
*Pim van Klij*

# The development of the non-perfect hip in young athletes

# The Development of the Non-Perfect Hip in Young Athletes

*De ontwikkeling van de niet-perfecte heup bij jonge atleten*

*Pim van Klij*

## Colophon

**ISBN**: 978-94-6361-515-0

**Illustrations**: Jiska de Waard (General introduction Figure 1 & 2)
**Figures**: Figures 4 & 7 (General introduction) and Figure 2 (Discussion) published with permission
**Cover by**: Sven Nardten (Design & illustration)
**Layout by**: Sven Nardten
**Printed by**: Optima
**Publisher**: Optima
**Online publication**: In YourThesis app



**The printing of this thesis was financially supported by:**

- Department of Orthopaedic Surgery, Erasmus MC, University Medical Centre Rotterdam, Rotterdam, the Netherlands
- Fysiotherapie Utrecht Oost
- Stichting OVO Gorinchem
- Nederlandse Orthopaedische Vereniging (NOV)

# The Development of the Non-Perfect Hip in Young Athletes

*De ontwikkeling van de niet-perfecte heup bij jonge atleten*

**Proefschrift**

ter verkrijging van de graad van doctor aan de
Erasmus Universiteit Rotterdam
op gezag van de
rector magnificus

Prof.dr. F.A. van der Duijn Schouten

en volgens besluit van het College voor Promoties.
De openbare verdediging zal plaatsvinden op

woensdag 10 maart 2021 om 15.30 uur

door

***Pim van Klij***
geboren te Gorinchem.

Erasmus University Rotterdam

## Promotiecommissie

| | |
|---|---|
| **Promotor:** | Prof.dr. J.A.N. Verhaar |
| **Overige leden:** | Prof.dr. G.J. Kleinrensink<br>Prof.dr. R.G.H.H. Nelissen<br>Prof.dr. J.L. Tol |
| **Copromotor:** | Dr. R. Agricola |

# Table of contents

*Chapter 01*

**General introduction** 11

*Chapter 02*

**Clinical function and strength tests in football** 25

*'Do hip and groin muscle strength and symptoms change throughout a soccer season in professional male soccer players? A prospective cohort study with repeated measures'* 25

Journal of Science and Medicine in Sport: under revision

*Chapter 03*

**Clinical function and strength tests in field hockey** 47

*'Normal values for hip muscle strength and range of motion in elite, sub-elite and amateur male field hockey players'* 47

Physical Therapy in Sport. 2020;46:169-176

*Chapter 04*

**Classifying cam morphology** 67

*'Classifying Cam Morphology by the Alpha Angle: A Systematic Review on Threshold Values'* 67

Orthopaedic Journal of Sports Medicine. 2020;8(8):2325967120938312.

*Chapter 05*

**The development of cam morphology during growth** 89

*'Cam morphology in young male football players mostly develops before proximal femoral growth plate closure: a prospective study with 5-year follow-up.'* 89

Br J Sports Med. 2019;53(9):532-538.

*Chapter 06*

**Parameters associated with and predictive for cam morphology (presence, size and development)** **105**

*'Clinical and radiological hip parameters do not precede but develop simultaneously with cam morphology: a 5 year follow-up study'* 105

Knee Surg Sports Traumatol Arthrosc. 2020 Oct 1.

*Chapter 07*

**The association between cam morphology and clinical signs and symptoms** **123**

*'The relationship between cam morphology and hip and groin symptoms and signs in young male soccer players'* 123

Scand J Med Sci Sports. 2020;30(7):1221-1231.

*Chapter 08*

**Prevalence of cam and pincer morphology and future hip osteoarthritis** **141**

*'The Prevalence of Cam and Pincer Morphology and Its Association With Development of Hip Osteoarthritis'* 141

J Orthop Sports Phys Ther 2018;48(4):230-238.

*Chapter 09*

**Summary** **163**

*Chapter 10*

**General discussion, conclusion and future perspectives** **169**

*General discussion* 171

*Conclusion* 185

*Future perspectives* 189

Appendices 195

Dutch summary Nederlandse samenvatting 205

References 211

PhD portfolio 231

List of publications 237

Curriculum vitae 241

Acknowledgements Dankwoord 245

*Chapter 01*

# General introduction

## The hip and groin

The groin is often described as the area between the abdomen and the thigh, on both sides of the pubic bone. The groin is an anatomically complex region as many structures are present in different layers. This is one of the reasons why diagnosing and treating groin pain in athletes is a challenge in clinical practice. The groin contains the origin of many musculotendinous structures such as the adductor longus, brevis and magnus, pectineus, gracilis and rectus abdominus muscles who converge around the pubic symphysis. The lower oblique abdominal muscles along with the inguinal ring and inguinal ligament are also located in the groin region. The iliopsoas muscle plays an important role with the distal insertion on the lesser trochanter and its origin at low thoracal and lumbar vertebra. The iliopsoas is in very close proximity to the hip joint, and this muscle can mimic hip-related pain just as the iliacus muscle which is also attached to the lesser trochanter. All these musculotendinous structures support the range of motion (ROM) of the hip and stabilise the pelvis. Groin injuries occur frequently in professional athletes who utilise extreme ROM and load the hip joint and its surrounding structures heavily.

The human hip joint is a bilateral mirrored ball and socket joint and is situated deep in the groin region. The pelvis comprises of the iliac, pubic and ischial bone. Roughly speaking, the socket (acetabulum) is formed by the convergence of the iliac, pubic and ischial bones. Second is the ball (femoral head), which is the proximal end of the femur. The femur accounts for about 27% of a person's height, and it has an important weight bearing function.[44] Many structures are situated in and around the hip joint, such as bony, chondral and labral tissue, ligaments, tendons, muscles, nerves, veins and arteries and the hip capsule with synovial membrane which produces synovial fluid. The proximal femur contains the following anatomic structures: the lesser trochanter, which is located on the medial side, distal to the hip joint, were the iliopsoas inserts *(Figure 1 & 2)*. The iliopsoas is an important hip flexor. On the lateral side, the greater trochanter is present where the vastus lateralis, obturator internus, gemelli, piriformis, gluteus minimus and gluteus medius muscles insert. These muscles facilitate predominantly abduction of the hip. The neck of the femur turns into the femoral head, which is covered with cartilage. This articular (chondral) cartilage also covers the acetabulum. Around the circumference of the acetabulum, the acetabular labrum attaches. The labrum enhances hip stability, functions as a suction seal and protects the articular surface. Further support to hip stability is provided by ligaments: the ischiofemoral, pubofemoral, and iliofemoral ligaments. These ligaments completely surround the hip joint and together merge to form the joint capsule. The fovea capitis is located in the femoral head where the ligamentum teres attaches and connects to the acetabulum. The ligamentum teres has a biomechanical role in stabilising the hip joint and might have a proprioceptive role. The ball and socket shape allows a large ROM in multiple directions: flexion, extension, internal and external rotation, abduction and adduction. Although being described as a ball and socket joint, the bony tissue of the hip can actually have several different shapes and its original function can be limited.

## Ventral view

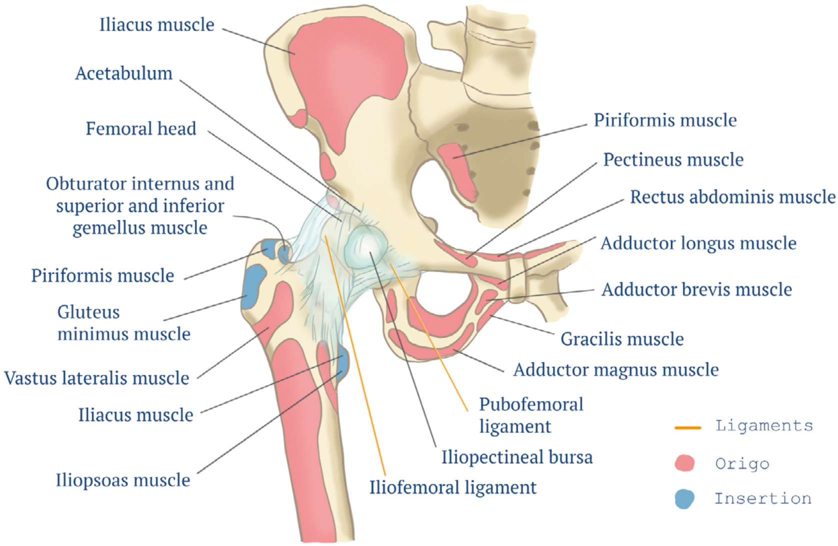



**FIGURE 1:** Structures of the pelvic area (ventral)

## Dorsal view

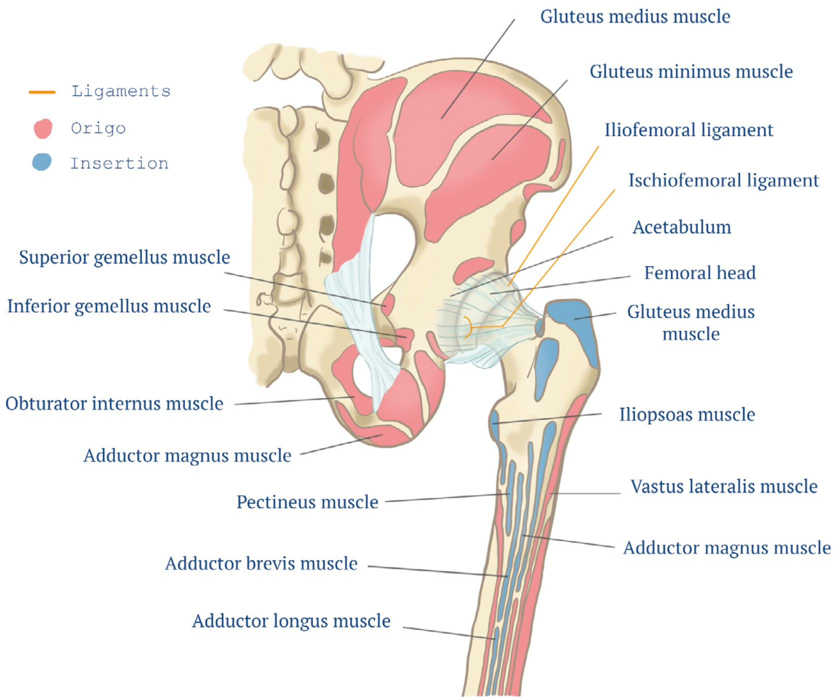



**FIGURE 2:** Structures of the pelvic area (dorsal)

## Development of the hip joint

The hip joint forms from birth until adulthood when the epiphyseal growth plate closes. In newly born babies, the femur is made up mostly of cartilage tissue, which gradually ossifies over the years. A large part of the cartilage ossifies and the other part remains functional cartilage.[144] The process of hip development is affected by many factors such as genetic and metabolic factors, but also by vascularisation and external factors such as how the hip joint is loaded.[113] This loading might influence the bony hip development and impact for example the varus/valgus alignment (neck-shaft angle [NSA]) of the proximal femur[10,154] *(Figure 3)*. Bone thickness can also increase when frequent high loads are applied during growth and development.[164] When hips are unloaded during growth, the femoral head can develop with thinner cartilage and cortical bone, lower trabecular thickness and increased trabecular space.[47] In the proximal femur, growth plates are present at three locations, one is the growth plate of the femoral head, one in the greater trochanter and one in the femoral neck isthmus.[162] The orientation of the proximal femoral growth plate is horizontal during infancy and early childhood. During growth, the endpoints of the growth plate get a more distal orientation, which results in a femoral growth plate with an arc shape with especially the lateral endpoint bending towards the greater trochanter. This can be explained by the fact that the orientation of the growth plate is preferably perpendicular to the stresses applied on it.[162] Extreme biomechanical forces are exerted on young athletes' hips which might influence the 'normal' development of the hip joint. This can result in a slightly different morphology, as bone is adaptive to the loads applied to it, especially during growth. The second growth spurt in children is of particular interest, as the bone is most responsive to loads in this time period. If a hip loses its congruent shape, the joint ROM can theoretically be limited, however only a few studies can support this statement.[50,84,117] This phenomenon of 'non-perfect' bony morphology is seen in athletes in several sports such as football[2,4,137], basketball[159], and ice hockey[160], and probably occurs already from a young age. It seems that several hip pathologies in athletes are associated with an anatomically 'non-perfect' hip joint.

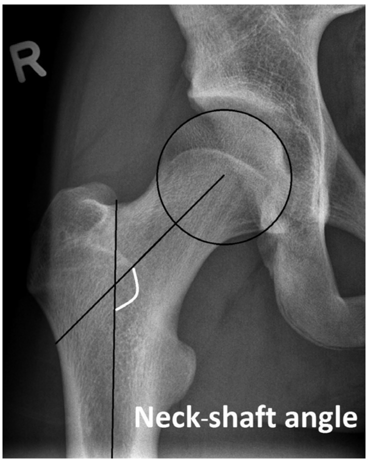



**FIGURE 3:** Neck-shaft angle measurement on an anteroposterior X-ray of the hip joint (white angle)

## Femoroacetabular impingement

Femoroacetabular impingement (FAI) is a motion-dependent clinical disorder of the hip, which involves a premature contact between the acetabulum and proximal femur.[157] The concept of FAI was extensively described by the Swiss group of Ganz et al.[53] around 2003. They proposed two types of FAI which were mainly determined based on the bony and chondrolabral changes observed during their open dislocations of the hip. The first is cam impingement, which is an extra bone formation on the anterolateral side of the femoral head-neck junction (resulting in a 'cam' shape), and is said to result in damage at the anterosuperior side of the chondrolabral junction of the acetabulum. The second type was called pincer impingement, which is an increased coverage of the femoral head by the anterolateral side of the acetabulum. Back then, suggestions were made about the pathological mechanism of the observed damage. A motion-dependent mechanism could cause an abnormal abutment between the proximal femur and the acetabulum during specific movements of the hip joint, such as flexion with or without rotation of the hip.[154]

Apart from during dislocation, bony morphology can also be observed with imaging, using X-rays, computed tomography (CT) and magnetic resonance imaging (MRI). Cam and pincer impingement were reported to be prevalent in approximately 15% of the general population.[59,65,81,149] As both types of impingement were observed to result in damage to the hip joint, it was proposed that these bony morphologies were the main cause of what was formerly believed to be 'secondary' or idiopathic hip osteoarthritis (OA). FAI quickly became of greater interest to researchers and clinicians as it was frequently observed in athletes and linked to hip-related symptoms. Especially when athletes' hips had to endure high load and extreme ROM, it was suggested that they were more prone to develop FAI. In the past decade, there was an increase of publications on the aetiology of FAI, its relationship with symptoms, clinical signs, and hip OA, but significant knowledge gaps remained.

## Femoroacetabular impingement syndrome

As cam and pincer 'impingement' are prevalent in the general population, but not always result in symptoms, a clear definition and clinical diagnostic criteria were necessary. Especially, because over the years, several different terminologies arose in order to describe hip morphology and pathology, such as 'symptomatic FAI', 'FAI deformity' or 'cam deformity, abnormality or lesion'. Therefore, during an international multi-disciplinary consensus statement ('Warwick Agreement'[62]) in 2016, previous terminology was unified in order to create clearer terminology, and diagnosis and treatment options were defined. 'Femoroacetabular impingement syndrome' (FAI syndrome) was introduced as "a motion-related clinical disorder of the hip with a triad of symptoms, clinical signs and imaging findings", and for cam and pincer the overall term 'morphology' was introduced. FAI syndrome is a clinical diagnosis in order to make a clear distinction from asymptomatic people who only have a certain bony morphology. For the diagnosis FAI syndrome, at least symptoms, clinical signs and imaging findings consistent with FAI have to be present *(Figure 4)*. Symptoms can primarily be experienced in the hip and groin region, but pain may also be felt in the back, buttock or thigh. Clinical signs can be a painful and limited ROM, stiffness, locking, catching, clicking or giving way. When performing a physical examination, limited flexion or internal rotation of the hip joint can often be observed. The most commonly performed test, the flexion adduction internal rotation (FADIR) can be used as to reproduce the typical pain.[153] Imaging findings have to be cam- or pincer morphology and an anteroposterior pelvic view and a lateral femoral neck view are recommended as the initial exam to detect those.


**FIGURE 4:** The Warwick Agreement management pathway (Griffin et al., British Journal of Sports Medicine[62])

## Cam morphology

Cam morphology is an extra bone formation on the anterolateral side of the head-neck junction of the proximal femur which results in a nonspherical femoral head. This morphology was described as a 'tilt deformity' by Murray in 1965.[123] It was then thought to be an asymptomatic and slightly slipped capital femoral epiphysis (SCFE) and a precursor for hip OA. In 1975 the term 'pistol grip deformity' was introduced as cam morphology was considered to be similar to the grip of a pistol on an anteroposterior pelvic view.[167] According to the Warwick Agreement, these terms are nowadays defined as 'cam morphology'.[62] Cam morphology can be classified by several measurement methods. The alpha angle is used most often in research and was introduced by Nötzli et al.[134] It is suggested to be an objective classification method which is reproducible. To date, there is still no agreement on which alpha angle threshold to use to define cam morphology. Utilising a consistent alpha angle threshold and imaging modality is needed to study the aetiology of cam morphology, to compare its prevalence between groups and to study its association with hip pathology *(Figure 5)*.

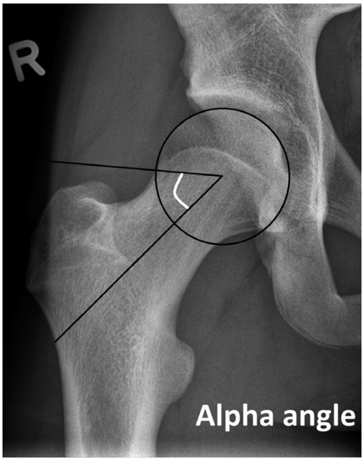



**FIGURE 5:** Alpha angle measurement on an anteroposterior X-ray of the hip joint (white angle)

### *Cam morphology development*

Over the years, the aetiology of cam morphology became of more interest because of the wide variation in cam morphology prevalence over different populations based on age, sex, athletic activity, ethnicity, and symptomatology. The starting point of the development of this cam morphology might be as early as 10 years old, when some cartilage changes may become first visible.[137] From the age of 12 to 14, osseous changes start to occur.[2,4] The hypothesis is that bone has a much greater adaptability during growth and that high loading patterns in athletes contribute to developing cam morphology.[154] Whether cam morphology only develops during adolescence or if it can also develop during adulthood remains unclear. What we do know is that cam morphology is more prevalent in males compared to females.[81,83,98,142] Genetic background is suggested to play a role, probably a minor role, however evidence to substantiate this statement is limited.[119] A higher prevalence of cam morphology is observed in athletes compared to non-athletes[2,159] with a prevalence between 50 and 80%[2,4,83,140,160,192], as compared to 15 to 50% in the general population.[35,36,60,65,149] To implement preventative strategies, the aetiology of cam morphology needs to be further elucidated.

### *Cam morphology and symptomatology*

The relationship between cam morphology and symptomatology is not fully clear. Only one small prospective study is available which found an association between cam morphology and hip pain.[89] Several other cross-sectional studies showed conflicting results.[12,13,59,95,111] Some studies suggest an association between cam morphology and limited ROM, with a limited flexion and internal rotation observed in most studies.[17,84,117] Whether the size of cam morphology or the duration that athletes have cam morphology influence these results is unknown. A larger cam morphology could theoretically result in more damage of the hip joint and subsequent symptoms and limited ROM, especially when present for a long period of time.

## Pincer morphology

Pincer morphology is characterised by an overcoverage of the acetabulum, relative to the femoral head. This can be global, which is an osseous overcoverage of the whole acetabulum or a deep socket, or focal, due to an acetabular retroversion. In 1939, Wiberg et al.[202] introduced the concept of acetabular under- and overcoverage and also a measure to quantify this, known as the Wiberg angle. Another measure to quantify this was called the lateral center-edge angle (LCEA) *(Figure 6)*. Measures for global overcoverage in case of a deep acetabular socket are ‘protrusio acetabuli’ and ‘coxa profunda’. Several indirect measures for acetabular retroversion such as the ‘cross-over sign’, ‘posterior wall sign’ and ‘ischial spine sign’ have been described but they have a poor reliability and specificity.[204] In literature, the LCEA is one of the most commonly used measurement methods to define pincer morphology and several different threshold values for undercoverage (dysplasia) and overcoverage (pincer morphology) have been reported.[29] It is unclear at what age pincer morphology starts to develop. It has been suggested that it, just like cam morphology, starts to develop from around 12 years of age.[114] The distribution in the general population and more specified for gender is very heterogeneous between different studies.[91,99] The relationship of pincer morphology with symptoms[49,108] and clinical signs is unclear. In this thesis, the focus will predominantly be on cam morphology, rather than pincer morphology.

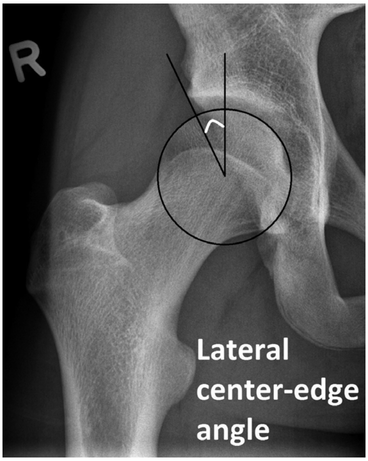



**FIGURE 6:** Lateral center-edge angle measurement on an anteroposterior X-ray of the hip joint (white angle)

## Hip and groin symptoms

Hip and groin symptoms are highly prevalent, especially in athletes.[185,196] As this can result in significant health burden and costs, more research is needed on the cause of symptoms and how to prevent injury. Historically, there was no clear agreement about the terminology and definition of groin pain in athletes. To reach agreement about this, an international multi-disciplinary consensus meeting was organised which resulted in the Doha Agreement in 2015.[197] Consensus was reached on terminology, definitions and how to classify groin pain in athletes. The classification system defined 4 clinical entities: which are adductor-related, iliopsoas-related, inguinal-related and pubic-related groin pain, and a fifth category was defined as hip-related *(Figure 7)*.

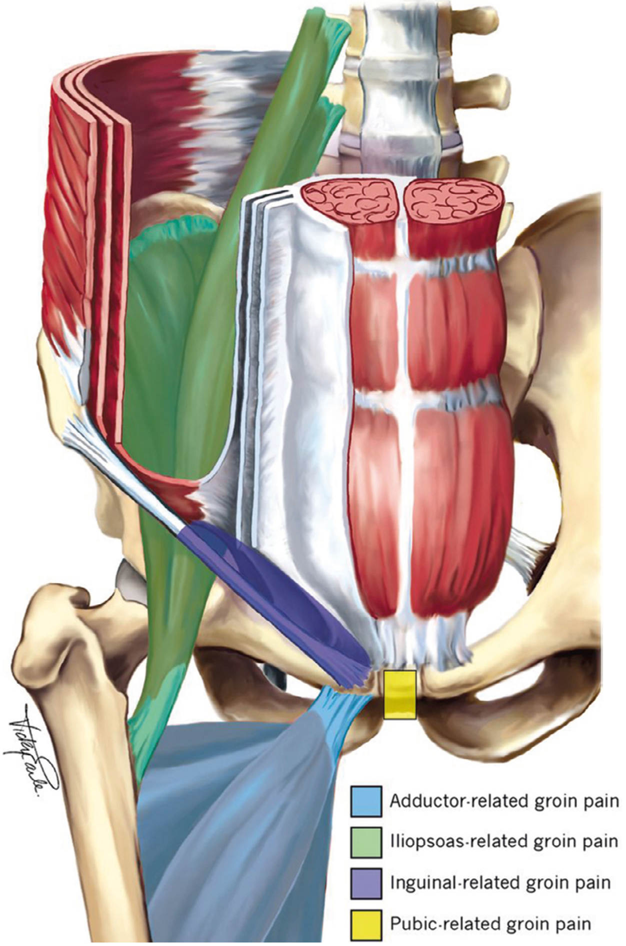



**FIGURE 7**: The clinical entities for groin pain according to the Doha Agreement (Weir et al., British Journal of Sports Medicine[197])

Hip and groin injuries are very common in athletes, especially in professional football where the groin injury incidence is around 0.2 to 2.1 injuries per 1000 hours of football[67,121,196,199] and a seasonal prevalence of 4 to 19%.[196] Injuries can be defined as 'time-loss' or 'non-time-loss'. The term time-loss injury is used to define the inability to take part in full training or match play through injury.[52] Non-time loss injuries are defined as the ability to take part in full training or match play, despite having symptoms. Hip and groin pain results in significant time-loss and non-time-loss injuries. When combined, this represents a significant injury burden and also conveys the risk of recurrent injuries in the future.[122,155,201] To assist clinicians and researchers who are working with athletes with hip and groin symptoms, consensus recommendations are defined. These can guide measuring physical capacity correctly[120], the correct classification, definition and the usage of diagnostic criteria[153] and also inform on physiotherapy-led treatment[88] and how to use patient-reported outcome measures (PROMs).[75] Specific PROMs for young-active adults with hip-related pain, such as the Hip And Groin Outcome Score (HAGOS) and the International Hip Outcome Tool (iHOT) can be used. Hip muscle strength can assist in the clinical examination and help to tailor management strategies for a specific athlete. Especially hip adductor strength is of special interest, as it can be reduced preceding and during the onset of groin pain.[30] Multiple studies found that the risk of future groin injuries is increased when adductor strength is reduced.[122,155,201] To use objective measurements and to compare them between studies, normal values for hip muscle strength for several hip muscle groups and ROM are reported. To date, these values are usually reported in football players at a single time point. A knowledge gap remains concerning normal values in other sports and whether these measures can be used at any moment throughout the season in healthy athletes.

## Femoroacetabular impingement syndrome and its relation with hip osteoarthritis

Over the years, increasing attention has been paid to the possible relationship between FAI syndrome and hip OA later in life. Previous research already showed that abnormal hip morphology such as seen in congenital hip dysplasia, Perthes disease and SCFE, increases the risk for early hip OA.[136,151,166] The relationship between the clinical entity of FAI syndrome and hip OA is not well investigated. However, the relationship between hip morphology consistent with FAI syndrome and development of hip OA is well studied. Cam morphology can theoretically result in repetitive minor trauma to the acetabular labrum and cartilage, which could increase the risk of the development of hip OA. This has been observed in multiple longitudinal cohort studies.[3,125,133,156,176] However, there does not seem to be a clear relationship between pincer morphology and hip OA.[5,125,133,156,176] Hip OA results in an enormous health burden and is one of the most important musculoskeletal problems, worldwide. Given the relationship between cam morphology and hip OA, a better understanding of the aetiology of cam morphology could help inform future strategies to prevent hip OA.

## Aims and focus of this thesis

The aims of this thesis on hip and groin problems in the young adult hip are:

- To establish normal values for hip muscle strength, ROM and symptoms (HAGOS questionnaire scores) in professional male football and professional male field hockey players.
- To summarise all available literature on the alpha angle threshold and propose an alpha angle threshold to classify cam morphology.
- To clarify the aetiology of cam morphology development, with the specific focus on the relationship with the proximal femoral growth plate status.
- To explore whether radiographic and clinical hip parameters precede the development of cam morphology or if parameters are associated with the presence of cam morphology.
- To study if the presence, size and duration of cam morphology are associated with clinical signs and symptoms.
- To summarise current evidence on the prevalence of cam and pincer morphology and their association with hip OA.

## Specified per chapter

In *chapter 2* we describe normal values of hip muscle strength and of the HAGOS questionnaire in professional male football players over the course of a full football season. We also investigate if certain clinical parameters affect these normal values. This is the first prospective cohort study on normal values of both hip muscle strength and HAGOS scores over the period of a full football season. *Chapter 3* focuses on normal values of hip muscle strength and ROM in professional male field hockey players and the influence of several clinical parameters on these values. Despite field hockey being a major sport in the Netherlands and globally, there are few studies on it. This study provides important information for clinicians who work with field hockey players. In *chapter 4*, a threshold value for the alpha angle is proposed based on a systematic literature search, as a uniform threshold value for cam morphology is still lacking. *Chapter 5* investigates the development of cam morphology in professional academy male football players and its association with the femoral growth plate status. This prospective 5-year follow-up cohort study provides insight as to when cam morphology stops developing. *Chapter 6* focuses on how different clinical and radiological hip parameters are associated with cam morphology or if they precede cam morphology development. Following *chapter 5 and 6*, *chapter 7* describes the clinical consequences of cam morphology for symptomatology and ROM. The influence of the duration of cam morphology presence is also discussed. The aims of *chapter 8* were to create an overview of the current available literature on cam and pincer morphology prevalence and its association with hip OA. The prevalence based on age, sex, ethnicity, athletic activity and symptomatology will be reported. Following this, the relationship between both morphologies and hip OA is discussed. All chapters are summarised in *chapter 9*. In *chapter 10*, the results of the work we performed in the different chapters will be discussed according to the most recent insights and literature. A final conclusion is drawn and future perspectives might shine light on the continuation of this line of research.

*Chapter 02*

# Clinical function and strength tests in football

***'Do hip and groin muscle strength and symptoms change throughout a soccer season in professional male soccer players? A prospective cohort study with repeated measures'***

*P. van Klij, R. Langhout, A.M.C. van Beijsterveldt, J.H. Stubbe, A. Weir, R. Agricola, Y. Fokker, A.B. Mosler, J.H. Waarsing, J.A.N. Verhaar, I.J.R. Tak*

Journal of Science and Medicine in Sport: under revision

# Materials and methods

Chapter 02

*Chapter 03*

# Clinical function and strength tests in field hockey

***'Normal values for hip muscle strength and range of motion in elite, sub-elite and amateur male field hockey players'***

*T.P.A. Beddows, P. van Klij, R. Agricola, I.J.R. Tak, T.M. Piscaer, J.A.N. Verhaar, A. Weir*

Physical Therapy in Sport. 2020;46:169-176

# Abstract


**Objectives**: To determine normal values for hip strength and range of motion (ROM) of elite, sub-elite and amateur male field hockey players and to examine the effect of age, leg dominance, playing position, playing level and non-time-loss groin pain on hip strength and ROM.

**Design**: Cross-sectional study.

**Setting**: Physical testing took place at field hockey clubs.

**Participants**: Male field hockey players competing in the three highest Dutch field hockey leagues (n = 104).

**Main outcome measures**: Eccentric adduction, eccentric abduction, adductor squeeze strength, adduction/abduction ratio, internal rotation, external rotation and bent knee fall out (BKFO).

**Results**: Strength and ROM values (mean ± standard deviation) were: adduction = 2.8 ± 0.4 Nm/kg, abduction = 2.6 ± 0.4 Nm/kg, adduction/abduction ratio = 1.1 ± 0.2, squeeze test = 4.5 ± 0.8 N/kg, internal rotation = 34˚ ± 11˚, external rotation = 47˚ ± 9˚, BKFO = 15 ± 4 cm. Age, leg dominance, playing position, playing level and non-time-loss groin pain had no effect on these profiles.

**Conclusions**: Normal values were established for hip strength and ROM of male field hockey players and showed to be independent of age, leg dominance, playing position, playing level and non-time-loss groin pain.

# Introduction

Over the past ten years the physical demands in the game of field hockey have increased significantly. The characteristic flexed hip/trunk positions, explosive accelerations and decelerations and sudden directional changes are strenuous, especially for the lumbar spine and lower limbs. Therefore injuries to the groin region are a common problem in field hockey, with a reported incidence rate of 10-12%.[34,74]

In field hockey, there is a lack of research regarding causal mechanisms and risk factors for injuries to the groin region. However, similar sports that involve the same characteristic quick movement patterns show that deficits in hip adduction strength and adduction to abduction ratios are important risk factors for future groin problems.[201]

Most groin problems appear to be of a gradual onset.[68] Research in football has shown that by regularly monitoring hip muscle strength, problems to the groin region can be detected in an early stage and allow timely management to prevent deterioration of the problem.[203] In players that already suffer from time-loss hip or groin problems, treatment response and the progress of rehabilitation can be determined.[103,129,186]

In addition to monitoring hip muscle strength, comparing these strength measures to established normal values can play an important role in identifying players at risk for developing injuries to the groin region.[118,187] Normal values for hip muscle strength differ between sports. Despite overlapping characteristics, differences in normal values may be due to differing sport-specific loading demands (i.e. kicking, erect trunk posture in football compared with drag flicking and running in trunk flexion during hockey). The respective values for adduction (ADD) to abduction (ABD) ratios, for example in football, Australian football and ice hockey, are 1.20[118], 1.07[147] and 0.95[187]. Normal ratios may thus differ up to 25% between sports. As such, the risk profile for future groin problems also may differ between sports. Tyler et al. found that ice hockey players with an ADD/ABD ratio of less than 0.8 were 17 times more likely to sustain an adductor muscle strain.[187] Mosler et al. found the injury risk threshold to be slightly higher in football players. Here the lower limit of the normal range in was 0.9.[118] Such normal values for hip muscle strength (and therefore also the risk profile) are not available for field hockey.

Hip range of motion (ROM) is another feature that is often determined in the screening and management of groin problems. While the role of strength seems to be well established, there is conflicting evidence on the relationship between ROM and injury risk.[201] There are no publications on normal values for ROM available in field hockey.

The primary aim of this study was to determine the normal profiles for hip muscle strength and ROM in male field hockey players. To assist clinicians in the interpretation of the normal values on clinical practice we had a number of secondary aims. These were to determine the effect that age, leg dominance, playing position, playing level and current presence of groin pain had on these profiles.

# Materials and methods

## Study design

Our study was cross-sectional. Players from 12 field hockey teams competing in the 3 highest Dutch field hockey leagues, representing respectively elite (Hoofdklasse), sub-elite (Promotieklasse) and recreational (Overgangsklasse) playing levels, were invited to participate in the study. Seven teams accepted the invitation and agreed to participate. Participation involved completing a questionnaire about groin pain and performing physical tests to determine hip strength and ROM. Prior to the study, approval of the Medical Research Ethics Committee Erasmus MC was obtained (MED-2018-1576). All participants provided written informed consent.



## Injury definitions

In our study, time-loss groin pain was defined as groin pain resulting in a player being unable to participate in training sessions and match play.[52] As such non-time-loss groin pain was defined as physical complaints to the groin region, but without time-loss. Players without any pain to the groin region were defined as asymptomatic players.

## Inclusion and exclusion

The inclusion criteria for participation were: male gender, age 18-40 years, ⩾ 3 hockey training sessions a week plus match play and able to fully participate in hockey training sessions and match play. Players with current groin pain were considered eligible for inclusion, as long as they were still able to fully participate in training sessions and match play (= non-time-loss groin pain). Players were excluded from participation if they suffered from time-loss groin pain or any other time-loss injury. Exceptions were made for players that sustained a time-loss ankle or foot injury within 7 days prior to testing. Secondly, exceptions were made for players who sustained a time-loss upper body injury within 14 days prior to testing. If players with these recent injuries could fully complete the testing procedures, there were included as we considered them to be capable of delivering representative strength and ROM values.

## Sport-specific questionnaire

A digital questionnaire was used to record the following information: age, leg dominance, playing level, playing position and current presence of groin pain *(see appendix 1 for questionnaire)*.[94] The presence of groin pain was asked using the question: "Do you currently have any groin pain?". When a player reported any groin pain to be present, the affected side and duration of the groin pain were recorded. Players had to confirm that they were able to take fully part in training sessions and match play.

## Physical testing

After completing the sport-specific questionnaire, players were physically tested for hip strength and ROM. All test procedures were conducted and standardised in the manner previously described by Mosler et al. (*Figure 1, see appendix 2 for protocol*).[118] Testing was completed prior to training sessions, to prevent different training intensities affecting strength and ROM measures. We omitted a warming-up to reflect the way strength measurements are done in clinical practice with injured athletes, where a warming-up is not performed. All physical tests were performed at the training facility of the participating club.


**FIGURE 1:** Test procedures

## Hip strength

The following tests were used to determine hip strength: eccentric hip ADD, eccentric hip ABD and the adductor squeeze test.[30,181] Strength testing was performed using a hand-held dynamometer (MicroFET, Hoggan Scientific, Salt Lake City, USA), measuring the maximum force in Newton (N). Hip ADD and ABD strength were measured in a side-lying position with the leg being tested in a horizontal straight position.[183] The hip and knee of the other leg were placed in 90˚ of flexion. Players exerted a 3 seconds maximum isometric contraction against the hand-held dynamometer, followed by a 2 seconds break test performed by the examiners to elicit the peak force.[118] For each leg, adduction and abduction strength tests were repeated three times, with the highest score used for the analysis.[118] There was a 30 seconds rest period between each attempt.[186] Eccentric adduction and abduction strength measures were reported as Newton-meters per kilogram body weight (Nm/kg).[118] The adduction squeeze test was only performed once[118], with the hand-held dynamometer placed between the knees with 45˚ of hip flexion. The player was asked to squeeze the knees together with maximum effort.[33,100] The score was reported as Newton per kilogram (N/kg).[118]

## Hip range of motion

Hip ROM was determined by measuring maximal internal rotation, external rotation and bent knee fall out (BKFO).[103] Internal and external rotation was measured in supine position with 90˚ of hip flexion using an extended goniometer.[135] End ROM was defined as the first moment that resistance was experienced by the examiner and/or the pelvis tended to tilt laterally as lateral tilting will result in overestimation of hip rotation.[170] Each measurement was performed twice and the average score was used for analysis.[118] The BKFO was measured in a crook lying position (i.e. 45˚ of hip and 90˚ knee flexion). Players were then instructed to let their knees 'fall' outwards, while keeping the soles of their feet together. At the end of ROM, little overpressure was given at both medial femoral condyles to ensure a relaxed end position. The distance from the fibular head to the top of the table was then measured in centimetres.



## Interrater reliability

Two examiners, a medical student (TB) and a medical doctor (PK), who performed all physical tests were trained in the methods for 15 hours by an experienced sports physician (AW). Interrater reliability was examined on 15 physically active men (⩾ 2 hours of physical activity a week), aged 18-40 years, outside the testing sessions. Interrater reliability results for both strength and ROM measures are presented in *Table 1*. In addition to the Intraclass Correlation Coefficient (ICC; two-way mixed, average measures, absolute agreement) results, we calculated the standard error (SE) of the difference in the measurement between the two observers (standard deviation of the mean difference between both observers divided by the square root of two as there were two observers). We also present the coefficient of variance for the measures (standard error divided by the mean of all measures multiplied by 100).

## Determining normal value profiles

After each single test attempt, any pain experienced by the player during strength testing was elicited using a 0-10 Numerical Rating Scale (NRS), where 0 represents no pain at all and 10 represents the worst pain imaginable. To ensure that normal values for strength data were not underestimated by players who exerted reduced force as result of pain during test attempts, the traffic light approach as used by Thorborg et al. was used as cut-off measurement.[177,180] The traffic light approach divides NRS-scores into three groups: (1) NRS 0-2, (2) NRS 3-5 and (3) NRS 6-10. We only used group 1 and 2 (NRS 0-2 and NRS 3-5) for normal value analysis. When a player reported two NRS-scores of 6 or higher within one muscle group (i.e. adductor muscle group left, adductor muscle group right, abductor muscle group left and abductor muscle group right), this muscle group was excluded from analysis for normal values. If two NRS-scores of 6 or higher occurred within an adductor muscle group, the outcome of the adductor squeeze test was also excluded from analysis. When the NRS-score of the adductor squeeze test was reported to be 6 or higher, this test was excluded from analysis for normal values.

## Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics (version 25, IBM, Armonk, USA). Hip strength and ROM data were first examined for normality by using the Shapiro-Wilk test and visual inspection of data histograms. All data was found to be normally distributed and presented as mean ± standard deviation (SD). One-way ANOVA analysis was used to assess if there were any significant differences in player characteristics (age, weight, height and body mass index [BMI]) between the playing levels and playing positions. If statistically significant differences between playing levels or playing positions occurred, post hoc analysis with Bonferroni adjustments were performed. Linear mixed model analysis was performed to investigate the effects of age, leg dominance, playing position, playing level and current presence of groin pain (non-time-loss) on hip strength and ROM measures. When a player did not have a preferred leg to kick a football, both legs were considered as dominant. Strength and ROM measures were entered as dependent variables. Leg dominance, playing position, playing level and presence of groin pain were entered as fixed factors. Age and BMI were entered as covariates. Side was entered as repeated measure. Value of P was set at < .05 to indicate statistical significance.

| | n (hips) | ICC† | 95% CI‡ | SE§ | CoV¶ |
|---|---|---|---|---|---|
| **Strength** | | | | | |
| • Adductor squeeze | 30 | 0.52 | -0.28-0.83 | 0.47 | 11.3 |
| • Eccentric ADD†† | 30 | 0.75 | 0.47-0.88 | 0.30 | 11.2 |
| • Eccentric ABD‡‡ | 30 | 0.75 | 0.48-0.88 | 0.25 | 10.0 |
| **Range of motion** | | | | | |
| • Internal rotation | 30 | 0.26 | -0.57-0.65 | 6.2 | 19.0 |
| • External rotation | 30 | 0.23 | -0.57-0.63 | 7.8 | 16.5 |
| • BKFO§§ | 30 | 0.93 | 0.85-0.97 | 1.4 | 8.9 |

**Abbreviations:** †ICC = intraclass correlation coefficient (two-way mixed, average measures, absolute agreement); ‡CI = confidence interval; §SE = Standard Error (of the mean difference between observers); ¶CoV = Coefficient of variance; ††ADD = adduction; ‡‡ABD = abduction; §§BKFO = bent knee fall out.

**TABLE 1:** Interrater reliability results

# Results

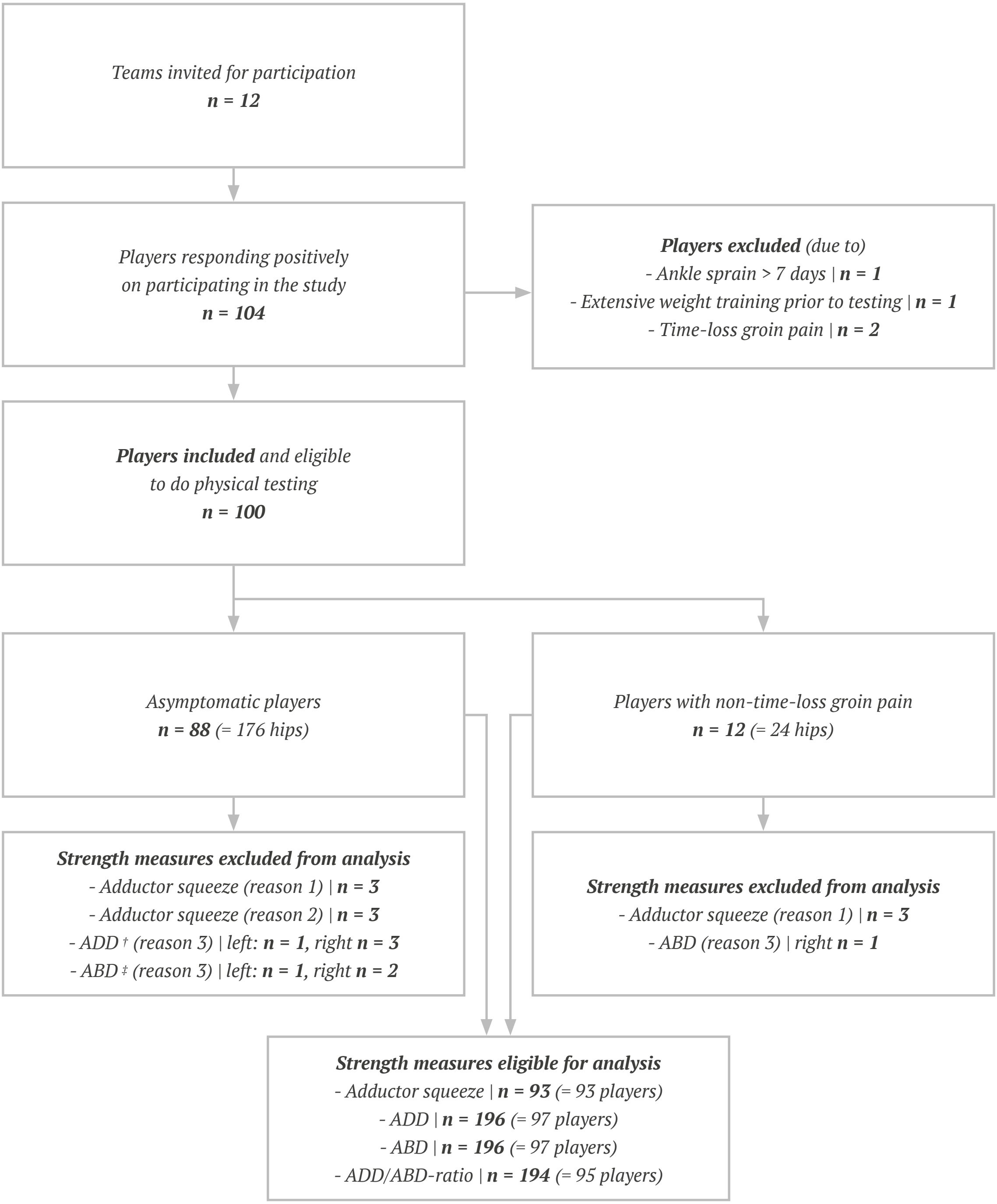
## Total number of players and exclusions

In total 104 players agreed to participate in this study. Four players were excluded from analysis; 2 players due to a groin injury, 1 player had a current ankle sprain and was therefore not able to participate in training sessions and match play for the last two weeks and 1 player because he did extensive weight training just prior to testing session. Eight players reported NRS scores of 6 or higher during strength testing, resulting in exclusion of strength measures. *Figure 2* shows the inclusion and exclusion of strength measures in the study.



## Player characteristics

The player characteristics are presented in *Table 2*. There were no statistically significant differences found in age, weight, height and BMI between the different playing levels. However, there were significant differences in weight between the different playing positions. Post hoc tests (multiple comparisons) demonstrated that goalkeepers were heavier than defenders (mean difference = 6.7 kilograms, 95% CI = 0.16-13.34, P = .04) and attackers (mean difference = 6.6 kilograms, 95% CI = 0.19-13.09, P = .04).




**Abbreviations:** †ADD = adduction; ‡ABD = abduction; §NRS = numerical rating scale. Reason 1 = NRS-score ⩾ 6; reason 2 = 2 ADD strength NRS-scores ⩾ 6; reason 3 = 2 NRS-scores ⩾ 6.

**FIGURE 2**: Inclusion of strength data

| | Mean ± SD† |
|---|---|
| **Age (years)** | 23 ± 3.3 |
| **Weight (kg‡)** | 78 ± 7.4 |
| **Height (cm§)** | 183 ± 6.1 |
| **BMI¶ (kg/$m^2$††)** | 23 ± 1.5 |
| | **Number (n)** |
| **Dominant leg**<br>• Left<br>• Right<br>• No preference | <br>11<br>86<br>3 |
| **Playing position**<br>• Goalkeeper<br>• Defender<br>• Midfielder<br>• Attacker | <br>12<br>29<br>25<br>34 |
| **Playing level**<br>• Elite (Hoofdklasse)<br>• Sub-elite (Promotieklasse)<br>• Recreational (Overgangsklasse) | <br>21<br>37<br>42 |
| **Abbreviations:** †SD = standard deviation; ‡kg = kilogram; §cm = centimetre; ¶BMI = body mass index; ††kg/$m^2$ = kilogram per square meter. | |

**TABLE 2:** Player characteristics (n = 100 players)

## Normal values for hip strength

The normal values for hip strength are presented in *Table 3*.

| | **Total** | **Profile ranges** | | | | |
|---|---|---|---|---|---|---|
| **Hip strength** | **Mean ± SD†** | **Very low (< 2 SD)** | **Low (1-2 SD)** | **Normal** | **High (1-2 SD)** | **Very high (> 2 SD)** |
| **Squeeze (N/kg‡)** | 4.53 ± 0.8 | < 2.9 | 2.9-3.7 | 3.7-5.3 | 5.3-6.1 | > 6.1 |
| **ADD§ (Nm/kg¶)** | 2.82 ± 0.4 | < 2.0 | 2.0-2.4 | 2.4-3.2 | 3.2-3.6 | > 3.6 |
| **ABD†† (Nm/kg)** | 2.60 ± 0.4 | < 1.8 | 1.8-2.2 | 2.2-3.0 | 3.0-3.4 | > 3.4 |
| **ADD/ABD ratio** | 1.09 ± 0.1 | < 0.9 | 0.9-1.0 | 1.0-1.2 | 1.2-1.3 | > 1.3 |

**Abbreviations**: †SD = standard deviation; ‡N/kg = Newton per kilogram; §ADD = adduction; ¶Nm/kg = Newton meter per kilogram; ††ABD = abduction.
Squeeze: n = 93; adduction: n = 97; abduction: n = 97; adduction/abduction ratio: n = 95.

**TABLE 3:** Normal values for hip strength

### *Age and BMI*

Age did not have an effect on strength values. Higher BMI values were statistically associated with less strong hip adduction (slope = -0.1 kilograms/square meter, 95% CI = -0.13--0.15, P = .01) and hip abduction (slope = -0.1 kilograms/square meter, 95% = -0.12--0.02, P = < .01).

### *Leg dominance*

We found no statistically significant differences between the dominant and non-dominant legs for eccentric ADD strength, ABD strength and the ADD/ABD ratio.

### *Playing level*

There were statistically significant differences in eccentric adduction strength between playing levels. Recreational players had higher adduction strength than sub-elite players (mean difference = 0.2 Nm/kg, 95% CI = 0.08-0.46, P = .04) as well as players from the 1$^{st}$ league (mean difference = 0.3 Nm/kg, 95% CI = 0.07-0.70, P = .01). Other strength measures did not differ between the playing levels.

### *Playing position*

There was no association between different playing positions and their strength values.

### *Presence of groin pain*

Players with non-time-loss groin pain had similar strength as asymptomatic players.

## Normal values for hip range of motion

The normal values for hip ROM are presented in *Table 4*.

| | **Total** | **Profile ranges** | | | | |
|---|---|---|---|---|---|---|
| *Range of motion* | **Mean ± SD**† | **Very low (< 2 SD)** | **Low (1-2 SD)** | **Normal** | **High (1-2 SD)** | **Very high (> 2 SD)** |
| **Internal rotation (°)** | 34 ± 11 | < 12 | 12-23 | 23-45 | 45-56 | > 56 |
| **External rotation (°)** | 47 ± 9 | < 29 | 29-38 | 38-56 | 56-65 | > 65 |
| **BKFO§ (cm¶)** | 15 ± 4 | < 7 | 7-11 | 11-19 | 19-23 | > 23 |

**Abbreviations:** †SD = standard deviation; §BKFO = bent knee fall out; ¶cm = centimetre.

**TABLE 4**: Normal values for hip range of motion (n = 100 players)

### *Age and BMI*

Both age and BMI did not have any significant effect on the ROM.

### *Leg dominance*

Range of motion did not statistically differ between the dominant and non-dominant legs for external rotation and bent knee fall out. Internal rotation was significantly lower on the dominant side when compared to the non-dominant side (mean difference = 2.3°, 95% CI = 0.52-4.16, P = .12) *(online Table 5)*.

### *Playing level*

Range of motion values did not differ between playing levels *(online Table 6)*.

### *Playing position*

When comparing ROM values between different playing positions we found no statistically significant differences *(online Table 7)*.

### *Presence of groin pain*

There was no difference in ROM values between asymptomatic players and players with non-time-loss groin pain *(online Table 8)*.

# Discussion

Our study is the first to report normal values for hip strength and ROM in male field hockey players. The results further demonstrated that there were no clinically relevant differences between the dominant and non-dominant leg, the different playing positions, the different playing levels and between asymptomatic players and players with non-time-loss groin pain. Additionally, age and BMI did not have clinically relevant effects on both hip strength and ROM values. This means that the values reported here can be used in clinical practice regardless of age, BMI, leg dominance, playing position, playing level and current presence of groin pain (non-time loss).



## Hip strength

In our study we found an eccentric hip ADD value of 2.8 ± 0.4 Nm/kg. In a similar study by Mosler et al. with football players, the outcome of eccentric hip ADD was 3.0 ± 0.6 Nm/kg.[118] Another study with football players showed a similar value of 3.1 ± 0.4 Nm/kg.[181] Adductor strength of field hockey players being slightly lower than the adductor strength of football players might lie in the reasoning that adductor muscles of field hockey players are not being exposed to kicking actions like in football eliciting peak adductor force in maximum abducted positions. The eccentric hip ABD value in our study was 2.6 ± 0.4 Nm/kg, which is in line with the findings of Mosler et al.[118] Taking the different playing levels into account, we found a statistically significant higher hip adduction value in recreational players in comparison to elite players (mean difference = 0.3 Nm/kg, 95% CI = 0.07-0.70, P = .01) and sub-elite players (mean difference = 0.2 Nm/kg, 95% CI = 0.08-0.46, P = .04). There is no clear reason why this difference in hip adduction strength reached the level of significance and as these differences did not exceed the standard error of measurement, we considered these differences not clinically relevant. It is possible that this result in a type 1 error.

The ADD/ABD strength ratio in our study was 1.1 ± 0.2. Previous studies by Mosler et al. and Tyler et al. found these ratios to be 1.2 ± 0.2 and 0.95 in football and ice hockey players respectively.[118,187] In a study with Australian football players in which the ADD/ABD strength ratio was categorised in three playing levels, the outcome values differed from 1.13 in elite players to 1.03 in amateur players. As described previously, the risk profile for future groin problems may differ between sports.[118] Tyler et al. found that ice hockey players were 17 times more likely to sustain an adductor muscle strain if their ADD/ABD ratio was less than 0.8.[187] Mosler et al., found this injury rate threshold to be at 0.9.[118] In our study the lower limit of the normal range for the ADD/ABD ratio was 1.0, and therefore field hockey players might already benefit from adductor strengthening programs if they have a ratio less than 1.0.

The outcome of the adductor squeeze test in field hockey players differed from those with football players.[118] In our study we found the mean adductor squeeze test value to be 4.5 ± 0.8 N/kg. In the study of Mosler et al. the adductor squeeze test value was 3.6 ± 0.8 N/kg. This can probably be explained by the different sport-specific demands between field hockey and football. During training and match play, hockey players spend more time than football players in a characteristic deep hip flexed position in a wide stance. Hence, this may lead to hockey players being stronger in adduction when their hips are flexed in comparison with football players when tested with squeeze. We found that our strength measures had a good interrater reliability.[90]

## Hip range of motion

In our study we found internal rotation to be 34˚ ± 11˚. This measure is comparable with the internal rotation values found in football players (32˚ ± 8˚) and Gaelic football players (dominant leg: 35˚ ± 6˚, non-dominant leg: 34˚ ± 6˚).[118,129] We also found slightly higher values for internal rotation in the dominant leg. Internal rotation was statistically higher for the dominant leg, than for the non-dominant leg (mean difference = 2˚, 95% CI = 0.43-4.48, P = .02). Given that the standard error of the measurement (6.2˚) is larger than the difference between leg dominance we deemed this finding not to be clinically relevant.

When taking the playing position into account, we found that goalkeepers had more internal rotation than midfielders (mean difference = 11˚, 95% CI = 0.21-21.21, P = .04). As this difference was larger than the standard error of measurement this may be clinically relevant. These differences could be explained by the fact that heavy physical load is associated with the development of cam morphology of the femoral head neck junction.[192] As goalkeepers likely have less intensive and strenuous demands on the hips compared with field players, they might not develop this morphology and resultant reduced motion. As no imaging was performed during our study this remains a hypothesis. The players in our study had 47˚ ± 9˚ of hip external rotation. This is substantially higher than previous observations of external rotation measures amongst football players (38˚ ± 8˚) and Gaelic football players (30˚ ± 5˚).[118,129] The reason for this difference is unclear and we cannot think of a simple explanation for this. There was no statistically significant difference found in leg dominance, playing position, playing level and current presence of groin pain.

The BKFO in our study for hockey players was 14.9 ± 4.3 cm. This is comparable to football players, who showed a BKFO of 13 ± 4.4 cm. The BKFO test for Gaelic football players also showed similar measures (dominant leg: 15.1, non-dominant leg: 15.2).[118,129] Again, there was no statistically significant difference found in leg dominance, playing position, playing level and current presence of groin pain. It is unclear why the external rotation was larger in hockey players and yet the BKFO was similar. The BKFO test contains a degree of external rotation but may also be limited by the adductor muscle group. It seems these two tests measure different aspects.

BKFO measures had a good interrater reliability.[90] However, internal and external rotation measures were less reliable. This is in accordance with other studies[145,146,195], which impedes the clinical appreciation of hip ROM in general.

## Strengths and limitations

Our study has several strengths. We examined a large population of 104 male field hockey players. This number is divided into three different playing levels. The number of individuals in each category is in line with another study among Australian football players.[147] In order to perform this study, we used a protocol used by Mosler et al. and Thorborg et al.[118,183] We practiced extensively with this protocol before carrying out the actual testing sessions. We measured hip strength by using a hand-held dynamometer and measured ROM with a goniometer in supine position. Both tests were performed without any additional stabilisation equipment like belts. Additional stabilisation may have improved the repeatability of the measurements. However, it is not common practice to take this kind of measures as clinicians favour a swift execution of the physical tests. Secondly, selection bias may have occurred in our study. We invited a large number of teams to participate in this study, however due to various limited time schedules of field hockey teams and players (important matches in the national and international leagues, work/study of players and/or other commitments), we had to be logistically efficient in the definite choice of available teams and players. In this study we only documented the normal values for male field players. As such, these normal values may not be applicable for female field hockey players. Finally, the single observer method of measuring hip ROM did not have good reliability in our study.

# Conclusion

Our study presents normal values for hip strength and ROM for field hockey players, which clearly differ in some aspects from other sports. Leg dominance, playing position, playing level and the current presence of groin pain (non-time-loss) did not have a clinically relevant influence on hip strength and ROM values.


## Ethical approval

Approval of the Medical Research Ethics Committee Erasmus Medical Centre was obtained (MED-2018-1576).

## Funding

None declared.

## Conflict of interest

None declared.

## Informed consent

All athletes provided their written informed consent.

## Acknowledgements

The authors would like to thank all the players, team physiotherapists and coaches who contributed to the data collection. The authors thank also Erwin Waarsing for his assistance with the statistical analysis for this study. Finally, we would like to thank Bas van Berge Henegouwen (De Nieuwe Velden) and Frank Hagenaars (Hagenaars Fysiotherapie) for allowing us to use their clinical equipment for the assessments.


## Supplementary data

Supplementary data to this article can be found online.

*Chapter 04*

# Classifying cam morphology

*'Classifying Cam Morphology by the Alpha Angle: A Systematic Review on Threshold Values'*

*P. van Klij, M.P. Reiman, J.H. Waarsing, M. Reijman, W.M. Bramer, J.A.N. Verhaar, R. Agricola*

Orthopaedic Journal of Sports Medicine. 2020;8(8):2325967120938312.

# Abstract

**Background**: The alpha angle is the most often used measure to classify cam morphology. There is currently no agreement on which alpha angle threshold value to use.

**Purpose**: To systematically investigate the different alpha angle threshold values used for defining cam morphology in studies aiming to identify this threshold and to determine whether data are consistent enough to suggest an alpha angle threshold to classify cam morphology.

**Study design**: Systematic review; Level of evidence, 3.

**Methods**: The Embase, Medline (Ovid), Web of Science, Cochrane Central, and Google Scholar databases were searched from database inception to February 28, 2019. Studies aiming at identifying an alpha angle threshold to classify cam morphology were eligible for inclusion.

**Results**: We included 4 case-control studies, 10 cohort studies and 1 finite element study from 2437 identified publications. Studies (n = 3) using receiver operating characteristic (ROC) curve analysis to distinguish asymptomatic people from patients with femoroacetabular impingement syndrome consistently observed alpha angle thresholds between 57° and 60°. A 60° threshold was also found to best discriminate between hips with and without cam morphology in a large cohort study based on a bimodal distribution of the alpha angle. Studies (n = 8) using the upper limit of the 95% reference interval as threshold proposed a wide overall threshold range between 58° and 93°. When stratified by sex, thresholds between 63° and 93° in male patients and between 58° and 94° in female patients were reported.

**Conclusion**: Based on the available evidence, mostly based on studies using ROC curve analysis, an alpha angle threshold of ⩾60° is currently the most appropriate to classify cam morphology. Further research is required to fully validate this threshold.

**Trial registration number**: PROSPERO CRD42019126021.

# Introduction

Femoroacetabular impingement syndrome (FAIS) is a motion-related disorder of the hip caused by a premature contact between the proximal femur and acetabulum.[62,157] FAIS can be diagnosed by the presence of hip pain, a clinical sign suggestive of FAIS during hip examination, and imaging findings. Imaging findings include the presence of cam morphology, which is an asphericity of the femoral head. This extra bone formation is often located in the anterolateral head-neck junction and in most cases develops during skeletal growth.[2,4,137,192]

The presence of cam morphology is a common imaging finding. The prevalence in the general population is roughly 15-25% in male patients and 5-15% in female patients.[60,65,149] The significance of cam morphology in isolation, without the presence of symptoms and clinical signs, is unknown. Although its presence is associated with limited range of motion[17,84,117] and the future development of osteoarthritis (OA)[3,125,133,156,176,191], the association with hip pain is conflicting.[89]

Cam morphology can be quantified by various means. Measures that have been described include the head-neck ratio[102], triangular index[58], beta angle[22], and the alpha angle.[134] To date, the alpha angle is the measure most often used to quantify cam morphology, and it has been used in various imaging modalities and views. The alpha angle, always measured in a 2-dimensional (2D) plane, quantifies the sphericity of the femoral head-neck junction on a location depending on the radiographic view. For example, on an anteroposterior (AP) view, the alpha angle quantifies the lateral head-neck junction, whereas on a frog-leg lateral or Dunn view, the alpha angle quantifies the anterolateral head-neck junction. The advantage of 3-dimensional (3D) imaging is that the alpha angle can be measured at multiple locations around the head-neck junction. Some analyse the alpha angle as a continuous variable[133], whereas others[125] use threshold values to binary classify the presence and absence of cam morphology. As the alpha angle per definition is a 2D measurement, it might be applied to all imaging modalities such as radiographs and 3D planes. However, the reported alpha angle threshold values to identify or diagnose cam morphology have been inconsistent. Threshold values used range from 50° to 83°.[48,58,134,142]

Because of the inconsistencies in alpha angle threshold values, prevalence data and associations between cam morphology and hip pain or pathology are difficult to interpret. Nötzli et al.[134] first described the alpha angle and suggested a 55° threshold, although a 50° threshold has frequently been used by others.[65,83,85,89,98] By an advanced understanding of cam morphology prevalence and its association with pathology, some authors[2-4,125,156,192] have suggested a higher alpha angle threshold to classify cam morphology.

A recent scoping review[105] suggested that a threshold around 60° would be more appropriate to classify cam morphology. In a recent consensus statement on FAIS and on the classification of hip-related pain, the authors acknowledged importance of the use of a consistent alpha angle threshold.[62] Particularly for research purposes, future studies are warranted to study a homogenous population and to classify the presence of cam morphology consistently. However, no exact alpha angle threshold value could be advised because of the lack of a systematic synthesis of this data.[62]

Therefore, the aims of this systematic review were to (1) appraise studies investigating alpha angle threshold values for cam morphology and (2) determine whether data are consistent enough to suggest an alpha angle threshold to classify cam morphology.

# Material and methods

## Protocol and registration

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed during the search and reporting phase.[169] This review was registered in PROSPERO after a pilot search and before the updated search and extraction of the data. Protocol details can be accessed via the online PROSPERO database (registration no. CRD42019126021).

## Identification and selection of the literature

The study protocol, with a PICO (patient-intervention-comparison-outcome) framework and eligibility criteria for the reports, was composed before the search was performed. We included (1) studies aiming at identifying an alpha angle threshold value based on imaging (e.g. radiographs, magnetic resonance imaging [MRI], computed tomography [CT], or ultrasound) to distinguish between hips with and without cam morphology. We considered (2) all types of methodology to identify a threshold value, including, for example, reference intervals and confidence intervals based on the alpha angle distribution, receiver operating characteristics (ROC) curve analyses or associations between alpha angle thresholds, and certain outcomes. For studies using ROC curve analyses or association studies, we included the ones that explained threshold values in relation to symptoms, range of motion, intra-articular hip pathology (labral tears/chondropathy), hip OA, and/or total hip replacement (THR). (3) Studies that primarily investigated the association between cam morphology and symptoms, intra-articular hip pathology, hip OA, and/or THR and used predefined threshold values to quantify cam morphology were only included when they studied ⩾3 alpha angle threshold values. The exclusion criteria were (1) studies including a group of patients with hip diseases such as dysplasia, Perthes, and slipped capital femoral epiphysis; (2) animal studies; (3) studies using 1 or 2 pre-defined alpha angle thresholds for cam morphology to study the association with hip symptoms, intra-articular hip pathology, hip OA, and/or THR; (4) systematic reviews, meta-analyses, case-series with fewer than 10 participants, and congress abstracts. No restrictions for publication language or publication period were used.

### Literature search strategy and information sources

A sensitive literature search strategy was conducted for several online databases, with assistance of a medical librarian. The following databases were searched from inception until the February 28, 2019 (date last searched): Embase.com, Medline (Ovid), Web of Science Core Collections, Cochrane Library Central Registry of Trials (Wiley), and Google Scholar. The searches combined terms for hip with alpha angle. The complete search strategy for each database can be found in the *online appendix*.

## Selection of studies

The titles, abstracts, and full-texts of all studies found using our search strategy were scored independently by 2 different raters (P.K., R.A.) to determine whether they met the inclusion criteria, resulting in an equal judgment between the raters. Disagreements were resolved by a consensus meeting. A third reviewer (M.R.) was involved for determination of full-text inclusion regarding 1 article because of failure to achieve consensus between the 2 main reviewers. Reference screening of included articles was also performed. The interrater reliability for final inclusion after full-text screening was 1.00 (100% agreement).

## Data extraction

The data extraction was performed by the 2 reviewers. Data that could answer the primary question were extracted, such as alpha angle thresholds for cam morphology (including alpha angle upper limits, 95% C.I. etc.), and the imaging modality used. The 2 reviewers extracted the data independently, with disagreements resolved through a consensus meeting.

## Risk of bias (quality) assessment

The risk of bias of the included studies was scored by the Cochrane Risk of Bias Tool (2.0)[73] for randomised controlled trials (RCTs), the MINORS (Methodological Index for Non-Randomised Studies) scale[163] for non-RCTs, and the Newcastle-Ottawa Scale (NOS)[198] for case-control and cohort studies, as described in the PROSPERO protocol. Ultimately, only case-control and cohort studies were included in this systematic review, meaning that only the NOS assessment was performed. This tool focuses on 3 areas: the selection of groups, comparability of groups, and ascertainment of outcome. This tool results in a total score from 0 to 9, with 9 indicating the highest study quality. The 2 reviewers independently performed the risk of bias assessment, and discrepancies between the reviewers were resolved by a consensus meeting. The interrater reliability for the NOS score was 0.93 (95% C.I. 0.81-0.98).

## Synthesis of the data

A meta-analysis was not performed because of significant methodological and clinical heterogeneity among included studies. Heterogeneity was primarily found in participant characteristics, imaging technique, exposures and outcomes, study designs, and risk of bias per study.

# Results

## Selection of studies

We identified 2437 titles after the initial review, of which 15 studies qualified for inclusion in the quality assessment and analysis *(Figure 1)*.

## Characteristics of the included studies

In this systematic review, 4 case-control studies[20,43,106,168], 10 cohort studies[8,26,46,48,57,58,92,96,107,142], and 1 finite element study[101] were included. All the findings are summarised in *Table 1 and 2*.

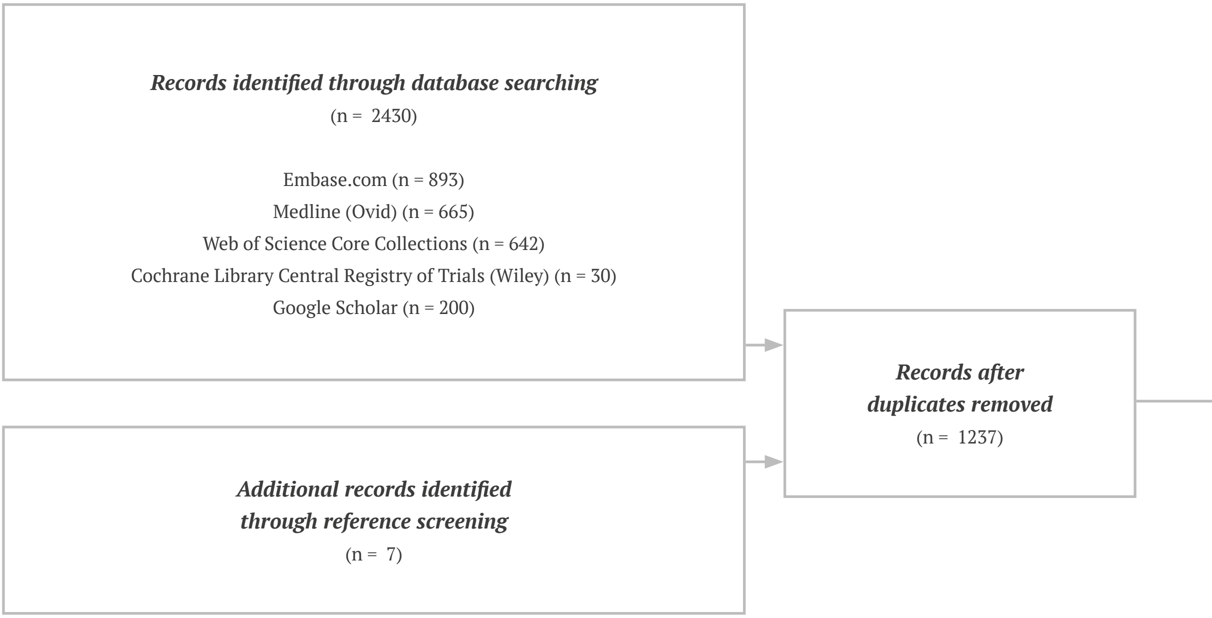
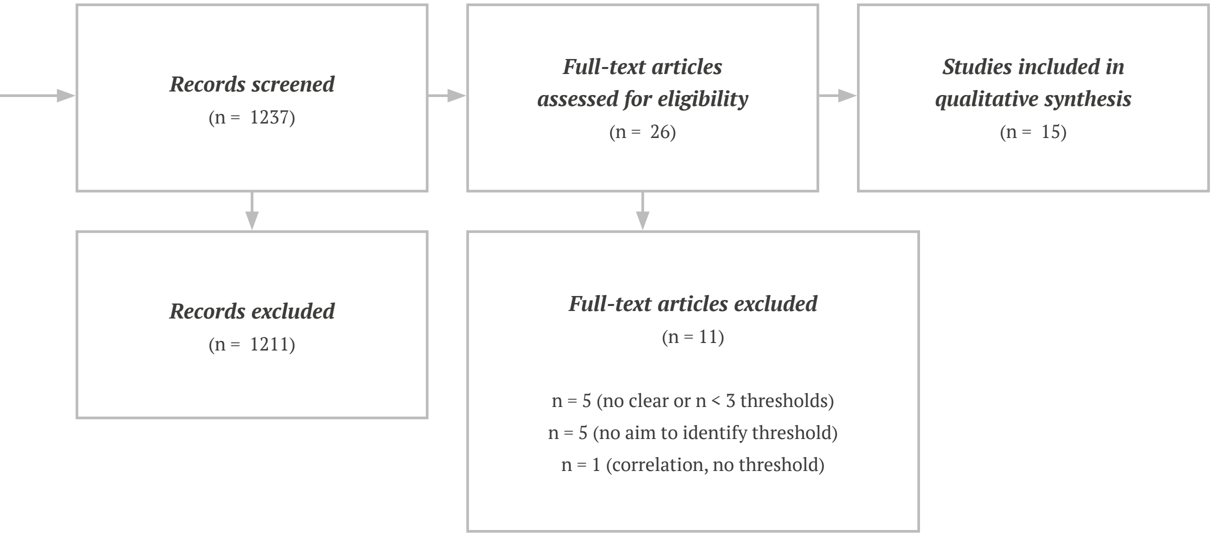



**FIGURE 1:** Flow diagram of the selection process, following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2009 guidelines.


Records screened
(n = 1237)
Full-text articles assessed for eligibility
(n = 26)
Studies included in qualitative synthesis
(n = 15)
Records excluded
(n = 1211)
Full-text articles excluded
(n = 11)
n = 5 (no clear or n < 3 thresholds)
n = 5 (no aim to identify threshold)
n = 1 (correlation, no threshold)

| Authors, year | Study design | Cases | | | | Controls | |
|---|---|---|---|---|---|---|---|
| | | *No. of cases (hips)* | *Mean age (measure of variation)* | *Sex (%, M/F)* | *(A)symptomatic* | *No. of controls (hips)* | *Mean age (measure of variation)* |
| **Barrientos[20], 2006** | case-control | 38 (38) | 36.1 ± 11.8 (SD) | 55/45 | symptomatic | 101 (202) | 36.8 ±14.4 (SD) |
| **Espié[43], 2014** | case-control | 75 (96) | 38 (95% C.I. 36-40) | 77/23 | both | 50 (100) | 36.2 (95% C.I. 34-38.4) |
| **Mascarenhas[106], 2018** | case-control | 176 (176) | 35.6 ± 9 (SD) | 50/50 | symptomatic | 372 (372) | 33.9 ± 8 (SD) |
| **Sutter[168], 2012** | case-control | 53 (NFS) | 35.6 (range, 20-50) | 62/38 | symptomatic | 53 (NFS) | 34.5 (range, 23-50) |

**Abbreviations**: AI, anteroinferior; AP, anteroposterior; AS, anterosuperior; C.I., confidence interval; CT, computed tomography; F, female; M, male; N/A, not available; NFS, not further specified; PS, posterosuperior; ROC, receiver operation characteristic; SD, standard deviation; THR, total hip replacement.

**TABLE 1**: Case-control studies

| | | Imaging modality used? | | Symptoms, intra-articular pathology, OA, THR? | Methodology of determining threshold | Suggested threshold value | Con-founders |
|---|---|---|---|---|---|---|---|
| *Sex (%, M/F)* | *(A)symptomatic* | *Type* | *Plane* | | | | |
| 41/59 | asymptomatic | CT | oblique axial, antero-lateral 1:30 o'clock | cases: symptomatic FAI, undergoing hip arthroscopy controls: asymptomatic | ROC | 57° | no differences in sex or age |
| 54/46 | asymptomatic | Radio-graph | frog-leg lateral | cases: (a) symptomatic FAI controls: asymptomatic | 95% reference interval | male: 63° female: 58° (total: 60°) | no significant difference in age and height |
| 50/50 | asymptomatic | MRI | 360° clockwise, radial (NFS) | cases: symptomatic FAI undergoing hip surgery controls: asymptomatic | ROC | 58° - 60° | weight, age, sex matched |
| 58/42 | asymptomatic | MRI | transverse-oblique: AI, anterior, AS, superior, PS | cases: symptomatic FAI with cam morphology. controls: asymptomatic. | ROC | 60° | age and sex matched |

| Authors, year | Study design | Cohort characteristics | | | | Imaging modality used? |
|---|---|---|---|---|---|---|
| | | *No. of cases (hips)* | *Mean age (measure of variation)* | *Sex (%, M/F)* | *(A) symptomatic* | *Type* |
| **Agricola[8], 2014** | prospective cohort | 1457 (2879) | CHECK: mean 55.9 (range, 45-65) Chingford: mean 54.2 (range, 44-67) | CHECK: 20/80 Chingford: 0/100 | both | radiograph |
| **Bouma[26], 2014** | cross-sectional cohort | 83 (155) | N/A | NFS | asymptomatic | radiograph |
| **Fischer[46], 2018** | cross-sectional cohort | 3226 (NFS) | 53 ± 14 (SD) (range, 21-90) | 49/51 | NFS | MRI (whole body) |
| **Fraitzl[48], 2013** | retrospective cohort | 339 (339) | male: 47 ± 17 (SD), female: 55 ±19 (SD) | 50/50 | NFS | radiograph |
| **Golfam[57], 2017** | cross-sectional cohort | 197 (394) | 29.4 (range, 21.4-50.6) | 44/56 | asymptomatic | MRI |
| **Gosvig[58], 2007** | cross-sectional cohort | 2803 (NFS) | NFS | 38/62 | NFS | radiograph |
| **Laborie[92], 2014** | cross-sectional cohort | 2005 (FLL: 3996, AP: 4004) | 18.6 (95% C.I. 17.2-20.1) | 42/58 | NFS | radiograph |
| **Lepage-Saucier[96], 2014** | cross-sectional cohort | 94 (188) | 49 ± 16.6 (SD) | 52/48 | asymptomatic | CT |
| **Liu[101], 2017** | experimental finite element study | 1 (1) multiple modeled hips | 35 | 0/100 | NFS | CT |
| **Masca-renhas[107], 2018** | cross-sectional cohort | 590 (1111) | 33 ± 8 (SD) | 46/54 | asymptomatic | CT |
| **Pollard[142], 2010** | cross-sectional cohort | 83 (166) | 46 (range, 22-69) | 47/53 | asymptomatic | radiograph |

**Abbreviations**: AP, anteroposterior; BMI, body mass index; CHECK, Cohort Hip & Cohort Knee; C.I., confidence interval; CT, computed tomography; F, female; FE, finite element; FLL, frog-leg lateral; M, male; MRI, magnetic resonance imaging; N/A, not available; NFS, not further specified; OA, osteoarthritis; ROC, receiver operation characteristic; SD, standard deviation; THR, total hip replacement.

| Plane | Symptoms, intra-articular pathology, OA, THR? | Methodology of determining threshold value | Suggested threshold value | Confounders |
|---|---|---|---|---|
| AP / coronal | pathological cam: end-stage OA within 5 to 19 years (n = 105) versus no end-stage OA (n = 2774) | Cam morphology: based on bimodal alpha angle distribution, pathological cam morphology: ROC | cam: 60°<br>pathological cam: 78° | separate male and female, uni/bilateral, no correction for age |
| cross-table lateral | | 95% reference interval | 66° (anatomical method)<br>58° (3-point method) | no significant difference in alpha angle in male/female |
| AP / coronal | | 95% reference interval | 71° | significant association between age, weight, waist, BMI, height, and alpha angle |
| AP / coronal and FLL | | 95% reference interval | male (AP/FLL): 70°/70°<br>female (AP/FLL): 61°/66° | no correlation between age and alpha angle |
| oblique<br>axial, radial, 1:30-o'clock | | 95% reference interval | axial: 63°<br>radial: 66° | insignificant relation age and alpha angle, significant relation sex and alpha angle |
| AP / coronal | | cam morphology: mean ± 1SD pathological cam morphology: mean ± 2SD | male: 69° (borderline), 83° (pathological), female: 51° (borderline), 57° (pathological) | specified for sex |
| AP / coronal (weight bearing) and FLL | | $97.5^{th}$ percentile | male (AP/FLL): 93°/68°<br>female (AP/FLL): 94°/56° | specified for sex and side |
| Oblique axial (90°) and double-oblique (45°) | | 95% reference interval | male (45°/90°): 93°/68°<br>female (45°/90°): 84°/69° | specified for sex and side |
| AP / coronal | peak acetabulum pressure:<br>60° = 6.295, 70° = 7.291, 80° = 10.620, 90° = 11.460 | peak pressure forces between various threshold values and motions | 80° | N/A |
| pelvis:<br>9 positions around head-neck | | 95% reference interval | 65°-70° for 12.00/3.00-o'clock<br>60° for 1 to 1.30-o'clock | age, side, limb dominance, and sex |
| cross-table lateral | | 95% reference interval | 62° | no significant difference between sex |

**TABLE 2:** Cohort studies (and 1 finite element study)

## Population characteristics

The sample size of the studies ranged from 1[101] to 3226[46] (median, 197), with the number of hips ranging between 1[101] and 4004[92] (median, 339). The mean age of all study populations ranged from 18.6[92] to 55.9[8] years (median, 38). In 4 studies[20,43,96,168], more male than female participants were included; in 8 studies[8,46,57,58,92,101,107,142], more women than men were included; in 1 study[26], participant sex was not specified; and in 2 studies[48,106], the sex distribution was equal. Of the 4 case-control studies[20,43,106,168], 3 studies[20,106,168] included patients with FAIS, while 1 study[43] defined patients with hip pain as cases without specifying whether they fulfilled the FAIS criteria. All control participants were asymptomatic. In the 10 cohort studies, 5 studies[26,57,96,107,142] specifically described their population as asymptomatic, 1 study[8] had both symptomatic and asymptomatic participants, and the remaining 4 studies[46,48,58,92] did not further specify this. The finite element study[101] also did not specify this.

## Risk of bias within studies

After inclusion, the interrater reliability for NOS scores suggested a moderate agreement (K = 0.69). According to the results of the NOS tool and the predefined criteria, 9 studies (3 case-control[43,106,168] and 6 cohort[8,46,58,92,96,107]) scored 5 points or higher *(Table 3)*.

| **Authors, year** | **Study design** | **NOS score** | | |
|---|---|---|---|---|
| | | *Selection* | *Comparability* | *Outcome* |
| **Agricola[8], 2014** | prospective cohort | ★★★ | ★ | ★★★ |
| **Barrientos[20], 2006** | case-control | ★★★ | | ★ |
| **Bouma[26], 2014** | cross-sectional cohort | ★★ | | ★ |
| **Espié[43], 2014** | case-control | ★★★★ | ★★ | ★ |
| **Fischer[46], 2018** | cross-sectional cohort | ★★★ | ★★ | ★ |
| **Fraitzl[48], 2013** | retrospective cohort | ★★ | | ★ |
| **Golfam[57], 2017** | cross-sectional cohort | ★★★ | | ★ |
| **Gosvig[58], 2007** | cross-sectional cohort | ★★★ | ★ | ★ |
| **Laborie[92], 2014** | cross-sectional cohort | ★★★ | ★★ | ★ |
| **Lepage-Saucier[96], 2014** | cross-sectional cohort | ★★ | ★★ | ★ |
| **Liu[101], 2017** | expirimental finite element study | ★ | | ★ |
| **Mascarenhas[106], 2018** | case-control | ★★★ | ★★ | ★★★ |
| **Mascarenhas[107], 2018** | cross-sectional cohort | ★★★ | ★★ | ★ |
| **Pollard[142], 2010** | cross-sectional cohort | ★★★ | | ★ |
| **Sutter[168], 2012** | case-control | ★★★ | ★★ | ★★ |

**Abbreviation:** NOS: Newcastle-Ottawa Scale.
The Newcastle-Ottawa Scale (NOS) score is a total score of three different domains, 'selection' (max. 4 stars), 'comparability' (max. 2 stars) and 'outcome' (max. 3 stars), with a maximum score of 9. Both cohort and case-control studies are presented. A blank cell indicates the lowest score (0 stars).

**TABLE 3**: The Newcastle-Ottawa Scale scores per study

## Results of individual studies

### *Imaging modality*

Various imaging modalities were utilised in the 15 studies, including radiographs[8,26,43,48,58,92,142], CT[20,96,101,107], and MRI[46,57,106,168]. Radiographic views included the AP[8,48,58,92], cross-table lateral[26,142], and frog-leg lateral[43,48,92]. CTs were performed in several planes, such as an oblique axial plane[20,96], of which 1 was reconstructed[20], double-oblique plane[96], coronal plane[101], and alpha angle measured at 9 different positions around the femoral head-neck junction.[107] The MRIs were performed in an oblique axial plane and radial view (1 study[57]), a coronal plane (1 study[46]), and a transverse-oblique plane parallel to the femoral neck axis (1 study[168]); and 1 study[106] did not specify the plane.

### *Symptoms, intra-articular pathology, OA, and THR*

Six studies[8,20,43,101,106,168] reported symptoms, intra-articular pathology, hip OA, and/or THR. One study[8] showed that an alpha angle of 78° gave the maximum area under the ROC curve, which was 0.69 (95% CI 0.62-0.75), for end-stage OA. A second study[101] investigated the alpha angle in relation to peak pressure in the acetabulum and showed that if the alpha angle increased, the peak pressure increased as well. All 4 case-control studies, of which three used the ROC[20,106,168], reported their diagnostic alpha angle threshold for their patients with FAIS as compared with their asymptomatic controls.

### *Method of determining alpha angle threshold*

Several methods of determining the alpha angle threshold were used in the studies. In 8[26,43,46,48,57,96,107,142] of the 15 studies, the 95% reference interval was used. This was measured as the mean ± 1.96 SD, and the upper limit was chosen as the threshold. In 1 study[92], the 97.5$^{th}$ percentile was used, and in 1 study[58] the mean ± 1SD for cam morphology and the mean ± 2SD for pathological cam were used. In 4 studies[8,20,106,168], ROC curve analysis was used to assess the alpha angle threshold, which best distinguished the presence and absence of FAIS[20,106,168] or end-stage OA[8]. One study[8] based their cam morphology threshold on the bimodal distribution of the alpha angle. The finite element study[101] measured peak contact pressure on the acetabular cartilage between various thresholds and motions.

### *Alpha angle threshold*

*Measurement methods*. Four studies[8,20,106,168] reported an alpha angle threshold for cam morphology by ROC curve analysis or by using the bimodal distribution. Three of these studies[20,106,168] studied FAIS versus asymptomatic participants and suggested that alpha angle thresholds ranged between 57° and 60°. The 8 studies[26,43,46,48,57,96,107,142] that reported alpha angle threshold values by using the 95% reference interval reported a range from 58° to 93°. In the 3 remaining studies, the study[58] reporting the mean ±

1SD for cam morphology determined a suggested alpha angle threshold of 51° and 69° for female and male patients, respectively, and the study[92] reporting the 97.5*th* percentile determined a suggested threshold for frog-leg lateral and AP views between 56° and 94° for female patients and 68° and 93° for male patients. The finite element study[101] suggested a threshold of 80° *(Figure 2)*.

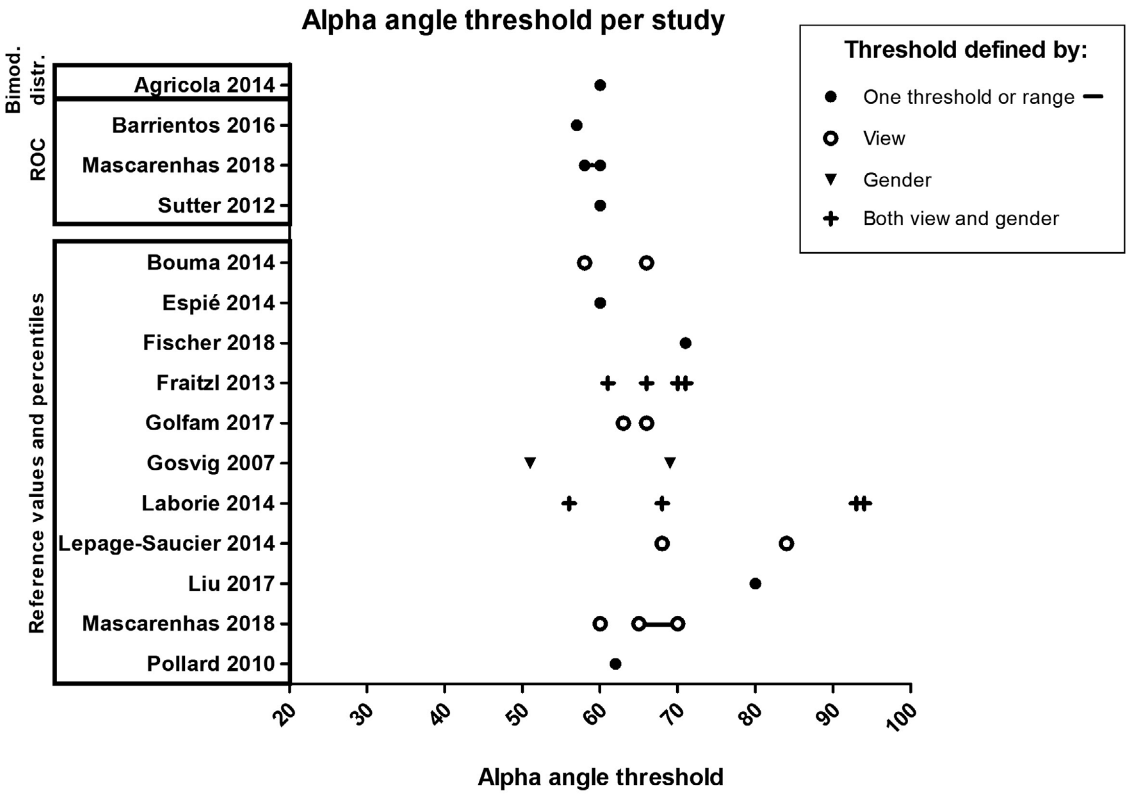



**FIGURE 2**: The alpha angle thresholds summarised across all included studies

*Sex-based differences*. Six studies[43,46,48,58,92,96], all using the 95% reference interval, mean ± 1SD or 2SD, or the 97.5*th* percentile, suggested different thresholds for male and female patients, with alpha angle thresholds ranging from 63 to 93° in men and 58° to 94° in women.

# Discussion

We found 15 studies aimed at determining an alpha angle threshold to distinguish between hips with and without cam morphology. Most studies proposed an alpha angle threshold based on the upper limit of the 95% reference interval, and 3 studies[20,106,168] were based on the ROC curve analyses as 1 study[8] was based on a bimodal distribution. Although a definite threshold value remains subjective, we suggest to report a threshold value of ⩾60° to classify cam morphology based on the currently available literature.

Most studies (12 of 15) used the upper limit of the 95% reference interval or comparable methods such as the +1SD, +2SD or 97.5$^{th}$ percentile as the cutoff value to define the presence of cam morphology. While reference values in an asymptomatic population might give an indication, it might for several reasons not be the optimal approach for quantifying cam morphology. The assumption that only the upper 2.5% of an asymptomatic population has cam morphology is probably incorrect, given the high prevalence of this abnormality in the asymptomatic population.[108] Cam morphology might be more prevalent in male than in female patients, resulting in higher mean alpha angles in men than in women when a given population is being studied.[81,83,98,142] Higher prevalence of mixed-type morphology is also observed in male compared with female patients.[28,127] However, this does not imply that the alpha angle threshold should automatically be lower in female than in male patients, something that was proposed by 3 studies[48,58,92] included in this systematic review. This is one of the reasons for the wide range of proposed alpha angle threshold values - between 51° and 94° - in studies using this methodology.

One study[8] used the distribution of the alpha angle to propose a threshold value. This study combined data of 2 large cohorts that both independently showed a bimodal distribution of the alpha angle. Combining these alpha angle data resulted in a non-sex specific threshold of 60° to discriminate between hips with and without cam morphology. Interestingly, a bimodal distribution naturally shows a distinction between normal and abnormal alpha angles and is therefore optimal to determine cutoff values. Three studies[20,106,168] used ROC curve analysis to distinguish asymptomatic people from patients with FAIS, which is clinically a much more relevant method, as cam morphology can be highly prevalent in asymptomatic people. These studies showed consistent threshold values ranging between 57° and 60°. Utilising a consistent alpha angle threshold and imaging modality to classify cam morphology is important to study aetiology, compare prevalence numbers, and study associations with concurrent pathology. Based on the above-mentioned current literature arguments, we feel that an alpha angle threshold of ⩾60° to quantify cam morphology would currently be the most appropriate value. This threshold was also found to be most appropriate by a recent scoping review.[105] However, we also acknowledge that it remains subjective as to where to draw the threshold line. There might also be reasons for not dichotomising the alpha angle and studying it as a continuous variable, for example in prognostic studies. Further research is required to determine this.

It is important to note that the ⩾60° threshold is proposed as a classification criterion for cam morphology, which is different from a diagnostic criterion. Classification criteria intend to create a relatively homogenous well-defined cohort for clinical research and do not intend to capture the more heterogeneous population of FAIS patients.[1] In order to use cam morphology for the clinical diagnosis of FAIS, more anatomic variables should be considered, such as the femoral torsion, neck-shaft angle, and acetabular morphology, as well as clinical findings and patient symptoms. We therefore do not suggest using this threshold value in isolation for clinical decision making. It should be kept in mind that, although studies[20,106,168] using ROC curve analysis generally showed that a 60° threshold could best distinguish patients with FAIS from asymptomatic people, there was still an overlap of these groups around the 60° threshold.



A wide range of imaging modalities and views were used in the included studies. For the purpose of the current systematic review, we described all outcomes of suggested alpha angle threshold values irrespective of the imaging modality or view used. Owing to study heterogeneity, it was not possible to pool studies based on the imaging modality or view used. Most studies used AP radiographs or 3D imaging reformatted as an AP view/coronal plane. Studies using ROC curve analyses, on which we mostly based our conclusions, also used different planes such as the coronal, oblique axial, clockwise radial (2-o'clock) and transverse-oblique planes. In these studies, a threshold of ⩾60° was suggested utilising these planes as well. Thus, despite heterogeneity in modalities and views, the studies concluded the same thresholds to distinguish between hips with and without cam morphology. Still, radiographs (2D view) are limited by the fact that positional differences can limit reproducibility, and only certain locations of the head-neck junction -depending on the type of view- can be studied, which might result in underestimation of cam morphology. Most included studies that used 3D imaging also reduced the analysis to 2 or 3 planes, thereby also suffering from potential cam morphology underestimation. Only the 2 studies by Mascarenhas et al.[106,107] used radial formatted reconstructions around the femoral head-neck junction and measured the alpha angle on multiple locations around the femoral neck. One of these studies[107], using the 95% reference interval to determine an alpha angle threshold value, suggested a 60° threshold for the 1- to 1:30-o'clock position and 65° and 70° for the 12-o'clock and 3-o'clock positions, respectively. Future studies should evaluate whether the suggested threshold of ⩾60° is applicable for all imaging modalities and/or views before diagnostic criteria can be introduced.

## Limitations

There are limitations related to the included studies, which need to be addressed. First, although some large studies with up to 3226 participants were included, 9 of the 15 studies had less than 200 participants. There were also studies with a high risk of bias. Most studies (11 out of 15) scored high (at least 3 out of 4 points) on the NOS item “selection”, as we considered most participants representative of people that can have cam morphology. However, only 2 studies scored 3 (of 3) points on the item “outcome”. As mentioned before, there was large heterogeneity in multiple factors, such as age, imaging modality and view used, sex, and the methodology used to study threshold values.

# Conclusion

Based on the available literature on alpha angle threshold values, we suggest reporting a non-sex specific threshold of ⩾60° to classify cam morphology.

Chapter 04

## Conflict of interest

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

## Supplementary data

Supplementary data to this article can be found online.

*Chapter 05*

# The development of cam morphology during growth

***'Cam morphology in young male football players mostly develops before proximal femoral growth plate closure: a prospective study with 5-year follow-up.'***

*P. van Klij, M.P. Heijboer, A.Z. Ginai, J.A.N. Verhaar, J.H. Waarsing, R. Agricola*

Br J Sports Med. 2019;53(9):532-538.

# Abstract

**Objectives**: Cam morphology is not completely understood. The aim of this study was threefold: (1) to investigate if cam morphology development is associated with growth plate status; (2) to examine whether cam morphology continues to develop after growth plate closure; and (3) to qualitatively describe cam morphology development over 5-year follow-up.

**Methods**: Academy male football players (n = 49) participated in this prospective 5-year follow-up study (baseline 12–19 years old). Anteroposterior and frog-leg lateral views were obtained at baseline (142 hips), 2.5-year (126 hips) and 5-year follow-up (98 hips). Cam morphology on these time points was defined as: (A) visual scores of the anterior head-neck junction, classified as: (1) normal, (2) flattening, and (3) prominence; and (B) alpha angle ⩾60°. Proximal femoral growth plates were classified as open or closed. Cam morphology development was defined as every increase in visual score and/or increase in alpha angle from <60° to ⩾60°, between two time points. This resulted in 224 measurements for cam morphology development analysis.

**Results**: Cam morphology development was significantly associated with open growth plates based on visual score (OR: 10.03, 95% CI 3.49 to 28.84, P < .001) and alpha angle (OR: 2.85, 95% CI 1.18 to 6.88, P = .020). With both definitions combined, cam developed in 104 of 142 hips during follow-up. Of these 104 hips, cam developed in 86 hips (82.7%) with open growth plate and in 18 hips (17.3%) with a closed growth plate. Cam morphology developed from 12 to 13 years of age until growth plate closure around 18 years.

**Conclusion**: Cam morphology of the hip is more likely to develop with an open growth plate.

# Introduction

Femoroacetabular impingement syndrome is a symptomatic motion-related disorder resulting from a premature contact between the proximal femur and acetabulum.[62] This is often due to pincer and/or cam morphology. Cam morphology is characterised by extra bone formation mostly located in the anterolateral head-neck junction, which can be forced into the acetabulum during hip flexion and internal rotation. In general, cam morphology does not necessarily lead to symptoms, but has a strong relationship with reduced function and future hip osteoarthritis.[3,7,9,56,156,176] The aetiology of cam morphology is not fully understood. It is more prevalent in athletes than in non-athletes,[2,159] with prevalence reported above 60% in high-impact sports such as football,[2,4,54,79,119] basketball[159] and ice hockey.[97,140,160] Finite element analysis revealed that repetitive movements of deep flexion and external rotation in hips with an open growth plate are possible triggers for extra bone formation in the anterolateral head-neck junction.[154] Cam morphology is first visible on radiographs from the age of 12 to 13 years and gradually increases in size during skeletal growth.[2,137,159] During this prepubertal phase, bone is more responsive to loading. This might be due to nutrients, sex steroids, growth hormone peaks, insulin-like growth factors and genetic factors.[113] Bone is likely to change to meet the demands of mechanical loading during childhood.[174] Interestingly, cam morphology typically develops at the location where the growth plate extends into the femoral neck.[4] Data from the 2.5-year follow-up of the current cohort suggested that cam morphology might only develop when the growth plate is open, but only a small number of hips had closed growth plates at 2.5-year follow-up.[4] If this observation proves correct, interventions to prevent cam morphology development are probably only useful during skeletal growth. To the best of our knowledge, no other prospective follow-up data are available on this topic. This study aimed to assess the association between growth plate status and future cam morphology development during a minimum of 5 years' follow-up, to investigate if cam morphology continues to develop after proximal femoral growth plate closure, and to qualitatively describe cam morphology development in this 5-year time period.

# Materials and methods

## Participants

All 89 academy male football players of Feyenoord Rotterdam (the Netherlands) who attended at baseline were invited to participate again and 49 of 89 (55.1%) joined this 5-year follow-up study. The football players were aged between 12 and 19 years at baseline. Recruitment for 5-year follow-up took place between June and October 2015. Inclusion criteria for the initial inclusion were playing in selection teams of Feyenoord Rotterdam (the Netherlands). Exclusion criteria were any hip disorder.[2,4] Each participant gave written consent. For individuals younger than 18 years, written consent was also obtained from at least one parent.

## Radiographs

The standardised radiographic protocol used for this 5-year follow-up was the same as at baseline and 2.5-year follow-up.[2,4] In short, three radiographs of the hip were obtained: a standardised anteroposterior (AP) view of the pelvis and a frog-leg lateral view of each hip. Using these projections we were able to examine the lateral (on AP view) and anterosuperior (on frog-leg lateral view) femoral head-neck junction to detect cam morphology. For the AP view, 15° internal rotation was ensured by positioning the participant supine with his feet in a special frame. For the frog-leg lateral view, the participant was placed in the supine position with the hip in flexion and abduction, using a 45° wedge under the knee to secure standardised position.

## Visual scores

The anterolateral head-neck junction in all radiographs was semiquantitatively scored (ordinal variable) as: (1) normal, (2) flattening or (3) prominence.

1. Normal: slight symmetric concavities of the anterior head neck junction with respect to the posterior head-neck junction.
2. Flattening: moderate decrease in the anterior head-neck offset with respect to the posterior head-neck junction.
3. Prominence: convexity in the anterior head-neck junction, as opposed to a concavity.

Cam morphology was defined as the presence of either a flattening or prominence of the proximal femur. An experienced orthopaedic surgeon and musculoskeletal radiologist determined the visual scores of all hips, based on consensus. Each hip was scored with the available radiographs of all three time points in one session. The visual scores showed a kappa of 0.68 for intraobserver reliability in the baseline study.[2]

## Alpha angle

The proximal femoral shape was outlined by a set of points that were manually positioned on anatomical landmarks using Statistical Shape Modelling software (ASM toolkit, Manchester University, Manchester, UK). Images of left-sided joints were mirrored to appear as right-sided joints. Using MATLAB V.7.1.0 (MathWorks, Natick, Massachusetts, USA), the alpha angle was automatically calculated in all radiographs from a set of points that were manually positioned on predefined anatomical landmarks of the proximal femur.[2,4] An alpha angle ⩾60° was defined as cam morphology.[8] The highest alpha angle value on the AP or frog-leg lateral views of each hip was used for analysis. When a hip had an alpha angle ⩾60° at a certain point, we defined this hip as having cam morphology at the subsequent follow-up time point as well. For alpha angle, the intraclass correlation coefficient (ICC) for interobserver reliability was 0.73. Intraobserver reliability ICC ranged from 0.85 to 0.99.[3] The measurement error is calculated by the root mean square error (RMSE). This resulted in an RMSE between 1.68 and 1.99.[3]

## Growth plate status

The growth plate status (open or closed) was scored at the same time, based on consensus. The growth plate was scored as closed, if the full growth plate was totally fused and visible as a sclerotic line. If only a small part of the growth plate remained open in any radiographic view, that growth plate was scored as open. Growth plate status was scored in 126 radiographs during 2.5-year follow-up, and those radiographs were scored again during 5-year follow-up, resulting in a kappa of 0.94 for intraobserver reliability.

## Definition of cam morphology development

Every increase in visual scores (dichotomous scale) and/or increase of alpha angle from <60° to ⩾60° (dichotomous scale) was defined as cam morphology development. As presented in *Figure 1*, we assessed the development of cam morphology by pairwise comparison between baseline and 2.5-year follow-up (63 participants, 126 hips), between baseline and 5-year follow-up, if participants did not attend the 2.5-year follow-up (8 participants, 16 hips), and between 2.5-year follow-up and 5-year follow-up (41 participants, 82 hips). This resulted in a total of 224 different pairwise comparisons.

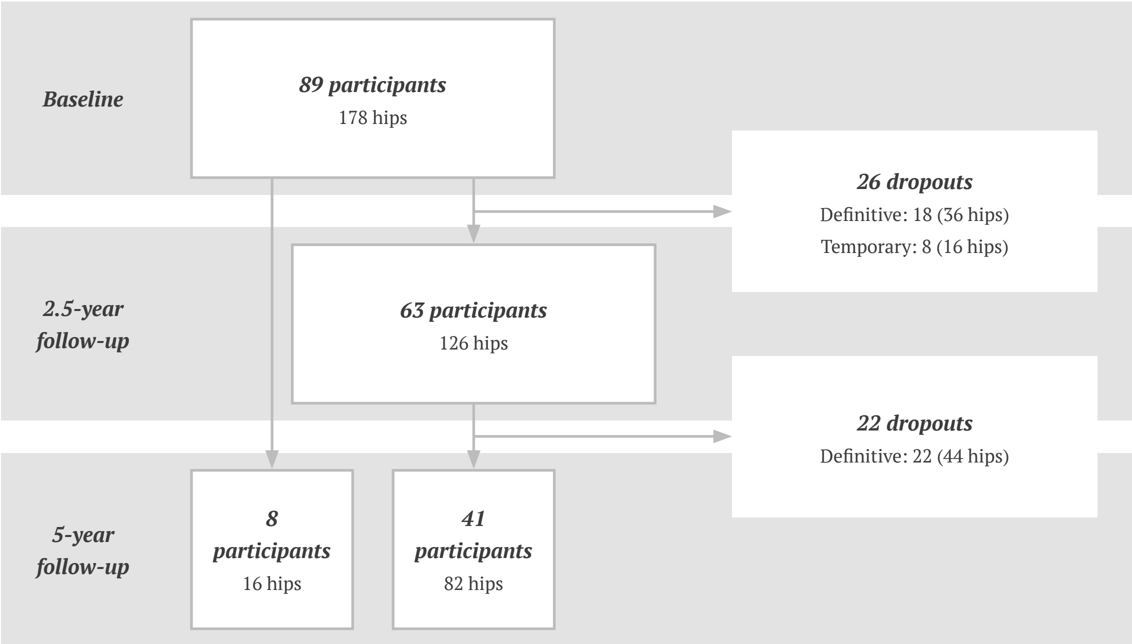



**FIGURE 1**: Flowchart of all analysed participants at baseline, 2.5-year follow-up and 5-year follow-up. Note: Temporary dropouts are dropouts which did not attend at 2.5-year follow-up. Definitive dropouts are dropouts who were not included in the next time point. Cam morphology development was measured between baseline and 2.5 years' follow-up (n = 126), between 2.5-year follow-up and 5-year follow-up (n = 82), and between baseline and 5-year follow-up in case participants who did participate at 5-year follow-up but not at 2.5-year follow-up (n = 16). This resulted in 224 measurements of cam morphology development.

## Statistical analysis

Differences in baseline characteristics between included participants and dropouts were tested using an independent samples t-test. Cam morphology prevalence was described per hip. Development of cam morphology is analysed blinded on hips of participants who attended at least two time points. This resulted in radiographs of 142 hips at baseline, 126 hips at 2.5-year follow-up, and 82 and 16 hips at 5-year follow-up *(Figure 1)*. Cam morphology development was analysed twice (for visual score and alpha angle) in 224 radiographs, which included repeated measurements. Growth plate status is presented in 71 persons (142 hips). The association between growth plate status and cam morphology development was calculated by means of logistic regression. By using logistic regression in a 'Generalised Estimated Equations' model, we were able to take into account the correlation that exists within a person regarding follow-up time and side. A sensitivity analysis was performed to see if defining hips with alpha angle <60° as cam morphology, when a previous time point had alpha angle ⩾60°, affected the results *(online supplementary Table 1)*. The statistical evaluation was performed using SPSS V.21.0 (Windows).

# Results

## Patient characteristics

Demographic data are presented in *Table 1*. The mean follow-up time was 5.3 ± 0.1 years (range 5.0–5.6 years). In total, 224 radiographs were analysed in 71 different football players with multiple time points *(Figure 1)*. Of 89 participants at baseline, 40 did not participate at 5-year follow-up (44.9%). Of these 40 participants, 24 rejected the invitation, 4 were playing football abroad, 11 were unreachable and 1 did not show up. At 5-year follow-up, all 49 participants were still playing football. Of those 49 participants, 28 (57.1%) were still active in the first or second team or youth academy of a professional football club. The remaining 21 players (42.9%) were active at an amateur football level. There were no significant differences in baseline demographic data between the 49 participants who attended the 5-year follow-up and the dropouts *(Table 2)*.

**Demographic data of baseline, 2.5-year follow-up and 5-year follow-up (n = participants)**

| | **Baseline (n = 89)** | **2.5-year follow-up (n = 63)** | **5-year follow-up (n = 49)** |
|---|---|---|---|
| **Age (years)** | 15.22 ± 1.97 | 17.25 ± 1.99 | 20.53 ± 2.17 |
| **Weight (kg)** | 59.37 ± 13.82† | 68.36 ± 11.11‡ | 73.77 ± 7.87 |
| **Height (cm)** | 170.28 ± 12.15† | 177.44 ± 7.96‡ | 180.33 ± 6.63 |
| **Body mass index (kg/m$^2$)** | 20.13 ± 2.25† | 21.58 ± 2.21‡ | 22.65 ± 1.59 |
| **Football experience (years)** | 8.97 ± 2.54† | 11.10 ± 2.49‡ | 14.29 ± 2.58 |
| **Training intensity (hour/week)** | 7.96 ± 1.77† | 8.68 ± 1.91§ | 9.30 ± 2.92 |

Values are expressed as mean ± standard deviation.
† Due to missing data, data of n = 87 are presented. ‡ Due to missing data, data of n = 58 are presented. § Due to missing data, data of n = 57 are presented.

**TABLE 1**: Demographic data during follow-up

| Demographic baseline data with 5-year follow-up participants compared with dropouts (n = participants) | | | |
|---|---|---|---|
| | **Baseline (n = 49)**<br>**5-year follow-up participants** | **Baseline (n = 40)**<br>**5-year follow-up dropouts** | **P-values** |
| **Age (years)** | 15.20 ± 2.13 | 15.25 ± 1.77 | .875 |
| **Weight (kg)** | 58.54 ± 14.71 | 60.43 ± 12.60† | .372 |
| **Height (cm)** | 169.35 ± 13.16 | 171.47 ± 10.67† | .253 |
| **Body mass index (kg/m$^2$)** | 20.01 ± 2.32 | 20.29 ± 2.17† | .416 |
| **Football experience (years)** | 8.84 ± 2.65 | 9.13 ± 2.40† | .449 |
| **Training intensity (hour/week)** | 7.87 ± 1.57 | 8.08 ± 2.00† | .446 |

Values are expressed as mean ± standard deviation.
† Due to missing data, data of n = 38 are presented.

**TABLE 2**: Demographic baseline data of 5-year follow-up participants compared with dropouts

## Cam morphology prevalence

Cam morphology based on visual scores was found in 77 of 142 hips (54.2%, 35 left and 42 right) at baseline, in 99 of 126 hips (78.6%, 47 left and 52 right) at 2.5-year follow-up and in 80 of 98 hips (81.6%, 39 left and 41 right) at 5-year follow-up. Cam morphology based on alpha angle was found in 70 of 142 hips (49.3%, 31 left and 39 right) at baseline, in 86 of 126 hips (68.3%, 42 left and 44 right) at 2.5-year follow-up and in 78 of 98 hips (79.6%, 37 left and 41 right) at 5-year follow-up. The highest visual scores and alpha angles were mostly (ranging from 90.1% to 94.5% during follow-up) found on frog-leg lateral views compared with AP views during follow-up.

## Growth plate status

In total, 42 of 142 (29.6%) growth plates were closed at baseline, 72 of 126 (57.1%) at 2.5-year follow-up and 92 of 98 (93.9%) at 5-year follow-up.

## Association between cam morphology development and growth plate status

Cam morphology development based on visual scores was observed in 80 of 142 (56.3%) hips. Of these 80 hips, 14 had development from normal to flattening and from flattening to prominence during follow-up. Of these 80 hips, 71 had an open and nine had a closed growth plate. This resulted in a strong association between cam morphology development based on visual scores and open growth plate status (OR: 10.03, 95%CI 3.49-28.84, P < .001), as portrayed in *Figure 2*. Cam morphology development based on alpha angle was observed in 43 of 142 (30.3%) hips. Of these 43 hips, 34 had an open and nine had a closed growth plate. This resulted in a significant association between cam morphology development based on alpha angle and open growth plate status (OR: 2.85, 95%CI 1.18-6.88, P = .020). Of the hips with a closed growth plate that developed cam morphology, seven were only classified by the visual score, eight only by the alpha angle and one was classified as development of cam morphology after growth plate closure by both the visual score and the alpha angle. This resulted in 16 hips (11.3%, in 10 persons) with a closed growth plate that developed cam morphology by either the visual score and/or the alpha angle.

## Qualitative description of cam morphology

Some anatomical changes not captured in quantifiable measures were observed during follow-up. In this study, a normal spherical anterolateral head-neck junction of the hip joint based on visual scoring was found in almost all (83.3%) 12-year-old boys. From around the age of 12 to 13 years, the first appearances of cam morphology became visible. Development of cam morphology can be observed via a change in the anterolateral head-neck junction, resulting in extra bone formation in that region. This extra bone formation gradually increased during growth until the age of around 18 years. Cam morphology development is demonstrated in several hips in *Figure 2*. Together with cam morphology development, the lateral side of the growth plate was positioned more distally, appearing like an extension of the growth plate bending towards the greater trochanter. The site of this extension also corresponds with the location of bone where the cam morphology forms. In hips which did not develop cam morphology, the head-neck junction does not undergo major changes. In most cases (82.7%) cam morphology developed in hips with an open growth plate and also when a small part of the growth plate remained open. Conversely, cam morphology development was also observed in 16 different hips with a closed growth plate. Of these 16 hips, 14 had signs of external hip rotation per time point on the radiographic projection during follow-up. These differences in hip rotation could be observed via the differences in projection of the greater trochanter over the neck and the appearance of the lesser trochanter *(Figure 3)*. During follow-up, two hips (in one person), with a closed growth plate status, showed cam morphology development without signs of rotation differences *(Figure 4)*. These two hips followed the outlined pattern of cam morphology development, more similar to cam morphology development when the growth plate is open.


**FIGURE 2:** Cam morphology development based on visual scores during follow-up in five different hips of five persons on frog-leg lateral radiographs. Note: In all presented hips, cam morphology development based on visual score from baseline to 2.5-year follow-up, and from 2.5-year follow-up to 5-year follow-up, is observed.

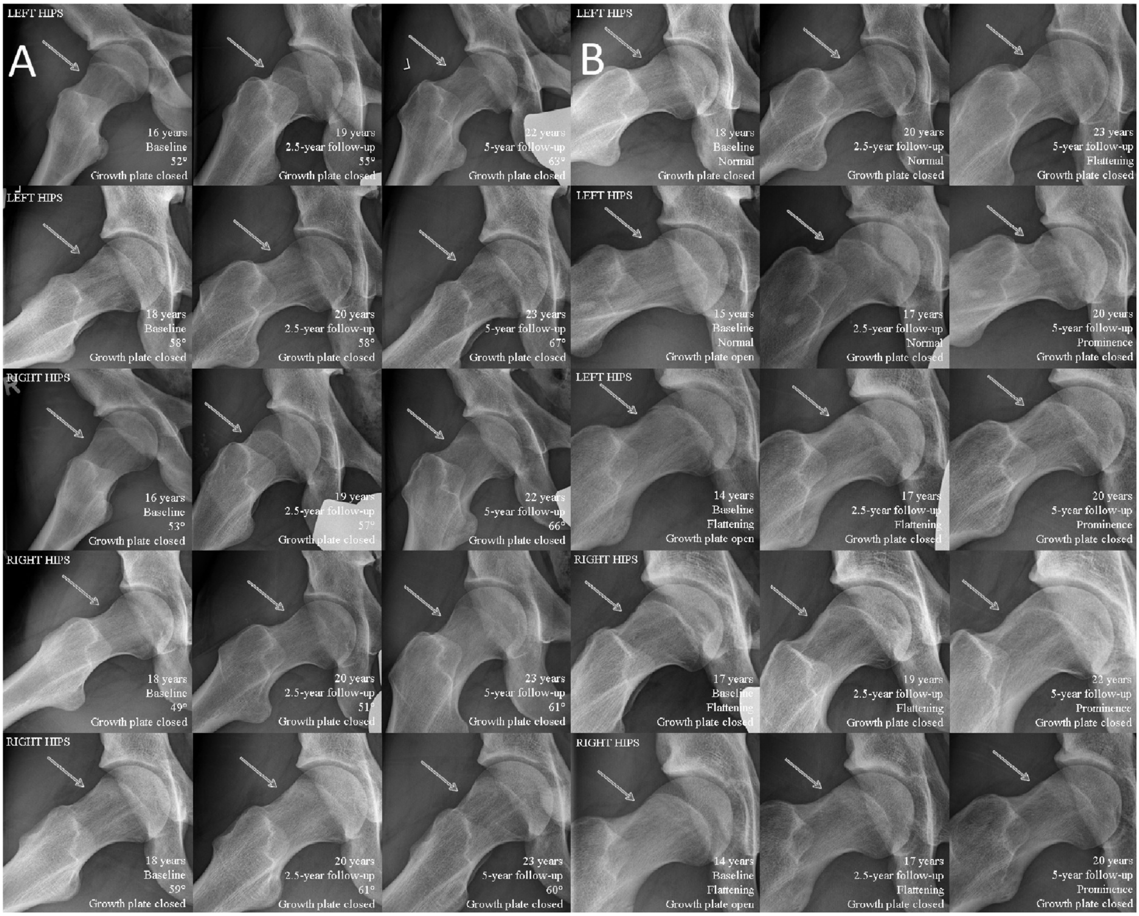



**FIGURE 3**: Cam morphology development (based on alpha angle (A) and visual score (B)) possibly caused by hip rotation (visible via greater trochanter projection) on frog-leg lateral radiographs. (A) Besides differences in rotation, the alpha angle increased with ≤10° from 2.5-year follow-up to 5-year follow-up in these hips. (B) Very subtle change in visual score was observed at 5-year follow-up while the femoral head-neck junction was normal or flattened at baseline and 2.5-year follow-up. This change in visual score is possibly due to the slight difference in rotation during the follow-up times.

# Discussion

Cam morphology development was strongly associated with growth plate status in this study, which represents the 5-year follow-up data of a cohort with football players. Gradual formation of additional bone at the femoral head-neck junction that ultimately forms cam morphology is mainly observed in participants with an open proximal femoral growth plate. After the growth plate closed, we observed no or little cam morphology development. Due to the prospective design of this study we were able to investigate cam morphology development throughout adolescence and young adulthood, with a sufficient follow-up of hips with closed growth plates.

## Aetiology and prevention

The aetiology of cam morphology development is not fully understood. Our results show that cam morphology develops almost exclusively during growth. Cam morphology development is first observed from an age of 12 to 13 years and the prevalence substantially increased during growth. A recent study by Palmer et al.[137] investigated cam morphology development in 103 professional male football players and 107 age-matched controls (52 male and 55 female). Corresponding with our results, they found that cam morphology first developed between 12 and 14 years of age. The likely explanation for cam morphology development around this age could be that the skeleton is highly responsive to mechanical loading during this period of growth.[113,174] Formation of cam morphology is probably triggered by high-impact sports, providing the potential for the implementation of preventative strategies. A dose–response relationship on training frequency in football players is described previously.[137,173] A training schedule with lower impact sports could therefore be a theoretical option to prevent development of cam morphology. A personalised schedule adapted to an individual's safe activity threshold, training frequency and intensity can be implemented. However, to date, the influence of low-impact sporting activities on cam morphology development is not exactly known and advice regarding preventive strategies for cam morphology remains premature.

## Cam morphology development after growth plate closure

Cam morphology development after growth plate closure was found in eight hips based on visual score and nine hips based on alpha angle. From six of eight hips scored by visual score and seven of nine hips scored by alpha angle, it was uncertain if cam morphology truly developed or whether it was quantified as such due to a slight different position of the radiographic view, despite the strict radiographic protocol *(Figure 3)*. Another explanation for cam morphology development after growth plate closure might be the use of radiographs instead of MRI. If the growth plate appears closed on a radiograph, it is unsure whether the growth plate is really closed or if there might still be growth potential. In only two hips of one person, development of cam morphology after growth plate closure was observed with certainty. These hips had nearly identical positions on the radiographs at all time points *(Figure 4)*. These cam morphologies appear more sclerotic and this might possibly be a result of a bony response due to impingement, the shape of head-neck junction or acetabular shape, rather than an adaptive response to loading. This could possibly be explained by the fact that repetitive stimulation of cortical bone due to the impingement may be a stimulus for bone formation.

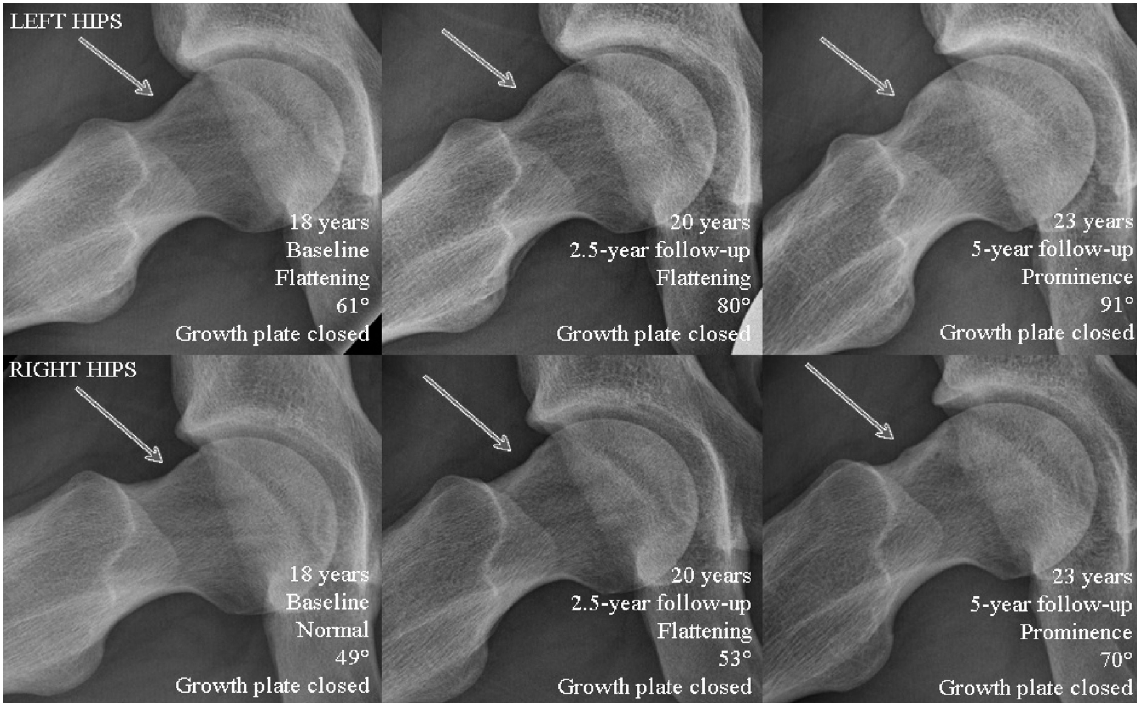



**FIGURE 4**: Cam morphology development based on alpha angle and visual score on frog-leg lateral radiographs of one person during follow-up. All presented hips have closed growth plates. Note: From baseline (normal) to 2.5-year follow-up (flattening) and from 2.5-year follow-up to 5-year follow-up (prominence), cam morphology development is observed. Cam morphology development based on alpha angle is noticed in the right hip from 2.5-year follow-up (53°) to 5-year follow-up (70°).

## Limitations

Some limitations of this study need acknowledgement. A high dropout rate of 44.9% is observed during follow-up which potentially has introduced bias. However, baseline characteristics were not statistically different between included football players and dropouts *(Table 2)*. Results of this study in male football players might not automatically be generalised to female football players. Given that 6 of 98 growth plates were still open at 5-year follow-up, the prevalence is expected to even increase slightly. Another limitation is the use of radiographs leading to an underestimation of both cam morphology prevalence and amount of open growth plates. Differences in rotation of the hip, especially external rotation, could potentially have influenced the results, but due to the same standardised radiographic protocol used at every time point, this effect is likely limited.

## Visual scores

Due to limitations of the alpha angle, the anterolateral head-neck junction was also semiquantitatively scored. All the available radiographs over time were presented and scored in one series, which could have introduced bias but also resulted in more reliable prospective visual scores. Bias could have been introduced because the observers were not blinded for growth plate status. However, by showing each hip of one person at the multiple follow-up times at once, the hips could be more reliably categorised into normal, flattening or prominence.

## Alpha angle

Although the alpha angle is the most commonly used quantitative measure for cam morphology, this measure does have its limitations. First, the alpha angle might be less valid in hips with an open growth plate since it results in a higher rate of false positive findings, as described previously in this cohort and also observed by others.[2,137] Another restriction is that the alpha angle, like every measurement method, has its measurement uncertainty. The values for the minimal detectable change are not available for the alpha angle. For example, of 43 hips that developed cam morphology based on alpha angle, 21 (48.8%) increased in alpha angle less than 10° and 9 (20.9%) of these 21 even less than 5°. This might very well be within the measurement uncertainty. It might therefore be possible that hips were misclassified as having or not having cam morphology. A dichotomous definition of cam morphology based on the alpha angle is used, with the risk of misclassifying hips that have alpha angles around 60°. Lastly, the risk of a false positive or false negative quantification of cam morphology is increased due to repetitive measurements during follow-up.

# Conclusion

Cam morphology of the hip develops mainly when the growth plate is open in young male football players. This suggests that cam morphology is a bony adaptation resulting from stimulating of the growth plate by sporting activities, which has implications for possible future preventative measures for cam morphology formation.

## Contributors

PK, RA: study conception/design, data acquisition, data analysis and interpretation, drafting of manuscript. MPH, AZG: data acquisition, data interpretation, critical revision. JANV: study conception/design, data acquisition, critical revision. JHW: study conception/design, data acquisition, data analysis and interpretation, critical revision.



## Ethical approval

Approved by the Medical Ethical Committee of Erasmus Medical Centre, Rotterdam, the Netherlands (METC: 2009-235).

## Funding

The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

## Conflict of interest

None.

## Informed consent

Obtained.

## Acknowledgements

The authors thank Raymond van Meenen, Rob Kurvers, Marcel de Geus and the other staff members of Feyenoord Football Academy for their collaboration in this study. This study would not have been possible without the study participants and their families, to whom we offer our sincerest gratitude.

*Chapter 06*

# Parameters associated with and predictive for cam morphology (presence, size and development)

***'Clinical and radiological hip parameters do not precede but develop simultaneously with cam morphology: a 5 year follow-up study'***

*P. van Klij, M.P. Heijboer, A.Z. Ginai, J.A.N. Verhaar, J.H. Waarsing, R. Agricola*

Knee Surg Sports Traumatol Arthrosc. 2020 Oct 1.

# Abstract

**Purpose:** The aim of this study was to (1) investigate whether radiographic and clinical parameters, which influence how stresses during sporting activities act on the proximal femur, are associated with cam morphology or (2) precede cam morphology development.

**Methods:** Young male football players participated at baseline (n = 89, 12-19 years of age), 2.5-year (n = 63) and 5-year follow-up (n = 49). Standardised anteroposterior pelvic and frog-leg lateral radiographs were obtained at each time point. Cam morphology was quantified by an alpha angle ⩾60°, and large cam morphology ⩾78°. The neck-shaft angle (NSA), epiphyseal extension (EE), lateral center-edge angle (LCEA) and hip internal rotation (IR) were also measured. Cross-sectional associations between NSA, EE, LCEA and IR and (large) cam morphology were studied at all time points. To study whether these variables preceded cam morphology development, hips without cam morphology at baseline were studied prospectively.

**Results:** A lower NSA, a higher EE and limited IR were consistently associated with cam morphology at all three time points. These differences were more pronounced in hips with large cam morphology. No association between cam morphology and the LCEA was found. None of the parameters studied preceded cam morphology development.

**Conclusion:** Cam morphology developed simultaneously with a varus orientation, growth plate extension towards the femoral neck and limited hip internal rotation. These parameters did not precede cam morphology development. The hip parameters studied cannot be used to identify individuals at risk of developing cam morphology.

**Level of evidence:** II

# Introduction

Cam morphology is extra bone formation on the anterolateral head-neck junction of the proximal femur and is associated with an increased risk of developing hip osteoarthritis (OA). [3,125,133,156,176]

The aetiology of cam morphology has still not been fully understood. Several studies have found that it forms during growth[137,159,192], is slightly more prevalent in males (15-25%) than in females (5-15%)[60,65,149], and is more common in professional athletes.[2,4,137,192] A finite element study showed that the stress distribution resulting from different loading patterns on the immature and growing proximal femur influenced the trigger for bone formation at the location where cam morphology normally develops.[154] Cam morphology development also depends on growth plate orientation, when the growth plate extends toward the neck. This results in a stimulus for bone formation at the anterolateral head-neck junction. Not only the orientation of the growth plate, but also varus/valgus orientation might influence the stress distribution through the growing proximal femur and thereby the risk of cam morphology development.[10,154] Since the development of the growing hip is an interplay between the proximal femur and the acetabulum, cam morphology development might also be influenced by acetabular coverage.

Clinically, cross-sectional studies have shown associations between lower neck-shaft angles (NSA)[111] and an extended growth plate towards the femoral neck[137] and cam morphology. The link between acetabular coverage and cam morphology development has not been examined. The relationship between cam morphology and the amount of hip joint internal rotation is also unclear.[17,84,117] Cam morphology might cause abutment between the proximal femur and acetabulum, thereby limiting hip internal rotation. Palmer et al.[137] showed that an osseous cam morphology might be preceded by a cartilaginous bump, which might even lead to limited internal rotation before osseous cam morphology is present.

To date, no longitudinal studies on the relationship between the above mentioned parameters and cam morphology are available. It is therefore unknown if these hip parameters develop simultaneously, or whether they actually precede cam morphology development, and therefore are a cause of cam morphology development. If the latter was true, one would be able to identify which adolescents are at highest risk of developing cam morphology before its actual presence, which allows a selection for preventative measures.

The study aims were (1) to investigate whether radiographic (NSA, EE, LCEA) and clinical (internal rotation) factors were associated with cam morphology presence and/or (2) whether these factors preceded cam morphology development. The hypothesis was that the hip parameters examined were associated with cam morphology presence and size, but that they did not precede the development of cam morphology. This might provide new insights into which radiographic or clinical factors could predict those who are susceptible to developing cam morphology.

# Materials and methods

The Medical Ethical Committee of Erasmus Medical Centre (Rotterdam, the Netherlands) approved this study (IRB: NL28614.078.09). Written consent was obtained from all participants. For participants aged under 18 years, written consent from at least one parent was also obtained. The inclusion and exclusion criteria for this study have been described previously.[2,4] Adolescent male football players who played in selection teams of Feyenoord football club in Rotterdam (the Netherlands) were included. Exclusion criteria were any known hip disorder. At baseline, information letters were sent to all eligible asymptomatic athletes (n = 141), of whom 101 gave informed consent and 89 (12-19 years of age) joined this study at baseline. At 2.5-year follow-up, 63 participants were included and at 5-year follow-up, 49 participants (mean age, 20.5 ± 2.2 years) *(Figure 1)*. The 5-year follow-up was performed between June and October 2015.

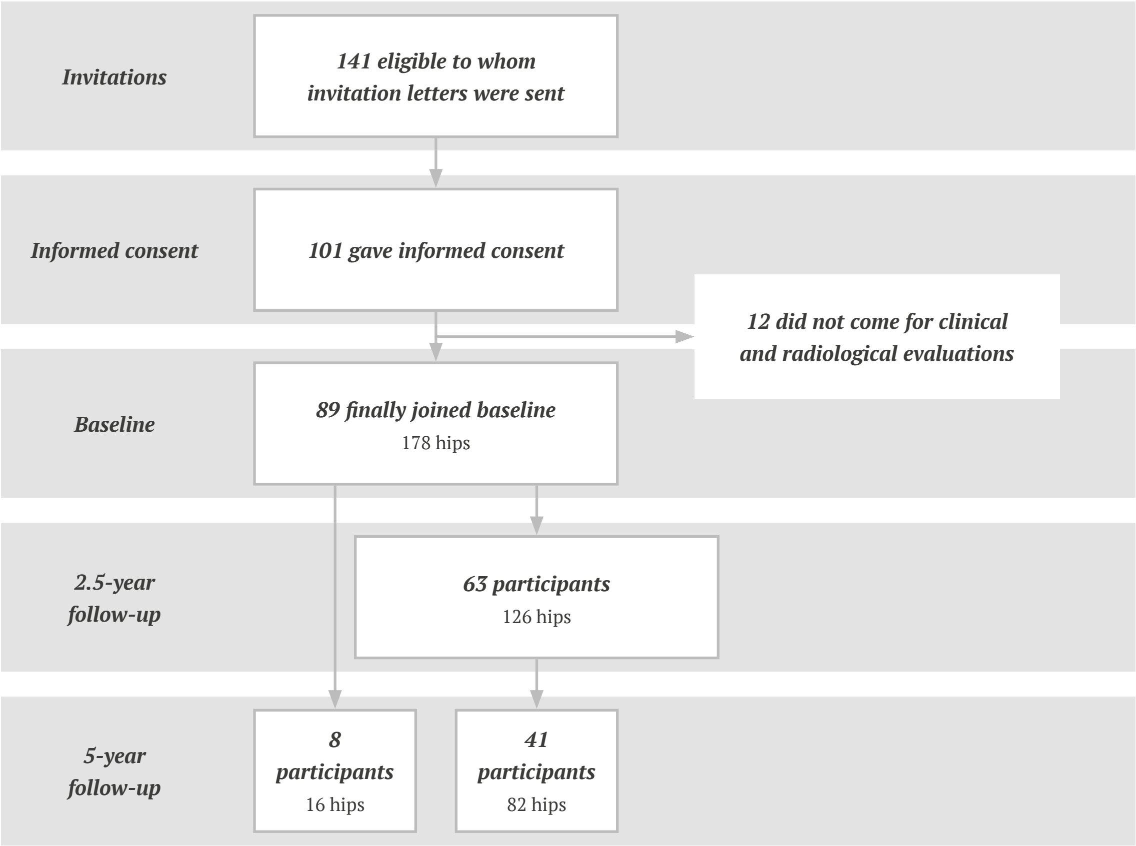



**FIGURE 1**: Flowchart of all participants at baseline, 2.5-year follow-up and 5-year follow-up Note: The 8 participants at 5-year follow-up, were participants who did not attend at 2.5-year follow-up.

Chapter 06

## Radiographs

A standardised radiographic protocol was used at baseline, 2.5-year and 5-year follow-up, which has been described previously.[2,4] In summary, three radiographs of the hip were obtained: a standardised supine anteroposterior (AP) radiograph of the pelvis and a frog-leg lateral radiograph of each hip.

## Cam morphology presence, size and development

The shape of the proximal femur was outlined by a manually positioned set of points on predefined anatomical landmarks, using Statistical Shape Modelling software (ASM tool kit, Manchester University, Manchester, UK) *(Figure 2A)*. Cam morphology was quantified using the alpha angle. The alpha angle was calculated automatically by using MATLAB v7.1.0 (MathWorks Inc, Natick, Massachusetts, USA) from the set of points on the AP and frog-leg lateral radiographs, placed by one observer (PvK), for all time points.[2,4] Cam morphology presence was defined as an alpha angle ⩾60°,[8] in either the AP or frog-leg lateral radiograph of each hip. Large cam morphology was defined as an alpha angle ⩾78° in either view.[8] When a hip had an alpha angle ⩾60° at a certain point, we defined this hip as having cam morphology at the subsequent follow-up time points as well.

Cam morphology development was defined as a change in alpha angle from <60° to ⩾60°. In order to study if the NSA, EE, LCEA and internal rotation preceded cam morphology development, we only analysed hips without cam morphology at baseline and with at least one follow-up time point available. If two follow-up time points were available (i.e. both 2.5-year and 5-year follow-up), the last time point was used for analysis. Of these hips, the baseline parameters NSA, EE, LCEA and internal rotation were compared between hips that did and did not develop cam morphology in time. The intra-class correlation coefficient (ICC) of the alpha angle for inter-observer reliability was 0.73 and for intra-observer reliability 0.85-0.99.[3]

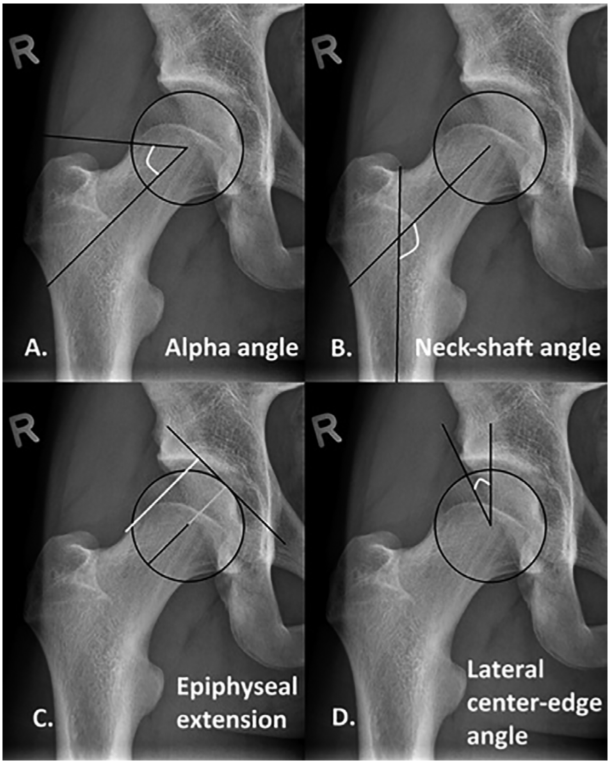



**FIGURE 2**: The radiographic measurements of the same right hip.

A. The alpha angle (white angle) is measured by drawing a best fitting circle around the femoral head and a line through the center of the neck and the center of the femoral head. From the center of the femoral head, a second line is drawn to the point where the superior surface of the head-neck junction departs from the circle the first time. The angle formed by these two lines is the alpha angle.

B. The neck-shaft angle (NSA, white angle) is the angle determined by a line through the middle of the femoral shaft and a line through the middle of the femoral head and neck, with a higher value indicating a valgus orientation and a lower value a varus orientation.

C. The epiphyseal extension (EE) was measured as described by Siebenrock et al.[161] First, a perpendicular line to the line through the middle of the femoral head and neck is drawn. From this line, again a perpendicular line (white line) is drawn to the lateral endpoint of the growth plate. The distance of this line is divided by the femoral head radius (grey line), which results in the EE.

D. The lateral center-edge angle (LCEA), also known as the Wiberg angle[202], measures the amount of lateral acetabular coverage relative to the femoral head. It is calculated by a vertical line from the middle of the femoral head, which is perpendicular to the horizontal line connecting the two superolateral portions of the obturator foramen, in order to correct for coronal balance. Then, the second line departs also from the middle of the femoral head towards the most lateral point of the acetabulum.

## Growth plate status

The proximal femoral growth plate was scored based on consensus by an experienced musculoskeletal radiologist (AZG) and an experienced orthopaedic surgeon (MPH). If only a small part of the growth plate remained open in any radiographic view, that growth plate was scored as open. If the full growth plate was totally fused and visible as a sclerotic line, this growth plate was scored as closed. A kappa of 0.94 for intra-observer reliability was observed.

## Radiographic and clinical parameters

The radiographic independent parameters NSA, EE and LCEA were all measured on AP radiographs. The measurement methods are described in *Figure 2*. The amount of hip internal rotation was determined by physical examination.[2] While maintained in neutral rotation, the first resistance/end feel during passive internal rotation was measured in supine position on a flat examination table with a goniometer. Internal rotation was measured with 90° of flexion in the hip joint. The inter-observer variability for NSA, EE and LCEA was determined by scoring 10 random radiographs by 2 persons (PvK, RA) and was 0.97 for NSA, 0.87 for EE and 0.94 for LCEA. The intra-observer variability was 0.98 for NSA, 0.86 for EE and 0.99 for LCEA.

## Statistical analysis

Differences in characteristics between participants and dropouts were tested by an independent samples t-test. Cam morphology presence and size was described per hip. The cross-sectional association between the variables NSA, EE, LCEA and internal rotation and cam morphology presence and size were analysed and calculated by a logistic regression at all three time points. This resulted in the analysis of 178 hips at baseline, 126 hips at 2.5-year follow-up and 98 hips at 5-year follow-up. By using logistic regression in a 'Generalised Estimated Equations' (GEE) model, we could model the correlations that existed within a person regarding side. The analyses were corrected for age and body mass index (BMI). For the associations between NSA, LCEA, internal rotation and cam morphology, the odds ratio (OR) and 95% confidence interval are presented per degree difference. For the EE, the OR and 95% confidence interval are presented for increments of 0.01. The NSA, EE, LCEA and internal rotation were studied in a longitudinal design to observe if there were any differences in these values at baseline between football players that did or did not develop cam morphology, using a GEE model with logistic links function, adjusted for age and BMI. The unadjusted data are presented in a sensitivity analysis *(online supplemental Table 1)*. SPSS25.0 (Windows) was used for statistical evaluation.

# Results

## Participant characteristics

The demographic data of all participants is presented in *Table 1*. The mean follow-up was 5.3 ± 0.1 years (range 5.0-5.6 years). No significant differences in demographic baseline characteristics were observed between the 5-year follow-up participants and dropouts *(Table 2)*.[192] At 5-year follow-up, all participants still played football, 28 of 49 (57%) at a professional level, 21 of 49 (43%) as an amateur. The prevalence of cam morphology and large cam morphology is presented in *Table 1*.

| *Participant characteristics* | **Baseline (n = 89)** | **2.5-year follow-up (n = 63)** | **5-year follow-up (n = 49)** |
|---|---|---|---|
| **Age, year** | 15.2 ± 2.0 | 17.3 ± 2.0 | 20.5 ± 2.2 |
| **Weight, kg** | 59.4 ± 13.8^ | 68.4 ± 11.1# | 73.8 ± 7.9 |
| **Height, cm** | 170.3 ± 12.2^ | 177.4 ± 8.0# | 180.3 ± 6.6 |
| **Body mass index, kg/m$^2$** | 20.1 ± 2.3^ | 21.6 ± 2.2# | 22.7 ± 1.6 |
| **Football experience, year** | 9.0 ± 2.5^ | 11.1 ± 2.5# | 14.3 ± 2.7 |
| **Training intensity, h/week** | 8.0 ± 1.8^ | 8.7 ± 1.9## | 9.3 ± 2.9 |
| | **178 hips** | **126 hips** | **98 hips** |
| **Cam morphology prevalence per hip**<br>• Cam<br>• Large cam | <br><br>87 (48.9%)<br>24 (13.5%) | <br><br>86 (68.3%)<br>25 (19.8%) | <br><br>78 (79.6%)<br>25 (25.5%) |

Due to missing data, data of n = 87 (^), n = 58 (#) and n = 57 (##) are presented.
Values are expressed as mean ± standard deviation, with n = participants.

**TABLE 1**: Demographic data and cam morphology prevalence at baseline, 2.5-year follow-up and 5-year follow-up

| *Participant characteristics* | **Baseline (n = 49) 5-year follow-up participants** | **Baseline (n = 40) 5-year follow-up dropouts** | **P-value** |
|---|---|---|---|
| **Age, year** | 15.2 ± 2.1 | 15.3 ± 1.8 | n.s. |
| **Weight, kg** | 58.5 ± 14.7 | 60.4 ± 12.6# | n.s. |
| **Height, cm** | 169.4 ± 13.2 | 171.5 ± 10.7# | n.s. |
| **Body mass index, kg/m$^2$** | 20.0 ± 2.3 | 20.3 ± 2.2# | n.s. |
| **Football experience, year** | 8.8 ± 2.7 | 9.1 ± 2.4# | n.s. |
| **Training intensity, h/week** | 7.9 ± 1.6 | 8.1 ± 2.0# | n.s. |
| *Radiographic and clinical parameters* | **n = 98 hips** | **n = 80 hips** | |
| **Cam morphology prevalence, %** | 48.0 | 50.0 | n.s. |
| **NSA** | 131.2° ± 5.3° | 131.8° ± 5.4° | n.s. |
| **EE** | 1.49 ± 0.19 | 1.58 ± 0.19 | **.004** |
| **LCEA** | 26.9° ± 6.1° | 27.9° ± 7.3° | n.s. |
| **Internal rotation** | 26° ± 8° | 25° ± 9° | n.s. |

**Abbreviations**: NSA: neck-shaft angle; EE: epiphyseal extension; LCEA: lateral center-edge angle; n.s. non-significant.
Values are expressed as mean ± standard deviation, with n = participants for baseline characteristics and n = hips for independent and dependent parameters.
Due to missing data, data of n = 38 (#) are presented.

**TABLE 2**: Demographic baseline data of 5-year follow-up participants and dropouts

## Cross-sectional associated parameters

### *Neck-shaft angle (NSA)*

The NSA was significantly associated with both cam morphology and large cam morphology at all three time points, compared to hips without cam morphology *(Figure 3/4 and online supplemental Table 2/3/4)*.

### *Epiphyseal extension (EE)*

EE was significantly associated with cam morphology presence at baseline and 2.5-year follow-up, and with large cam morphology at baseline and 5-year follow-up, when compared to hips without cam morphology *(Figure 3/4 and online supplemental Table 2/3/4)*.

### *Lateral center-edge angle (LCEA)*

No association between the LCEA and cam morphology was observed at any time point. The LCEA was associated with large cam at 2.5-year follow-up *(Figure 3/4 and online supplemental Table 2/3/4)*.

### *Internal rotation*

The amount of internal rotation was associated with cam morphology presence and size at all time points, compared to hips without cam morphology *(Figure 3/4 and online supplemental Table 2/3/4)*.

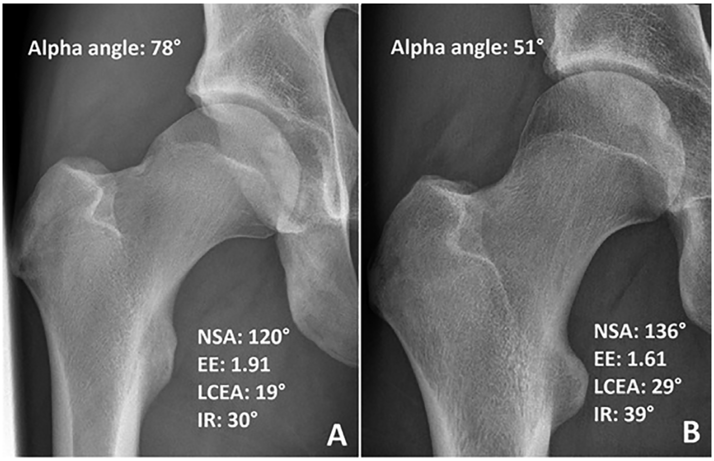



**FIGURE 3**: An example of two hips of different participants with closed growth plates, both at 5-year follow-up.

A. A typical hip with cam morphology, varus orientation and an extended growth plate towards the neck.

B. A hip without cam morphology with a more valgus orientation and without an extension of the growth plate towards the femoral neck.

EE: epiphyseal extension; IR: internal rotation; LCEA: lateral center-edge angle; NSA: neck-shaft angle.

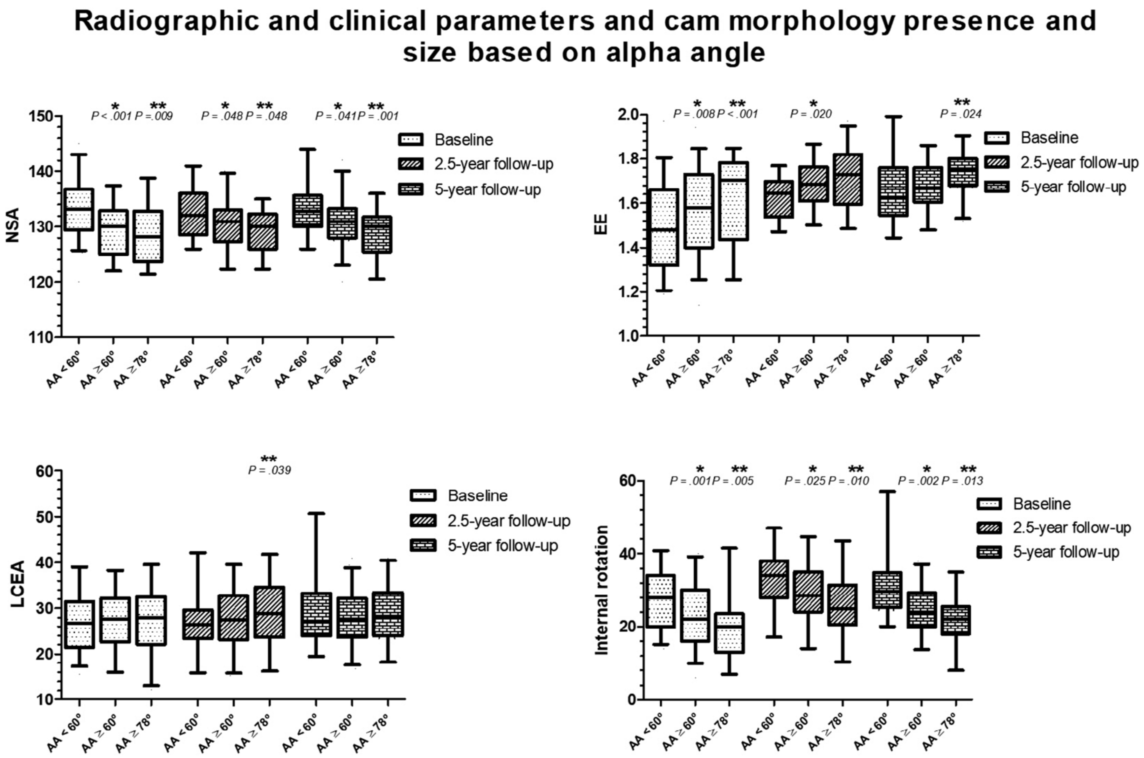



**FIGURE 4**: The associations between the NSA, EE, LCEA, hip internal rotation and cam morphology presence and size visualised in a boxplot. In these plots, the box with 25-75$^{th}$ percentile and median (horizontal line) are presented. The whiskers represent the 5-95$^{th}$ percentile. The associations are corrected for age and BMI.

* = significant association between the parameter and cam morphology, compared to hips without cam morphology.

** = significant association between the parameter and large cam morphology, compared to hips without large cam morphology.

## Preceding baseline parameters

Seventy-two hips had no cam morphology at baseline, and 55 of them an open growth plate (77%). During follow-up, 43 of 72 hips (60%) developed cam morphology, of which 37 had an open growth plate (86%) at baseline. The NSA, EE, LCEA and internal rotation were not significantly different between hips that did or did not develop cam morphology during follow-up *(Table 3)*.

| | Development (n = 43) | No development (n = 29) | P-value |
|---|---|---|---|
| **NSA** | 133.60° ± 4.78° | 133.18° ± 5.34° | n.s. |
| **EE** | 1.41 ± 0.15 | 1.47 ± 0.19 | n.s. |
| **LCEA** | 26.56° ± 6.07° | 26.25° ± 6.31° | n.s. |
| **Internal rotation** | 28° ± 8° | 28° ± 8° | n.s. |

**Abbreviations**: NSA: neck-shaft angle; EE: epiphyseal extension; LCEA: lateral center-edge angle; n.s. non-significant; Values are expressed as mean ± standard deviation, with n = participants and all P-values were corrected for age and BMI.

**TABLE 3**: Cam morphology development during follow-up and baseline preceding parameters

# Discussion

The main finding of this study is that a lower NSA, higher EE and decreased hip internal rotation developed simultaneously with cam morphology. This suggests that certain biomechanical stresses on the growing hip that predispose to developing cam morphology can also lead to a more varus orientation and growth plate extension towards the neck. This process of proximal femoral anatomy development during growth occurs simultaneously. This is in keeping with a finite element study[154] which observed that loading conditions influences growth plate shape and cam morphology development. Interestingly, these factors did not precede cam morphology development. In other words, there does not seem to be a causative relationship between these factors and subsequent cam morphology development. These parameters cannot assist in the prediction of cam morphology development.

This study found that increasing varus orientation of the hip was associated with cam morphology presence and size. This corresponds with a recent study[111] of 33 professional ballet dancers and 33 age- and sex-matched athletes. They found a lower NSA in athletes than in ballet dancers (130.8° ± 4.7° vs 134.6° ± 4.6°). Interestingly, the athletes also had a higher cam morphology prevalence. Other studies also found an association between lower NSA and symptoms.[61,130-132] This may imply that a lower NSA is not only associated with cam morphology but may also lead to more symptoms. A possible explanation is that cam morphology in varus hips might lead to premature contact with the acetabulum when compared to hips with cam morphology with a valgus orientation. This is in keeping with the CHECK prospective study[6], where hips with cam morphology and a varus orientation had higher risk of developing OA than hips without a varus position.

In this study, an increased EE was cross-sectionally associated with cam morphology, but did not precede cam morphology development. This is in line with Siebenrock et al.[161] who described an association between epiphyseal extension and cam morphology in a group of 15 participants with cam morphology compared with 15 controls. Three other studies also found a correlation between epiphyseal extension and the alpha angle.[116,137,158] There is no previous longitudinal study available on EE and the development of cam morphology. These clinical studies fit with a finite element study[154], which showed higher shear stresses (a trigger for bone formation) at the location where cam morphology develops when the growth plate extended towards the femoral neck. However, in the current study there was no evidence that an extended growth plate preceded cam morphology development. It is therefore probably a simultaneously occurring adaptive response to mechanical load applied to the growing hip.

The absence of a significant association between the LCEA and cam morphology corresponds with the previous findings of Anderson et al.[14] Although there is an interplay between the acetabulum and proximal femur during growth, the lateral acetabular coverage apparently does not have an effect on developing cam morphology. However, the true morphology and orientation of the acetabulum is difficult to measure on AP radiographs and we therefore acknowledge that we were limited to measuring the LCEA.

The amount of internal rotation of the hip was associated with cam morphology presence and size, but limited internal rotation did not precede the development of cam morphology. This implies that hip internal rotation decreased as cam morphology develops. It may well be that the rotation is limited by the bony morphology. Several other studies in athletes, such as collegiate football and football players, also showed an association between limited internal rotation and cam morphology.[17,84,117] The differences in internal rotation observed between hips with and without cam morphology range from 3 to 6 degrees, depending on cam morphology size. Although this is interesting when trying to understand the aetiology and consequences of cam morphology, for clinical purposes this value is below the minimal clinical important difference for measuring internal rotation.

Given the relationship between cam morphology and development of hip OA, there is a need for strategies to prevent the development of cam morphology. Primary prevention would ideally consist of avoiding cam morphology from developing. Given the lower cam morphology prevalence in non-athletes[2,159], this might be possible by adjusting the loads applied to the athlete's hip during the second growth spurt. However, to date it is unknown how and when to adjust variables which determine the loads applied to the hip in terms of the exact time frame, frequency, duration and loading patterns. The athletes at highest risk of developing cam morphology could not be identified with the hip parameters studied. The distribution of biomechanical stresses through the proximal femur, as determined by the NSA and EE, were playing a role in the aetiology of cam morphology during growth.[154] The risk of cam morphology development in high loading sports must be acknowledged by the clinician, which might also include informing parents of adolescent footballers about these specific potential health disadvantages. These will have to be weighed up against the health benefits of an active lifestyle.

The loss of 40 (45%) of 89 baseline participants might have biased the results. However, the participant characteristics at baseline for the included participants and dropouts did not differ significantly *(Table 2)*. Of the 40 participants lost to follow-up, 24 rejected the invitation, 11 were not reachable, 4 were playing football abroad and 1 person failed to show up. The longitudinal analyses might have been underpowered as these comprised only 72 hips without cam morphology at baseline. However, there were almost no absolute differences in the parameters studied between hips that did and did not develop cam morphology, which limits the risk of a type-2 error.

A strength of the study was having three follow-up time points throughout adolescence and a substantial number of hips having normal morphology at baseline, which is important to study parameters that might precede the development of cam morphology. As only males were included in this study, it is unknown if the results are generalisable to females. Radiographs instead of 3-dimensional imaging modalities were used, which could have slightly influenced the results. First, it may have led to an underestimation of cam morphology prevalence. Secondly, the NSA, EE and LCEA were only 2-dimensional. However, the correlation between NSA-scores on radiographs and CT is excellent.[143] The NSA on radiographs can be measured optimally on long-leg AP radiographs to optimise the position of the femoral shaft midpoint. The AP radiographs in our study generally showed 5-10 centimetres below the lesser trochanter, resulting in reliable measurements. The hip internal rotation measurements were performed using a goniometer, which can result in a slight overestimation and measurement errors. Apart from these measurement limitations, physical examination by goniometry is acceptable and reliable for longitudinal studies.[135]

For the clinician it is important to understand that this is the first longitudinal study which showed that the studied radiographic and clinical parameters cannot predict cam morphology development. For the clinician and patient, this creates more insight in the aetiology of cam morphology and might therefore be useful information in daily practice. Prevention of cam morphology development purely based on the predictive value of specific radiographic or clinical parameter of the hip is not yet possible.

# Conclusion

In conclusion, a varus orientation of the hip, an extended growth plate, and limited hip internal rotation developed simultaneously with cam morphology. None of these hip parameters preceded cam morphology development. These findings underline the importance of the distribution of biomechanical stresses on the growing proximal femur in the aetiology of cam morphology.

*Chapter 06*

## Ethical approval

The Medical Ethical Committee of the Erasmus Medical Centre (Rotterdam, the Netherlands) approved this study (IRB: NL28614.078.09).


## Funding

The authors declare that they received no funding.


## Conflict of interest

The authors declare that they have no conflict of interest.

## Informed consent

Written consent was obtained from all participants. For participants aged under 18, written consent from at least one parent was also obtained.

*Chapter 07*

# The association between cam morphology and clinical signs and symptoms

***'The relationship between cam morphology and hip and groin symptoms and signs in young male soccer players'***

*P. van Klij, A.Z. Ginai, M.P. Heijboer, J.A.N. Verhaar, J.H. Waarsing, R. Agricola*

Scand J Med Sci Sports. 2020;30(7):1221-1231.

# Abstract

**Background**: Conflicting and limited high-quality prospective data are available on the associations between cam morphology and hip and groin symptoms and range of motion (ROM).

**Objectives**: This cross-sectional cohort study investigated associations between cam morphology presence, size and duration and symptoms and ROM.

**Methods**: Academy male football players (n = 49, 17-24 years) were included. Standardised anteroposterior pelvic and frog-leg lateral radiographs were obtained at baseline, 2.5- and 5-year follow-up. The femoral head-neck junction was quantified by:

- Visual score. Cam morphology (flattening or prominence), large cam (prominence).
- Alpha angle. Cam morphology (⩾60°), large cam (⩾78°).

Cam morphology duration was defined as long (first present at baseline) or short (only from 2.5 or 5-year follow-up). Current symptoms at 5-year follow-up were assessed using a hip and groin pain question and by the ‘Hip and Groin Outcome Score‘ (HAGOS). HAGOS scores were categorised into: most symptoms (⩾2 domains in lowest interquartile range [IQR]), least symptoms (⩾2 domains in highest IQR). Hip ROM was measured by goniometry at 5-year follow-up.

**Results**: Large cam morphology based on visual score was associated with hip and groin pain (23.8% vs. 7.1%, OR: 3.17, CI: [1.15-8.70], P = .026), but not with HAGOS scores. Cam morphology presence, size and duration were associated with limited flexion of around 6° and/or 3° to 6° for internal rotation.

**Conclusion**: Cam morphology presence, size and duration were associated with limited hip flexion and/or internal rotation, but differences might not exceed the minimal clinical important difference. Whether cam morphology results in symptoms is uncertain.

# Introduction

Hip and groin symptoms are frequently observed in professional sports and football in particular. The prevalence of hip and groin symptoms in (elite) football is reported as 49% per season[185], while the incidence varies between 4 and 19%. One of the causes of hip and groin symptoms in athletes is femoroacetabular impingement (FAI) syndrome.[62] FAI syndrome is defined by a triad of symptoms, clinical signs, and imaging findings.[62]

Imaging findings consistent with FAI syndrome include cam and/or pincer morphology. Cam morphology is an extra bone formation on the anterolateral side of the head-neck junction of the femur which arises during growth.[2,4,137,159,192] It can potentially damage intra-articular structures such as the cartilage and acetabular labrum and might cause symptoms.[23,71]

Cam morphology prevalence in football players is high.[2,4,137,191,192] Although there is an association between cam morphology and hip osteoarthritis (OA)[3,125,133,156,176,191], the association between cam morphology and symptoms in athletes remains contradictory. Several cross-sectional studies showed conflicting results.[12,13,59,95,111] One available longitudinal case-control study[89] showed an association between cam morphology and development of hip pain in the general population with a relative risk of 4.3 (95% confidence interval [CI]: 2.3-7.8). Another prospective cohort study[122] found no association between cam morphology and groin injuries in professional football players. A large cam morphology is associated with a higher risk for developing hip OA[3] and cartilage damage[21,80,141]. It might therefore hypothetically result in more symptoms and more limited range of motion (ROM). The influence of cam morphology duration on both symptoms and ROM has never been investigated and can only be assessed when information on when cam morphology arises is available.

Therefore, the study aims of this cohort with young academy male football players were to assess the association between the cam morphology presence, size and duration and hip and groin symptoms and ROM within 5-year follow-up.

# Materials and methods

## Study participants

At baseline, all academy male football players of the Feyenoord Academy aged between 12 and 19 years (n = 141) received an invitational letter of whom 89 finally participated. All 89 baseline participants were invited again to participate at 2.5-year follow-up (n = 63 participants) and the 5-year follow-up (n = 49 participants) *(Figure 1)*. Inclusion and exclusion criteria were described previously.[2,4] The inclusion for the 5-year follow-up took place between June 2015 and October 2015. Ethical approval was obtained from the Medical Ethical Committee of the Erasmus Medical Centre (Rotterdam, the Netherlands). Each participant gave written consent. For participants under 18 years, written consent was gathered from at least one parent. Participant characteristics, such as age, weight, height (and BMI), football experience, training intensity and self-reported hip and/or groin symptoms, were collected *(Table 1)*.

## Radiographs

Three radiographs were obtained during this study by the same standardised radiographic protocol as described previously[2,4]; one supine anteroposterior pelvic radiograph and a frog-leg lateral radiograph of each hip.

## Visual scores

The femoral head-neck junction of all hips was scored qualitatively as normal, flattening or prominence.[2,4] This additional method was used because of alpha angle limitations, especially in hips with an open growth plate.[2,192] An experienced musculoskeletal radiologist and orthopaedic surgeon determined all visual scores simultaneously, and any discrepancies were directly resolved based on consensus. Visual scores were obtained by scoring each hip of all three time points in one session. Visual scores showed a kappa of 0.68 for intra-observer reliability in the baseline study.[2]

## Alpha angle

The alpha angle was automatically calculated on all radiographs, as described by Nötzli et al.[134] and was used previously.[2,4] In short, the shape of the proximal femur was outlined by a manually positioned anatomical set of points by one observer, by using Statistical Shape Modelling (ASM tool kit, Manchester University, Manchester, UK). The alpha angle was automatically calculated from this point set by using MATLAB v7.1.0 (MathWorks Inc, Natick, Massachusetts, USA). Intraclass correlation coefficient (ICC) for interobserver reliability was 0.73 (95% confidence interval [CI] 0.56-0.86). Intra-observer reliability ICC scores ranged from 0.85 (95% CI 0.49-0.96) to 0.99 (95% CI 0.93-1.00). The standard error of measurement (SEM) was 3.45.

## Definition of cam morphology and large cam morphology

The independent variables cam morphology presence and size were analysed on both the AP view and frog-leg lateral view at 5-year follow-up. The highest score of one of both views was used for analysis. Cam morphology was defined twice, based on the visual score and alpha angle. Cam morphology based on the visual score was defined when either a flattening or prominence was present. Cam morphology based on the alpha angle was defined as alpha angle ⩾60°. Large cam morphology based on the visual score was defined as having a prominence. Large cam morphology based on the alpha angle was defined as alpha angle ⩾78°.[8]

## Cam morphology duration

The third independent variable cam morphology duration was scored dichotomously as 'long' or 'short' for all radiographs from baseline, 2.5-year follow-up and at 5-year follow-up. Long duration was defined as the first presence of cam morphology at baseline and short duration as having cam morphology for the first time at 2.5 and/or 5-year follow-up.

## Hip and groin pain / symptoms

### *Questionnaire on hip pain and participant characteristics*

Every participant filled out a questionnaire on several participant characteristics at 5-year follow-up *(Figure 1)*. This questionnaire contained a question about hip pain: 'Do you sometimes have pain in your hips?'. A dichotomous answer was possible, 'yes' or 'no'. When answered positive, the painful side was specified (left, right, bilateral). They also filled in, if pain occurred during or after sporting activities, or in rest. As this question might include groin pain, we choose 'hip and groin pain' as the overall term to define this outcome measure.

### *Hip and Groin Outcome Score*

The 'Copenhagen Hip and Groin Outcome Score' (HAGOS) is a valid patient-reported outcome measure to quantify hip and groin symptomatology.[184] The validated Dutch HAGOS translation was filled out by all participants only at the 5-year follow-up[172,182,184] *(Figure 1)*. This questionnaire obtained information from six domains, specified per person. Each domain is scaled between 0 and 100, with 100 as indicator for no problems, and a lower score for hip and groin symptoms.[182] The football players completed the questionnaires before or on the day at which the radiographs were obtained. All participants were divided into 3 groups based on the level of symptomatology, as described before by Tak et al.[171] The first group is the most symptomatic group in this cohort, defined by at least 2 domains in the lowest interquartile range (IQR) of the HAGOS scores. The group with the least symptomatic participants was defined as having at least 2 domains in the highest IQR of the HAGOS scores. The middle group was the remaining group.

## Hip range of motion

The researcher performing the physical examination was blinded to the outcome of the HAGOS scores and for the radiographs. The same physical examination protocol was used at all time points.[2,4] In short, while maintained in neutral rotation, the first resistance/end feel during passive flexion, abduction, adduction, internal rotation and external rotation were measured in supine position and extension in prone position on a flat examination table with a goniometer. Internal and external rotation were measured with 90° of flexion in the hip joint. Stabilisation was provided by the free hand of the examiner to the adjacent joints and regions.

## Statistical analysis

The association between cam morphology presence, size and duration at 5-year follow-up and hip and groin pain (per hip) and most versus least hip and groin symptoms (based on HAGOS per person) were calculated by means of logistic regression and adjusted for age and body mass index (BMI). The association between cam morphology presence, size and duration at 5-year follow-up and ROM was calculated by a linear regression model, adjusted for age and BMI. All per hip regression analyses were performed in a Generalised Estimated Equations (GEE) model. These were all cross-sectional associations at 5-year follow-up. The only longitudinal outcome of this study was the duration of cam morphology which was measured at baseline, 2.5-year, and 5-year follow-up. Absolute rounded ROM averages are presented in *Table 5 and 6*, with differences observed in the statistical tests presented as estimated mean differences. Differences in baseline characteristics between included participants and dropouts were tested using an independent-samples t-test. A sensitivity analysis was performed to see if analysing the HAGOS outcome defined as most symptoms vs middle and least symptoms, gave different results than defining the HAGOS outcome as most vs least symptoms *(online supplemental Table 1)*. SPSS25.0 (Windows) was used.

# Results

## Participant characteristics

Demographic data of the participants are summarised in *Table 1*. The mean follow-up time was 5.3 ± 0.1 years (range 5.0–5.6 years). Of the 89 baseline participants (12-19 years old), 49 (55%) participated at 5-year follow-up. No differences in baseline demographic data between these 49 participants and 40 dropouts were observed, *Table 2*.[192] Participants dropped out for various reasons: 24 rejected the invitation, 11 were unreachable, 4 lived abroad and 1 person accepted the invitation but did not appear during the allocated time-slot. All 49 included participants still played football at the time of the 5-year follow-up study. Of those, 28 (57%) were still active in a first or second team of a professional football club. All other 21 football players (43%) played football at an amateur level. Cam morphology prevalence was 82% (80 of 98 hips) based on visual score and 80% (78 of 98 hips) based on the alpha angle.

| | |
|---|---|
| **Number of participants (hips), n** | 49 (98) |
| **Age, mean ± SD (range), y** | 20.53 ± 2.17 (17 – 24) |
| **Weight, mean ± SD (range), kg** | 73.77 ± 7.87 (57 – 91) |
| **Height, mean ± SD (range), cm** | 180.33 ± 6.63 (165 – 190) |
| **Body mass index, mean ± SD (range), kg/m$^2$** | 22.65 ± 1.59 (18.5 – 27.0) |
| **Football experience, mean ± SD (range), y** | 14.29 ± 2.58 (9 – 19) |
| **Training intensity, mean ± SD (range), h/w** | 9.30 ± 2.92 (5 – 20) |
| **Self-reported hip- and/or groin symptoms per hip, n (%)**<br>• Left<br>• Right | 14 / 98 (14.3%)<br>7 (50%)<br>7 (50%) |
| **HAGOS domain scores, median (IQR, 25$^{th}$ -75$^{th}$ centile)**<br>• Pain<br>• Symptoms<br>• Activities of daily living<br>• Sports and recreational activity<br>• Physical activity<br>• Quality of life | <br>97.50 (92.50 – 100.00)<br>82.14 (73.21 – 92.86)<br>100.00 (95.00 – 100.00)<br>100.00 (87.50 – 100.00)<br>100.00 (87.50 – 100.00)<br>95.00 (80.00 – 100.00) |
| **Cam morphology based on alpha angle (⩾60°) per hip (n = 98), n (%)** | 80 (81.6) |
| **Cam morphology based on visual score (flattening or prominence) per hip (n = 98), n (%)** | 78 (79.6) |
| **Abbreviations:** HAGOS, Hip and Groin Outcome Score; IQR, interquartile range; SD, standard deviation. | |

**TABLE 1**. Participant characteristics at 5-year follow-up

| *Participant characteristics* | **Baseline (n = 49)**<br>**5-year follow-up participants** | **Baseline (n = 40)**<br>**5-year follow-up dropouts** | **P** |
|---|---|---|---|
| **Age, y** | 15.20 ± 2.13 | 15.25 ± 1.77 | .88 |
| **Weight, kg** | 58.54 ± 14.71 | 60.43 ± 12.60† | .37 |
| **Height, cm** | 169.35 ± 13.16 | 171.47 ± 10.67† | .25 |
| **Body mass index, kg/m$^2$** | 20.01 ± 2.32 | 20.29 ± 2.17† | .42 |
| **Football experience, y** | 8.84 ± 2.65 | 9.13 ± 2.40† | .45 |
| **Training intensity, h/w** | 7.87 ± 1.57 | 8.08 ± 2.00† | .45 |
| *Prevalence of cam, symptoms and ROM* | | | |
| **Cam morphology prevalence (VS / AA), %** | | | |
| • Visual score | 48.0 | 62.5 | .05 |
| • Alpha angle | 48.0 | 50.0 | .80 |
| **Hip and groin pain, % per hip** | 20.4 | 13.2 | .20 |
| **Range of motion** | | | |
| • Flexion | | | |
| - *Left* | 123.88° ± 6.54° | 123.87° ± 6.64° | .99 |
| - *Right* | 125.92° ± 8.05° | 123.45° ± 8.84° | .05 |
| • Abduction | | | |
| - *Left* | 41.92° ± 10.26° | 39.83° ± 9.40° | .16 |
| - *Right* | 41.22° ± 7.78° | 38.60°± 8.25° | **.031** |
| • Adduction | | | |
| - *Left* | 30.80° ± 3.95° | 28.80° ± 5.21° | **.005** |
| - *Right* | 30.06° ± 5.27° | 28.55° ± 5.64° | .07 |
| • Internal rotation | | | |
| - *Left* | 27.57° ± 8.15° | 26.33° ± 8.36° | .32 |
| - *Right* | 23.71° ± 7.39° | 22.75° ± 9.40° | .46 |
| • External rotation | | | |
| - *Left* | 40.35° ± 8.82° | 35.50° ± 9.06° | **< .001** |
| - *Right* | 37.22° ± 9.45° | 34.23° ± 8.74° | **.031** |
| • Extension | | | |
| - *Left* | 14.89° ± 2.39° | 14.31° ± 3.22° | .19 |
| - *Right* | 15.03° ± 2.53° | 14.56° ± 2.89° | .26 |

**Abbreviations**: AA, alpha angle; ROM, range of motion; VS, visual score.
† Data of n = 38 are presented, due to missing data.
Values are expressed as mean ± standard deviation. Bolded P-values indicate a statistically significant difference.

**TABLE 2**: Demographic baseline data of 5-year follow-up participants compared to dropouts

## Cam morphology and hip and groin pain

Nine players (18.4%) reported hip and groin pain (5 bilateral and 4 unilateral). Of these 14 hips, 10 hips were painful at one occasion and 4 at two occasions; 1 hip both during sports and at rest and 3 hips directly after sports and at rest. In total, 4 hips were painful during sports, 6 hips directly after sports and 8 hips at rest.

Of 80 hips with cam morphology based on visual score, 11 hips (13.8%) had hip and groin pain compared to 3 of 18 hips (16.7%) without cam (OR: 0.51, CI: [0.15-1.69]). Of 78 hips with cam morphology based on alpha angle, 9 hips (11.5%) had hip and groin pain, compared to 5 of 20 hips (25.0%) without cam (OR: 0.42, CI: [0.13-1.32]). Of the 42 hips with large cam morphology based on visual score, 10 hips (23.8%) had hip and groin pain compared to 4 of 56 hips (7.1%) without large cam (OR: 3.17, CI: [1.15-8.70], P = .026). Of 25 hips with large cam morphology based on alpha angle, 4 hips (16.0%) had hip and groin pain compared to 10 of 73 hips (13.7%) without large cam (OR: 1.21, CI: [0.60-2.43]) *(Table 3)*.

| *HAGOS questionnaire (per person)* | **Normal** | **Flattening** | **Prominence** | **AA < 60°** | **AA 60° - 78°** | **AA ≥ 78°** | **Cam, P† (VS / AA)** | **Large cam, P‡ (VS / AA)** |
|---|---|---|---|---|---|---|---|---|
| **Most symptoms** | 2/4 (50.0%) | 3/16 (18.8%) | 7/25 (28.0%) | 3/5 (60.0%) | 5/22 (22.7%) | 4/18 (22.2%) | .21 / .14 | .88 / .95 |
| **Least symptoms** | 2/4 (50.0%) | 13/16 (81.3%) | 18/25 (72.0%) | 2/5 (40.0%) | 17/22 (77.3%) | 14/18 (77.8%) | | |
| *Hip and groin pain (per hip)* | | | | | | | | |
| **Yes** | 3/18 (16.7%) | 1/38 (2.6%) | 10/42 (23.8%) | 5/20 (25.0%) | 5/53 (9.4%) | 4/25 (16.0%) | .27 / .14 | **.026** / .60 |

† Cam morphology versus having no cam morphology. For associations between cam morphology presence and size and HAGOS, 'most versus least symptoms' is used.
‡ Large cam morphology versus having no large cam morphology.
Bolded P-values indicate a statistically significant difference.

**TABLE 3**: Association between cam morphology based on both visual score (VS) and alpha angle (AA) and symptoms at 5-year follow-up

Of 47 hips with long cam morphology duration based on visual score, 7 hips (14.9%) had hip and groin pain compared to 4 of the 33 hips (12.1%) with short cam duration (OR: 1.99, CI: [0.19-21.19]). Long cam morphology duration defined by the alpha angle, resulted in 6 of 47 hips (12.8%) with hip and groin pain, compared to 3 of 31 hips (9.7%) with short cam duration (OR: 1.63, CI: [0.24-10.93]).

## Cam morphology and hip and groin symptoms

Hip and Groin Outcome scores were not normally distributed. The median and IQRs of all 6 HAGOS domains of this cohort are presented in *Table 1*. An overview of the distribution of the HAGOS domains per HAGOS group (most, middle and least symptoms) in this cohort is presented in *Table 4*. The group with most symptoms consisted of 12 of 49 football players (25%), the group with the least symptoms consisted of 33 football players (67%) and the middle group consisted of 4 football players (8%).

| *HAGOS group†* | **Persons** | **Pain** | **Symptoms** | **Function in DL** | **S&R** | **PA** | **QoL** |
|---|---|---|---|---|---|---|---|
| **Most symptoms** | 12 | 87.50 (80.63-94.38) | 66.07 (58.04-76.79) | 90.00 (85.00-95.00) | 82.81 (67.97-84.38) | 81.25 (75.00-100.00) | 70.00 (61.25-80.00) |
| **Middle** | 4 | 96.25 (93.13-99.38) | 80.36 (67.86-82.14) | 100.00 (96.25-100.00) | 92.19 (81.25-96.09) | 87.50 (78.13-87.50) | 85.00 (68.75-97.50) |
| **Least symptoms** | 33 | 100.00 (95.00-100.00) | 89.29 (82.14-96.43) | 100.00 (100.00-100.00) | 100.00 (100.00-100.00) | 100.00 (100.00-100.00) | 100.00 (90.00-100.00) |

**Abbreviations**: DL, daily living; PA, physical activities; QoL, quality of life; S&R, sports & recreation;
Values are expressed as median (IQR, $25^{th}$ -$75^{th}$ centile).
† Most symptoms are defined by at least 2 domains in the lowest interquartile range (IQR), least symptoms by at least 2 domains in the highest IQR and the middle group is the remaining group.

**TABLE 4**: Spreading of all 6 HAGOS domain medians for the 3 different HAGOS groups at 5-year follow-up

In the group with cam morphology based on visual score, 10 of 41 persons (24.4%) were classified into the group with most symptoms. In the group without cam, most symptoms were observed in 2 of 4 persons (50.0%) (OR: 0.24, CI: [0.03-2.20]). In the group with cam morphology based on alpha angle, 9 of 40 persons (22.5%) were classified into the group with most symptoms. In the group without cam, most symptoms were observed in 3 of 5 persons (60.0%) (OR: 0.22, CI: [0.03-1.67]). Large cam morphology based on visual score was observed in 25 persons (51.0%) and

7 of them (28.0%) were classified in the group with most symptoms. In the group without large cam, most symptoms were observed in 5 of 20 persons (25.0%) (OR: 1.12, CI: [0.28-4.46]). Large cam morphology based on alpha angle was observed in 18 persons (36.7%), and 4 of them (22.2%) were classified into the group with most symptoms. In the group without large cam, most symptoms were observed in 8 of 27 persons (29.6%) (OR: 0.95, CI: [0.21-4.30]) *(Table 3)*.

Long cam morphology duration defined by the visual score, resulted in 9 of 27 persons (33.3%) in the group with most symptoms. Short cam duration was observed in 1 of 14 persons (7.1%) in the group with most symptoms (OR: 12.92, CI: [0.88-188.93], P = .062). Long cam morphology duration defined by the alpha angle resulted in 8 of 29 persons (27.6%) in the group with most symptoms. Short cam duration was observed in 1 of 11 persons (9.1%) in the group with most symptoms (OR: 4.27, CI: [0.40-45.52]).

## Cam morphology and range of motion

The average flexion was lower in hips with cam morphology than in hips without cam based on visual score (116° ± 6° vs 121° ± 8°, P = .001) and alpha angle (116° ± 6° vs 122° ± 9°, P = .032) *(Tables 5 and 6)*. Lower average internal rotation was observed in hips with cam morphology based on alpha angle, compared to hips without cam (24° ± 7° vs 30° ± 9°, P = .005) *(Table 6)*. The average internal rotation in hips with large cam morphology based on visual score was lower than in hips without large cam (24 ± 8° vs 27° ± 7°, P = .033) *(Table 5)*. Limited flexion was observed in hips with large cam morphology based on alpha angle, compared to hips without large cam (113° ± 7° vs 118° ± 7°, P = .049) *(Table 6)*. Lower flexion was observed in hips with cam morphology based on alpha angle for at least 5 years (long duration), than hips with cam for 2.5 years or less (short duration) (115° ± 6° vs 116° ± 7°, P = .016).

| *Range of motion* | **Normal (n = 18)** | **Flattening (n = 38)** | **Prominence (n = 42)** | **Cam, P (degrees)†** | **Large cam, P (degrees)‡** |
|---|---|---|---|---|---|
| **Flexion** | 121° ± 8° | 116° ± 6° | 116° ± 7° | **.001** (6°) | .30 (2°) |
| **Abduction** | 43° ± 6° | 41° ± 4° | 42° ± 5° | .40 (1°) | .71 (0°) |
| **Adduction** | 26° ± 6° | 27° ± 6° | 27° ± 6° | .80 (0°) | .90 (0°) |
| **Internal rotation** | 28° ± 10° | 26° ± 6° | 24° ± 8° | .12 (3°) | **.033** (3°) |
| **External rotation** | 36° ± 6° | 34° ± 5° | 34° ± 7° | .17 (2°) | .84 (0°) |
| **Extension** | 22° ± 4° | 23° ± 5° | 22° ± 5° | .06 (1°) | .58 (1°) |

**Note**: values are expressed as mean ± standard deviation.
† Cam morphology versus having no cam morphology. Difference between groups is also presented in degrees range of motion.
‡ Large cam morphology versus having no large cam morphology. Difference between groups is also presented as the estimated mean difference in degrees range of motion.
Bolded P-values indicate a statistically significant difference.

**TABLE 5:** Association between cam morphology based on visual score and range of motion at 5-year follow-up (n = hips)

| *Range of motion* | **AA < 60° (n = 20)** | **AA 60° - 78° (n = 53)** | **AA ⩾ 78° (n = 25)** | **Cam (P)†** | **Large cam (P)‡** |
|---|---|---|---|---|---|
| **Flexion** | 122° ± 9° | 117° ± 6° | 113° ± 7° | **.032** (5°) | **.049** (3°) |
| **Abduction** | 44° ± 5° | 41° ± 5° | 42° ± 5° | .18 (2°) | .42 (1°) |
| **Adduction** | 26° ± 5° | 27° ± 5° | 26° ± 6° | .99 (0°) | .48 (1°) |
| **Internal rotation** | 30° ± 9° | 26° ± 7° | 21° ± 7° | **.005** (4°) | .05 (3°) |
| **External rotation** | 35° ± 6° | 34° ± 6° | 33° ± 7° | .55 (1°) | .28 (2°) |
| **Extension** | 23° ± 5° | 23° ± 5° | 20° ± 4° | .25 (1°) | .11 (1°) |

**Note**: values are expressed as mean ± standard deviation.
† Cam morphology versus having no cam morphology. Difference between groups is also presented in degrees range of motion.
‡ Large cam morphology versus having no large cam morphology. Difference between groups is also presented as the estimated mean difference in degrees range of motion.
Bolded P-values indicate a statistically significant difference.

**TABLE 6**: Association between cam morphology based on alpha angle (AA) and range of motion at 5-year follow-up (n = hips)

# Discussion

The relationship between cam morphology and hip and groin symptoms is inconsistent. A large cam morphology based on the visual score in young male academy football players showed an association with hip and groin pain, but not with more hip and groin symptoms as defined by the HAGOS score. A longer cam morphology duration was not significantly associated with more hip and groin symptoms. Cam morphology presence and size were associated with limited flexion and internal rotation, whereas a longer cam morphology duration was only associated with limited flexion.

## Cam morphology and hip and groin pain / symptoms

Large cam morphology was significantly associated with hip and groin pain, but not with the HAGOS scores. Other cross-sectional studies on this association showed conflicting results. Mayes et al.[111] did not find an association between cam morphology and with HAGOS scores <100 in ballet dancers. Anderson et al.[13] who investigated 547 individuals (1081 hips, mean age 67 years), did not find a significant association between cam morphology and the 'modified Harris Hip Scores' or 'Hip Outcome Scores'. Also no association between cam morphology and self-reported hip pain was found by Gosvig et al.[59] who studied 3202 participants from the general population. A longitudinal study by Mosler et al.[122] could not identify an association between cam morphology and groin injuries in professional athletes.

However, other studies did show an association between cam morphology and hip and groin symptoms. A longitudinal study by Khanna et al.[89] focused on the development of hip pain at 4.4 years follow-up in 170 asymptomatic volunteers (mean age 29.5 years) at baseline. Seven of 14 (50.0%) painful hips had cam morphology compared to 37 of 318 (11.6%) painless hips at follow-up (RR: 4.3, $P = .0002$). Other cross-sectional studies also found an association. Larson et al.[95] studied 125 National Football League prospects and observed a significantly higher cam morphology prevalence in the symptomatic group ($P = .009$). Allen et al.[12] demonstrated a significant association between higher alpha angles in painful hips (mean 69.9°) than in asymptomatic hips (mean 63.1°). In a retrospective study of 334 patients, a significant association between hip symptoms and increased alpha angles ($P < .001$) was observed as well.[64]

An explanation for the absence of association between cam morphology (flattening or prominence and/or alpha angle ⩾60°) and symptoms within 5-year follow-up could be that only larger cam morphology can cause rapid intra-articular damage. This is in line with the higher risk of developing hip OA when cam morphology is bigger.[8,191] No association between cam morphology and HAGOS scores was observed in this study.

HAGOS scores in the group classified as most symptoms in this cohort were ranging between 66.07 and 90.00, indicating that symptoms were mild. Also, the HAGOS score is a score per person rather than per hip, which might dilute the association in the presence of unilateral cam morphology. Also the HAGOS questionnaire captures hip and groin symptoms and not only hip-related pain, as other entities of groin pain might be more prevalent in football players than pain arising from the hip joint. Another explanation could be that participants were young. Cam morphology arises from 12 to 14 years old[2,4,137,159,173,192] and continues to grow thereafter until growth plate closure. During 5-year follow-up, participants were aged 20.5 years (17-24 years) on average. Therefore, the cam morphology duration might have been too short to create hip damage and symptoms. This is supported by our findings that 33.3% of the group with long cam morphology duration based on visual score was classified in the most symptoms group, compared to 7.1% in the short duration group. Although not statistically significant (P = .06), future studies on the relationship between cam morphology and symptoms should also take into account the duration of cam morphology. It could also be that football players are not keen to report about their (hip and groin) complaints as they may be afraid of losing their place on the pitch. Finally, the pathway from having cam morphology into developing the clinical entity of FAI syndrome and thus pain is complex and also involves the amount of femoral and acetabular version, soft tissue structures, activities which a person undertakes and many other person-specific factors. Obviously, it can also be that the presence of cam morphology itself is not associated with symptoms or reduced range of motion, as cam morphology is also highly prevalent in asymptomatic populations.[71]

## Cam morphology and range of motion

Significant associations between cam morphology presence and limited flexion and internal rotation were observed and influenced by cam morphology size. A longer cam morphology duration only negatively influenced the amount of flexion. Our findings partly correspond with current available literature. Audenaert et al.[17] observed a significantly lower range of internal rotation in the cam morphology group (based on CT) vs a group without cam morphology. In collegiate football players, Kapron et al.[84] found a significant association between alpha angle and limited internal rotation. Mosler et al.[117] screened 426 male professional football players in Qatar for 2 consecutive seasons and observed that asymptomatic hips with cam morphology and large cam morphology were associated with lower internal rotation. Interestingly, a systematic review of Freke et al.[50] did only find limited and conflicting evidence on the association of cam morphology and limited ROM in symptomatic patients. However, ROM in symptomatic hips might also be influenced by pain rather than cam morphology only.[171] In the current study, the average differences between hips with and without cam morphology were around 6° for flexion and 3°-6° for internal rotation. This raises questions on whether these differences are clinically relevant.

Not all growth plates were closed (93.9%) at 5-year follow-up. This means that hips with open growth plates might still have the potential to develop cam morphology or increase to a large cam morphology.[192] This can possibly cause more severe impingement, and therefore result in more symptoms and limited ROM in the future.

## Limitations

Some limitations in this study have to be acknowledged. During 5-year follow-up, 40 participants (44.9%) were lost to follow-up. Although there were no differences in baseline characteristics between participants and dropouts, it has bias, as it resulted in a relatively small sample size. Due to the small sample size and low proportion of hips without cam morphology, the resulting findings have wide confidence intervals. Of the included 49 participants, 42.9% played football at an amateur level, with lower intensity and training hours per week. This could have resulted in lower cam morphology prevalence[173,191], and might have influenced symptoms.[72] A possible limitation of the patient characteristics questionnaire is that it cannot be excluded that the question 'Do you sometimes have pain in your hips?' also included patients with groin symptoms and made no distinction between long standing and acute hip and groin symptoms. However, large cam morphology based on the alpha angle was associated with hip and groin pain based on this question, which indicates that type II errors are not likely. As the HAGOS-domain scores were not normally distributed and as the median scores in 3 out of 6 domains are having the maximum score of 100, a ceiling effect cannot be ruled out.

By using radiographs, the prevalence of cam morphology might have been underestimated as compared to cross-sectional imaging such as magnetic resonance imaging (MRI) or computed tomography (CT). However, by using two radiographic views (AP and frog-leg lateral), as recommended by the Warwick Agreement[62], the risk of false negative measurements was minimalised.



## Range of motion

The ROM was obtained before or after training, which could have resulted in different outcomes. Range of motion measurement by goniometry could result in measurement errors and can give an overestimation of the ROM.[135] Beside this limitation, ROM is an acceptable and reliable measurement method for longitudinal studies in FAI syndrome patients. The reliability of ROM testing of the hip is described in literature as good to excellent by Prather et al.[146]

# Conclusion

Data of this cohort study suggest that the presence, size and duration of a bony cam morphology have a direct but small effect on the ROM. Symptoms might develop in some football players with large cam morphology or several years after cam morphology development. A larger prospective cohort is needed to further elucidate these findings.

## Perspectives

Our study showed that large cam morphology is only associated with hip and groin symptoms but not with HAGOS scores. The presence, size and duration of cam morphology are associated with limited flexion and/or internal rotation, although the clinical relevance of these differences is questionable. This suggests that a bony cam morphology has a direct but small effect on the ROM and symptoms which might develop in some players several years after cam morphology has developed. More factors are involved in the complex pathway between cam morphology and developing the clinical entity of FAI syndrome with symptoms and limited function, such as femoral and acetabular orientation, soft tissue condition (e.g. labrum, cartilage, ligamentum teres), activity level, and many other person-specific factors. This needs further investigation in a larger cohort.



### Conflict of interest

The authors declare that they have no conflicts of interest.

### Acknowledgements

We want to thank Raymond van Meenen, Rob Kurvers, Marcel de Geus, and other staff members of Feyenoord Football Academy for their collaboration in this study. This study would not have been possible without its participants and their families, to whom we offer our sincerest gratitude.

*Chapter 08*

# Prevalence of cam and pincer morphology and future hip osteoarthritis

***'The Prevalence of Cam and Pincer Morphology and Its Association With Development of Hip Osteoarthritis'***

*P. van Klij, J. Heerey, J.H. Waarsing, R. Agricola*

J Orthop Sports Phys Ther 2018;48(4):230-238.

# Abstract

Our understanding of femoroacetabular impingement syndrome is slowly improving. The number of studies on all aspects (aetiology, prevalence, pathophysiology, natural history, treatment, and preventive measures) of femoroacetabular impingement syndrome has grown exponentially over the past few years. This commentary provides the latest updates on the prevalence of cam and pincer hip morphology and its relationship with development of hip osteoarthritis (OA). Cam and pincer morphology is highly prevalent in the general population and in this paper is presented for different subgroups based on age, sex, ethnicity, and athletic activity. Methodological issues in determining prevalence of abnormal hip morphology are also discussed. Cam morphology has been associated with development of hip OA, but the association between pincer morphology and hip OA is much less clear. Results from reviewed studies, as well as remaining gaps in literature on this topic, are critically discussed and put into perspective for the clinician.

# Introduction

Femoroacetabular impingement (FAI) syndrome has recently been defined by authors of an international consensus statement as “a motion-related clinical disorder of the hip with a triad of symptoms, clinical signs, and imaging findings.”[62] They also described the most commonly seen symptoms and clinical signs. The primary symptom of FAI syndrome is motion-related or position-related pain in the hip or groin. Pain may also be felt in the back, buttock, or thigh. In addition to pain, patients may also describe clicking, catching, locking, stiffness, restricted range of motion, or giving way. Diagnosis of FAI syndrome does not depend on a single sign. The flexion, adduction, internal rotation test is most commonly used, and is sensitive but not specific. There is often limited hip motion, especially restricted internal rotation when in hip flexion.[62] Imaging findings, the focus of this clinical commentary, include the presence of cam and/or pincer hip morphology. Cam hip morphology is characterised by a nonspherical femoral head, while pincer morphology is defined as overcoverage of the acetabulum relative to the femoral head, which can be either global (bony overgrowth of the acetabulum or a deep socket) or focal (acetabular retroversion). This clinical commentary provides an overview of studies that report on the prevalence of cam and pincer morphology, as well as studies investigating the relationship between cam and pincer morphology and hip osteoarthritis (OA). Future research directions for FAI syndrome will be discussed.

## Cam morphology

***Prevalence***

A recent systematic review[35] that included 30 studies showed that the prevalence of cam morphology has yet to be defined in an overall population–based cohort. The prevalence of cam morphology in that systematic review ranged from 5% to 75%. This wide variation in prevalence among studies was based on population characteristics (age, sex, ethnicity, athletic activity, presence/absence of symptoms), the measures and concurrent threshold values used to quantify hip morphology, and the imaging techniques.

***Age***

Cam morphology is less prevalent in adolescents than in adults and has been shown to gradually increase during skeletal growth.[2,4,137,140,159,160,173] Cam morphology can first be identified and starts to develop from the age of 12 years[2,137,159], with prevalence increasing with age until the completion of growth.[4] In addition, the extent of athletic activity during skeletal growth may increase the risk of cam morphology development.[4,137,160] Cam morphology is, therefore, an acquired phenomenon during the second growth spurt and highly influenced by exercise-related loads applied to the hip during this phase.

### *Sex*

Cam morphology is probably more common in males. The prevalence of cam morphology in asymptomatic males ranges from 13.0% to 72.0%, compared to 0.0% to 11.7% in asymptomatic women *(Table 1)*.[81,83,98,142] Studies on symptomatic individuals are more inconsistent because of the selection bias related to symptomatic status. A study by Clohisy et al.[28] showed an average prevalence of cam morphology of 47.6% in a symptomatic group of 1076 patients (55% women and 45% men) who underwent surgery for FAI syndrome. Symptomatology and functional limitations are preoperatively significantly more severe in females compared with males.[76,127]

### *Ethnicity*

Mosler et al.[119] identified a significantly lower prevalence of cam morphology among young East Asian (19%) professional football players when compared to other ethnicities, including Arabic, black, Persian, and white players, in whom the prevalence ranged between 58% and 72%. Similarly, cam morphology prevalence was shown to be lower in asymptomatic Chinese men and women compared to Caucasians in another article.[188] In contrast, another prevalence study of asymptomatic older-aged individuals reported that East Asian populations have a high prevalence of cam morphology (45.3% of 1178 hips).[112]

### *Athletic activity*

In their systematic review and meta-analysis, Nepple et al.[128] reported that professional athletes exhibit a higher prevalence of cam morphology relative to non-athletic individuals. The pooled prevalence of cam morphology in male athletes was 41%, compared with 17% in male controls. In another systematic review[49], the authors reported prevalence of cam morphology in up to 55% of male athletes, compared with 23% in the general population. In their systematic review, Dickenson et al.[35] reported prevalence of cam morphology in athletes ranging from 48% to 75%.

### *Symptomatology*

It is currently unknown whether the presence of cam morphology by itself is associated with symptoms. Only 1 prospective study is available, which investigated 200 asymptomatic volunteers over a period of 4.4 years and showed that the presence of cam morphology resulted in a relative risk of 4.3 (95% confidence interval [CI]: 2.3, 7.8) of developing hip pain.[89] Similarly, a cross-sectional study found an association between an increased alpha angle (indicative of cam morphology) and prior or current athletic-related groin pain in 125 collegiate National Football League prospects.[95] This is consistent with the results of another study that showed a relationship between cam morphology based on higher alpha angles and hip symptoms.[12] However, Gosvig et al.[59], studying a large population of 3202 individuals, showed no significant association between self-reported hip pain and cam morphology. Other studies also could not identify an association between symptoms and cam morphology.[13,85,124] When asymptomatic and symptomatic subgroups were compared, Mascarenhas et al.[108] found a higher prevalence of cam morphology in symptomatic hips compared to asymptomatic hips. However, these studies consisted generally of less than 50 participants per subgroup.

| Study (follow-up) | Group | Definition of cam morphology | Individuals (hips), n |
|---|---|---|---|
| **Agricola et al.**[2] | Athletes: football | AA >60° and/or VS: flattening or prominence | 89 (178) cases, 92 (184) controls |
| **Agricola et al.**[4] **(2 y)** | Athletes: football | AA >60° and/or VS: flattening or prominence | 62 (126) |
| **Anderson et al.**[13] | Senior athletes | NA | 547 (1081) |
| **Hack et al.**[65] | Volunteers | AA >50.5° | 200 (400) |
| **Jung et al.**[81] | Abdominal pelvic, or other medical issue | AA >68° (men), AA >50° (women) | 380 (755) |
| **Kang et al.**[82] | Abdominal trauma or nonspecific abdominal pain | AA >55° | 50 (100) |
| **Kapron et al.**[83] | Athletes: collegiate football | AA >50° and/or HNO <8 mm | 67 (134) |
| **Kapron et al.**[85] | Athletes: collegiate volleyball, football, track and field | AA >50° and/or HNO <8 mm | 63 (126) |
| **Khanna et al.**[89] **(4.4 y)** | Volunteers | AA >50.5° and second analysis with AA >60° | Baseline, 200 (400); follow-up, 170 (340) |
| **Laborie et al.**[91] | Follow-up of initial newborns | Pistol-grip deformity, flattening and prominence | 2060 (4120) |
| **Larson et al.**[95] | Athletes: collegiate football | AA >55° | 125 (239) |
| **Lerebours et al.**[97] | Athletes: ice hockey | AA ⩾55° | 130 (260) |
| **Leunig et al.**[98] | Females from vocational/grammar school, males from Swiss Army | AA >50.5° | 324 (324) |
| **Li et al.**[99] | Children with disorder unrelated to hip | AA ⩾55° | 558 (1116) |
| **Mineta et al.**[112] | Disorder unrelated to hip (Japanese) | AA >55° and/or FHNO ratio <0.15 | 1178 (1178) |
| **Mosler et al.**[119] | Athletes: football | AA >60° | 445 (890) |
| **Philippon et al.**[140] | Athletes: ice hockey | AA ⩾55° | 61 (NA) cases, 27 (NA) controls |

**TABLE 1A**: Prevalence of cam morphology in asymptomatic individuals

| Age, y* | Sex (male, female), % | Imaging modality | Prevalence (male, female), %† |
|---|---|---|---|
| Cases 14.8 (12-19); controls, 13.8 (12-19) | 100, 0 | AP and FLL radiography | Cases: AA, 26; VS, 66<br>Controls: AA, 17; VS, 18 (per hip) |
| 16.63 ± 2.07 | 100, 0 | AP and FLL radiography | AA, 38.9; VS, 69.0 (per hip) |
| 67 ± 8 | 55, 45 | AP and FLL radiography | 66.7 (per hip) |
| 29.4 (21.4-50.6) | 44, 56 | MRI | 24.7, 5.4 (per person) |
| 60.4 (25-92) | 28, 72 | Abdominal or pelvic AP scout CT | 28.8, 11.7 (per hip) |
| NA (15-40) | 46, 54 | Abdominal CT | 10.0 (per hip) |
| 21 ± 1.9 | 100, 0 | AP and FLL radiography | AA, 72; HNO, 64 (per hip) |
| 19.6 ± 1.4 | 0, 100 | AP and FLL radiography | 48 (per hip), 60 (per person) |
| Follow-up, 29.5 (25.7–54.5) | 45.3, 54.7 | MRI | Follow-up, 25.9 (per hip) |
| 18.6 (17.2-20.1) | 42.1, 57.9 | AP and FLL radiography | 35.0, 10.2 (per person) |
| NA | 100, 0 | AP and FLL radiography | 65.3 (per hip), 75.2 (per person) |
| 24.4 ± 4.3 | NA | AP and FLL radiography | 69.4 (per hip) |
| Male 20.0 ± 0.9; female, 19.3 ± 1.3 | 75.3, 24.7 | MRI | 24.0, 0.0 (per person) |
| 14.4 (10-18.2) | 49.5, 50.5 | Pelvic CT | 23.9, 9.9 (per person) |
| 58.2 ± 14.8 (20-89) | 59, 41 | Abdominal and pelvic CT | 54.4, 32.3 (per hip) |
| 25 ± 4.9 | 100, 0 | AP pelvic and Dunn-view radiography | 72 (per person) |
| Cases 14.5 ± 2.7 (10-18); controls, 15.2 ± 2.7 (10-18) | 100, 0 | MRI | Cases, 75;<br>controls, 42 (per person) |

| Study (follow-up) | Group | Definition of cam morphology | Individuals (hips), n |
|---|---|---|---|
| **Pollard et al.**[142] | General population | AA >62° and AOR <0.14 | 83 (166) |
| **Reichenbach et al.**[149] | Swiss Army recruiters | 2: cam, AHNO <10mm<br>3: severe cam, AHNO >10mm | 244 (244) |
| **Van Houcke et al.**[188] | Chinese and Belgian | AA >55° | Chinese 102 (204);<br>Belgian, 99 (198) |

**Abbreviations**: AA, alpha angle; AHNO, anterior head-neck offset; AOR, anterior offset ratio; AP, anteroposterior; CT, computed tomography; FHNO, femoral head-neck offset; FLL, frog-leg lateral; HNO, head-neck offset; MRI, magnetic resonance imaging; NA, not available; VS, visual scoring.
* Values are mean ± SD (range) or mean (range).
† If prevalence per sex is not specified, then the overall prevalence is presented.

**TABLE 1B**: Prevalence of cam morphology in asymptomatic individuals

| Age, y* | Sex (male, female), % | Imaging modality | Prevalence (male, female), %† |
|---|---|---|---|
| Male, 47.5 (25-69); female, 44.4 (22-67) | 47, 53 | Cross-table lateral radiography | 13.0, 7.0 (per person) |
| 19.9 (18-24) | 100, 0 | MRI | 24.0 (per person) |
| NA (18-40) | 52.2, 47.8 | CT | Chinese: 31, 17; Belgian: 41, 39 (per hip) |

## Pincer morphology

### *Prevalence*

Pincer morphology is even more heterogeneously defined than cam morphology. However, similar to cam morphology, the prevalence of pincer morphology appears to vary across different subpopulations.

### *Age*

Only a few studies have been published on how the prevalence of pincer morphology changes with age. A study on an asymptomatic paediatric and adolescent population with a mean age of 10.4 years identified the presence of pincer morphology starting at 12 years of age.[114] In adolescents with an average age of 14.4 years, Li et al.[99] reported a prevalence of pincer morphology of 32.4%. Laborie et al.,[91] in a study of 2081 young adults with an average age of 18.6 years, reported the prevalence of pincer morphology to be 34.3% in men and 16.6% in women *(Table 2)*.

### *Sex*

Multiple studies have directly compared the incidence of pincer morphology between males and females, showing very little difference. Li et al.[99] did not find a difference in prevalence of pincer morphology between asymptomatic males and females. Prevalences of 29.7% and 35.1% in males and females ($P = .17$) were presented. Other studies showed conflicting results. A higher prevalence of pincer morphology in males was observed in the study of 2081 individuals by Laborie et al.[91], who reported a prevalence of pincer morphology of 34% in males, compared to 17% in females ($P < .001$). In contrast, coxa profunda was found to be significantly associated with female sex in 3 studies.[31,37,70] Two additional studies provided data on the prevalence of pincer morphology only in women, which ranged between 1% and 10%.[85,98] In comparison, the reported prevalence in males has ranged between 3% and 66%.[83,119] There is also probably not a great difference in prevalence of pincer morphology between sexes in symptomatic individuals, based on a study by Nepple et al.[127], who showed a prevalence of isolated pincer morphology in 56% of males and 47% of females ($P = .46$) undergoing FAI surgery.

### *Ethnicity*

Less is known about the association between pincer morphology and ethnicity. The study of Mosler et al.[119] compared the prevalence of pincer morphology (lateral center-edge angle [LCEA] greater than 40°) between young football players with different ethnic backgrounds. No pincer morphology was found in white and East Asian football players. Arabic (3.6%), black (2.3%), and Persian football players (1.7%) also showed a low prevalence. Tannenbaum et al.[175] did not find a difference in acetabular retroversion of pelvic specimens between African Americans and Caucasians. Several studies only investigated Asian persons, specifically Japanese, and found a prevalence of pincer morphology ranging from 7.4% to 37.4%.[11,51,112,115]

### *Athletic activity*

The prevalence of pincer morphology in athletes is highly variable. Harris et al.[70] investigated a group of elite ballet dancers and found a prevalence of 74%. In studies that investigated football players, prevalence of pincer morphology ranged from 3% to 66%.[54,83,119] A study that combined different types of athletes (volleyball, football, and track and field) found a pincer morphology prevalence of 1%.[85] In elite ice hockey players, Lerebours et al.[97] found a prevalence of pincer morphology of 59.8%. Systematic reviews by Frank et al.[49] and Mascarenhas et al.[108] found a prevalence of pincer morphology in athletes of 49.5% and 51.2%, respectively.

### *Symptomatology*

Comparisons between symptomatic and asymptomatic subgroups were presented in a recent systematic review by Mascarenhas et al.[108], which included 60 studies. Pincer morphology prevalence in the asymptomatic subgroup, as reported in only 1 study, was 57%. In symptomatic individuals across studies, the average mean ± SD prevalence of pincer morphology was 28.5% ± 19.2%. The reported prevalence of pincer morphology in asymptomatic individuals in the systematic review by Frank et al.[49] was 67% (range, 61%-76%). That systematic review, which included 26 studies, did not report on symptomatic individuals. These results differ from data of Gosvig et al.[60], who reported lower prevalence rates of pincer morphology in men (15.2%) and women (19.4%) in a population-based study. A study by Ahn et al.[11] showed pincer prevalence rates in asymptomatic males and females of 27% and 21%, respectively.

## Relationship between cam morphology and hip OA

In most studies, cam morphology has been associated with hip OA. The strength of association in several cross-sectional and retrospective studies has varied between odds ratios (ORs) of 2.2 (95% CI: 1.7, 2.8) and 20.6 (95% CI: 3.4, 34.8).[19,38,60] The number of well-designed epidemiological studies assessing the relationship between cam morphology and hip OA is limited. Three prospective cohort studies and 2 nested case-control studies that included people without hip OA at baseline demonstrated an association between cam morphology and development of hip OA later in life *(Table 3)*.[3,125,133,156,176] The strength of association varies between ORs of 2.1 (95% CI: 1.6, 2.9) and 9.7 (95% CI: 4.7, 19.8), primarily depending on the alpha angle threshold used for diagnosis. The positive predictive value for developing end-stage OA within 5 years when having cam morphology was 10.9% for an alpha angle greater than 60° and 25.0% for an alpha angle greater than 83°.[3]

| Study | Group | Definition of pincer morphology | Individuals (hips), n |
|---|---|---|---|
| **Ahn et al.**[11] | Korean volunteers | COS, PWS, or LCEA >40° | 200 (400) |
| **de Bruin et al.**[31] | Pelvic radiography patients | CEA >39°, AI <0°, CP, PA, AR | 262 (522) |
| **Diesel et al.**[37] | Volunteers | LCEA >40°, AI <0°, COS, CP | 226 (452) |
| **Gerhardt et al.**[54] | Athletes: elite football | COS | 95 (190) |
| **Harris et al.**[70] | Athletes: elite ballet | PWS, COS, ISS, LCEA >40°, CP, PA | 47 (94) |
| **Kang et al.**[82] | Abdominal trauma or nonspecific abdominal pain | AV <15°, COS, AO/CP (CEA >40°) | 50 (100) |
| **Kapron et al.**[83] | Athletes: collegiate football | LCEA >40°, AI <0°, and/or COS | 67 (134) |
| **Kapron et al.**[85] | Athletes: collegiate volleyball, football, track and field | LCEA >40°, LCEA >40 and AI <0° | 63 (126) |
| **Laborie et al.**[91] | Follow-up of initial newborns | 1 or more findings: COS, PWS, AO | 2060 (4120) |
| **Lerebours et al.**[97] | Athletes: ice hockey | COS | 130 (260) |
| **Leunig et al.**[98] | Females from vocational/grammar school, males from Swiss Army | AD ≤3 mm | 324 (324) |
| **Li et al.**[99] | Children with disorder unrelated to hip | LCEA >40° | 558 (1116) |
| **Mineta et al.**[112] | Japanese population, reason unrelated to hip | LCEA >40°, AI <0°, COS | 1178 (1178) |
| **Monazzam et al.**[114] | Abdominal problems | LCEA >40°, TA ≤0°, AR (AV ≤0° and LCEA >40°) | 225 (450) |
| **Mosler et al.**[119] | Athletes: elite football | LCEA >40° | 445 (890) |

**Abbreviations**: AD, acetabular depth; AI, acetabular index; AO, acetabular overcoverage; AP, anteroposterior; AR, acetabular retroversion; AV, acetabular version; CEA, center-edge angle; COS, crossover sign; CP, coxa profunda; CT, computed tomography; FLL, frog-leg lateral; ISS, ischial spine sign; LCEA, lateral center-edge angle; MRI, magnetic resonance imaging; NA, not available; PA, protrusion acetabuli; PWS, posterior wall sign; TA, Tönnis angle.

**TABLE 2**: Prevalence of pincer morphology in asymptomatic individuals

| Age, y* | Sex (male, female), % | Imaging modality | Prevalence (male, female), %† |
|---|---|---|---|
| 34.7 (21-49) | 36.5, 63.5 | AP, Sugioka, and 45° Dunn radiography | 27, 21 (per person) |
| NA | 38, 62 | AP radiography | 63.2 (per hip) |
| 36.5 (28-50) | 46.3, 53.7 | AP radiography | 10.9, 10.9; 30.3, 31.2; 10.9, 16.7; 60.5, 92 (per hip); |
| 25.4 ± 4.2 | 79, 21 | AP pelvis and FLL radiography | 26.7, 10 (per person) |
| 23.8 ± 5.4 | 45, 55 | AP pelvis, false-profile, and Dunn 45° radiography | 74 (per person) |
| NA (15-40) | 46, 54 | Abdominal CT | 13, 1<br>20<br>9, 7 (per hip) |
| 21 ± 1.9 | 100, 0 | AP pelvis and FLL radiography | 52 (1 sign), 10 (2 signs), 4 (3 signs) (per hip) |
| 19.6 ± 1.4 | 0, 100 | AP pelvis and FLL radiography | 1 (per hip), 2 (per person)<br>1 (per hip), 2 (per person) |
| 18.6 (17.2-20.1) | 42.1, 57.9 | AP and FLL radiography | 34.3, 16.6; 51.4, 45.5; 23.4, 11; 14.6, 4.9 (per person) |
| 24.4 ± 4.3 | NA | AP and FLL radiography | 59.8 (per person) |
| Male, 20.0 ± 0.9; female, 19.3 ± 1.3 | 75.3, 24.7 | MRI | 6, 10 (per person) |
| 14.4 (10-18.2) | 49.5, 50.5 | Pelvic CT | 29.7, 35.1 (per person) |
| 58.2 (20-89) | 59, 41 | Pelvic CT | 41.7, 31.3 (per hip) |
| 10.4 (2-19) | 45.8, 54.2 | Pelvic CT | 5.8, 2.0<br>4.4, 5.3<br>6.8, 4.1 (per hip) |
| 25 ± 4.9 | 100, 0 | AP and Dunn radiography | 3.0 (per person) |

* Values are mean ± SD, mean ± SD (range), or mean (range).
† If prevalence per sex is not specified, then the overall prevalence is presented.

| Study (follow-up) | Individuals (hips), n | Age, y* | Sex (male, female), % | Definition of cam and pincer morphology |
|---|---|---|---|---|
| **Agricola et al.[3] (5 y)** | 723 (1411) | 55.9 ± 5.2 (45-65) | 20, 80 | Cam: AA >60°, AA >83°, AA >83° and IR ≤20° |
| **Agricola et al.[5] (5 y)** | 720 (1391) | 55.9 ± 5.2 (45-65) | 21, 79 | Pincer: LCEA >40° or ACEA >40° |
| **Nelson et al.[125] (6 y, 12.7 y)** | 120 (239: cases, 71; controls, 168) | Cases 63 ± 8; controls, 62 ± 9 | 25, 75 | Cam: AA >60° Pincer: LCEA >40° |
| **Nicholls et al.[133] (19 y)** | 135 (268: cases, 25; controls, 243) | 55 (50-60) | 0, 100 | Cam: AA Pincer: LCEA |
| **Saberi Hosnijeh et al.[156] (9.2 y)** | 4438 (RS-1, 2960; RS-II, 1478) | RS-I, 65.1 ± 6.4; RS-II, 62.9 ± 6.4 | RS-I: 43, 57; RS-II: 44, 56 | Cam: AA >60° Pincer: CEA >40° |
| **Thomas et al.[176] (19 y)** | OA group, 340 (634); THR group, 734 (1466) | 54.2 (44-67) | 0, 100 | Cam: AA >65° Pincer: LCEA >33.7° |

**Abbreviations:** AA, alpha angle; ACEA, anterior center-edge angle; AP, anteroposterior; CEA, center-edge angle; IR, internal rotation; KL, Kellgren-Lawrence; LCEA, lateral center-edge angle; NA, not applicable; NS, not significant; OA, osteoarthritis; RS, Rotterdam study; THR, total hip replacement.

**TABLE 3**: Characteristics of multiple longitudinal studies on relationship between cam/pincer morphology and OA, all based on AP radiographs

| Cam morphology prevalence, % | Pincer morphology prevalence, % | Definition of OA | Odds ratio for hip OA† |
|---|---|---|---|
| 11.1 | NA | End-stage OA: KL grade ⩾3 or THR | 3.67 (1.68, 8.01)<br>9.66 (4.72, 19.78)<br>25.21 (7.89, 80.58) |
| NA | 54.6 | End-stage OA: KL grade ⩾3 or THR | 0.34 (0.13, 0.87) |
| Male: cases, 59; controls, 40;<br>Female: cases, 47; controls, 18 | Male: cases, 10; controls, 6<br>Female: cases 24, controls, 17 | OA: KL grade ⩾3 or THR | Male, 3.57 (1.17,10.90)<br>Female, 4.61 (2.09,10.16)<br>NS in males and females |
| NA | NA | End-stage OA: THR | 1.052 per 1° increase<br>NS |
| RS-I: left, 8.3; right, 6.4<br>RS-II: left, 7.2; right, 7 | RS-I: left, 10,9; right, 8.9<br>RS-II: left, 13.5; right, 8.6 | Incident OA: KL grade ⩾2 or THR | 2.11 (1.55, 2.87)<br>NS |
| NA | NA | OA: KL grade ⩾2; end-stage OA: THR | OA, 1.05 (1.01, 1.09)<br>THR, 1.04 (1.00, 1.08)<br>NS for OA and THR |

* Values are mean ± SD, mean ± SD (range), or mean (range).
† If odds ratios per sex are not specified, then the overall odds ratio is presented. Values in parentheses are 95% confidence interval.

## Relationship between pincer morphology and OA

Pincer morphology does not appear to play a role in the development of hip OA. Three prospective cohort studies defined the presence of pincer morphology by a center-edge angle of greater than 33.7° or 40°.[5,156,176] In the CHECK cohort[5], pincer morphology was measured both laterally (on anteroposterior [AP] pelvic radiographs) and anteriorly (on false-profile lateral radiographs). Neither anterior pincer morphology nor lateral pincer morphology was associated with development of hip OA within 5 years. Surprisingly, when pincer morphology was present both anteriorly and laterally, a significant protective effect for development of end-stage OA was found (OR = 0.34; 95% CI: 0.13, 0.87). This is consistent with the data from the Chingford cohort[176], which did not identify an association between higher LCEAs (only measured on AP radiographs) and development of hip OA. In this cohort, the continuous measure of the LCEA was divided into tertiles. Having a LCEA in the highest tertile (greater than 33.7°) was neither associated with development of radiographic hip OA (defined as a Kellgren and Lawrence[86] grade of 2 or greater [P = .64]) nor with the need for total hip replacement (P = .67) 19 years later. Finally, results from the Rotterdam study[156] also failed to show an increased risk of developing hip OA at a follow-up of 9.2 years, with an OR of 1.24 (95% CI: 0.93, 1.66) for pincer morphology.

# Discussion

Cam and pincer morphology is common in the general population, but the prevalence rates vary greatly among studied subpopulations. Cam morphology is associated with future development of hip OA, whereas a link between pincer morphology and OA has never been identified in epidemiological studies. It is important to recognize that all of the studies on the prevalence of cam morphology and its association with OA investigated morphology only and that cam morphology does not equate to FAI syndrome, which also includes the presence of symptoms and clinical findings.[62]

## Differences and limitations in quantifying cam morphology

There is a large variation in the reported prevalence of cam and pincer morphology between subgroups, with some of that variation attributed to the variability in methodology used to determine the presence of cam and pincer morphology. In the literature, while the alpha angle is an accepted measure to define cam morphology[134], the angular thresholds that are used vary from 50° to 83°.[7,58,134] Furthermore, alpha angles can be measured by different imaging techniques, including radiographs, computed tomography, and magnetic resonance imaging. Generally, using radial imaging (computed tomography and magnetic resonance imaging) with multiple measurement points around the femoral neck is more likely to detect the presence of cam morphology than 2-dimensional imaging (radiographs), and thus results in higher prevalence.[39] However, the use of multiple measurement points might increase the false-positive rate.

## Differences in cam morphology prevalence in subgroups

The differences in the prevalence of cam morphology between subgroups might provide some clues on aetiology. The greatest differences in prevalence are observed between athletes and non-athletes. The high prevalence of cam morphology observed in athletes might be due to repetitive axial loading, especially during skeletal maturation.[4,137,154,160] This might also partly explain the lower prevalence in females, as they mature earlier than males and probably have less exposure to repetitive axial loading during the second growth spurt, when cam morphology usually develops in males. Cam morphology is probably less frequent in the East Asian population, even in those with an athletic background. However, evidence is conflicting, and no direct relationship between genetics and cam morphology has been established yet. Finally, whether the isolated presence of cam morphology is associated with, or predictive for, symptoms and/or hip pain is unknown. Though subgroups with a higher prevalence of cam morphology have been identified, it should be emphasised that most of these studies suffer from a high risk of bias[35], and caution should be exercised when interpreting their findings.

## Differences and limitations in quantifying pincer morphology

The prevalence of pincer morphology is also highly dependent on how it is quantified and the imaging technique used.[5] Pincer morphology can be further defined as having focal or global (acetabular) overcoverage. Focal overcoverage has been defined by several indirect measures, such as the crossover sign, posterior wall sign, and ischial spine sign, which all have generally poor reliability and validity to define true retroversion/pincer morphology.[204] Global overcoverage can be defined by the presence of coxa profunda or protrusio acetabuli or the center-edge angle.[15,126] Coxa profunda and protrusio acetabuli do not seem to be associated with the presence of pincer morphology.[126] Therefore, due to this heterogeneity in definition, it is difficult to compare prevalence studies on pincer morphology.

## Pincer morphology and hip OA

The prospective studies on the association between pincer morphology and hip OA all used the LCEA on AP radiographs and are therefore comparable.[5,125,133,156,176] However, none of these epidemiological studies could identify an association between pincer morphology and development of OA. It is also notable that 2 systematic reviews found a higher prevalence of pincer morphology in asymptomatic individuals than in symptomatic patients.[49,108] The reader should also bear in mind that although discussed separately, cam and pincer morphology types are frequently found together, also known as a mixed-type morphology.[109]

## Cam morphology and hip OA

Despite the reported association between cam morphology and development of hip OA, one should keep in mind that the majority of people with cam morphology will not develop hip OA. Of the hips with cam morphology, between 6% and 25% will develop future OA within 5 to 19 years.[3,133] For cross-sectional and retrospective studies, an important confounder is that the radiographic appearance of OA might mimic cam morphology. For example, the presence of osteophytes on the femoral head and/or flattening of the femoral head may be related to the OA process. This is hard to distinguish when OA and cam morphology are assessed on the same radiographs. This is less of an issue in a few well-designed prospective studies summarised in *Table 3*, but these studies have other methodological limitations, such as the imaging modalities used and age of the participants.[3,5,125,133,156,176] All of these studies used AP pelvic radiographs, and although this is the gold standard to quantify hip OA, it is suboptimal to define the presence of cam morphology. Only the more laterally located cams are seen on AP radiographs, and the prevalence is therefore underestimated. The influence of this underestimation on the true association with hip OA is unknown. Further, the studies summarised only included middle-aged to older people. The youngest participants included in the CHECK[3] and Chingford[176] cohorts were approximately 45 years of age, with mean ages of 56 and 54 years, respectively. The oldest people were included in the Rotterdam study[156] (minimum age, 55 years; mean age, 64 years) and in the Johnston County OA cohort study[125] (mean age, 62 years). As cam morphology develops during skeletal growth, in most cases, it is already present during early adulthood. Therefore, the relationship between cam morphology and hip degeneration between early adulthood and the age of 45 years is unknown. Some indications suggest that this relationship might be stronger in younger people than in middle-aged to older people. First, the Rotterdam study showed a stronger relationship between cam morphology and OA in people 65 years of age or younger (OR = 3.1; 95% CI: 2.1, 4.6), while the association disappeared in people over 65 years of age (OR = 1.4; 95% CI: 0.9, 2.2).[156] Second, features known to be associated with hip OA have been identified in younger populations[18,110,148], with the severity of cam morphology associated with the presence of labral tears and chondral defects.[148] A cross-sectional study of asymptomatic participants with a mean age of 20 years showed a decrease in cartilage thickness in those with cam morphology.[150] Finally, from intraoperative findings, it is known that severe cartilage damage can already exist in young people with cam morphology.[23,28] However, well-designed studies in young adults are lacking.

## Future studies

Based on the results of this overview, there is a need for standardising criteria to determine the presence of cam and pincer morphology. The alpha angle is most often used and, despite its limitations, is probably the best measure to date of cam morphology. Future studies should therefore, at least, report the alpha angle. An alpha angle threshold of 60° has been proposed for AP radiographs[8], but there is no validated threshold for other radiographic views. To aid future comparison between studies, it might be helpful to present results for different alpha angle threshold values. Many people with cam or pincer morphology will not develop any symptoms from this bony variant. Future studies should, therefore, also focus on characteristics that can differentiate persons with cam and pincer morphology who will become symptomatic and/or develop hip OA. Characteristics that may be worth considering include hip muscle strength, hip range of motion, gait-pattern characteristics, the size of cam morphology, and the type and amount of physical activities performed. This might lead to the identification of modifiable risk factors to prevent, stop, or slow down disease progression and also help avoid overtreatment. Future studies should also monitor whether treatment for FAI syndrome, nonsurgical or surgical, can stop or slow down the progression toward hip OA.

# Conclusion

Cam and pincer morphology is highly prevalent in the general population. Cam morphology is linked to hip OA in the middle-aged population, but no data are available on its relationship among younger people. The association between pincer morphology and hip OA has not been demonstrated in the available prospective cohort studies. The presence of cam and/or pincer morphology does not always lead to FAI syndrome and subsequent hip OA, and future research should focus on identifying factors that may predict who becomes symptomatic (FAI syndrome) in the presence of cam and/or pincer morphology and who subsequently will progress to have hip OA later in life.

## Conflict of interest

The authors certify that they have no affiliations with or financial involvement in any organisation or entity with a direct financial interest in the subject matter or materials discussed in the article.

*Chapter 09*

# Summary

In this chapter, the most important findings of all chapters based on the pre-defined aims will be summarised and highlighted. The chapters will touch upon normal values of hip muscle strength, range of motion (ROM) and symptoms in athletes, an evidence summary and proposed alpha angle threshold for cam morphology, the association between cam morphology presence, size and duration and growth plate status, hip parameters, clinical signs and symptoms, and finally the prevalence of cam- and pincer morphology and association with hip osteoarthritis (OA).

In *chapter 2* we presented normal values of hip muscle strength and the Hip And Groin Outcome Score (HAGOS) questionnaire in professional male football players. This validated questionnaire represents hip and groin symptoms. Unique about this chapter is the fact that we obtained information at three prospective time points within one season; at the start, at the middle and at the end of the football season. This gave us extra information about how hip muscle strength and symptoms evolved during a full season, something which was not yet known in literature. Important is the fact that no clinically important differences in hip muscle strength and HAGOS scores over the season were observed, which means that the same normal values can be applied as reference values at any time point during the season. Participants with a previous groin injury or a previous injury other than the groin had significantly lower HAGOS scores, which means that they still had more hip and groin symptoms than their non-injured peers.

*Chapter 3* connects to *chapter 2*, as it also investigated normal values of hip muscle strength in professional athletes. However, this study is performed in professional field hockey players and no reference literature about this sport was available. Normal values for hip ROM were also determined. Several other parameters such as age, leg dominance, playing position, playing level and non-time-loss groin pain had no clinical effect on these values. This chapter helps clinicians to get insight into reference values for professional field hockey players and guide them in the assessment and management of hip and groin injuries.

Thereafter in *chapter 4*, the focus is shifted to cam morphology. This extra bone formation on the anterolateral side of the head-neck junction is mostly classified by measuring the alpha angle and a consistent threshold value is warranted. This is necessary to study the aetiology of cam morphology, to compare prevalence numbers between studies and explore its association with hip pathology. In this systematic review we included 15 studies, of which 3 used a receiver operating characteristics (ROC) curve analysis to distinguish asymptomatic people from people with femoroacetabular impingement (FAI) syndrome, which is in our opinion a very relevant method to classify cam morphology. Another study showed a bimodal distribution of the alpha angle in two large independent cohorts. Interestingly, these four studies all showed a threshold value of around 60° to classify cam morphology. All other studies, who mostly used 95% reference intervals, showed a much wider distribution of proposed alpha angle thresholds. We suggested to report a non-sex specific alpha angle threshold value of at least 60° to classify cam morphology.

To further clarify the aetiology of cam morphology, in *chapter 5* we studied the development of cam morphology during and after growth in adolescent male football players. This study was a 5-year follow-up cohort study of professional football players of whom X-rays of their pelvis and both hips were obtained, as well as questionnaires and a physical examination. This study focused on the relationship between cam morphology development and the growth plate status, as it was not yet known if cam morphology only developed during growth or also after growth plate closure. We observed a clear association between cam morphology development and an open growth plate, which means that cam morphology only develops during growth. This can be a very interesting finding because it provides a window in which cam morphology develops and thus might be prevented.

*Chapter 6* studied the same cohort of professional male football players as in *chapter 5*. In *chapter 6* the focus lies on hip parameters who might influence the biomechanical stress through the hip joint. Radiological and clinical parameters were investigated, such as the varus or valgus position (neck-shaft angle [NSA]), shape and position of the femoral growth plate (epiphyseal extension [EE]), shape of the lateral acetabulum (lateral center-edge angle [LCEA]) and function of the hip by measuring the amount of internal rotation. The aims were to study whether these parameters precede cam morphology development and if they are associated with cam morphology presence and size. The most important findings were that none of these parameters preceded cam morphology development, but NSA, EE and internal rotation were associated with cam morphology. This means that these parameters develop simultaneously with cam morphology.

In *chapter 7*, data from the same cohort as *chapters 5 and 6* were used to study if cam morphology presence, size and duration are associated with hip and groin symptoms (HAGOS questionnaire) and hip ROM as measured by goniometry. The association between cam morphology and symptoms is not fully unraveled in current literature and this study might be an important addition for the clinician. Main findings were that cam morphology presence and size are associated with a limited flexion of 6° and internal rotation of 3-6° and that no clinical relevant association was found between cam morphology presence, size or duration and symptoms. This means that the relationship between cam morphology and symptoms remains unclear and urgently needs more longitudinal research in the future.

*Chapter 8* provides a general overview of the prevalence of cam and pincer morphology and the association with future hip OA. For cam morphology, a prevalence between 5 and 75% was observed, depending on the population characteristics (e.g. age, sex, ethnicity, athletic activity, symptomatology). Pincer morphology is even more heterogeneously defined and therefore its prevalence has a wide variation across different subpopulations. Hip OA will be an increasing problem in the future and will result in a huge health burden and costs. This overview showed a clear association between cam morphology and the development hip OA, but no association between pincer morphology and hip OA was observed.

*Chapter 10*

# General discussion, conclusion and future perspectives

# General discussion

Chapter 10

This general discussion is partly based on recent international consensus statements and recommendations on hip-related pain in young active adults in which I participated. This resulted in 5 papers which I co-authored.

***'Consensus recommendations on the classification, definition and diagnostic criteria of hip-related pain in young and middle-aged active adults from the International Hip-related Pain Research Network, Zurich 2018.'***

M.P. Reiman et al., Br J Sports Med. 2020 Jan 20

***'Standardised measurement of physical capacity in young and middle-aged active adults with hip-related pain: recommendations from the first International Hip-related Pain Research Network (IHiPRN) meeting, Zurich, 2018.'***

A.B. Mosler et al., Br J Sports Med. 2019 Dec 19

***'Patient-reported outcome measures for hip-related pain: a review of the available evidence and a consensus statement from the International Hip-related Pain Research Network, Zurich 2018.'***

F. Impellizeri et al., Br J Sports Med. 2020 Jan 24

***'Physiotherapist-led treatment for young to middle-aged active adults with hip-related pain: consensus recommendations from the International Hip-related Pain Research Network, Zurich 2018.'***

J.L. Kemp et al., Br J Sports Med. 2019 Nov 15

***'Infographic. Consensus recommendations on the classification, definition and diagnostic criteria of hip-related pain in young and middle-aged active adults from the International Hip-related Pain Research Network, Zurich 2018.'***

M.P. Reiman et al., Br J Sports Med. 2020 Jul 29

In this chapter, the results and findings of the previous chapters will be discussed and future perspectives highlighted. First, athletes' normal values of hip muscle strength, range of motion (ROM) and Hip And Groin Outcome Score (HAGOS) questionnaires will be touched upon. Followed by the classification and development of the 'non-perfect hip' in young athletes, by means of its bony morphology and clinical consequences.

## From mess to consensus

Over the last years, several consensus meetings were held to agree on terminology, classification, diagnosis and treatment strategies of hip and groin related issues. Before this, it was a 'messy' area because multiple definitions for the same pathology existed, classification criteria were unclear and there was no consensus on the diagnosis nor the treatment. Firstly, in 2015, the clinical entities for groin pain were agreed upon to use as consistent terminology.[197] This resulted in the introduction of four clinical entities for groin pain (adductor-, iliopsoas-, inguinal- and pubic-related) and recognition of a fifth entity, hip-related pain. Hip-related groin pain was further discussed in 2016, with an international consensus statement meeting focusing on the terminology and clinical diagnosis of femoroacetabular impingement (FAI) syndrome. FAI syndrome was defined as: the presence of a triad of symptoms, clinical signs and radiological findings.[62] Also agreement was reached about consistent terminology for the radiological findings associated with FAI syndrome. Previously terminology such as 'symptomatic FAI', 'FAI deformity' or 'cam deformity, cam abnormality or cam lesion' was used. In the Warwick Agreement, consensus was reached to use the term 'morphology' for radiological findings. All three criteria for FAI syndrome (symptoms, clinical signs, diagnostic imaging) are discussed in this thesis.

Following these consensus meetings, in 2018, the first International Hip-related Pain Research Network (IHiPRN) meeting was held to reach consensus about recommendations for young active adults with hip pain. Recommendations for the classification, definition, diagnostic criteria[153], standardised measurement of physical capacity[120], patient reported outcome measures (PROMs)[75] and physiotherapy-led treatment[88] of hip-related pain were agreed upon. These recommendations will be summarised in above mentioned order.

## Classification of hip pain

The first IHiPRN consensus agreed on a classification of hip-related pain with three well-defined hip conditions:

1. FAI syndrome.
2. Acetabular dysplasia and/or hip instability.
3. Other causes without osseous morphology which can include soft tissue conditions such as labral, chondral and/or ligamentum teres conditions.

## Diagnosing hip-related pain in young adults

The literature shows that the FADIR (flexion, adduction, internal rotation) has a high sensitivity and low specificity and can therefore be used to rule out hip-related pathology when it is negative. The utility of imaging alone in hip-related pain patients is limited as it must be combined with patients' symptoms and clinical signs.[62] For imaging, agreement was reached that an anteroposterior pelvis and lateral femoral heck-neck radiograph could assist for diagnosing hip-related pain. Additional three-dimensional imaging could help to diagnose cartilage and soft tissue injuries. However, imaging should never be used in isolation to define a clinical diagnosis.

If standardised, measurements of physical capacity can be performed: hip ROM can be measured with a goniometer or inclinometer, hip muscle strength can be measured and impairments during functional tasks can be demonstrated. Hip muscle strength normal values in professional athletes are presented in *chapter 2 and 3*. Patients' activity should be measured objectively and clinicians should manage patient expectations, advise physical activity and guide athletes to return to sport by using sport-specific activities *(Figure 1)*.

## Patient reported outcome measures

It is recommended to use HAGOS or the international Hip Outcome Tool (iHOT) instruments to objectively score hip-related pain. The EQ-5D and SF-36 questionnaires can be used for a more general quality of life measurement. However, the utility of these questionnaires in non-surgical treatment setting needs to be further investigated.

## Conservative treatment

For physiotherapy-led treatment, exercise-based treatments for at least 3 months are advised. More specific advice regarding conservative treatment was not agreed upon, partly because high quality literature is lacking.

In conclusion, all these recommendations are important steps to better understand hip and groin related topics and to better diagnose, treat and study patient groups with clear terminology in comparable future study cohort settings. For example, in the daily routine setting, it could help the clinician to better understand physiology and recognise pathology and to make the right diagnosis when everybody 'speaks the same language'. This results in a more patient-specific treatment strategy which could be further scientifically unfolded in coming prospective studies.

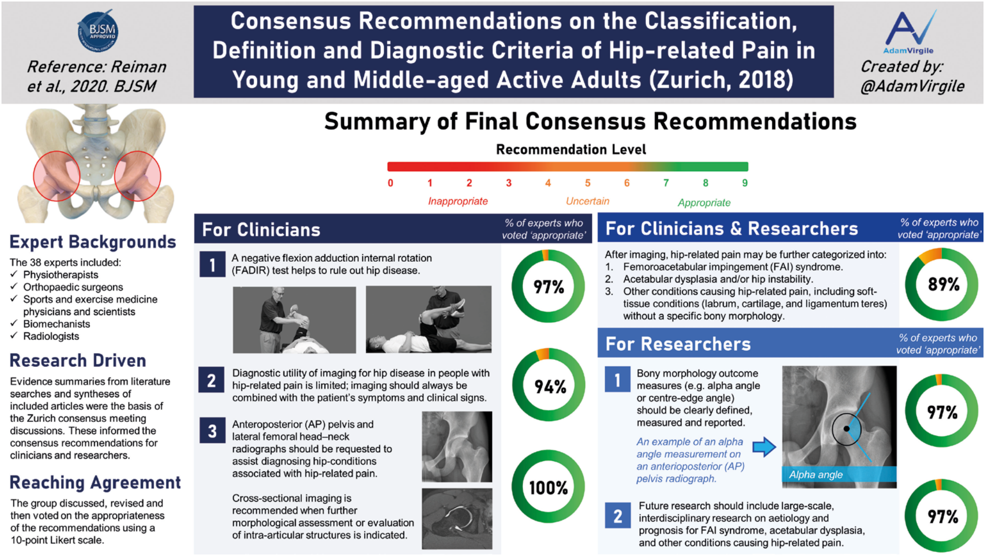



FIGURE 1: Infographic IHiPRN consensus recommendations on classification, definition and diagnostic criteria of hip-related pain (Reiman et al., British Journal of Sports Medicine[152]).

## Clinical tests in professional athletes

Hip muscle strength and hip ROM are often used as methods of assessment to monitor professional athletes with hip-related problems. In the Zurich Agreement[120] we agreed to include hip strength and ROM in the standard physical examination when a patient suffers from hip-related pain. These measurements assist in more objective follow-up and could be an indicator for the next steps in rehabilitation and return to play. In *chapter 2 and chapter 3* we aimed to provide normal values for professional male football during a full season and in field hockey players. These normal values may be helpful to detect hip muscle strength and ROM deficits in athletes.

### *Hip muscle strength throughout a season*

In *chapter 2* we observed a significant, though not clinically relevant, decrease in abduction strength over a full season (3.45 ± 0.67 to 3.28 ± 0.61 Nm/kg [$P < .001$]). Hip adductor strength remained constant over the season. This means that the often used adduction/abduction ratio significantly increased over the season. Hip abduction and adduction strength was higher than in several other studies on normal values of hip muscle strength in professional athletes. The reason for this is unclear. We speculate that geographical differences might have played a role in these strength measures. Genetical, environmental, social-demographical differences, and training components (e.g. skill level, training hours, additional training) might also impact hip muscle strength development. Research protocols between studies are often heterogeneous, which makes comparing studies difficult. In conclusion, small non-clinically relevant changes in hip muscle strength over the course of a full football season are observed. This means that these normal values are applicable over the full course of the season for professional male football players. These hip muscle strength normal values are useful for assessment, management and preventative strategies of hip and groin injuries. They can also guide clinicians for rehabilitation purposes throughout the whole season. However, the applicability of normal values in football to other sports is questioned because of other sport-specific demands.

### *Professional field hockey players*

To get more insight in normal values of hip muscle strength and ROM in other professional sports, we investigated professional field hockey players in *chapter 3*. Especially because no literature is available for field hockey, despite being popular and frequently played at a high level in the Netherlands. We observed that the eccentric adductor muscle strength was lower in field hockey players (2.8 ± 0.4 Nm/kg)[24] than in football players (3.0 ± 0.6 Nm/kg)[118]. It might be suggested that their adductors are not exposed to a kicking action and therefore are not having peak adductor forces in an abduction position. However, the adductor squeeze test was higher than compared with football players (4.5 ± 0.8 N/kg vs 3.6 ± 0.8 N/kg) which immediately raises questions about the sport-specific demands of hockey players compared to football players. Hockey players are frequently positioned in deep hip flexion and in a wide stance. Their abductor strength is comparable with other sports. We also investigated the influence of several clinical parameters on hip muscle strength and ROM in both *chapter 2 and 3*. Only leg dominance might influence hip muscle strength, as a marginally higher abduction strength was measured on the dominant side of the football players, but not in field hockey players. The ROM of hockey players was comparable with values known from other sports[118,129], however an interesting finding of internal rotation difference of 11° was observed between midfielders and goalkeepers, with the larger range in goalkeepers. One potential explanation may be the intensive and strenuous demands on the hips of midfielders, compared to goalkeepers. This might result in the development of cam morphology during growth and as result a reduced amount of internal rotation of the hip. More prospective research in field hockey is needed to support this statement.

### *Research into practice: measurement of hip muscle strength*

We recommend measuring hip muscle strength in athletes presenting with hip and groin pain.

- The technique used is described on page 201-203 *(protocol chapter 3)*.
- For professional male football players normal values are provided on page 34-35.
- For professional male field hockey players normal values are provided on page 58.
- Important notice: values for professional male football players do not change over the course of a season *(chapter 2)*.

## Cam morphology classification, development and consequences

Cam morphology has gathered increasing interest in the past two decades, as it is highly prevalent in athletes and its relationship with future hip osteoarthritis (OA) became apparent in prospective studies. We studied cam morphology because the aetiology, its quantification (e.g. measurement methods and threshold values), and the consequences (e.g. symptoms, limitation of ROM, hip OA) were, and still are, not fully elucidated.

### *Classification of cam morphology*

To classify cam morphology, the most commonly used measurement method is the alpha angle. This measurement is used on different imaging techniques, with different threshold values proposed in several populations. However, a uniform alpha angle threshold to classify the presence of cam morphology was lacking and urgently needed. Therefore we performed a systematic review and included 15 studies from which most presented the upper limit of the 95% reference interval. One study looked at the distribution of the alpha angle in a large population and demonstrated a bimodal distribution between normal and abnormal alpha angles which was useful to determine a threshold value. Three studies performed a receiver operating characteristic (ROC) curve analysis to discriminate between asymptomatic individuals and patients with FAI syndrome. These studies tried to make a distinction between normal and abnormal alpha angles by distinguishing asymptomatic people from patients with FAI syndrome. This analysis method is very clinically relevant because cam morphology is highly prevalent in the asymptomatic population. Largely based on the studies with a bimodal distribution and with ROC curve analyses, we proposed an alpha angle threshold of ⩾60°. In the studies investigating the alpha angle threshold based on reference values/intervals, differences in alpha angle between males and females were observed. However, in these studies reference intervals take into account a low cam morphology prevalence, while the true prevalence is much higher. This can also unfairly result in different threshold values for males and females because cam morphology prevalence is higher in males compared to females. The studies using ROC-analysis did not observe these sex specific differences. Therefore, a non-sex specific threshold was suggested. A clear non-sex specific alpha angle threshold can assist in studying aetiology, compare study group prevalence and the association with hip pathology. In prognostic studies, analysing the alpha angle as a continuous variable might be preferable.

### *Alpha angle: a clinical pearl*

When we try to incorporate these findings into the clinical setting, the clinician must be aware that an alpha angle threshold is a measure to classify hip morphology, not a diagnostic criterion. Especially when diagnosing FAI syndrome, more than just imaging findings must be considered, such as symptoms and clinical signs. As different imaging modalities and planes were used across the included studies, such as X-ray, computed tomography (CT) and magnetic resonance imaging (MRI), literature was too limited to speculate about a modality or plane specific threshold. All together the results showed that a non-sex, non-imaging specific alpha angle threshold of ⩾60° to classify cam morphology is currently most appropriate based on the available literature.[194]

***Step-by-step development of the 'non-perfect' hip***

Despite increasing scientific attention over the past decades, the aetiology of cam morphology is still not completely unraveled. It is suggested that the skeleton is highly responsive to loading, particularly during growth *(chapter 4)* and that there might be a dose-response relationship between loading and cam morphology development.[137,173] The resulting distribution of stress on the proximal femur depends on the shape of the hip (e.g. varus/valgus position). We observed that the shape of the proximal femoral growth plate changed during growth, from a more horizontal growth plate before the second growth spurt to a more arc shaped growth plate afterwards, in most participants.[192] This was also suggested using computer modelling (finite element analysis[154]), which showed that during flexion and external rotation large compressive stresses on the lateral side of the growth plate occur *(Figure 2, E1/2)*. A more varus position of the hip, might even increase the compressive stress at the lateral endpoint. This results in more bone formation on the medial side of the growth plate as compared with the lateral side, and therefore the growth plate bends towards the femoral neck[161] *(Figure 2, E3)*. This was observed in our clinical study in *chapter 6*, where a varus position of the hip developed simultaneously with cam morphology and a growth plate extension towards the neck.[193]

A possible explanation for this phenomenon might be that the growth plate tries to adapt in a way that the loads on the growth plate are perpendicular to it.[10] However, this bent lateral end-point of the proximal femoral growth plate actually results in more shear stresses compared to compressive stresses. Based on finite element analysis, these shear stresses are absorbed by the growth plate and trigger extra bone formation on the anterolateral head-neck junction.[10] Interestingly, with a closed growth plate, the stresses are not absorbed by the growth plate but are instead distributed equally through the proximal femur. Based on finite element analysis, there should be no cam morphology development anymore after growth plate closure. In *chapter 5*, we clinically confirmed the theory that cam morphology only develops during growth in professional male football players. This is also supported by the fact that after hip arthroscopy in adults, there has been no reporting of recurrence of cam morphology.[189] This defines the important timeframe in which cam morphology may develop.

In summary, based on previous finite element analysis and our findings in *chapters 5 and 6*, we believe that the development of the 'non-perfect' hip is a step-by-step process:

**Step 1**: Vigorous loading of the hip joint with an open growth plate.
**Step 2**: A synergetic development of below mentioned steps is observed:

- Distribution of compressive stress dependent from hip loading patterns (flexion and/or external rotation).
- Change in varus/valgus position (shear stresses) and growth plate position (lateral end-point moves more towards the femoral neck due to more bone formation on medial side).
- Decrease of compressive stresses and stress becomes more perpendicular to the growth plate position.
- Increase of shear stresses on the anterolateral head-neck junction.
- Extra bone formation on the anterolateral head-neck junction: cam morphology development.

**Step 3**: No more cam morphology development after growth plate closure.

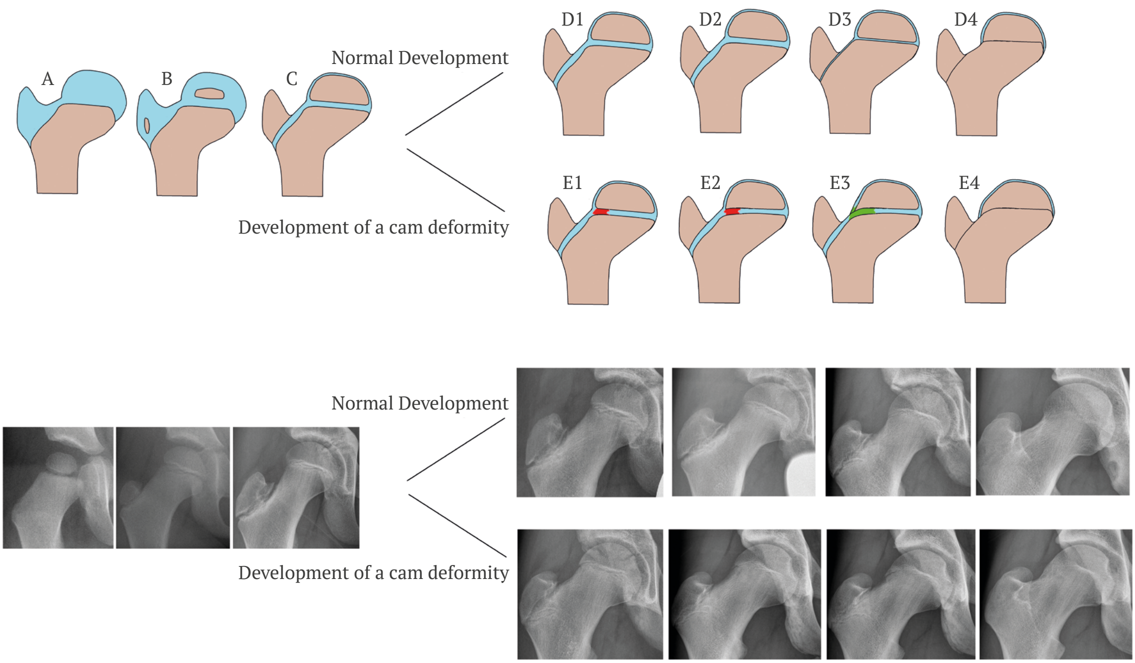



**FIGURE 2**: The development of the hip joint and influence of stresses on the proximal femoral growth plate orientation (Agricola et al., British Journal of Sports Medicine[10])

***Consequences: symptoms***

In the literature, only one prospective study is available which longitudinally investigated the relationship between cam morphology and symptoms. This found a 4 times increased risk for developing symptoms when cam morphology was present.[89] Therefore, in *chapter 7,* we focused on the association between cam morphology presence, size, and duration, and symptoms.[190] Our main findings were an inconsistent relationship between cam morphology and hip and groin symptoms. This might be explained by the fact that the participants were around 20 years old. This means that, if cam morphology developed at an age of 12 to 14 years, repetitive minor trauma was just present for around 6 years. This period might be too short to create damage and result in hip-related symptoms on a group level. The duration from which moment cam morphology was present for the first time might be interesting to further explore in future studies, as we observed a trend towards significance for symptoms if cam morphology was present for a longer period of time. This remains a theoretical suggestion and might be explained by the fact that cam morphology simply had more time to repetitively cause minor trauma to its surrounding structures. Our study power might have been too low to find a statistical significant association. In the future, when cam morphology is present for more than a decade, the first signs of soft tissue damage or even early signs of hip OA might be present.

We studied both the HAGOS questionnaire and a separate dichotomous question about 'sometimes having hip pain'. Interestingly we found an association between a large cam morphology (prominence) and 'sometimes having hip pain'. As this was not associated with one of the 6 HAGOS-domain scores, this may suggest a relationship between larger cam morphology and symptoms. A larger cam morphology is theoretically more likely to create damage to intra-articular structures and might also create a synovial reaction in the joint itself. Cam morphology is also highly prevalent in the asymptomatic population, and until now it is not exactly known why some become symptomatic or not. It is speculated that the location of cam morphology, severity of cartilage and labral damage, unilateral or bilateral presence of cam morphology, and psychosocial pain perception might play a role.

***Consequences: limited range of motion.***

In *chapter 7* the focus shifts from symptoms to the association between cam morphology, size, and duration, and ROM. An association between cam morphology and limited flexion (6° less) and internal rotation (3-6° less) was observed. This limitation in hip ROM is in keeping with other studies[17,84,117], but the magnitude of the differences did not reach the minimal clinical important difference. This limits the applicability of this finding for the clinician to the individual patient.

***Consequences: hip osteoarthritis***

The hypothesis for the mechanism for the association between cam morphology and hip OA is that the osseous bump repetitively impinges against the acetabular rim. This damages several structures, mostly located around the anterosuperior acetabular labrum and the femoral and acetabular cartilage. This eventually results in hip OA. There are 5 well-designed epidemiological studies that investigated this association: 3 prospective cohort studies[3,156,176] and 2 nested case-control studies[125,133]. Together this results in an increased risk of hip OA, with odds ratios (OR) varying from 2.1 to 9.7 depending on the alpha angle threshold used. When the alpha angle was higher than 83° with an internal rotation of less than 20° included, the OR increases to more than 25. This indicates that if the size of cam morphology increases, the risk for developing hip OA increases as well. Hip OA is an invalidating disease which is increasingly prevalent in the general population. The health burden and costs will increase in the future and limit the quality of life of millions of people all over the world. Given the fact that cam morphology is a bony adaptation largely dependent on the external loads applied to the hip joint during growth, there might be possibilities for primary and secondary prevention of hip OA. This is discussed further in the future perspectives section.

## Pincer morphology

In *chapter 9* we provided an overview of the studies on pincer morphology prevalence in different study populations. We observed a wide range of pincer morphology prevalence between the different subgroups, based on age, sex, athletic activity, ethnicity and symptomatology. A very wide range of pincer morphology in athletes was observed and therefore no clear difference between its prevalence in the general population and athletes can be observed, which might indicate that extreme loading of the hip is not the trigger for pincer morphology formation. In conclusion, due to the heterogeneity of definitions of pincer morphology and threshold values used, a wide prevalence of pincer morphology over different subgroups is observed.

The consequence of pincer morphology presence is still not fully understood. A relationship between pincer morphology and labral tears has been suggested in literature; where pincer morphology results in abutment between the femoral neck and the overcovered acetabular rim during movement.[5] Based on this, in *chapter 9* we also created an overview of studies investigating the association between pincer morphology and hip OA. Three prospective studies[5,156,176] investigated this association and none observed an association with hip OA. In fact, a protective effect of pincer morphology was observed in one study when pincer morphology is both anteriorly and laterally present (OR 0.34, 95% CI: 0.13, 0.87).[5] This casts doubt of the relevance of further research on pincer morphology. For future studies it will however remain difficult to compare study populations, due to the wide heterogeneity of its classification. Therefore, a clear definition and quantification for pincer morphology is warranted.

## Treatment of FAI syndrome

FAI syndrome can be diagnosed if patients have a triad of symptoms, clinical signs and either cam or pincer morphology on diagnostic imaging as described in the Warwick Agreement.[62] While several studies tried to find the prognostic factors for its initial development, others focused on how to treat these patients. In practice there is often discussion about whether to treat them conservatively or surgically. Recently three randomised controlled trials have been published comparing both treatments.[63,104,138] All studies favour arthroscopic treatment above conservative treatment for FAI syndrome, however the differences reported were only just above the minimal clinical important difference. It must be acknowledged that the conservative treatment protocols were heterogeneous and not all extensively described. This might partly be explained by the fact that a clear conservative treatment strategy for FAI syndrome rehabilitation is not yet defined and therefore urgently needed. When purely investigating the effect of surgical intervention, a recent randomised controlled trial investigated the efficacy of an arthroscopic osteochondroplasty with or without labral repair, compared to an arthroscopic lavage with or without labral repair.[45] Both groups were effective for treatment of pain and function at 1 year follow-up and the reoperation rate was lower in the osteochondroplasty group. A longer period of follow-up is needed to investigate the long term effect.

We reached consensus about recommendations for clinical practice in a recent consensus meeting.[88] We agreed that patients first need to undergo an optimal conservative treatment protocol to strengthen hip, trunk and functional components. A physiotherapist can guide this process and advise to perform resistance and strength training, all for at least 3 months. However, evidence to substantiate this is limited. The effective type, dose, loading and progression of exercises is still under debate and being investigated in several ongoing studies. If patients do not experience any relief of pain and increase of quality of life, surgical intervention can be considered. When we discuss this with athletes it is important to discuss the data investigating the return to sport and return to previous level in athletes who underwent hip arthroscopy. A study of Ishøi et al.[78] observed that only 57% of the athletes returned to preinjury sport at their preinjury level, but only one third of them reported that their performance was at an optimal level. So, like for conservative treatment, there is also room for improvement in the surgical approach of patients with FAI syndrome.

In the future, a post-operative rehabilitation programme must incorporate relevant conservative therapy strategies from onset until return to sport and preinjury level. Future studies will create more clarity in this field.[87] In conclusion this means that for this motion-related disorder of the hip, important knowledge gaps remain in terms of the aetiology, association with symptoms, optimal conservative and surgical treatment and post-operative treatment.

# Conclusion

In this thesis, we presented normal values for hip strength and ROM in professional male football players and in male field hockey players. These values together with hip and groin symptoms, did not change over the cause of a season. Injuries in the previous season were associated with more symptoms in the following season. This can assist and guide the clinician in their assessment and management strategies of professional athletes throughout the season. We also demonstrated that cam morphology can be classified by a proposed non-sex specific alpha angle threshold of ⩾60°. Cam morphology develops during growth when the growth plate is open. It develops simultaneously with a varus orientation of the hip and change of the growth plate towards the lateral femoral neck. Cam morphology is also associated with limited hip function, but the relationship with symptoms remains uncertain. Finally, a clear association between cam morphology and future hip OA was observed in the literature, whereas no association between pincer morphology and hip OA was found. This means that cam morphology, 'the non-perfect hip', might be a modifiable parameter during growth and be the next target for preventative strategies in future studies.

# Future perspectives

## Managements strategies of athletes

As observed in *chapter 2 and 3*, several measurements can assist clinicians in the assessment, diagnosis, treatment, and follow-up of their patients, such as normal values of hip muscle strength, hip ROM and HAGOS-domain scores. Especially in field hockey, limited literature is available on hip muscle strength and injuries of the hip and groin. In the future, patient studies on hip and groin symptomatology (e.g. non-time-loss and/or time-loss injuries) of hockey players would give insight in its symptom prevalence and incidence. This would raise awareness of these injuries in field hockey and create room for preventative training methods. The study of *chapter 3* was performed in professional male field hockey players and a future study in larger groups with also females and amateur hockey players included will assist to extrapolate the findings also to these subgroups. These future studies need to use widely supported terminology, clear homogeneous classification or quantification methods and standardised measurement methods to make the results easier to compare between studies and study groups.

***Future research direction hip muscle strength***

Several studies already published about hip muscle strength and function in professional male football and ice hockey. However, every sport has its sport-specific demands and therefore it is still unknown how these values can be interpreted and extrapolated to other sports. As suggested, not only differences in type of sport can influence normal values of hip muscle strength and function, it must also be considered that gender, age and ethnicity could play a role. Therefore, it might be very useful to prospectively study these subgroups. Recent years, professional female football is increasingly receiving attention and is being played more and more professionally. Therefore, in the future, comparisons between gender can be made between both optimal trained athletes. It might also be interesting to observe if age and ethnicity influences these normal values. In a professional football team, ages can range between around 16 and 36 years and the ethnic diversity can vary. To create patient specific training regimes this must be further elucidated in the future.

There are other aspects that also need further investigation in coming studies, for example the clinical utility of strength measurements in terms of readiness for return to play. A threshold percentage of strength, probably compared with the non-injured side, which reduces the risk of re-injury would be useful as well. Prospective studies on strength measurements could investigate if measurements are associated with better outcomes in terms of symptoms, ROM and quality of life.

## Cam morphology

### *Classification*

Cam morphology is mostly classified by the alpha angle and we presented a systematic review that proposed an alpha angle threshold for the classification of cam morphology in this thesis. The proposed alpha angle threshold is presented to be non-sex specific, but might not be applicable for all imaging modalities, planes and views. This needs further investigation in the future, as there was a wide variation in types of imaging and planes in the included studies. When an imaging and plane specific alpha angle threshold becomes available in the future, one could think of the introduction of diagnostic criteria.

### *Importance of imaging*

In upcoming studies on cam morphology and FAI syndrome, 3D-imaging (e.g. MRI) of the hip joint can assist in several measurements such as the alpha angle and visualise the full femoral growth plate and its status. It also can present a 3D-perspective of the full hip joint, which results in a more reliable assessment of the prevalence of cam morphology. Currently, 2D-imaging, such as X-rays, are mostly performed as they are quick, cheap, and widely available. However, X-rays only have a 2D-perspective and can project in a plane in which cam morphology is not completely visible. We acknowledge that in the studies we performed with X-rays of the hip joint, cam morphology prevalence is probably underestimated. The relationship between bony cam morphology and symptoms is not clear, and several other tissues around the hip joint might play an important role in this complicated area. When adding contrast to MRI (MRA), also soft tissues around the hip joint can be visualised and therefore MRA might be helpful in the path to discover which structures play a role in hip and groin symptomatology. However, giving contrast to healthy volunteers can also result in side effects and could therefore be difficult to implement in big cohort studies.

### *Moving towards preventative strategies*

Cam morphology develops during growth when bone is at its most adaptive to loading. In our study in *chapter 4*, we observed that during growth the proximal femoral growth plate mostly bends on the lateral side, towards the greater trochanter. In this study, we observed that some cam morphologies developed, even when only still a small part of the lateral growth plate remained opened. Apparently, only small growth potential is required to develop cam morphology. Future studies might add more information about the exact aetiology of cam morphology development. It would be important to investigate who develops cam morphology (e.g. risk factors) and especially at what period of growth the lateral growth plate endpoint is most susceptible for loading. We need to have a better understanding of the biomechanical pathway behind its development. Future studies could focus on which movement can trigger cam morphology development and to which extend a dose-response relationship is present. We need to find out if there is a loading threshold for bony femoral tissue to induce cam morphology development and which parameters influence this. After that, prediction models on who develops cam morphology could be created and the next steps to prevention can be undertaken. This targeted prevention might be further specified for gender and ethnicity as it seems that sex and genetic background might influence cam morphology development. For females, lower cam morphology prevalence might be explained by an earlier maturation and growth plate closure compared to males. However, this theory must be confirmed in future studies. New studies can show if comparable loading between research groups (e.g. male vs. female, Caucasian vs. Asian) show a comparable cam morphology incidence. However, the clinical applicability of these findings might be limited as it not appears to play a big role and a persons' genetic profile is not modifiable. In the end, it would be great to incorporate evidence based risk factors for cam morphology development based on several personal, clinical and radiological parameters in future preventative strategies.

***Suggestions for preventative strategies***

If above mentioned questions can be answered in future studies, the next step to preventative strategies can be undertaken. This might be a really difficult topic because histological, metabolical, biomechanical and environmental factors might all play a role in cam morphology development. Based on a more pragmatically biomechanical point of view, it could be proposed to lower the axial loading of the hip joint, for example by reducing the exposure hours on the football field, especially in the phase during or following the second growth spurt. This might be achieved by alternating or replacing parts of sporting activity with axial loading with sporting activity without axial loading (e.g. ball games in a swimming pool). However, competitive athletes and their coaches might not be really keen on lowering their practicing hours on the field, afraid of lagging behind in their football specific technique and cardiorespiratory fitness level. On the other hand, for amateur football players, axial loading might be beneficial because other health problems such as obesity and osteoporosis are on the rise because of physical inactivity without axial loading. This suggestion might only hold for young professional football players and there is a good chance that this will remain only a theoretical suggestion in the future.

## Consequences of cam morphology

In *chapter 7*, we presented data on the association between cam morphology and symptoms. As the power was limited, a future follow-up might add information about how the symptomatology and association with hip OA evolves in this specific population of football players. We presented a unique prospective cohort with 5-year follow-up, but this however might still be too short. Therefore a 10-year follow-up study would add very important information about the, until now, unclear association between cam morphology and symptoms. Also the first signs of early hip OA in these young athletes could possibly be observed and can shine a new light on who develops early hip OA and who does not. Three-dimensional imaging can add a great amount of information in a study setting to generate more insight on factors associated with cam morphology (e.g. labral, cartilage, and/or ligamentum teres damage) and its association with future symptoms, clinical signs and development of early hip OA. Large prospective studies are needed with more power to answer these questions. In this line, we are aiming to follow-up the cohort presented in *chapter 5, 6 and 7* in the future, and find out in this selected group, how the association between cam morphology and intra-articular pathology, symptoms, clinical signs and early hip OA evolves.

***How to manage cam morphology treatment in the future?***

In my opinion, the focus will shift more and more to preventative and conservative strategies as not all surgical interventions for FAI syndrome are showing to be beneficial for the patient and its physical, mental and quality of life measures. More studies must be performed trying to explore what the optimal effective type, dose, loading and exercise progression is for conservative therapy of FAI syndrome, but also for post-operative rehabilitation. Future trials which compare arthroscopic intervention versus conservative treatment, should also consider sham surgery to test the efficacy of the surgical intervention with a long follow-up timeframe. A broad approach of conservative therapy, with all pragmatic issues should be considered and optimised in future studies. If both treatment options are both equally scientifically substantiated, a true comparison can be made. It is possible that in the future a large proportion of patients with FAI syndrome will be adequately treated by solely optimised conservative treatment.

## Pincer morphology

In *chapter 9*, we presented an overview of the prevalence of pincer morphology in several subpopulations. No clear difference in prevalence was observed based on age, sex, athletic activity, ethnicity or symptomatology. This was partly due to the heterogeneous definition of pincer morphology. To get a more reliable insight in the true prevalence of pincer morphology, an internationally accepted and consequent use of one definition and clear cut-offs are warranted for research purposes. Until now, no associations between pincer morphology and hip OA are observed in literature.

# Appendices

# Appendix 1: Sport-specific questionnaire (chapter 3)

## Player details

**Study number**: ______________________________

**Age**: ______________________________

**Club**: ______________________________

**Team**: ______________________________

**Division**:

- ☐ Hoofdklasse
- ☐ Promotieklasse
- ☐ Overgangsklasse
- ☐ Eerste klasse
- ☐ Promotieklasse

## Contact details*

**Email**: ______________________________

**Mobile number**: ______________________________

*If you have given permission for the collection of your personal data, you can fill it in here. At the end of the research, you will receive a summary of the most important outcomes of this study and your personal strength measures.

## Sport-specific questionnaire about groin pain

1. What position do you play? (Which position did you play most during the first half of the season?)

☐ Goalkeeper
☐ Defender
☐ Midfielder
☐ Attacker

2. Which is your dominant leg? (With which foot do you prefer to kick a football?)

☐ Left
☐ Right
☐ No preference

3. Which is your dominant hand? (With which hand do you prefer to throw a ball?)

☐ Left
☐ Right
☐ No preference

4. How many hockey training sessions (field) do you have a week?

____________ training sessions a week.

5. On average, how much time do you spend on hockey training sessions and match play a week?

____________ hours of training a week AND ____________ minutes of match play a week.

6. Besides your hockey training sessions do you also spend time in the gym doing weight training? If so, how many hours a week?

☐ No
☐ Yes, ____________ hours of weight training a week.

**7.** Besides hockey do you also do other sports? If so, how many hours/minutes a week?

☐ No

☐ Yes (fill in the table below)

| | Sport 1: | Sport 2*: |
|---|---|---|
| Which sport(s) do you play besides hockey? | ____________ | ____________ |

On average, how much time (hours) do you spend on training sessions per 4 weeks (!!)?

____________ ____________

On average, how much time (minutes) do you spend on match play per 4 weeks (!!)?

____________ ____________

*If you only practise one extra sport, please fill in "DNA" in all fields beneath "Sport 2".

**8.** Do you currently have any groin pain?

☐ No
(carry on with question 17)

☐ Yes, but I am still able to participate in training sessions and match play.
(carry on with question 10)

☐ Yes, but I am not able to participate in match play but can participate in training sessions.
(carry on with question 10)

☐ Yes, and that is why I cannot participate in training sessions and match play.
(carry on with question 9)

**9.** How long have not been able to participate in training sessions and match play?

____________ days.

**10.** On which side do you have groin pain?

☐ Left

☐ Right

☐ Both sides

**11.** How long have you had groin pain?

____________ days.

**12.** On a scale of 0-10, how much groin pain do you experience during sports?
(Please circle one, whereas 0 = no pain at all and 10 = worst pain imaginable)

0 1 2 3 4 5 6 7 8 9 10

**13.** On a scale of 0-10, how much groin pain do you experience in the first 24 hours after exercise?

(Please circle one, whereas 0 = no pain at all and 10 = worst pain imaginable)

0 1 2 3 4 5 6 7 8 9 10

**14.** On a scale of 0-10, how much groin pain do you experience in normal life (walking, climbing stairs, driving a car, dressing and undressing, etc.) after a period of 24 hours rest from exercise?

(Please circle one, whereas 0 = no pain at all and 10 = worst pain imaginable)

0 1 2 3 4 5 6 7 8 9 10

**15.** Do you use any medication in relation to your groin pain? If so, which medication do you use?

☐ No
(carry on with question 17)

☐ Yes, namely:
- ☐ Paracetamol
- ☐ Aspirin
- ☐ Ibuprofen
- ☐ Other, namely: ________________________________
- ☐ I do not know

**16.** When do you use this medication in relation to your groin pain?

☐ Only in training

☐ Only during match play

☐ Both in training and match play

**17.** Do you currently have another injury, which prevents you from participating in training and/or match play?

☐ No

☐ Yes, namely: ________________________________

**18.** Did you have groin pain during last year's season (2017/2018) of during the current season (2018/2019)?

☐ No
(carry on with part 2 of this questionnaire: the HAGOS questionnaire)

☐ Yes, but I was still able to participate in training sessions and match play.
(carry on with question 20)

☐ Yes, but I was not able to participate in match play but can participate in training sessions.
(carry on with question 20)

☐ Yes, and that is why I was not able to participate in training sessions and match play.
(carry on with question 19)

**19.** How long were you not able to participate in training sessions and match play?

___________ days.

**20.** On which side did you have groin pain?

☐ Left
☐ Right
☐ Both sides

**21.** How long did you have groin pain?

___________ days.

**22.** Did you use medication in relation to your groin pain? If so, which medication did you use?

☐ No
(carry on with question 20)
☐ Yes, namely: ☐ Paracetamol
☐ Aspirin
☐ Ibuprofen
☐ Other, namely: ________________________________
☐ I do not know

**23.** When did you use this medication in relation to your groin pain?

☐ Only in training
☐ Only during match play
☐ Both in training and match play

## Thank you filling in this questionnaire.

# Appendix 2: Protocol for measuring hip strength and range of motion (chapter 3)

**Necessities**

1. 1 stadiometer
2. 1 weighing scale
3. 1 examination table
4. 1 tape measure, flexible
5. 1 skin marker
6. 1 clock/stopwatch
7. 1 supportive box (~ 40x30x20 cm)
8. 1 hand-held dynamometer (microFET)
9. 1 extended goniometer (arm = 15 cm)

**1. Measuring leg length**

- Player is in supine position (examination table flat during physical tests)
- Mark a line around the tibia 8 cm proximally from the lateral malleolus (both sides)
- Leg length: measure leg length from ASIS (Anterior Superior Iliac Spine) to marked line with the flexible tape measure
- Round off to the nearest half cm

**2. Measuring eccentric hip adduction and abduction strength**

- Player starts in side-lying position (left side first)
- Order: (1) adduction left, (2) abduction right, (3) adduction right and (4) abduction left
  - Focus areas positioning
    - › The leg being tested is fully stretched (180°). Hip, knee and foot of the leg not being tested are in 90° flexion
    - › The leg not being tested rests on the supportive box (adduction left and right)

    - › The leg being tested is held ~10 cm above the examination table (break-test)
  - Focus areas measurement
    - › Instruction: “3, 2, 1, go ahead, push, push, push, push, push.”
    - › Round off to whole Newton
    - › Ask for NRS-score

- 30 seconds rest between attempts



### 3. Measuring adductor squeeze strength

- Player in supine position
  - Focus areas positioning
    - › Hip is in 45° flexion (greater trochanter is used as axis), knees are in 90° flexion
    - › Feet are flat on examination table
  - Focus areas measurement
    - › Dynamometer is fixed between knees at medial femur condyle
    - › Instruction: “3, 2, 1, go ahead, push, push, push, push, push.”
    - › Round off to whole Newtons
    - › Ask for NRS-score

4. **Measuring internal and external rotation**

- Player is in supine position
- Order: (1) internal rotation right, (2) external rotation right, (3) internal rotation left and (4) external rotation left
  - Focus areas positioning
    - › Hip and knee of the leg being tested are in 90° flexion, the leg not being tested is relaxed and stretched
    - › Pelvis assessed to be level by visual inspection
  - Focus areas measurement
    - › The axis of the goniometer is placed on the apex patella. Fixed arm is parallel to the examination table. Moving arm is parallel to the tibia
    - › Round of whole degrees



5. **Measuring bent knee fall out**

- Player is in supine position
  - Focus areas positioning
    - › Hip is in 45° flexion (greater trochanter is used as axis), knees are in 90° flexion
    - › Foot soles are together
    - › Instruction: "Let your knees fall outwards and relax." Use little overpressure to ensure full flexion, abduction and external rotation
  - Focus areas measurement
    - › Bent knee fall out: measure BKFO from fibula head to surface examination table with flexible tape measure
    - › Round off the nearest half centimetre

# Dutch summary
# Nederlandse samenvatting

In dit hoofdstuk worden de meest belangrijke bevindingen van alle hoofdstukken, gebaseerd op vooraf gedefinieerde onderzoeksdoelen, samengevat en uitgelicht. De hoofdstukken beschrijven onder andere: normaalwaarden van heup spierkracht, -beweeglijkheid en -symptomen in atleten, een samenvatting van literatuur en voorgestelde alfa hoek afkapwaarde voor cam morfologie en de associatie tussen de aanwezigheid, ernst en duur van cam morfologie en groeischijf status, heup parameters en heup- en lies symptomen. Tot slot wordt de prevalentie van cam en pincer morfologie en de associatie met heupartrose gepresenteerd.

In *hoofdstuk 2* zijn normaalwaarden van professionele mannelijke voetballers voor heup spierkracht en -symptomen (middels HAGOS vragenlijsten) weergegeven. In dit hoofdstuk is prospectieve data verzameld middels observaties op drie verschillende tijdspunten gedurende het voetbalseizoen: aan het begin, tijdens en aan het einde. Deze data geeft ons extra informatie over hoe heup spierkracht en symptomen zich ontwikkelen tijdens het voetbalseizoen, wat tot op heden nooit eerder onderzocht is. De belangrijkste bevindingen van dit onderzoek zijn dat gedurende het seizoen er geen klinisch belangrijke verschillen in heup spierkracht en HAGOS vragenlijst scores optreden. Dit betekent feitelijk dat dezelfde normaalwaarden kunnen worden gehanteerd als referentiewaarden gedurende het gehele voetbalseizoen. Deelnemers met een eerdere blessure van de lies, of anders dan de lies, hadden significant verlaagde HAGOS vragenlijst scores, wat betekent dat zij nog steeds meer heup- en lies symptomen ervaren vergeleken met hun niet eerder geblesseerde collega voetballers.

*Hoofdstuk 3* sluit aan op *hoofdstuk 2*, mede omdat dit onderzoek ook normaalwaarden van heupkracht onderzocht en ook verricht is bij professionele atleten. Deze studie is echter verricht bij professionele veldhockeyers. In dit onderzoek werden ook normaalwaarden van de heup beweeglijkheid beschreven. Voor deze sporters is tot op heden geen andere literatuur beschikbaar over deze normaalwaarden. Parameters zoals leeftijd, dominantie, positie in het veld en lichte blessures hadden allen geen klinisch effect op deze waarden. Dit hoofdstuk helpt de clinicus om meer inzicht te krijgen in de referentiewaarden van heup spierkracht en heup beweeglijkheid van professionele hockeyers en hen te begeleiden in de beoordeling en behandelstrategie van heup- en liesblessures.

In *hoofdstuk 4* wordt dieper ingegaan op de vorm van de heup en dan voornamelijk cam morfologie. Cam morfologie is een extra bot formatie aan de anterolaterale zijde van de kop-hals overgang van het femur en wordt geclassificeerd middels de alfa hoek. Een consistente afkapwaarde van deze alfa hoek is noodzakelijk om cam morfologie te classificeren. Vervolgens kan de etiologie van cam morfologie worden bestudeerd, prevalenties tussen studies worden vergeleken en cam morfologie worden geassocieerd met heup pathologie.

In dit systematische review hebben we 15 studies geïncludeerd, waarvan er drie een ‘receiver operating characteristic’ (ROC) analyse hanteerden om onderscheid te maken tussen asymptomatische personen en personen met femoroacetabulair impingement (FAI) syndroom. Dit is naar onze mening een zeer relevante manier om cam morfologie te classificeren. Een andere studie liet een bimodale distributie van de alfa hoek zien in twee verschillende grote cohort studies. Gezamenlijk lieten deze vier studies allen een alfa hoek afkapwaarde zien van ongeveer 60° om cam morfologie te classificeren. Alle andere geïncludeerde studies gebruikten meestal een 95% referentie interval en lieten een veel bredere distributie zien van de voorgestelde alfa hoek afkapwaarden.

De etiologie van cam morfologie werd verder bestudeerd in *hoofdstuk 5*. In dit hoofdstuk werd de ontwikkeling van cam morfologie tijdens en na de groei onderzocht. In deze studie, met een prospectieve opzet met 5-jaar follow-up met daarin professionele voetballers geïncludeerd, zijn röntgenopnames gemaakt van beide heupen. Daarnaast werden vragenlijsten afgenomen en lichamelijk onderzoek verricht. In dit hoofdstuk ligt de focus met name op de ontwikkeling van cam morfologie in relatie tot de groeischijf status. Tot op heden was het niet bekend of cam morfologie alleen ontwikkelde tijdens de groei of ook na het sluiten van de proximale femorale groeischijf. Wij vonden een duidelijke associatie tussen cam morfologie ontwikkeling en een open groeischijf, wat feitelijk inhoudt dat cam morfologie alleen ontwikkelt tijdens de groei. Deze bevinding kan zeer belangrijk zijn in de verduidelijking van de etiologie van cam morfologie. Deze studie schetst nu namelijk de periode waarin cam morfologie kan ontwikkelen en biedt daarom ruimte voor de ontwikkeling van preventieve strategieën.

Hetzelfde cohort als gepresenteerd in *hoofdstuk 5*, werd bestudeerd in *hoofdstuk 6*. In dit hoofdstuk werd onderzocht of bepaalde radiologische of klinische parameters gerelateerd aan de heup geassocieerd zijn met cam morfologie (⩾ 60°) of een grote cam morfologie (⩾ 78°) of voorafgaan aan cam morfologie ontwikkeling. Deze parameters zijn: de varus/valgus positie van de heup (‘neck-shaft angle’), de vorm en positie van de femorale groeischijf (‘epiphyseal extension’), de vorm van het laterale acetabulum (‘lateral center-edge angle’ [LCEA]) en de heup functie middels het meten van de endorotatie. De belangrijkste bevindingen uit dit onderzoek zijn dat geen van deze heup parameters voorafgaan aan cam morfologie ontwikkeling, maar dat ze allen, behalve de LCEA, wel geassocieerd zijn met cam morfologie. Concluderend betekent dit dat deze radiologische en klinische heup parameters tegelijkertijd ontwikkelen met cam morfologie.

*Hoofdstuk 7* staat in het teken van de associatie tussen (grote) cam morfologie, de duur van het bestaan van cam morfologie en heup en lies symptomen (HAGOS vragenlijst) en heupfunctie (gemeten middels goniometrie). Om dit te kunnen bestuderen wordt gebruik gemaakt van hetzelfde cohort met adolescente mannelijke professionele voetballers als in *hoofdstuk 5 en 6.* In eerdere literatuur is de associatie tussen cam morfologie en symptomen niet volledig opgehelderd en mede daarom kan deze studie een belangrijke bijdrage leveren voor de clinicus. De belangrijkste bevindingen in deze studie waren dat cam morfologie en grote cam morfologie geassocieerd zijn met een beperkte flexie van het heupgewricht (6°) en beperkte endorotatie (3° tot 6°). Er werd geen klinisch relevante associatie waargenomen tussen cam morfologie, grote cam morfologie, duur van het bestaan ervan en symptomen. Concluderend betekent dit dat de relatie tussen cam morfologie en symptomen onduidelijk blijft. In de toekomst is er meer longitudinaal onderzoek nodig om te zien of het langer bestaan van cam morfologie mogelijk alsnog voor symptomen zorgt.

In *hoofdstuk 8* werd een algemeen overzicht gegeven van de bekende literatuur over de prevalentie van cam- en pincer morfologie en de associatie met heupartrose. Voor cam morfologie werd een prevalentie tussen 5 en 75% geobserveerd, wat afhankelijk bleek te zijn van de karakteristieken van de onderzoeksgroepen (leeftijd, geslacht, etniciteit, sportbeoefening, symptomen). Aangezien pincer morfologie vaak nog heterogener gedefinieerd werd, is in de literatuur een brede variatie in prevalentie gezien tussen de verschillende onderzoeksgroepen. Heupartrose zal in de toekomst een verder toenemend probleem worden en uiteindelijk resulteren in enorme gezondheidsbelasting en kosten. Dit literatuur overzicht toonde een duidelijke associatie tussen cam morfologie en heupartrose, welke echter niet tussen pincer morfologie en heupartrose bleek te bestaan.

# References

1. Aggarwal R, Ringold S, Khanna D, et al. Distinctions between diagnostic and classification criteria? Arthritis Care Res (Hoboken). 2015;67(7):891-897.

2. Agricola R, Bessems JH, Ginai AZ, et al. The development of Cam-type deformity in adolescent and young male soccer players. Am J Sports Med. 2012;40(5):1099-1106.

3. Agricola R, Heijboer MP, Bierma-Zeinstra SM, Verhaar JA, Weinans H, Waarsing JH. Cam impingement causes osteoarthritis of the hip: a nationwide prospective cohort study (CHECK). Ann Rheum Dis. 2013;72(6):918-923.

4. Agricola R, Heijboer MP, Ginai AZ, et al. A cam deformity is gradually acquired during skeletal maturation in adolescent and young male soccer players: a prospective study with minimum 2-year follow-up. Am J Sports Med. 2014;42(4):798-806.

5. Agricola R, Heijboer MP, Roze RH, et al. Pincer deformity does not lead to osteoarthritis of the hip whereas acetabular dysplasia does: acetabular coverage and development of osteoarthritis in a nationwide prospective cohort study (CHECK). Osteoarthritis Cartilage. 2013;21(10):1514-1521.

6. Agricola R, Reijman M, Bierma-Zeinstra SM, Verhaar JA, Weinans H, Waarsing JH. Total hip replacement but not clinical osteoarthritis can be predicted by the shape of the hip: a prospective cohort study (CHECK). Osteoarthritis Cartilage. 2013;21(4):559-564.

7. Agricola R, Waarsing JH, Arden NK, et al. Cam impingement of the hip: a risk factor for hip osteoarthritis. Nat Rev Rheumatol. 2013;9(10):630-634.

8. Agricola R, Waarsing JH, Thomas GE, et al. Cam impingement: defining the presence of a cam deformity by the alpha angle: data from the CHECK cohort and Chingford cohort. Osteoarthritis Cartilage. 2014;22(2):218-225.

9. Agricola R, Weinans H. Femoroacetabular impingement: what is its link with osteoarthritis? Br J Sports Med. 2016;50(16):957-958.

10. Agricola R, Weinans H. What causes cam deformity and femoroacetabular impingement: still too many questions to provide clear answers. Br J Sports Med. 2016;50(5):263-264.

11. Ahn T, Kim CH, Kim TH, et al. What is the Prevalence of Radiographic Hip Findings Associated With Femoroacetabular Impingement in Asymptomatic Asian Volunteers? Clin Orthop Relat Res. 2016;474(12):2655-2661.

12. Allen D, Beaule PE, Ramadan O, Doucette S. Prevalence of associated deformities and hip pain in patients with cam-type femoroacetabular impingement. J Bone Joint Surg Br. 2009;91(5):589-594.

**13.** Anderson LA, Anderson MB, Kapron A, et al. The 2015 Frank Stinchfield Award: Radiographic Abnormalities Common in Senior Athletes With Well-functioning Hips but Not Associated With Osteoarthritis. Clin Orthop Relat Res. 2016;474(2):342-352.

**14.** Anderson LA, Erickson JA, Swann RP, et al. Femoral Morphology in Patients Undergoing Periacetabular Osteotomy for Classic or Borderline Acetabular Dysplasia: Are Cam Deformities Common? J Arthroplasty. 2016;31(9 Suppl):259-263.

**15.** Anderson LA, Kapron AL, Aoki SK, Peters CL. Coxa profunda: is the deep acetabulum overcovered? Clin Orthop Relat Res. 2012;470(12):3375-3382.

**16.** Ardern CL, Glasgow P, Schneiders A, et al. 2016 Consensus statement on return to sport from the First World Congress in Sports Physical Therapy, Bern. Br J Sports Med. 2016;50(14):853-864.

**17.** Audenaert EA, Peeters I, Vigneron L, Baelde N, Pattyn C. Hip morphological characteristics and range of internal rotation in femoroacetabular impingement. Am J Sports Med. 2012;40(6):1329-1336.

**18.** Ayeni OR, Banga K, Bhandari M, et al. Femoroacetabular impingement in elite ice hockey players. Knee Surg Sports Traumatol Arthrosc. 2014;22(4):920-925.

**19.** Bardakos NV, Villar RN. Predictors of progression of osteoarthritis in femoroacetabular impingement: a radiological study with a minimum of ten years follow-up. J Bone Joint Surg Br. 2009;91(2):162-169.

**20.** Barrientos C, Barahona M, Diaz J, Branes J, Chaparro F, Hinzpeter J. Is there a pathological alpha angle for hip impingement? A diagnostic test study. J Hip Preserv Surg. 2016;3(3):223-228.

**21.** Beaule PE, Hynes K, Parker G, Kemp KA. Can the alpha angle assessment of cam impingement predict acetabular cartilage delamination? Clin Orthop Relat Res. 2012;470(12):3361-3367.

**22.** Beaule PE, Zaragoza E, Motamedi K, Copelan N, Dorey FJ. Three-dimensional computed tomography of the hip in the assessment of femoroacetabular impingement. J Orthop Res. 2005;23(6):1286-1292.

**23.** Beck M, Kalhor M, Leunig M, Ganz R. Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of early osteoarthritis of the hip. J Bone Joint Surg Br. 2005;87(7):1012-1018.

**24.** Beddows TPA, van Klij P, Agricola R, et al. Normal values for hip muscle strength and range of motion in elite, sub-elite and amateur male field hockey players. Physical Therapy in Sport. 2020;46:169-176.

**25.** Bolling C, Delfino Barboza S, van Mechelen W, Pasman HR. How elite athletes, coaches, and physiotherapists perceive a sports injury. Translational Sports Medicine. 2019;2(1):17-23.

**26.** Bouma H, Slot NJ, Toogood P, Pollard T, van Kampen P, Hogervorst T. Where is the neck? Alpha angle measurement revisited. Acta Orthop. 2014;85(2):147-151.

**27.** Bourne MN, Williams M, Jackson J, Williams KL, Timmins RG, Pizzari T. Preseason Hip/Groin Strength and HAGOS Scores Are Associated With Subsequent Injury in Professional Male Soccer Players. J Orthop Sports Phys Ther. 2020;50(5):234-242.

**28.** Clohisy JC, Baca G, Beaule PE, et al. Descriptive epidemiology of femoroacetabular impingement: a North American cohort of patients undergoing surgery. Am J Sports Med. 2013;41(6):1348-1356.

**29.** Clohisy JC, Carlisle JC, Beaule PE, et al. A systematic approach to the plain radiographic evaluation of the young adult hip. J Bone Joint Surg Am. 2008;90 Suppl 4:47-66.

**30.** Crow JF, Pearce AJ, Veale JP, VanderWesthuizen D, Coburn PT, Pizzari T. Hip adductor muscle strength is reduced preceding and during the onset of groin pain in elite junior Australian football players. J Sci Med Sport. 2010;13(2):202-204.

**31.** de Bruin F, Reijnierse M, Farhang-Razi V, Bloem JL. Radiographic signs associated with femoroacetabular impingement occur with high prevalence at all ages in a hospital population. Eur Radiol. 2013;23(11):3131-3139.

**32.** Delahunt E, Fitzpatrick H, Blake C. Pre-season adductor squeeze test and HAGOS function sport and recreation subscale scores predict groin injury in Gaelic football players. Phys Ther Sport. 2017;23:1-6.

**33.** Delahunt E, Kennelly C, McEntee BL, Coughlan GF, Green BS. The thigh adductor squeeze test: 45 degrees of hip flexion as the optimal test position for eliciting adductor muscle activity and maximum pressure values. Man Ther. 2011;16(5):476-480.

**34.** Delfino Barboza S, Nauta J, van der Pols MJ, van Mechelen W, Verhagen E. Injuries in Dutch elite field hockey players: A prospective cohort study. Scand J Med Sci Sports. 2018;28(6):1708-1714.

**35.** Dickenson E, Wall PD, Robinson B, et al. Prevalence of cam hip shape morphology: a systematic review. Osteoarthritis Cartilage. 2016;24(6):949-961.

**36.** Dickenson EJ, Wall PDH, Hutchinson CE, Griffin DR. The prevalence of cam hip morphology in a general population sample. Osteoarthritis Cartilage. 2019;27(3):444-448.

**37.** Diesel CV, Ribeiro TA, Coussirat C, Scheidt RB, Macedo CA, Galia CR. Coxa profunda in the diagnosis of pincer-type femoroacetabular impingement and its prevalence in asymptomatic subjects. Bone Joint J. 2015;97-B(4):478-483.

**38.** Doherty M, Courtney P, Doherty S, et al. Nonspherical femoral head shape (pistol grip deformity), neck shaft angle, and risk of hip osteoarthritis: a case-control study. Arthritis Rheum. 2008;58(10):3172-3182.

**39.** Dudda M, Albers C, Mamisch TC, Werlen S, Beck M. Do normal radiographs exclude asphericity of the femoral head-neck junction? Clin Orthop Relat Res. 2009;467(3):651-659.

**40.** Ekstrand J, Hagglund M, Walden M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med. 2011;39(6):1226-1232.

**41.** Ekstrand J, Hagglund M, Walden M. Injury incidence and injury patterns in professional football: the UEFA injury study. Br J Sports Med. 2011;45(7):553-558.

**42.** Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for groin injuries among male soccer players: a prospective cohort study. Am J Sports Med. 2010;38(10):2051-2057.

**43.** Espie A, Chaput B, Murgier J, Bayle-Iniguez X, Elia F, Chiron P. 45 degrees -45 degrees -30 degrees Frog-leg radiograph for diagnosing cam-type anterior femoroacetabular impingement: Reproducibility and thresholds. Orthop Traumatol Surg Res. 2014;100(8):843-848.

**44.** Feldesman MR, Kleckner JG, Lundy JK. Femur/stature ratio and estimates of stature in mid- and late-Pleistocene fossil hominids. Am J Phys Anthropol. 1990;83(3):359-372.

**45.** Femoroacetabular Impingement Randomized Controlled Trial I, Ayeni OR, Karlsson J, et al. Osteochondroplasty and Labral Repair for the Treatment of Young Adults With Femoroacetabular Impingement: A Randomized Controlled Trial. Am J Sports Med. 2020:363546520952804.

**46.** Fischer CS, Kuhn JP, Ittermann T, et al. What Are the Reference Values and Associated Factors for Center-edge Angle and Alpha Angle? A Population-based Study. Clin Orthop Relat Res. 2018;476(11):2249-2259.

**47.** Ford CA, Nowlan NC, Thomopoulos S, Killian ML. Effects of imbalanced muscle loading on hip joint development and maturation. J Orthop Res. 2017;35(5):1128-1136.

**48.** Fraitzl CR, Kappe T, Pennekamp F, Reichel H, Billich C. Femoral head-neck offset measurements in 339 subjects: distribution and implications for femoroacetabular impingement. Knee Surg Sports Traumatol Arthrosc. 2013;21(5):1212-1217.

**49.** Frank JM, Harris JD, Erickson BJ, et al. Prevalence of Femoroacetabular Impingement Imaging Findings in Asymptomatic Volunteers: A Systematic Review. Arthroscopy. 2015;31(6):1199-1204.

**50.** Freke MD, Kemp J, Svege I, Risberg MA, Semciw A, Crossley KM. Physical impairments in symptomatic femoroacetabular impingement: a systematic review of the evidence. Br J Sports Med. 2016;50(19):1180.

**51.** Fukushima K, Uchiyama K, Takahira N, et al. Prevalence of radiographic findings of femoroacetabular impingement in the Japanese population. J Orthop Surg Res. 2014;9:25.

**52.** Fuller CW, Molloy MG, Bagate C, et al. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. Clin J Sport Med. 2007;17(3):177-181.

**53.** Ganz R, Parvizi J, Beck M, Leunig M, Notzli H, Siebenrock KA. Femoroacetabular impingement: a cause for osteoarthritis of the hip. Clin Orthop Relat Res. 2003(417):112-120.

**54.** Gerhardt MB, Romero AA, Silvers HJ, Harris DJ, Watanabe D, Mandelbaum BR. The prevalence of radiographic hip abnormalities in elite soccer players. Am J Sports Med. 2012;40(3):584-588.

**55.** Gerodimos V, Karatrantou K, Paschalis V, et al. Reliability of concentric and eccentric strength of hip abductor and adductor muscles in young soccer players. Biol Sport. 2015;32(4):351-356.

**56.** Glyn-Jones S, Palmer AJ, Agricola R, et al. Osteoarthritis. Lancet. 2015;386(9991):376-387.

**57.** Golfam M, Di Primio LA, Beaule PE, Hack K, Schweitzer ME. Alpha Angle Measurements in Healthy Adult Volunteers Vary Depending on the MRI Plane Acquisition Used. Am J Sports Med. 2017;45(3):620-626.

**58.** Gosvig KK, Jacobsen S, Palm H, Sonne-Holm S, Magnusson E. A new radiological index for assessing asphericity of the femoral head in cam impingement. J Bone Joint Surg Br. 2007;89(10):1309-1316.

**59.** Gosvig KK, Jacobsen S, Sonne-Holm S, Gebuhr P. The prevalence of cam-type deformity of the hip joint: a survey of 4151 subjects of the Copenhagen Osteoarthritis Study. Acta Radiol. 2008;49(4):436-441.

**60.** Gosvig KK, Jacobsen S, Sonne-Holm S, Palm H, Troelsen A. Prevalence of malformations of the hip joint and their relationship to sex, groin pain, and risk of osteoarthritis: a population-based survey. J Bone Joint Surg Am. 2010;92(5):1162-1169.

61. Grammatopoulos G, Speirs AD, Ng KCG, et al. Acetabular and spino-pelvic morphologies are different in subjects with symptomatic cam femoro-acetabular impingement. J Orthop Res. 2018;36(7):1840-1848.

62. Griffin DR, Dickenson EJ, O'Donnell J, et al. The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. Br J Sports Med. 2016;50(19):1169-1176.

63. Griffin DR, Dickenson EJ, Wall PDH, et al. Hip arthroscopy versus best conservative care for the treatment of femoroacetabular impingement syndrome (UK FASHIoN): a multicentre randomised controlled trial. Lancet. 2018;391(10136):2225-2235.

64. Guler O, Isyar M, Karatas D, Ormeci T, Cerci H, Mahirogullari M. A retrospective analysis on the correlation between hip pain, physical examination findings, and alpha angle on MR images. J Orthop Surg Res. 2016;11(1):140.

65. Hack K, Di Primio G, Rakhra K, Beaule PE. Prevalence of cam-type femoroacetabular impingement morphology in asymptomatic volunteers. J Bone Joint Surg Am. 2010;92(14):2436-2444.

66. Hagglund M, Walden M, Ekstrand J. Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. Br J Sports Med. 2006;40(9):767-772.

67. Hagglund M, Walden M, Ekstrand J. Risk factors for lower extremity muscle injury in professional soccer: the UEFA Injury Study. Am J Sports Med. 2013;41(2):327-335.

68. Haroy J, Clarsen B, Thorborg K, Holmich P, Bahr R, Andersen TE. Groin Problems in Male Soccer Players Are More Common Than Previously Reported. Am J Sports Med. 2017;45(6):1304-1308.

69. Haroy J, Clarsen B, Wiger EG, et al. The Adductor Strengthening Programme prevents groin problems among male football players: a cluster-randomised controlled trial. Br J Sports Med. 2019;53(3):150-157.

70. Harris JD, Gerrie BJ, Varner KE, Lintner DM, McCulloch PC. Radiographic Prevalence of Dysplasia, Cam, and Pincer Deformities in Elite Ballet. Am J Sports Med. 2016;44(1):20-27.

71. Heerey JJ, Kemp JL, Mosler AB, et al. What is the prevalence of imaging-defined intra-articular hip pathologies in people with and without pain? A systematic review and meta-analysis. Br J Sports Med. 2018;52(9):581-593.

72. Herrero H, Salinero JJ, Del Coso J. Injuries among Spanish male amateur soccer players: a retrospective population study. Am J Sports Med. 2014;42(1):78-85.

73. Higgins JS JS, J; Page, MJ; Hróbjartsson, A; Boutron, I; Reeves, B; Eldridge, S;. A revised tool for assessing risk of bias in randomized trials. Cochrane Database of Systematic Reviews. In: Chandler J, McKenzie J, Boutron I, Welch V (editors). Cochrane Methods. 2016(10).

74. Hollander K, Wellmann K, Eulenburg CZ, Braumann KM, Junge A, Zech A. Epidemiology of injuries in outdoor and indoor hockey players over one season: a prospective cohort study. Br J Sports Med. 2018;52(17):1091-1096.

75. Impellizzeri FM, Jones DM, Griffin D, et al. Patient-reported outcome measures for hip-related pain: a review of the available evidence and a consensus statement from the International Hip-related Pain Research Network, Zurich 2018. Br J Sports Med. 2020.

76. Impellizzeri FM, Mannion AF, Naal FD, Hersche O, Leunig M. The early outcome of surgical treatment for femoroacetabular impingement: success depends on how you measure it. Osteoarthritis Cartilage. 2012;20(7):638-645.

77. Ishoi L, Sorensen CN, Kaae NM, Jorgensen LB, Holmich P, Serner A. Large eccentric strength increase using the Copenhagen Adduction exercise in football: A randomized controlled trial. Scand J Med Sci Sports. 2016;26(11):1334-1342.

78. Ishoi L, Thorborg K, Kraemer O, Holmich P. Return to Sport and Performance After Hip Arthroscopy for Femoroacetabular Impingement in 18- to 30-Year-Old Athletes: A Cross-sectional Cohort Study of 189 Athletes. Am J Sports Med. 2018;46(11):2578-2587.

79. Johnson AC, Shaman MA, Ryan TG. Femoroacetabular impingement in former high-level youth soccer players. Am J Sports Med. 2012;40(6):1342-1346.

80. Johnston TL, Schenker ML, Briggs KK, Philippon MJ. Relationship between offset angle alpha and hip chondral injury in femoroacetabular impingement. Arthroscopy. 2008;24(6):669-675.

81. Jung KA, Restrepo C, Hellman M, AbdelSalam H, Morrison W, Parvizi J. The prevalence of cam-type femoroacetabular deformity in asymptomatic adults. J Bone Joint Surg Br. 2011;93(10):1303-1307.

82. Kang AC, Gooding AJ, Coates MH, Goh TD, Armour P, Rietveld J. Computed tomography assessment of hip joints in asymptomatic individuals in relation to femoroacetabular impingement. Am J Sports Med. 2010;38(6):1160-1165.

83. Kapron AL, Anderson AE, Aoki SK, et al. Radiographic prevalence of femoroacetabular impingement in collegiate football players: AAOS Exhibit Selection. J Bone Joint Surg Am. 2011;93(19):e111(111-110).

**84.** Kapron AL, Anderson AE, Peters CL, et al. Hip internal rotation is correlated to radiographic findings of cam femoroacetabular impingement in collegiate football players. Arthroscopy. 2012;28(11):1661-1670.

**85.** Kapron AL, Peters CL, Aoki SK, et al. The prevalence of radiographic findings of structural hip deformities in female collegiate athletes. Am J Sports Med. 2015;43(6):1324-1330.

**86.** Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis. 1957;16(4):494-502.

**87.** Kemp JL, King MG, Barton C, et al. Is exercise therapy for femoroacetabular impingement in or out of FASHIoN? We need to talk about current best practice for the non-surgical management of FAI syndrome. Br J Sports Med. 2019;53(19):1204-1205.

**88.** Kemp JL, Risberg MA, Mosler A, et al. Physiotherapist-led treatment for young to middle-aged active adults with hip-related pain: consensus recommendations from the International Hip-related Pain Research Network, Zurich 2018. Br J Sports Med. 2019.

**89.** Khanna V, Caragianis A, Diprimio G, Rakhra K, Beaule PE. Incidence of hip pain in a prospective cohort of asymptomatic volunteers: is the cam deformity a risk factor for hip pain? Am J Sports Med. 2014;42(4):793-797.

**90.** Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. J Chiropr Med. 2016;15(2):155-163.

**91.** Laborie LB, Lehmann TG, Engesaeter IO, Eastwood DM, Engesaeter LB, Rosendahl K. Prevalence of radiographic findings thought to be associated with femoroacetabular impingement in a population-based cohort of 2081 healthy young adults. Radiology. 2011;260(2):494-502.

**92.** Laborie LB, Lehmann TG, Engesaeter IO, Sera F, Engesaeter LB, Rosendahl K. The alpha angle in cam-type femoroacetabular impingement: new reference intervals based on 2038 healthy young adults. Bone Joint J. 2014;96-B(4):449-454.

**93.** Langhout R, Tak I, van Beijsterveldt AM, et al. Risk Factors for Groin Injury and Groin Symptoms in Elite-Level Soccer Players: A Cohort Study in the Dutch Professional Leagues. J Orthop Sports Phys Ther. 2018;48(9):704-712.

**94.** Langhout R, Weir A, Litjes W, et al. Hip and groin injury is the most common non-time-loss injury in female amateur football. Knee Surg Sports Traumatol Arthrosc. 2019;27(10):3133-3141.

95. Larson CM, Sikka RS, Sardelli MC, et al. Increasing alpha angle is predictive of athletic-related “hip” and “groin” pain in collegiate National Football League prospects. Arthroscopy. 2013;29(3):405-410.

96. Lepage-Saucier M, Thiery C, Larbi A, Lecouvet FE, Vande Berg BC, Omoumi P. Femoroacetabular impingement: normal values of the quantitative morphometric parameters in asymptomatic hips. Eur Radiol. 2014;24(7):1707-1714.

97. Lerebours F, Robertson W, Neri B, Schulz B, Youm T, Limpisvasti O. Prevalence of Cam-Type Morphology in Elite Ice Hockey Players. Am J Sports Med. 2016;44(4):1024-1030.

98. Leunig M, Juni P, Werlen S, et al. Prevalence of cam and pincer-type deformities on hip MRI in an asymptomatic young Swiss female population: a cross-sectional study. Osteoarthritis Cartilage. 2013;21(4):544-550.

99. Li Y, Helvie P, Mead M, Gagnier J, Hammer MR, Jong N. Prevalence of Femoroacetabular Impingement Morphology in Asymptomatic Adolescents. J Pediatr Orthop. 2017;37(2):121-126.

100. Light N, Thorborg K. The precision and torque production of common hip adductor squeeze tests used in elite football. J Sci Med Sport. 2016;19(11):888-892.

101. Liu Q, Wang W, Thoreson AR, Zhao C, Zhu W, Dou P. Finite element prediction of contact pressures in cam-type femoroacetabular impingement with varied alpha angles. Comput Methods Biomech Biomed Engin. 2017;20(3):294-301.

102. Lohan DG, Seeger LL, Motamedi K, Hame S, Sayre J. Cam-type femoral-acetabular impingement: is the alpha angle the best MR arthrography has to offer? Skeletal Radiol. 2009;38(9):855-862.

103. Malliaras P, Hogan A, Nawrocki A, Crossley K, Schache A. Hip flexibility and strength measures: reliability and association with athletic groin pain. Br J Sports Med. 2009;43(10):739-744.

104. Mansell NS, Rhon DI, Meyer J, Slevin JM, Marchant BG. Arthroscopic Surgery or Physical Therapy for Patients With Femoroacetabular Impingement Syndrome: A Randomized Controlled Trial With 2-Year Follow-up. Am J Sports Med. 2018;46(6):1306-1314.

105. Mascarenhas VV, Ayeni OR, Egund N, et al. Imaging Methodology for Hip Preservation: Techniques, Parameters, and Thresholds. Semin Musculoskelet Radiol. 2019;23(3):197-226.

106. Mascarenhas VV, Rego P, Dantas P, et al. Can We Discriminate Symptomatic Hip Patients From Asymptomatic Volunteers Based on Anatomic Predictors? A 3-Dimensional Magnetic Resonance Study on Cam, Pincer, and Spinopelvic Parameters. Am J Sports Med. 2018;46(13):3097-3110.

**107.** Mascarenhas VV, Rego P, Dantas P, et al. Hip shape is symmetric, non-dependent on limb dominance and gender-specific: implications for femoroacetabular impingement. A 3D CT analysis in asymptomatic subjects. Eur Radiol. 2018;28(4):1609-1624.

**108.** Mascarenhas VV, Rego P, Dantas P, et al. Imaging prevalence of femoroacetabular impingement in symptomatic patients, athletes, and asymptomatic individuals: A systematic review. Eur J Radiol. 2016;85(1):73-95.

**109.** Matsuda DK, Gupta N, Khatod M, et al. Poorer Arthroscopic Outcomes of Mild Dysplasia With Cam Femoroacetabular Impingement Versus Mixed Femoroacetabular Impingement in Absence of Capsular Repair. Am J Orthop (Belle Mead NJ). 2017;46(1):E47-E53.

**110.** Mayes S, Ferris AR, Smith P, Garnham A, Cook J. Atraumatic tears of the ligamentum teres are more frequent in professional ballet dancers than a sporting population. Skeletal Radiol. 2016;45(7):959-967.

**111.** Mayes S, Ferris AR, Smith P, Garnham A, Cook J. Bony morphology of the hip in professional ballet dancers compared to athletes. Eur Radiol. 2017;27(7):3042-3049.

**112.** Mineta K, Goto T, Wada K, et al. CT-based morphological assessment of the hip joint in Japanese patients: association with radiographic predictors of femoroacetabular impingement. Bone Joint J. 2016;98-B(9):1167-1174.

**113.** Mirtz TA, Chandler JP, Eyers CM. The effects of physical activity on the epiphyseal growth plates: a review of the literature on normal physiology and clinical implications. J Clin Med Res. 2011;3(1):1-7.

**114.** Monazzam S, Bomar JD, Dwek JR, Hosalkar HS, Pennock AT. Development and prevalence of femoroacetabular impingement-associated morphology in a paediatric and adolescent population: a CT study of 225 patients. Bone Joint J. 2013;95-B(5):598-604.

**115.** Mori R, Yasunaga Y, Yamasaki T, et al. Are cam and pincer deformities as common as dysplasia in Japanese patients with hip pain? Bone Joint J. 2014;96-B(2):172-176.

**116.** Morris WZ, Weinberg DS, Gebhart JJ, Cooperman DR, Liu RW. Capital Femoral Growth Plate Extension Predicts Cam Morphology in a Longitudinal Radiographic Study. J Bone Joint Surg Am. 2016;98(10):805-812.

**117.** Mosler AB, Agricola R, Thorborg K, et al. Is Bony Hip Morphology Associated With Range of Motion and Strength in Asymptomatic Male Soccer Players? J Orthop Sports Phys Ther. 2018;48(4):250-259.

**118.** Mosler AB, Crossley KM, Thorborg K, et al. Hip strength and range of motion: Normal values from a professional football league. J Sci Med Sport. 2017;20(4):339-343.

**119.** Mosler AB, Crossley KM, Waarsing JH, et al. Ethnic Differences in Bony Hip Morphology in a Cohort of 445 Professional Male Soccer Players. Am J Sports Med. 2016;44(11):2967-2974.

**120.** Mosler AB, Kemp J, King M, et al. Standardised measurement of physical capacity in young and middle-aged active adults with hip-related pain: recommendations from the first International Hip-related Pain Research Network (IHiPRN) meeting, Zurich, 2018. Br J Sports Med. 2019.

**121.** Mosler AB, Weir A, Eirale C, et al. Epidemiology of time loss groin injuries in a men's professional football league: a 2-year prospective study of 17 clubs and 606 players. Br J Sports Med. 2018;52(5):292-297.

**122.** Mosler AB, Weir A, Serner A, et al. Musculoskeletal Screening Tests and Bony Hip Morphology Cannot Identify Male Professional Soccer Players at Risk of Groin Injuries: A 2-Year Prospective Cohort Study. Am J Sports Med. 2018;46(6):1294-1305.

**123.** Murray RO. The aetiology of primary osteoarthritis of the hip. Br J Radiol. 1965;38(455):810-824.

**124.** Nardo L, Parimi N, Liu F, et al. Femoroacetabular Impingement: Prevalent and Often Asymptomatic in Older Men: The Osteoporotic Fractures in Men Study. Clin Orthop Relat Res. 2015;473(8):2578-2586.

**125.** Nelson AE, Stiller JL, Shi XA, et al. Measures of hip morphology are related to development of worsening radiographic hip osteoarthritis over 6 to 13 year follow-up: the Johnston County Osteoarthritis Project. Osteoarthritis Cartilage. 2016;24(3):443-450.

**126.** Nepple JJ, Lehmann CL, Ross JR, Schoenecker PL, Clohisy JC. Coxa profunda is not a useful radiographic parameter for diagnosing pincer-type femoroacetabular impingement. J Bone Joint Surg Am. 2013;95(5):417-423.

**127.** Nepple JJ, Riggs CN, Ross JR, Clohisy JC. Clinical presentation and disease characteristics of femoroacetabular impingement are sex-dependent. J Bone Joint Surg Am. 2014;96(20):1683-1689.

**128.** Nepple JJ, Vigdorchik JM, Clohisy JC. What Is the Association Between Sports Participation and the Development of Proximal Femoral Cam Deformity? A Systematic Review and Meta-analysis. Am J Sports Med. 2015;43(11):2833-2840.

**129.** Nevin F, Delahunt E. Adductor squeeze test values and hip joint range of motion in Gaelic football athletes with longstanding groin pain. J Sci Med Sport. 2014;17(2):155-159.

**130.** Ng KC, Lamontagne M, Adamczyk AP, Rakhra KS, Beaule PE. Patient-specific anatomical and functional parameters provide new insights into the pathomechanism of cam FAI. Clin Orthop Relat Res. 2015;473(4):1289-1296.

**131.** Ng KCG, Lamontagne M, Beaule PE. Differences in anatomical parameters between the affected and unaffected hip in patients with bilateral cam-type deformities. Clin Biomech (Bristol, Avon). 2016;33:13-19.

**132.** Ng KCG, Lamontagne M, Jeffers JRT, Grammatopoulos G, Beaule PE. Anatomic Predictors of Sagittal Hip and Pelvic Motions in Patients With a Cam Deformity. Am J Sports Med. 2018;46(6):1331-1342.

**133.** Nicholls AS, Kiran A, Pollard TC, et al. The association between hip morphology parameters and nineteen-year risk of end-stage osteoarthritis of the hip: a nested case-control study. Arthritis Rheum. 2011;63(11):3392-3400.

**134.** Notzli HP, Wyss TF, Stoecklin CH, Schmid MR, Treiber K, Hodler J. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. J Bone Joint Surg Br. 2002;84(4):556-560.

**135.** Nussbaumer S, Leunig M, Glatthorn JF, Stauffacher S, Gerber H, Maffiuletti NA. Validity and test-retest reliability of manual goniometers for measuring passive hip range of motion in femoroacetabular impingement patients. BMC Musculoskelet Disord. 2010;11:194.

**136.** Okano K, Enomoto H, Osaki M, Shindo H. Outcome of rotational acetabular osteotomy for early hip osteoarthritis secondary to dysplasia related to femoral head shape: 49 hips followed for 10-17 years. Acta Orthop. 2008;79(1):12-17.

**137.** Palmer A, Fernquest S, Gimpel M, et al. Physical activity during adolescence and the development of cam morphology: a cross-sectional cohort study of 210 individuals. Br J Sports Med. 2018;52(9):601-610.

**138.** Palmer AJR, Ayyar Gupta V, Fernquest S, et al. Arthroscopic hip surgery compared with physiotherapy and activity modification for the treatment of symptomatic femoroacetabular impingement: multicentre randomised controlled trial. BMJ. 2019;364:l185.

**139.** Patrick DL, Burke LB, Powers JH, et al. Patient-reported outcomes to support medical product labeling claims: FDA perspective. Value Health. 2007;10 Suppl 2:S125-137.

**140.** Philippon MJ, Ho CP, Briggs KK, Stull J, LaPrade RF. Prevalence of increased alpha angles as a measure of cam-type femoroacetabular impingement in youth ice hockey players. Am J Sports Med. 2013;41(6):1357-1362.

**141.** Pollard TC, McNally EG, Wilson DC, et al. Localized cartilage assessment with three-dimensional dGEMRIC in asymptomatic hips with normal morphology and cam deformity. J Bone Joint Surg Am. 2010;92(15):2557-2569.

**142.** Pollard TC, Villar RN, Norton MR, et al. Femoroacetabular impingement and classification of the cam deformity: the reference interval in normal hips. Acta Orthop. 2010;81(1):134-141.

**143.** Pons C, Remy-Neris O, Medee B, Brochard S. Validity and reliability of radiological methods to assess proximal hip geometry in children with cerebral palsy: a systematic review. Dev Med Child Neurol. 2013;55(12):1089-1102.

**144.** Ponseti IV. Growth and development of the acetabulum in the normal child. Anatomical, histological, and roentgenographic studies. J Bone Joint Surg Am. 1978;60(5):575-585.

**145.** Poulsen E, Christensen HW, Penny JO, Overgaard S, Vach W, Hartvigsen J. Reproducibility of range of motion and muscle strength measurements in patients with hip osteoarthritis - an inter-rater study. BMC Musculoskelet Disord. 2012;13:242.

**146.** Prather H, Harris-Hayes M, Hunt DM, Steger-May K, Mathew V, Clohisy JC. Reliability and agreement of hip range of motion and provocative physical examination tests in asymptomatic volunteers. PM R. 2010;2(10):888-895.

**147.** Prendergast N, Hopper D, Finucane M, Grisbrook TL. Hip adduction and abduction strength profiles in elite, sub-elite and amateur Australian footballers. J Sci Med Sport. 2016;19(9):766-770.

**148.** Register B, Pennock AT, Ho CP, Strickland CD, Lawand A, Philippon MJ. Prevalence of abnormal hip findings in asymptomatic participants: a prospective, blinded study. Am J Sports Med. 2012;40(12):2720-2724.

**149.** Reichenbach S, Juni P, Werlen S, et al. Prevalence of cam-type deformity on hip magnetic resonance imaging in young males: a cross-sectional study. Arthritis Care Res (Hoboken). 2010;62(9):1319-1327.

**150.** Reichenbach S, Leunig M, Werlen S, et al. Association between cam-type deformities and magnetic resonance imaging-detected structural hip damage: a cross-sectional study in young men. Arthritis Rheum. 2011;63(12):4023-4030.

151. Reijman M, Hazes JM, Pols HA, Koes BW, Bierma-Zeinstra SM. Acetabular dysplasia predicts incident osteoarthritis of the hip: the Rotterdam study. Arthritis Rheum. 2005;52(3):787-793.

152. Reiman MP, Agricola R, Kemp JL, et al. Infographic. Consensus recommendations on the classification, definition and diagnostic criteria of hip-related pain in young and middle-aged active adults from the International Hip-related Pain Research Network, Zurich 2018. Br J Sports Med. 2020.

153. Reiman MP, Agricola R, Kemp JL, et al. Consensus recommendations on the classification, definition and diagnostic criteria of hip-related pain in young and middle-aged active adults from the International Hip-related Pain Research Network, Zurich 2018. Br J Sports Med. 2020.

154. Roels P, Agricola R, Oei EH, Weinans H, Campoli G, Zadpoor AA. Mechanical factors explain development of cam-type deformity. Osteoarthritis Cartilage. 2014;22(12):2074-2082.

155. Ryan J, DeBurca N, Mc Creesh K. Risk factors for groin/hip injuries in field-based sports: a systematic review. Br J Sports Med. 2014;48(14):1089-1096.

156. Saberi Hosnijeh F, Zuiderwijk ME, Versteeg M, et al. Cam Deformity and Acetabular Dysplasia as Risk Factors for Hip Osteoarthritis. Arthritis Rheumatol. 2017;69(1):86-93.

157. Sankar WN, Nevitt M, Parvizi J, Felson DT, Agricola R, Leunig M. Femoroacetabular impingement: defining the condition and its role in the pathophysiology of osteoarthritis. J Am Acad Orthop Surg. 2013;21 Suppl 1:S7-S15.

158. Siebenrock KA, Behning A, Mamisch TC, Schwab JM. Growth plate alteration precedes cam-type deformity in elite basketball players. Clin Orthop Relat Res. 2013;471(4):1084-1091.

159. Siebenrock KA, Ferner F, Noble PC, Santore RF, Werlen S, Mamisch TC. The cam-type deformity of the proximal femur arises in childhood in response to vigorous sporting activity. Clin Orthop Relat Res. 2011;469(11):3229-3240.

160. Siebenrock KA, Kaschka I, Frauchiger L, Werlen S, Schwab JM. Prevalence of cam-type deformity and hip pain in elite ice hockey players before and after the end of growth. Am J Sports Med. 2013;41(10):2308-2313.

161. Siebenrock KA, Wahab KH, Werlen S, Kalhor M, Leunig M, Ganz R. Abnormal extension of the femoral head epiphysis as a cause of cam impingement. Clin Orthop Relat Res. 2004(418):54-60.

162. Siffert RS. Patterns of deformity of the developing hip. Clin Orthop Relat Res. 1981(160):14-29.

163. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (minors): development and validation of a new instrument. ANZ J Surg. 2003;73(9):712-716.

164. Strope MA, Nigh P, Carter MI, Lin N, Jiang J, Hinton PS. Physical Activity-Associated Bone Loading During Adolescence and Young Adulthood Is Positively Associated With Adult Bone Mineral Density in Men. Am J Mens Health. 2015;9(6):442-450.

165. Stubbe JH, van Beijsterveldt AM, van der Knaap S, et al. Injuries in professional male soccer players in the Netherlands: a prospective cohort study. J Athl Train. 2015;50(2):211-216.

166. Stulberg SD, Cooperman DR, Wallensten R. The natural history of Legg-Calve-Perthes disease. J Bone Joint Surg Am. 1981;63(7):1095-1108.

167. Stulberg SDC LDH, W.H. Ramsey, P.L. MacEwan, G.D. . Unrecognized childhood hip disease: a major cause of idiopathic osteoarthritis of the hip. In: Cordell LD, Harris WH,Ramsey PL, MacEwen GD, eds The Hip: Proceedings of theThird Open Scientific Meeting of the Hip Society 1975:212–228.

168. Sutter R, Dietrich TJ, Zingg PO, Pfirrmann CW. How useful is the alpha angle for discriminating between symptomatic patients with cam-type femoroacetabular impingement and asymptomatic volunteers? Radiology. 2012;264(2):514-521.

169. Swartz MK. The PRISMA statement: a guideline for systematic reviews and meta-analyses. J Pediatr Health Care. 2011;25(1):1-2.

170. Tak I, Engelaar L, Gouttebarge V, et al. Is lower hip range of motion a risk factor for groin pain in athletes? A systematic review with clinical applications. Br J Sports Med. 2017;51(22):1611-1621.

171. Tak I, Glasgow P, Langhout R, Weir A, Kerkhoffs G, Agricola R. Hip Range of Motion Is Lower in Professional Soccer Players With Hip and Groin Symptoms or Previous Injuries, Independent of Cam Deformities. Am J Sports Med. 2016;44(3):682-688.

172. Tak I, Tijssen M, Schamp T, et al. The Dutch Hip and Groin Outcome Score: Cross-cultural Adaptation and Validation According to the COSMIN Checklist. J Orthop Sports Phys Ther. 2018;48(4):299-306.

173. Tak I, Weir A, Langhout R, et al. The relationship between the frequency of football practice during skeletal growth and the presence of a cam deformity in adult elite football players. Br J Sports Med. 2015;49(9):630-634.

**174.** Tan VP, Macdonald HM, Kim S, et al. Influence of physical activity on bone strength in children and adolescents: a systematic review and narrative synthesis. J Bone Miner Res. 2014;29(10):2161-2181.

**175.** Tannenbaum E, Kopydlowski N, Smith M, Bedi A, Sekiya JK. Gender and racial differences in focal and global acetabular version. J Arthroplasty. 2014;29(2):373-376.

**176.** Thomas GE, Palmer AJ, Batra RN, et al. Subclinical deformities of the hip are significant predictors of radiographic osteoarthritis and joint replacement in women. A 20 year longitudinal cohort study. Osteoarthritis Cartilage. 2014;22(10):1504-1510.

**177.** Thomee R. A comprehensive treatment approach for patellofemoral pain syndrome in young women. Phys Ther. 1997;77(12):1690-1703.

**178.** Thorborg K, Bandholm T, Holmich P. Hip- and knee-strength assessments using a hand-held dynamometer with external belt-fixation are inter-tester reliable. Knee Surg Sports Traumatol Arthrosc. 2013;21(3):550-555.

**179.** Thorborg K, Bandholm T, Schick M, Jensen J, Holmich P. Hip strength assessment using handheld dynamometry is subject to intertester bias when testers are of different sex and strength. Scand J Med Sci Sports. 2013;23(4):487-493.

**180.** Thorborg K, Branci S, Nielsen MP, Langelund MT, Holmich P. Copenhagen five-second squeeze: a valid indicator of sports-related hip and groin function. Br J Sports Med. 2017;51(7):594-599.

**181.** Thorborg K, Branci S, Nielsen MP, Tang L, Nielsen MB, Holmich P. Eccentric and Isometric Hip Adduction Strength in Male Soccer Players With and Without Adductor-Related Groin Pain: An Assessor-Blinded Comparison. Orthop J Sports Med. 2014;2(2):2325967114521778.

**182.** Thorborg K, Branci S, Stensbirk F, Jensen J, Holmich P. Copenhagen hip and groin outcome score (HAGOS) in male soccer: reference values for hip and groin injury-free players. Br J Sports Med. 2014;48(7):557-559.

**183.** Thorborg K, Couppe C, Petersen J, Magnusson SP, Holmich P. Eccentric hip adduction and abduction strength in elite soccer players and matched controls: a cross-sectional study. Br J Sports Med. 2011;45(1):10-13.

**184.** Thorborg K, Holmich P, Christensen R, Petersen J, Roos EM. The Copenhagen Hip and Groin Outcome Score (HAGOS): development and validation according to the COSMIN checklist. Br J Sports Med. 2011;45(6):478-491.

**185.** Thorborg K, Rathleff MS, Petersen P, Branci S, Holmich P. Prevalence and severity of hip and groin pain in sub-elite male football: a cross-sectional cohort study of 695 players. Scand J Med Sci Sports. 2017;27(1):107-114.

**186.** Thorborg K, Serner A, Petersen J, Madsen TM, Magnusson P, Holmich P. Hip adduction and abduction strength profiles in elite soccer players: implications for clinical evaluation of hip adductor muscle recovery after injury. Am J Sports Med. 2011;39(1):121-126.

**187.** Tyler TF, Nicholas SJ, Campbell RJ, McHugh MP. The association of hip strength and flexibility with the incidence of adductor muscle strains in professional ice hockey players. Am J Sports Med. 2001;29(2):124-128.

**188.** Van Houcke J, Yau WP, Yan CH, et al. Prevalence of radiographic parameters predisposing to femoroacetabular impingement in young asymptomatic Chinese and white subjects. J Bone Joint Surg Am. 2015;97(4):310-317.

**189.** van Klij P, Agricola R. Editorial on 'Functional outcomes and cam recurrence after arthroscopic treatment of femoroacetabular impingement in adolescents'. Annals of Joint. 2018.

**190.** van Klij P, Ginai AZ, Heijboer MP, Verhaar JAN, Waarsing JH, Agricola R. The relationship between cam morphology and hip and groin symptoms and signs in young male football players. Scand J Med Sci Sports. 2020;30(7):1221-1231.

**191.** van Klij P, Heerey J, Waarsing JH, Agricola R. The Prevalence of Cam and Pincer Morphology and Its Association With Development of Hip Osteoarthritis. J Orthop Sports Phys Ther. 2018;48(4):230-238.

**192.** van Klij P, Heijboer MP, Ginai AZ, Verhaar JAN, Waarsing JH, Agricola R. Cam morphology in young male football players mostly develops before proximal femoral growth plate closure: a prospective study with 5-yearfollow-up. Br J Sports Med. 2019;53(9):532-538.

**193.** van Klij P, Heijboer MP, Ginai AZ, Verhaar JAN, Waarsing JH, Agricola R. Clinical and radiological hip parameters do not precede, but develop simultaneously with cam morphology: a 5-year follow-up study. Knee Surg Sports Traumatol Arthrosc. 2020.

**194.** van Klij P, Reiman MP, Waarsing JH, et al. Classifying Cam Morphology by the Alpha Angle: A Systematic Review on Threshold Values. Orthopaedic Journal of Sports Medicine. 2020;8(8):2325967120938312.

**195.** van Trijffel E, van de Pol RJ, Oostendorp RA, Lucas C. Inter-rater reliability for measurement of passive physiological movements in lower extremity joints is generally low: a systematic review. J Physiother. 2010;56(4):223-235.

**196.** Walden M, Hagglund M, Ekstrand J. The epidemiology of groin injury in senior football: a systematic review of prospective studies. Br J Sports Med. 2015;49(12):792-797.

**197.** Weir A, Brukner P, Delahunt E, et al. Doha agreement meeting on terminology and definitions in groin pain in athletes. Br J Sports Med. 2015;49(12):768-774.

**198.** Wells GS BOC, D; Peterson, J; Welch, V; Losos, M; Tugwell, P;. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses.http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp Access date: 27-11-2018.

**199.** Werner J, Hagglund M, Ekstrand J, Walden M. Hip and groin time-loss injuries decreased slightly but injury burden remained constant in men's professional football: the 15-year prospective UEFA Elite Club Injury Study. Br J Sports Med. 2019;53(9):539-546.

**200.** Werner J, Hagglund M, Walden M, Ekstrand J. UEFA injury study: a prospective study of hip and groin injuries in professional football over seven consecutive seasons. Br J Sports Med. 2009;43(13):1036-1040.

**201.** Whittaker JL, Small C, Maffey L, Emery CA. Risk factors for groin injury in sport: an updated systematic review. Br J Sports Med. 2015;49(12):803-809.

**202.** Wiberg G. The anatomy and roentgenographic appearance of a normal hip joint. Acta Chir Scand 1939;83:7–38.

**203.** Wollin M, Thorborg K, Welvaert M, Pizzari T. In-season monitoring of hip and groin strength, health and function in elite youth soccer: Implementing an early detection and management strategy over two consecutive seasons. J Sci Med Sport. 2018;21(10):988-993.

**204.** Zaltz I, Kelly BT, Hetsroni I, Bedi A. The crossover sign overestimates acetabular retroversion. Clin Orthop Relat Res. 2013;471(8):2463-2470.

# PhD portfolio

| **Name PhD student:**<br>P. van Klij<br>**Erasmus MC Department:**<br>Orthopaedic Surgery | **PhD period:**<br>01-01-2018 – 31-12-2020 | **Promotor:**<br>Prof.dr. J.A.N. Verhaar<br>**Copromotor:**<br>Dr. R. Agricola |
|---|---|---|
| | **Date:** | **Workload (ECTS):** |
| **General courses** | | |
| • Course 'Biostatistical methods 1: basic principles part A' (CC02A) | 09 – 2018 | 5,7 |
| • Biomedical English Writing and Communication | 11 – 2018 | 3,0 |
| • CPO (Course Patient Oriented Research: design, conduct and analysis) course | 07 – 2018 | 0,3 |
| • Research Integrity | 07 – 2018 | 0,3 |
| • Endnote course Erasmus Library | 08 – 2018 | 0,3 |
| • Pubmed 1 course Erasmus Library | 08 – 2018 | 0,3 |
| • Pubmed 2 course Erasmus Library | 09 – 2018 | 0,3 |
| **Specific courses** | | |
| • Basic Life Support (BLS) course | 04 – 12 – 2019 | 0,3 |
| **Seminars and workshops** | | |
| • Erasmus Medical Centre – Orthopaedic Science Day 2018 (pitch) | 17 – 01 – 2018 | |
| • ROGO-day | 21 – 11 – 2018 | |
| • Workshop 'Sportgeneeskunde MEETS Radiologie, 1+1=3' | 28 – 11 – 2018 | |
| • Monthly ACE-meeting Erasmus Medical Centre | 06 – 2018 / 06 – 2019 | |
| • Production of your thesis 'ProefschriftMaken' | 15 – 05 – 2019 | |
| **Consensus meetings** | | |
| • 'Femoroacetabular impingement syndrome rehabilitation after arthroscopy' – Warwick (UK) | 04 – 07 – 2018 | 0,3 |
| • The International Hip Pain Research Network consensus group – Zurich (SWI) | 17/18 – 11 – 2018 | 0,6 |
| • Delphi consensus study design on RTP criteria in athletes affected by LARGP – Aspetar (QAT) | 02 – 2020 / 07 – 2020 | 0,6 |
| **Oral and poster presentations**<br>*Oral presentations:* | | |
| • Sports Medicine annual congress 2017 – Ermelo (NL)<br>*'Heup- en liesklachten bij jeugdvoetballers met cam morfologie van de heup: een prospectieve studie met 5 jaar follow-up'*<br>*'Cam morfologie van de heup ontstaat vóór én neemt verder toe na sluiting van de proximale femorale groeischijf bij jeugdvoetballers: een prospectieve studie met minimaal 5 jaar follow-up.'* | 11 – 2017 | 1,0 |
| • XXVII Isokinetic Medical Group Conference 2018 – Camp Nou, Barcelona (ESP)<br>*'Cam morphology in young male soccer players only develops before proximal femoral growth plate closure.'* | 06 – 2018 | 1,0 |
| • Sports Hip Conference 2018 – Warwick (UK)<br>*'When does a cam shape develop?'* | 07 – 2018 | 1,0 |

| | Date: | Workload (ECTS): |
|---|---|---|
| • Sports Medicine annual congress 2018 – Ermelo (NL) (Invited speaker)<br>*'Cam morphology and its association with growth plate status, symptomatology and range of motion. A prospective study with 5-year follow-up'* | 11 – 2018 | 1,0 |
| • Orthopedic Science Day 2019 – Rotterdam (NL)<br>*'The shape of the hip in athletes: Does it matter?'* | 16 – 01 – 2019 | 1,0 |
| • NOV annual congress 2019 – 's-Hertogenbosch (NL)<br>*'Heup- en lies symptomen en functiebeperking bij mannelijke voetballers en de relatie met cam morfologie: een prospectieve studie met 5-jaar follow-up.'* | 24 – 01 – 2019 | 1,0 |
| • ACE Bone&Joint meeting – Rotterdam (NL)<br>*'Does the shape of the hip change during growth?* | 21 – 02 – 2019 | 1,0 |
| • Idrettsmedisinsk Hostkongress 2019 – Lillehammer (NOR) (Invited speaker)<br>*'Development and prevalence of cam morphology'* | 23 – 11 – 2019 | 1,0 |
| • La Trobe Student Showcase Zoom meeting<br>*'The aetiology, associated hip parameters and clinical consequences of cam morphology'* | 28– 10 – 2020 | 1,0 |
| • The Oxford-Aspetar-La Trobe Young Athlete's Hip Webinar Series (Invited speaker)<br>*'What are the possible risk factors for primary cam morphology?'* | 15 – 01 – 2021 | 1,0 |
| *Poster presentations:* | | |
| • OARSI – Liverpool (UK)<br>*'Cam morphology of the hip arises before, and does not further increase after closure of the proximal femoral growth plate in youth soccer players: a prospective study with a minimum of 5-years follow-up'* | 04 – 2018 | |
| • 1st Sportfisio & Swiss Sports Medical Conference – Bern (SWI)<br>*'Hip- and groin symptoms in young male soccer players and its relation with cam morphology: a prospective study with 5-year follow-up'* | 11 – 2018 | |
| **National and international conferences** | | |
| • Sports Medicine annual congress – Ermelo (NL) | 11 – 2013 | 1,0 |
| • Sports Medicine annual congress – Eindhoven (NL) | 11 – 2015 | 1,0 |
| • CCC congress – Tilburg (NL) | 12 – 2015 | 1,0 |
| • Sports Medicine annual congress – Ermelo (NL) | 11 – 2017 | 1,0 |
| • OARSI – Liverpool (UK) | 04 – 2018 | 1,0 |
| • XXVII Isokinetic Medical Group Conference 2018 – Barcelona (ESP) | 06 – 2018 | 1,0 |
| • Sports Hip Conference 2018 – Warwick (UK) | 07 – 2018 | 1,0 |
| • NOV autumn conference – Rotterdam (NL) | 10 – 2018 | 1,0 |
| • Sports Medicine annual congress – Ermelo (NL) | 11 – 2018 | 1,0 |
| • 1st Sportfisio & Swiss Sports Medical Conference – Bern (SWI) | 11 – 2018 | 1,0 |
| • NOV annual conference – 's-Hertogenbosch (NL) | 01 – 2019 | 1,0 |
| • Idrettsmedisinsk Hostkongress 2019 – Lillehammer (NOR) | 11 – 2019 | 1,0 |
| • Sports Medicine annual congress – Ermelo (NL) | 11 – 2019 | 1,0 |
| • La Trobe Student Showcase Zoom meeting | 10 – 2020 | 1,0 |
| • Sports Medicine annual congress digital | 11 – 2020 | 1,0 |
| • The Oxford-Aspetar-La Trobe Young Athlete's Hip Webinar Series | 11 – 2020 / 09-2021 | At least: 1,0 |

| | Date: | Workload (ECTS): |
|---|---|---|
| **Publications** | | |
| • van Klij P, Lagas I, Groot FP, van Ochten JM, de Vos RJ. *Klinisch toepasbare functie- en krachttesten voor mannelijke jeugdspelers van een betaald voetbal organisatie* **Sport en Geneeskunde** 2018;1:1-9 | 01 – 2018 | |
| • van Klij P, Heerey J, Waarsing JH, Agricola R. *The Prevalence of Cam and Pincer Morphology and Its Association With Development of Hip Osteoarthritis* **J Orthop Sports Phys Ther** 2018 Apr;48(4):230-238. | 04 – 2018 | |
| • van Klij, P, Agricola R. *Functional outcomes and cam recurrence after arthroscopic treatment of femoroacetabular impingement in adolescents (Editorial)* **Ann Joint** 2018;3:55. | 06 – 2018 | |
| • van Klij P, Heijboer MP, Ginai AZ, Verhaar JAN, Waarsing JH, Agricola R. *Cam morphology in young male football players mostly develops before proximal femoral growth plate closure: a prospective study with 5-year follow-up.* **Br J Sports Med**. 2019;53(9):532-538. | 10 – 2018 | |
| • van Klij P, Ginai AZ, Heijboer MP, Verhaar JAN, Waarsing JH, Agricola R. *The relationship between cam morphology and hip and groin symptoms and signs in young male football players* **Scand J Med Sci Sports** 2020;30(7)-1221-1231 | 03 – 2020 | |
| • van Klij P, Reiman M, Waarsing JH, Reiman M, Bramer W, Verhaar JAN, Agricola R. *Classifying Cam Morphology by the Alpha Angle: A Systematic Review on Threshold Values.* **Orthopaedic Journal of Sports Medicine.** 2020;8(8):2325967120938312. | 03 – 2020 | |
| • The International Hip Pain Research Network consensus group' (5 publications in **British Journal of Sports Medicine**) | 12 – 2019 / 08 – 2020 | |
| • Beddows TPA, van Klij P, Tak IJR, Agricola R, Piscaer T, Verhaar JAN, Weir A. *Normal values for hip muscle strength and range of motion in elite, sub-elite and amateur male field hockey players.* **Physical Therapy in Sport**. 2020;46:169-176. | 09 – 2020 | |
| • van Klij P, Ginai AZ, Heijboer MP, Verhaar JAN, Waarsing JH, Agricola R. *Clinical and radiological hip parameters do not precede but develop simultaneously with cam morphology: a 5 year follow-up study.* **Knee Surg Sports Traumatol Arthrosc**. 2020 Oct 1. doi: 10.1007/s00167-020-06282-0. Epub ahead of print. | 09 – 2020 | |
| **Submitted papers:** | | |
| • van Klij P, Langhout R, van Beijsterveldt AMC, Stubbe JH, Weir A, Agricola R, Fokker Y, Waarsing JH, Verhaar JAN, Tak IJR' *Do hip and groin muscle strength and symptoms change throughout a soccer season in professional male soccer players? A prospective cohort study with repeated measures'* **Journal of Science and Medicine in Sport** | Under revision | |

| | Date: | Workload (ECTS): |
|---|---|---|
| **Scholarships and Travel Grants** | None | |
| **Awards**<br>• Sport & Geneeskunde 'Aanmoedigingsprijs 2018' | 11 – 2018 | |
| **Teaching/working:**<br>• At Feyenoord Youth Academy as a medical doctor:<br>- Working on prevention of physical and mental health issues.<br>- Present at several youth tournaments in several countries (United Kingdom, Germany, France, Portugal, Switzerland and the Netherlands).<br>- Especially in teams: U10, U11, U12 and 2nd team of Feyenoord (U23/U21).<br>• Teaching students who are performing their Master thesis at the Department of Orthopaedics at the Erasmus Medical Centre. | | |
| **Supervising Masters theses**<br>• Supervising Master thesis of Tom Beddows about hip muscle strength, hip function and groin injuries in professional male field hockey players.<br>• Partly supervising Master thesis of Astrid van Ovost about the development of the pubic symphysis in professional athletes. | 11 – 2018 / 04 – 2019<br>11 – 2020 / now | 5,0 |
| **Reviewing**<br>• Jacobs Journal of Orthopedics and Rheumatology<br>• Arthritis Care & Research<br>• Physical Therapy in Sport | 2019<br>2020<br>2020 | |
| **Other**<br>• Organising committee of the 'Traumadag' at Erasmus MC (Orthopaedic Surgery/Sports Medicine)<br>• Co-author of ISAKOS book 'Management of Track and Field injuries' chapter about FAI in Track and Field athletes. | 15 – 09 – 2018<br>07 – 2020 | 0,3<br>1,0 |
| **Total ECTS** | | **44,3** |

# List of publications

**‘Cam morphology in young male football players mostly develops before proximal femoral growth plate closure: a prospective study with 5-year follow-up’**
British Journal of Sports Medicine: published.

**‘Classifying Cam Morphology by the Alpha Angle: A Systematic Review on Threshold Values’**
Orthopaedic Journal of Sports Medicine: published.

**‘Clinical and radiological hip parameters do not precede but develop simultaneously with cam morphology: a 5 year follow-up study.’**
Knee Surgery, Sports Traumatology, Arthroscopy: published.

**‘Clinical applicable functional and strength test for male adolescent football players of a professional soccer club.’ (Translated from Dutch)**
Sport & Geneeskunde: published.

**‘Consensus recommendations on the classification, definition and diagnostic criteria of hip-related pain in young and middle-aged active adults from the International Hip-related Pain Research Network, Zurich 2018.’**
British Journal of Sports Medicine: published.

**‘Do hip and groin muscle strength and symptoms change throughout a soccer season in professional male soccer players? A prospective cohort study with repeated measures’**
Journal of Science and Medicine in Sport: under revision.

**‘Functional outcomes and cam recurrence after arthroscopic treatment of femoroacetabular impingement in adolescents’**
Annals of Joint: published.

**‘Infographic. Consensus recommendations on the classification, definition and diagnostic criteria of hip-related pain in young and middle-aged active adults from the International Hip-related Pain Research Network, Zurich 2018.’**
British Journal of Sports Medicine: published.

**‘Normal values for hip muscle strength and range of motion in elite, sub-elite and amateur male field hockey players’**
Physical Therapy in Sport: published.

**‘Patient-reported outcome measures for hip-related pain: a review of the available evidence and a consensus statement from the International Hip-related Pain Research Network, Zurich 2018.’**
British Journal of Sports Medicine: published.

**‘Physiotherapist-led treatment for young to middle-aged active adults with hip-related pain: consensus recommendations from the International Hip-related Pain Research Network, Zurich 2018.’**
British Journal of Sports Medicine: published.

**‘Standardised measurement of physical capacity in young and middle-aged active adults with hip-related pain: recommendations from the first International Hip-related Pain Research Network (IHiPRN) meeting, Zurich, 2018.’**
British Journal of Sports Medicine: published.

**‘The Prevalence of Cam and Pincer Morphology and Its Association With Development of Hip Osteoarthritis’**
Journal of Orthopaedic & Sports Physical Therapy: published.

**‘The relationship between cam morphology and hip and groin symptoms and signs in young male soccer players’**
Scandinavian Journal of Medicine & Science in Sports: published.

# Curriculum vitae

Pim van Klij is geboren op 22 juni 1992 te Gorinchem. Hij volgde het VWO op het Merewade College met profielkeuze 'Natuur & Gezondheid' en 'Natuur & Techniek', alwaar hij zijn diploma behaalde in 2010. Via een decentrale selectie procedure werd hij in 2010 toegelaten tot de opleiding Geneeskunde in Rotterdam aan de Erasmus Universiteit. Tijdens deze opleiding was zijn aandacht tijdens de bachelor-fase gericht op cardiologie (deelonderwijs) en orthopaedische sporttraumatologie (minor). Tijdens de master-fase was zijn master-onderzoek volledig gewijd aan de ontwikkeling van de heup van professionele voetballers. Hierna heeft hij keuze coschappen orthopaedische chirurgie (AZ Maria Middelares, Gent (België)) en sportgeneeskunde (Isala, Zwolle) gevolgd, afgesloten met een oudste coschap orthopaedische chirurgie (Reinier de Graaf Gasthuis, Delft). Tijdens deze master-fase was hij ook actief als ambassadeur van de Erasmus Universiteit en behartigde hij de belangen van coassistenten in de Co-Raad Rotterdam. In zijn vrije tijd was hij onder andere werkzaam op de afdeling audiovisuele ondersteuning en afdeling longziekten in het Erasmus MC, was hij medeoprichter van bedrijf PScreative (ontwikkeling websites, huisstijlen en print) met Sven Nardten (grafisch vormgever proefschrift) en daarnaast actief in de medische staf van de Feyenoord Academy, op het Future Tennis Tournament Alkmaar en op het NK Turnen. In 2018 behaalde hij zijn doctoraal. De mogelijkheid werd geboden om het reeds opgezette master-onderzoek verder uit te breiden tot een promotietraject. Dit traject heeft hij vol enthousiasme afgerond onder leiding van zijn promotor Prof.dr. J.A.N. Verhaar en copromotor Dr. R. Agricola. Dit in totaal ongeveer 2.5 jaar durende traject richtte zich met name op de morfologische ontwikkeling van de heup bij professionele voetballers en de potentiële gevolgen hiervan. Daarnaast bepaalde hij normaalwaarden van heup spierkracht en beweeglijkheid bij professionele voetballers en hockeyers. Na dit traject heeft hij 7 maanden gewerkt als arts-assistent (ANIOS) cardiologie in het Haaglanden Medisch Centrum (opleider Drs. P.R.M. van Dijkman). Per 1 januari 2020 is hij gestart aan de opleiding tot sportarts (AIOS) in de Isala Klinieken te Zwolle (opleider Drs. T. Brandon).

# Acknowledgements

# Dankwoord

In dit dankwoord wil ik graag mijn grote dank uiten naar iedereen die, op wat voor manier dan ook, heeft bijgedragen aan dit proefschrift. In het specifiek wil ik een aantal van hen uitlichten.

**Prof. dr. J.A.N. Verhaar (promotor)**, geachte professor, ik wil u bedanken voor het vertrouwen wat u in mij had, nadat ik tijdens mijn coschappen en master-onderzoek met mijn eigen plan bij u op gesprek mocht komen. U gaf mij de kans mij op wetenschappelijk gebied, met een scherpe planning, te ontwikkelen. Daarnaast wil ik u bedanken voor de kritische blik op de artikelen in dit proefschrift en fijne begeleiding en ondersteuning tijdens deze periode.

**Dr. R. Agricola (copromotor)**, beste Rintje waar zal ik beginnen. Ik kan onze eerste 'afspraak' in het onderwijscentrum, het uitwerken van de master-onderzoek plannen in café L'Ouest eind 2014 en de trips naar Zwitserland, Spanje en Groot-Brittannië nog als de dag van vandaag herinneren. Het zijn voor mij prachtige herinneringen waarin we elkaar ook beter hebben leren kennen. Dank voor je ongelooflijke wetenschappelijke passie, je broodnodige kritische blik, enthousiasme en je bereidheid mij van feedback te voorzien, tot midden in de nacht en soms nog sneller dan ik voor mogelijk hield. Jij bent in die zin cruciaal geweest in het tijdig kunnen afronden van dit project. Rintje, enorm bedankt, ik stel voor dat we gauw weer in een café kunnen afspreken, maar dan terugkijkend op deze mooie tijd!

Alle andere leden van de promotiecommissie, ook jullie wil ik natuurlijk hartelijk danken voor de beoordeling van dit proefschrift. Daarnaast wil ik de opponenten tijdens de verdediging van dit proefschrift danken voor hun deelname en aanwezigheid.

**Daan en Huub (paranimfen)**, de gezamenlijke passie voor wielrennen, voetbal, tennis, een pot FIFA en uiteraard borrelen buiten op het terras in de Witte de Withstraat is voor mij de ideale uitlaatklep geweest en is dé sleutel geweest om dit project tot een goed einde te brengen. Ik wil jullie danken voor de mooie tijd als huisgenoten maar ook als goede vrienden. Ondanks het feit dat ik mij inmiddels in Zwolle bevind, hoop ik dat we elkaar vaak blijven zien en spreken, op of naast de fiets of baan!

**Dr. ir. J.H. Waarsing**, beste Erwin, samen met Rintje heb jij mij, zeker in het begin van deze periode, enorm geholpen met je scherpe adviezen, kritische analytische blik en hulp bij het samenstellen en opzetten van diverse onderzoeken. Je was een rustgevende factor in mijn soms te volle en strakke planning. Enorm dank daarvoor.

**Dr. A. Weir**, beste Adam, ik wil je bedanken voor je grenzeloze enthousiasme en passie voor de heup en lies en de altijd fijne overleggen, discussies en het samen opzetten van de heup-lies groep in het Erasmus MC. Ook de leuke trips naar onder andere Groot-Brittannië en Spanje zal ik niet snel vergeten. Als toekomstig collega sportarts, hoop ik je nog vaak tegen te komen in het veld!

**Drs. M.P. Heijboer,** via een 'brutale' e-mail aan u is dit hele project ontstaan. U bracht mij in contact met onder andere Rintje. Ik wil u bedanken voor de kans die u mij bood en de fijne samenwerking bij meerdere artikelen in dit proefschrift.

**Dr. A.Z. Ginai**, ik wil u bedanken voor de fijne samenwerking op radiologisch gebied, deze ondersteuning is van groot belang geweest voor dit proefschrift.

Uiteraard de collega's van HS-104 en NC-424, beste **Max, Eline, Arco, Annika, Abi, Lichelle, Iris, Michiel, Joost, Susanne, Mark, Robert-Jan, Duncan, Tom Piscaer, Tom Beddows en Tim**: bedankt voor de leuke tijd en natuurlijk ook de ronde met een aantal van jullie rondom het IJsselmeer, borrels in de binnenstad en nog veel meer.

Mijn nieuwe collega's in het Isala ziekenhuis in Zwolle op afdeling Sportgeneeskunde: **Tom, Sietske, Mineke, Aernout, Marloes, Jaap, Laura, Annemiek, Rick, Liesbeth, Anne, Yvette, Alice, Cocky, Inge en Suzan**, dank voor jullie fijne ontvangst in Zwolle. Ik weet zeker, we gaan nog leuke en leerzame jaren met elkaar tegemoet!

**Igor en Rob**, dank voor de prettige samenwerking bij onder andere de GRIP en hockey studie en hopelijk zien we elkaar nog veel vaker terug op de sportmedische congressen en bij toekomstige projecten.

**Joshua**, Josh mate, thank you for the nice work together on some papers. It was really nice to have you here in the Netherlands and to guide you through Rotterdam. Had a great time in Switzerland as well. Keep in touch and all the best in finalising your own thesis.

Jeugdspelers, trainers en andere stafleden van de Feyenoord Academy, bedankt voor jullie deelname en de ondersteuning van de onderzoeken die wij hebben kunnen verrichten. Mede door jullie inzet en support is dit proefschrift tot stand gekomen. De Rotterdamse mentaliteit, voetbalpassie en het feit dat ik, nog steeds, bij jullie actief kan en mocht zijn tijdens mijn PhD in de jeugdopleiding is voor mij heel speciaal. In het specifiek wil ik hiervoor **Marcel en Tijs** bedanken. **Martijn, Dylan en Brian** dank voor de mooie trips met jullie fantastische onder-11 en onder-12 teams!

Mijn (tennis)vrienden uit Gorinchem, beste **Joost, Niels, Jeroen, Bart en Roel**. Bedankt voor de mooie zondagen, thuiswedstrijden maar met name uitwedstrijden waardoor we ons hele zondagen in verre oorden bevonden. Maar ook 'trainingsweekenden', laten we dit er vooral in houden. Vriendschap, humor en niet te vergeten gezonde dosis sport, hopelijk ook in de toekomst.

**Dr. Ingeborg Wijting**, Borg, als internist en reeds gepromoveerde, kon jij mij tijdens onze 'koffiebreaks' van zeer geruststellende en voetbal gerelateerde feedback voorzien. Maar ook op wetenschappelijk gebied waren jouw tips & tricks heel belangrijk, bedankt.

**Sven Nardten**, compagnon. Dank voor de lang bestaande vriendschap, maar daarnaast natuurlijk ook de gave samenwerking voor dit proefschrift. Jij hebt al je passie (& tijd) gestopt in het ontwerp van de omslag en de huisstijl van dit proefschrift. Het is prachtig geworden!

Vrienden en vriendinnen van de eetclub, dank voor de gezellige diners, verjaardagen en feestjes. In het specifiek **Gijs**, jij als osteopaat hebt me regelmatig ook op een andere manier laten kijken naar 'mijn heupjes'. Tot het volgende diner met elkaar!

## Ook mijn familie wil ik graag bedanken:

Allereerst **pap en mam**, dankzij jullie liefdevolle ondersteuning voor en tijdens dit gehele traject heb ik dit kunnen volbrengen. Jullie ondersteuning is niet hier op papier te omschrijven of mijn dank daarvoor in letters uit te drukken. De fijne vakanties met elkaar die mij even uit de werkomgeving haalden, even bellen of FaceTimen als het tegenzat of gewoon met elkaar in Gorinchem een hapje eten. Bedankt voor alles.

Lieve **Lotte en Bas**, ondanks dat het voor jullie geen gemakkelijke tijd geweest is, kon ik altijd op jullie rekenen. Lekker met elkaar naar Friesland (waar ik overigens bijna m'n eigen heup brak met wielrennen, maar dat ter zijde), Limburg en Zeeland. Heel blij was ik met jullie lieve ondersteuning in voor- en tegenspoed.

Lieve **Guusje en Cato**, donderstenen, jullie zullen waarschijnlijk nog niet zoveel begrijpen wat hier vandaag plaatsvindt. Dat maakt ook helemaal niet uit. Heel bijzonder vind ik het dat jullie nu ook deel uit maken van onze familie.

Tot slot lieve **Rebecca**, altijd was je mijn steun en toeverlaat. Ondanks dat 'mijn heupjes' op een gegeven moment je neus uitkwamen, bleef je mijn Engelse stukken lezen en van feedback voorzien. Met jouw psychologische blik was je daarbij van grote waarde. Trots ben ik op jou, jouw ambities en het feit dat je in opleiding bent tot GZ-psycholoog. Op naar nieuwe uitdagingen en hoofdstukken in ons leven, ik hou van je.