenning van cam of pincer morfologie, vergeleken met röntgenfoto's. Als controle gebruikten we de operatieve identificatie van een cam of pincer morfologie.

Modificeren van de inklemmende heup

In hoofdstuk 5 beschrijven we de trekkracht die nodig was om de heup te luxeren als onderdeel van de operatieve ingreep. Hoofddoel van deze studie was om de kracht te meten die nodig was om de heup adequaat te luxeren. Tweede doel was om de relatie te bekijken van deze kracht en de hoeveelheid gewrichtspleet verruiming die dit tot gevolg had en of hier correlaties in te herkennen waren. Voor deze studie hebben we een speciale krachtmeter ontwikkeld om aan de operatietafel te bevestigen. De gemeten kracht was 714 N (390-1362, IQR 315) die significant verlaagde naar 520 N (119-780, IQR 172) na het aanprikken van de heup, en zelfs daalde tot 473 N (63-750, IQR 152) na het arthroscopisch openen van het kapsel. Dit leidde tot een gewrichtspleet verruiming van 8.8mm (5.6-13.8mm, IQR 2,82). Er kon geen correlatie worden aangetoond tussen de benodigde kracht voor deze gewrichtspleet verruiming en patiënt-parameters zoals leeftijd, BMI, geslacht en potentieel aanwezige artrotische kenmerken van de heup.

De uitkomsten van een chirurgische behandeling kunnen op verschillende manieren worden gemeten. Een van die manieren is het gebruiken van specifieke vragenlijsten: patient reported outcome measure (PROM). Een PROM functioneert optimaal als deze wordt gebruikt voor de populatie waar die voor ontwikkeld is. De Hip Outcome Score (HOS) is een bekende en veelgebruikte PROM bij heupscopie voor FAI-syndroom. Daarom hebben we een vertaal- en validatie studie verricht en beschrijven de resultaten hiervan in hoofdstuk 6. We concludeerden dat de Nederlandse versie van de HOS, de HOS NL, een valide vragenlijst was om de functionele uitkomsten in jonge en actieve patiënten te meten met FAI-syndroom.

In hoofdstuk 7 beschrijven we functionele uitkomstmaten met PROMs gemeten, op de korte termijn follow-up in 80 patiënten die prospectief werden geregistreerd en geopereerd in 2012 tot 2013. De hoeveelheid pijn, gemeten met de visuele analoge score (VAS), verbeterde van 6.5 preoperatief naar 1.0 postoperatief. De scores van de modified Harris Hip Score vragenlijst (mHHS) verbeterden van 59.0 naar 85.0 (p<0.001), de HOS-ADL verbeterde van 57.5 naar 87.5 (p<0.001) en de HOS-Sports verbeterde van 44.4 naar 79.8 (p<0.001). Deze studie toonde aan dat de behandeling voor FAI-syndroom middels heupscopie een goede verbetering gaf in functie en pijn bij patiënten met FAI-syndroom. We weten echter dat niet alle patiënten even goed of slecht herstellen. Het is daarom van belang te weten welke patiënten van een operatie zullen herstellen in functie en verbeteren in klachten en welke niet. Voor dit doel hebben we in, hoofdstuk 8, 203 patiënten geanalyseerd uit ons prospectieve cohort, geregistreerd en geopereerd in 2011 tot 2015. We hebben een voorspellend model ontwikkeld met parameters die preoperatief bekend zijn. Na uitvoerige statistische analyse werden uiteindelijk de volgende parameters in dit model geïncludeerd: vrouwelijk geslacht, pincer morfologie, labrum letsel, hoge preoperatieve HOS-ADL score, hoge preoperatieve World Health Organization Quality Of Life (WHOQOL) fysieke score en een hoge WHOQOL psychologische score preoperatief. Succes van de ingreep was gedefinieerd als een totale uitkomst van >80 in de HOS-ADL of een verbetering van tenminste 23 in de HOS-ADL (wat het klinisch relevante verschil is). Dit model voorspelde met 71% nauwkeurigheid het succes van de behandeling voor FAI-syndroom middels heupscopie. Dit model en andere dergelijke voorspellende modellen zijn belangrijk in de preoperatieve counseling van patiënten om iedereen goed te informeren over het mogelijke succes en het herstel van functioneren na de ingreep.

In hoofdstuk 9 gebruikten we een specifieke statische methode, de Latente Klasse Groei Modellen (LCGM), om verschil in herstel tussen groepen patiënten na de heupscopie voor FAI-syndroom te onderzoeken. We gebruikten de LCGM in 100 patiënten uit ons prospectieve cohort, geregistreerd en geopereerd in 2015 tot 2018. De minimale follow-up na de operatie was twee jaar. We gebruikten deze statistische methode om twee type patronen te identificeren waarin patiënten postoperatief herstellen, gemeten met de HOS. Deze twee patronen definieerden we als "Improvers" en "non-Improvers". De Improvers konden worden beschreven als patiënten met een snelle verbetering in de HOS-score na 3 maanden. Deze verbetering werd gedurende de twee jaar follow-up behouden. Van alle patiënten uit het cohort behoorden 78% tot deze groep. De non-Improvers verbeterden niet significant na de operatie in de HOS-score na 3 maanden en geen verdere stijging hierin gedurende de follow-up. Een univariabele analyse toonde een significant risico op het behoren tot de non-Improvers bij een hoge preoperatieve pijn score (VAS) en bij artrotische afwijkingen van de femurkop die tijdens de operatie werden waargenomen. Risicofactoren om een non-Improver te worden moeten tijdens de

preoperatieve gesprekken met patiënten worden uitgezocht en zijn van belang in de counseling van patiënten bij de beslissing om wel of niet te opereren. Dergelijke risicofactoren zijn te combineren met bijvoorbeeld de facturen uit het model in hoofdstuk 8. Zo kan preoperatief een betere inschatting gemaakt worden naar de mate van succes en herstel van een arthroscopische ingreep voor FAI-syndroom.

Meerdere vragen blijven bestaan en er zijn veel meer onderzoekprojecten te realiseren in de toekomst. In hoofdstuk 11 bediscussiëren we enkele belangrijke resterende vragen en benoemen we ook de uitdagingen voor de komende jaren.

LIST OF ABBREVIATIONS

ADL	activities of daily live/living
AIC	Akaike information criteria
AOFAS	American Orthopaedic Foot & Ankle Society
AP	anteroposterior
ASA	American Society of Anaesthesiologists
AUC	area under the curve
BIC	Bayesian information criteria
BLRT	bootstrapped likelihood ratio test
BMI	body mass index
CI	confidence interval
COSMIN	consensus-based standards for the selection of health measurement instruments
CT	computed tomography
DALY	disability-adjusted life years
EMTS	electromagnetic tracking system
EPV	events per variable
EQ5D	EuroQol 5D
FABER	flexion, abduction, external rotation
FADIR	flexion, adduction, internal rotation
FAI	femoroacetabular impingement
GMM	growth mixture modelling
GP	general practitioner
HAGOS	hip and groin outcome score
HOS	hip outcome score
HHS	Harris hip score
ICC	intraclass correlation coefficient
iHOT-12	international hip outcome tool 12
I.E.	id est
IQR	interquartile range
LCEA	lateral centre edge angle
LCGM	latent class growth modelling
LCP	Legg-Calve Perthes
LL	log likelihood
LROI	landelijk register orthopaedische implantaten
MAR	missing at random

MDC	minimal detectable change
MCID	minimal clinically important difference
MEP	motor-evoked potential
METC	medisch ethische toetsingscommissie (medical ethical committee)
mHHS	modified Harris hip score
MRI	magnetic resonance imaging
N/A	not applicable
NAHS	non-arthritic hip score
NPV	negative predictive value
NRS	numerical rating scale
OR	odds ratio
OA	osteoarthritis
PE	physical examination
PPV	positive predictive value
PROM	patient-reported outcome measure
QALY	quality-adjusted life years
ROC	receiver operating characteristic
ROM	range of motion
SCFE	slipped capital femoral epiphysis
SD	standard deviation
SDC	smallest detectable change
SE	standard error
SEM	standard error mean
SF-12	short form 12
Sig	significance
SRM	standardized response mean
SSEP	somatosensory evoked potential
THA	total hip arthroplasty
TRIPOD	transparent reporting of a multivariable prediction model for individual prognosis of diagnosis
VAS	visual analogue scale
WHOQOL	World Health Organization quality of life assessment
YLD	years lived with disability
3D	three-dimensional
4-DSQ	four-dimensional symptom questionnaire
4-DKL	vier-dimensionele klachten lijst

CURRICULUM VITAE

Maarten Röling was born in Heemstede, the Netherlands on December 28, 1985. He is the youngest child of Ben Röling and Tonny Ouddeken and brother of Casper, with whom he grew up in Nieuw-Vennep. After high school graduation at the Rijnlands Lyceum in Oegstgeest in 2004, Maarten started medical school at the Erasmus University Rotterdam. For his research essay, he started his first research project at the Department of Orthopaedic Surgery, Reinier de Graaf Gasthuis, Delft, under supervision of Peter Pilot, which led to his first publication in Orthopaedics. In January 2011, Maarten completed his medical degree and started working as a researcher and, three months later, as a resident (non-training) at the Department of Orthopaedic Surgery, Reinier de Graaf Gasthuis (supervisor R.M. Bloem) Delft, followed by a resident (non-training) function in the Albert Schweitzer Hospital, general surgery, Dordrecht (supervisor P. Plaisier). His specialist orthopaedic training started in 2013 at the department of general surgery in Dordrecht and continued in the orthopaedic department of the Reinier de Graaf Gasthuis, Delft, and the Erasmus University Medical Centre, Rotterdam.

During his study and residency, Maarten has continued his scientific ambition and research work. Under supervision of Nina Mathijssen, he conducted several studies to obtain his PhD degree. The research department in Delft has provided time, equipment and many research facilities to start and continue these research projects, even after leaving Delft as his teaching hospital.

After finishing his orthopaedic training, Maarten was certified as an Orthopaedic Surgeon in January 2019 and commenced a visiting fellowship in the St Gallen Hospital in Switzerland, under supervision of prof. B. Jost. In February 2019, Maarten started working in the department of Orthopaedic Surgery in Gelre Hospital Apeldoorn and became a permanent consultant in 2020, specialized in hip arthroscopy, hip surgery, traumatology, and general knee, foot, and ankle surgery.

Maarten lives in Ugchelen with his wife Carlijne and his sons Lucas (2019) and Laurens (2021).

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SUMMARY OF PHD TRAINING AND TEACHING ACTIVITIES

Activity	Year	Workload ECTS
Algemene academische vaardigheden		
Wetenschappelijk schrijven in het Engels	01-06-2011	2.0
Evidence based medicine AMC	13-06-2014	1.0
Good clinical practice course, Leerhuis Apeldoorn	03-05-2021	0.5
Scientific integrity, Department Medical Ethics EMC	21-09-2021	0.3
Good clinical practice, Roche	23-04-2014	0.5
Wetenschappelijke onderzoek trajecten		
Analyse heup revisie uitkomsten Rdgg, NtvO publicatie	2009	1.0
Risk factors prospective hip fracture study	07-02-2012	0.5
Contralateral hip fractures observational cohort	24-02-2012	0.5
Frequently missed groin pain, NtvG publication	28-10-2012	1.0
Reamer-irrigator-aspirator outcome results analysis: EJTES publication	03-10-2013	1.0
Quantitative non-invasive FAI assessment; cadaveric study EMC	11-03-2015	1.0
Incidence study in general practitioners' prospective registration study	25-03-2016	1.0
Clinical outcome analysis hip arthroscopy prospective registration study	02-06-2016	1.0
Development prediction model from prospective cohort registration	19-04-2018	1.0
Traction force measuring device development and implementation study	23-12-2018	1.0
Diagnostic sensitivity analysis of 3D modeling in FAI	16-01-2020	1.0
Recovery pattern analysis with latent class growth modeling	30-06-2021	1.0
Validating study on PROM HOS NL	16-09-2021	1.0
(Inter)nationale voordrachten		
Sport-medisch Wetenschappelijk Jaarcongres: chronische liespijn bij sporters	02-12-2011	1.0
European Hip Society 3D CT movement analysis	22-09-2012	1.0
International Society of Hip Arthroscopy, non-invasive dynamic identification FAI	12-10-2013	1.0
Wetenschapsdag RdGG Leerhuis, functional outcome results FAI; 1e prijs beste onderzoek 2015	01-12-2015	1.0
ROGO Rotterdam vrije voordracht FAI	28-11-2014	1.0

Activity	Year	Workload ECTS
ROGO Rotterdam vrije voordracht FAI	25-11-2016	1.0
European Hip Society traction force FAI	21-09-2018	1.0
(Inter)nationale posters		
European Hip Society Results of three years hip arthroscopy	22-09-2012	1.0
European Hip Society, results of revision hip arthroscopy	11-10-2014	1.0
Onderwijsactiviteiten		
Communicatieve vaardigheden, AMC medische psychologie	08-05-2014	0.5
Supervising medical students attending the minor "Orthopaedic Sport Traumatology"	19-10-2016	1.0
Overige cursussen/activiteiten		
Ziekenhuis management, Desiderius School EMC	11-05-2016	1.0
Gezondheidsrecht, Desiderius School EMC	27-05-2015	0.5
Reviewer Clinical Orthopaedics and Related Research 2016-present	2016-present	5.0
Opleidingsvisitatie RGS training, RGS	11-12-2017	0.5
EMSG emergengy medicine	06-10-2021	1.0