The complexity of groin injury

In search of the injury mechanism

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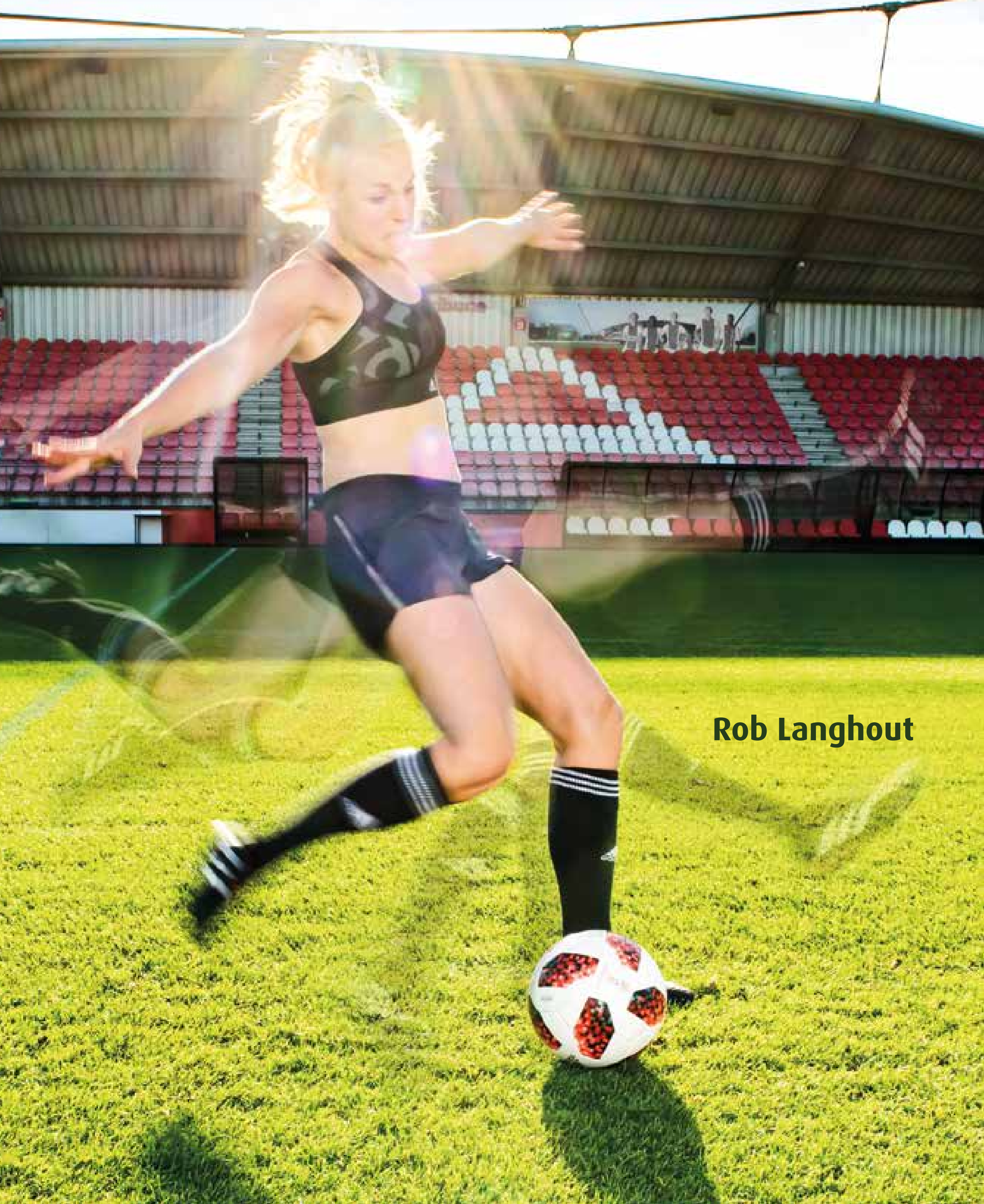

Rob Langhout

THE COMPLEXITY OF GROIN INJURY

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Rob Langhout

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The complexity of groin injury
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TABLE OF CONTENTS

CHAPTER

1

General Introduction

Groin injury is the fourth most prevalent injury in field-based sports that include agility such as football.[1,2] It is the most frequent reported overuse injury and the adductors are the second most injured muscles after hamstring injury in male professional football players.[1] The groin injury burden is substantial as the incidence and risk of chronicity and recurrence is high and leads to reduced performance, time-loss and may prelude the end of an athlete's career.[3,4] Athletes with groin injury frequently consult (sports) physicians, physiotherapists and surgeons. Appropriate diagnosis and treatment demands homonymous taxonomy of groin injury, which was recently facilitated by the Doha consensus statement on terms and definitions in athletes with groin pain.[5] Pathologic changes or failure of groin structures is most adequately described using the International Classification of Diseases.[6] The lack of correlation between morphological changes and groin problems experienced asks for an additional analysis on functional levels. Functional disorders or deficits are described using the International Classification of Functioning.[7] Combining these two allows drawing the most complete clinical picture of the injured athlete.

A substantial burden of groin injury warrants prevention and treatment interventions. In the injury prevention research sequence, van Mechelen et al.[8] proposed that prevalence, incidence and severity of groin injury should be assessed first in the target population. Secondly risk factors and the injury mechanism of groin injury should both be studied.[9] Subsequently, interventions likely reducing the risk of groin injury are introduced, based on information of the second step and the evaluation of its results are considered the last step of the model (**figure 1**).

In the introduction of this thesis recent information is presented concerning groin anatomy, physical examination of athletes with groin injury, injury definitions, epidemiology of groin injury, injury mechanisms, treatment of athletes with groin injury and return to sport in football players after groin injury.

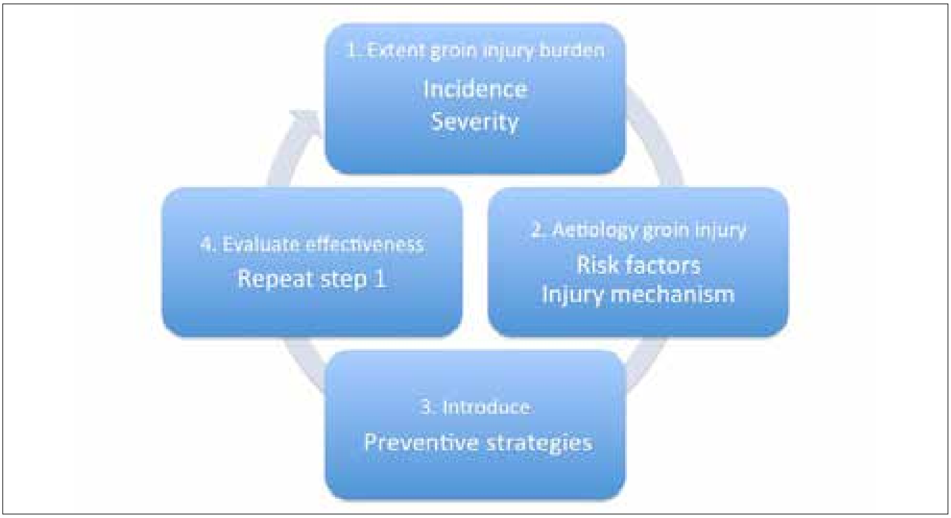

Figure 1 *The injury prevention sequence according to Van Mechelen[8]*

ANATOMY OF THE GROIN REGION

The groin region has a complex anatomy and several structures can be involved in case of injury.[10]

Descriptive anatomy

Falvey et al. presented a clock-wise anatomical approach to locate the inguinal ligament, superficial ring, conjoint tendon, rectus abdominis, pubic symphysis and adductor longus (**figure 2**).[11]

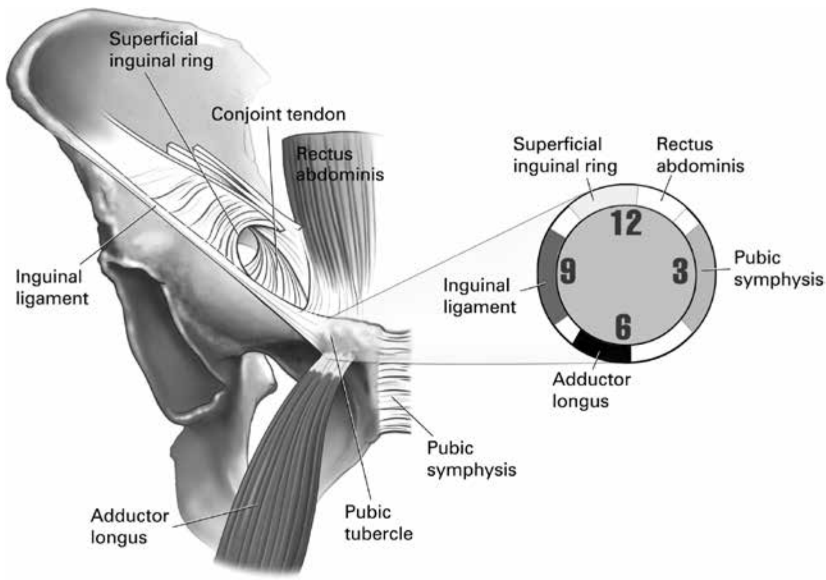

Figure 2 *The pubic tubercle for the orientation of the pubic symphysis related to the anatomical structures of the groin region. BJSM, with permission*[11]

The external oblique muscle is connected with the contralateral adductor longus via the superficial layer of the anterior pubic ligament being situated anterior to the pyramidalis muscle (**figure 3a**). The superficial inguinal ring is the medio-caudal end of the inguinal canal and located supero-lateral from the pubic tubercle. The medio-caudal fibres of the internal oblique and transverse abdominis (conjoint tendon) run caudally and attach to the inferior part of the rectus sheath and form, together with the external oblique, the medio-superior border of the inguinal ring (**figure 3b**).

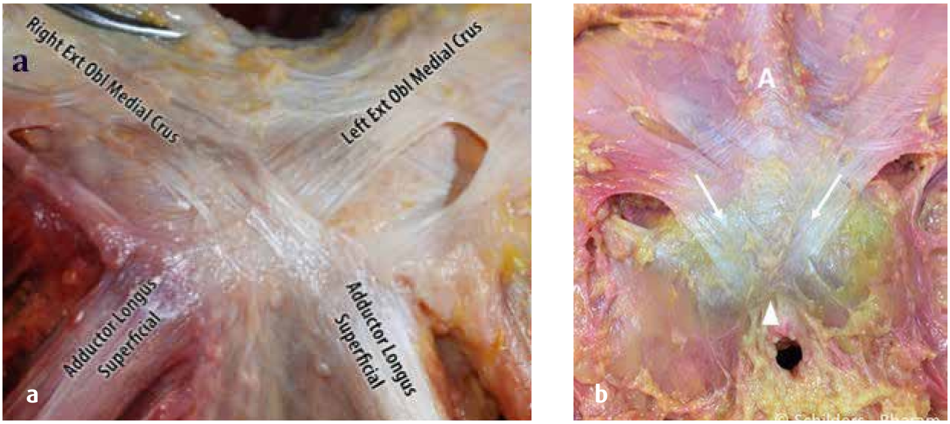

Figure 3a *Fusion of the fibres of the external oblique muscle with the adductor longus.* ***b*** *The external oblique forms the medio-superior border of the superficial inguinal ring (arrows) and fuse with the superficial layer of the anterior pubic ligament (arrowhead). Permission from Read (Clinical anatomy and correlative imaging of the ligamentous and muscular attachments of the pubic symphysis: a new description of the anterior pubic ligament. Honours thesis of Isaac Lui, UNSW 2012. Supervisor: Dr Dzung Huu Vu MD, MBBS, Dip Anat Grad Cert H Ed SOMS. Co-supervisor: Dr John Read MBBS, FRANZCR, DDU) (**a**) and BJSM (**b**)*[12]

The pyramidalis muscle is proximally connected to the linea alba and distally to the adductor longus tendon via the deep layer of the anterior pubic ligament. This ligament spans between both tubercles and runs anteriorly to the symphyseal joint (**figure 4a**).[13,14] The adductor longus also contains a fibrocartilaginous enthesis inserting inferior to the pubic tubercle (**figure 4b**).

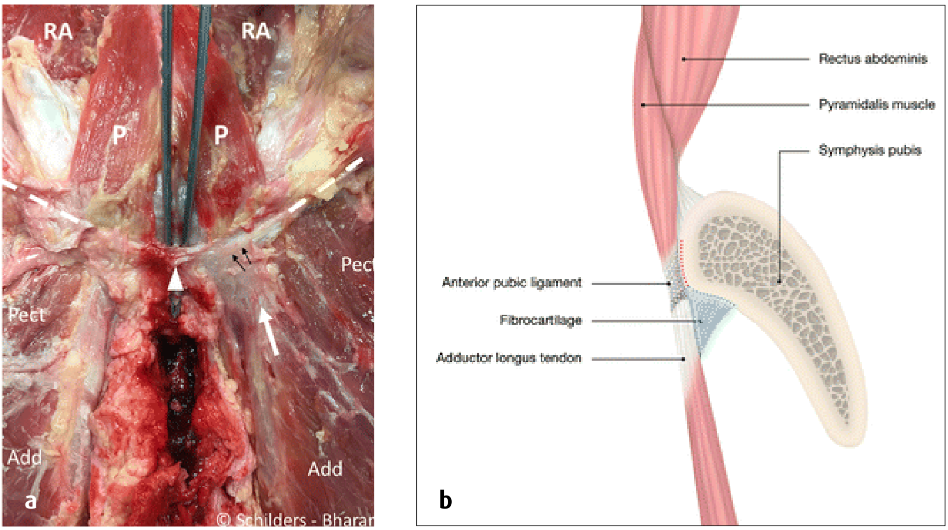

Figure 4a *The proximal adductor longus tendon (white arrow) fuses with the pyramidalis muscle via the deep anterior pubic ligament (black arrows). This anatomical relationship implies a cranially oriented reinforcement*

of the adductor longus during contraction of the pyramidalis. The superficial anterior pubic ligament=arrowhead. Abbreviations: RA=rectus abdominis; Pect=pectineus; Add=adductor longus; P=pyramidalis ***b*** *The adductor longus also contains a fibrocartilaginous enthesis inserting inferior to the pubic tubercle. The pyramidalis is the only muscle in front of the os pubis. BJSM, with permission*[12]

The rectus abdominis inserts with its external tendon on top of the os pubis (**figure 5a**). The internal tendon passes anterior to the symphyseal joint and connects with both gracilis muscles (**figure 5b**).[12] The proximal tendon of the gracilis fuses with the adductor brevis.[14] The fusion patterns of the musculotendinous units in this region show inter individual variety but symmetry is observed in most cases.[14]

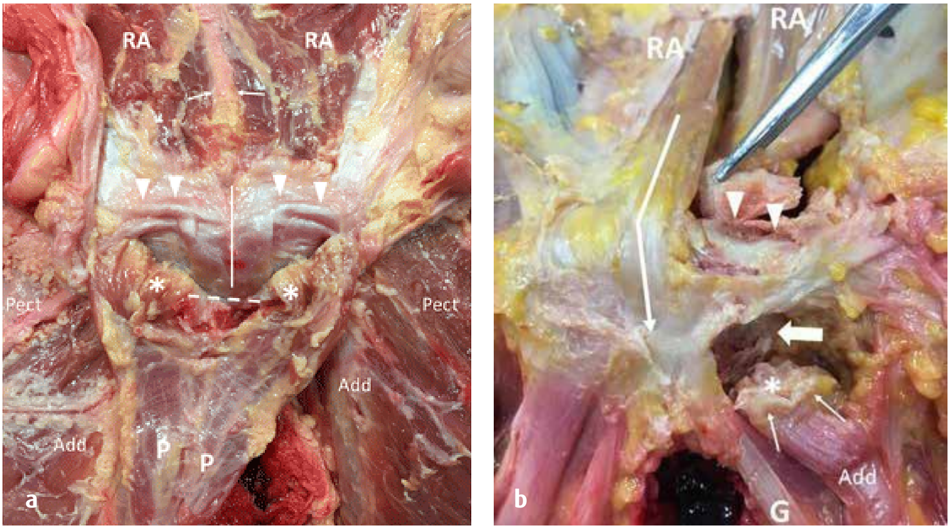

Figure 5a *The external tendon of the rectus abdominis attaches to the cranial aspect of the os pubis (arrowheads). The internal tendon runs anterior to the symphyseal joint (white line). Dashed line region=anterior pubic ligament (resected)* ***b*** *The internal tendon of the rectus abdominis (white arrow) runs distally to fuse with the gracilis (G) tendons. Adductor fibrocartilage (*) and tendon (white arrows). Abbreviations: RA=rectus abdominis; Pect=pectineus; Add=adductor longus; P=pyramidalis; G=gracilis. BJSM, with permission*[12]

Functional anatomy

Three functional connections between abdominal and adductor muscles can be distinguished: (1) the external oblique with the contralateral adductor longus, (2) the pyramidalis with the ipsilateral adductor longus and (3) the rectus abdominis with the ipsilateral gracilis.[12] Controversy exists on whether or not a direct fusion is present between the adductor longus and the rectus abdominis.[13,14] Instead, Schilders et al. demonstrated a direct fusion between the pyramidalis and adductor longus.[12] The pyramidalis assists in tensioning the abdominal aponeurosis and helps the rectus abdominis transferring force to the oblique and transverse muscles.[15,16] Distally,

the attachment of the pyramidalis reinforces the adductor longus origin together with the fibrocartilage attachment (**figure 4b**). The long intramuscular tendon of the adductor longus, up to a quarter of the femur length[14], provides extra strength during contraction.[17]
Although all these structures can be described separately it is obvious that the fused structures will assist one another during functional movement. The numerous myofascial connections are thought to control and transfer forces between the upper body and lower extremities during sports actions thereby controlling pelvic movement.[13]
The muscles, the inguinal structures, the pubic bone, the symphysis and the hip joint may all be involved in groin injury.[5] The interdependency of anatomical structures hinders to examine these structures in isolation, which agrees with the low validity of hip and groin tests in order to rule in the presence of specific pathology.[17–19] It is thus of interest for clinicians to quantify (loss of) function in terms of sport specific demands. No such tests have been described yet.

EXAMINATION OF GROIN INJURY

Groin injuries are rather complex because of the many anatomical structures possibly involved, their interdependency and the high frequency of 'pathological findings' in asymptomatic athletes.[5] Heterogeneous taxonomy used adds to further confusion and attributes to the wide range of prevalence rates of groin injury. This has led to the acceptance of clinical entities describing signs and symptoms of four functional groin regions instead of pathomorphology or structural tissue damage.[5] The clinical examination of these entities is reliable and four clinical entities can be defined (**table 1** and **figuur 6a, b**).[20]

Table 1 *Classification of groin injury*[5]

1. Defined clinical entities	**Examination**
• Adductor-related	Adductor pain on palpation and resistance against adduction
• Iliopsoas-related	Iliopsoas pain on palpation, resistance against hip flexion and/or stretching
• Inguinal-related	Pain on palpation of the inguinal canal and/or against resistance of the abdominal muscles or by Valsalva/cough/sneeze. A palpable inguinal hernia is not present
• Pubic-related	Local pain on palpation of the symphyseal joint and the adjacent bone
2. Hip-related	Clinical suspicion that the hip joint is the source of groin pain, through history taking and clinical examination
3. Other	Musculoskeletal disorders: nerve entrapment, sacroiliac joint, lumbar spine, inguinal hernia
	Medical disorders: Orthopaedic, neurologic, rheumatologic, urologic, gastrointestinal, dermatologic, oncologic or surgical conditions

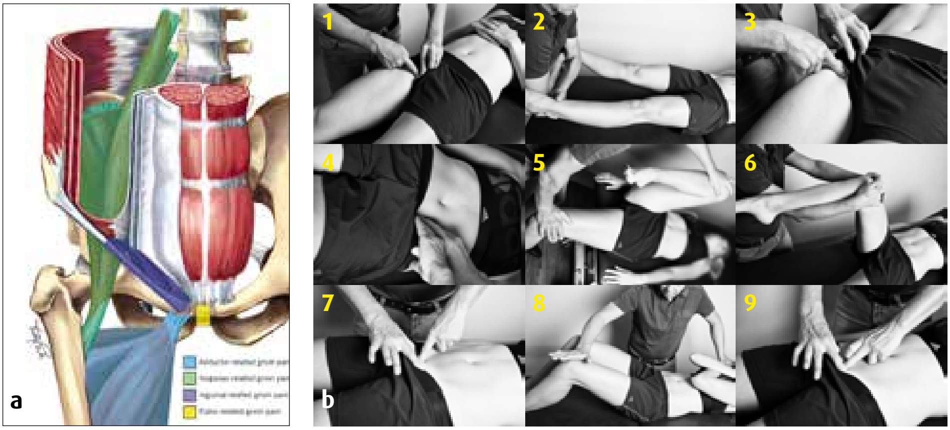

Figure 6a *Clinical entities according to the Doha agreement. BJSM, with permission*[5] ***b*** *The assessment of groin injury on clinical entities: adductor-related figure 6b1-2; iliopsoas-related figure 6b3-6; inguinal-related figure 6b7-8 and pubic-related figure 6b9*

GROIN INJURY DEFINITIONS

An injury was defined by a consensus statement in injury definitions in football as "any physical complaint sustained by a player that results from a football match or training, irrespective of the need for medical attention or time-loss from football activities".[21] Despite this definition, groin injury studies predominantly use the time-loss definition.[22] This will likely underestimate the groin injury burden in football as many players continue to train and play with groin complaints, eventually resulting in reduced performance.[3,22–24] The latter can be referred to as non-timeloss groin injury (**figure 7**). [25,26]

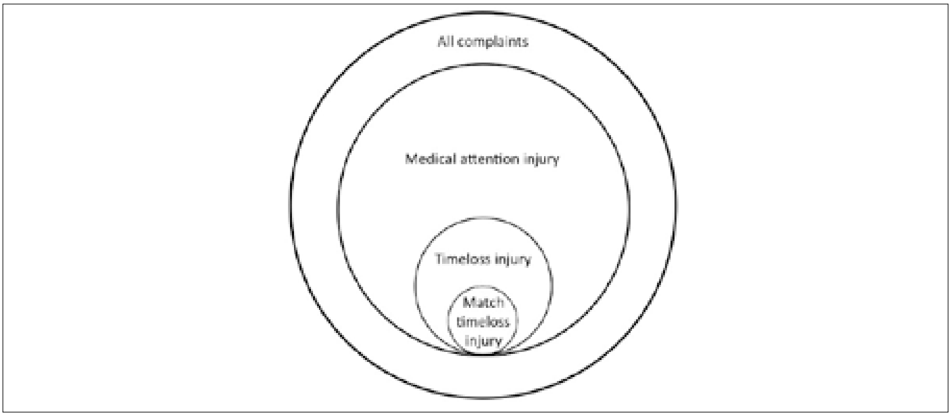

Figure 7 *Representation of injury definitions and injury frequency (unscaled). All complaints minus time-loss injury represent non-timeloss injury*[27]

EPIDEMIOLOGY OF GROIN INJURY

To assess the need for prevention measures, the groin injury burden of the target population should be established by examining injury frequency, severity and risk factors of both time-loss and non-time-loss groin injury.[8]

Incidence, prevalence and severity

The prevalence of time-loss groin injury in male professional football players varies between 4-19%.[22,27] Reported groin incidence rates differ between Dutch, (total/training/match 0.7/0.4/2.9 injury/1000 hours)[28], Arabic (1.0/0.7/3.5 injury/1000 hours)[29] and Swedish cohorts (1.3/1.0/3.7 injury/1000 hours)[30]. Total groin injury incidences in other field-based sports were 0.1 injury/1000 hours for baseball, 0.6 for basketball, 0.3-2.7 for rugby, 2.0-2.7 for Australian football, 5.8 for Gaelic football and 17.1 for ice hockey.[31]

It was reported that groin injury frequency was lower for females than males (2-9% versus 4-19%) in professional football[22] and other athletic populations.[32] The incidence rates reported are also lower in female football players (0.1-0.6 injury/1000 hours versus 0.2-2.1 injury/1000 hours).[23,32] The wide range of reported prevalence and incidence rates may be attributed to differences between studies regarding the methodological quality and the variety in taxonomy, injury classifications and definitions used.[5,32]

The severity of time-loss groin injury is usually expressed as the duration of time-loss. The average time-loss in players with groin injury ranges between 15 and 20 days. Recurrent injuries last longer with more than 28 days before return to play.[1,22,28,33–35] Levels of symptoms and problems experienced in case of time-loss and non-time-loss groin injuries are evaluated using PROMs (patient-reported outcome measures). PROMs are the gold standards when assessing an individual's health status.[36] For young individuals suffering hip and groin pain, the HAGOS (hip and groin outcome score) was developed. It scores the severity of groin-related problems in 6 separate domains, described by Thorborg et al. as "pain, symptoms, physical function in daily living, physical function in sport and recreation, participation in physical activities, and hip and groin-related quality of life".[36] The HAGOS is reliable, valid and available in several languages, including Dutch.[37]

Female football nowadays is popular and the numbers of players are rising rapidly. Currently it is the largest female team sport in Holland.[38] Still, only few injury data are available from female football. So far, studies were performed in (semi-) professional Scandinavian and German female players.[22] The growing numbers of participants result in more frequent visits of injured female football players to our clinics, the majority being amateurs. Little is known from this population thus new studies are warranted on groin injuries in female football from different countries as well as from amateur levels.[23]

Once the burden of the groin problem is established, further studies on risk factors can be undertaken.[8]

Risk factors

Groin injuries with a sudden onset are defined as acute. Mostly are groin injuries accumulating groin-related problems resulting in overuse injury. It is advocated that an inciting event triggering the injury may result from the interaction between risk factors and sports biomechanics making an athlete vulnerable to sports actions (**figure 8**).[9,39]

There is high-level evidence that reduced hip adductor strength and previous groin injury are internal risk factors and higher level of play and reduced sport specific training external risk factors for a recurrent time-loss groin injury.[4] A higher acute/chronic workload ratio increases the injury risk, typically when players return to sport after being substantially injured.[40]

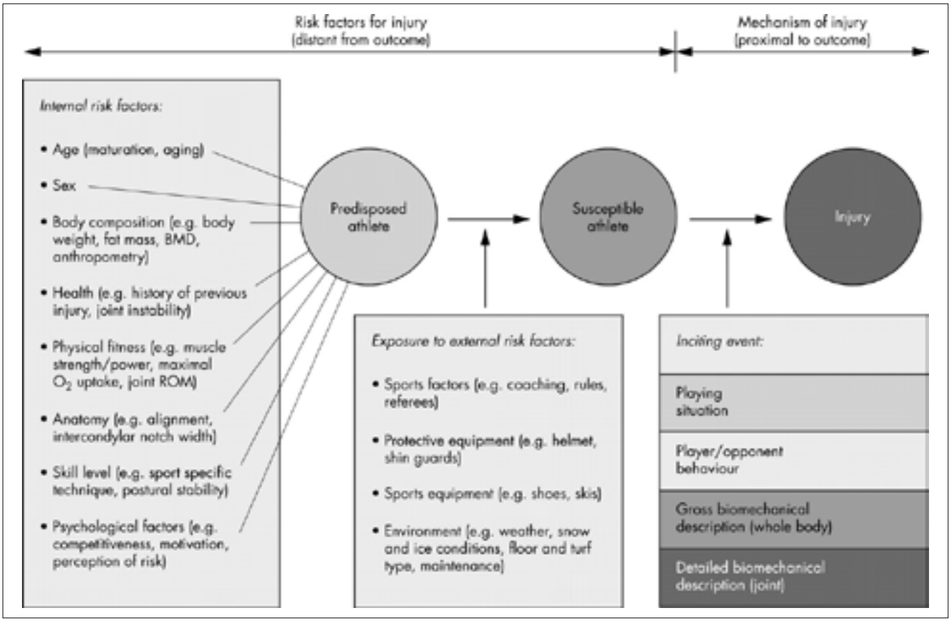

Figure 8 *Comprehensive model for injury causation derived form the epidemiological model from Meeuwisse.[41] Abbreviations: BMD=body mass density; ROM=range of motion. BJSM, with permission[9]*

It is rarely considered that the risk for a subsequent injury increases after sustaining injury on different locations.[42] Previous anterior cruciate ligament injury and low back injury seemed to be associated with subsequent hamstring injury. The same applied for previous lower limb muscle injury being associated with subsequent lower limb injury in the other leg.[43] Previous knee injury was related to subsequent groin injury in one study yet it is interesting to examine whether or not other previous injuries would be risk factors as well.[43]

Contradictory findings have been reported for hip range of motion (ROM) being a risk factor for groin injury.[24,44] A recent targeted review on this topic found lower total (internal and external) rotation of both hips to increase the risk of groin injury while decreased hip internal rotation,

abduction and extension did not. Athletes with groin injury have reduced hip internal rotation when compared to those without.[45] It was proposed to expand the limited body of knowledge on this topic by examining ROM of several combinations of hip movements.[25]
A long duration of groin onjury in the previous season was found related to high levels of groin-related problems (HAGOS) in the next preseason in football players.[3,46] As this was studied in male professionals it is interesting to examine if this is also true for female amateur football players.
Minimum standards of reporting for study methodology, participants, injury history and clinical assessment and examination were proposed for groin injury studies in athletes.[32] Prospective studies should preferably report the individual exposure time. This represents the time a player is at risk and thus is an important factor. Playing time differs between a squad's best eleven and substitute players for matches, training and also for those being frequently injured.[35] Regression models should be used that censor for the cause of abbreviated exposure time like groin injury, general injury and other causes for time lost to play.[30]
New information on risk factors of groin injury will provide a more stable basis for prevention programs and will add to further understanding the groin injury mechanism.

INJURY MECHANISM: THE FOOTBALL KICK

In football, groin injury is most frequently incited by kicking (40%)[47], whereas players with chronic groin injury avoid maximal kicking and switch to submaximal performance.[48] The injury mechanism, often referred to as the inciting event, is defined as "the fundamental biomechanical process responsible for a given action, reaction or result".[49] In the epidemiological model of Meeuwisse et al., internal risk factors (decreased load tolerance) and external risk factors (increased load) make an athlete vulnerable for injury as they modulate sports biomechanics (**figure 8**).[39,49]
In the next paragraph we describe the coordination and range ROM of body segments as important biomechanical factors for maximal kicking performance in non-injured players.[50]

Coordination

The dynamical systems approach provides a framework for the coordination of body segments in a linked-system like the human body.[51,52] Coordination is defined as the process by which neurally recruited motor patterns, so-called muscle synergies, reduce abundant degrees of freedom to simplify movement of body segments in time and sequence.[53–56] The kinematic sequence of the kicking leg starts by pelvis rotation consecutively followed by hip flexion, knee extension and finally ankle dorsiflexion (**figure 9**).[57–59] This proximal to distal sequence summates segmental speed to maximize foot (and ball) speed by acceleration of the most proximal segment first and progressing to the distal segments.[60,61]
Well timed muscle contractions result in an organized acceleration and deceleration of body segments in the kinematic chain by transferring kinetic energy (intersegmental dynamics).[62–64]
Segmental energy will transfer when peak segmental velocity and acceleration time at square

(90° flexion) and collinear segment positions, respectively.[64] The energy flow, being the result of these segmental interactions, allows a player to kick a ball with high speed and precision without the use of extreme muscle work.[65]
Targeted neurophysiologic motor commands create noise affecting velocity and precision ("Optimization in the Presence of Signal-dependent Noise model")[66]. So increased muscle work during kicking is likely to negatively affect the optimal combination of high ball speed and precision required.[66,67] Pain, disturbing inter-muscular coordination, reduces energy flow and increases muscle work during kicking[30,68] so groin pain negatively affects maximal kicking.[47,48] Hence, it is interesting to establish a biomechanical blue print for the maximal football kick by quantifying timing characteristics of body segment kinematics.

Range of motion

Adductor-related groin injury is consistently reported to be the most prevalent clinical entity (66%) and located in the kicking leg in the majority of cases (81%).[47,69]

***Figure 9**. The proximal to distal kinematic sequence of the kicking leg during the backswing, leg cocking, acceleration and follow through phases*

The football kick can be distinguished in several phases: preparation, backswing, leg cocking, acceleration and follow through (**figure 9**).[69] At the end of the backswing, the spine is maximally rotated and the kicking leg and non-kicking arm are extended. This so-called tension arc creates prestretch of the myofascial adductor/abdominal lines to store potential energy (**figure 10**).[70] A larger tension arc increases prestretch resulting in more explosive contraction of hip flexor muscles (adductors and iliopsoas).[71,72] The accelerating hip is the most important determinant for foot- and ball velocity using energy transfer.[60,73,74,75] Remarkably, the hip reverses from flexion into extension prior to ball impact.[59,73,74] A fast hip deceleration assists in efficient energy transfer and as such contributes to knee velocity.[76,77] Hip deceleration is caused by the swing of the lower leg that creates backward forces acting at the knee.[74] A second decelerating mechanism acting on the hip was suspected yet never demonstrated in biomechanical studies of the kicking leg.[74] Hip reversal occurs mainly in the dominant leg and fatigue seems to negatively affect this mechanism.[58,78,79]
It is unclear if hip reversal, ROM of the tension arc and ROM of body segments vary between kicks with different ball speeds. It is interesting to examine if players with adductor-related

groin injury show reduced hip and/or pelvic ROM during maximal kicking. New information on risk factors modulating kicking biomechanics fits in the second step of van Mechelen's prevention model[8] and assist in further understanding the groin injury mechanism.

Figure 10. *The full-body backswing, also referred to as tension arc*[70]

TREATMENT

The increased risk for recurrence after sustaining a groin injury underlines the importance of effective treatment and secondary prevention.[4] In 40% of the injured players recovery lasts 1 week and more than 4 weeks in 10%.[10] Recovery time not only affects the player but also the whole team.[28] There is moderate evidence for adductor-related groin injury that

- active treatment regimes are more effective than passive
- the periods to return to sport are shorter when active treatment is combined with manual therapy of the adductors
- adductor longus release (surgery) reduces pain and enables return to play over time.[79,80]

There is moderate evidence that athletes with inguinal-related groin injury have better outcomes after surgery than conservative treatment.[80] For those with pubic-related groin injury conservative treatment showed significantly quicker return to sport than surgery.[81] It should be acknowledged that the body of evidence is small and these findings are derived from a systematic review with a small number of studies included.[81]
In a previous study a multimodal treatment regime including manual therapy of the adductor muscles was compared to an active exercise program.[82,83] Manual therapy consisted of an applied stretch of the adductor muscles and resulted in reduced recovery times of 12 weeks, which was 18 weeks for the active program, both with low success rates (50% versus 55%).[83]
In general many players tend to play with symptoms up to some degree.[36,46,68] Players who return to sport when the level of symptoms allows them to, will be prevented from unnecessary treatment delay that may occur in time-contingent rehabilitation programs. This points out that time to return to sport should not be the only criterion for treatment success.[83]
It is of interest to analyse the clinical course of players with adductor-related groin injury after a manually applied adductor stretch without a predefined return to sport program. The applied stretch direction should preferably agree with kicking biomechanics. Self-guided return to sport after this treatment may show early return to sport time. It is of interest to examine the levels of groin-related problems over time.

AIMS OF THIS THESIS

This thesis will further try to unravel the complexity of groin injury aiming to:

- describe the incidence, prevalence and severity of groin injury in Dutch female and male football players
- examine risk factors and their effect on kicking biomechanics elucidating the injury mechanism
- develop new sport specific assessment tests
- study return to sport after manual therapy of the adductor muscles

For a complete overview of the groin injury burden in the Euro-Arabic continent, incidence and prevalence rates from more countries and regions are required, especially in female amateur players as no study reported on them before.[23,84,87] **Chapter 2** presents prevalence rates of general injury and groin injury in a Dutch population of female amateur football players. Groin injury was studied in terms of time-loss and non-time-loss and severity of groin-related problems was assessed (HAGOS). Factors relating to increased risk of recurrence and chronicity were studied. **Chapter 3** retrospectively studied the relationship between injuries from the previous and current season (both definitions) in the same female population. Whether previous injury to locations other than the groin relates to subsequent groin injury is unknown. A prospective study was designed (GRoin Injury Prevention (GRIP) study) and performed in the

Dutch Professional Football Leagues to examine prevalence and incidence rates for new groin injury, groin-related problems and risk factors for subsequent groin injury, which is presented in **Chapter 4**.

In football, kicking is the most frequent sport action leading to groin injury.[47] Players with chronic groin pain tend to avoid maximal kicking and switch to submaximal strategies.[48] Recognizing players with good technical kicking skills is difficult due to the short duration of the kick (± 0.25 seconds), the high segmental speed and interdependency of body segments. A biomechanical blue print of the maximal football kick is mandatory for understanding kicking performance and mechanisms for groin injury. A kicking study was conducted to analyse the segmental coordination and ROM during the submaximal and maximal instep kick through full body three-dimensional motion capture. **Chapter 5** presents the results of this study on coordination of the kick expressed by the timing of peak velocities of body segments relating to kicking leg configuration (keypoints). **Chapter 6** presents the results of this study comparing the submaximal to the maximal instep kick for ROM of the tension arc and of the motion trajectories of the pelvis, spine, kicking knee and hip.

Classic examination of hip ROM targets the hip joint in isolation, disregarding the accepted functional anatomical demands of groin structures and the interdependency of body segments in the kinematic chain. A new, passive sport specific assessment test was developed, mimicking the tension arc of the football kick. We studied its reliability and compared reference values from non-injured footballer players with those from injured players. This study is presented in **chapter 7**.

Pelvic movement is considered important regarding force and energy transfer between upper body en lower extremities during sport actions with respect for the anatomical relation between adductor and abdominal muscles. Optimal energy transfer may be hindered by sub-optimal pelvic function. Whether pelvic ROM is reduced in players with groin injury is unknown. We developed a test to measure active ROM of anterior, posterior and total pelvic tilt and studied differences between non-injured athletes and athletes with groin injury. The findings are presented in **chapter 8**.

Active therapy shows effectiveness for athletes with adductor-related groin injury.[82] It was demonstrated that manual therapy of the adductor muscles shortens the recovery process. The effect of manual therapy as a single treatment is not clear as this was studied earlier in an active, time contingent treatment regimen.[86] We performed a prospective study to examine the clinical course after a manually applied adductor stretch with self-guided return to sport instruction. We present the results of this study in **chapter 9**.

The results of these studies are discussed in **chapter 10** and **chapter 11** contains the summary in English, Dutch, Spanish, Italian and Chinese language.

CHAPTER

2

Hip and groin injury is the most common non-time-loss injury in female amateur football.

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Knee Surg Sports Traumatol Arthrosc. 2018 [Epub ahead of print]

ABSTRACT

Purpose: Hip and groin injuries in football are problematic due to their high incidence and risk of chronicity and recurrence. The use of only time-loss injury definitions may underestimate the burden of hip and groin injuries. Little is known about hip and groin injury epidemiology in female football. The first aim of this study was to examine the within-season (2014-2015) prevalence of total injury with and without time-loss in female amateur football players. The second aim was to study the within-season and preseason (2015-2016) prevalence of hip/groin injuries with and without time-loss. The third aim was to study the association between the duration of hip and groin injury in the 2014-2015 season and the severity of hip/groin problems during the 2015-2016 preseason.

Methods: During the preseason, 434 Dutch female amateur football players completed an online questionnaire based on the previous season and current preseason. The hip and groin outcome score (HAGOS) was used to assess the severity of hip and groin injuries.

Results: The hip/groin (17%), knee (14%) and ankle (12%) were the most frequent non-time-loss injury locations. The ankle (22%), knee (18%), hamstring (11%), thigh (10%) and hip/groin (9%) were the most common time-loss injury locations. The previous season prevalence of total injury was 93%, of which non-time-loss injury was 63% and time-loss injury was 37%. The prevalence of hip/groin injury was 40%, non-time-loss hip/groin injury was 36% and time-loss hip/groin injury was 11%. The preseason prevalence of hip/groin injury was 27%, non-time-loss hip/groin injury was 25% and time-loss hip/groin injury was 4%. Players with longstanding hip/groin injury (>28 days) in the previous season had lower HAGOS scores at the next preseason than players with short-term (1-7 days) or no hip/groin injury ($p<0.001$). From all players with hip/groin injury from the previous season, 52% also sustained hip/groin injury in the following preseason, of which 73% were recurrent and 27% were chronic hip/groin injuries.

Conclusion: Injury risk, and especially non-time-loss hip and groin injury risk, is high in female amateur football. Three-quarters of the players with longstanding hip and groin injuries in the previous season have residual problems at the start of the following season.

Level of evidence: II

Keywords: Female football (soccer), Female athlete, Groin pain, Hip and groin injury.

INTRODUCTION

The number of female football players in Europe is growing rapidly, and female participation rates in the US almost equal those of males.[38] Dutch female football has increased rapidly, with 23% more players over the past five years and 153001 registered players in the 2016-2017 season. It is now the largest female team sport in Holland.[38]

Despite its popularity and growth, injury studies in female football lag far behind those in male football.[84] Additionally, most injury or risk factor studies use only time-loss injury (TLI) definitions.[21,22] The within-season prevalence of TLI in elite female football ranges between 38% and 48%.[25,68,85-89] Non-time-loss injury (NTLI) has been less studied in football.[22] The little available data suggest, as expected, that NTLI is more common than TLI. [23,26]

Studies reporting specifically on hip and groin injury (HGI) are hard to compare, as they use different injury terminologies and definitions.[5,32] A study in elite female football players found that injury rates were four times higher (36% vs. 9%) for non-time-loss HGI (NTL-HGI) than for time-loss HGI (TL-HGI).[23] A recent systematic review showed that in elite female studies, prevalence rates of TL-HGI ranged from 2% to 11%.[22] The use of TL-HGI definitions probably underestimates the true burden of HGI.[3,21] HGI is common in (sub-) elite male football and is known for its high incidence, chronicity and risk of recurrence.[2–4] Injury risk and prevention has yet not been studied in female amateur football players.[22]

Patient-reported outcome measures (PROs) are the gold standard for assessing the perceived health status of specific populations and injuries.[90] The hip and groin outcome score (HAGOS) was developed for young and active individuals, measures the severity of hip and groin-related problems and is validated in several languages, including Dutch.[3,46,84,88]

Limited literature exists on female football players and especially on the hip/groin injuries. Most literature on this topic studied professional players although the amount of amateur football players is the majority of the people that visit the sports clinic. Therefore the first aim of this study was to examine the within-season (2014-2015) prevalence of total injury burden (NTLI and TLI) in female amateur football. The second aim was to study the within-season and preseason (2015-2016) prevalence of hip and groin injury (NTL-HGI and TL-HGI). The third aim was to examine the association between the duration of HGI in the 2014-2015 season and the severity of hip/groin problems during the 2015-2016 preseason.

MATERIALS AND METHODS

In this cross-sectional survey study, female amateur football players completed an online questionnaire during the 2015-2016 preseason. The 'Strengthening the Reporting of Observational Studies in Epidemiology' (STROBE) statement was used to report the findings of this study.[91] By clicking the "I participate" link in the electronic questionnaire, the participants gave their consent that their anonymized data could be used for research purposes.

Participants

All participants were female amateur players in the Dutch women's football league, as registered by the Royal Dutch Football Association (KNVB). To obtain a large sample size, 43 teams (645 players), representing all amateur playing levels (Top Class, Sub-top Class, 1st - 6th Class) from all KNVB districts were selected and invited by email to participate in this general injury survey. Every player received information by e-mail about the study and instructions for completing the questionnaire (Appendix). Players were included if they were female, were between the ages of 18 and 40, and had played amateur football during the previous season, regardless of being injured or not. Professional players and those from the veteran's leagues were excluded. The parameters of age, height, weight, weekly average exposure (training and matches), leg dominance (defined as the preferred kicking leg) and playing levels were self-reported.

Injury registration

Time-loss injury (TLI) was defined as "Any physical complaint sustained by a player as a result of a football match or training, resulting in a player being unable to fully take part in future football training or match play".[21] Non-time-loss injury (NTLI) was defined as a situation where players experienced "Any physical complaint as a result of a football match or training, but without time-loss".[21] The same definitions applied for hip and groin injury, referring to NTL-HGI and TL-HGI. The presence of injury was scored by dichotomous answer options (yes/no).

When present, the duration (days) of both NTL-HGI and TL-HGI was noted and classified as minor (1-7 days), moderate (8-28 days) or major (>28 days), according to the international classification for football injuries.[21] Additionally, the manner of onset (maximal kicking, sprinting/running, cutting/pivoting, and other) of HGI was registered for the 2014-2015 season. An online registration system was used (Google Forms).

Injury region

A body chart was used to illustrate all locations of NTLI and TLI based on the Dutch Injury Information System framework and Orchard Sports Injury Classification System[18]. For this study, the hip/groin was referred to as 'the region between the front of the hip and the inner front of the thigh'.[92] A chart of the hip and groin region was used to address the location of HGI in this region.

Hip and groin outcome score (HAGOS)

The HAGOS was used to assess the severity of hip and groin-related problems for all players on 6 subscales: pain (P), symptoms (S), activities of daily living (ADL), sport and recreation (SR), participation in physical activities (PA) and quality of life (QOL).[93] Subscale scores range from 0 to 100, where 0 indicates severe hip and groin symptoms and problems and 100 indicates no symptoms or problems.[93] HAGOS is available in the Dutch language and was found to be reliable (ICCs between 0.83-0.87), internally consistent (Cronbach's α between 0.81-0.92), valid in young athletes (including football players) and comparable to the original Danish version.[37] The mean±SD test-retest differences for the six subscales were 0.5±10.9 (P), 1.7±10.4 (S), 0.4±14.2 (ADL), 2.8±15.8 (SR), 2.3±18.9 (PA) and 2.5±11.5 (QOL).

Survey period

Participants were asked to complete the injury questionnaire (including HAGOS) during an eight-week period in the preseason of 2015-2016 (August, September and October 2015). Non-time-loss and time-loss injury were retrospectively assessed per body location for the previous season (1 August 2014 to 15 June 2015). Non-time-loss HGI and TL-HGI were assessed for the previous season and for the current preseason. History of HGI was assessed for the period prior to the 2014-2015 season. The HAGOS scores concerned the player's health status for the week prior to completing the questionnaire. See the Appendix for the survey and HAGOS at www.koos.nu.

Bias

To minimize recall bias, dichotomous answer options, definitions of the terms used, and assisting figures that specified anatomical regions were employed[16]. Adequate reliability between retrospective and prospective dichotomous registration of self-reported injuries has been previously observed.[94]

Approval

This study complied with the requirements of the declaration of Helsinki.[95] The Dutch Central Committee on Research Involving Human Subjects (CCMO) states that no medical ethical approval was necessary for this questionnaire study. Participants were neither physically examined nor treated by any means. As such no burden existed nor were they denied any treatment. This is stated in the Dutch Medical Research Involving Human Subjects Act (WMO; http://wetten.overheid.nl/ BWBR0009408).

Statistical analysis

The data were tested for normality by use of the Kolmogorov-Smirnov test. Normally distributed data are presented as a mean and standard deviation (SD). Non-normally distributed data are presented as a median and interquartile range (IQR, 25%-75%). The presence and locations of NTLI and TLI are presented as absolute (counts) and relative (percentage of total). To avoid overestimation, HGI was defined as the total number of players with NTL-HGI and TL-HGI minus the number of players with both injuries. The duration (days) of NTL-HGI and TL-HGI was analysed by frequencies and percentage of the total number of players. The average number of players for an average squad was calculated to examine the number of injuries per squad per season. To calculate duration (days) of NTL-HGI and TL-HGI per squad, an arbitrary duration of 3 days was chosen for minor HGI, 18 days for moderate HGI and 28 days for major HGI, in order to prevent overestimation.

Match and training exposure were determined (hours) and 1 match represented 1.5 hours. A Mann-Whitney U test was used to examine differences between HAGOS scores for HGI, no HGI and HGI duration groups. Incorrect or missing data were reported and corrected by the means of the variables and frequencies. The level of significance was set at $\alpha<0.05$. The data were analysed using SPSS 23 (IBM, Armonk, USA).

RESULTS

Of the 43 teams invited, 8 teams (120 players) declined the invitation and 35 teams participated in this study (response rate 81%). This resulted in 525 female players, from which 91 (17%) failed to meet the inclusion criteria of being at least 18 years of age (n=89) or participating in the included playing levels (n=2 veterans league). Data from 434 players were used for the analysis (**figure 1**).

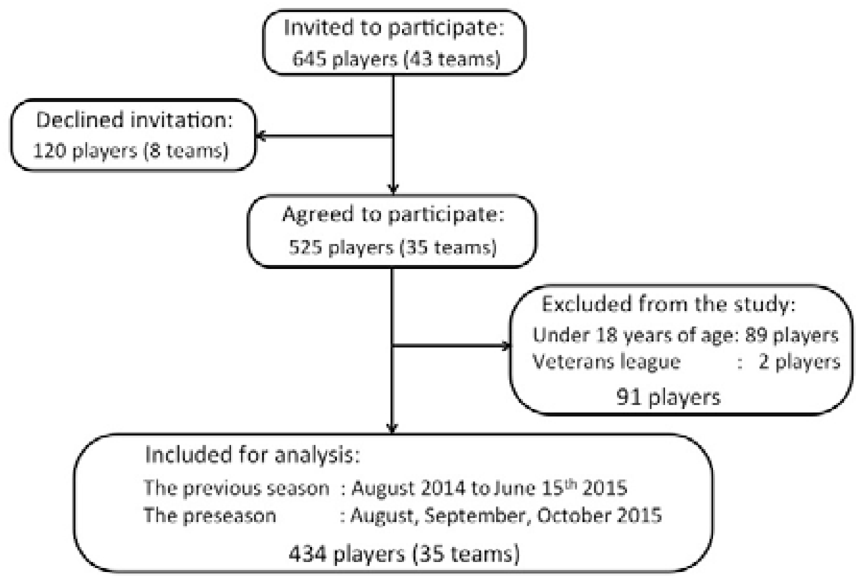

Figure 1 *Flowchart showing player inclusion and exclusion*

During the previous season, the 434 players had a total exposure time of 64034 hours (50720 training and 13314 match hours). On average, each player spent 148±58 hours playing football (117±54 training and 31±12 match hours) during the 40-week competitive season. An average team consisted of 14.7±0.7 players. Player characteristics are shown in **table 1**.

Table 1 *Player characteristics (n= 434)*	
Age (y)	24.2 (5.1; 18-52)
Height (cm)	170.7 (6.0; 155-190)
Weight (kg)	66.4 (8.7; 46-110)
Body mass index (kg/m^2)	22.6 (2.7; 17.1-40.0)
Match exposure (total matches per season)	20.9 (8.7; 0-60)
Training exposure (hours per week)	3.0 (1.4; 0-12)
Playing level, n (%)	
Top Class	23 (5)
Sub-top Class	48 (11)
1st Class	60 (14)
2nd Class	51 (112)
3rd Class	35 (8)
4th Class	95 (22)
5th Class	89 (21)
6th Class	33 (8)
Leg dominance, n (%)	
Left	45 (10)
Right	389 (90)
HAGOS subscales	
Pain (P)	100.0 (90.0-100.0)
Symptoms (S)	89.3 (78.6-100.0)
Function in daily living (ADL)	100.0 (95.0-100.0)
Function in sport and recreation (SR)	100.0 (87.5-100.0)
Participation in Physical Activity (PA)	100.0 (75.0-100.0)
Hip and groin-related Quality of Life (QOL)	100.0 (85.0-100.0)

Player characteristic presented as the mean (SD, range) or median (IQR 25-75). Exposure is presented for the previous season (2014-2015). Abbreviations: y=years; cm=centimetre; kg=kilogram; kg/m^2=kilogram/square metre; IQR=interquartile range; n=number

Total injury during the previous season

For the previous season, 404 players (93%) reported 1439 injuries, of which 904 (63%) were NTLI and 535 (37%) were TLI. Most injured players had one NTLI (n=136, 31%) or one TLI (n=175, 40%) (**table 2**). An average squad of 15 players can expect 49 injuries (31 NTLI and 18 TLI) per season.

Table 2 *non-time-loss and time-loss injury frequency in the previous season, presented per player*

Players NTLI	56	136	109	67	27	13	16	5	2	1	2	**434**
(n,%)	(13)	(31)	(25)	(15)	(6)	(3)	(4)	(1)	(1)	(0.2)	(0.8)	**(100)**
Injury (n)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Players TLI	109	175	103	36	10	-	1	-	-	-	-	**434**
(n,%)	(25)	(40)	(24)	(8)	(2)		(1)					**(100)**

Abbreviations: NTLI=non-time-loss injury; TLI=time-los injury; n=number; %=percentage

The most affected NTLI locations were the hip/groin (17%), knee (14%) and ankle (12%). The most affected TLI locations were the ankle (22%), knee (18%), hamstring (11%), thigh (10%) and hip/groin (9%) (**table 3**). Of all 1439 injuries, 1261 (88%) were located in the lower body (including lumbar spine and pelvis).

Table 3 *Injury location and ranking. Body location and ranking of non-time-loss and time-loss injuries for all players (n=434) in the previous season*

Non-time-loss Injury (NTLI)			**Time-loss Injury (TLI)**		
Body location	**Rank**	**n (%)**	**Body location**	**Rank**	**n (%)**
Hip/Groin	**1**	154 (17)	Ankle	**1**	118 (22)
Knee	**2**	123 (14)	Knee	**2**	94 (18)
Ankle	**3**	110 (12)	Hamstring	**3**	57 (11)
Lumbar spine	**4**	92 (10)	Thigh	**4**	52 (10)
Thigh	**5**	83 (9)	Hip/Groin	**5**	46 (9)
Hamstring	**6**	69 (8)	Lumbar spine	**6**	40 (8)
Calf	**7**	59 (7)	Calf	**7**	33 (6)
Foot	**8**	43 (5)	Foot	**8**	24 (4)
Shoulder	**9**	39 (5)	Head	**9**	14 (2)
Neck	**10**	30 (3)	Lower leg (front)	**10**	13 (2)
Lower leg (front)	**11**	29 (3)	Wrist/hand	**11**	12 (2)
Wrist/hand	**12**	22 (2)	Shoulder	**12**	10 (2)
Head	**13**	20 (2)	Pelvis	**13**	9 (1)
Pelvis	**14**	13 (1)	Trunk	**14**	6 (1)
Trunk	**15**	8 (1)	Neck	**15**	4 (1)
Elbow	**16**	6 (0.6)	Face	**16**	2 (0.8)
Face	**17**	4 (0.4)	Elbow	**17**	1 (0.2)
Total		**904 (100)**			**535 (100)**

Abbreviations: NTLI=non-time-loss injury; TLI=time-loss injury; n=number

Hip and groin injury during the previous season

For the previous season, 172 players (40%) reported 200 HGI. Of these 172 players, 28 players (6%) had both NTL-HGI and TL-HGI, 126 players (30%) sustained only NTL-HGI and 18 players (4%) sustained only TL-HGI. The prevalence of NTL-HGI was 36% (154 injuries) and prevalence of TL-HGI was 11% (46 injuries) (**table 4**). A history of HGI prior to the 2014-2015 season was reported in 166 players (38%). Of those, 101 players (23%) also sustained HGI in the 2014-2015 season.

Table 4 *Self-reported prevalence of hip and groin injury (both non-time-loss and time-loss) in the previous season (2014-2015) and preseason (2015-2016) (n=434), also reported for all duration groups (n,%)*

Players with HGI	**Previous Season**	**Preseason**
	172 (40)	117 (27)
Players with NTL-HGI	154 (36)	109 (25)
Duration		
Minor (1-7 days)	98 (22)	71 (16)
Moderate (8-28 days)	28 (7)	28 (7)
Major (>28 days)	28 (7)	10 (2)
Players with TL-HGI	46 (11)	23 (5)
Duration		
Minor (1-7 days)	22 (5)	14 (3)
Moderate (8-28 days)	11 (2)	2 (1)
Major (>28 days)	13 (3)	7 (2)

Abbreviations: HGI=hip and groin injury; NTL-HGI=non-time-loss hip and groin injury; TL-HGI=time-loss hip and groin injury

The dominant leg was affected in 100 players (58%), and the non-dominant leg was affected in 33 players (19%); 39 players (23%) sustained bilateral HGI. The onset for HGI was maximal kicking (24%), sprinting/running (21%), pivoting/cutting (11%) and other (44%). An average amateur squad of 15 players can expect 5 NTL-HGIs and 2 TL-HGIs per season, resulting in 53 days of on-going hip and groin problems and 21 days of play lost.

Hip and groin injury during the preseason

During the preseason, 117 players (27%) reported 132 HGIs. Of these 117 players, 15 (3%) had both NTL-HGI and TL-HGI, 94 players (22%) sustained only NTL-HGI, and 8 players (2%) sustained only TL-HGI. The prevalence of NTL-HGI was 25% (109 injuries) and prevalence of TL-HGI was 5% (23 injuries) (**table 4**). The dominant leg was affected in 60 players (51%), and the non-dominant leg was affected in 28 players (24%); 29 players (25%) sustained bilateral HGI.

Severity of hip and groin injury

Players with HGI in the previous season had lower HAGOS scores in the preseason than players without HGI in the previous season (p<0.001). Players with major HGI in the previous season had lower HAGOS scores in the preseason than those with minor HGI (p<0.001) (**table 5**).

Table 5 *HAGOS subscale-scores (median, IQR) from players with HGI, with no HGI and for the duration groups minor (1-7 days), moderate (8-28 days) and major (>28 days) HGI in the 2014-2015 season. Data obtained at the current preseason*

HGI subgroups	Pain	Symptoms	ADL	SR	PA	QOL
No HGI	100.0	92.9	100.0	100.0	100.0	100.0
(n=262)	(97.5-100.0)	(85.7-100.0)	(100.0-100.0)	(100.0-100.0)	(75.0-100.0)	(100.0-100.0)
Δ *HGI-No HGI*	***<0.001***	***<0.001***	***<0.001***	***<0.001***	***<0.001***	***<0.001***
HGI	92.5	78.6	95.0	89.1	87.5	90.0
(n=172)	(80.0-97.5)	(71.4-89.3)	(80.0-100.0)	(74.3-100.0)	(75.0-100.0)	(75.0-100.0)
Δ *Min-No HGI*	***<0.001***	***<0.001***	***<0.001***	***<0.001***	***<0.001***	***<0.001***
Minor HGI	95.0	82.1	100.0	93.8	87.5	95.0
(n=103)	(85.0-100.0)	(75.0-92.9)	(85.0-100.0)	(78.1-100.0)	(75.0-100.0)	(85.0-100.0)
Δ *Min-Mod HGI*	***0.034***	*0.062*	*0.285*	*0.306*	*0.320*	***0.008***
Moderate HGI	90.0	75.0	95.0	87.5	87.5	77.5
(n=30)	(77.5-95.0)	(67.9-89.3)	(80.0-100.0)	(71.9-100.0)	(75.0-100.0)	(70.0-95.0)
Δ *Mod-Maj HGI*	*0.078*	*0.283*	*0.170*	***0.046***	***0.012***	***0.016***
Major HGI	77.5	75.0	90.0	75.0	75.0	70.0
(n=39)	(70.0-95.0)	(60.7-82.1)	(70.0-100.0)	(56.3-93.8)	(50.0-87.5)	(55.0-85.0)
Δ *Min-Maj HGI*	***<0.001***	***<0.001***	***<0.001***	***<0.001***	***<0.001***	***<0.001***

For the difference between groups P<.005 (**bold**). Abbreviations: HAGOS=Hip And Groin Outcome Score; HGI=Hip and Groin Injury; Min=Minor; Mod=Moderate; Maj=Major; ADL=function in daily living; SR=function in sport and recreation; PA=participation in Physical Activity: QOL=hip and groin-related Quality of Life; IQR=inter quartile range; n=number; Δ=difference

Duration of hip and groin injury

From the 172 players with HGI in the previous season, 82 (48%) had recovered and 90 (52%) sustained HGI in the following preseason. Of these, 66 (73%) were recurrent and 24 (27%) were chronic HGI. There were 50 recurrent HGI (47%) from the minor HGI group in the previous season and 16 (52%) from those with moderate HGI. The 24 chronic HGIs originated from the major HGI group (71%) in the previous season. Of the 117 HGIs in the preseason, 27 (23%) were new HGIs (**figure 2** and **table 4**).

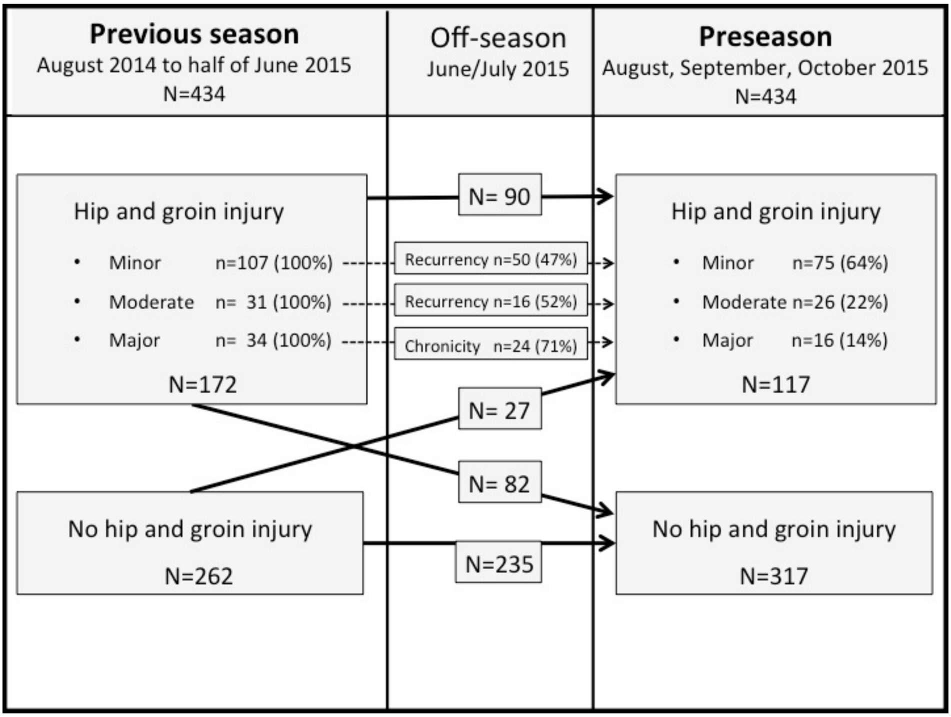

Figure 2 *Diagram presenting the flow of players without injury and players with different durations of hip and groin injury in the previous season towards the current preseason*

DISCUSSION

The most important finding of the present study was that hip and groin injury was the most prevalent non-time-loss injury in female amateur football players (17%). There was a high within-season prevalence of total injury (93%) and hip and groin injury (40%) and a high preseason prevalence of HGI (27%). Non-time-loss injuries were more prevalent than time-loss injuries. More than half of all hip and groin injuries in the previous season were recurrent or chronic injuries in the following preseason. The longer the duration of HGI in the previous season, the higher the chance of carrying over hip and groin problems into the following season.

Presence of total injury

Non-time-loss injury rates (63%) were almost double that of time-loss injury rates (37%), which is in line with previous studies in female collegiate sports.[25,26] A TLI prevalence of 37% agrees with previous studies in female football that used only a TLI definition (38%-48%).[86-89] Of all injuries, 88% were located in the lower body, which was also found in previous studies (82%[87], 87%[96], 89%[89]). The hip/groin was the most frequently affected injury location (17%) for NTLI. TLI most often affected the ankle (22%) and knee (18%), which agrees with previous reports in time-loss injury locations in elite female football.[86-89] Non-time-loss injuries accounted for 63% and time-loss accounted for 37% of all injuries. Therefore, an average team of 15 players had 49 injuries (31 NTLI and 18 TLI) in the 2014-2015 season.

Presence of hip and groin injury

Nearly half of the female amateur players (40%) sustained HGI in the previous season, which is similar to injury rates found in a Norwegian survey study in elite female players (45%).[23] A Swedish survey study showed lower rates (28%) in sub-elite female players.[97] Seasonal incidences of 49%[3] and 55%[97] were found in male players. Female and male HGI incidence may be much more comparable than previously reported.[22] In this study, an average team had 7 hip and groin injuries (5 NTL-HGI and 2 TL-HGI) in 1 season, resulting in 53 days of on-going hip and groin problems and 21 days of play lost.

In the previous season, 36% of all players continued playing despite hip and groin problems (NTL-HGI), whereas 11% had stopped playing for at least 1 day due to these problems (TL-HGI). Similar findings (36% vs. 9%) were recently shown in elite Norwegian female players.[23] Previous studies on female time-loss groin injury reported similar findings (2%-11%)[23,28,34,88], and a recent review reported that TL-HGI rates in males were twice as high as in females.[22] All of these studies had more or less comparable exposure rates (148 in this study vs. 198[88], 212[34] and 213[28] hours/player), yet a study with a higher exposure rate (393 hours/player) also had a much higher injury rate (46%).[35] It may be that injury rates depend more on exposure than on gender or playing level.[1,98,99]

Duration and severity of hip and groin injury

Half of the players (52%) with HGI in the previous season were still injured or re-injured after the off-season. This proportion was found to be one-third in male sub-elite players.[3] In the new preseason, a quarter of all players (27%) reported hip and groin problems, with a full season still to come. This was also reported by male players, with a preseason prevalence of 36%.[3] As longstanding HGI related to more severe hip and groin problems (low HAGOS scores), not only a previous time-loss injury but also the duration of hip and groin problems may relate to the risk of recurrence, chronicity and time-loss.[3,4,69]

Players with longstanding HGI (>1 month) had identical HAGOS scores on the subscales of pain and participation as those from a study in male players (>1.5 months).[3]

Clinical implications

Our study shows that there is a significant injury burden in female amateur football. Prevention of injuries has a high priority within the sport. We also found that how injuries are measured and defined affects the incidence rates, with TLI being only the tip of the injury iceberg. With regard to HGI, this study demonstrates the importance of a measurement tool to quantify not only time-loss yet also the severity of hip and groin problems for trainers, players and medical staff. The results of this study showed that nearly half of the players with short-term HGI (<1 week) sustained recurrent hip and groin injury during the following preseason. To identify players with increased risk for longstanding and severe hip and groin-related problems, regular assessment of hip and groin symptoms and sports performance should be performed.[3,69] As the HAGOS has been developed and validated to measure symptoms and sports performance in detail, it is a useful tool for measuring severity of HGI instead of dichotomous reporting on time loss injury.[3]

This study used players from all KNVB districts across the whole country, instead of regional allocation that can possibly lead to allocation bias. To avoid underestimation of the actual injury burden of (overuse) injuries, both NTLI and TLI were assessed.[98] Players self-reported their injuries instead of medical staff, as many amateur clubs have no structured medical care. To increase the precision of reporting and target recall, we chose to use figures to specify anatomical regions.

We acknowledge a number of limitations. As this was a surveillance study without assessment by a medical professional, the classification of groin pain following the clinical entity approach, as recommended by the DOHA-agreement, could not be performed.[5] A correct diagnosis is mandatory for effective management and prognosis. Despite the type of questions used, recall bias may exist to some extent.[92] Retrospective, self-reported registration of the exact number of injuries, body region and diagnosis may underestimate the prevalence of injuries, as minor injuries tend to be forgotten.[92] As the onset and recovery of injury were not registered, TL-injury numbers during a time-loss period could not be accounted for. Registration of the full length of training sessions and matches could have overestimated exposure. Players who responded at the beginning of the surveillance period had less time to become injured than players who responded at the end. Due to the retrospective study design, the influence of potential confounders could not be assessed. Further studies should consider the use of standardized clinical examination by medical professionals with a prospective design during a one-season period.

CONCLUSION

Injury risk is high in female amateur football, with 93% of players sustaining an injury in a single season. Hip and groin injury is the most common non-time-loss injury and is three times more prevalent than time-loss HGI. Most players with longstanding HGI in the previous season still have residual hip and groin problems at the beginning of the new season.

Appendix

Questionnaire

Instruction:
Please, answer all questions by ticking the appropriate box or formulating the answer as accurately as possible. Choose the answer option that most applies. The questionnaire consists of 2 parts and answering all questions will take 10 minutes. There is room for any comments or questions at the end of the questionnaire.

Question 1. What is your age?
Question 2. What is your weight (rounded up to full kg)?
Question 3. What is your length (rounded to full cm)?
Question 4. At what level did you play during the 2014-2015 season (field football only)? Top Class, Sub-Top Class, 1st Class, 2nd Class, 3rd Class, 4th Class, 5th Class, 6th Class
Question 5. How many matches did you play in the last season (2014-2015)? (field football only)?
Question 6. How many hours did you train last season on average per week (season 2014-2015) (field football only)? ...... hour
Question 7. What is the preferred leg to kick with (one answer)?: Left / Right
Question 8. Did you sign up as part of your team or as individual?

QUESTIONS CONCERNING THE PREVIOUS SEASON 2014-2015, FIELD FOOTBALL:
The following questions relate to the previous season (2014-2015) from the period 01-08-2014 to 15-06-2015.

Question 9:
Have you had hip and groin injury in the period prior to the start of the previous season 2014-2015 (31-07-2015)?
☐ Yes.
☐ No.
☐ I do not know

Definition hip and groin injury: *Physical complaints in the region between the front of the hip and the inside of the upper leg, sustained as a result of a football match or training, resulting in being unable to fully take part in future football training or match play (time loss)*

Question 10:
Please indicate per body location (**figure 1A**), the injuries you had during the 2014-2015 season (01-08-2014 to 15-06-2015).

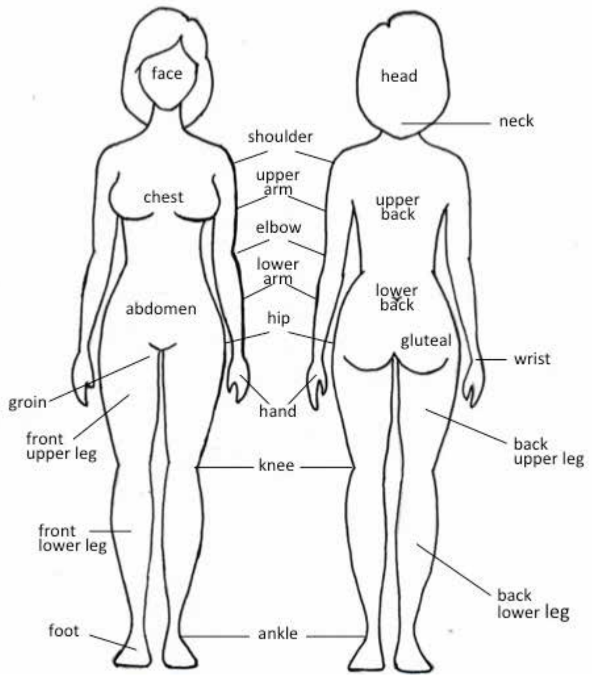

Figure 1A. *Body chart of the locations of injuries and complaints: Head, face, neck, shoulder, upper arm, elbow, lower arm, wrist, hand, upper back, lower back, abdomen, gluteal, hip, groin, front upper leg, back upper leg, knee, front lower leg, back lower leg, ankle, foot, no injury.*

Definition *injury:* *Any physical complaint sustained as a result of a football match or training, resulting in being unable to fully take part in future football training or match play (time loss)*
Definition *complaint:* *Any physical complaints that are bothering you, but who do not prevent you from playing field football or being unable to play the next field match (es) or field training (s) (non-time loss).*

Question 11:
Please indicate per body location (**figure 1A**), the area where you have had complaints during the 2014-2015 season (01-08-2014 to 15-06-2015).

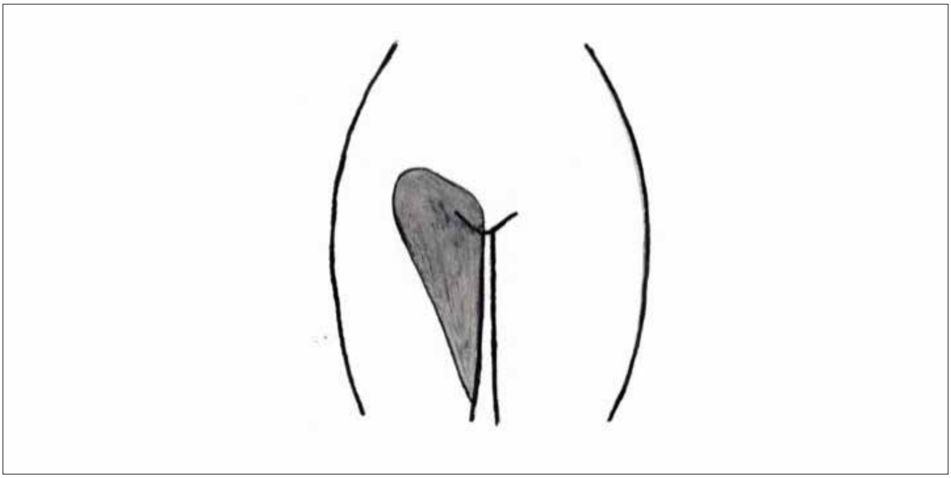

***Figure 1B** The hip/groin region is defined as the front part of the hip and the inner part of the thigh*[103]

Definition hip and groin *complaints:* *Physical complaints in the region between the front of the hip and the inside of the upper leg that are bothering you, but that do not prevent you from playing field football or being unable to play the next field match (s) or field training(s) (non-time loss).*

Question 12:

What kind of hip and groin complaints (one or more) did you suffer during the 2014-2015 season (01-08-2014 to 15-06-2015):

□ Symptoms of hip groin region: feeling of discomfort, clicks or other sounds, bending sideways outwards, difficulty in taking full fit, sudden stabbing or shoots.
□ Stiffness in hip groin region in the morning or later in the day.
□ Hip groin pain in a region that you think is related to hip and groin complaints
□ Pain during bending/stretching of the hip/groin, stair walking, sleeping, lying, sitting, standing, walking (on hard or uneven ground)
□ Restrictions in daily life in activities such as stair walking upwards, bending, getting in/out of cars, lying in bed/turning, household work
□ Restrictions in sports practice by hip and groin complaints: squatting, running, turning/walking, walking on uneven surfaces, sprinting, shooting.
□ I do not know
□ Not applicable: No complaints.

Question 13:
How long have you experienced hip and groin complaints during the 2014-2015 season (01-08-2014 to 15-06-2015):
☐ Because of my hip pains I did not play football.
☐ I had 1-7 days hip/groin complaints, but I have been able to play football.
☐ I had 8-28 days hip/groin complaints, but I have been able to play football.
☐ I had more than 28 days hip/groin complaints, but I have been able to play football.
☐ I do not know.
☐ Not applicable: No complaints

Definition hip and groin *injury:* *Physical complaints in the region between the front of the hip and the inside of the upper leg, sustained as a result of a football ball match or training, resulting in being unable to fully take part in future football training or match play (time loss)*

Question 14:
How many days have you not been able to play football due to this particular hip and groin injury in the 2014-2015 season?
☐ Despite the complaints, I have just been able to play football.
☐ I could not play football for 1-7 days due to my hip/groin complaints.
☐ I could not play football for 8-28 days due to my hip/groin complaints.
☐ I could not play football for more than 28 days due to my hip/groin complaints.
☐ I do not know.
☐ Not applicable: No complaints.

Question 15:
Which side was affected by hip and groin complaints during the 2014-2015 season?
☐ Left.
☐ Right.
☐ I do not know.
☐ Not applicable: No complaints.

QUESTIONS CONCERNING THE CURRENT PRESEASON 2015-2016, FIELD FOOTBALL: The following questions relate to the current preseason (2015-2016) from the period 01-08-2014 to 04-11-2016.

Definition hip and groin complaints: *Physical complaints in the region between the front of the hip and the inside of the upper leg that are bothering you, but who do not prevent you from playing field football or being unable to play the next field match (s) or field training (s) (non-time loss).*

Question 16:
How long have you experienced hip and groin complaints in the period from 01-08-2015 to 04-11-2015?:
☐ Because of my hip/groin complaints I can not play football.
☐ I have 1-7 days hip/groin complaints, I can play football.
☐ I have 8-28 days hip/groin complaints, I can play football.
☐ I have more than 28 days hip/groin complaints, I can play football.
☐ I do not know
☐ Not applicable, no complaints.
☐ Not applicable, I am currently not playable for reasons other than hip and nose complaints

Question 17:
From what football activities do you experience your current hip and groin complaints (between 01-08-2015 and 04-11-2015, multiple answers possible):
☐ Because of my hip and groin complaints I can not play football.
☐ Maximum (at your hardest) kicking a ball.
☐ jogging
☐ Sprinting.
☐ Turn and turn.
☐ Otherwise; ....

Question 18:
When do you expierience your current hip and groin complaints (between 01-08-2015 and 04-11-2015, multiple answers are possible):
☐ Only after field football.
☐ At the start of field football, but not during field football.
☐ At start, during and after field football.
☐ At start-up, during and after field football, with performance reduction due to my hip and groin complaints.
☐ Otherwise: ....

Definition hip and groin *injury:* *Physical complaints in the region between the front of the hip and the inside of the upper leg, sustained as a result of a football match or training, resulting in being unable to fully take part in future football training or match play (time loss)*

Question 19:

How many days have you not been able to play football due to your hip and groin injury in the current season (01-08-2015 to 04-11-2015)?

☐ Despite the complaints, I have just been able to play football.
☐ I could not play football for 1-7 days due to my hip/groin complaints.
☐ I could not play football for 8-28 days due to my hip/groin complaints.
☐ I could not play football for more than 28 days due to my hip/groin complaints.
☐ I do not know.
☐ Not applicable, no complaints.
☐ Not applicable, I am currently not playable for reasons other than hip and groin complaints.

CHAPTER

3

The complexity of hip and groin injury in female amateur football; A survey study in 434 players in The Netherlands

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ABSTRACT

Purpose: To examine (1) the severity of hip/groin injury (HGI) and the relationship with (2) previous HGI and (3) previous injury to locations different than the hip/groin in female amateur football players.

Methods: In the preseason 2015-2016, 434 players completed an online injury questionnaire concerning the previous season 2014-2015 and the current preseason (August, September, October). The severity of HGI was recorded using the Hip And Groin Outcome Score (HAGOS).

Results: Football players with timeloss HGI had the lowest HAGOS-scores (P<.009) and the highest recurrence (63%). Players with HGI had more injuries to general locations (median 4, IQR 3-6) than those without (median 2, IQR 1-4) (P<.001). Preseason HGI was associated with previous HGI (OR 9.6, 95% BI 5.8-15.7), non-timeloss ankle injury (OR 4.6; 95% BI 1.0-20.7) and timeloss knee injury (OR 2.1; 95% BI 1.1-4.2) in the previous season.

Conclusion: Players with hip/groin injury in the preseason sustain groin-related problems and are associated with previous HGI, ankle and knee injury.

Key words: Female football, Sports injury, Groin pain, Groin injury, Timeloss, Non-timeloss.

INTRODUCTION

The number of registered Dutch female football players has increased in the last five years up to 153.001 players (23%) in the season 2016-2017.[38] Football has become the greatest female team sport in The Netherlands.[85] Still, there are much less female injury studies in football than male, which mainly concern professional players.[22]

For female professional football players, the seasonal prevalence of timeloss injuries varies between 38% and 48% with the ankle, knee and thigh most affected.[22,25,26,35,87-89,100] A recent study among female amateur football players showed that non-timeloss injuries (63%) are nearly twice as many as timeloss (37%).[101] Hip and groin pain was the most reported non-timeloss injury (17%) being three times more frequent than timeloss hip and groin pain (36% and 11%, respectively).[101] This is in line with data from Norwegian professional football[11].

Hip and groin injuries (HGI) show high incidence rates and high risk of re-injury and chronicity.[3,46] Professional male football players with longstanding HGI (> 4 weeks) in the previous season reported more serious hip/groin-related problems in the next preseason than players without HGI in the previous season.[3,46,88] Female amateur football players with HGI shorter than 4 weeks showed recurrence rates of 48% in the next preseason, which was 74% for those with HGI longer than 4 weeks.

A previous HGI is a risk factor for a new HGI but it is less familiar that a previous injury can be a risk factor for subsequent injury to different locations.[4,42,102] A recent study in the Dutch Premier League showed that male football players with previous injuries to other locations than the groin had a 5.1 (hazard ratio, 95% CI 1.8-14.6) greater risk of a subsequent timeloss HGI in the next season.[88]

To have more insight in the complexity of HGI in female amateur football players, the objective of this study was to examine (1) the severity of hip/groin injury and the relationship with (2) previous HGI and (3) previous injury to locations different than the hip/groin.

METHODS

Design and participants

This was a cross-sectional cohort study to the severity of hip and groin injuries and the relationship with previous injury in female amateur football players in The Netherlands. A previous study reported on the prevalence of general injury and hip/groin injury within this population.[101] For a complete description of Material en Methods we refer to that study.[101] Medical ethical approval was not necessary for this questionnaire study according to the Dutch Central Committee on Research Involving Human Subjects (CCMO). The 'Strengthening the Reporting of Observational Studies in Epidemiology' (STROBE) statement was used to report the findings of this study.[91] All participants were female amateur players in the Netherlands and registered by the Royal Dutch Football Association (KNVB).

Study procedure

Participants were asked to complete the injury questionnaire (including the HAGOS) in the preseason of 2015-2016 (August to October 2015) and to send them via an online registration system (Google Forms, Google LLC, Mountain View, USA) (see Appendix of a previous study[101]). All participants gave permission for the use of their anonymized data for research purposes. Questions and remarks concerning the study could be made via email and the questionnaire.

Timeloss and non-timeloss general- and hip/groin injuries were inventoried for the season 2014-2015.[21] HGI was also inventoried for the preseason 2015-2016 and for the seasons prior to the season 2014-2015. Due to possible recall bias no specific season was questioned for this period. To reduce the chance for recall bias, definitions and figures with injury locations were used (**figure 1a and 1b**).[92,94] For this study, the hip/groin was referred to as 'the region between the front of the hip and the inner front of the thigh'.[103] Also, dichotomous answer options were used.[92]

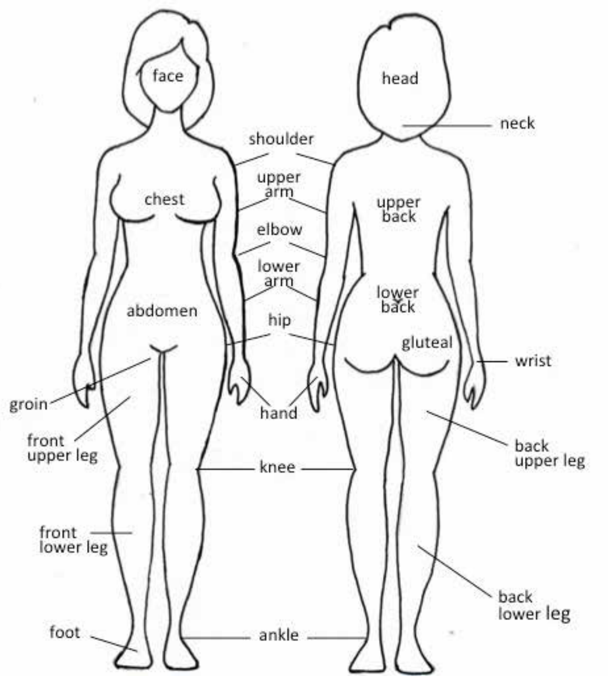

Figure 1a *Body chart according the Orchard Sports Injury Classification System*[92]

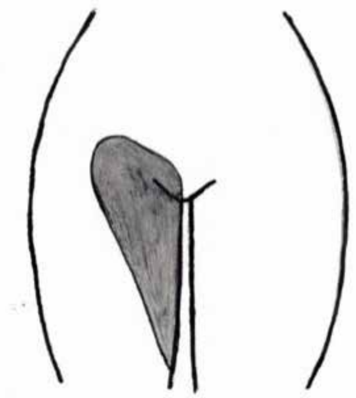

Figure 1b *The hip/groin region is defined as the front part of the hip and the inner part of the thigh*[103]

The HAGOS is a questionnaire with 37 items to assess the level of hip and groin-related problems for all players on 6 subscales.[93] The HAGOS is available in the Dutch language and was found to be reliable (ICCs 0.83-0.87), internally consistent (Cronbach's α between 0.81-0.92) and valid in young athletes (including football players) and comparable to the original Danish version.[37,93] The HAGOS is freely available in several languages (www.koos.nu).

Statistical analysis

The data were tested for normality using the Kolmogorov-Smirnov test. Normally distributed data are presented as a mean and standard deviation (SD). Non-normally distributed data are presented as a median and interquartile range (IQR, 25%-75%). The presence and locations of all injuries are presented as absolute (counts) and relative (percentage of total).

A Mann-Whitney U test was used to examine differences between HAGOS scores for player groups. Univariate logistic regression was used to calculate associations between HGI in the preseason 2015-2016 as dependent variable and previous HGI and general injury as independent variables. Variables with P<.2 were subsequently tested in a multivariate model. Odds ratio and its 95% confidence interval were used to compare risk factors for HGI. Incorrect or missing data were reported and corrected by the means of the variables and frequencies. The level of significance was set at α<0.05. The data were analysed using SPSS 23 (IBM, Armonk, USA).

RESULTS

Participants

The invitation to participate in this study to 43 teams from all KNVB districts and amateur playing levels was declined by 8 teams (120 players) and accepted by 35 teams (response rate 81%). This resulted in 525 female players, from which 91 (17%) failed to meet the inclusion criteria of being at least 18 years of age (n=89) or participating in the included playing levels (n=2 veterans league). There were no dropouts so data from 434 players were used for the analysis. For player characteristics we refer to **table 1** from a previous study.[101]

Severity of hip and groin injury in the preseason 2015-2016

There were 117 female players (27% of all players) with HGI in the preseason 2015-2016 from which 94 non-timeloss (22% of all players) and 23 timeloss (5% of all players). There were 172 female players (40%) with HGI in the season 2014-2015 from which 126 non-timeloss (29%) and 46 timeloss (11%).[101] There were 166 players (38% of all players) with a history of HGI before season 2014-2015.

There were 82 players (19% of all players) in the preseason 2015-2016 who were recovered from HGI in the previous season. They had lower HAGOS-scores than 235 players (54%) who did not sustain HGI in both seasons (P<.001).

There were 90 players (21%) with HGI (29 timeloss, 61 non-timeloss) in the preseason 2015-2016 who also had sustained HGI in the previous season. They had lower HAGOS-scores than 27 players (6%) with new HGI in the preseason (P<.028). Players with timeloss HGI had lower HAGOS-scores (P<.009) than those with non-timeloss HGI for subscales Sport and recreation (SR), Participation in physical activities (PA) and quality of life (QOL). The range for subscale SR was 0-88 for timeloss HGI and 35-100 for non-timeloss HGI; for subscale PA 0-88 for timeloss and 0-100 for non-timeloss HGI and for subscale QOL 30-100 for timeloss and 20-100 for non-timeloss HGI. This shows that scores lower than 35 for subscale SR discriminate between players with non-timeloss and timeloss HGI (**table 1** and **figure 2**).

Table 1 *Levels of hip and groin-related problems expressed in HAGOS subscale-scores (median, IQR) in the preseason 2015-2016 for players without hip and groin injury (HGI) in both seasons (NONE), players who had recovered from HGI (RECOVERED), players with new HGI (NEW) and those with (TL) and without (NTL) timeloss HGI. For the difference between groups P<.005*

	Pain	Symptoms	ADL	S&R	PA	QOL
NONE (n=235)	100	96	100	100	100	100
	100-100	89-100	100-100	100-100	75-100	100-100
RECOVERED (n=82)	98	86	100	100	100	100
	87-100	75-96	95-100	90-100	75-100	84-100
P	***<0.001***	***<0.001***	***<0.001***	***<0.001***	*0.051*	***<0.001***
	Pain	**Symptoms**	**ADL**	**S&R**	**PA**	**QOL**
NEW (n=27)	90	79	100	84	75	95
	80-95	79-89	80-100	66-94	63-88	70-95
TL (n=29)	81	71	80	59	63	68
	68-92	57-85	75-94	40-82	50-75	56-80
P	*.335*	***.001***	*.053*	***.017***	*.089*	***.001***
	Pain	**Symptoms**	**ADL**	**S&R**	**PA**	**QOL**
NEW (n=27)	90	79	100	84	75	95
	80-95	79-89	80-100	66-94	63-88	70-95
NTL (n=61)	85	79	90	81	75	85
	79-95	71-83	75-100	72-94	75-100	70-95
P	*.223*	***.017***	***.028***	*.359*	*.648*	*.152*
	Pain	**Symptoms**	**ADL**	**S&R**	**PA**	**QOL**
NTL (n=61)	85	79	90	81	75	85
	79-95	71-83	75-100	72-94	75-100	70-95
TL (n=29)	81	71	80	59	63	68
	68-92	57-85	75-94	40-82	50-75	56-80
P	*.386*	*.496*	*.110*	***.009***	***.002***	***<.001***

Abbreviations: IQR=interquartile range; HAGOS=Hip And Groin Outcome Score; ADL=function in daily living; SR=function in Sport and Recreation; PA=participation in Physical Activity; QOL=hip and groin-related Quality of Life; n=number

Relation between hip and groin injury in the preseason 2015-2016 and previous seasons

From 262 players without HGI in the previous season, 27 had new HGI the next preseason (6% of all players) and 235 remained free of HGI (54% of all players). From 172 players with HGI

in the season 2014-2015, 82 had recovered in the next preseason (19% of all players) and 90 remained injured (21% of all players).
From 126 players with non-timeloss HGI in the previous season (100%), 65 had recovered in the next preseason (52%) and 61 remained injured (48%). From 46 players with timeloss HGI in the previous season (100%), 17 had recovered in the next preseason (37%) and 29 remained injured (63%) (**figure 2**).

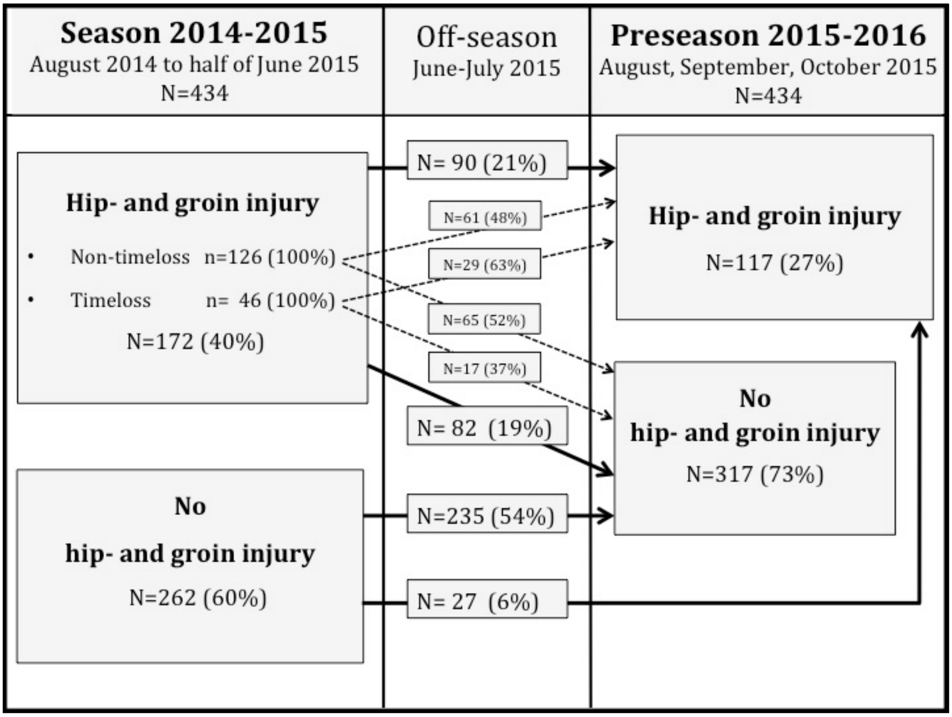

Figure 2 *Player's flow (n=434) from the season 2014-2015 to the preseason 2015-2016 with and without hip and groin injury (continuous arrows) and divided into timeloss and non-timeloss hip and groin injury (broken arrows) in number and percent*

The association between timeloss HGIs of both seasons was the strongest (OR 12.1, BI 5.0-30.0). Non-timeloss HGI from the previous season was not associated with timeloss HGI in the preseason (**table 2**).

Table 2 *Association between hip and groin injury in the preseason 2015-2016 and hip and groin injury in the season 2014-2015 and before*

HIP AND GROIN INJURY SEASON 2014-2015	**HIP AND GROIN INJURY PRESEASON 2015-2016**		
	TL & NTL (n=117)	**TL** (n=23)	**NTL** (n=94)
TL & NTL (n=172)	OR 9.6 CI 5.8-15.7	OR 8.0 CI 2.7-24.0	OR 7.3 CI 4.3-12.3
	P<.001	**P<.001**	**P<.001**
TL (n=46)	OR 5.8 CI 3.1-11.1	OR 12.1 CI 5.0-30.0	OR 2.4 CI 1.2-4.5
	P<.001	**P<.001**	**P=.009**
NTL (n=126)	OR 4.2 CI 2.7-6.7	OR 1.1 CI 0.4-2.7	OR 5.0 CI 3.1-8.2
	P<.001	P=.879	**P<.001**
<2014-2015 (n=166)	OR 3.2 CI 2.1-4.7	OR 2.7 CI 1.2-5.9	OR 2.8 CI 1.8-4.3
	P<.001	**P=.017**	**P<.001**

Abbreviations: OR=odds ratio; CI=95% confidence interval; TL=time-loss; NTL=non-timeloss; n=number. For the difference between groups P<.005

Relation between hip and groin injury in the preseason 2015-2016 and general injury in the season 2014-2015

In the 2014-2015 season there were 1439 general injuries, located in the foot, ankle, calf, tibia, knee, thigh, hamstring, hip, groin, low back, trunk, shoulder, elbow, wrist, hand, neck, head and face. Of these, 904 were non-timeloss (63%) and 535 timeloss (37%). The top three non-timeloss injuries were hip/groin (17%), knee (14%) and ankle (12%) and for timeloss injuries ankle (22%), knee (18%) and hamstring (11%) with hip/groin injury in fifth place (9%).

In the 2014-2015 season, players with HGI (n = 172) had more injuries at locations different than the hip/groin (median 4, IQR 3-6) than players without HGI (median 2, IOR 1-4) (P < .001). Non-timeloss HGI in the preseason was associated with timeloss knee injury in the previous season (OR 2.1, 95%CI 1.1-4.2). Timeloss HGI in the preseason was associated with non-timeloss ankle injury in the previous season (OR 4.6; 95%CI 1.0-20.7) (**table 3**).

Table 3 *Association between hip and groin injury (preseason 2015-2016; previous season 2014-2015) and general injury to different locations than the groin in the season 2014-2015*						
Hip and groin injury	**Association**			**Other injury 2014-2015**		
2015-2016 (n=117)	*OR*	*95%CI*	*P*	*Location*	*TL/NTL*	*n*
TL (n=23)	4.6	1.0 -20.7	.045	Ankle	NTL	110
NTL (n=94)	2.1	1.1 - 4.2	.029	Knee	TL	94
Hip and groin injury	**Association**			**Other injury 2014-2015**		
2014-2015 (n=172)	*OR*	*95%CI*	*P*	*Location*	*TL/NTL*	*n*
TL (n=46)	2.6	1.1 - 6.1	.034	Lower back	TL	40
NTL (n=126)	2.8	1.5 - 5.2	.001	Knee	TL	94

Abbreviations: OR=odds ratio; CI=confidence interval; TL=timeloss; NTL=non-timeloss; n=number. For the difference between groups P<.005

DISCUSSION

Hip and groin injuries in amateur football players in the Netherlands are complex due to severe hip and groin-related problems (low HAGOS scores), the relationship with injuries in the previous season and the high risk of recurrence and chronicity. A previous study in this population showed high within season prevalence of general injury (93%) and hip and groin injury (within season 40% and preseason 27%).[101]

Severity of hip and groin injury in the preseason 2015-2016

Previous studies demonstrated that professional male football players with HGI in the previous season had higher level of hip/groin-related problems in the next preseason than players without HGI in the previous season.[3,46,104] Football players with injury periods of more than 4 and 6 weeks[3, 101] and those with a history of two or more timeloss HGI suffered the most severe hip/groin-related problems.[88] The results of this study show that female amateur football players with timeloss HGI experience higher level of hip/groin-related problems than those with non-timeloss or new HGI. Players who had recovered from HGI in the previous season had higher level of hip/groin-related problems than those without previous or current HGI. It also appeared that players who did not play football due to hip/groin problems had lower HAGOS scores than players who still played football despite hip/groin problems for subscales Sport and Recreation, Participation in Physical Activities and Quality of Life (**table 1**). In this study, a lower HAGOS-score than 35 for subscale Sport and Recreation was discriminative for players with timeloss HGI.

Relationship between hip and groin injury in the preseason 2015-2016 and injury in the previous season 2014-2015

It is known that a previous HGI is a risk factor for a new one, but it is rarely accepted that a previous injury is a risk factor for a new injury to a different location.[4,42,102] A recent study demonstrated that players with previous injury to locations different than the hip/groin were at five times greater risk for a new hip/groin injury than those without.[88] The results of this study demonstrated a relationship between hip/groin injury in the preseason and the seasons before. Players with timeloss HGI suffered the most recurrence (63%) and a strong association with timeloss HGI in the previous season (OR 12.1; 95%CI 5.0-30.0) (**table 2**). Players with HGI had significantly more general injury to different locations than the hip/groin than those without HGI.

These findings are clinically important for sports physicians and physical therapists and give insight to the injury relationship.[42,102] Epidemiologic studies have reported earlier about the injury relationship in the lower extremities.[35,42] Remaining deficits from previous injury could overload other body regions through inadequate compensatory motoric behaviour during kicking, sprinting[29,30] and cutting/pivoting.[35,43,103,105]

Another explanation for a new HGI is that previous injury reduce training load and result in unfit players.[106] A previous study demonstrated that players with longstanding timeloss (median 9 weeks) of general previous injury had 5 times more risk of a new HGI than those with none or shorter timeloss (median 6 weeks).[88] It has been demonstrated that a reduced chronic workload followed by a high acute workload increases the risk of injury.[40,110]

For optimal management and secondary prevention of HGI, sports physicians and physiotherapists should consider previous timeloss duration and the extent of recovery of previous injury to locations different than the hip/groin.

Instead of regional allocation, this study used players from all KNVB districts to prevent from allocation bias. Both non-timeloss and timeloss definitions were used to avoid underestimation of the actual injury burden.[22,98] Players reported their injuries themselves instead of medical staff, as many amateur clubs have no structured medical care. To increase the precision of reporting and target recall, we chose to use figures to specify anatomical regions (**figure 1a and 1b**). All 434 players provided fully completed surveys because the electronic system did not allow the sending of non- or partially completed surveys.

Limitations

As this was a surveillance study without physical assessment by a (para)medical professional, the classification of hip/groin pain following the clinical entity approach, as recommended by the DOHA-agreement, could not be performed.[5] Despite the type of questions used, recall bias may exist to some extent.[93] Retrospective, self-reported registration of the exact number of injuries, body region and diagnosis may underestimate the prevalence of injuries, as minor injuries tend to be forgotten.[92] As the onset and recovery of injury were not registered, TL-injury numbers during a time-loss period could not be accounted for. Due to the retrospective study design, the influence of potential confounders could not be assessed. Further studies should consider the use of standardized clinical examination by medical professionals with a prospective design during a one-season period. Given the large number of variables in the analysis (34), the association between HGI in the preseason and knee/ankle injuries in the previous season could be based on a type I error.

CONCLUSION

The complexity of hip and groin injury in female amateur football players is high. Players with timeloss hip and groin injury have the highest level of hip and groin-related problems and the highest recurrence rates. Players, who are recovered from hip and groin injury in the previous season, still sustain hip and groin problems in the next preseason. Hip and groin injury in the preseason is related to ankle-, knee- and hip/groin injury in the previous season.

CHAPTER

4

Risk factors for groin injury and groin symptoms in elite-level soccer players: A cohort study in the Dutch professional leagues

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ABSTRACT

Study design: Cohort study with prospective and retrospective elements.

Background: Groin injury and symptoms are common in soccer players. Their relationship with reduced hip range of motion (ROM) and previous injury is unclear.

Objectives: To conduct a retrospective assessment of associations between previous injury and pre-season hip ROM and pre-season prevalence of severe groin symptoms; and prospective identification of risk factors for within-season groin injury.

Methods: During 2015-2016, 190 players from 9 Dutch professional soccer clubs participated. Univariate and multivariate logistic regression were used to predict pre-season severe groin symptoms, identified using the Copenhagen Hip And Groin Outcome Score, from a history of previous groin injury, general injury (minimum 1 week duration) in previous season, and hip ROM. Cox regression was used to predict within-season groin injury.

Results: Point-prevalence of severe groin symptoms was 24% and within-season incidence of groin injury 11%. Total/training/match groin injury incidence was 0.5/0.2/2.6 injuries/1000 playing hours. A history of more than 1 previous groin injury was associated with current severe groin symptoms (Odds Ratio=3.0; 95% CI=1.0, 8.3; P=.038). General injury sustained in the previous season (ankle, knee, thigh, shoulder; median 9 weeks time-loss) was a risk factor for groin injury (Hazard Ratio=5.1; 95% CI=1.1, 14.6; P=.003).

Conclusion: Severe injuries in the previous season to locations other than the groin increase the risk of groin injury the next season. A history of groin injury is associated with current severe groin symptoms. Pre-season hip ROM does not identify players at risk for groin injury.

Level of evidence: Prevention, level 2b.

Keywords: Groin pain, Hip range of motion, Injury prevention, Football (soccer)

INTRODUCTION

Muscle injury is very common in professional soccer players and accounts for one-third of all time-loss injury.[33,107,108] Muscle injury to the lower extremity accounts for more than 90% of all muscle injuries.[34] Injury prevalence per muscle group was 25% for adductors, 42% for hamstring, 19% for quadriceps, and 14% for calf.[108] Recurrence rates were highest for adductors and hamstring (29% and 30%) and overuse injuries (34%) were mostly adductor-related in elite European soccer players.[108] A recent systematic review demonstrated that adductor- or groin injury[41] is problematic due to the high incidence and risk of chronicity and recurrence.[4]

Each season up to 19% of all professional soccer players sustain a time-loss groin injury with an average time-loss between 15 and 20 days[1,21,22,28,34,35,109] and more than 28 days for recurrent groin injury.[33] Groin injury incidence rates vary between European countries,[99] with total/training/match groin injury incidences for a Dutch cohort[28] being 0.7/0.4/2.9 and for a Swedish cohort[30] 1.3/1.0/3.7 injuries per 1000 playing hours. Time-loss injury data underestimate the full extent of the injury burden as groin symptoms are highly prevalent in professional soccer and many players continue to train and play with pain.[3,22,23,36,46]

Previous groin injury is a known risk factor for a future groin injury, yet it is rarely considered that a previous injury may increase the risk of an injury to a different location.[4,102] A recent systematic review demonstrated that there is an injury relationship between various lower extremity muscles.[42] Another study showed a relationship between previous knee injury and subsequent groin injury.[43] Although subsequent injuries are common, the relationship with previous injuries to different locations is not well understood.[102] Another recent systematic review identified lower total hip range of motion (ROM) of both hips as the most consistent factor related to the development of groin injury in athletes, whereas reduced hip internal rotation, abduction, and extension ROM were not.[24] However, the literature was found to be inconsistent on terms and definitions used for groin pain, injury, and hip ROM measurements.[24,44] In previous studies, athletes with current groin pain showed reduced hip internal rotation and reduced hip ROM during the backswing of the soccer kick.[45,104]

Accordingly, the first aim of our study was to examine point-prevalence of severe pre-season groin symptoms and its association with previous injuries and hip ROM at baseline. The second aim was to examine the within-season groin injury incidence rate and risk factors for prospective groin injury during the 2015-2016 season.

METHODS

Design

Cohort study with prospective and retrospective elements. The protocol for the study, consistent with the requirements of the declaration of Helsinki, was approved by the Medical Ethics

Examination Committee (Amsterdam Medical Centre, AMC) under number W15_086#15.0100.[95] All participants gave their written informed consent.

Participants

Sixteen Dutch professional soccer clubs were invited to participate in the GRoin Injury Prevention (GRIP) study. Players were included when the following criteria were met: 18 years of age or older, able to follow Dutch or English instructions, and capable of undergoing hip ROM testing. Data were collected at baseline (pre-season, June-July 2015) and within-season (August 2015-May 2016) at the clubs' facilities (**figure 1**). A standardized questionnaire was used to collect data on age (years), height (cm), weight (kg), body mass index (BMI, kg/m^2), and leg dominance (right/left, defined as the preferred kicking leg) at baseline.

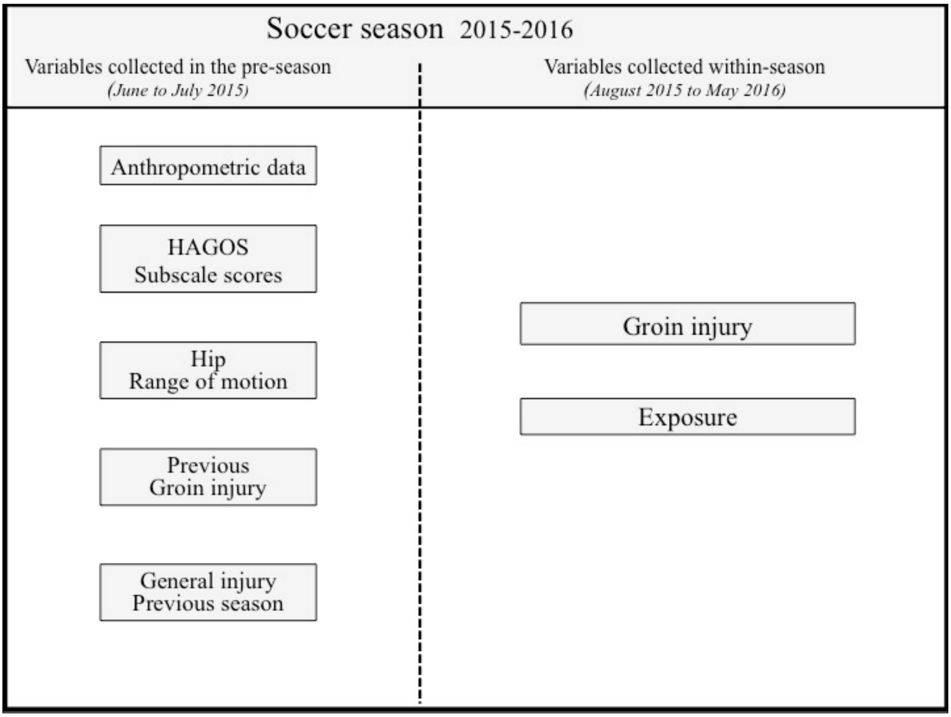

Figure 1 *Retrospective and prospective data collection*

Retrospective injury registration

A history of previous groin injury was recorded categorically as (1) no, (2) yes: once, or (3) yes: more than once. General injury in the previous season was defined as time-loss due to injury to any body region in the 2014-2015 season. Injury body location and time-loss duration, defined from the day getting injured to the day being able to play a match,[110] were also recorded. Data for players with moderate (8-28 days time-loss) and severe (> 28 days time loss) general injury were recorded using dichotomous outcome options (yes/no), whereas history of minor general injury (1-7 days) was not recorded.[21]

Baseline hip ROM

The test procedures to measure hip ROM were consistent with those used in previous studies.[96,111] Six physiotherapists with clinical experience (5 to 31 years) performed 9 hours of training over 3 sessions to enhance uniformity of testing. Both hips were assessed using the following order: hip internal rotation, external rotation, abduction and adduction. ROM of hip rotation was measured using a universal goniometer with increments of 1° (Baseline evaluation instruments, Fabrication Enterprises Inc, New York, US). The players were positioned supine with their hips and knees 90 degrees flexed.[112,113] For ROM hip abduction and adduction the players were in a side-lying position with the trunk contra-laterally rotated and the non-tested leg in 90 degrees hip and knee flexion using a digital inclinometer (Baseline evaluation instruments, Fabrication Enterprises Inc, New York, US).[111] All ROM measurements were performed twice and values were averaged. Assessors were blinded for leg dominance and any history or presence of symptoms or injury. One assessor performed the test while the other recorded ROM values. These values were used to calculate ROM of several combinations of hip positions (total internal rotation, external rotation, adduction and abduction of both hips; total internal and external rotation per hip and for both hips; total adduction and abduction per hip and for both hips; difference between internal rotation, external rotation, adduction and abduction of both hips; difference between internal and external rotation per hip and between both hips; difference between adduction and abduction per hip and between both hips).

Intra- and inter-rater reliability and precision of hip ROM measurement was determined prior to the study using 2 randomly selected assessors who tested 20 hips from 10 collegiate students on 2 occasions on the same day.[114]

Baseline groin symptoms

The Copenhagen Hip and Groin Outcome Score (HAGOS, www.koos.nu), a patient reported outcome measure to assess levels of perceived hip and groin problems in young and active individuals,[93] was used to quantify groin symptoms at baseline. The HAGOS contains 37-items grouped into 6 separate subscales: Pain, Symptoms, Physical function in daily living, Physical function in sport and recreation, Participation in physical activities, and hip and groin-related Quality of Life. Subscale scores range from 0 to 100, where 0 indicates extreme groin symptoms and problems and 100 indicates no symptoms or problems.[93] The HAGOS is available in Dutch language and is valid, reliable (reported ICCs (test-retest) ranging 0.83-0.87) and internally consistent (Cronbach's α 0.81-0.92).[37] The smallest detectable change (SDC) ranged from 17.7 to 32.0 points at individual level and from 1.1 to 2.7 points at group level.[119] These values are comparable to that of the original Danish version of HAGOS.[95] Players proficient in Dutch

completed the HAGOS online (digital platform QuestBack, Almere, NL), while the others completed an officially translated paper version in English.
Based on the HAGOS at baseline, players who scored in the lower quartile (IQR 0-25%) for 2 or more subscales were allocated to the severe groin symptoms group. Players who scored in the upper quartile (IQR 75-100%) for 2 or more subscales formed the minor groin symptoms group. Players who scored in the upper or lower quartile for none or 1 subscale, with the rest of the subscales being in the middle 2 quartiles (IQR 25-75%) were referred to as 'all others'.[46] Subscale scores were calculated for the severe and minor groin symptoms groups, and both were included in retrospective analysis. HAGOS scores from 'all others' were not used.

Prospective injury registration

Club medical staff had received instructions for within-season recording of time-loss due to groin injuries according to a previous injury consensus statement in soccer.[21] A player was considered injured when any symptom to the front of the hip or the antero-medial part of the thigh was sustained during a soccer training or match and resulted in the inability to participate fully in at least 1 training session or match.[21] Groin injury was diagnosed according to the Doha consensus statement and was classified for severity into minor (1-7 days), moderate (8-28 days), or severe (>28 days) based on time loss.[5,21]

Exposure

Training and match exposure from August 2015 to May 2016 were recorded separately. Training exposure was defined as all individual and team physical activities led by a technical staff member, including friendly matches. Club medical staff recorded individual training exposure in minutes using a standardized Excel form and reported the data to the research team on a weekly basis. Individual match exposure was registered in minutes by Gracenote (Emeryville, CA, USA) and was reported each month. Causes of time-loss from training or match were recorded as: (1) groin injury, (2) other injury, and (3) other reasons.

Statistical analysis

Statistical analyses were performed using SPSS version 23 (IBM, Armonk, New York, USA). The Shapiro-Wilk test was used to confirm the normality of distribution of continuous variables. Normally distributed data are presented as mean ± standard deviation (SD) and non-normal data as median and inter quartile range (IQR 25%-75%). Descriptive analyses were conducted for variables for the total group of players. For ROM measurements generalized estimating equations were used to model the interdependency between dominant and non-dominant hips.[46]
Hip ROM intra- and inter-rater reliability (intraclass correlation, ICC 2.2) and minimal detectable change for 95% confidence interval (MDC95) were calculated. Training and match within-season exposure were calculated in hours for all players individually. Total, training, and match

groin injury incidence rates were calculated per 1000 hours of exposure with 95% confidence intervals by dividing the total number of injuries by total exposure time. Previous general injury was recorded for locations and time-loss duration in numbers and percent of the total.
For the retrospective analysis, uni- and multivariate logistic regression models were used to calculate associations between the severe groin symptoms group as dependent variable (recorded at baseline) and player characteristics (age, height, weight, BMI, leg dominance, previous groin injury, general injury previous season, hip ROM) as independent variables. For the prospective analysis, a Cox regression model was used. This model takes exposure into account and censors for abbreviated length of follow up due to other injury or other reasons. In this model, the time (hours of exposure) from the start of the follow up period (August 2015) until the event (groin injury) or the end of follow up (May 2016) was the main variable. Formerly mentioned covariates (including severe groin symptoms) were used as independent variables to identify risk factors for prospective groin injury as dependent variable. Odds ratios (logistic regression) and Hazard ratios (Cox regression) and their 95% confidence intervals were used to compare risks for severe groin symptoms and groin injury respectively.
Absolute risks for severe groin symptoms and groin injury were calculated and reported as the percentage of players with and without the risk factor. For players with previous general injury, a Mann-Whitney U test was used to compare differences in time-loss duration between those who sustained a future groin injury and those who did not.

RESULTS

Participants

From the 16 invited Dutch professional soccer clubs (362 players), 11 teams (239 players) from the Premier League (Eredivisie, 9 teams) and First Division (Jupiler League, 2 teams) agreed to participate. From these, 2 teams (41 players) were lost to follow-up, as the club management did not approve the pre-season physical testing. Eight players were excluded from analysis: 4 players were unable to perform ROM tests due to acute groin and low back injury and another 4 did not complete the HAGOS due to language issues. The remaining 190 players were included for retrospective analysis (53%). Ten players with general injury in the previous season who were diagnosed with groin injury were excluded from the risk factor analysis between previous general injury to locations other than the groin and prospective groin injury. Another 9 were excluded, as they had no exposure in anticipation of pending transfers. The remaining 171 players were included for prospective analysis (47%) (**figure 2**). There were no missing data.

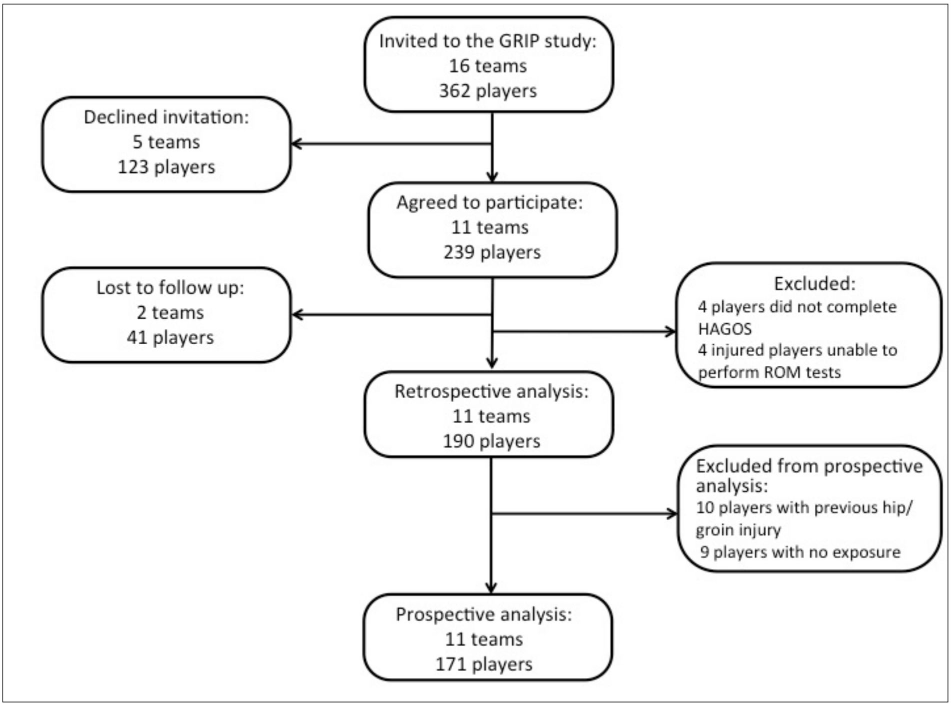

Figure 2 *Flowchart showing the inclusion and exclusion of players in the study*

At baseline, 25 players (13%) reported >1 previous groin injury and 39 players (21%) reported 1 previous groin injury. There were 91 players (52%) reporting 108 general injuries in the previous season 2014-2015 (**table 1**). Numbers and locations of previous general injury were: 31 knee/lower leg (28%), 29 ankle/foot (27%), 17 thigh (16%), 10 hip/groin (9%), 8 shoulder (8%), 4 spine (4%), 4 wrist (4%), and 3 head (4%). There were 28 moderate (26%) and 80 severe (74%) general injuries.

Table 1 *Baseline characteristics for all players (n=190) presented (mean, SD) and (median, IQR 25%-75%)*	
Age (y)	23.3 ± 3.8
Height (cm)	182.4 ± 7.2
Weight (kg)	77.8 ± 7.3
BMI (kg/m2)	23.4 ± 1.4
Leg Dominance (n,%)	
Right	150 (79)
Left	40 (21)
Previous groin injury (n,%)	
No	126 (66)
Yes, 1 injury	39 (21)
Yes, >1 injury	25 (13)
Minor, moderate and severe general injury previous season (n,%)	
No: no injury or minor injury (<1 week)	99 (48)
Yes: moderate or severe injury (>1 week)	91 (52)
HAGOS subscale scores (median, IQR)	
Pain	98 (93-100)
Symptoms	86 (79-93)
ADL	100 (95-100)
SR	97 (91-100)
PA	100 (88-100)
QOL	90 (75-100)

Severity of general injury was classified as minor (1-7 days), moderate (8-28 days) and severe (>28 days). Abbreviations: y=years; cm=centimetre; kg=kilogram; kg/m2=kilogram/square metre; n=number; BMI=body mass index; HAGOS=Hip and Groin Outcome Score; ADL=Physical function in daily living; PA=Participation in physical activity; SR=Physical function in sport and recreation; QOL=Hip and groin-related quality of life. SD=standard deviation; IQR=inter quartile range

Hip Range Of Motion

For intra-rater reliability, ICCs were 0.95 (95%CI 0.95,0.98) for internal rotation, 0.88 (95%CI 0.68,0.96) for external rotation, 0.79 (95%CI 0.37,0.93) for abduction, and 0.95 (95%CI 0.81,0.98) for adduction. The corresponding MDC95 values ranged from 6° to 8°. For inter-rater reliability, ICCs for the same 4 motions were 0.86 (95%CI 0.64,0.95), 0.77 (95%CI 0.38,0.92),

0.58 (95%CI 0.35,0.87), and 0.84 (95%CI 0.52,0.95), respectively. The corresponding MDC95 values ranged from 8° to 11°.
Baseline hip ROM values are provided in **table 2** and combinations of hip ROM measurements in Appendix.

Table 2 *Hip ROM values (degrees) for all players (n=190) (mean, SD)*	
Internal rotation dominant leg	19 ± 9
Internal rotation non-dominant leg	20 ± 10
External rotation dominant leg	36 ± 8
External rotation non-dominant leg	36 ± 8
Abduction dominant leg	37 ± 8
Abduction non-dominant leg	35 ± 9
Adduction dominant leg	22 ± 6
Adduction non-dominant leg	22 ± 6

Baseline prevalence of groin symptoms

The pre-season point-prevalence for players with severe groin symptoms was 24% (46 players) and 60% (114 players) for those with minor groin symptoms. HAGOS subscale scores are provided in **table 3**.

Table 3 *HAGOS subscale scores for players with severe (lower quartile) and minor (upper quartile) groin symptoms, depicted in median (IQR 25%-75%).*

HAGOS subscales	**Severe groin symptoms N=46**	**Minor groin symptoms N=114**
Pain	86 (80-91)	100 (98-100)
Symptom	75 (63-86)	89 (86-96)
ADL	90 (85-95)	100 (100-100)
SR	84 (74-91)	100 (97-100)
PA	88 (75-100)	100 (100-100)
QOL	75 (60-85)	100 (90-100)

Abbreviations: HAGOS=Hip and Groin Outcome Score; IQR=Inter Quartile Range; n=number; ADL=Physical function in daily living; PA=Participation in physical activity; SR=Physical function in sport and recreation; QOL=Hip and groin-related quality of life

Retrospective associations with severe groin symptoms

Univariate logistic regression analysis revealed that greater than 1 previous groin injury was associated with baseline severe groin symptoms (OR=3.7; 95%CI=1.4, 9.9; P=.009;). Multivariate logistic regression analysis with previous general injury and the difference of adduction between both hips as potential risk factors (P<0.1 from univariate analysis) confirmed the association of greater than 1 previous groin injury with severe groin symptoms (OR=3.0; 95%CI=1.0, 8.3, P=.038;) (**table 4**). Absolute risk findings showed that 44% of the players with more than 1 previous groin injury had severe groin symptoms during the pre-season, compared to 15% of those with 1 previous groin injury and 23% of those with no previous groin injury.

Table 4 *Multivariate logistic regression analysis (N=190) for associations between severe groin symptoms and player variables with P<.10 from the univariate model.*

Player variables	OR	P-value	95% CI
General injury previous season	1.519	.290	0.700-3.296
Difference adduction both hips	1.161	**.011**	1.035-1.303
Greater than 1 previous groin injury	2.975	**.038**	1.061-8.343

Abbreviations: CI, confidence interval; OR, Odds Ratio. P<.05

Exposure

Within-season exposure time was 37543 hours, consisting of 33483 training hours and 4060 match hours. On average (± SD), each player spent 198 ± 86 hours playing soccer, which included 176 ± 85 training hours and 21 ± 20 match hours during the 39 week competitive season.

Prospective groin injury

Within-season groin injury incidence rate was 0.5 injury per 1000 playing hours (95%CI: 0.5, 0.1). Incidence rate was 0.2 (95%CI=0.1, 0.4) injury per 1000 training hours and 2.6 (95%CI=1.5, 4.9) injury per 1000 match hours.

A total of 24 groin injuries (11%) were reported in 18 players (10%). Diagnoses were: adductor-related (n=16, 67%), iliopsoas-related (n=1, 4%), inguinal-related (n=1, 4%), pubic-related (n=5, 21%), and hip-related (n=1, 4%). Four players sustained one re-injury and one player two. There were 8 minor (33%), 10 moderate (42%) and 6 severe (25%) groin injuries, resulting in a median time-loss of 13 days per player per season. An average squad of 21 ± 3 players thus can expect 2.7 groin injuries per season, resulting in 35 days lost to play.

Prospective risk factor analysis for groin injury

Univariate Cox regression analysis revealed that general injury in the previous season in regions other than the groin was a risk factor for groin injury (HR=4.6; 95%CI: 1.6, 13.2; P=.004;). Multivariate Cox regression analysis with weight and the difference of external rotation between both hips as potential risk factors confirmed this risk factor relation (HR=5.1; 95%CI: 1.8, 14.6; P=.003) (**table 5**).

Table 5 *Multivariate Cox regression analysis (N=171) for associations between prospective groin injury and player variables with P<.10 from the univariate model.*

Variables	HR	P-value	95% CI
Difference external rotation both hips	1.049	0.124	0.944-1.215
Weight	0.924	**0.012**	0.869-0.983
General injury previous season	5.070	**0.003**	1.766-14.562

Abbreviations: CI, Confidence Interval; HR, Hazard Ratio. P<.05

Absolute risk findings showed that 5% of the players without previous general injury sustained a future groin injury compared to 15% of those with previous general injury. Post-hoc analysis showed that the injury locations from the latter group were ankle (38%), knee (23%), shoulder (23%), and thigh (15%). These players (15%) had significant longer time-loss in the previous season (median 9 weeks, IQR 8-22) than players with previous general injury who did not sustain a future groin injury (85%) (median 6 weeks, IQR 4-12; P=.03).

DISCUSSION

The main finding of this study is that elite level soccer players with previous severe ankle, knee, thigh, and shoulder injury were at high risk to develop groin injury the next season. The within-season groin injury incidence was 11% and an average team of 21 players can expect 3 time-loss groin injuries per season and 35 days time-loss. Severe groin symptoms were associated with a history of more than one previous groin injury. Pre-season hip ROM testing does not identify individual players at risk of groin injury.

Baseline prevalence of severe groin symptoms

The high pre-season point-prevalence of severe groin symptoms (24%) in this study is consistent with the findings from Dutch (20%)[46] and Danish (36%)3 cohorts, suggesting that players do not fully recover during the off-season. This prevalence of symptoms has been reported to increase during the competitive season to 29% (Norwegian),[23] 49% (Denmark),[3] and 55% (Sweden).[97] In this study, severe groin symptoms were defined as the lower quartile HAGOS-scores as used in a previous study.[46] Median subscale-scores for pain (86) and symptoms (75) in players with severe groin symptoms (**table 3**) showed good agreement with Australian soccer players with current groin pain (pain 88 and symptoms 73).[115]

The high prevalence of severe groin symptoms reflects a serious problem in soccer across multiple cohorts and shows the relevance of assessing groin symptoms using more than only a time-loss groin injury definition.

Within-season groin injury incidence and exposure

Groin injury incidences from this study (total: 0.5, training: 0.2, match: 2.6 injury) and prevalence of 11% are comparable to a previous Dutch study in professional soccer players (total: 0.7, training: 0.4, match: 2.9 injury and 14%).[28] The small differences are reflected by seasonal exposure findings from both studies (21/176 and 24/189[28] match and training player/hours respectively).[116] These differences may be explained by decreased playing load of the Dutch national and competition teams in recent years.
The reported exposure in a Swedish study[30] was about twice as high (53/340 match and training player/hours) and this may explain higher groin injury incidence rates (total: 1.3, training: 1.0, match: 3.7 injury)[30] for teams from North European countries.[22]

Retrospective associations with severe groin symptoms

The relationship between greater than 1 previous groin injury and severe pre-season groin symptoms is consistent with the outcomes of 2 previous studies.[3,46] Absolute risk findings showed that nearly half of the players with greater than 1 previous groin injury had severe pre-season groin symptoms. For clinicians, this means that successful and complete management of current groin injury may lower the burden of groin symptoms during the following pre-season. Treatment should preferably target prevention for a re-injury and not solely be focussed on lessening symptoms and return to play.[42] From all combinations of hip measurements, only the difference of adduction between both hips was associated with severe groin symptoms (P=.011), yet can be deemed clinically non-relevant (difference adduction<MDC95; OR 1.2).

Risk factors for prospective groin injury

The main finding of this study is that players with general injury (>1 week) in regions other than the groin were at a 5.1 (hazard ratio; 95%CI: 1.8, 14.6) greater risk of sustaining a groin injury the next season compared to players without previous general injury. This important clinical finding adds to the recent insight that a previous injury may relate to a subsequent injury to different locations, which is rarely considered.[42,102]
Some epidemiologic studies demonstrated relationships between injuries at different locations in the lower extremities[17] due to changes in running[43,106] and kicking[119] biomechanics causing inadequate compensatory movement and motor control strategies.[108] The Sport Injury Classification (SIC) facilitates more accurate documentation on the within-player relations.[102,117,120] It describes the first injury as the index injury and subsequent injuries as recurrent (identical to location and nature compared to the index injury), local (identical to location but different in nature), and new (different location).[120] It was demonstrated in Australian professional football that the majority of subsequent injuries were not related to the index injury (81%), yet 16% were local/recurrent and 3% were new index-related injuries.[102]
In our study, 15% of the players with a previous general (index) injury related to a new groin injury, yet they had significant longer time-loss in the previous season (median 9 weeks) than

85% of the players who were not related to a new groin injury (median 6 weeks). Severe time-loss results in unfit players due to a reduced training load.[40,106] It has been demonstrated that a reduced chronic workload followed by a high acute workload increases the risk of injury.[40,106] Given the 5 times greater risk of groin injury throughout the next season, physical therapists should assess the extent of recovery from severe injuries in the previous season sustained to locations other than the groin.

Another important clinical finding of this study was that pre-season hip ROM was not a useful screening tool for groin injury, even though a wide range of ROM variables were analysed.[24] A strong relationship between reduced unilateral hip ROM and groin injury has never been demonstrated, and this study adds to that information.[117]

Study strengths

A strength of this study was the use of 2 groin injury definitions; both time-loss and symptoms, recorded using HAGOS. Groin injuries were classified according to the Doha Agreement Meeting[5] and a wide range of hip ROM combinations were studied.[24]

Study limitations

The available sample for analysis limits the generalizability to the primary potential pool of 362 players as 123 players declined the invitation, 41 were lost to follow up, 8 were excluded for total analysis, and another 19 for prospective analysis resulting in a sample of 190 players (51%) for retrospective and 171 players (47%) for prospective analysis. Although the sample size was good compared to many similar studies,[25,109,117] Cox regression analysis reduced power from 24 to 18 groin injuries. To detect moderate or strong associations, 20-50 cases are required.[121] Although used before, severe groin symptoms based upon the lower quartile HAGOS scores has not yet been validated in literature.[24]

CONCLUSION

This study demonstrates that elite level soccer players with severe injury to locations other than the groin in the previous season are at high risk for groin injury during the next season. Severe groin symptoms in the pre-season are associated with a history of more than 1 previous groin injuries. Physical therapists should assess the extent of recovery of severe injuries in the previous season sustained to locations other than the groin. Hip ROM testing during the pre-season for screening purposes to identify footballers at risk for groin injury does not seem valuable.

KEY POINTS

FINDINGS: Elite level soccer players with ankle, knee, thigh, and shoulder injury in the previous season with median time-loss of 9 weeks are at 5.1 times greater risk of groin injury the next season compared to those with less time-loss or no previous injury. High pre-season prevalence (24%) of severe groin symptoms is associated with a history of more than one groin injury. Pre-season hip ROM does not identify individual players at risk of within-season groin injury.

IMPLICATIONS: The findings of this study suggest that rehabilitation and training should ensure complete recovery of significant injuries sustained during the previous season. Also, that persistent groin symptoms from groin injuries sustained in the previous seasons should also be addressed during the off-season or early in the season.

CAUTION: The association of more than 1 previous groin injury with severe pre-season groin symptoms should be interpreted with caution due to borderline coefficients. Due to the strong relationship between exposure and injuries, the low groin injury incidence in this study limits generalizability to soccer teams with higher or lower (amateurs) exposure.

Appendix

Hip ROM (degrees) for combinations of hip measurements for all players (n=190)	
Hip rotation	**Degrees**
Difference internal rotation both hips	5 ± 5
Difference external rotation both hips	5 ± 4
Total internal rotation both hips	39 ± 18
Total external rotation both hips	72 ± 15
Total internal and external rotation dominant hip	55 ± 13
Total internal and external rotation non-dominant hip	55 ± 12
Total internal and external rotation both hips	110 ± 24
Difference total rotation both hips	6 ± 6
Hip abduction and adduction	
Difference abduction both hips	5 ± 4
Difference adduction both hips	4 ± 3
Total abduction both hips	72 ± 16
Total adduction both hips	44 ± 12
Total abduction and adduction dominant hip	59 ± 12
Total abduction and adduction don-dominant hip	57 ± 12
Total abduction and adduction both hips	116 ± 23
Difference abduction and adduction both hips	6 ± 5
Abbreviations: ROM=range of motion;n=number; SD=standard deviation	

CHAPTER

5

Timing characteristics of body segments during the maximal instep kick in experienced football players

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ABSTRACT

Aim. The first aim of this study was to describe duration and relative timing of the phases of the maximal instep kick. The second aim was to describe the concurrence of maximal range of motion, maximal angular acceleration, maximal angular deceleration and maximal angular velocity of body segments with four keypoints.

Methods. Twenty experienced football players performed three maximal instep kicks. The kicks were analysed using a full body, three-dimensional motion capture system. Camera recordings determined kicking leg events. The concurrence of peak kinematics of body segments with four keypoints was calculated.

Results. Duration and timing of five phases were identified. Keypoint maximal hip extension (51.4±5.0%) concurred significantly with maximal range of motion (ROM) of shoulder extension. Keypoint maximal knee flexion (63.6±5.2%) concurred significantly with maximal angular acceleration of spine flexion and pelvis posterior tilt. Keypoint knee flexion 90 degrees (69.3±4.9%) concurred significantly with maximal angular velocity of shoulder flexion and spine flexion, maximal angular deceleration of hip flexion and maximal angular acceleration of knee extension. Keypoint ball impact (75.2±5.2%) concurred significantly with maximal ROM of hip deflexion and pelvis anterior rotation and with maximal angular deceleration of spine flexion and pelvis anterior rotation.

Conclusion. This study demonstrated that eleven peak kinematics of upper body and kicking leg segments, significantly concurred with four kicking leg positions. These results provide keypoints for kicking coordination and stress the importance of dynamical coupling as a kicking mechanism.

Key words: Biomechanics, Coordination, Dynamic coupling, Energy transfer, Kicking, Relative timing, Upper body

INTRODUCTION

In football is kicking an essential part of the game.[57,122] The instep kick produces the highest foot speed to kick a ball with maximal velocity.[61,58,77,123,124] The underlying biomechanical mechanism how skilled players generate segment motion and enhance foot speed successfully, is of interest for researchers, coaches, football players and physiotherapists with respect to research, performance, injury prevention and rehabilitation.[61,125,126] The coordination of the instep kick can be expressed as timing of muscles and body segments and as kinematic sequence. As to the latter, the kick can be divided in the preparation, back swing, leg cocking, acceleration and follow through phases. The start of each phase is marked by kicking leg events, consecutively heel strike, toe off, maximal hip extension, maximal knee flexion and ball impact and ends with toe velocity inflection (**figure 1**).[72] The phases involve a sequential wind up of the footballer's body that leads to the formation of a tension arc at the end of the backswing. The tension arc is formed by hip extension, pelvis posterior rotation at the kickside, pelvis anterior tilt, trunk extension/rotation and shoulder extension at the non-kickside.[66,71,127] During leg cocking and acceleration, the unwinding of the tension arc is characterized by pelvis anterior rotation, hip flexion and knee extension at the kickside, pelvis posterior tilt, trunk flexion/rotation and shoulder flexion to the kickside. Kicking coordination might be elucidated by the dynamical systems approach, which supplies a framework for modelling athletic performance.[51,128] Scholtz defined coordination as "the process by which the degrees of freedom are organized in time and sequence to produce a functional movement pattern or synergy".[53] During the instep kick, abundant degrees of freedom are eliminated by coordinative structures like muscle synergies.[54,55,56] Muscle synergies are neurally recruited motor patterns that act to simplify full body movement and control.[52] For the kicking leg, they account for the characteristic proximal to distal sequence, in which hip flexor muscles accelerate the hip first and subsequently knee extensor muscles accelerate the knee.[52,59] Angular velocity of knee extension has been identified as the main contributor to the generation of foot speed.[52,61,75,78,79,129,130] Putnam studied the punt kick and demonstrated that angular velocity of knee extension not only originates from the knee extensor muscles but also from acceleration of hip flexion.[60] Other studies demonstrated that also hip deceleration at square knee angle induced acceleration of knee extension.[59,60,75] In the more complex instep kick, also upper body and support leg events contribute to kicking knee extension. Naito et al. showed that upper body and support leg events supply energy for the development of angular velocity of knee extension.[66] Shan and Westerhoff showed that effective trunk rotation is key for a more explosive muscle contraction to enhance foot speed.[71] Muscle contractions not only accelerate segments to which the muscles attach, but also distant segments to which they are not attached. This is called dynamic coupling and arises from the multiarticular nature of the body.[63,131,132] Muscle synergies induce segmental accelerations that cause mechanical energy to flow among segments in order to kick efficiently and to avoid extreme muscle work.[132] In the dynamic systems approach, the magnitude and direction of energy flow in a multiarticular system can be computed as an expression of dynamic coupling.

As muscle forces and moments determine the magnitude of the energy flow, segment positions and velocities determine its direction.[131] From this perspective, the authors assumed that during the instep kick, peak kinematics of upper body and kicking leg segments should concur with important kicking leg events. The events maximal hip extension (MHE), maximal knee flexion (MKF), knee flexion 90 degrees (KF90) and ball impact (BI), the so-called keypoints, were considered important as MHE, MKF and BI define the leg cocking and acceleration phases.[70] In addition, MHE and MKF concur with maximal muscle forces[59,60,74], KF90 marks the moment of maximal energy transfer[59] and hip deceleration[133] and BI marks maximal foot speed.[134] To our knowledge, there have been no reports in literature of previous attempts to quantify relative timing of peak segment kinematics during the maximal instep kick. Therefore, the first aim of this study was to describe the duration and relative timing of phases during the maximal instep kick. The second aim was to describe the concurrence of maximal range of motion, maximal angular acceleration, maximal angular deceleration and maximal angular velocity of upper body and kicking leg segments with four keypoints.

Figure 1a-g: *Phases and kicking leg events during the maximal instep kick.* ***a*** *start preparation phase at heel strike.* ***b*** *start backswing phase at toe off.* ***c*** *start leg cocking phase at maximal hip extension.* ***d*** *start acceleration phase at maximal knee flexion.* ***e*** *event knee flexion 90 degrees at mid-acceleration.* ***f*** *start follow through phase at ball impact.* ***g*** *end follow through phase at toe velocity inflection*

MATERIAL AND METHODS

Participants

Twenty male professional and semi-professional football players (age 21.5±4.0 years, height 1.83±0.07 m and body mass 80.5±8.31 kg) volunteered to participate in this study. All participants were invited from elite and sub-elite clubs. All reported to be free from injury. They had been informed prior to testing and signed informed consent, allowing them to withdraw at any given time. Approval was obtained from the medical staff of the football clubs.

Measurement set-up

The procedures were completed in the clinical movement laboratory of the Maastricht University Medical Centre+. Motion was recorded using a three-dimensional motion-capture system with eight infrared cameras (VICON Motion Systems, Oxford Metrics Ltd., Oxford, England) and two high-speed Digital Video (DV) cameras (Basler AG, Ahrensburg, Germany). The infrared cameras recorded motion at a rate of 200 frames per second. The DV cameras recorded at a rate of 100 frames per second. The cameras were set up and calibrated in accordance with VICON's guidelines. Reflective 14 mm markers were attached to 31 body landmarks on the upper and lower body using VICON's full body model: four on the head, one on the spinous process of the 7th cervical vertebrae, the manubrium and xiphoid process of the sternum, acromioclavicular joints, lateral epicondyles, wrist bar thumb sides, wrist bar 5th finger sides, anterior superior iliac spines, posterior superior iliac spines, lower lateral 1/3 surface of the thighs, lower 1/3 of the shanks, lateral epicondyle of the knees, lateral malleoli, both the calcaneus and the fourth metatarsal heads. A standardized static motion capture of every subject served as reference to be able to correct ROM and absolute joint angles. In this way, the anatomical position was used to gauge the output obtained from VICON. VICON Nexus was used for calibrating, recording and analysing the data. Nexus presented 3D-constructions, marker labelling and kinematic calculations; everything being synchronized with video-recordings and analogue data.

Measurements

All participants performed a standardized fifteen-minute warm up of stationary cycling. Consecutively, height and weight of the footballers were assessed. Leg length, knee width, ankle width, elbow width, wrist width, hand thickness and shoulder offset were determined and entered into Nexus to provide the VICON Motion System with information needed for the representation of a full body model, corresponding with the marker placement. Participants were then instructed to perform three maximal instep kicks. Every kick was performed with the dominant leg, with a 20 second interval in between. The ball was an official FIFA size-5 football (Derbystar, Goch, Germany™). Target was a marked spot (one meter above the ground) on a two by three meter goal at four meters distance from the ball.

Data analysis

Data analysis was performed using the Statistical Package for Social Sciences, version 21. The standard static motion capture was analysed first, and basic values were noted for correction of ROM values during the performance of the instep kick. First, the relative timing of kicking leg events en peak segment kinematics was calculated. Therefore, the events heelstrike, toe off, maximal hip extension, maximal knee flexion, knee flexion 90 degrees, ball impact and toe velocity inflection were determined accompanying the camera recordings (**figure 1**). VICON Nexus provided peak kinematics of body segments, which concerned maximal range of motion, maximal angular acceleration, maximal angular deceleration and maximal angular velocity of the shoulder at non-kickside, lumbar spine, pelvis, kicking hip and knee. The absolute timing of events and peak kinematics was registered in the timeline in frames of 5 milliseconds, conditioned by the 200 Hz VICON recording frequency. From the three kicks of each participant, mean and standard deviation of events and peak kinematics were calculated, whereupon the mean and standard deviation for the group were calculated. Then, the duration of the kicking phases and total kick were determined.[70] First, the individual mean and standard deviation of phase and total duration were calculated, thereafter for the group. Absolute and relative timing of kicking leg events and duration of phases were calculated in seconds and percent of the total kick (**table 1**).

Table 1 *Duration of the phases and total kick (mean, SD) and start of each phase (event)*

Phases	**Duration**		**Event**	**Timing**	
	%	*seconds*		*%*	*seconds*
Preparation	32.9±5.7	0.200±0.050	**TO**	0.0±0.0	0.0±0.0
Backswing	18.5±3.8	0.112±0.026	**HS**	32.9±5.7	0.20±0.050
Leg cocking	12.2±2.2	0.072±0.009	**MHE**	51.4±5.0	0.31±0.058
Acceleration	11.7±1.5	0.070±0.007	**MKF**	63.6±5.2	0.38±0.059
Follow through	24.7±5.2	0.150±0.038	**BI**	75.2±5.2	0.45±0.061
Total kick	100.0±0.0	0.603±0.074			

Abbreviations: TO=toe off; HS=heel strike; MHE=maximal hip extension; MKF=maximal knee flexion; BI=ball impact; SD=standard deviation; %=percent

Relative timing of peak segment kinematics was calculated in percent of the total kick (**table 2**). Subsequently, the concurrence of peak segment kinematics with four keypoints was determined. For each peak segment kinematic was analysed, which keypoint showed the smallest difference in relative timing. Then, the differences between relative timing of peak segment kinematics and accessory keypoints were calculated. Because of the small sample size, a non-parametric Wilcoxon signed rank test was used to calculate P-values for differences in timing. Concurrence of peak segment kinematics and accessory keypoints was accepted, when the difference in timing was not significant. Peak segment kinematics that showed significant concurrence with a keypoint, are presented in **table 2**. The level for significance was set at 0.05.

***Table 2** Timing of peak kinematics of body segments relative to keypoint timing (mean, SD) in percentage (%) of the total kick duration*

Keypoint timing	Timing of peak segmental kinematics	Δ	P
Maximal hip extension	ROM shoulder extension		
51.4±5.0 (%)	49.9±6.7 (%)	1.6±4.3 (%)	0.206
Maximal knee flexion	Angular acceleration spine flexion		
63.6±5.2 (%)	63.6±4.7 (%)	0.0±1.8 (%)	0.444
	Angular acceleration pelvis posterior tilt		
	63.9±4.7 (%)	0.3±1.9 (%)	0.920
Knee flexion 90°	Angular velocity spine flexion		
69.3±4.9 (%)	68.7±4.5 (%)	0.6±1.4 (%)	0.054
	Angular velocity pelvis posterior tilt		
	68.1±4.7 (%)	1.2±1.5 (%)	0.006*
	Angular velocity shoulder flexion		
	69.1±4.9 (%)	0.1±1.9 (%)	0.751
	Angular acceleration knee extension		
	69.3±5.2 (%)	0.0±2.8 (%)	0.602
	Angular deceleration hip flexion		
	69.6±5.5 (%)	0.3±1.5 (%)	0.327
Ball Impact	ROM pelvis anterior rotation		
75.2±5.2 (%)	75.4±5.4 (%)	0.1±2.1 (%)	0.777
	ROM hip deflexion		
	76.0±5.5 (%)	0.4±1.0 (%)	0.173
	Angular deceleration pelvis anterior rotation		
	75.3±5.2 (%)	0.0±2.5 (%)	0.970
	Angular deceleration spine flexion		
	75.8±4.9 (%)	0.5±1.5 (%)	0.107

Δ: Difference between timing peak kinematics relative to four keypoints. Non-significant differences indicate similar timing of peak segmental kinematics and keypoint. Level of significance P<.05. *

RESULTS

Participants

Twenty male participants were recruited and completed the study. Eighteen players displayed right leg dominance and two players displayed left leg dominance. All had been playing football for at least 13 years at the time of measurement. None of the players reported any discomfort during kicking.

Duration and timing of phases

Six kicking leg events defined the five phases of the instep kick (**figure 1**). The mean duration of the kick was 0.603 (±0.074) seconds. The relative and absolute duration of each phase were determined and are reported in **table 1**.

The preparation phase and the follow-through phase took up more than 50% of the total movement. The leg cocking and acceleration phases were relatively short and showed almost similar duration. These phases were most consistent because of the small standard deviations.

The relative and absolute timing of the kicking leg events and phases were also determined and are reported in **table 1**. Keypoint knee flexion 90 degrees (KF90) timed at 69.3(±4.9)% and was located nearly in the middle of the acceleration phase, 5.7(±1.2)% after keypoint maximal knee flexion and at 6.0(±1.5)% before ball impact.

Concurrence of relative timing of body segments and keypoints

Eleven peak kinematics of upper body and kicking leg segments, significantly concurred with four keypoints during the leg cocking and acceleration phases. Keypoint maximal hip extension timed similar with maximal ROM of shoulder extension. Keypoint maximal knee flexion timed similar with maximal angular acceleration of spine flexion and pelvis posterior tilt. Keypoint knee flexion 90 degrees timed similar with maximal angular velocity of shoulder flexion and spine flexion, maximal angular deceleration of hip flexion and maximal angular acceleration of knee extension. Keypoint ball impact timed similar with maximal ROM of hip deflexion and pelvis anterior rotation and with maximal angular deceleration of spine flexion and pelvis anterior rotation. A complete overview of significant concurrence of relative timing of keypoints and body segments, are reported in **table 2**. Maximal angular velocity of pelvis posterior tilt (68.1±4.7%) showed almost similar relative timing as keypoint knee flexion 90 degrees, but was not significant.

DISCUSSION

In this study we described the duration and relative timing of the five phases of the maximal instep kick. Comparison of the results of the present study to those of Brophy et al., showed almost similar duration for the preparation, backswing and acceleration phases.[70] Our results demonstrated a longer leg cocking phase (0.072±0.009 s against 0.040±0.030 s) but a shorter follow through phase (0.150±0.038 s against 0.350±0.110 s) compared to the study of Brophy et al.[70] As both studies used the same definition on phases, the level of players might explain the differences. Brophy et al. used collegiate football players as in our study professional and semi-professional football players participated.[70] This is supported by the longer total duration of the kick in the study of Brophy et al., which lasts 0.790(±0.12) s as for our study 0.603(±0.074) s. Egan et al. also demonstrated a longer total duration for backswing, leg cocking and acceleration in non-experienced players (0.263±0.047 s) than in experienced players (0.223±0.035 s).[67,70] Nunome et al. described the kick for three phases, the backswing (0.180±0.026 s), leg cocking (0.062±0.020 s) and acceleration phase (0.051±0.074 s).[59] These results were almost similar as the results in our study. In both studies, experienced players performed the kick. In our study, the kicking movement within the population was fairly consistent. The measurements of dispersion were low for the backswing, leg cocking and acceleration phase. The preparation phase and the follow-trough phase had the highest values of dispersion, but also the longest duration.

Furthermore, we reported significant concurrence of relative timing of eleven peak kinematics of upper body and kicking leg segments, with relative timing of four keypoints. For the upper body, three peak pelvic kinematics, three peak spine kinematics and two peak shoulder kinematics displayed significant concurrence with keypoints. For the kicking leg, two peak hip kinematics and one peak knee kinematic significantly concurred with keypoints (**table 2**). As acceleration and deceleration of body segments induce intersegmental energy flow, it might be suspected that the findings of our study reflect dynamic coupling between upper body and kicking leg.[63,71,131,132135]

Previous studies reported the importance of shoulder extension at the non-kickside in order to stabilise the trunk and to produce a tension arc.[69,71] Data from this study support these theories, as relative timing of maximal ROM shoulder extension occurred with keypoint MHE.

Keypoint MKF concurred significantly with maximal acceleration of spine flexion and pelvis posterior tilt. This in agreement with the study of Lees et al., who reported a quick pelvis posterior tilt 50 ms before ball impact.[77] No previous study has reported on the function of pelvis posterior tilt during the kick. However, this function might become more clear when we consider the function of the kicking leg on keypoint MKF.[132,133] Nunome et al. and Lees et al. demonstrated that at keypoint MKF, the hip started to decelerate through the maximal backward knee muscle moment.[52,129] Data from this study demonstrated that at the same time, maximal acceleration of pelvis posterior tilt initiated hip extension.[136,149] Therefore it might be suspected that simultaneous timing of maximal acceleration of pelvis posterior tilt and the backward maximal knee muscle moment will cause effective hip deceleration. As spine flexion is associated with pelvis posterior tilt, the spine might reinforce pelvis tilt, as they both accelerate maximally at keypoint MKF.[137]

Keypoint KF90 concurred significantly with maximal deceleration of hip flexion and maximal acceleration of knee extension, which confirms the proximal to distal sequence of the kicks of our participants and of several other studies.[46,57,59,60,61,66,70,71,74,77,138] Although keypoint KF90 separated the acceleration phase in two almost equal parts, the knee extended approximately 21 degrees between keypoints MKF and KF90, whereas approximately 65 degrees between keypoints KF90 and BI. This supports the findings of Naito et al. that hip induced centrifugal forces reach maximal values at a square knee angle in order to enhance knee extension velocity.[132] Furthermore, the concurrence of maximal velocity of spine flexion and shoulder flexion with KF90, might reflect intersegmental energy flow.[79]

At keypoint BI, our study reported significant concurrence with maximal deceleration of spine flexion and pelvis anterior rotation and maximal ROM of pelvis anterior rotation and hip deflexion. Therefore, pelvis and hip motion comes to a halt at ball impact. This is in agreement with the study of Shan and Westerhoff, who observed zero hip angular velocity just before ball impact.[71] Lees et al.[33] stated that during the instep kick a complex of segment events acts to control and to perturb body motion as little as possible, providing a stable platform for ball contact to take place. In view of this, body segment events that occur during kicking not only enhance foot speed, but also might reflect this goal.[138]

It seems that the constraints of the maximal instep kick increase towards the moment of ball impact. Firstly, phase's duration decrease towards ball impact. Secondly, the duration of the leg cocking and acceleration phase are most precise, as to the small dispersion. Thirdly, during these two phases, eleven peak body segment kinematics concur with four keypoints, which may reflect the outcome of a well-coordinated kick. Muscle synergies play a key role in the coordination of body segments. Muscle-induced accelerations account for dynamic coupling and thus determine the concurrence of peak kinematics and keypoints.[131] Each keypoint concurs with a cluster of peak upper body and kicking leg segment kinematics, which presumes a biomechanical interaction to exchange energy between the upper body and kicking leg.[63] It suggests that the upper body (tension arc) assists in acceleration of hip flexion during leg cocking and in deceleration of hip flexion during the acceleration phase. Simultaneous timing of peak hip deceleration and peak knee acceleration at keypoint KF90 suggests optimal energy transfer from thigh to shank.[63,131,132] Further, our data suggest that hip deceleration is not only caused by the backward knee muscle moment but also by simultaneous timing of spine and pelvis.[4,21]

We acknowledge some limitations. The segment events heelstrike, toe off and ball impact were visual determined using the DV images with a sampling rate of 100 Hz. A higher frequency should facilitate visual determination of these three events with even more precision. Furthermore, the laboratory set up did not allow participants to make wide approach angles towards the ball, which might affect ball velocity.[138] Finally, for a complete overview of kicking technique, relative timing of all relevant body segments should be studied, including the support leg segments.[139]

CONCLUSIONS

Data from this study demonstrate consistent phase timing and duration. Eleven peak kinematics of upper body and kicking leg segments, significantly concur with four kicking leg positions. These results provide keypoints for kicking coordination and stress the importance of dynamical coupling as a kicking mechanism. The findings of this study suggest that muscle synergies play a key role in the coordination of body segments during kicking. As to dynamic coupling, precise timing of upper body and kicking leg segments presume a biomechanical interaction. This suggests that during leg cocking the upper body (tension arc) induces hip acceleration. During the acceleration phase, the upper body may assist in hip deceleration, in order to accelerate knee extension through intersegmental energy transfer. Precise timing not only enhances foot speed, but also aims to control body segments at ball impact. To enhance kicking skills, future research should focus on the biomechanical interaction of the upper body, support leg and kicking leg and extrapolate new findings to football training programmes.

CHAPTER

6

Range of motion of body segments is larger during the maximal instep kick than during the submaximal instep kick in experienced football players

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ABSTRACT

Background: Football players with groin injury refrain from maximal kicking. Previous groin injury is related to decreased hip range of motion (ROM). Information on ROM differences between maximal and submaximal kicking within players is lacking. The first aim of this study is to quantify ROM of body segments during the maximal (MaxK) and submaximal (SubK) instep kick at four keypoints. The second aim is to study ROM differences of tension arc and movement trajectories between MaxK and SubK.

Methods: Maximal (100% ball speed) and submaximal (70% ball speed) instep kicks from 15 experienced football players were registered with motion capture. ROM of hip, spine, pelvis and knee segments were determined at four keypoints. Differences in segmental ROM for the tension arc and movement trajectories between MaxK and SubK were studied. Effect sizes (ES) were calculated.

Results: Ball speed was 98.8(±9.0) km/h for Maxk and 69.5(±7.1) km/h for SubK. Three keypoints timed similarly ($p<0.05$) for MaxK and SubK. MaxK shows increased ROM for all segments ($p<0.05$) but not for hip flexion. MaxK results in enlargement of tension arc and movement trajectories. Spine flexion (ES 3.2) and pelvis posterior tilt (ES 2.2) show the greatest relative increase.

Conclusions: Maximal kicking shows larger segmental ROM than submaximal kicking. Enlargement of tension arc and movement trajectories relate to increased segmental velocity, according to biomechanical concepts. Central body actions play an important role in kicking. This information can be used to further identify kicking strategies in athletes with injury.

Keywords: Range of motion, Football, Maximal instep kick, Submaximal instep kick, Pre-stretch, Groin injury

INTRODUCTION

Football players are skilled to kick the ball over long distances with high speed and precision to the target.[122,140,141] The maximal instep kick is most suitable for this as this technique produces the highest ball speed when compared to other techniques.[140] Powerful kicking is associated with large muscle forces and is the most frequent injury mechanism in football for acute groin pain.[47,75] The dominant leg is most often affected.[75]

The instep kick can be divided in phases, all marked by defined keypoints (**figure 1**).[70,71,105] During the backswing phase, maximal hip, spine, pelvis and knee movements generate a full body tension arc. This creates pre-stretch of muscles connecting the segments of upper body and kicking leg.[71] Pre-stretch enlarges muscle contraction forces, by use of a stretch-shorten cycle mechanism, resulting in acceleration of segments during the leg cocking and acceleration phases.[72] The greater the distance is over which these segments move (movement trajectory), the greater the potential to develop segmental velocity.[142] Summation of segmental velocities finally determines ball speed.[57,61,129,133]

The adductor longus and the iliopsoas are the most affected muscles in football players with groin pain.[47] These are proposed to be at risk during the backswing of the kick because of coincident timing of maximal eccentric contraction, maximal rate of lengthening and maximal hip range of motion (ROM).[143]

Figure 1 *Phases and keypoints during the instep kick: A-B backswing phase from key point TO to MHE. B-C leg cocking phase from key point MHE to MKF. C-E acceleration phase from key point MKF to BI, with key point KF90 (D) in-between*

Football players with previous groin injury are prone to re-injury and remaining physical deficits or altered movement patterns are considered risk factors.[4,35] Decreased hip ROM is related to groin pain in athletes, however mechanisms explaining this relation are lacking.[45,46,107,144,145] During an injury episode, powerful kicking remains affected as this provokes groin structures, forcing the footballer to switch to submaximal kicking strategies.[4,10,146]

In order to identify possible atypical ROM characteristics of players with groin injury, quantification of the typical ROM characteristics of maximal and submaximal kicking is needed. To our best knowledge, no studies have been performed investigating ROM of hip, spine, pelvis and knee segments during the maximal and submaximal instep kick. Therefore, the first aim of this study is to quantify range of motion (ROM) of body segments during the maximal (MaxK) and submaximal (SubK) instep kick at four keypoints. The second aim is to study ROM differences of the tension arc and movement trajectories between MaxK and SubK.

The hypothesis tested is that segmental ROM increases from submaximal to maximal kicking.

METHODS

Subjects

Adult football players from a Dutch professional club were invited to participate in this study. They were informed prior to testing, giving them the opportunity to withdraw from this study at any moment. All players signed informed consent. The medical staff approved their participation. This study complied with the requirements of the declaration of Helsinki.[95] No ethical approval was needed, as stated in the Dutch Medical Research Involving Human Subjects Act (WMO). Players were found eligible when they reported to be free from injury in the lower back, hip and groin over the last 6 months.

Motion capture

Motion was recorded using a three-dimensional motion-capture system with eight infrared (IR) cameras (VICON Motion Systems, Oxford Metrics Ltd., Oxford, England) and two high-speed digital video (DV) cameras (Basler AG, Ahrensburg, Germany). The IR cameras recording rate was 200 Hz. The DV cameras recording rate was 100 Hz. The cameras were set up and calibrated in accordance with VICON's guidelines. A standardized static motion capture of every subject served as reference to be able to correct ROM and/or absolute joint angles (**figure 2**).

Figure 2. *Standardized static motion captures from all subjects served as reference to correct for ROM and absolute joint angles.*

The anatomical position was used to gauge the output obtained from VICON. VICON Nexus was used for all the steps, calibrating, recording and analysing the data. Nexus presented 3D-constructions, marker labelling and kinematic calculations. Reflective 14-mm markers were attached to 31 body landmarks according to VICON's full body model.[105] Height and weight as well as leg length, knee width, ankle width, elbow width, wrist width, hand thickness and shoulder offset were registered for all participants. These data were entered in Nexus to provide the VICON Motion System with further information corresponding with the marker placement. The electronic data were synchronized with video-recordings and analogue data.

Preparation

All players performed a fifteen-minute standardized warming up before the motion capture procedures started. All were instructed to perform two maximal and submaximal instep kicks, aiming for a marked spot that was located one meter above the ground and four meters away from the ball position.

Data recording procedures

All procedures were completed in the clinical movement laboratory of the Maastricht University Medical Centre+, The Netherlands. Players were free in their ball approach. For players with right leg dominance, approach angles up to 45 degrees could be performed at voluntary approach speed due the kicking pitch set up in the laboratory (**figure 3**).

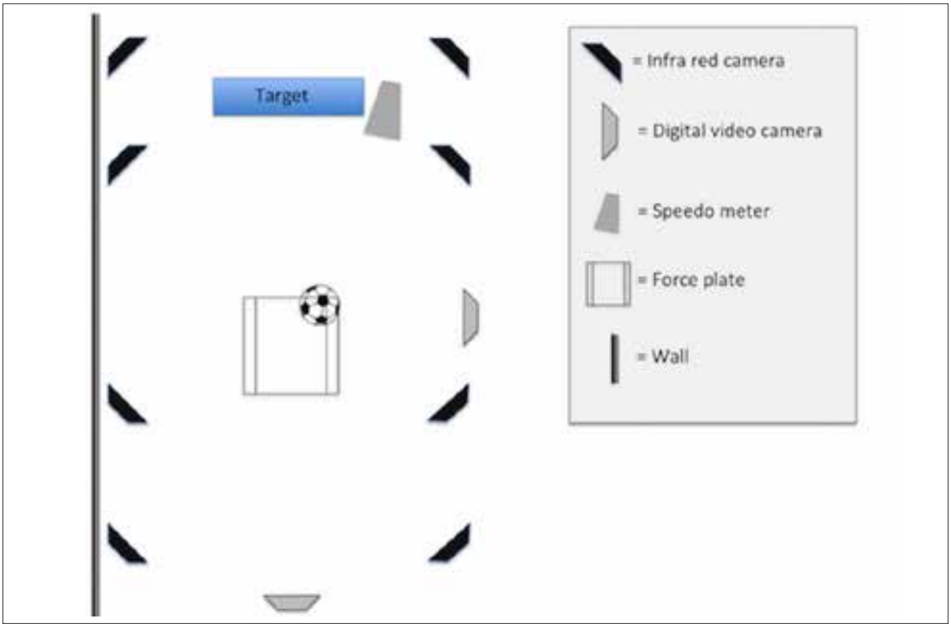

Figure 3 *Laboratory set-up*

Maximal and submaximal instep kick

Ball velocity was assessed with a ball speedometer (WG 54, D&L, Utrecht, The Netherlands). Maximal instep kicks were defined as kicks performing 100% of ball speed. Submaximal instep kicks were defined as kicks performing 65-75% of maximal ball speed. Every kick was performed with the dominant leg with a 20 second interval in between. The ball used was an official FIFA size 5 football (Derbystar, Goch, Germany).

Kinematic analysis

Basic values of the standard static motion capture were noted in order to correct for ROM values during the performance of the kicks. Definition and determination of keypoints are consistent with a previous study.[109] Toe off of the kicking foot was defined as the start (0%) and ball impact as the end of the kicking motion (100%) (**figure 1**).[59,70] Duration of the maximal and submaximal kick was calculated and relative timing of keypoints was expressed as percentage (%) of the kicking motion. Parameters that adequately described the kinematic curves in amplitude and time for hip, spine, pelvis and knee were extracted from VICONS's output.

ROM at keypoints

ROM of hip, spine, pelvis and knee was determined for both the maximal and submaximal kick at 4 keypoints; maximal hip extension (MHE), maximal knee flexion (MKF), knee flexion 90 degrees (KF90) and ball impact (BI) (**figure 1**).[105]

Tension arc and movement trajectories

The tension arc is the posture that is related to the wind-up of the body in order to store energy and stretch muscles before unwinding.[71] The tension arc is defined as ROM of hip extension, spine extension, spine rotation to the non-kickside and pelvis anterior tilt at keypoint MHE and ROM of knee flexion at keypoint MKF. The movement trajectories for hip flexion, spine flexion, spine rotation to the kickside and pelvis posterior tilt were defined from keypoint MHE till BI. The movement trajectory for knee extension was defined from keypoint MKF till BI.

Statistical analysis

Data were analysed for normality of distribution by the Shapiro-Wilk test. When found normally distributed, these are presented as mean (±standard deviation). Paired samples t-tests were used to detect differences between MaxK and SubK. Differences were studied on the timing of keypoints and on ROM of hip, spine, pelvis and knee at keypoints (MHE, MKF, KF90 and BI). Differences in ROM between MaxK and SubK were calculated and analysed for the tension arc with paired samples t-tests. Differences in ROM of the movement trajectories were analysed accordingly. In order to study contributions of individual segmental changes to the hypothesized ROM differences between MaxK and SubK, effect sizes (ES) were calculated ((mean^{MaxK} - mean^{SubK})/SD^{SubK}). Data were processed using SPSS 20 (Statistical Package for the Social Sciences, IBM, Chicago, US). The α-level for statistical significance was set at 0.05.

RESULTS

Subjects

From 28 players who were invited, 10 players sustained low back pain, hip or groin pain over the last 6 months, 2 did not want to participate and 1 was not able to participate on the assessment day due to club professional obligations elsewhere. Finally, 15 football players (age 22.1(±5.0) yrs, height 1.81(±0.09) m and weight 80.8(±8.42) kg) were recruited. Of all these, 13 players displayed right and two players left leg dominance. All had played football for at least 13 years. None of the players reported discomfort during kicking.

Ball speed, kick duration and timing of keypoints

Ball speed was 98.8(±9.0) km/h for the maximal kick and 69.5(±7.1) km/h for the submaximal kick. Total duration of the kick was 0.256(±0.047) seconds for MaxK and 0.268(±0.048) seconds for SubK. There were no differences in timing of keypoints MHE, MKF and BI between MaxK and SubK (MHE: 46.0(±4.9)%, MKF: 72.9(±2.4)% and BI: 100.0(±0.0)%, all $p<0.05$). Keypoint KF90 timed differently: MaxK 86.7(±2.2)% vs SubK 79.4(±4.3)%.

ROM at keypoints

Segmental ROM for MaxK and SubK at four keypoints is shown in **table 1** and illustrated in **figure 4**. When compared to SubK, MaxK shows increased ROM at keypoint MHE for hip extension (mean difference (MD) 9.0°, ES 1.1), spine rotation (MD 8.5°, ES 1.1), spine extension (MD 2.9°, ES 0.4) and pelvis anterior tilt (MD 1.3°, ES 0.2). Keypoint MKF shows increased ROM for knee flexion (MD 18.1°, ES 2.0).

Keypoint KF90 shows increased ROM for hip flexion (MD 7.6°, ES 0.8), spine rotation (MD 8.5°, ES 0.7), spine flexion (MD 14.6°, ES 1.6) and pelvis posterior tilt (MD 4.2°, ES 0.8). Keypoint BI shows increased ROM for spine flexion (MD 19.0°, ES 2.4), pelvis posterior tilt (MD 14.2°, ES 2.1) and spine rotation (MD 3.0°, ES 0.4) (all $p<0.05$). In contrast, keypoint BI shows decreased ROM of hip flexion for MaxK when compared to SubK (MD 5.4°, ES -0.6). Post hoc analysis of the kinematic data shows that this is the result of reversed hip motion prior to ball impact during MaxK, which is not observed for SubK.

Knee angles at ball impact show no difference between both kicks.

Table 1 Range of motion (degrees) at four keypoints for MaxK and SubK (mean, SD)								
Keypoint	**MHE**		**MKF**		**KF90**		**BI**	
Segment	*MaxK*	*SubK*	*MaxK*	*SubK*	*MaxK*	*SubK*	*MaxK*	*SubK*
Hip flexion	-31.8*	-22.8*	-7.1	-5.4	6.7*	-0.9*	6.4*	11.8*
	(±6.0)	(±8.4)	(±8.8)	(±9.2)	(±9.8)	(±10.0)	(±11.1)	(±9.2)
Spine flexion	-3.8*	-0.9*	2.1	4.1	24.2*	9.6*	41.4*	22.4*
	(±7.2)	(±8.2)	(±8.9)	(±8.1)	(±10.9)	(±9.4)	(±8.8)	(±7.8)
Spine rotation	-21.4*	-12.9*	-14.1	2.6	4.3*	0.3*	12.4*	9.4*
	(±6.6)	(±7.8)	(±23.9)	(±7.5)	(±7.1)	(±6.1)	(±6.3)	(±8.3)
Pelvis posterior tilt	-19.5*	-18.4*	-4.7	-6.3	9.0*	4.8*	29.5*	15.3*
	(±6.8)	(±5.5)	(±5.2)	(±4.9)	(±7.3)	(±5.4)	(±5.1)	(±6.8)
Knee flexion	63.8	60.1	111.8*	93.7*	90.3	89.1	35.3	35.4
	(±11.5)	(±11.8)	(±7.1)	(±9.1)	(±1.4)	(±1.1)	(±10.0)	(±6.2)

Positive values indicate hip, spine and knee flexion, pelvis posterior tilt and spine rotation to the kick side. Negative values indicate, spine and knee extension, pelvis anterior tilt and spine rotation to the non-kick side. Abbreviations: MaxK=maximal instep kick; SubK=submaximal instep kick. MHE=maximal hip extension; MKF=maximal knee flexion; KF90=knee flexion 90 degrees; BI=ball impact. * = P value < 0.05

Tension arc and movement trajectories

Differences between ROM of the tension arc and movement trajectories for MaxK and SubK are shown in **table 2** and illustrated in **figure 4**.

Table 2 *Range of motion (in degrees) of tension arc and movement trajectories for MaxK and SubK*

	Tension arc		Movement trajectory	
Segment	*MaxK*	*SubK*	*MaxK*	*SubK*
Hip flexion	-31.8*	-22.8*	38.5	34.6
	(±6.0)	(±8.4)	(±9.2)	(±4.7)
Spine flexion	-3.8*	-0.9*	45.3*	23.3*
	(±7.2)	(±8.2)	(±7.4)	(±6.8)
Spine rotation	-21.4*	-12.9*	33.8*	22.3*
	(±6.6)	(±7.8)	(±8.4)	(±7.3)
Pelvis posterior tilt	-19.5*	-18.4*	49.0*	33.7*
	(±5.5)	(±6.8)	(±11.1)	(±5.9)
Knee flexion	111.8*	93.7*	76.6*	58.3*
	(±7.1)	(±8.7)	(±11.9)	(±10.2)

Positive values indicate hip, spine and knee flexion, pelvis posterior tilt and spine rotation to the kick side. Negative values indicate hip, spine and knee extension, pelvis anterior tilt and spine rotation to the non-kick side. Abbreviations: ROM=range of motion; MaxK=maximal instep kick; SubK=submaximal instep kick. * Significant difference with P<.05

The tension arc increases for MaxK compared to SubK, which is mainly due to the increase of ROM of knee flexion (keypoint MKF), hip extension and spine rotation (keypoint MHE). When compared to SubK, MaxK shows increased ROM of movement trajectories for spine flexion (MD 21.9°, ES 3.2), pelvis posterior tilt (MD 15.2°, ES 2.2), spine rotation (MD 11.5, ES 1.6) and knee extension (MD 18.3°, ES 1.8).

The movement trajectory of hip flexion does not differ between MaxK and SubK, which is due to the reversed hip motion prior to ball impact during MaxK (**figure 4a**).

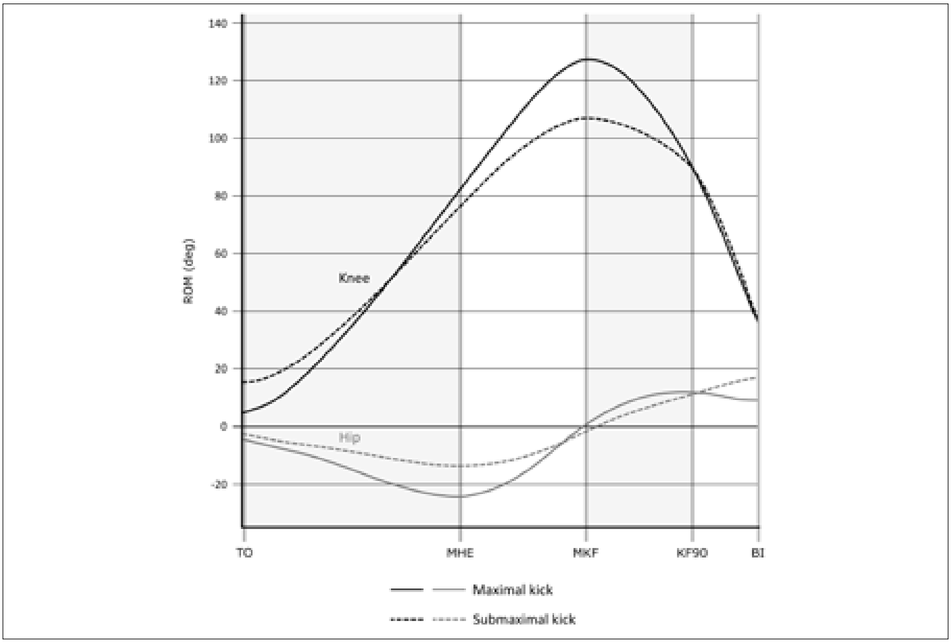

Figure 4a *Range of motion curves (in degrees) for the hip and knee from player 4 for MaxK and SubK. Positive values indicate hip and knee flexion. Negative values indicate hip and knee extension. Key point MHE marks the greatest difference for hip extension and MKF for knee flexion. KF90 marks maximal hip flexion for MaxK and BI marks maximal hip flexion for SubK. BI shows equal knee ROM for MaxK and SubK. MHE=maximal hip extension; MKF=maximal knee flexion; KF90=knee flexion 90 degrees; BI=ball impact*

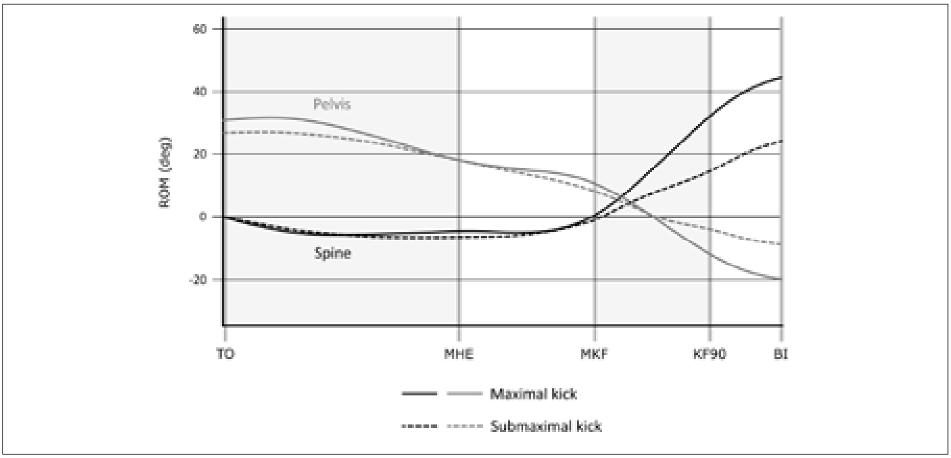

Figure 4b *ROM curves for the spine and pelvis from player 4 for MaxK and SubK. Positive values indicate spine flexion and pelvis anterior tilt. Negative values indicate spine extension and pelvis posterior tilt. Spine flexion and pelvis posterior tilt show the greatest difference at key point BI. MHE=maximal hip extension; MKF=maximal knee flexion; KF90=knee flexion 90 degrees; BI=ball impact*

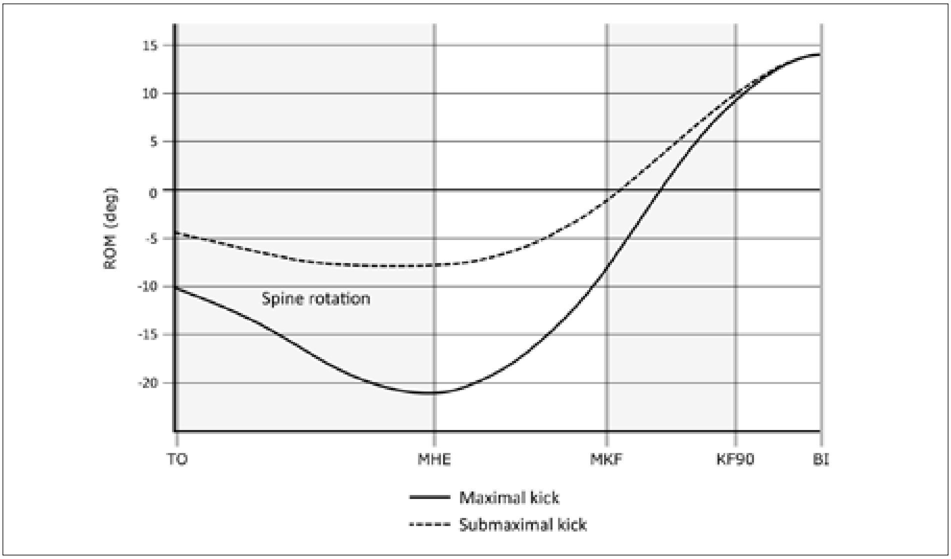

Figure 4c *Range of motion curves (in degrees) for spine rotation from player 4 for MaxK and SubK. Positive values indicate spine rotation to the kickside. Negative values indicate spine rotation to the non-kick side. Key point MHE marks the greatest difference of spine rotation. Abbreviations: ROM=range of motion; MaxK=maximal instep kick; SubK=submaximal instep kick; MHE=maximal hip extension; MKF=maximal knee flexion; KF90=knee flexion 90 degrees; BI=ball impact*

DISCUSSION

The maximal instep kick shows increased ROM of upper body and kicking leg segments at predefined keypoints when compared to the submaximal kick. From these keypoints can be derived that maximal kicking leads to enlargement of the tension arc and movement trajectories when compared to submaximal kicking. Reversal of hip motion is found during MaxK prior to ball impact, which does not occur during SubK. Spine flexion and pelvis posterior tilt show the largest relative differences between MaxK and SubK.

This is the first study that reports in detail on ROM characteristics for the maximal and submaximal kick in experienced football players. In order to be able to identify possible atypical kinematic patterns that may relate to groin injury in football players, a detailed description of the typical ROM characteristics of the hip, spine, pelvis and knee during the maximal and submaximal instep kick must first be obtained.

Ball speeds are consistent with previous studies for the maximal and submaximal kick in experienced football players.[59,71,78,147] Ball speed is the result of summation of segmental velocities.[61] Different ball speeds relate to different kinematic patterns. Studies on kinematics of kicking should thus preferably present data on ball speed.

The maximal kick shows shorter duration and increased ROM of body segments when compared to the submaximal kick. This may be due to increased segmental velocity[12] and agrees with the pre-stretch concept that increased ROM of the tension arc invokes larger muscle contraction forces.[71,72] Therefore MaxK exerts higher loads on groin structures than SubK.[147] This agrees with the clinical observation that players with groin pain avoid maximal performance.[4,146]

Increased segmental ROM for MaxK when compared to SubK was found at keypoint MHE and MKF. This enlargement of the tension arc is mainly due to increased hip extension, spine rotation and knee flexion. Contribution of spine extension and pelvis anterior tilt is only small. For the tension arc, ROM of knee flexion shows the greatest relative difference between maximal and submaximal kicking. The tension arc provides potential for utilizing energy from pre-stretch and elastic components of the muscle–tendon complexes to increase muscle contraction forces.[72,74,148]

Keypoints KF90 and BI also showed increased segmental ROM for MaxK when compared to SubK, which corresponds with the increased movement trajectories of spine, pelvis and knee. Spine flexion and pelvis posterior tilt show the greatest relative difference of movement trajectories between MaxK and SubK. This assumes an important role of central segment actions during maximal kicking. Spine rotation and knee extension also show substantially increased trajectories. The increased movement trajectory of knee extension for MaxK leads to higher angular velocity of knee extension.[72,142] Angular velocity of knee extension is strongly related to foot and ball speed.[80] Correlation coefficients between foot and ball speed reported in the literature are high ($r > 0.74$).[75,78,132]

The hip flexion trajectory did not increase for MaxK when compared to SubK. This is due to the reversed motion of the hip during MaxK prior to ball impact. At keypoint BI, MaxK shows decreased ROM of hip flexion when compared to SubK.

Between keypoints KF90 and BI, spine flexion and pelvis posterior tilt coincide with hip extension for MaxK (**figure 4a,b**).[105] Pelvis posterior tilt and hip extension are identical osteokinematic movements of the hip joint.[149] From KF90 to BI, the pelvis shows increased posterior tilt for MaxK compared to SubK resulting in hip extension.[124] Other studies reported on hip extension but never explained this phenomenon as pelvic action.[59,76,134,147,148,150] Spine flexion and pelvis posterior tilt are coupled motions that cause lumbopelvic flexion.[60] This may assist in the proximal to distal kinematic sequence of the kicking leg, thereby enhancing ball speed.[131]

Movement trajectories of spine and pelvis affect ball speed through dynamic coupling. Movements of distant segments attribute to ball speed by exchanging intersegmental forces that are the result of precise timing of peak velocities and ROM of these segments.[105,151]

This study demonstrates increased ROM of hip extension during the backswing of the maximal kick, which causes pre-stretch and energy storage to increase muscle contraction force.[72,74,148] When ROM of hip extension is decreased, this may affect pre-stretch and thus the energy transfer to develop the physiologic muscle contraction force. Hypothetically, hip flexors may compensate with extreme muscle work to induce high segmental velocity. This may explain the relationship between deficits of hip ROM and groin injury during the backswing.[45,46,107,143-145] The increased ROM of lumbopelvic flexion we observe during MaxK prior to ball impact, may serve as a safety mechanism. Hip extension, as induced by lumbopelvic action, causes elongation of the hip flexors due to separation of their attachments. A previous study demonstrated maximal elongation of the adductor longus prior to ball impact.[143] Lumbopelvic flexion may reduce the load exerting on the groin by elongation of the hip flexors, thereby preventing them from concentric contractions at ball impact.

Hypothetically, deficits of pelvis posterior tilt or increased pelvis anterior tilt may relate to groin injury. It was demonstrated that muscle strain injuries were associated with lumbar lordosis and pelvis anterior tilt in football players.[152] For running, increased pelvis anterior tilt is related to hamstring injuries and low back pain.[46]

The results of this study demonstrate that the hip extends prior to ball impact during maximal kicking in 13 out of 15 players, while no hip extension occurred during submaximal kicking. Previous studies showed hip extension during kicks with the preferred leg but not with the non-preferred leg and during kicks with non-fatigued muscles but not during kicks with fatigued muscles.[75,79,153]

We acknowledge some limitations. We observed a slightly longer duration of the maximal instep kick than reported in previous studies.[59,67] Kicks with approach angles that exceeded 45 degrees showed reduced approach distance due to the kicking pitch set up in the laboratory (**figure 3**). Although approach angles do not affect ball speed, lower approach speed may have influenced ball speed and therefore kicking duration.[67,140] Furthermore, keypoint BI was visually determined using DV images at 100 Hz frequency. A higher frequency should facilitate precision of visual determination of this keypoint. This has relevance for kicking duration as ball impact lasts 10-15 msec.[78,124] At last, as ball speed has been recorded from two positions, precise measurement could be affected. As this applies to both kicks, possible measurement failure might be equal for both kicks.

CONCLUSIONS

This study demonstrates that segmental ROM increases during the maximal instep kick when compared to the submaximal kick. The enlargement of the tension arc is related to higher pre-stretch and the increased movement trajectories enhance the potential to achieve high segmental velocity. Our findings suggest that the athlete's flexibility is imperative for powerful kicks. Data from this study may serve as a basis for future studies to investigate ROM characteristics of players with recurrent injury, with emphasis on flexibility and timing of body segments.

CHAPTER

7

A new clinical test for measurement of lower limb specific range of motion in football players: Design, reliability and reference findings in non-injured players and those with long-standing adductor-related groin pain

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ABSTRACT

Objective: The association between groin pain and range of motion is poorly understood. The aim of this study was to develop a test to measure sport specific range of motion (SSROM) of the lower limb, to evaluate its reliability and describe findings in non-injured (NI) and injured football players.

Design: Case-controlled.

Setting: 6 Dutch elite clubs, 6 amateur clubs and sports medicine practice.

Participants: 103 NI elite and 83 NI amateurs and 57 football players with unilateral adductor-related groin pain.

Main outcome measures: Sport specific hip extension, adduction, abduction, internal and external rotation of both legs were examined with inclinometers. Test-retest reliability (ICC), standard error of measurement (SEM) and minimal detectable change (MDC) were calculated. Non-injured players were compared with the injured group.

Results: Intra and inter tester ICCs were acceptable and ranged from 0.90-0.98 and 0.50-0.88. SEM ranged from 1.3-9.2° and MDC from 3.7-25.6° for single directions and total SSROM. Both non-injured elite and amateur players had very similar total SSROM in non-dominant and dominant legs (188-190, SD±25)°. Injured players had significant ($p<0.05$) total SSROM deficits with 187(SD±31)° on the healthy and 135(SD±29)° on the injured side.

Conclusion: The SSROM test shows acceptable reliability. Loss of SSROM is found on the injured side in football players with unilateral adductor-related groin pain. Whether this being cause or effect of groin pain cannot be stated due to the study design. Whether restoration of SSROM in injured players leads to improved outcome should be investigated in new studies.

Keywords: Groin pain, Range of motion, Football, Reliability

INTRODUCTION

Groin injuries account for 4-19% of football injuries. [22,116] Two recent systematic reviews of prospective studies on risk factors for groin injury included 9 studies where hip ROM was examined. In 3 studies hip ROM deficits conferred a higher risk of groin injury and no increased risk was found in 6 studies.[2,4] Another recent systematic review pooled data on studies examining whether hip ROM differentiated between athletes with and without groin pain.[45] A reduced hip internal rotation and bent knee fall out was found in athletes with current groin pain but hip external rotation was similar.

These conflicting results may have several explanations; different age groups (youth and adults) as well as different levels (elite or amateur) and type of sports (football (soccer), Gaelic or Australian Rules football, rugby and ice hockey) were studied. Additionally ROM was assessed in different postures (i.e. supine or prone) but also the movement excursions that were taken into the analyses differed (rotations of the injured versus the non-injured leg or total rotation of one leg versus that of both legs). Many different definitions of groin pain were used in these studies. This may contribute to the inconsistency of findings in reviews reporting on ROM as risk factor.[2,4,45,154]

Adductor-related groin pain is the most common groin injury in football.[47,69] Due to the inconsistency in findings between clinical examination and imaging findings in athletes with groin pain, a clinical classification was proposed.[10] This was modified and embraced by the recent Doha agreement on terminology and definitions in groin pain in athletes.[5]

Hip ROM is usually assessed in hip flexion or with the hip in a neutral position and targets one joint or muscle in isolation[113,114] while sporting actions like kicking are multi-segmental movements.[71] Conceptual ideas why reduced hip ROM may lead to overloading of the anterior groin structures were presented long ago.[155] A cadaver study showed that the presence of a cam deformity, an aspherical appearance of the femoral head that is associated with reduced hip ROM, leads to increased shear forces of the pubic symphysis. A conceptual model relating reduced ROM to groin pain and physical demands in sporting activities that has been tested in vivo is currently lacking.[156-158] The debate on the association between ROM and groin pain may therefore continue.[158]

Football players with long-standing adductor-related groin pain (LARGP) often complain about their inability to kick a ball with maximal power[166] and kicking is the most frequent injury mechanism.[47,159] A maximal kick is usually performed using the instep kick as this is the most powerful kick in football.[71] Five phases (preparation, back swing, leg cocking, acceleration and follow through) have been described for the instep kick.[69] These phases involve a sequential wind up followed by a proximal-to-distal wind off.[65,71] During back swing and leg cocking, potential energy is stored to be converted into kinetic energy to accelerate body segments. The end of the backswing is known as the tension arc. This tension arc consists of maximal kicking hip extension, a large knee flexion, contralateral trunk rotation and horizontal arm abduction.[65] A kinematic study on differences between submaximal and maximal kicking shows that segmental ROM is larger in maximal kicking than in submaximal kicking.[118] This also applies to the involved central body segments.

To explore the relationship between ROM of the lower limb and LARGP, accounting for the biomechanical concept of kicking, a new way of testing may be beneficial to gain further understanding in this area. In the current study, a measurement of sport specific ROM of the lower limb is proposed. The first objective of this study was to develop a new measurement method for football specific ROM in footballers. The second objective was to examine the intra- and inter-observer reliability of this test and establish reference values in the non-injured and injured population. The third objective was to evaluate differences between non-injured footballers and those with unilateral LARGP. The hypothesis tested is that footballers with unilateral LARGP show reduced ROM in the tension arc position of the instep kick.

METHODS

Participants

All participating footballers signed informed consent and the local medical ethics committee approved this study (METC Noord Holland, registration number M011-030). This study was performed in accordance with the 1964 Declaration of Helsinki.

Non-injured players

Professional footballers from 6 clubs of the Dutch professional premier football league (Eredivisie) were invited to participate. Amateur football players from the 1st team of 6 3rd and 4th division clubs were also invited. Inclusion and exclusion criteria (**table 1**) were checked by interview and standardized physical examination by three experienced physical therapists working fulltime in outpatient clinics and athlete care to streamline the assessments.

***Table 1** Inclusion and exclusion criteria for the football players*

Inclusion	Exclusion
Non-injured football players	
Amateur • Age between 18 and 45 years • Minimal playing load of two times and maximal load of four times per week (training and match)	• Back, hip or groin injury in the last 12 months resulting in > 1 week out of play (training and match) or • Complaints of groin pain in daily life or sports at the time of examination • Tenderness on palpation of the adductor origin at the symphysis pubis[5, 10] or • Groin pain on resisted hip adduction[5,10]
Elite • Age > 18 years. • Participation in training and match >5 days per week	
Inclusion	**Exclusion**
Injured football players	
• Age 18-45 • Groin pain > 8 weeks • Not able to play unrestrictedly due to groin symptoms • Tenderness on palpation of proximal insertion of Adductor Longus origin on injured [5,10] and • Pain on resisted adduction testing in supine[5,10] • Minimal playing load of two times per week (training and match)	• Groin pain < 8 weeks • Football players with bilateral groin pain. • High impact acute onset of injury[5]

Thorborg et al. showed that footballers have hip and groin symptoms to some extent, even when not deemed to be injured. Those with a time loss injury in the previous season show substantially more ongoing symptoms than those without.[36,48,119] Therefore players with more than one week out of play in the previous 12 months due to groin injury were excluded in the non-injured groups. The pain as provoked by testing should exacerbate the athletes' recognizable pain.[5] Palpation and resistance provocation testing for LARGP are reliable.[20] All players were tested on location at their football clubs.

Injured players

Players suffering unilateral LARGP were recruited from and tested at our outpatient primary healthcare clinics. They were referred by other physiotherapists, sports physicians or self-referral.

Test technique

All test positions mimic the full body backswing during kicking.[71] ROM of hip extension is examined as this facilitates pre-stretch and motion-dependent moments that both assist in developing hip velocity.[72,133] As football players need to adapt body positions to varying football situations, the tension arc includes more degrees of freedom than isolated hip extension. The available biological workspace of the tension arc shows multi-dimensional ROM, which allows variability during different kicking situations.[64] From the transition of the backswing to leg cocking, Coriolis forces accelerate hip external rotation and abduction to create momentum.[65] Therefore, test positions also consist of abduction-adduction and external-internal rotation ROM. During the tension arc, knee flexion influences hip ROM because of bi-articular muscles and fascia and can reach up to 100 degrees.[118,162] All tests were performed with the knee in 90 degrees of flexion to take this into account and to standardize the test procedure.

Before data collection a 30 cm metal semi-rigid ruler was attached to the lower and upper leg with Velcro straps. A magnetic digital inclinometer (Wixey, Seattle, US) was fixed at the middle of the ruler. All measurements in each direction were performed twice for reliability assessment. The leg was moved and the inclinometer measurement button was locked when marked resistance restricted further movement. The inclinometer was then loosened from the ruler and values were recorded by an assistant. This procedure was identical in test 1-3. Observers (RL and IT) were blinded for the side of dominance, injured side of patient footballers and for the readings of values. As a consequence of the assessments to be performed on location at the clubs the observers were not blinded for the level of play of the players. The testing time was around ten minutes per player.

Test 1: The extension test.

Player position: The body position at the end of the back swing was mimicked. Body position was derived from biomechanical studies on football kicking.[160] See **Table 2** for the segment positions.

Table 2 *Segmental characteristics of the leg-cocking phase for the kicking leg and the non-kickside upper extremity*[160]

Kicking leg	**Non-kick side arm**
• Pelvis: anterior rotation • Hip: from 30 degrees to 0° extension and 25° abduction and decreasing external rotation • Knee: to a minimum of 90° flexion • Ankle: submaximal plantar flexion	• Arm: from extension to horizontal flexion • Shoulder: from retraction to protraction • Trunk: from extension rotation towards flexion and rotation of the kick side • Stance leg: foot makes ground contact while hip and knee flex.

The extension measurement was performed in prone lying with the non-kicking leg supported in 45 degrees hip and knee flexion (**figure 1a**) mimicking the stance leg position while kicking. The ruler was placed in the midline of the back of the thigh. The upper body was lifted 10 degrees in extension from the Iliac crest and pushed into further extension and rotation by a 20-degree wedge cushion (Michel Koene, Grou, Netherlands, **figure 1b**) to recreate the trunk rotation during the kick. The lower side of the cushion was placed at the umbilical level and the higher side supported the contralateral shoulder. The inclinometer was calibrated to 0 degrees for extension in the resting position. The knee was held at 90 degrees of flexion throughout the testing procedure.[161] A maximum extension position of the leg was created while the buttock was fixed downwards with the ispilateral forearm without restriction of anterior pelvic tilt.

Figure 1a *Extension test. Note the replication of the stance leg position to be placed in hip and knee flexion*

Figure 1b *Extension test. The knee position is 90° of flexion. Full hip extension with anterior pelvic tilt allowance is measured.*

Test 2: The adduction/abduction test.

Player position: The player was positioned in side lying. A post was used for pelvic fixation at the L5 level to prevent the body shifting backwards on the table. The ipsilateral knee was strapped to the table. Then the upper body was turned into full extension and rotation. In this position the hip was fully extended with 90 degrees of knee flexion.[161] Adduction (**figure 2**) and abduction (**figure 3**) were measured with the inclinometer placed halfway along the lateral side in the midline of the upper leg.

Figure 2 *Adduction*

Figure 3 *Abduction*

Test 3: The internal/external rotation test.

Player position: In the same position as the abduction and adduction test the leg was supported by a standard 18 cm roll (Enraf Nonius, Delft, The Netherlands) directly above the medial femoral condyle. With the hip in maximal extension and the knee in 90 degrees flexion on the roll, a maximal internal (**figure 4**) and external rotation (**figure 5**) of the hip was performed. Inclinometers were placed halfway on the lateral side in the midline of the lower leg.

Figure 4 *Internal rotation*

Figure 5 *External rotation*

Pain

Pain felt by the non-injured players while testing was determined to be the cut-off point to further increase tension. Instructions were given to express pain verbally. No attempt was made to score the pain using an NRS scale. Two days after testing the club physical therapists of the elite players were asked to check for pain and/or time lost to play due to the testing procedure by a standardized direct mail. This mail requested that we be informed if any player had felt pain that they attributed to the testing procedure. No thresholds for pain levels or pain measure scales were used. The same was asked to the club staff of the amateurs. Injured players were asked whether this was the case at their next visit after the testing procedure.

Reliability testing

The reliability of the measurement protocol was tested in a sub-group of 20 professional football players who were randomly tested. Each player was tested by two observers on two occasions on the same day. The order of the observers was determined randomly using a coin toss. As the observers were blinded to their previous recorded values they could not be aware of the values measured in the previous test. The order in which the tests were performed were extension, adduction, abduction, external and internal rotation and was not changed between the series.

Statistical analysis

All parameters were tested for normal distribution using the Kolmogorov–Smirnov test. Normally distributed data ($p>0.05$) were analysed parametrically and presented as mean (±standard deviation) and not normally distributed variables as median (inter quartile range). Mann-Whitney U test and Wilcoxon signed rank test were used for non-parametric analyses. Group differences for subject characteristics were tested using a t-test for independent samples. For the analysis of ROM either the Mann–Whitney U for differences between injured and non-injured subjects was used, or the Wilcoxon signed rank test for comparisons between legs in subjects was used. Intra and inter observer reliability (ICC) was assessed by a two way mixed single measures (model 2.1) procedure and absolute agreement for all directions separately and for the total ROM scores. Standard error of measurements (SEM) and minimal detectable change (MDC) were obtained. The rating of Landis and Koch,[20] for ICCs was followed where ICCs<0.00= poor, 0.0-0.20= slight, 0.21-0.40= fair, 0.41-0.60= moderate, 0.61-0.80= substantial and 0.81-1.00= almost perfect agreement.
Cut off values for the percentage of asymmetry between legs were determined to discriminate between non-injured and injured footballers using a Receiver Operator Characteristics (ROC) curve analysis. The ROC curve ideally identifies the threshold for a test score while keeping the greatest sensitivity and specificity [171]. Data were processed using SPSS 20 (IBM, Chicago, US). The α-level for statistical significance was set at 0.05.

RESULTS

All tests for the non-injured players were performed between August and October 2011. The data collection of injured players was from August 2011 until October 2012. A flowchart for the inclusion and exclusion process can be found in **figure 6**. Of the 57 injured players there were 4 elites and 53 amateurs. The characteristics of all subjects are presented in **table 3**. No significant differences between groups were found ($p>0.10$).

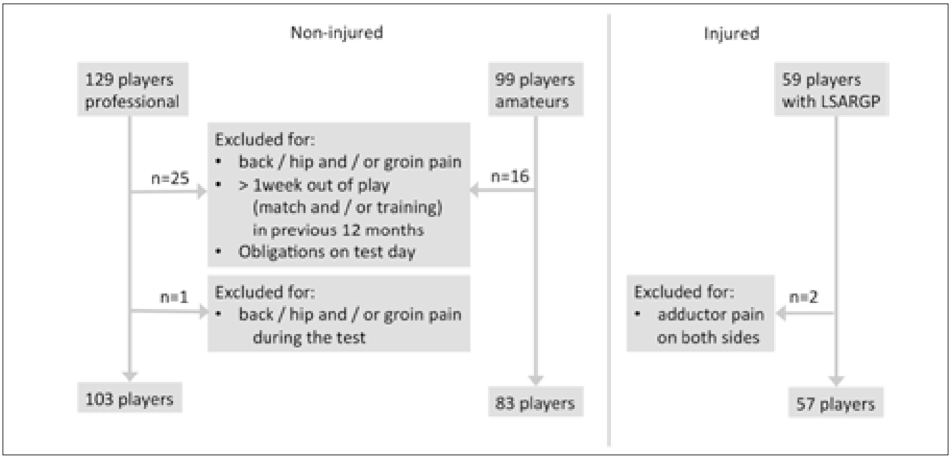

Figure 6 *Inclusion and exclusion process of non-injured and injured players.*

Table 3 *Subject characteristics of healthy elite, healthy amateur and injured football players (mean, SD)*

Player category	**Elite non-injured players**	**Amateur non-injured players**	**Injured**	**players with LARGP**
	n=103	n=83	n=57	
Age (yr)	23 (4.1)	24 (5.5)	26 (7.0)	
Height (cm)	182 (7)	182 (6)	180 (7)	
Weight (kg)	76.3 (7.5)	76.3 (7.7)	73 (7.3)	
BMI (kg/m2)	23.1 (1.6)	23.0 (1.7)	22.3 (1.7)	
Dominance (% right-left)	71-29	81-19	84-16	
Frequency sport (x/week)	≥ 5	2-4	2-4 (53/57)	≥5 (4/57)
Injured side (% dominant)	-	-	70	
Time out of play (weeks)	-	-	15 (2-27)	

Abbreviations: y=years; cm=centimetre; kg=kilogram; kg/m2=kilogram/square metre; n=number; SD=standard deviation

The results for interobserver and intraobserver reliability testing are shown in **table 4**. ICCs for intraobserver reliability range from 0.90 - 0.98. The SEM for single directions ranges from 1.3 - 2.4° with an MDC of 3.7 - 6.6°. The SEM for total ROM is 5.9° with a MDC of 16.4°. Between observers the ICCs range from 0.50 - 0.88. SEM for single directions is 2.9 - 6.9° with MDC ranging from 7.9 - 19.0°. For total ROM the SEM and MDC were respectively 9.2° and 25.6°.

Table 4 *The ICC values of intra and inter observer reliability for specific directions and total ROM, SEM and MDC*

	INTRA ICC	SEM (d)	MDC (d)	INTER ICC	SEM (d)	MDC (d)
Extension	0.92	2.4	6.6	0.88	2.9	7.9
Adduction	0.96	1.3	3.7	0.57	4.3	11.8
Abduction	0.90	1.9	5.4	0.81	3.9	10.7
Internal rotation	0.98	2.0	5.5	0.50	6.9	19.0
External rotation	0.95	2.3	6.3	0.63	5.6	15.4
Total ROM	0.92	5.9	16.4	0.88	9.2	25.6

Abbreviations: ICC=intra class correlation; SEM=standard error of the measurement; MDC=minimal detectable change; ROM=range of motion; d=degrees

Table 5 *Reference values of sport specific hip ROM of the non-injured and injured legs in degrees (mean ±SD).*

LEGS ROM	Elite NonDom	Elite Dom	Amateur NonDom	Amateur Dom	Non-Injured	Injured
Extension	35 (9)*	35 (8)*	29 (10)*	30 (10)*	26 (11)	21 (11)^
Adduction	18 (6)	19 (6)	22 (6)**	23 (7)**	23 (6)	11 (6)^
Abduction	41 (7)**	39 (7)**	40 (7)	39 (7)	40 (8)	28 (9)^
Internal ROT	31 (12)	30 (12)	31 (12)	30 (11)	34 (11)	21 (12)^
External ROT	66 (9)	65 (11)	66 (17)	66 (17)	64 (20)	55 (22)^
Total ROM	191 (25)	188 (25)	188 (25)	188 (25)	187 (31)	136 (29)^

* = Significant difference of dominant and non-dominant legs between amateurs and elite
** = Significant difference between non-dominant and dominant leg in elite or amateur players. ^ = Significant difference between injured side and non-injured side in injured players. Abbreviations: ROM=range of motion; NonDom=non dominant; Dom=dominant

The single directions and total ROM scores for the three groups of football players are shown in **table 5**. Except for a 2° abduction difference in elites and a 1° adduction difference in amateurs no significant differences between the non-dominant and dominant leg of non-injured footballers were found. Between elite and amateur footballers no significant differences in ROM were found, except for extension, which was found to be larger in the elites (Elite; D 35(8)°, ND 35(9)°, Amateur; D 30(10)°, ND 29(10)°, $p<0.01$).

In injured players the ROM of the injured leg was significantly lower in all directions compared to the non-injured leg (all $p<0.01$) and larger than the MDC for adduction, abduction, internal and external rotation. The ROC curve analysis showed the area under the curve varied from 0.88 to 0.98, indicating that the ROC curve presented suitable accuracy to correctly distinguish between healthy and injured subjects. The ROC curve revealed that, in terms of sensitivity and specificity, the optimal cut-off point for the total ROM would be at 17% asymmetry between legs (then sensitivity and specificity is respectively 0.91 and 0.94).

Pain

Marked end range stiffness noted by the observer was obtained before pain occurred in all but one healthy and injured players. Evaluation of the elite and amateur players two days after testing revealed no physical complaints or time lost to play due to the testing procedure. None of the injured football players reported aggravation of their groin pain after testing. As such we consider the test protocol to be safe.

DISCUSSION

A new, reliable and safe sport specific test for ROM of the lower limb in football players was introduced and analysed in this study. The test has clinically acceptable reliability and reference values are presented for amateur and professional players. The hypothesis that footballers with unilateral LARGP show loss of sport specific ROM on the injured side was tested and confirmed. From a biomechanical point of view it seems that this ROM deficit may be of importance.

Agreement testing revealed almost perfect values for intraobserver measurements of separate and total ROM scores ($p<0.05$). Interobserver reliability testing shows moderate agreement for adduction and internal rotation, substantial agreement for external rotation and almost perfect agreement for extension and abduction as well as total ROM. This suggests that the test is acceptable for use in clinical practice. These intraobserver ICCs are comparable to previous work that studied ROM testing with the assistance of an inclinometer[163,164] but the interobserver ICCs for adduction and internal rotation are somehow lower than in these studies. This may be the result of testing all through the end of range of motion and across multiple joints eventually being a more complex method. As football players perform through range we chose to test through maximum range until marked stiffness was observed. It seems that this stiffness within one observer is experienced quite similarly but between observers lower agreement is obtained. Testing with pressure quantification may help improve the reliability[113] but this requires high tech testing devices. The SEM is small for intraobserver measurements. It is substantially larger for interobserver measurements but still clinically acceptable. Relative left-right differences (as expressed in percentage) therefore are preferred for use in individual players. The differences between injured and non-injured sides exceed the MDC for adduction abduction, internal and external rotation.

In both elite and amateur healthy players no clinically relevant side-to-side difference was found. The statistically significant differences found for adduction and abduction, were 1° and 2°. These do not exceed the SEM and only represent a very small proportion of the ROM values obtained, thus were deemed by us clinically irrelevant. The absence of side-to-side difference in non-injured players can only be compared to studies that measure classic rotational hip joint ROM as previous studies of sport specific flexibility have not been performed. These studies on rotational hip joint ROM also found no side-to-side differences.[44,165,166]

Comparing elite and amateur players there was a small statistically significant difference between extension of non-injured amateurs and elite football players of 6 degrees that does exceed the SEM. This may be associated with clinical findings of increased lordosis as a result of hip flexor stiffness of the lower back of elite football players existing as a functional adaptation.[167]

In the players with LARGP a large and clinically relevant decrease was found on the injured side. No previous studies have examined sport specific ROM but two previous cross sectional studies report on internal and external rotation (IR and ER), both assessed in neutral (0 degrees) hip extension. One found IR and ER of both legs were restricted in adult Gaelic football players with groin pain when compared to those without.[168] The majority (14/18 injured players) reported unilateral and the remaining 4 reported bilateral long-standing adductor related groin pain. The other study, performed in a group of young elite Australian football/soccer players found no differences.[164] In this study 8/10 injured players reported bilateral pain and only 2 reported unilateral groin pain. The majority (9/10 players) had adductor related pain. The inclusion criteria in these studies differed. The sum of (dominant and non-dominant) IR and ER (hips flexed) has been reported to be lower in adult professional Australian football players with groin pain when compared with those without.[145] In a study comparing athletes with sportsman's hernia[178] with those without, a decreased hip IR and ER were reported on the injured side. Neither ROM data for the uninjured side nor type of sports of the participants were reported. One study performed a reliability analysis for the ROM assessment.[173] Another study followed this same protocol but did not perform a reliability analysis.[177] Two studies assessing hip ROM in flexion[145,169] do not report any reliability measures nor do they refer to a protocol that has been tested as such. No effect studies have been performed correlating hip ROM with changes in groin pain.

This new test was developed because hip ROM is usually measured with the hips in a flexed or neutral position. Examining one joint does not measure functional ROM according to recent insights that motion-dependent moments are important for body segment velocity.[65] The total body position and adequate biological work space is important in order to create moments and therefore a more functional test was warranted.[118,144,164] The current study shows that in a sport specific posture the ROM deficit is located on the injured side and not on the non-injured side. This is a new finding when compared to previous work that, if present, the association finds both hips are restricted in those with groin pain.

With respect to treatment we think that this hip extension, rotation and ab- and adduction deficit (HERAD) may lead to compensatory muscle contractions compared to when full motion is present.[65] When HERAD is detected we suggest this deficit should be improved so that speed of movement can be achieved through movement related moments instead of muscle related moments.[160] This would mean that less muscle force is needed to generate speed. To prove this concept an effect study should be performed to see whether restoring ROM affects symptoms. Manual therapy in which a forceful stretch was applied to the adductors with a large hip joint motion has been shown to be an effective treatment for athletes with long standing adductor related groin pain.[84] In this randomised trial no measurements of hip joint ROM were performed. Some limitations of this study should be considered. An important limitation is the fact that the observational design cannot answer the question whether the left-right differences observed in injured players is cause or effect of groin pain. As this is the first study to evaluate lower limb ROM measured over multiple joints no comparisons can thus be made with other studies. The interobserver ICCs are clinically acceptable but they are lower than the intraobserver measurements. This decreased reliability with multiple testers should be considered when considering how to apply our results in practice. Standardization of the testing position needs attention and takes time and this may complicate use in daily clinical practice. When introducing this test to professionals in the field, emphasis should be placed on this. Media like movie fragments may be used to transfer this information. The use of pressure quantification with instrumentally assisted measurements may improve the reliability but would make the test less simple. The cohort of non-injured elite footballers was available for the test-retest assessment. We were allowed to perform these on two moments on one day but it was impossible to plan this with a larger time interval because of the tight playing schedule at that time of the season. Regarding the populations tested more work should be done. Homogeneity of groups of injured players may need attention and data should also be derived from athletes like female players. It would have been of interest to assess classical ROM findings in the injured and non-injured players but this was not performed.

CONCLUSION

This study presents a new sport specific lower limb ROM measurement that is reliable, safe and provides reference values for elite and amateur football players. Total ROM is very similar between the dominant and non-dominant legs in elites and amateurs. Players with unilateral long-standing adductor-related groin pain show marked reduction of ROM on the injured side. These preliminary data provide a basis for further research aiming to clarify whether or not restricted sport specific ROM is a risk factor for development of groin injury.

CHAPTER

8

Active pelvic tilt is reduced in athletes with groin injury; A case-controlled study

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ABSTRACT

Objective: To study if athletes with groin injury had less active pelvic tilt (APT) than non-injured controls.

Design: Case-control.

Setting: Sports physiotherapy clinics and sports clubs

Participants: 17 athletes with groin injury (Tegner>5, age 25.1±5.2) and 27 healthy controls (Tegner>5, age 24.4±3.6).

Main outcome measures: Active pelvic tilt, defining the ability of an individual to actively tilt the pelvis anteriorly and posteriorly over a frontal axis, and hip range of motion (HROM) parameters.

Results: Linear regression model associations with generalized estimated equations revealed that APT was lower on injured sides compared to non-injured for total (21.1±7.1 vs. 27.2±8.0, P=.003, effect size (ES)=0.8) and anterior (10.2±5.9 vs. 13.7±4.8, P=.004, ES=0.65) APT. Posterior APT (-10.9±3.6 vs. -13.4±5.2, P=.06, ES=0.56) showed a trend towards being lower in those with groin injury. HROM parameters were not found associated.

Conclusions: Total active and anterior pelvic tilt were lower on the injured side in athletes with groin injury when compared to non-injured sides and healthy controls. This may be a relevant factor to consider in rehabilitation. Whether this is a cause or effect cannot be ascertained due to the cross sectional study design.

Keywords: Groin pain, Football, Range of motion, Adductor

INTRODUCTION

Groin injury is common in sports that include agility and is well-known for high incidence, re-injury and chronicity.[2,23,88] The within-season prevalence of groin injury in professional football ranges between 4-19% leading to reduced performance, time-loss or sometimes even the end of career.[4,22] Previous injury, reduced adductor strength, lower levels of sport-specific training and lower total range of motion (ROM) of both hips are considered risk factors for subsequent groin injury.[4,24,88] A previous injury resulting in a higher risk to sustain a new injury may imply that we neither understand the re-injury mechanism, nor that we are aware of the most important factors that need targeted interventions.[171,172]

Pelvic movement is essential during sprinting and kicking in football. [105,137] In sprinting the pelvis tilts posteriorly during early stance as a result of ground reaction forces (GRF) and then quickly reverses to anterior tilt (**figure 1**).[137,173] In kicking, spinal flexion and pelvic posterior tilt are coupled movements occurring prior to ball impact.[105,193] When changing from submaximal to maximal kicking, ROM of spinal flexion and pelvic posterior tilt showed the greatest relative increase.[118] The GRF induces pelvis posterior tilt, thus hip extension and results in energy transfer to the ipsilateral kicking leg assisting in the proximal-to-distal kinematic sequence of the forward swing.[59,174] A deficit in the ability to tilt the pelvis is likely to negatively affect energy transfer, resulting in compensating movement strategies of adjacent segments with concomitant increased muscle load.[65] It was recently found that football players with a history of groin injury had decreased pelvic tilt during a kicking task compared to those without.[119]

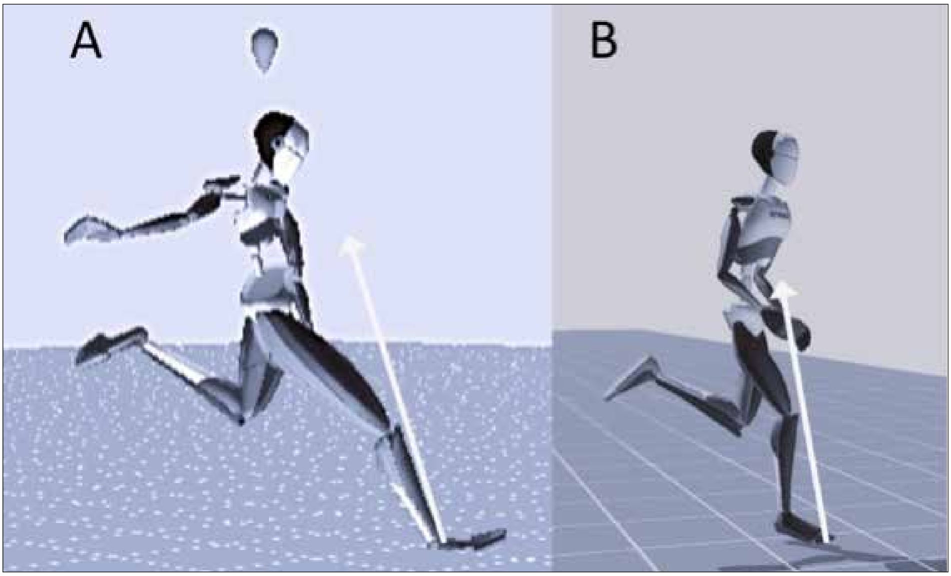


Figure 1 *Visual representation of ground reaction force passing in front of knee and hip joint during early stance phase in kicking (A) and sprinting (B), resulting in an extension moment in the support hip inducing posterior tilt of the pelvis*

Little has been documented on the relationship between pelvic movement in sport specific tasks and groin injury in athletes.[119,152] Hip ROM, which on itself was found to be reduced in athletes with groin injury, was not reported.[45] Hip ROM is related to pelvic position and movement[155,156,170,175] Insight in this relationship could establish criteria for pelvic function as part of rehabilitation programs. The main aim of this study was to examine whether differences in active pelvic tilt exist between athletes with groin injury compared to those without. We hypothesize that active pelvic tilt would be reduced in athletes with groin injury. The secondary aim was to study hip ROM parameters in athletes with and without groin injury.

MATERIALS AND METHODS

Design

Our study was a case-control study. All participants gave their written consent to participate, based on the requirements of the Declaration of Helsinki.[95] The Dutch Central Committee on Research Involving Human Subjects (CCMO) confirmed exemption from full ethical approval prior to the study as stated in the Dutch Medical Research Involving Human Subjects Act (https://wetten.overheid.nl/BWBR0036864/2018-08-01). Reporting the study findings was performed according to the Strengthening The Reporting of OBservational Studies in Epidemiology (STROBE) guideline.[91]

Participants

Participants were athletes (male or female), aged between 18-35 years and competing in track and/or field based sports (Tegner>5).[176]
Inclusion criteria:
Non-injured athletes had no current groin injury neither had they suffered a groin injury over the past 2 years. This was asked to them specifically on the day of measurement. Injured athletes had a current groin injury, classified as a clinical entity according to the Doha agreement, on the day of measurements with symptoms for at least 5 days.[5] The injury could be either with or without time loss.
Exclusion criteria:
Athletes were considered non-eligible in case of:

- History of fractures, dislocation and/or surgery of lower back, pelvis and/or upper leg (including knee)
- Chronic lower back pain (>6 months)
- Hamstring injury in the past 12 months
- Clinical suspicion of specific hip pathologies, nerve entrapment, referred pain, intra-abdominal abnormality (e.g. prostatitis or urinary tract infections), spondylarthropathy or tumors.

All athletes were recruited in two sports physiotherapy clinics and the collaborating sport clubs that these clinics provide health services for. They were invited by email through their trainers and treating therapists, enrolled consecutively and divided between two groups.
Athletes' characteristics and information about current or previous injuries were obtained by paper questionnaires on the day of measurement (Appendix 1). Data collection was between March-August 2018 and either on the sport club site (non-injured athletes) or in the clinic (injured athletes).

Injury

An injury can be either 'non-time loss' or 'time loss'. According to a previous consensus statement on injury definitions, time loss-injury was defined as: "the athlete is not able to participate in training or matches due to groin injury".[21] Non-time loss injury was defined as: "pain in the groin region while the athlete is still participating in training and matches". The duration of groin injury present was registered in weeks. Participants were instructed to report any pain or discomfort during the test protocol.
The Copenhagen Hip And Groin Outcome Score (HAGOS) was used to quantify the levels of hip and groin problems experienced. The HAGOS is a valid (R=0.55 to 0.78) and reliable (ICC=0.63-0.86) patient reported outcome measure to assess levels of hip and groin related problems in young and active individuals and available in Dutch language.[37,93] Standard error of measurement (SEM) for the subscales range from 6.5–11.6.[37]

Clinical examination

Groin injury was assessed along the clinical entities approach as to the Doha agreement on terminology and definitions in athletes with hip and groin pain.[5] These clinical data were collected on a standardized form with entity scoring instructions as used in a previous study (Appendix 2).[37,88]

Outcome measures

Active pelvic tilt (APT)

Active pelvic tilt was defined by the degree of rotation in the sagittal plane around a medio-lateral axis through both hips. The degree of APT was measured with the CoreX Therapy application (Perfect Practise, Ohio, USA) on a smart phone (iPhone type 5c, Apple Inc., California, USA) using the inclinometer properties of the device. This application was found valid ($R2=0.89$ and $R=0.76$, $p\leq.001$) for the study of pelvic movement when compared to an optical motion capture system (Vicon, MX-F40, Vicon Peak, Oxford), with an acceptable intra-class reliability of $\alpha=0.89-0.93$.[177,188]
A pilot study to assess the intra- and interrater reliability of the APT measurement was performed in 9 non-injured individuals (18 legs). The SEM and MDC were calculated, based on data obtained by both researchers on the same day. They were blinded for each other's results during testing.

Maximum anterior and posterior APT were measured and combined for total APT. Results of measurements were saved in the application and exported to a cloud database.
Active pelvic tilt was measured according a standardized protocol for both legs separately. The telephone was connected to an elastic band and placed directly under the anterior and posterior iliac spines on a fixed position on the sacrum of the participant (**figure 2A**).[177,188] The starting position was based on the "golden position" described by Mann: standing upright with one leg in a midstance position and with the trailing swing leg in high knee position.[179] To prevent rectus femoris muscle length affecting pelvic tilt, excessive knee flexion was avoided. The toe of the swing leg was placed on the ground in line with the heel of the standing leg with both knees parallel. The front leg carries the body weight with the knee slightly flexed. The shoulder of the swing leg was placed against the wall for support to avoid lateral tilt. The maximal lateral tilt allowed was limited in the app settings (+5°/0/-5°). When these were exceeded a warning signal was produced and the test was stopped. Data from the trials with excessive lateral tilt were deleted.

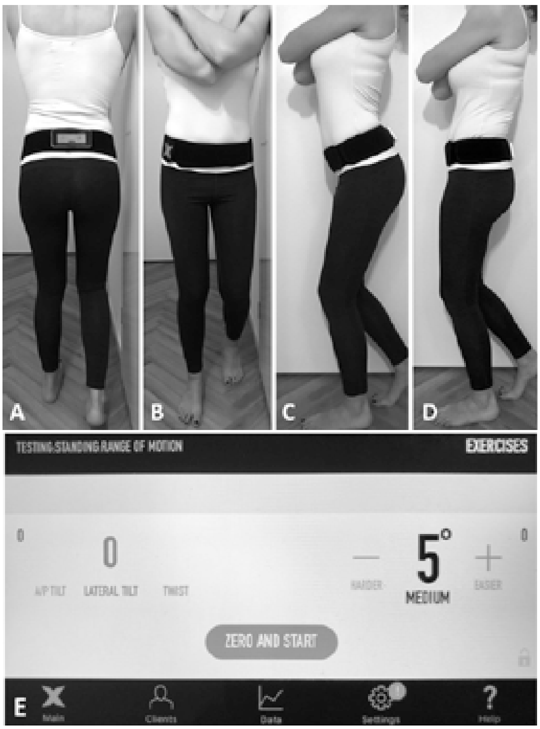


Figure 2A *Positioning of the elastic band with iPhone just below the spina iliaca posterior on the sacrum with the athlete in the test position (rear view).* ***B*** *Athlete position in standing (frontal view).* ***C*** *Maximum anteriorly tilted position.* ***D*** *Maximum posteriorly tilted position.* ***E*** *Print screen of CoreX Therapy application. Maximum tilt allowed can be set and the tilting position is displayed in degrees*

Figure 2A-E Prior to measurement a maximum of three trial repetitions on each leg were completed to avoid learning effects during measurement. The participants were instructed to stand in a neutral relaxed position while no instructions were given about anterior or posterior tilt. From this starting position the participant maximally tilted their pelvis anteriorly and posteriorly (**figure 2C** and **2D**), both three times following a standard verbal instruction: "Tilt your pelvis maximally forward to create a hollow lower back. Keep both knees parallel and your shoulder against the wall while the front leg carries body weight. Now tilt the lower back maximally backward to create a flat back, while keeping your shoulder against the wall and body weight on the front leg"

Bent knee fall-out (BKFO)

Hip flexibility towards combined flexion, abduction and external rotation was assessed using the BKFO test. The participant was in a supine position with the knees 90° flexed, as confirmed with a goniometer, and the soles of both feet against each other. Both hips were rotated outwards to end range and the examiner gave gentle overpressure.[24] The distance between the fibular head and the top of the table was measured in centimetres (cm) with a rigid tape measure. The BKFO has excellent intrarater and interrater reliability with ICC's of 0.89 and ICC 0.91 respectively. The SEM for this protocol is 1.0 cm.[164]

Hip range of motion (HROM)

Internal and external rotation of the hip were measured with a goniometer (in a supine position with knee and hip flexed to 90°) and added to give the total ROM score per hip. One arm of the goniometer was placed on the apex of the patella through the tuberositas tibiae and the other in line with both spina iliaca anterior (SIAS). The observer then performed rotation until the earliest visible lateral rotation of the pelvis. Further hip rotation can be achieved by lumbar spine lateral flexion resulting in an overestimation of hip rotation.[24] This HROM assessment method has a high intrarater (ICC 0.95) and interrater (ICC 0.91) reliability. The SEM is 2.4° for internal and 2.5° for external rotation with a MDC of 7° each.[24,46]

Statistical analysis

Data analyses were completed with the Statistical Package Social Sciences (SPSS, v. 20, IBM, Armonk, USA). Intra- and interrater reliability for the measurement protocol were assessed calculating intraclass correlations (two way mixed for absolute agreement) for single measures with 95% confidence intervals (CI). Standard error of measurement (SEM) was calculated as: standard deviation (SD) x $\sqrt{(1\text{-ICC})}$ and minimal detectable change (MDC) as 1.96 x SEM x $\sqrt{2}$. A statistical power analysis was performed a priori for sample size estimation. It was expected that differences in the primary outcome between groups (APT) would be at least moderate in size. At least 17 injured (considering presence of unilateral injury of 17 hips) and 17 non-injured athletes would be required (alpha=0.05 and power=0.80) to detect an effect of d=0.5.

The Shapiro-Wilk test was used to test for normal distribution of all parameters. Normally distributed data were presented by mean (SD). When data were not normally distributed it was presented as median and 25-75% interquartile range (IQR). Comparisons between groups for descriptive data were performed with independent samples T-tests (age, weight, height, BMI) or Mann Whitney U tests (HAGOS). Differences for APT and HROM variables (BKFO, internal, external and total rotations) between non-dominant and dominant sides in the No-GI group were tested with a paired sample T-test. Linear regression model associations between APT and HROM (as dependent) variables and the presence/absence of GI per side (non-injured and injured) were calculated per hip using univariate linear regression with generalized estimating equations (GEE). By using GEE the interdependency between dominant and non-dominant hips could be modelled. Statistical significance was defined as P≤0.05. Effect sizes were calculated using Cohen's d to guide on the relevance of significant findings. Effects sizes were rated as weak (≥0.2), average (≥0.5) or strong (≥0.8).[180] As HROM relates to pelvic position, HROM variables were entered as co-variate in the regression model in case univariate testing revealed P<.2.

RESULTS

Reliability of the APT measurement protocol

Both intra-rater and inter-rater reliability testing in 9 non-injured athletes (5 female and 4 male, age 24.8(1.5) yrs, length 1.80(0.1) m, weight 70.5(8.6) kg and BMI 21.8(1.2) kg/m2) revealed that the APT measurements were reliable. Reliability data (ICC, SEM and MDC) are presented in t**able 1**.

Table 1 *Results for intra- and inter reliability testing of the APT measures, presented as intra-class correlation coefficient and 95% CI, including SEM and MDC*

	Posterior APT	Anterior APT	Total APT
Intra-rater	0.87 (0.69-0.95)	0.89 (0.74-0.96)	0.97 (0.93-0.99)
Inter-rater	0.57 (0.30-0.75)	0.83 (0.69-0.91)	0.94 (0.88-0.97)
SEM (°)	2	2	1
MDC (°)	5	4	4

Abbreviations: APT = active pelvic tilt; CI = confidence interval; ICC = intraclass correlation; SEM = standard error of measurement, MDC = minimal detectable change

Participants

In total 44 athletes were included. Characteristics for both non-injured (n=27) and injured (n=17) groups are presented in **table 2** as well as the results for testing differences between groups. No significant differences between groups were found for age, height, weight and BMI. All HAGOS subscale scores were significantly lower (all P≤.001) for the injured group when compared to the non-injured group (see **table 2**) confirming correct group allocation. No participant reported any pain or discomfort during testing of APT or hip ROM.

Table 2 *Athletes' characteristics presented as mean (SD) or median (25%-75% IQR) or absolute numbers (n) and percentages (%)*

	Non-injured (n=27/100%)	**Injured** (n=17/100%)	**P**
Sex (n,%)			
Male	11 (41%)	9 (53%)	
Female	16 (59%)	8 (47%)	
Age (y)	24.4 (3.6)	25.1 (5.2)	P=.565
Height (m)	1.78 (0.08)	1.75 (0.11)	P=.513
Weight (kg)	71.9 (7.2)	72.2 (13.6)	P=.928
BMI (kg/m2)	22.8 (1.6)	23.2 (2.8)	P=.501
Sporting level (Tegner)	7 (7-8)	7 (7-9)	P=.229
Sport type (n)			
Football	0 (0%)		7 (41%)
Hockey	11 (41%)	1 (6%)	
Athletics	0 (0.0%)	8 (47%)	
Korfball	0 (0.0%)	1 (6%)	
Handball	16 (59%)		0 (0%)
Dominant side (n,%)			
Left	5 (19%)	4 (23%)	
Right	22 (81%)		13 (77%)
Injured side (n,%)			
Non-dominant	NA	7 (41%)	
Dominant	NA	7 (41%)	
Both	NA	3 (18%)	
Doha classification (n,%)			
Adductor-related	NA	10 (60%)	
Iliopsoas-related	NA	7 (40%)	
Type of injury (n,%)			
Non-timeloss	NA	3 (18%)	
Timeloss	NA	14 (82%)	

Duration of symptoms (wks)	NA	4 (2-7)	
HAGOS			
Symptoms	96 (93–100)	57 (36–66)	P≤.001
Pain	100 (100–100)	73 (65–79)	P≤.001
ADL	100 (100–100)	80 (63–90)	P≤.001
S&R	100 (100–100)	56 (33–66)	P≤.001
PA	100 (100–100)	38 (25–63)	P≤.001
QOL	100 (95–100)	45 (40–60)	P≤.001
Abbreviations: y=years; cm=centimetre; kg=kilogram; kg/m2=kilogram/square metre; BMI=body mass index IQR=interquartile range; n=number; wks=weeks; SD=standard deviation; NA=not applicable; HAGOS=hip and groin outcome score; ADL=function in daily life; S&R=function in sport and recreation; PA=participation in physical activities; QOL=hip and groin-related quality of life			

Main outcome variables

The results of testing for differences between non-injured and injured sides for the outcome variables of APT are presented in **table 3**. Total APT (Cohens' d=0.80, OR=1.1, 95%CI=1.04-1.27) and anterior APT (Cohens' d=0.65, OR=1.2, 95%CI=1.06-1.36) were found to be significantly lower at the injured sides when compared to non-injured sides. Pelvic posterior tilt showed a trend towards being reduced (Cohens' d=0.56, OR=0.9, 95%CI=0.80-1.01).

Table 3 *Main outcome measures for APT in non-injured and injured sides presented as mean (SD) and P-values (presented after correction for dominance)*

	Non-injured side (n=68)	**Injured side** (n=20)	**P**
Posterior APT (°)	-13.4 (5.2)	-10.9 (3.6)	P=.061
Anterior APT (°)	13.7 (4.8)	10.2 (5.9)	**P=.004**
Total APT (°)	27.2 (8.0)	21.1 (7.1)	**P=.003**
Abbreviations: APT=active pelvic tilt; SD=standard deviation; n=number; Significant P-values<.05 presented in bold			

The results of statistical analysis between non-injured and injured sides for the outcome variables for HROM are presented in **table 4**. None of these were found to be different between injured and non-injured sides.

Table 4 *Main outcome measures for HROM in non-injured and injured sides presented as mean (SD) (presented after correction for dominance)*

	Non-injured side (n=68)	**Injured side** (n=20)	***P***
BKFO (cm)	21.3 (4.5)	19.1 (5.1)	P=.074
HROM Internal (°)	20.1 (7.0)	18.0 (5.7)	P=.209
HROM External (°)	36.3 (8.7)	36.8 (8.5)	P=.793
HROM Total (°)	56.5 (13.3)	54.8 (12.7)	P=.626

Abbreviations: HROM=hip range of motion; SD=standard deviation; n=number; BKFO=bent knee fall out

BKFO showed a trend (P=.074) towards being 2.2 cm higher (indicating less flexibility) at the non-injured side (see **table 4**). When entered as co-variate in the regression model, BKFO did not affect the association found between APT and presence or absence of groin injury. No significant differences were found between dominant and non-dominant sides in the non-injured group for APT and all HROM parameters (see **table 5**).

Table 5 *HROM and APT for dominant and non-dominant sides in athletes without groin injury presented as mean (SD). P-values are provided for testing on differences between sides*

	Non-dominant side (n=27)	**Dominant side** (n=27)	**P**
HROM BKFO (cm)	21.9 (4.2)	21.6 (4.4)	P=.399
HROM IR (°)	21.3 (6.3)	19.6 (7.2)	P=.071
HROM ER (°)	36.7 (8.3)	36.5 (9.5)	P=.876
HROM Total (IR+ER) (°)	58.0 (13.0)	56.1 (13.7)	P=.252
APT Anterior (°)	13.7 (4.5)	12.8 (4.3)	P=.244
APT Posterior (°)	-13.8 (5.6)	-13.9 (5.9)	P=.835
APT Total (°)	27.5 (8.3)	26.7 (8.7)	P=.368

Abbreviations: HROM = hip range of motion; APT = active pelvic tilt; d = degree; n = number; cm = centimetre; SD = standard deviation; BKFO = bent knee fall out; IR = internal rotation; ER = external rotation

DISCUSSION

In this study we found that active anterior and total pelvic tilt was reduced on the injured sides in athletes with groin injury. We did not identify any of the hip range of motion (HROM) variables for bent knee fall out, internal, external or total rotations to be different. No differences between dominant and non-dominant sides were found in non-injured controls.

Active pelvic tilt

Kinematics of the hip and pelvis during sport specific tasks like kicking, a single leg drop landing and a change of direction task are different in athletes with groin injury when compared to athletes without.[119,181,182] It is not explained however, why this might be of importance from a biomechanical point of view, nor does this assist the clinician in further determination of relevant parameters to be targeted during rehabilitation. Our current study demonstrates significantly decreased active total and anterior pelvic tilt on the injured sides of athletes with groin injury. Posterior APT was found to be lower on the injured side, yet this did not reach statistical significance. All differences found exceeded the standard error of measurement (SEM). The difference in total APT exceeded the minimal detectable change (MDC) threshold but this was not true for single anterior and posterior APT measures. The effect sizes were strong for total APT and average for anterior and posterior APT. We suggest targeting APT in rehabilitation programs for athletes with groin pain.[189] Improvements on this task can be assessed reliably according the presented measurement for total APT.

APT was measured starting from a predefined midrange body position. Ideally the midrange pelvic position (more or less pronounced anterior or posteriorly oriented pelvis) is determined and controlled in 3D space in relation to a fixed raster of coordinates along the X-, Y- and Z-axes. This was not possible with the mobile device used and may have influenced measurement outcome for single posterior and anterior APT yet not for total APT. Using a similar type of mobile device increases the generalizability of this type of assessments. It is easily accessible, cheap and quickly applied in clinical settings. Studies should thus report if pelvis motion was captured relative to fixed 3D coordinates of the testing area, or relative to the pelvis itself, upper leg or lumbar spine. Transparency on definitions and measurement techniques to assess pelvic ROM is thus warranted in future studies.

Total range of APT in relation to trunk and both legs as tested in this study was found impaired. We deem these findings clinically relevant for sports performance and injury prevention. Pelvis, spine and hip kinematics are coupled movements during sporting tasks like sprinting and running.[137,170] It was observed in football kicking and baseball pitching that knee extension of the support leg attributes to increased ball speed and that the pelvis plays an important role in processing GRF's by transferring mechanical energy to the kicking or throwing extremity.[62,131,173,174,183] The pelvis is considered one of the central segments assisting in proximo-to-distal sequencing of high speed body movements.[71,131] Impaired pelvic movement may negatively affect the athlete's performance and as such induce a higher risk of recurrence and chronicity of groin injury.[22]

We propose restoring APT should be considered part of rehabilitation regimes for injured athletes as it allows mechanical energy transfer during sports actions.[132] Physical therapists should consider core mobility apart from core stability strategies.

Hip range of motion parameters

We found BKFO to be slightly increased on the injured side when compared to the non-injured side yet this did not reach statistical significance. In contrast, previous studies on Australian and Gaelic football players with groin pain found lower BKFO on both sides when compared to non-injured controls.[164,168] Both studies however did not correct for the interdependency of BKFO of the left and right hip within one person.[24] One study in professional footballers that controlled for this interdependency did not found painful hips to be less flexible at BKFO but established that lower BKFO was found to be associated with the presence of cam type morphology.[46] At the time of these studies the Doha agreement to categorise injured athletes in any of the clinical entities was not yet incorporated. One study was on athletes with (a combination) of adductor-related and/or symphysis related groin pain.[168] The other studies did not categorise injured athletes into any of the entities.[46,164]

The findings on hip internal rotation not being significantly lower on the injured side, contributes to the little available existing literature. We found a difference of 2.1 degrees after correction for dominance as recently suggested.[24] When group size is increased this may reach significance but its value should then be questioned as this difference would not exceed the MDC value and thus can be deemed non-relevant.[24] The HROM variables studied did not affect the observed association of lower APT and groin pain in our cohort.

The absence of differences on hip rotations and BKFO between dominant and non-dominant sides in non-injured athletes agrees with previous findings.[164,168]

Meaning of the study

Lumbopelvic motion is important in sprinting as it is highly coordinated with hip movement and pelvic anterior tilt is related to swing hip flexion and high contraction forces of the adductor longus.[173,184] In maximal kicking it showed the greatest relative ROM increase and acts as a safety mechanism due to elongation of the adductors at ball impact.[105] Results of this study are of importance for performance and prevention.

Strengths

This is the first study on active pelvic tilt that adds new information to the field of groin injury research. Many studies on groin injury have been performed in football, as its prevalence in this sport is high. The differences we found in a homogenous group regarding age and athletic levels adds to the body of knowledge on groin injuries in athletes besides football. The use of a wearable, low cost and generally available app is new and suits the technological advances in health care to assess more complex dynamic parameters. Rehabilitation programs focussing on adductor related groin pain mainly contain strengthening exercises of the adductor and abdominal muscles.[83,84] A multi-modality approach, combining these exercise regimes with manual therapy of the adductor muscles found equally good results but reported a faster return to sport.[185] None of the exercise regimes had specific elements aiming to improve active pelvic tilting actions.[8] Future research is needed to establish whether restoring normal APT adds to further improvement of any of the clinical outcome measures of athletes with groin injury.

Limitations

The case-control design prohibits drawing conclusions on whether the lower APT is the cause or effect of groin injury. As this is the first study to evaluate APT as outcome measure no strict comparisons can be made with other studies on this variable. Although this is a case-controlled design and we had homogenous groups for activity levels (Tegner score, track and/or field based), the individual matching was not performed for the type of sport. If and how this may have affected the outcome measures remains unknown. As per our power analysis there were enough participants/injured legs in this study but having 2 clinical entities of groin pain may raise the question whether or not APT relates more to one entity than another. This may have affected measurement outcome.

Unanswered questions and needs for future research

It remains unclear if restoration of APT in both directions may assist in a quicker or more robust recovery per entity of groin injury. It is also unknown if addressing the APT deficit may prevent from recurrent groin injury and lower the groin injury burden in football teams.

CONCLUSION

This is the first study to use a novel mobile phone based device to measure APT in athletes with and without groin injury. Total and anterior active pelvic tilt was lower on the injured side in athletes with groin injury. APT is a newly identified variable and its role in the rehabilitation and prevention of groin injury should be explored in future studies.

Compliance	Thank you for your cooperation in our research! We would like to ask you to fill in the form below truthfully and as completely as possible. In case of questions and / or ambiguities ask the researcher.		
Name:			
Participants number: (for researcher)			
Date of birth:			
Weight:			
Height:			
Gender:			
Sports:			
Level:			
Leg dominance:	Left	Right	
Surgery:			
Diseases:			
Injury history:			
Actual injury:			
Injured side:	Left	Right	Both
Duration actual injury:	Weeks		
Timeloss due to injury:	Yes	No	
Inclusion: (researcher)	Yes	No	

Appendix 1. *In- and exclusion questionnaire form*

Cliënt en Testinformatie
Naam Cliënt: ________________________ Geb Datum: ___ - ___ - _____ m / v
Datum Test: ___ - ___ - 2015

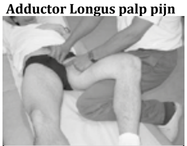
PROVOCATIETESTEN ☑ **Ja/Nee aanvinken s.v.p** **P=Pijn (herkenbaar)** **B=Beperkt** **R=Weerstand**

Adductor related

Weerstand (R) Adductie

Pijn □ Ja □ Nee

Adductor Longus palp pijn



Pijn □ Ja □ Nee

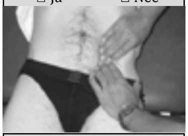
Iliopsoas related

Rek+R iliopsoas

P bij Rek □ Ja □ Nee
P bij R □ Ja □ Nee

Iliopsoas palp pijn

Pijn □ Ja □ Nee



Pijn □ Ja □ Nee

Inguinal related

Achterwand palp pijn

Pijn □ Ja □ Nee

Weerstand Buikspieren

Pijn □ Ja □ Nee

Valsalva
Pijn □ Ja □ Nee

Liesbreuk palpabel
□ Ja □ Nee

Pubic related

Symphyse palp pijn

Pijn □ Ja □ Nee

Hip Joint Related

Flexie/Add/Endo heup

Pijn* □ Ja □ Nee
*pijn anterieur=pos

Flexie/Abd/Exo heup

Pijn □ Ja □ Nee
Beperkt □ Ja □ Nee

(Medische) Diagnose en/of Opmerkingen

Onderzoeksformulier o.b.v. Consensus statement Groin Pain (Nog niet gepubliceerd)

Appendix 2. *Physical examination scoring sheet according to the DOHA agreement*

CHAPTER

9

Manual therapy and early return to sport in football players with adductor-related groin pain: A prospective case series

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ABSTRACT

Objectives: To study the clinical course including return to sport success rates of football players with adductor-related groin pain (ARGP) after manual therapy of the adductor muscles.

Design: Prospective case series.

Methods: Thirty-four football players with ARGP with median pre-injury Tegner scores of 9 (IQR 25-75: 9-9) were treated with manual therapy of the adductor muscles. Main outcome measures were numeric pain rating scale (NPRS), Hip And Groin Outcome Score (HAGOS) and global perceived effect (GPE) for treatment and patient satisfaction at 2, 6 and 12 weeks. Return to sport was documented.

Results: Pain during (NPRS 7; 6-8) and after (NPRS 8; 6-8) sports decreased to NPRS 1 (0.2-3) and 1 (0.8-3) respectively ($p<0.001$). Within 2 weeks 82% of the players returned to pre-injury playing levels with improved ($p<0.001$) HAGOS subscale scores. Eighty-five percent reported clinically relevant improvement, 82% reported to be satisfied. At 12 weeks 88% had returned to pre-injury playing levels. HAGOS showed that symptoms were still present.

Conclusion: Early return to sport seems possible and safe after manual therapy of the adductor muscles in football players with ARGP in the short term. While the majority of injured football players return to sport within two weeks, caution is advised regarding effectiveness as hip and groin symptoms were still present and no control groups were available.

Key words: Groin Pain, Football, Play, Manual Therapy

INTRODUCTION

Groin injury is common in football with prevalence rates reported up to 19%.[22,116] Groin injury incidence rates in football are 0.2-2.1 per 1000 playing hours for men.[22] Recovery from groin injury takes at least 1 week in 40% of cases, and 10% take more than a month.[10] When groin pain lasts for more than 2 months it is said to be long-standing.[10] Medical interventions and rehabilitation time affect both player and team performance.[28]

Adductor-related groin pain (ARGP) is the most common groin injury in football players.[10,81] The term ARGP and the clinical characteristics of pain on palpation and resistance testing have been described previously.[10,47] The recent Doha agreement confirmed ARGP to be the preferred term.[5] A recent systematic review on the treatment of groin pain in athletes found that there was moderate evidence that multimodal treatment including manual therapy may shorten the time to return to sport (RTS).[185] This finding was based upon a previous randomised study in which manual therapy, combined with a return to running program, was compared to the well established use of active exercises.[84] The manually applied stretch of the adductor muscles used in this randomised study was followed by two weeks of active stretching and a gradual return to running program. Manual therapy offered a significantly quicker recovery (12 weeks) compared to active exercises (18 weeks) with comparable but equally low success rates regarding RTS of 50% versus 55%.[84]

In our clinical practice we observed that players tend to return to their sport when their levels of symptoms allow them to. Unnecessary treatment delay may occur when stretching and return to running programs are applied for a pre-determined fixed period. The RTS decision then neglects the important early symptom alleviation. Additionally, previous studies found that many players tend to play with a degree of symptoms, even when they are not deemed injured[36,46]. This at least questions the need to strive to a symptom free situation before sport participation is commenced.

This study was conducted considering that (1) two weeks of stretching after manual therapy is often felt to be too long, and some players return to play earlier. (2) A manual muscle manipulation technique that is derived from one that was previously described[84,185] is in use by experienced clinicians in practice in combination with early to RTS.

The first aim of this study was to investigate time to RTS for football players with ARGP following manual therapy of the adductors without time contingent after care protocols. The second aim was to investigate pain intensity, function and symptom recurrence.

METHODS

Participants

This was a prospective case series of consecutive football players presenting with groin pain. From July 2013 to January 2014 players with groin pain were asked to participate in this study before their visit at 2 outpatient sports medicine /physiotherapy clinics where this treatment is commonly used. This study complied with the requirements of the declaration of Helsinki. As anonymized data from standard medical care was used and patient reported outcomes as routinely scored were used, the Dutch Central Committee on Research Involving Human Subjects (CCMO) confirmed no ethical approval was needed, as stated in the Dutch Medical Research Involving Human Subjects Act (WMO). Written informed consent was obtained from all participants for permission to use their anonymized data.

Patient enrolment

Patients were referred by (sports) physical therapists working in a primary health care setting, medical specialists from regional hospitals, or by self-referral. When making their first appointment at the clinic, all patients were asked what type of injury they had. In cases of groin pain, questionnaires asking for pain and symptoms experienced were electronically sent before the first visit. The inclusion and exclusion criteria are shown in **table 1**.

Table 1 *Inclusion and exclusion criteria.*

Inclusion	**Exclusion**
• Male football players aged 18-45 years • Groin pain during or after football • Groin pain for >8weeks • Not able to fully participate in football, due to groin pain • Pain at palpation of the origin of the adductors • Pain on resistance against adduction • Willing to undergo this treatment without any other during evaluation • Pain could be uni- or bilateral	Clinical suspicion of: • Prostatitis • Urinary infections • Malignancy • Spinal pathology • Hip joint osteoarthritis • Inguinal-related groin pain

In all cases where a patient attended with groin pain, their suitability for inclusion was checked at the first visit (by IT/RL). The first appointment was scheduled maximal 5 days after the initial telephone contact. All patients were informed a priori on the treatment according to Dutch health care regulations. When patients came for treatment but also wanted to continue their treatment elsewhere, they were excluded from this study. Use of any medication (also for pain reduction) was asked for during this clinical contact.

Patient characteristics

Baseline anthropometric data regarding height and weight were obtained. Additionally leg dominance, injury side, duration of complaints, time of absence from sports and previous interventions were noted. Pre-injury activity levels were assessed using Tegner scores.[191] A three-point scale was used to assess sports participation: ceased sports, decreased sports and unrestricted sports participation. As we have observed that football players with groin pain are often restricted when maximally kicking a ball, patients were asked whether they experienced any problems while kicking, even if the injured leg was not the kicking leg. Answer scores were dichotomous (yes/no).

Examination

Baseline anthropometric data regarding height and weight were obtained. Patients were assessed for inclusion according the criteria for ARGP thus a clinical diagnosis was made. This examination of the groin is reliable.[20,186] The presence of iliopsoas and pubic related groin pain was assessed but not systematically recorded. No imaging was performed due to the clinical setting in primary health care.

Questionnaires

Pain

Pain during and after sports participation was measured using an 11-item Numeric Pain Rating Scale (NPRS), ranging from 0-10.20 NPRS has excellent inter-rater reliability (100%), excellent internal consistency (Cronbach's alpha 0.84) and high sensitivity for changes of pain in control and effect studies.[187] Changes of ≥2 points are considered clinically relevant.[188,192]

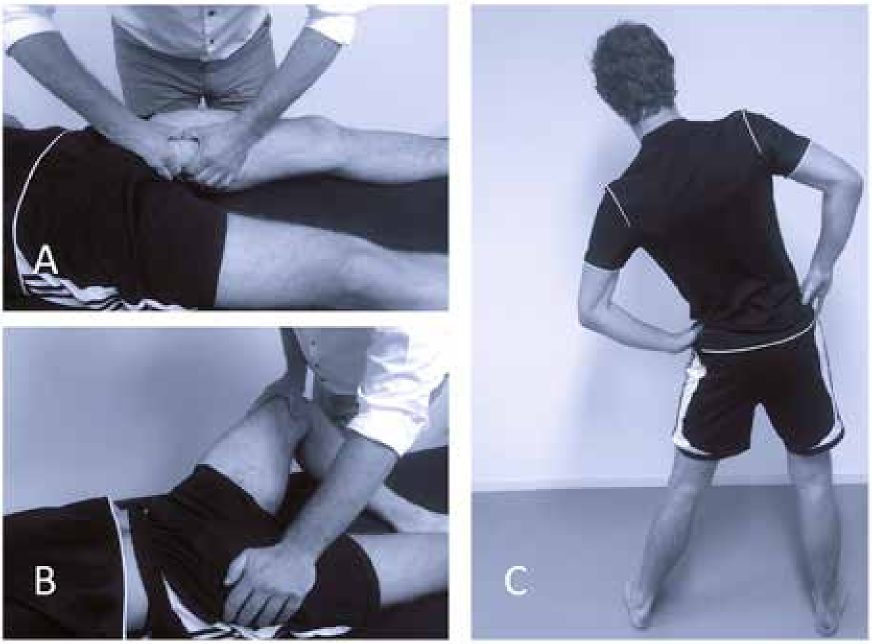
Patient reported outcome

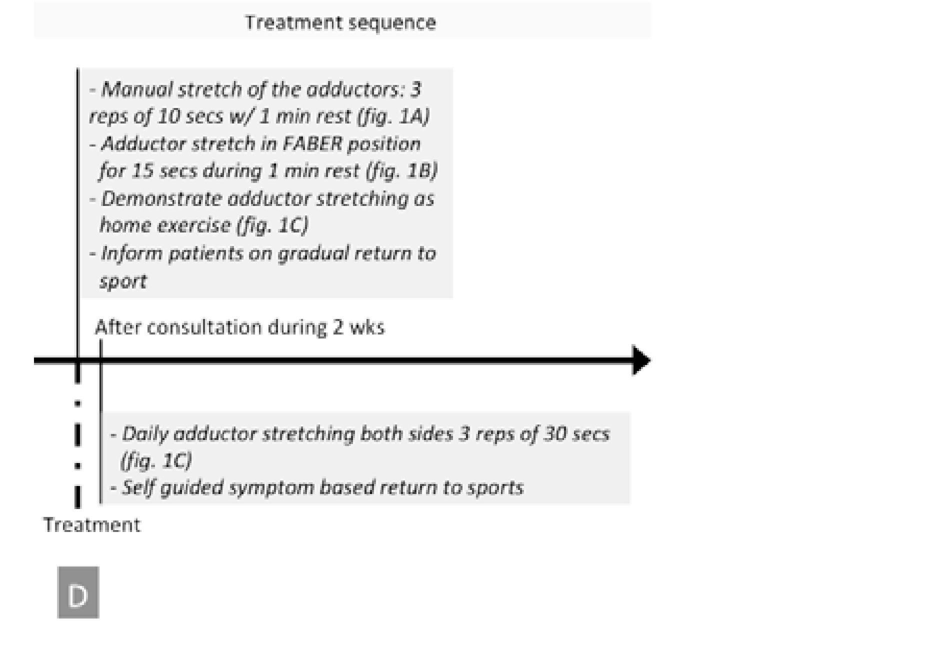
The Hip And Groin Outcome Score (HAGOS) was used to monitor hip and groin related pain and symptoms. The HAGOS is a 37-item questionnaire. It covers 6 subscales on pain, symptoms, physical activity, sports and recreational activity, physical activity and hip and groin related quality of life. Inter tester reliability for all domains is 0.8-1.0.[3] The smallest detectable change for group level is 2.7-5.2 and the minimal individual detectable change is 17.7-33.8 points for the individual subscales.[3] The HAGOS has been translated into Dutch language following international guidelines and approved by the originators.[37]

NPRS and HAGOS were recorded electronically. The system allowed submission of the patients' data only when all questions were answered thus no data were incomplete when submitted.

Intervention

All patients who were included gave their written informed consent before being treated once according to the treatment protocol. Two sports physiotherapists (15 and 30 years of experience) had one session together for standardization of treatment. They treated the patients' injured side and in those with bilateral symptoms, both sides were treated. Patients were positioned supine, with their hips in neutral position and the knees extended. While the ipsilateral hand of the therapist fixated the entire belly of the adductor muscles, the contralateral hand grasped the adductors proximally and stretched them within the surrounding tissues for ten seconds. Adductor stretch was performed in both transverse and proximal directions towards the pubic bone (See **figure 1A** and video). The manoeuvre was repeated three times with a 1-minute break in between. The rationale for the stretch direction was to elongate the adductors in a proximal direction to enable the pelvis to tilt posteriorly, which occurs during kicking and sprinting.[105,150] After this manually applied stretch and during the 1-minute break a gentle 15-seconds stretch in the FABER position was performed also aiming to stretch the adductors (See **figure 1B**).[190] Patients were advised to stretch the adductors once daily (standing position, hips and knees straightened, 3 series of 30 seconds stretching per side in the first two weeks following the intervention (See **figure 1C**).[191] All players were instructed to decide for themselves at what intensity to participate in sports (self management of loading). They were advised to commence with training at a level they felt they would be able to achieve. They were instructed to adapt the intensity and duration of the training depending on the symptoms they felt. They were allowed to participate fully and unrestrictedly in any load bearing condition including maximal sports. No other treatment was applied after treatment or during the period of evaluation.





Abbreviations; reps=repetitions; FABER=flexion/abduction/external rotation; secs=seconds; w=with; min=minute; wks=weeks

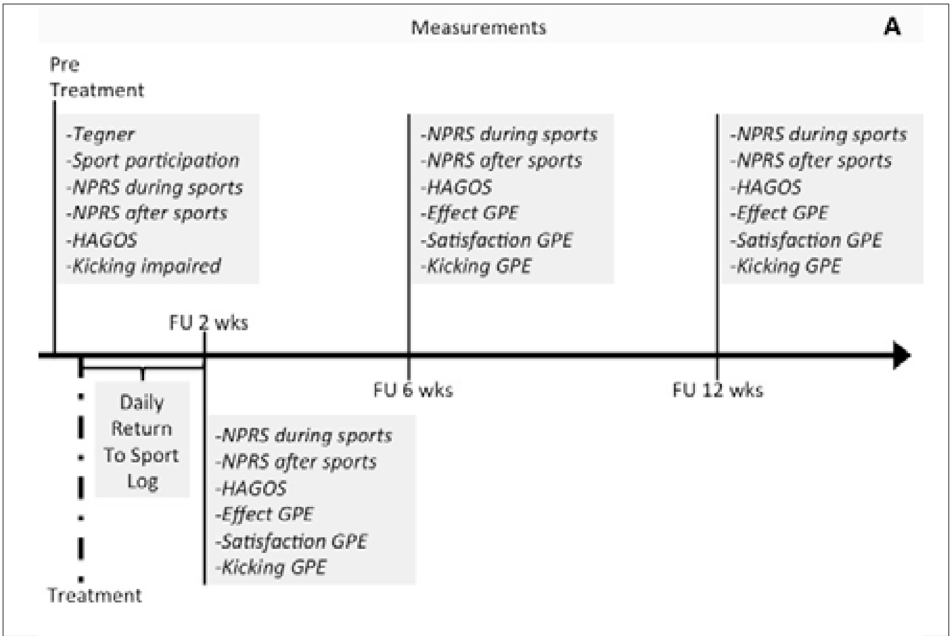
Figure 1A *Treatment with* ***A*** *manually applied stretch of the adductors,* ***B*** *stretching in FABER position and* ***C*** *home based stretching.* ***D*** *The treatment sequence*

Follow up

Return to sport in the first two 2 weeks after treatment was scored daily with a self-designed scale with scores "I did not participate in sports due to hip or groin pain", "I participated in sports, but at a lower level than I used to", "I participated in sports at my pre-injury level", "I did not participate in sports, this is usually not my day of sporting activity". The time to RTS was the number of days between the treatment and when the patient first reported "I participated in sports at my pre-injury level".

After the initial 2 week period of daily reporting digital questionnaires were used at 2, 6 and 12 weeks after treatment. No clinical visits were repeated. The questionnaires contained the following items: pain (NPRS), HAGOS, treatment effects (GPE), patient satisfaction (GPE) and effect on kicking capacity (GPE). The Global Perceived Effect (GPE) scores were on a 7-point Likert scale were; 1 reflects "worse than ever", 2 is "much worse", 3 is "a little worse", 4 is "no change", 5 is "a little better", 6 is "much better" and 7 scoring "fully recovered". The GPE was used because a translated and cross-culturally adapted Dutch version of HAGOS was available but not yet validated, thus clinimetric properties were not available for detailed interpretation of the values obtained.

The GPE has a high test-retest reliability (ICC 0.99 first week, 0.96 six weeks).[198] Changes in perceived health status are considered clinically relevant with scores 1 and 2 (worse) and 6,7 (better).[197,203] See **figure 2** for a comprehensive overview of all outcome measures used at each follow-up time point.



Abbreviations: NPRS=numeric pain rating scale; HAGOS=hip and groin outcome score; GPE=global perceived effect; FU=follow-up; wks=weeks

Figure 2 *Presentation of measures at baseline and follow up*

Analysis

Descriptive statistics were used for both demographic variables (patient characteristics) including the presentation of numbers and percentages and scores on the questionnaires. Demographic data were checked for normality of distribution by a Kolmogorov-Smirnov procedure. When normally distributed they were presented as mean (standard deviation). Otherwise they were displayed as median (inter quartile range 25%-inter quartile range 75%). Friedman tests were applied for repeated measures of the NPRS and HAGOS scores (all ordinal data). In cases of significant main effects a post hoc (Wilcoxon) test with Bonferroni correction was performed.

Treatment effects are then assumed to be significant when the p-value is <0.016 (0.05 divided by the total amount (3) of follow-up time points). This correction was applied to reduce the chances of obtaining false-positive results (type I errors) when multiple pair wise tests are performed on a single set of data.[200] A linear mixed model (LMM) was used to analyse the influence of pre-injury level of play (Tegner score) and duration of symptoms (in months) on individual outcomes (HAGOS subscales and NPRS scores). Data analyses were completed with the Statistical Package Social Sciences (SPSS, v. 20 IBM, Armonk, USA).

RESULTS

Eighty-nine football players presented to the clinics with groin pain and were considered for participation. Twenty refused; 8 because they did not want to fill out a questionnaire on several occasions, 3 did not want to participate in scientific research, 7 wanted to continue other treatment that was previously started with their own physiotherapist as well and 2 did not want to give a reason. Twenty were excluded because they had groin complaints existing less then two months. Nine were excluded after examination as they had inguinal-related groin pain. Forty male players finally could be included for treatment. None of them used pain medication.
See **figure 3** for a flow chart of patient participation.

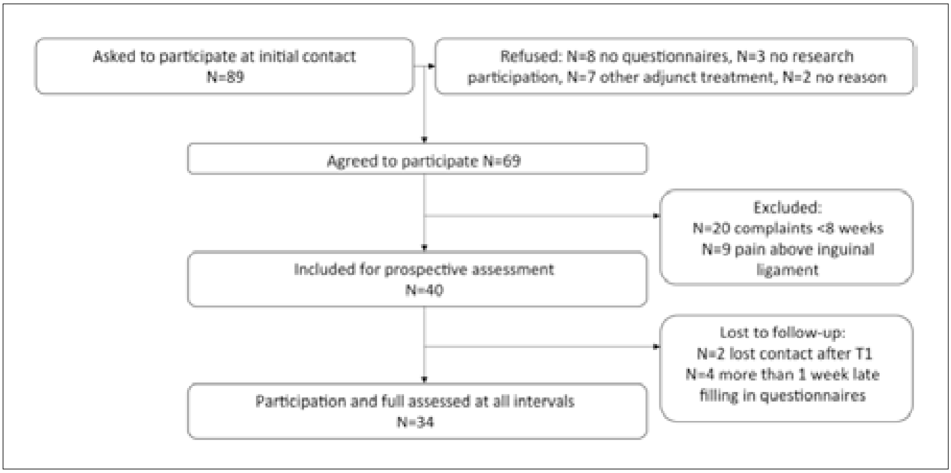


Figure 3 *Flow chart of patient participation*

The baseline characteristics of the patients of whom a full dataset was obtained is shown in **table 2**.

Table 2 *Characteristics of the football players (n=34) with groin injury. Values are mean (±standard deviation), median (IQR25-IQR75) or n (%)*

Age (years)	27.3 (5.6)
Height (m)	1.8 (0.07)
Weight (kg)	77.8 (7.5)
BMI (kg/m2)	23.5 (7.5)
Duration of complaints (months)	4 (3-7.8)
Time of absence original sport level (weeks)	8 (2-12)
Dominance (n,%)	
Right	30 (88)
Left	4 (12)
Injured side (n,%)	
Dominant	14 (41)
Non-dominant	18 (53)
Both	2 (3)
Kicking capacity affected per injured side (n,%)	
Dominant side	14 (100)
Non-dominant side	18 (100)
Both sides	2 (100)
Level of football activity (n,%)	
Elite (>5x/week)	5 (15)
Competitive (3-4x/week)	23 (68)
Recreational (1-2x/week)	6 (17)
Sports activity at baseline (n,%)	
Ceased	12 (35)
Reduced	22 (65)
Unchanged	0 (0)

Values are mean (± standard deviation), median (IQR25-IQR75). Abbreviations: y=years; m=meter; kg=kilogram; kg/m2=kilogram/square meter; n=number; %=percent

Follow up

Six players were lost to follow-up for the following reasons: two could not be reached after failing to fill in the questionnaires at two weeks. Four were more than one week late returning the questionnaires and were therefore excluded because of the short measurement intervals. These six did not differ from the rest of the group on any score at baseline (all $p>0.10$).

Outcomes

Return to sport (RTS)

At 2 weeks 28 (82%) patients reported playing football at their pre-injury level. Three patients (9%) were playing at a reduced level and three (9%) were unable to play due to their groin complaints. The average reported time for RTS was 5.3 (1-14) days. At 6 weeks 27 (79%) patients reported playing football at their pre-injury level. Four patients (12%) were playing at a reduced level and three (9%) were unable to play due to their groin complaints. At 12 weeks 30/34 (88%) resumed play at pre-injury level. Two played at a reduced level (6%) and 2 (6%) were unable to play.

Patient reported outcome (HAGOS)

A significant main effect over time was found for all HAGOS subscales (all p<0.05). Post hoc analyses showed improvements on all HAGOS subscales from baseline to T1 (p<0.016, see **table 3**). At T2 there was a trend, but no significant change, for decreasing symptoms (p=0.14). From T2 to T3 further improvement was noted on the subscales Pain (p=0.004), Symptoms (p=0.007), ADL (p=0.001), Sports and Recreation (p=0.001), Physical Activity (p=0.001), but not for Quality of Life (p=0.043), which was not significant after Bonferroni correction. LMM analyses showed no effects of pre-injury Tegner scores (p> 0.162) or duration of symptoms (p> 0.344) on improvements on individual HAGOS subscales over time.

Table 3 *HAGOS scores (presented as median and IQR 25-75) before (T0) and after treatment at 2 weeks (T1), 6 weeks (T2) and 12 weeks (T3).*

HAGOS subscales	T0	T1	T2	T3
Pain	74	81	91	94
	(59-85)	(73-95)*	(67-98)	(88-98)*^
Symptoms	64	73	82	86
	(54-72)	(60-84)*	(68-93)	(77-96)*^
ADL	70	90	90	100
	(58-85)	(80-100)*	(80-100)	(90-100)*^
SR	42	72	78	88
	(28-50)	(59-88)*	(49-94)	(75-100)*^
PA	25	63	75	100
	(0-50)	(38-88)*	(59-100)	(75-100)*^
QOL	50	65	78	84
	(35-60)	(54-85)*	(49-91)	(74-95)*^

Significant differences between HAGOS measurements (T1-T0 and T4-T3) are labelled * (p<0.016). Differences from T0-T3 are labelled ^ (p<0.05). Abbreviations: HAGOS=hip and groin outcome score; ADL=activity in daily life; PA=Participation in physical activity; SR=Physical function in sport and recreation; QOL=Hip and groin-related quality of life. SD=standard deviation; IQR=inter quartile range

NPRS

A significant main effect on NPRS scores during and after (both $p<0.05$) sports was found. Post hoc comparisons showed that at 2 weeks (T0-T1) the NPRS during and after sports decreased significantly. No significant improvement was found between 2 and 6 weeks and further improvements were observed between 6 and 12 weeks ($p<0.016$ see **table 4**). Twenty-nine/34 (85%) had experienced clinically relevant pain reduction (≥2 points) during and after sports at 12 weeks when compared to T0. One player showed a relevant increase of pain after sports. At 12 weeks this same player reached the pre-injury playing level with clinically relevant improvements when compared to T0. LMM analyses showed that improvements in individual NPRS scores during and after sports over time were not influenced by pre-injury Tegner scores ($p> 0.177$) or duration of symptoms ($p> 0.415$).

GPE

At 2 weeks 25/34 (74%) players reported a positive and clinically relevant (GPE score 6 or 7) improvement of which 7 (21%) reported full recovery (GPE 7) whereas 9/34 (26%) reported no difference or slight (but not a clinically relevant) change (GPE score 3, 4 and 5). The GPE scores can be found in **table 4**. GPE scores of 1 and 2 were not reported. AT 6 weeks 26/34 (76%) showed clinically relevant improvement when compared to T0. Eight/34 (24%) reported no difference or slight improvement. At 12 weeks 29/34 (85%) reported clinically relevant improvement and 10/34 (29%) were fully recovered (GPE 7). Twenty-eight/34 (82%) reported to be very satisfied (score 6 and 7) with the treatment and no dissatisfaction (GPE score 1 and 2) was reported.

Kicking capacity

Every footballer reported power of the kick to be affected by their groin pain before treatment, regardless whether the dominant or non-dominant side was affected. After treatment, at T3, GPE for kicking capacity was not changed (score 3,4 or 5) in 7/34 (21%), much improved (score 6) in 13/34 (38%) and totally recovered (score 7) in 14/34 (41%) players.

Table 4 *NPRS scores (presented as median and IQR 25-75) and GPE scores for recovery and satisfaction before (T0) and after treatment at T1 (2 weeks), T2 (6 weeks) and T3 (12 weeks)*

	T0	**T1**	**T2**	**T3**
NPRS during sports	7 (6-8)	3 (2-5)*	2 (1-6)	1 (0-2.3)*^
NPRS after sports	8 (6-8)	4 (2-7)*	3 (1-6)	1 (0.8-3)*^
GPE Recovery (score 6 and 7 in %)	-	74	77	85
GPE Satisfaction (score 6 and 7 in %)	-	65	75	83

Significant differences between NPRS scores are labelled * ($p <0.016$). Differences from T0-T3 (0-12 weeks) are labelled ^ ($p<0.05$). Abbreviations: NPRS=numeric pain rating scale; IQR=inter quartile range; GPE=global perceived effect

Complications

No complications or adverse effects in terms of clinical worsening after treatment were reported at follow-up by any of the patients. This result was supported by the absence of clinical relevant worsening of perceived health status as determined by GPE.

DISCUSSION

This prospective case series shows that adductor muscle manual manipulation and early RTS is promising in terms of participation in sports (83%), reduction of pain (85%) and clinical improvement (85%) in football players with long-standing adductor-related groin pain. The majority (82%) returned to football at pre-injury levels within two weeks but with symptoms present as could be identified by using the HAGOS scores. A further careful consideration of these data is thus warranted and will be discussed in detail.

Time to return to sport (RTS)

The time to RTS in this case series is quicker than previously reported. Shorter RTS times (12.8 weeks) were found in an RCT using manual muscle manipulation of the adductors with a return to running program, when compared to exercise therapy alone (17.3 weeks). A high quality RCT on exercise therapy also reported a time to RTS of 18.5 weeks.[83,194] It is important to note that the populations studied may differ in terms of severity and chronicity reflecting the setting of the studies. Our study was performed in a primary care setting. The players in our study had symptoms for 16 (IQR25-75: 12-31) weeks and altered their playing level for 8 weeks, with 1/3 having stopped play at the time of inclusion. In the studies of Weir et al. and Hölmich et al. this was 32/38 weeks of symptoms, 14/16 weeks altered playing and 62/71% stopped playing at inclusion respectively.[83,84] This probably represents the secondary/tertiary care settings of these two RCTs with patients experiencing pre-existent problems for a longer period with higher percentage of time-loss. In our current study all athletes played football whereas other sports made up 24-31% of the patients in the 2 RCT's.[83,198]

Additionally it should be acknowledged that most players still experienced a substantial level of hip and groin related problems even though they had returned to sports. This points out that the time to RTS as single factor is not a valid indicator of treatment success as recently acknowledged.[114]

Pain (NPRS)

Eighty five per cent of the players experience significant and clinically relevant (≥2 points) decrease of pain in sports and 30/34 (88%) after sports at 12 weeks, which is comparable with a previous case series of adductor manipulation.[110] This improvement is despite a quicker RTS being allowed. Previous studies, assessing the results of manual interventions, lack use of pain scores.[83,195] As almost half of all football players will encounter hip and groin pain at a given moment during the season3 but as many of them keep on playing, it adds value to report the levels of symptoms experienced.[202] Reporting pain levels seems important from a patient and clinician's perspective as its presence and aggravation is their reason to lower their sport participation levels. Lower pain is associated with improved sport participation.[196]

Global Perceived Effect (GPE)

We also used GPE as an outcome measure alongside NPRS as a significant decrease of pain does not always mean the patient considers this a worthwhile change. The patients with GPE scores 6 and 7 all exhibited an improvement on NPRS of >2 points. Patients with GPE 4 and 5 had unchanged NPRS scores. This fits the assumption that slight improvement on the GPE does not imply a clinically relevant improvement for pain, supporting the use of a 7-point Likert scale.

The level of improvement in the GPE was consistent with the percentage of participants that were able to RTS. Nineteen out of 29 players reported a GPE of 6, demonstrating that they clinically improved but were not fully recovered. These findings are in line with recent studies showing that football players with previous groin injury RTS while symptoms are still present.[36,46] This may yield an increased risk to sustain a new injury with time-loss.

Patient reported outcome (HAGOS)

Measuring pain and general treatment effects using GPE or reporting about RTS does not specifically address all problems encountered by patients with hip and groin pain. To measure these issues a patient reported outcome (PRO) is considered the gold standard.[90] The HAGOS is specifically designed to target this and it is advised to use it in clinical research on groin pain.[90] Use of this PRO was stressed in recent work that showed hip and groin related symptoms are prevalent in football players who are not considered to be injured using a time loss definition.[32] Our study shows that HAGOS is a useful outcome tool as it adds information on levels of problems experienced rather than on time loss alone. Although a quick RTS time is reported by our patients, the HAGOS data show that considerable hip and groin related problems are still experienced two weeks post treatment (P 81, S 73, ADL 90, SR 72, PA 63, QoL 62). These data are clearly lower for the Symptoms, Physical Activity and Sports and Recreation subscales when compared to available data from players who are playing at the season start but with previous hip and groin pain (different playing levels: P 95, S 82, ADL 100, SR 91, PA 100, QoL 90)[36] or hip and groin related time loss injury (elite: P 78, S 64, ADL 90, SR 69, PA 75, QoL 60).[46] At 12 weeks FU the HAGOS scores seem to be at least comparable or higher than these previously published values. Nevertheless a very recent study showed that a score of 87,5 on the SR subscale of HAGOS as unique factor results in an odds ratio of 8.94 for sustaining a groin injury.[46] This encourages future screening and assessment of treatment results with the HAGOS, avoiding over-estimation of positive results.[32] The HAGOS makes it clear that while the football players are back playing and report clinically relevant reductions in pain, the majority are not symptom free.

Satisfaction

Twenty-eight patients (82%) reported to be very satisfied with the treatment. These data are difficult to compare to other studies of Weir and Holmich as these applied a 5-point scale for GPE of their groin problems.[32] A 7-point scale has the advantage of distinguishing between apparent effect sizes of no and little change from relevant changes where the 5-point scale is less likely to as a result of interpolation.[205]

Mechanism

Increased tone and dysregulated muscle activity have been cited as a possible explanation of genesis of groin pain.[199] Manual therapy of the adductor muscles may help to normalize muscle tone by restoring Renshaw inhibition; the re-regulation of muscle activity by dampening anterior motor horn activity.[200] Clinical experience is that athletes feel a release of tension and improved range of motion in the groin region after treatment. Until valid measurement methods of adductor muscle tone are found, this explanation remains hypothetical.

Recent studies seem to support the rationale for this treatment. Hyperalgesia was recently observed at the adductor longus tendon site in athletes with current groin pain, which is considered a marker of central sensitization.[115] The manual manipulation studied in this cohort is a painful manoeuvre, likely inducing a noxious inhibitory control (DNIC) response thereby improving pressure pain thresholds through the facilitation of the descending inhibitory pathway. In terms of central sensitization the reassuring effect of early RTS allowance should not be underestimated as an adjunct working mechanism.[200]

It has been suggested that active treatment approaches, when combined with adjunct manual therapy, could speed up the recovery process.[202] The advice regarding return to play in our study follows the principle of adaptation of load based upon symptom response. The previously published RCTs both used a time contingent approach where patients performed exercises or stretches for a pre determined duration independent of symptoms. We pose that this approach may lead to unnecessary delay in some cases. Future studies could examine combination of therapies and a symptom contingent approach.

Limitations

Despite the promising results we are aware of shortcomings due to the study design. As there is no control group, a comparison with any other treatment is impossible so any definite advice towards practitioners to use this treatment cannot be given. This therapy could be adjuvant on the current and proven concept of exercise therapy but this could not be tested with this design. Furthermore this treatment is clearly not a solution for every footballer with adductor related groin pain. Whether or not athletes participating in other sports may benefit from positive results of this treatment is unknown. No patients with groin pain less than 8 weeks were treated so our results should not be extrapolated to this group. Not all players improved but we are unaware of clear identifiers that were related to this inferior outcome. It is important to emphasize that no additional diagnostics were performed. Imaging could have shown underlying pathology of the hip, like hip labral or chondral damage, as its presence may be related to higher levels of complaints.[201,203] The follow-up period is short and relapses and deterioration of the treatment effects is not assessed on the longer term. To compare better with other studies this should have been longer allowing insight in relapse rates. Although the use of pain medication was asked at initial contact (none of the patients reported to use this) it was not controlled at the follow-up time points whether they had used any over that previous period. It should be acknowledged that selection bias might exist as injured players can have applied for this treatment because they knew this was offered in these clinics. Randomisation of treatment allocation is therefor needed in future studies on this type of treatment. Therefore short and long term follow up is preferably performed using outcome measures like repeated physical assessment that have been used in other studies to enhance comparing results.

CONCLUSION

Manual adductor muscle manipulation and early return to play seems to have promise in the treatment of football players with long-standing adductor-related groin pain. In this prospective case series we found a quick RTS in the majority, who can play with co-existing symptoms, which further decrease over time. High quality comparative studies with both short term and longer follow-up times and interactions with other interventions like exercise therapy are needed.

CHAPTER

10

General discussion

Groin injury is a serious problem for football players. Those who get injured sustain problems with football performance that may result in chronicity or time-loss. Sometimes it's the end of an athlete's carrier. These individual problems also affect the performance level of the whole team.[4] In this thesis, we studied the groin injury burden in Dutch female and male football players and assessed risk factors for groin injury. For a better understanding of the groin injury mechanism, we studied the kinematic characteristics of the football kick. As classic hip assessment tests showed low validity[17-19], we developed a sport specific assessment test containing relevant parameters derived from the analysis of the football kick. Due to the anatomical relation between the adductor muscles, the femur and the pelvis, we analysed pelvic motion in athletes with groin injury. Manual therapy of the adductors when combined with exercise therapy seems to speed up return to sport in athletes with groin injury when compared with exercise therapy alone. The clinical of course of these athletes after manual therapy of the adductors alone is unknown and was studied as well.

THE GROIN INJURY BURDEN

The four-step process of the injury prevention model of Van Mechelen starts with establishing the prevalence, incidence and severity of an injury.[8] Only few injury studies were performed in female professional football players reporting prevalence rates of groin injury ranging between 2 and 9%.[85-87,89] No studies were performed in female players from lower (amateur) playing levels. Injury studies traditionally focus on time-loss while many players who continue to play experience groin related problems to some degree.[99,204] In **chapter 2 and 3** we examined the groin injury burden in a large cohort of female amateur football players in The Netherlands using both the time-loss and non-time-loss injury definition. Injury duration was categorized into minor (1-7 days), moderate (8-28 days) and severe (>28 days).[36,46] Levels of groin-related problems (or 'hip and groin-related problems')[21] were scored with the Hip And Groin Outcome Score (HAGOS). In **chapter 2** we found that groin injury in female amateur players was the most frequent non-time-loss injury with a within season prevalence of 36% and 11% for time-loss. The preseason prevalence was 25% for non-time-loss and 5% for time-loss groin injury. These prevalence rates were comparable with those found in Norwegian female professionals.[5,93] Players with longlasting groin injury of more than 28 days in the previous season sustained more severe groin-related problems in the next preseason than those with shorter duration or without injury (**figure 1**).

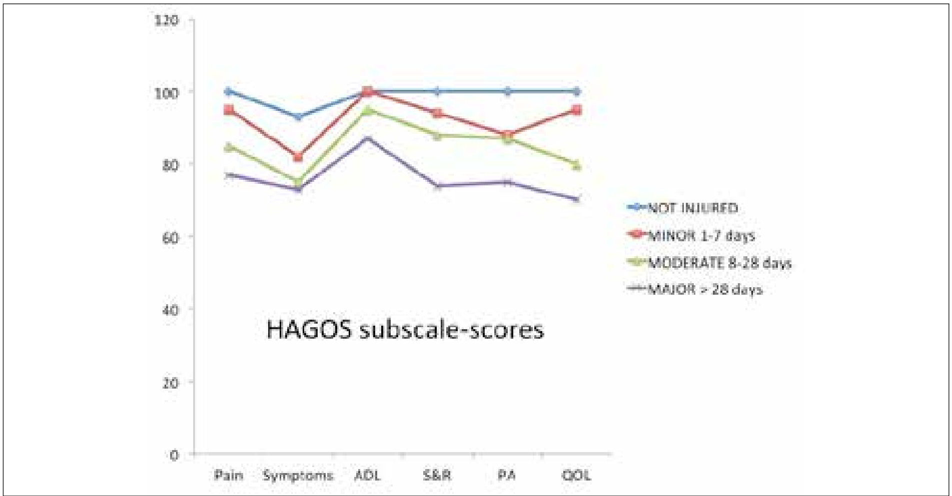


Figure 1. *The relation between duration of groin injury in the previous season and the levels of groin-related problems in the next preseason. Abbreviations: HAGOS=hip and groin outcome score; ADL=function in daily living; S&R=function in sport and recreational activities; PA=participation in physical activity; QOL= hip and groin-related quality of life*

From all female amateur players with groin injury in the previous season, 52% showed recurrence or chronicity of groin injury in the next preseason. The longer the duration of groin injury in the previous season, the higher were the recurrence and chronicity rates in the preseason.

In **chapter 3** we examined in the same female amateur population the preseason levels of groin-related problems. Those being recovered from groin injury in the previous season sustained more groin problems in the following preseason than those without any previous and current groin injury. Players with groin injury in the previous and preseason experienced higher levels of groin-related problems compared to those with a new groin injury in the preseason. Players with time-loss groin injury in the preseason reported the most severe groin-related problems. They had substantial problems with football performance (low subscales scores sport and recreation, participation in physical activities, quality of life). This is in line with previous suggestions that groin injury presents as a spectrum rather than a clinical state that is only dichotomously scored (**figure 2**).[23]

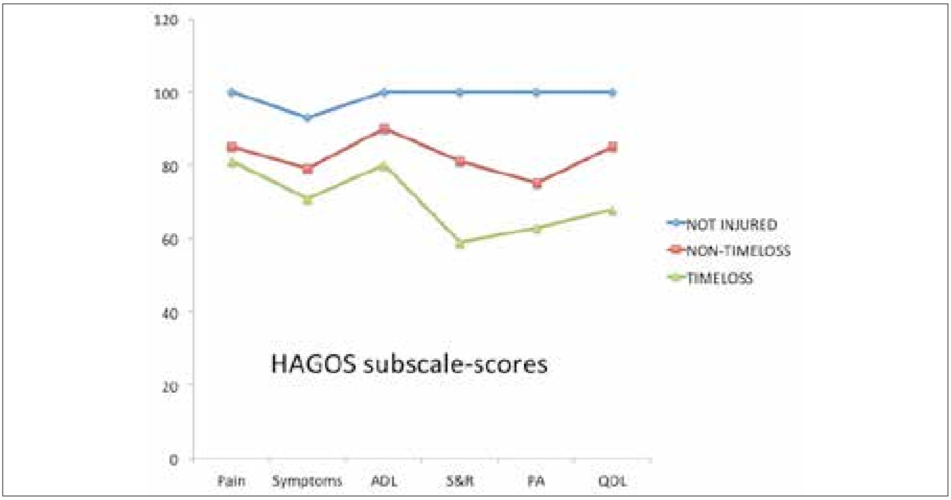


Figure 2. *Players with time-loss groin injury in both seasons have the most severe groin-related problems compared to those with non-time-loss or no groin injury. Abbreviations: HAGOS=hip and groin outcome score; ADL= Abbreviations: ADL=function in daily living; S&R=function in sport and recreational activities; PA=participation in physical activity; QOL= hip and groin-related quality of life*

A possible explanation for the high groin injury burden in Dutch female players may be the rapid growth of this population over the past years. These 'new' players may not be trained well enough and therefore be more vulnerable to injury.[46]

For male football players, prevalence rates of groin injury were studied mainly in professional football teams from North European and Arabic countries and ranged between 4-19%.[40] Considering this, it was suggested that more injury studies are warranted, especially in countries other than Scandinavia and Germany.[23] Additionally, it was suggested that studies should investigate levels of groin pain and symptoms, besides groin injury according to the time-loss definition.[22,29] In **chapter 4** we prospectively studied the prevalence and incidence of groin injury in male professional football players in the Netherlands. In a population of 190 players, we found a within-season prevalence of time-loss groin injury of 11% and total/training/match groin injury incidence was 0.5/0.2/2.6 injuries/1000 playing hours. The preseason prevalence of groin-related problems was 24%, which was lower compared to Danish high-level male players (36%).[5,22,24] Time-loss prevalence of 11% was lower than that in Swedish male professionals, which also accounts for groin injury incidence rates (total/training/match 1.3/1.0/3.7 in the Swedish cohort).[3] The differences in incidence and prevalence rates can be explained by differences in exposure time, (21/176 match-training player-hours in our study versus 53/340 in the Swedish cohort). We conclude that a higher groin injury frequency is not only related to higher exposure numbers but also factors like regional differences, playing style, type of training (intensity) and climate conditions.[35]

An average female Dutch amateur squad of 15 players may experience 5 non-time-loss groin injuries and 2 time-loss groin injuries per season resulting in 53 days of on-going groin-related problems and 21 days lost to play. An average professional male squad of 21 players can expect 3 time-loss groin injuries per season and 35 days lost to play.
The prevalence in The Netherlands is substantial with a quarter of all players sustaining groin-related problems in the preseason period. Once injured, half of them get re-injured, chronic or out of play. Once recovered, players continue sustaining groin problems (HAGOS).
We conclude that groin injuries play a more important role in female football than previously thought. The few studies available in this fast growing population warrant more studies on the frequency, characteristics and risk factors of groin injury. Female and male players with a previous groin injury have high risk on a subsequent groin injury (50%). Clinicians working with football players should be aware of this in their screening, providing the most effective treatment in case of current groin injury and consider a careful work-up towards return to sports. Many groin injuries occur in the preseason. Training load should be fine-tuned in the beginning of the new season and treatment and prevention measures should be considered during the off-season. This in line with a previous study that demonstrated that ice hockey players with lower levels of sport specific training during the off-season had significantly higher risk of groin injury the next season.[99]

RISK FACTORS

Previous studies consistently found previous groin injury and weakness of the adductors to increase the risk for time-loss groin injury.[205] However, these findings have not resulted in effective preventive measures that reduce the burden of groin injuries in professional football players.[4] Besides previous groin injury, previous injury to locations other than the groin should be considered as risk factors for subsequent groin injury.[81] In **chapter 3** we retrospectively assessed the relationship between time-loss and non-time-loss groin injuries in the preseason and general injury in the previous season in female amateur football players. We found that time-loss groin injury in the preseason was associated with non-time-loss ankle injury (Odds Ratio (OR) 4.6; 95%CI 1.0-20.7) and time-loss groin injury (OR 12.1; 95%CI 5.0-30.0) in the previous season. Non-time-loss groin injury in the preseason was associated with time-loss knee injury (OR 2.1; 95%CI 1.1-4.2), non-time-loss groin injury (OR 5.0; 95%CI 3.1-8.2) and time-loss groin injury (OR 2.4; 95%CI 1.2-4.5) in the previous season.
In **chapter 4** we prospectively studied the association between previous injury to locations different than the groin and subsequent time-loss groin injury in male professional football players. We found that previous ankle, knee, thigh and shoulder injury with (median) 9 weeks of time-loss were risk factors for subsequent time-loss groin injury (hazard ratio 5.1; 95%CI 1.8-14.6).
In this population we retrospectively assessed the relationship of groin-related problems in the preseason with groin injury in the previous season and hip ROM at baseline. Groin-related

problems were associated with a history of more than 1 time-loss groin injury (OR 3.0; 95CI 1.0-8.3) indicating that more than one-third (39%) of the players with previous time-loss groin injury had a recurrence or chronicity in the next preseason period. Groin-related problems were also associated with difference in ROM adduction between hips (OR 1.2; 95CI 1.0-1.3). The observed difference was small (4 degrees) and we deemed it clinically non-relevant as it did not exceed the standard error of measurement thus not the minimal detectable change. All other ROM parameters and combinations were not found to be associated.

Due to these findings we recommend clinicians in managing actual groin injury to screen for severe time-loss injury in the previous season on different locations than the groin. The other way around, general longstanding injury should be regarded as a potential risk factor for groin injury and carefully managed. Preseason hip ROM is not a useful screening tool to identify the individual athlete at risk for groin injury, which is in line with a recent review.[42,102]

In both female and male football populations (**chapter 3 and 4**) the observed relationship between previous knee and ankle injury and subsequent groin injury is interesting from a clinical point of view. The remaining deficits from previous injury may affect biomechanics during kicking or sprinting, resulting in compensatory behaviour of the groin muscles.[24,212] Biomechanical studies on kicking may reveal the sport specific function of important regions (**chapter 5 and 6**).

Chapter 4 on risk factors complied with the "minimum reporting standards for clinical research on groin pain in athletes on study methodology, participants, injury history and clinical assessment and examination".[35] Our statistics controlled for the confounding influence of potential risk factors and for the cause of abbreviated exposure time such as time-loss groin injury, other injury or other reasons.[32] As female players were retrospectively assessed by survey, bias may exist to some extent and the injury associations found did not prove causality. As we prospectively studied male players, causal relationships could be identified.

Although previous groin injury is considered a strong predictor for recurrence we did not found this relationship in our prospective study (**chapter 4**).[4] This may be due to the low power. A minimum of 20 cases is considered appropriate to find moderate associations.[4,34] As we had 18 cases in our dataset, power was on the low side to detect an association.

INJURY MECHANISM: THE FOOTBALL KICK

Besides epidemiological factors, the injury mechanism for groin injury should be understood to design effective prevention programs.[98] The football kick was the most frequent reported injury mechanism for groin injury, mostly affecting the adductors (66%) of the kicking leg (81%).[9] This is in line with the findings in **chapter 2** that showed kicking and sprinting to be the most frequent reported inciting events causing groin injury and provoking groin pain in the female population (24% and 21%, respectively). Disturbed biomechanics negatively affect load tolerance during sports actions like kicking, likely resulting in groin injury.[47,48,212] Deterioration of sport specific technique (coordination and joint ROM) were considered internal risk factors for sports injuries in general (**figure 8** on page 10).[9,41] In order to understand the injury mechanism, a biomechanical blue print of coordination and ROM parameters of the kick in non-injured football players is needed.

Summation of segmental velocity determines ball speed.[9,39] Segmental velocity originates from muscle contractions and from velocity-exchange of the adjacent segment referred to as energy transfer.[61,97,206] Kicking with optimal energy transfer goes along with the least required (economic) muscle contractions.[60,132] Conversely, non-optimal energy flow induces compensating kicking strategies with concomitant increased muscle work.[64,65,68] Especially groin muscles may compensate as hip flexion strongly associates with ball speed.[60,75]

Optimal energy transfer between segments occurs when maximal segmental velocity and acceleration times at square (90° flexion) and collinear segment (neutral and end) positions, respectively.[42,132,207] Therefore in **chapter 5** we quantified the coordination of the maximal instep kick for the timing of maximal velocity of body segments and the configuration of the kicking leg.[60,63] We found that 11 segmental velocity parameters (peak angular velocity, acceleration and deceleration) coincided with 4 keypoints, each characterized by neutral, square or end positions of the kicking hip and knee. The similar timing of maximal non-kickside shoulder and kickside hip extension (keypoint 1) resulted in a full body tension arc stretching the anterior myofascial lines.[71] This stretch is reinforced by timing of pelvis anterior rotation being the start of the kinematic sequence. Maximal acceleration of spine flexion and pelvic posterior tilt (lumbopelvic flexion) timed at maximal ROM knee flexion (keypoint 2) and maximal lumbopelvic and non-kickside shoulder velocity timed at square knee angle (keypoint 3). Maximal hip deceleration also timed at square knee angle, transferring energy to the lower kicking leg.[71] Zero angular velocity of the hip, spine and pelvis timed at ball impact (keypoint 4) indicated that central body segments then come to a halt providing a stable platform to kick the ball.

Next to coordination, joint ROM increases the risk of injury during sport actions in general (**figure 8** page 10).[206] The maximal kick is the most consistently reported groin injury mechanism. Football players with groin injury tend to switch to submaximal kicking performance. We therefore analysed differences in ROM of body segments between the maximal and submaximal kick (**chapter 6**). Increased ROM of the tension arc and increased motion trajectories of the lumbar spine, pelvis and knee joint were found for maximal kicking. Despite the increased ROM, the duration of the maximal kick (mean 0.256 sec) was shorter than for the submaximal kick (mean 0.268 sec) indicating increased segmental velocity and tissue loading. The greatest relative increase of ROM occurred in the central body segments with effect sizes of 3.2 for spine flexion, 2.2 for pelvic posterior tilt, 1.8 for knee extension and 1.1 for the tension arc. During the maximal kick the hip reversed its movement from flexion to extension prior to ball impact. This phenomenon did not occur during the submaximal kick.

We conclude that precise timing (**chapter 5**) and flexibility (**chapter 6**) of the kinematic chain of upper body and kicking leg are required to generate maximal ball velocity.

The increase of ROM tension arc enlarges the prestretch trajectory of the adductors during the backswing. This assists in increasing muscle contraction levels and helps energy transfer.[9,39] The increased ROM of pelvic posterior tilt elongates the adductors during the acceleration phase (prior to ball impact), which may serve as a safety mechanism; once lengthening, the adductors can't assist in kicking the ball by concentric contraction thereby avoiding extreme muscle work at ball impact. This is in line with a previous study demonstrating a safety mechanism for the knee extensor muscles during kicking.[72,73] Another effect of the enlarged ROM of pelvic posterior tilt is hip reversal. Both these phenomena exclusively occur during maximal kicking at square knee angle. Thus, the enlargement of pelvis ROM not only ensures safe kicking yet also attributes to energy transfer as a kicking strategy (**figure 3**).

Conversely, ROM deficits of the tension arc and the pelvis may reduce load tolerance of the groin region during kicking.[132] The backswing was proposed as the injury mechanism due to the highest rate of adductor elongation and maximal contraction force.[9] We propose that reduced ROM of the tension arc affects prestretch and thus hip speed and energy transfer. Impaired pelvic posterior tilt may pervert the adductor safety mechanism: the adductors yet dispose of a stable pubic insertion and may contract forcefully to develop hip speed thereby exerting high load on the groin during ball impact. These biomechanical disorders suggest the backswing and the acceleration phases as the groin injury mechanisms during maximal kicking.

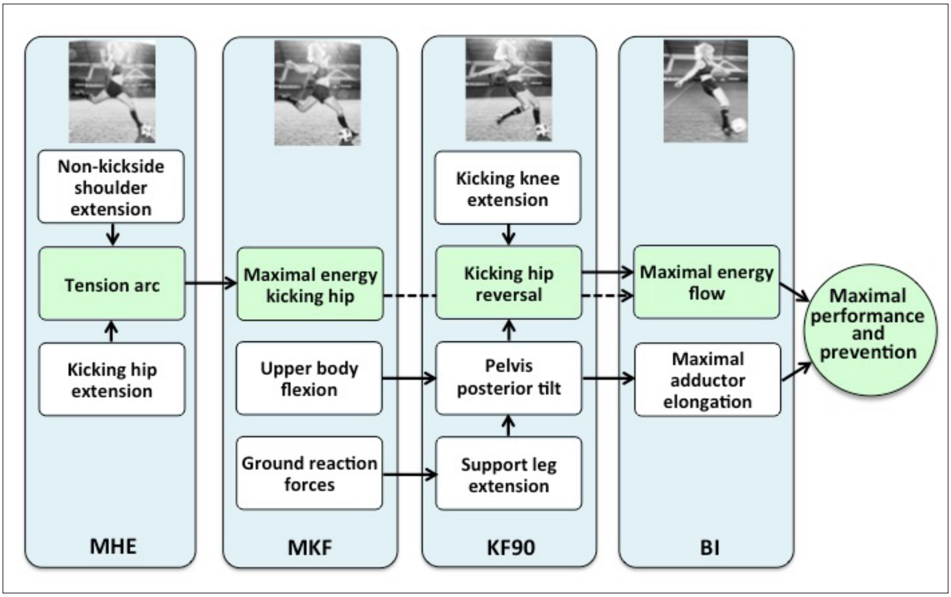


Figure 3 *The kinematic sequence, timing, ROM and interdependency of body segment actions during the maximal football kick. The green boxes represent main body segment actions for optimal energy transfer. The coordination of the kick is depicted by four keypoint: MHE = maximal hip extension; MKF = maximal knee flexion; KF90 = knee flexion 90 degrees; BI = ball impact*

EXAMINATION AND TREATMENT

Athletes with groin injury visiting sports physicians and physiotherapists expect to get a diagnosis on structural and functional levels that explain their impairments in sports activities and participation (ICD[6] and ICF[7]). However, true tissue damage is often not present nor do eventual structural changes explain longstanding time-loss or severe groin-related problems.[7] Biomechanical analysis of the football kick showed increased ROM of the tension arc for maximal kicking performance. In **chapter 5 and 6** we hypothesized that reduced ROM of the tension arc and the pelvis are part of the groin injury mechanism. Therefore we introduced two sport specific assessment tests and one specific treatment technique; in **chapter 7** we developed a passive sport specific hip ROM test mimicking the tension arc and studied its clinimetric properties. In **chapter 8** we examined pelvic motion in athletes with and without groin injury and in **chapter 9** we evaluated the clinical course of athletes with groin injury treated with manual therapy of the adductors.

Examination

In **chapter 7** we hypothesized that the tension arc was decreased in players with adductor-related groin injury compared to those without. This agrees with a previous study suggesting a relation between ROM tension arc and adductor injury.[5,73] The rationale for this hypothesis was that decreased ROM of the tension arc would result in lower hip velocity disturbing energy transfer between segments, causing compensating groin muscle force. We developed a passive test with the player in a tension arc position. Sport specific hip ROM was tested towards extension, adduction, abduction, internal and external rotation. This could be measured with a clinically acceptable reliability. Then, we acquired reference values from both non-injured male amateur and professional football players. The dominant and non-dominant leg in non-injured players had a mean symmetrical sport specific hip ROM of 188 (25)°. Those with adductor-related groin injury showed a mean sport specific hip ROM of 187 (31)° on the non-injured side and 136 (29)° on the injured side (28% deficit). This difference exceeded the minimal detectable change (MDC) of 25° so the mean difference of 52° was considered substantial and clinically relevant. This sport specific restriction is a result from groin pain rather than a precursor.[73] Our results from the prospectively designed Groin Injury Prevention (GRIP) study (**chapter 4**) are in line with this assumption.

We conclude that sports physiotherapists should assess football players with groin injury for sport specific hip ROM. Medical staff should address this ROM deficit before return to sports being aware for recurrent groin injury. Criteria should be to strive to symmetrical sport specific ROM between left and right tension arc.

Chapter 8 studied the active ROM of pelvic tilt in field-based athletes with and without groin injury. We hypothesized that active pelvic tilt would be reduced in players with groin injury compared to those without hindering efficient energy transfer. In order to examine pelvic movement, we developed a test to measure the active ROM of anterior, posterior and total pelvic tilt for both legs. Inter- and intratester reliability were moderate to excellent. ROM of total tilt was significantly reduced for the injured sides (21±7)° compared to the non-injured sides (27±8)° with a strong effect size (Cohen's d=0.80). Pelvic anterior tilt was also significantly reduced (10±6 vs. 14±5)° with d=0.65 and there was a trend for reduced pelvic posterior tilt (11±4 vs. 13±5)° with P=.06. The mean difference of total pelvic tilt (6°) exceeded the SEM (1°) and MDC (4°) indicating that the testing protocol was useful for detecting differences in ROM of total pelvic tilt between injured and non-injured sides. These results are in line with the findings on pelvic kinematics during a maximal kicking task in football players with and without a history of groin injury. Players with previous groin injury showed lower ROM of total pelvic tilt.[124] We conclude that football players with adductor-related groin injury should be assessed for active pelvic ROM. The club's medical staff should be aware of this for the risk of recurrent groin injury. Pelvic ROM should be restored before return to sports.

Treatment

Adding manual therapy of the adductor muscles can speed up the recovery process when compared to exercise therapy alone.[119] In **chapter 9** we studied the clinical course of football players with adductor-related groin injury after manual therapy when combined with a self-guided return to sports program. Manual therapy consisted of a manual stretching technique of the adductors in proximal direction towards to pubic bone, in line with pelvic kicking biomechanics (**figure 4**). Return to sport was self-guided based on symptoms experienced. We found that 82% of these football players had returned to sport within 2 weeks and 88% at 12 weeks. Most players (79%) reported much to complete recovery of the kicking capacity. HAGOS subscale scores improved during follow-up, however most players still experienced substantial levels of groin problems despite returning to sport. This is in line with previous reporting in this thesis (**chapter 2 and 4**). None of the players reported side effects after treatment at follow-up. There are several possible explanations for the main finding of this study. A biomechanical explanation compromises the recovery of the original adductor lengthening. This fits in with previous findings on reduced ROM of the tension arc and pelvis posterior tilt.[211] Secondly, the manual therapy studied is an intense and painful treatment. This may induce a noxious inhibitory control response that improves pressure pain thresholds through the facilitation of the descending inhibitory pathway.[83,84] The reassuring effect of early return to sports allowance should not be underestimated as an adjunct working mechanism.[202] It may be worthwhile to involve players in the decision making process on return to play for studying outcomes of time contingent treatment procedures.[202]

Figure 4. *Manually applied stretch of the adductor muscles towards the pubic bone (arrow)*

SYNTHESIS

Groin injury mechanism

It was suggested that remaining deficits from previous injury induce compensation of the hipflexor muscles during kicking and sprinting.[110,208] This makes sense as hip flexion speed is highly related to speed of the lower leg and ball.[75] The finding from **chapter 4** that previous shoulder injury is a risk factor of groin injury fits well in the findings of **chapter 7**. As remaining deficits of previous injury of the non-kickside shoulder may affect precise timing or maximal ROM shoulder extension, this can affect the ROM of the tension arc. The findings from **chapter 4** that previous ankle, knee and thigh injury are risk factors of groin injury fit well in the findings of **chapter 8**. It was recently demonstrated that the extension velocity of the support leg generates pelvic posterior tilt stimulating the kinematic sequence of the kicking leg and increasing the forward swing of the kicking lower leg through intersegmental dynamics.[35,42] Remaining deficits from previous injury of the support leg that reduce velocity of support leg extension will consequently affect pelvis motion/timing. This will affect energy transfer and the safety mechanism and facilitate compensation adductor contraction force at ball impact (**figure 4**).[174]

Groin re-injury mechanism

Chapter 3 demonstrated that a previous groin injury was related to a subsequent groin injury in female players, which agrees with a previous study.[9] This was also demonstrated in male players.[4] Remaining deficits like groin pain and weakness from a previous groin injury increase the risk of recurrence.[4] Noxious stimuli or groin pain interferes with muscle synergies and alters motor control strategies.[35] Groin pain hinders adductor mechanics showing increased resistance against elongation, causing reduced tension arc and pelvis posterior tilt.[69] This agrees with our findings in **chapter 7 and 8** disturbing biomechanics turning the kick into a (re-) injury mechanism.

Pain also changes the coordination of 'distant' muscles in the kinematic chain.[68] A lower resting thickness and delayed onset of the transversus abdominis muscle was found in football players with longstanding adductor-related groin injury compared to non-injured players.[191,208] This may also be true for the pyramidalis muscle, being a functional extension of the adductor longus, however not studied yet.

Advice for clinical practice

We recommend physiotherapists and (sport) physicians to diagnose athletes with groin injury according to the clinical entity approach as management and prognosis vary per entity.[5] To estimate the risk for recurrence and groin-related problems (HAGOS), previous groin injury should be inventoried for frequency, duration and timeloss. Inventory of previous groin injury and previous injury to locations other than the groin should be followed by physical examination on remaining deficits. Assessment of ROM tension arc and pelvis tilt determines the kick being an injury mechanism or not. Players recovered from long lasting injury and those not well-trained, especially Dutch female amateur players, should be assessed for their physical fitness. Training load should be fine-tuned and targeting local and sport specific deficits should be considered for treatment and prevention.

In case of current long lasting timeloss injury to other locations than the groin, physiotherapists and (sport) physicians should be aware for the risk of subsequent groin injury. As hip ROM does not identify players at risk for groin injury, preseason screening may be abandoned.

CONCLUSIONS

Groin injury burden

- Groin injury is more frequent in Dutch female football players than previously expected
- Half of all female and male Dutch football players with previous groin injury sustain recurrence or chronicity
- Players with longstanding, frequent and/or timeloss previous groin injury have the highest risk for recurrence, chronicity and groin-related symptoms and problems
- In the preseason a quarter of all female and male players experience groin-related symptoms and problems

Risk factors and injury mechanism

- Longstanding ankle, knee, thigh and shoulder injury is a strong risk factor for subsequent groin injury
- Normal kicking biomechanics comprise precise timing of body segment actions and flexibility of ROM tension arc and pelvic motion, reflecting energy transfer as a kicking strategy
- Kicking is the groin injury mechanism in case of reduced ROM of the tension arc and pelvis tilt, which can be assessed by two new reliable sport specific assessment tests

Return to sport

- Players with adductor-related groin injury benefit from manual therapy of the adductor muscles by early return to sport and improved kicking capacity

FUTURE PERSPECTIVES

Based on the outcomes of this thesis, we have some recommendations for future research.

1. Groin injury studies should report on non-time-loss and time-loss groin injury to more appropriately represent the true groin injury burden. Duration and severity of groin-related problems are preferably measured with the Hip and Groin Outcome Score (HAGOS). Exposure time of the athletes should be taken into account and corrected for to precise risk estimates. Injury scoring should follow generally accepted homonymous taxonomy allowing comparison between topographic regions, gender and different playing levels.
2. The interrelationship between previous injury to different body locations than the groin and subsequent groin injury is a matter of interest and requires attention.
3. Biomechanical studies in healthy and injured athletes should focus on the contribution of body segment actions and distal end speed as main outcome measure of sport specific actions. Intersegmental dynamics from all segments involved may deliver new information on the injury mechanism.
4. Reference values should be developed for sport specific hip ROM and active ROM of pelvis posterior tilt in football players with psoas-, pubic-, inguinal- and hip-related groin injury for different gender, age and sports level.
5. The effect of manual therapy in football players with adductor-related groin injury should preferably be studied in a randomized clinical trial.

CHAPTER 11

Summary

Summary in English

THE COMPLEXITY OF GROIN INJURY
In search of the injury mechanism

The anatomy of the groin region shows an intense fusion of abdominal and groin structures presuming a functional interdependency during sports performance. The complex groin anatomy hinders reliable and valid assessment of local anatomical structures in case of injury. Groin injury is common in field-based sports and is the most frequent reported overuse injury in football. The high incidence and risk of recurrence and chronicity is yet poorly understood. Incidence numbers show regional differences across the Euro-Arabic continent and the incidence rates in male professional players seem to be twice as high as in female players. Incidence and prevalence numbers vary as most injury studies suffer from substantial heterogeneity on methodology, classification and definitions of groin injury and as a result these blur the true groin injury burden. Therefore the recent Doha agreement meeting on terminology and definitions in groin pain in athletes proposed a clinical classification system and uniformity on terminology for groin injury in athletes. There is strong evidence that previous groin injury and reduced adductor strength increase the risk of subsequent groin injury but the relation with re-injury during kicking and sprinting has never been explained. Despite successful multimodal treatment regimes the groin injury burden in football is still substantial, which is at odds with the absence of clinically relevant groin pathology or functional disorders.
The aim of this thesis was to add new information to assist in unravelling the complexity of groin injury. For that purpose we examined the incidence and levels of problems of groin injury in female and male football players in the Netherlands and studied new risk factors and the kicking mechanism. We developed functional assessment tests and studied early return to sport by manual therapy of the adductor muscles.

INJURY BURDEN

In **chapter 2** we examined the prevalence and recurrence of injury in 434 Dutch female amateur football players, a population never studied before. The overall injury prevalence was high (93%) with non-timeloss injuries being twice the rate that of timeloss. Groin injury was the most common non-timeloss injury, being three times more prevalent (36%) than timeloss groin injury (11%). We also found that about half of the population with previous groin injury sustained a subsequent groin injury during the next preseason. High frequency, long duration and time-loss of previous groin injury were factors increasing the risk of recurrence, chronicity and severity of groin-related problems (low scores on the Hip And Groin Outcome Score-HAGOS). In **chapter 3** we studied the relationship between injuries in subsequent seasons. Remarkably, players with groin injury suffered twice as much other injuries compared to those without for the same season. Injuries in the previous season located in the groin, knee and

ankle were associated with groin injury during the next preseason (odds ratio 9.6, 4.6 and 2.1, respectively).

Chapter 4 presents a prospective study investigating incidence and risk factors for groin injury in 190 Dutch male professional football players. Total/training/match groin injury incidence was 0.5/0.2/2.6 injuries/1000 playing hours. We found a within-season prevalence of timeloss groin injury of 11% and a preseason point-prevalence of 24% of groin-related symptoms and problems (HAGOS), both results resembling those in female players (**chapter 2 and 3**). The prevalence and incidence rates we found in this cohort were lower than those from studies in professional North-European and Arabic teams. This can be explained by differences in exposure, regions, playing style, training intensity and climate conditions.

The main finding of this study was that longstanding timeloss injury (median 9 weeks) of the ankle, knee, thigh and shoulder in the previous season was a risk factor for a subsequent timeloss groin injury in the next season (hazard ratio 5.1; 95%CI 1.8-14.6). It was suggested that remaining deficits from previous injury affect kicking and running biomechanics inadequately compensated by hip flexor work. The results of this study seem to be in line with that assumption. Additionally we found that two or more previous timeloss groin injuries increased the risk on experiencing higher levels of groin-related problems in the preseason (OR 3.0; 95% CI=1.0, 8.3). Limited evidence exists for reduced hip ROM being a risk factor for groin injury but adequately estimating who is at risk on individual levels seems to be impossible due to low precision of ROM measurements. Indeed hip ROM screening did not allow us to identify players at risk for subsequent groin injury. For this reason we cannot advise the club's medical staff to perform these measures at the preseason screening.

INJURY MECHANISM

Kicking is the most frequent reported football action inciting groin injury. For injury prevention it was proposed to analyse how risk factors modulate biomechanics of sporting task mechanisms. Normally these mechanisms show that deceleration of fast moving segments at square or collinear joint angles transfer mechanical energy through the kinematic chain contributing to high ball speed and precision. **Chapter 5** presents a study investigating the coordination of body segments during the maximal kick in (sub) elite football players. We identified eleven peak segmental velocities timing at four specific moments (keypoints) reflecting energy transfer as a kicking mechanism. During the backswing, kickside hip and non-kickside shoulder extension timed simultaneously thereby creating a full body tension arc. A large tension arc produces explosive hip muscle contractions inducing high velocity of the kicking leg (hip flexion). Another important finding was that peak hip flexion deceleration (hip reversal) and peak velocity of pelvis posterior tilt timed simultaneously at square knee angle (keypoint KF90). Hip reversal is a phenomenon in which the hip reverses its motion from flexion to extension prior to ball impact. As pelvis posterior tilt results in hip extension, we suggest that precise pelvic timing induces hip reversal, transferring energy efficiently from upper to lower leg.

Range of motion of the backswing is important to allow prestretch of myofascial structures and ROM of the forward swing is mandatory to develop segmental velocity. In **chapter 6** we investigated both ROM of body segments and the presence of hip reversal during submaximal and maximal kicking in experienced football players. When compared to submaximal kicking we found increased ROM of the tension arc, knee flexion and increased motion trajectories of knee extension, pelvic posterior tilt and spinal flexion during the maximal kick. The enlargement of the tension arc was mainly the result of increased hip extension and spinal rotation (effect size (ES) 1.1 and 1.6, respectively). Lumbar spinal flexion and pelvic posterior tilt, being coupled motions in sporting actions, showed the largest relative increase of movement trajectories (ES 3.2 and 2.2, respectively). These findings suggest that flexibility of the tension arc and pelvis are essential in developing ball speed. Hip reversal was found present during maximal bot not during submaximal kicking.

EXAMINATION AND THERAPY

Examination of the athlete with groin injury according to the clinical entity approach (Doha agreement meeting on terminology and definitions in groin pain in athletes) can be performed in a reliable manner. It does however not clarify why sporting actions like maximal kicking and sprinting are most often provoking groin injury. For a better understanding of the groin injury mechanism, we analyzed two sport specific biomechanical phenomena in athletes. In **chapter 7** we developed a sport specific passive ROM test mimicking the tension arc and studied this as outcome measure in amateur and professional football players with and without adductor-related groin injury. According this standardized test procedure we examined passive ROM of hip extension, adduction, abduction, external and internal rotation, measuring the biological workspace of the tension arc. We summated ROM of these five dimensions up to a total ROM score. We found that reference values of non-injured dominant and non-dominant legs were similar in amateur and professional players (mean total ROM of 188°) that could be assessed reliably. Sport specific ROM was decreased in the injured leg (mean total ROM 136°). The ROC-curve revealed that the optimal cut-off point was 17% asymmetry (32°) to accurately distinguish between the injured and non-injured leg. The clinical consequence of this finding is that injured players lack sufficient sport specific prestretch and consequently generate lower hip velocity during kicking.

Chapter 8 presents a study on active pelvic tilting in non-injured athletes and athletes with groin injury. We developed a reliable active testing procedure during which the athletes had to perform active pelvic anterior tilt (‘hollow back’) and active pelvic posterior tilt (‘flat back’). The ROM of both pelvic movements was summated into one total active pelvic tilt score. We found that reference values of the dominant and non-dominant legs were similar in non-injured athletes. Active pelvic tilt was lower on the injured side when compared the non-injured side (mean 21.1° versus 27.2°, ES Cohens’ d=0.8). We deem this pelvic dysfunction clinically relevant as limited kickside hip deceleration hinders efficient energy flow being compensated by hip

flexor work. From this point of view restoring active pelvic tilting capability seems warranted in rehabilitation programs.
There is moderate evidence that treatment regimes incorporating manual therapy reduces the time to return to sport (12 weeks) when compared to active exercise regimes (18 weeks). Unnecessary treatment delay may occur when rehabilitation programs are applied for a predetermined fixed period. The return to sport decision then neglects early symptom alleviation. Clinicians observe that players tend to return to sport once their symptom level is acceptable. Therefore **chapter 9** studied the time to Return To Sport after manual therapy of the adductor muscles without time contingent protocols in athletes with adductor-related groin injury. The manual therapy technique of the adductor muscles consisted of a stretching maneuver in proximal direction towards the pubic bone. At 2 weeks 82% and at 12 weeks 88% of the athletes were able to play football at their pre-injury level. It should be acknowledged that most players still experienced a substantial level of groin-related problems even though they had returned to sport. This suggests that the time to return to sport as single factor is not a valid indicator of treatment success.

CONCLUSION

Groin injury risk in Dutch football players is high. Especially those with multiple and longstanding timeloss groin injury seem to be at risk for recurrence and severe groin-related problems. Groin injury prevalence in Dutch female amateurs is comparable to that in Dutch male professionals with non-timeloss groin injury frequency being 3 times higher than that of timeloss. Previous longstanding timeloss ankle, knee, thigh and shoulder injury was a risk factor for a subsequent groin injury. Remaining deficits from previous injuries may modulate kicking biomechanics, which can be assessed by two newly developed sport specific assessment tests. These tests reliably demonstrated reduced ROM of the tension arc and of active pelvic tilt in athletes with groin injury. During kicking these injured players likely lack potential for proper energy transfer resulting in compensatory hip flexor work. Restoring the injury mechanism by manual therapy of the adductor muscles and targeted interventions to dissolve ROM tension arc, ROM pelvic tilt and remaining injury deficits seem to deserve a place in the treatment sequence of groin injury. Consecutive inventory of levels of groin symptoms and problems may prevent from long injury duration or recurrence in the next preseason. Hip ROM screening for prevention was not found to be useful from this perspective.

Nederlandse samenvatting

DE COMPLEXITEIT VAN LIESBLESSURES
Op zoek naar het blessure mechanisme

De anatomie van de liesregio laat zien dat de adductoren gefuseerd zijn met spieren en pezen van de buikregio hetgeen een onderlinge functionele afhankelijkheid veronderstelt tijdens sportacties. De complexe liesanatomie bemoeilijkt valide onderzoek van lokale anatomische structuren bij blessures. Liesblessures komen veel voor bij veldsporters en zijn de meest voorkomende overbelasting blessures in voetbal. De reden voor de hoge incidentie en risico op recidief en chroniciteit is echter niet bekend. Incidentiecijfers tonen regionale verschillen binnen het Euro-Arabische continent en zijn bij mannelijke voetballers twee keer hoger dan bij vrouwelijke. De incidentie- en prevalentiecijfers variëren omdat de meeste blessurestudies aanzienlijke heterogeniteit vertonen van methodologie, classificatie en definities van liesblessures hetgeen de actuele blessurelast vertroebelt. Daarom heeft de recente Doha-overeenkomst betreffende terminologie en definities van liespijn bij sporters een klinisch classificatiesysteem geïntroduceerd ten behoeve van de uniformiteit en terminologie van deze liesblessures. Er is sterk bewijs dat eerdere liesblessures en zwakke adductoren risicofactoren zijn voor nieuwe liesblessures, maar waarom blessures consistent recidiveren tijdens schieten en sprinten is nooit beschreven. Ondanks succesvolle multimodale behandelprogramma's is de prevalentie van liesblessures in het voetbal nog steeds aanzienlijk en staat in contrast met de afwezigheid van klinisch relevante liespathologie of functie stoornissen.
Het doel van dit proefschrift is het verminderen van de complexiteit van liesblessures. Daartoe onderzochten we de prevalentie, incidentie en het niveau van lies-gerelateerde problemen van liesblessures bij vrouwelijke en mannelijke voetballers in Nederland en bestudeerden nieuwe risicofactoren en de biomechanica van de voetbaltrap. We ontwikkelden functionele onderzoektesten en bestudeerden vervroegde return to sport door manuele therapie van de adductoren.

BLESSURE LAST

Hoofdstuk 2 onderzocht de prevalentie en recidivering van liesblessures bij 434 Nederlandse vrouwelijke amateurvoetballers, een populatie die nog niet eerder bestudeerd is. De algemene blessure prevalentie was hoog (93%) met tweemaal zoveel non-timeloss als timeloss blessures. Van alle non-timeloss blessures kwamen liesblessures het meest voor en wel driemaal vaker (36%) dan timeloss liesblessures (11%). Het bleek dat de helft van de populatie met eerdere liesblessures (52%) een recidief kreeg tijdens het volgende voorseizoen. Langdurige liesblessures hadden een grotere kans op recidief, chroniciteit en ernstige lies-gerelateerde problemen (lage scores op de Hip And Groin Outcome Score-HAGOS) in het volgend voorseizoen. In **hoofdstuk 3** hebben we in dezelfde populatie de onderlinge blessurerelatie bestudeerd. Opmerkelijk was dat de spelers met liesblessures in hetzelfde seizoen twee keer zo veel andere blessures hadden vergeleken met speelsters zonder liesblessures. Blessures van de lies, knie en enkel in het vorige seizoen waren geassocieerd met liesblessures in het volgende voorseizoen (odds ratio 9,6; 4,6 en 2,1 respectievelijk). We vonden ook dat spelers met timeloss liesblessures de ernstigste lies-gerelateerde problemen (HAGOS) ondervonden.

Hoofdstuk 4 presenteert een prospectief onderzoek naar de incidentie, prevalentie en risicofactoren van liesblessures bij 190 Nederlandse mannelijke profvoetballers. De totale/training/wedstrijd incidentie was 0.5/0.2/2.6 blessures/1000 voetbal uren. We vonden een seizoen prevalentie van timeloss liesblessures van 11% en een kwart van alle mannelijke spelers (24%) bleek lies-gerelateerde problemen (HAGOS) te hebben in het voorseizoen. Deze resultaten zijn vergelijkbaar met die van de vrouwen amateurvoetballers (**hoofdstuk 2 en 3**). De prevalentie en incidentiecijfers die we in het Nederlandse mannen cohort vonden, waren lager dan die in studies van Noord-Europese en Arabische (semi) profvoetballers. Dit kan worden verklaard door verschillen in exposure, regio's, speelstijlen, trainingsintensiteit en klimaat.

Het belangrijkste resultaat van deze studie was dat langdurige timeloss blessures (mediaan 9 weken) van enkel, knie, bovenbeen en schouder in het vorige seizoen risicofactoren waren voor een timeloss liesblessure in het volgende seizoen (hazard ratio 5,1; 95%BI 1,8-14,6). Er werd beweerd dat resterende functiestoornissen van eerdere blessures de biomechanica van schieten en sprinten beïnvloeden die inadequaat gecompenseerd wordt door de heup flexoren. De resultaten van onze studie zijn in overeenstemming met die veronderstelling. Tevens konden we vaststellen dat twee of meer eerdere timeloss liesblessures een verhoogd risico hebben op lies-gerelateerde problemen in het voorseizoen (OR 3,0; 95%BI 1,0-8,3). Er is beperkt bewijs dat verminderde heup range of motion (ROM) een risicofactor is voor een liesblessure, maar adequaat inschatten wie er op individueel niveau risico loopt lijkt onmogelijk vanwege de lage precisie van ROM-metingen. Dienovereenkomstig bleek uit onze studie dat heup ROM-screening in het voorseizoen ons niet in staat stelt om spelers met verhoogd risico op liesblessures te identificeren. Het is voetbalclubs af te raden deze maatregel nog uit te voeren tijdens de screening in het voorseizoen.

BLESSURE MECHANISME

In vergelijking met andere voetbal acties ontstaan of recidiveren de meeste liesblessures tijdens de voetbaltrap. In het kader van blessure preventie werd voorgesteld om de interactie tussen risicofactoren en de biomechanica van sportacties te analyseren. Onder normale omstandigheden vertonen sportacties vertragingen van snel bewegende segmenten waardoor mechanische energie verplaatst wordt door de kinematische keten en tot hoge balsnelheid en precisie leidt. **Hoofdstuk 5** onderzocht de coördinatie van lichaamssegmenten tijdens de maximale voetbaltrap bij ervaren voetballers. We vonden dat de maximale snelheid van elf segment acties plaatsvonden op vier specifieke momenten (keypoints) waaruit af te leiden is dat energie transmissie een belangrijk trap mechanisme is.

Tijdens de backswing worden de heup (schietkant) en de schouder (niet-schietkant) tegelijkertijd geëxtendeerd, waardoor een grote prestretch van anterieure myofasciale structuren wordt gecreëerd (tension arc). Een grote tension arc produceert explosieve spiercontracties en genereert een hoge snelheid van het schietbeen (heupflexie). Een andere belangrijke bevinding was dat de timing van de maximale vertraging van heupflexie (heup reversal) en van maximale snelheid van bekkenkanteling samenvielen op 90 graden knieflexie (keypoint KF90). Heup reversal is het fenomeen waarbij de beweging van de heup omkeert van flexie naar extensie voorafgaand aan bal contact. Aangezien bekkenkanteling in heupextensie resulteert, zal optimaal getimede bekkenkanteling vertraging van de heup veroorzaken waarbij energie transmissie van boven- naar onderbeen plaatsvindt.

Een grotere backswing maakt hogere heupsnelheid mogelijk en een groot bewegingstraject van de forward swing is noodzakelijk om segment snelheid te kunnen ontwikkelen. In **hoofdstuk 6** onderzochten we de ROM van gewrichten en segmenten en de aanwezigheid van heup reversal tijdens de submaximale en maximale trap bij ervaren voetballers. Als we de twee trappen met elkaar vergelijken blijkt significant grotere ROM tijdens de maximale trap van tension arc, heup, knie, bekken en lumbale wervelkolom. De toename van de tension arc was voornamelijk het gevolg van toegenomen heupextensie en wervelkolom rotatie (effectgrootte (ES) 1,1 en 1,6 respectievelijk). Wervelkolom flexie en achterwaartse bekkenkanteling zijn gekoppelde bewegingen tijdens sportacties en vertoonden de grootste relatieve bewegingstoename (ES 3,2 en 2,2 respectievelijk). Deze bevindingen suggereren dat ROM van de tension arc en het bekken essentieel is bij het ontwikkelen van de balsnelheid. Heup reversal bleek aanwezig tijdens maximale maar niet tijdens de submaximale voetbaltrap.

ONDERZOEK EN THERAPIE

Het onderzoek van atleten met liesblessures volgens het concept van de klinische entiteiten (Doha-overeenkomst betreffende terminologie en definities van liespijn bij sporters) kan op betrouwbare wijze worden uitgevoerd. Onderzoek heeft echter niet aangetoond waarom sportacties zoals schieten en sprinten de meeste liesblessures veroorzaken. Voor een beter begrip van het blessure mechanisme van de lies hebben we twee sport specifieke biomechanische fenomenen bij sporters geanalyseerd.

In **hoofdstuk 7** hebben we een sport specifieke passieve ROM-test ontwikkeld die de tension arc tijdens schieten nabootst en deze bestudeerd als uitkomstmaat bij amateur- en professionele voetballers met en zonder adductor-gerelateerde liesblessures. Volgens een gestandaardiseerde testprocedure onderzochten we de passieve ROM van heupextensie, adductie, abductie, exorotatie en endorotatie, gelijkend op de tension arc. We hebben de ROM van deze vijf dimensies berekend tot een totale ROM-score en vonden dat de referentiewaarden van niet-geblesseerde dominante en niet-dominante benen vergelijkbaar waren in amateur- en professionele spelers (gemiddelde totale ROM van 188°) die betrouwbaar konden worden beoordeeld. Sport specifieke ROM was verminderd van het geblesseerde been (gemiddelde totale ROM 136°). De ROC-curve toonde dat het optimale afkappunt 17% asymmetrie was om nauwkeurig onderscheid te maken tussen het geblesseerde en het niet- geblesseerde been. De klinische consequentie van deze bevinding is dat tijdens schieten geblesseerde spelers tijdens de backswing onvoldoende prestretch kunnen generen en dientengevolge lagere heupsnelheid.

Hoofdstuk 8 presenteert een onderzoek naar actieve bekkenkanteling bij gezonde atleten en atleten met een liesblessure. We ontwikkelden een betrouwbare, actieve testprocedure waarbij de atleten actief een voorwaartse ('holle rug') en achterwaartse ('platte rug') bekkenkanteling moesten uitvoeren. De ROM van beide bekkenbewegingen werd samengevoegd tot één totale actieve bekken score. De referentiewaarden van de dominante en niet-dominante benen waren vergelijkbaar bij niet-geblesseerde atleten. Aan de geblesseerde zijde bleek de ROM van actieve bekkenkanteling verminderd vergeleken met de niet-geblesseerde zijde (gemiddeld 21.1° versus 27.2°, ES Cohens' d=0.8). Aangezien de bekkenfunctie bepalend blijkt voor heup reversal en energie transmissie achten we deze bekken dysfunctie klinisch relevant.

De in **hoofdstuk 7 en 8** aangetoonde dysfuncties van tension arc en bekken kan de reden zijn voor het frequente recidief tijdens maximaal schieten. ROM tension arc en ROM bekkenkanteling zijn belangrijke targets voor revalidatieprogramma's.

Een multimodaal behandelprogramma inclusief manuele therapie van de adductoren resulteerde in een snellere return to sport (RTP, 12 weken) in vergelijking met actieve oefenprogramma's (18 weken). Onnodige tijdverlies kan optreden wanneer tijd contingente behandelprogramma's worden toegepast waarbij de beslissing tot RTP geen rekening houdt met het niveau van symptomen. In onze klinische praktijk hebben we vastgesteld dat spelers weer gaan sporten wanneer hun symptomen dit toelaten. **Hoofdstuk 9** onderzocht de tijd tot RTP na manuele therapie van de adductoren zonder tijd contingente protocollen bij voetballers met adductor-gerelateerde liesblessures. De manuele therapie bestond uit een rek manoeuvre van de adductoren in de richting van het os pubis. Na 2 weken meldde 82% en na 12 weken 88% van de spelers dat ze weer konden voetballen op het niveau van vóór de blessure. Ook bleek de schiet capaciteit van veel spelers (79%) substantieel tot volledig te zijn verbeterd. De meeste spelers meldden echter nog steeds een aanzienlijke mate van lies-gerelateerde problemen, ook al waren ze weer in staat te sporten. Dit suggereert dat de tijd tot RTP niet de enige valide indicator is voor behandel succes.

CONCLUSIE

De prevalentie van liesblessures bij Nederlandse vrouwen amateurvoetballers is hoger dan vooraf verwacht en gelijk aan dat van mannen profvoetballers. Voetballers met eerdere liesblessures hebben een grote kans op recidief en chroniciteit. Degene met frequente, langdurige en/of timeloss liesblessures hebben de hoogste kans op recidief en ernstige lies-gerelateerde problemen (HAGOS). Langdurige timeloss enkel-, knie-, bovenbeen- en schouderblessures in het vorige seizoen zijn sterke risicofactoren voor een timeloss liesblessure. Resterende functiestoornissen van eerdere blessures kunnen de biomechanica van de voetbaltrap veranderen waardoor de kans op liesblessures tijdens schieten toeneemt. Twee betrouwbare nieuwe sport specifieke onderzoektesten toonden aan dat de ROM van de tension arc en actieve bekkenkanteling verminderd zijn bij atleten met liesblessures. Manuele therapie van de adductoren en gerichte interventies om resterende functiestoornissen van eerdere blessures en sport specifieke functiestoornissen te herstellen verdienen een plaats in de sequentie van blessure preventie. Vanuit preventief oogpunt blijkt het screenen van heup ROM niet zinvol.

Resumen en Español

LA COMPLEJIDAD DE LA LESIÓN EN LA INGLE
En busca del mecanismo de lesión.

La anatomía de la región de la ingle muestra una fusión intensa de estructuras abdominales y de la ingle, suponiendo una interdependencia funcional durante el desempeño deportivo. La compleja anatomía de la ingle dificulta la evaluación válida de las estructuras anatómicas locales en caso de lesión. La lesión en la ingle es común en los deportes de campo y es la lesión más frecuente por uso excesivo en el fútbol. La alta incidencia y el riesgo de recurrencia y cronicidad aún no se conocen bien. Los números de incidencias muestran diferencias regionales en el continente euroárabe y las tasas de incidencia en los jugadores profesionales masculinos son dos veces más altas que en las jugadoras femeninas. Los números de incidencia y prevalencia varían, ya que la mayoría de los estudios sobre lesiones sufren una heterogeneidad sustancial en la metodología, la clasificación y las definiciones de la lesión en la ingle y, como resultado, difuminan la verdadera carga de la lesión. Por lo tanto, la reciente reunión del acuerdo de Doha sobre terminología y definiciones en el dolor en la ingle en atletas propuso un sistema de clasificación clínica y uniformidad en la terminología para lesiones en la ingle en atletas. Existe una fuerte evidencia de que la lesión previa en la ingle y los músculos aductores débiles son factores de riesgo de una nueva lesión en la ingle, pero nunca se ha explicado la relación con la nueva lesión durante las patadas y los esprints. A pesar de los tratamientos multimodales, la carga de lesiones en la ingle en el fútbol sigue siendo considerable, lo que se contradice con la ausencia de patología de la ingle clínicamente relevante o trastornos funcionales.

El objetivo de esta tesis era añadir nueva información para ayudar a desentrañar la complejidad de la lesión en la ingle. Para ello, examinamos la incidencia y el nivel de los síntomas y problemas de lesión en la ingle en jugadores de fútbol femenino y masculino en los Países Bajos y estudiamos los nuevos factores de riesgo y el mecanismo de patadas. Desarrollamos pruebas de evaluación funcional y estudiamos el retorno temprano al deporte mediante la terapia manual de los músculos aductores.

CARGA DE LESIONES

En el **capítulo 2**, examinamos la prevalencia y la recurrencia de lesiones en la ingle en 434 jugadoras de fútbol amateur holandesas, una población nunca antes estudiada. La prevalencia general de lesiones fue alta (93%), con lesiones que no requieren reposo siendo el doble de la tasa de lesiones que requieren inactividad por un período de tiempo. La lesión en la ingle fue la lesión más frecuente que no requiere reposo, siendo tres veces más frecuente (36%) que la lesión en la ingle que requiere inactividad (11%). También descubrimos que la mitad de la población con lesiones en la ingle previa (52%) sufrió una lesión en la ingle durante la siguiente pretemporada. A mayor duración de la lesión en la ingle, mayor fue el riesgo de recurrencia, cronicidad y problemas graves relacionados con la ingle en la siguiente pretemporada (puntajes bajos en el resultado de cadera e ingle-HAGOS). En el **capítulo 3** estudiamos la relación entre las lesiones en la misma población. Sorprendentemente, los jugadores con lesión en la ingle sufrieron en la misma temporada el doble de otras lesiones en comparación con los que no lo hicieron. Las lesiones en la temporada anterior localizadas en la ingle, la rodilla y el tobillo se asociaron con una lesión en la ingle durante la siguiente pretemporada (índice de probabilidad (OR, por sus siglas en inglés) 9.6, 4.6 y 2.1, respectivamente). También encontramos que los jugadores con lesión en la ingle que requiere reposo experimentaron problemas relacionados con la ingle más graves (HAGOS).

El **Capítulo 4** presenta un estudio prospectivo que investiga la incidencia y los factores de riesgo de lesión en la ingle en 190 jugadores de fútbol profesional masculinos holandeses. Encontramos una prevalencia dentro de la temporada de lesión en la ingle que require inactividad común del 11% y una cuarta parte de todos los jugadores masculinos (24%) que sostienen niveles altos de síntomas y problemas relacionados con la ingle (HAGOS) en la pretemporada. Ambos resultados se asemejan a los de las jugadoras (**capítulos 2 y 3**). Las tasas de prevalencia e incidencia que encontramos en esta población fueron más bajas que las de los estudios en equipos profesionales del norte de Europa y árabes. Esto puede explicarse por las diferencias en exposición, regiones, estilo de juego, intensidad de entrenamiento y condiciones climáticas. El principal hallazgo de este estudio fue que la lesión con reposo de larga duración (media de 9 semanas) del tobillo, la rodilla, el muslo y el hombro en la temporada anterior fueron factores de riesgo para una lesión posterior en la ingle en la próxima temporada (índice de riesgo 5.1; 95%CI 1.8-14.6). Se sugirió que los déficits restantes de lesiones previas afectan la patada y la ejecución de la biomecánica, en consecuencia, compensada por el trabajo del flexor de cadera. Los resultados de este estudio están en línea con esa suposición. Además, encontramos que dos o más lesiones previas en la ingle que requieren inactividad aumentaron el riesgo de experimentar mayores niveles de problemas relacionados con la ingle en la pretemporada (OR 3.0; 95%CI=1.0-8.3). Existe evidencia limitada de que la reducción del ROM de la cadera es un factor de riesgo para la lesión en la ingle, pero estimar adecuadamente quién está en riesgo en los niveles individuales es imposible debido a la baja precisión de las mediciones del Rango de Movimiento. De hecho, la prueba del Rango de Movimiento de la cadera no nos permitió identificar a los jugadores en riesgo de sufrir una lesión en la ingle en el futuro. Por esta razón, no podemos recomendar al personal médico del club que realice estas medidas en la selección de pretemporada.

MECANISMO DE LA LESIÓN

Dar patadas es la acción de fútbol más frecuente que incita una lesión en la ingle. Para la prevención de lesiones se propuso analizar cómo los factores de riesgo modulan la biomecánica de los mecanismos de tareas deportivas. Normalmente, estos mecanismos muestran que la desaceleración de los segmentos de movimiento rápido en ángulos de articulación cuadrados o colineales transfiere energía mecánica a través de la cadena cinemática, lo que contribuye a una alta velocidad y precisión del balón. El **Capítulo 5** presenta un estudio que investiga la coordinación de segmentos corporales durante la patada máxima en jugadores de fútbol experimentados. Identificamos once velocidades segmentarias pico en cuatro momentos específicos (puntos clave) que reflejan la transferencia de energía como un mecanismo de patada. Durante el impulso hacia atrás, el golpe de cadera lateral y la extensión del hombro cronometrada simultáneamente se crea un arco de tensión de todo el cuerpo. Un arco de tensión grande produce contracciones musculares explosivas de la cadera que inducen una alta velocidad de la pierna que patea (flexión de la cadera). Otro hallazgo importante fue la desaceleración máxima de la flexión de la cadera (inversión de cadera) y la velocidad máxima de la inclinación pélvica posterior cronometrada simultáneamente en el ángulo cuadrado de la rodilla (punto clave KF90). La inversión de cadera es un fenómeno en el que la cadera invierte su movimiento de flexión a extensión antes del impacto del balón. Como la inclinación pélvica posterior da como resultado la extensión de la cadera, sugerimos que la sincronización pélvica precisa induce la inversión de la cadera, transfiriendo energía de manera eficiente de la parte superior a la inferior de la pierna.

El rango de movimiento del impulso hacia atrás es importante para permitir el pre-lanzamiento de las estructuras miofasciales y el ROM del impulso hacia adelante es obligatorio para desarrollar la velocidad segmentaria. En el **capítulo 6** investigamos tanto el ROM de los segmentos del cuerpo como la presencia de inversión de la cadera durante las patadas submáximas y máximas en jugadores de fútbol experimentados. En comparación con las patadas submáximas, encontramos un aumento del ROM del arco de tensión, la flexión de la rodilla y el aumento de las trayectorias de movimiento de la extensión de la rodilla, la inclinación pélvica posterior y la flexión de la columna vertebral durante la patada máxima. La ampliación del arco de tensión se debió principalmente al aumento de la extensión de la cadera y la rotación de la columna (tamaño del efecto (ES, por sus siglas en inglés) 1.1 y 1.6, respectivamente). La flexión de la columna lumbar y la inclinación pélvica posterior, al ser movimientos acoplados en las acciones deportivas, mostraron el mayor aumento relativo de las trayectorias de movimiento (ES 3.2 y 2.2, respectivamente). Estos hallazgos sugieren que la flexibilidad del arco de tensión y la pelvis son esenciales para desarrollar la velocidad del balón. La inversión de cadera se encontró presente durante la patada máxima, no durante la patada submáxima.

EXAMEN Y TERAPIA

El examen del atleta con lesión en la ingle según el enfoque de la entidad clínica (reunión del acuerdo de Doha sobre terminología y definiciones del dolor en la ingle en atletas) se puede realizar de manera fiable. Sin embargo, no aclara por qué las acciones deportivas como las patadas máximas y los esprints son las que con más frecuencia provocan lesiones en la ingle. Para una mejor comprensión del mecanismo de lesión en la ingle, analizamos dos fenómenos biomecánicos específicos del deporte en atletas. En el **capítulo 7** desarrollamos una prueba de ROM pasiva específica para el deporte que simulaba el arco de tensión y estudiamos esto como

medida de resultado en jugadores de fútbol amateur y profesionales con y sin lesión en la ingle relacionada con aductores. De acuerdo con este procedimiento de prueba estandarizado, examinamos el ROM pasivo de la extensión de la cadera, aducción, abducción, rotación interna y externa, midiendo el espacio de trabajo biológico del arco de tensión. Sumamos el ROM de las cinco dimensiones hasta una puntuación total del ROM. Encontramos que los valores de referencia de las piernas dominantes y no dominantes no lesionadas fueron similares en los jugadores amateurs y profesionales (ROM total media de 188°) que podrían evaluarse de manera fiable. El ROM deportivo específico se redujo en la pierna lesionada (ROM total media 136°). La curva ROC reveló que el punto límite óptimo era un 17% de asimetría (32°) para distinguir con precisión entre la pierna lesionada y la no lesionada. La consecuencia clínica de este hallazgo es que los jugadores lesionados carecen de un entrenamiento previo al deporte suficiente y, por consiguiente, generan una menor velocidad de la cadera durante la patada.
El **Capítulo 8** presenta un estudio sobre la inclinación pélvica activa en atletas sin lesiones y atletas con lesión en la ingle. Desarrollamos un procedimiento de prueba activo fiable durante el cual los atletas tuvieron que realizar una inclinación pélvica anterior activa ("espalda cóncava") y una inclinación pélvica posterior activa ("espalda plana"). El ROM de ambos movimientos pélvicos se sumó en una puntuación total de inclinación pélvica activa. Encontramos que los valores de referencia de las piernas dominantes y no dominantes fueron similares en los atletas no lesionados. La inclinación pélvica activa fue más baja en el lado lesionado cuando se comparó con el lado no lesionado. Consideramos que esta disfunción pélvica es clínicamente relevante ya que la desaceleración limitada de la cadera del lado de la patada dificulta el flujo de energía eficiente que se compensa con el trabajo del flexor de cadera. Desde este punto de vista, la restauración de la capacidad de inclinación pélvica activa es justificada en los programas de rehabilitación.
Existe evidencia moderada de que el tratamiento multimodal, incluida la terapia manual, reduce el tiempo para volver al deporte (12 semanas) en comparación con el uso bien establecido de ejercicios activos (18 semanas). La demora innecesaria del tratamiento puede ocurrir cuando los programas de rehabilitación se aplican durante un período fijo predeterminado. El regreso a la decisión deportiva entonces descuida el alivio temprano de los síntomas. En nuestra práctica clínica observamos que los jugadores tienden a volver al deporte cuando sus síntomas se lo permiten. Por lo tanto, en el **capítulo 9** se estudió el tiempo para volver al deporte después de la terapia manual de los músculos aductores sin protocolos contingentes de tiempo en atletas con lesión en la ingle relacionada con el aductor. La técnica de terapia manual de los músculos aductores consistió en un movimiento de estiramiento en dirección proximal hacia el hueso púbico. A las 2 semanas, el 82% y a las 12 semanas el 88% de los atletas informaron de que volvieron a jugar al fútbol en su nivel previo a la lesión. Se debe reconocer que la mayoría de los jugadores experimentaron un nivel sustancial de problemas relacionados con la ingle, incluso cuando habían regresado a los deportes. Esto sugiere que el momento de volver al deporte como factor único no es un indicador válido del éxito del tratamiento.

CONCLUSIÓN

El riesgo de lesión en la ingle en los futbolistas holandeses es alto. Especialmente aquellos con lesiones en la ingle que requieran reposo de larga duración están en riesgo de recurrencia y problemas graves relacionados con la ingle. La prevalencia de lesiones en la ingle en las mujeres amateurs holandesas es comparable a la de los hombres profesionales holandeses. La frecuencia de lesiones en la ingle que no requieren reposo fue 3 veces mayor que las que sí requieren un período de inactividad. Las lesiones previas que requieren reposo de larga duración en el tobillo, la rodilla, el muslo y el hombro fueron factores de riesgo para una lesión posterior en la ingle. Las deficiencias remanentes de lesiones previas pueden modular la biomecánica de patadas, que puede evaluarse mediante dos pruebas de evaluación específicas de deporte desarrolladas recientemente. Estas pruebas demostraron de manera fiable la reducción del ROM del arco de tensión y del movimiento pélvico activo en atletas con lesiones en la ingle. Durante la patada, estos jugadores lesionados probablemente carecerán de potencial para una transferencia de energía adecuada, lo que resultará en un trabajo compensador de flexión de cadera. El restablecimiento del mecanismo de lesión mediante la terapia manual de los músculos aductores y las intervenciones dirigidas para disolver el ROM del arco de tensión, el ROM de la inclinación pélvica posterior y los déficits de lesiones restantes merecen un lugar en la secuencia de tratamiento de la lesión de la ingle. El inventario consecutivo de los niveles de síntomas y problemas de la ingle puede evitar una lesión de larga duración o una recurrencia en la próxima pretemporada. El examen del ROM de cadera para la prevención no se encontró útil desde esta perspectiva.

Riassunto in Italiano

LA COMPLESSITÀ DEGLI INFORTUNI INGUINALI
Alla ricerca del meccanismo degli infortuni

L'anatomia della regione inguinale mostra un'intensa fusione di strutture addominali e inguinali che presumono un'interdipendenza funzionale durante le prestazioni sportive. La complessa anatomia inguinale impedisce una valutazione affidabile e valida delle strutture anatomiche locali in caso di infortuni. L'infortunio all'inguine è comune negli sport da campo ed è l'infortunio da sovra utilizzo più frequente riportato nel calcio. L'alta incidenza e il rischio di ricorrenza e cronicità sono ancora poco conosciuti. I numeri di incidenza mostrano differenze regionali nel continente euro-arabo e i tassi di incidenza nei giocatori professionisti maschili sembrano essere il doppio rispetto a quelli delle giocatrici femminili. I numeri di incidenza e di prevalenza variano in quanto la maggior parte degli studi sulle lesioni soffre di una sostanziale eterogeneità nella metodologia, nella classificazione e nelle definizioni delle lesioni all'inguine, e di conseguenza queste rendono meno chiaro il vero impatto della lesione all'inguine. Pertanto, il recente incontro di Doha per accordarsi sulla terminologia e le definizioni del dolore all'inguine negli atleti ha proposto un sistema di classificazione clinica e l'uniformità della terminologia per le lesioni all'inguine negli atleti. Ci sono prove evidenti che infortuni precedenti all'inguine e muscoli adduttori deboli sono fattori di rischio di nuovi infortuni all'inguine, non è mai stato spiegato il rapporto con il nuovo infortunio durante il calciare e lo sprint. Nonostante il successo dei regimi di trattamento multimodale, l'impatto degli infortuni all'inguine nel calcio è ancora notevole, il che è in contrasto con l'assenza di patologie all'inguine clinicamente rilevanti o disturbi funzionali.

Lo scopo di questa tesi era quello di aggiungere nuove informazioni per aiutare a svelare la complessità degli infortuni all'inguine. A tale scopo abbiamo esaminato l'incidenza e il livello dei sintomi e dei problemi degli infortuni all'inguine nei giocatori di calcio di sesso femminile e maschile nei Paesi Bassi e abbiamo studiato nuovi fattori di rischio e il meccanismo del calciare. Abbiamo sviluppato test di valutazione funzionale e studiato il ritorno precoce allo sport attraverso la terapia manuale dei muscoli adduttori.

IMPATTO DEGLI INFORTUNI

Nel **capitolo 2** abbiamo esaminato la prevalenza e la reiterazione degli infortuni in 434 giocatrici femmine di calcio dilettanti olandesi, una popolazione mai studiata prima. La prevalenza complessiva degli infortuni è stata elevata (93%) con il doppio degli infortuni senza perdita di tempo rispetto a quelli con perdita di tempo. Gli infortuni all'inguine sono stati gli infortuni senza perdita di tempo più comuni, essendo tre volte più prevalenti (36%) rispetto a quelli con perdita di tempo (11%). Abbiamo anche riscontrato che metà della popolazione con un precedente infortunio all'inguine (52%) ha subito un infortunio all'inguine successivo durante il successivo precampionato. Maggiore era la durata degli infortuni all'inguine, maggiore era il rischio di ricorrenza, cronicità e gravi problemi legati all'inguine (punteggi bassi sull'Hip And Groin Outcome Score-HAGOS). Nel **capitolo 3** abbiamo studiato la relazione tra infortuni nella stessa popolazione. Sorprendentemente, i giocatori con infortuni all'inguine hanno subito nella stessa stagione il doppio degli altri infortuni rispetto a quelli senza. Gli infortuni nella stagione precedente all'inguine, ginocchio e caviglia furono associati a infortuni all'inguine durante il successivo precampionato. (odds ratio (OR) rispettivamente 9.6, 4.6 e 2.1). Abbiamo anche scoperto che i giocatori con infortuni all'inguine con perdita di tempo hanno sperimentato i più alti livelli di problemi relativi all'inguine (HAGOS).

Il **Capitolo 4** presenta uno studio prospettico che esamina l'incidenza e i fattori di rischio degli infortuni all'inguine in 190 calciatori professionisti maschi olandesi. Abbiamo riscontrato una prevalenza all'interno della stagione degli infortuni all'inguine con perdita di tempo dell'11% e un quarto di tutti i giocatori maschi (24%) che sostengono alti livelli di sintomi e problemi legati all'inguine (HAGOS) nel precampionato, entrambi i risultati sono simili a quelli dei giocatori di sesso femminile (**capitolo 2 e 3**). I tassi di prevalenza e incidenza che abbiamo riscontrato in questo gruppo erano inferiori a quelli ottenuti da studi in squadre professionistiche nordeuropee e arabe. Ciò può essere spiegato dalle differenze di esposizione, regioni, stile di gioco, intensità dell'allenamento e condizioni climatiche.

Il risultato principale di questo studio è stato che gli infortuni da lunga data con perdita di tempo (di media 9 settimane) di caviglia, ginocchio, coscia e spalla nella stagione precedente erano fattori di rischio per un successivo infortunio all'inguine con perdita di tempo nella successiva stagione (hazard ratio 5.1; 95%CI 1.8-14.6). È stato suggerito che i deficit residui di infortuni precedenti influenzano la biomeccanica dei calci e della corsa, di conseguenza compensata dal lavoro dei flessori dell'anca. I risultati di questo studio sembrano essere in linea con tale assunto. Inoltre, abbiamo scoperto che due o più precedenti infortuni all'inguine con perdita di tempo aumentavano il rischio di sperimentare livelli più alti di problemi relativi all'inguine nel precampionato (OR 3.0; 95%CI=1.0, 8.3). Esistono prove limitate che il ROM (intervallo di movimento) dell'anca ridotto è un fattore di rischio per gli infortuni all'inguine, ma stimare adeguatamente chi è a rischio a livello individuale sembra essere impossibile a causa della scarsa precisione delle misurazioni del ROM. Infatti, Il controllo del ROM dell'anca non ci ha permesso di identificare i giocatori a rischio di infortunio all'inguine successivo. Per questo motivo non possiamo consigliare al personale medico del club di eseguire queste misure durante il controllo di precampionato.

MECCANISMO DEGLI INFORTUNI

Il calciare è l'azione calcistica più frequente segnalata che provoca infortuni all'inguine. Per la prevenzione degli infortuni si è proposto di analizzare come i fattori di rischio modulano la biomeccanica dei meccanismi dei compiti sportivi. Normalmente questi meccanismi mostrano che la decelerazione di segmenti in rapido movimento ad angoli di giunzione quadrati o collineari trasferisce energia meccanica attraverso la catena cinematica contribuendo ad un'elevata velocità e precisione della palla. Il **Capitolo 5** presenta uno studio che indaga il coordinamento dei segmenti corporei durante il calcio massimo in giocatori di calcio esperti. Abbiamo identificato undici velocità segmentali di picco, cronometrando in quattro momenti specifici (punti chiave) che riflettono il trasferimento di energia come meccanismo di calcio. Durante la flessione della gamba indietro, l'estensione del fianco del calcio e l'estensione della spalla non sul calcio sono cronometrate simultaneamente creando così un arco di tensione completo del corpo. Un ampio arco di tensione produce contrazioni muscolari dell'anca esplosive che inducono un'alta velocità della gamba che calcia (flessione dell'anca). Un altro risultato importante è stato che il picco di decelerazione della flessione dell'anca (inversione dell'anca) e la velocità di picco dell'inclinazione posteriore pelvica sono stati cronometrati simultaneamente all'angolo quadrato del ginocchio (punto chiave KF90). L'inversione dell'anca è un fenomeno in cui l'anca inverte il suo movimento dalla flessione all'allungamento prima dell'impatto della palla. Poiché l'inclinazione posteriore del bacino determina l'estensione dell'anca, suggeriamo che il preciso tempo pelvico induce l'inversione dell'anca, trasferendo l'energia in modo efficiente dalla parte superiore a quella inferiore della gamba.

L'intervallo di movimento (ROM) della flessione all'indietro della gamba è importante per consentire il prestiramento delle strutture miofasciali e il ROM dell'oscillazione in avanti è necessaria per sviluppare la velocità segmentale. Nel **Capitolo 6** abbiamo studiato sia il ROM dei segmenti corporei sia la presenza di inversione dell'anca durante il calcio submassimale e massimale nei calciatori esperti. Rispetto al calcio submassimale abbiamo riscontrato un aumento della ROM dell'arco di tensione, flessione del ginocchio e aumento delle traiettorie di estensione del ginocchio, inclinazione posteriore pelvica e flessione spinale durante il calcio massimale. L'allargamento dell'arco di tensione era principalmente il risultato di un aumento dell'estensione dell'anca e della rotazione spinale (dimensione dell'effetto (ES) rispettivamente 1.1 e 1.6). La flessione vertebrale lombare e l'inclinazione posteriore pelvica, essendo i movimenti accoppiati nelle azioni sportive, hanno mostrato il maggiore aumento relativo delle traiettorie di movimento (ES rispettivamente 3.2 e 2.2). Questi risultati suggeriscono che la flessibilità dell'arco di tensione e del bacino sono essenziali nello sviluppo della velocità della palla. L'inversione dell'anca è stata trovata presente durante il bot massimo e non durante il calcio submassimale.

ESAME E TERAPIA

L'esame dell'atleta con infortuni all'inguine secondo l'approccio dell'entità clinica (incontro di Doha per accordarsi sulla terminologia e le definizioni del dolore all'inguine negli atleti) può essere eseguito in maniera affidabile. Tuttavia non chiarisce il motivo per cui le azioni sportive come il calcio massimo e lo sprint provocano più spesso infortuni all'inguine. Per una migliore comprensione del meccanismo degli infortuni all'inguine, abbiamo analizzato due fenomeni biomeccanici specifici dello sport negli atleti. Nel **capitolo 7** abbiamo sviluppato un test ROM passivo specifico per lo sport, simulando l'arco di tensione e lo abbiamo studiato come misura di risultato in giocatori di calcio dilettanti e professionisti con e senza infortuni all'inguine correlati agli adduttori. Secondo questa procedura di test standardizzata abbiamo esaminato il ROM passivo dell'estensione dell'anca, dell'adduzione, dell'abduzione, della rotazione esterna e interna, misurando lo spazio di lavoro biologico dell'arco di tensione. Abbiamo sommato i ROM delle cinque dimensioni fino a un punteggio totale ROM. Abbiamo scoperto che i valori di riferimento delle gambe dominanti e non dominanti non infortunate erano simili in giocatori dilettanti e professionisti (ROM media totale di 188°) che potevano essere valutati in modo affidabile. Il ROM specifico per lo sport era diminuito nella gamba infortunata (ROM totale medio 136 °). La curva ROC ha rivelato che il punto di taglio ottimale era del 17% di asimmetria (32°) per distinguere accuratamente tra la gamba infortunata e quella non infortunata. La conseguenza clinica di questo risultato è che i giocatori infortunati non dispongono di un sufficiente pretensionamento specifico per lo sport e di conseguenza generano una velocità dell'anca più bassa durante il calcio.

Il **Capitolo 8** presenta uno studio sull'inclinazione pelvica attiva in atleti non infortunati e atleti con infortuni all'inguine. Abbiamo sviluppato una procedura di test attiva affidabile durante la quale gli atleti hanno dovuto eseguire l'inclinazione anteriore pelvica attiva ("lordosi") e l'inclinazione posteriore pelvica attiva ("schiena piatta"). Il ROM di entrambi i movimenti pelvici è stato sommato in un punteggio totale di inclinazione pelvica attivo. Abbiamo trovato che i valori di riferimento delle gambe dominanti e non dominanti erano simili negli atleti non infortunati. L'inclinazione pelvica attiva era più bassa sul lato infortunato rispetto al lato non infortunato. Riteniamo che questa disfunzione pelvica sia clinicamente rilevante in quanto la limitata decelerazione del fianco dell'anca impedisce che il flusso di energia efficiente sia compensato dal lavoro dei flessori dell'anca. Da questo punto di vista, il ripristino della capacità di inclinazione pelvica attiva sembra giustificato nei programmi di riabilitazione.

Vi è una moderata evidenza che il trattamento multimodale, inclusa la terapia manuale, accorcia il tempo necessario per tornare allo sport (12 settimane) rispetto all'uso ormai consolidato di esercizi attivi (18 settimane). Un ritardo di trattamento non necessario può verificarsi quando i programmi di riabilitazione sono applicati per un periodo fisso predeterminato. La decisione di tornare allo sport trascura poi la riduzione precoce dei sintomi. Nella nostra clinica abbiamo osservato che i giocatori tendono a tornare allo sport quando i loro livelli di sintomi lo consentono. Perciò nel **capitolo 9** si è studiato il tempo per tornare allo sport dopo la terapia manuale dei muscoli adduttori senza protocolli temporali contingenti in atleti con infortuni all'inguine legati all'adduttore. La tecnica di terapia manuale dei muscoli adduttori consisteva in una manovra di stretching in direzione prossimale verso l'osso pubico. Dopo 2 settimane l'82% e dopo 12 settimane l'88% degli atleti hanno riferito di giocare a calcio a livello pre-infortunio. Dovrebbe essere riconosciuto che la maggior parte dei giocatori ha ancora riscontrato un notevole livello di problemi relativi all'inguine, anche se erano tornati allo sport. Questo suggerisce che il tempo per tornare allo sport come fattore singolo non è un valido indicatore del successo del trattamento.

CONCLUSIONE

Il rischio di infortuni all'inguine nei giocatori olandesi è elevato. Soprattutto quelli con infortuni all'inguine con perdita di tempo di lunga data sembrano essere a rischio di recidiva e di gravi problemi legati all'inguine. La prevalenza degli infortuni all'inguine nelle donne dilettanti olandesi è paragonabile a quella dei professionisti olandesi maschi. La frequenza di infortuni all'inguine senza perdita di tempo era 3 volte superiore a quella con perdita di tempo. Precedenti infortuni alla caviglia, al ginocchio, alla coscia e alla spalla sono stati fattori di rischio per un successivo infortunio all'inguine. I deficit residui di infortuni precedenti possono modulare la biomeccanica dei calci, che può essere valutata con due nuovi test di valutazione specifici per lo sport di recente sviluppo. Questi test hanno dimostrato in modo affidabile un ROM ridotto dell'arco di tensione e del movimento pelvico attivo negli atleti con infortuni all'inguine. Durante il calcio, questi giocatori infortunati probabilmente non hanno il potenziale per un adeguato trasferimento di energia con conseguente compensazione del lavoro di flessione dell'anca. Il ripristino del meccanismo di infortunio mediante terapia manuale dei muscoli adduttori e interventi mirati per sciogliere l'arco di tensione ROM, l'inclinazione pelvica del ROM e il deficit di infortunio residuo sembrano meritare un posto nella sequenza di trattamento degli infortuni all'inguine. L'inventario consecutivo dei livelli dei sintomi e dei problemi dell'inguine può impedire che si verifichino infortuni di lunga durata o che si ripetano nel successivo precampionato. Da questo punto di vista non è stato ritenuto utile il controllo del ROM dell'anca per la prevenzione.

总结

探寻腹股沟损伤机理的复杂性

假设腹部和腹股沟结构在运动期间存在功能性上的相互依赖，则解剖结构体现了二者的融合紧密。复杂的腹股沟解剖结构阻碍了在损伤情况下评估局部解剖结构的可靠性和有效性。腹股沟损伤在田径运动中很常见，也是足球比赛中最常见的过劳损伤。尚不清楚是否存在高发病率、易复发及成为慢性病的风险。发病率统计数据表明了从欧洲到阿拉伯大陆的区域差异性，同时男性职业运动员的发病率似乎是女性运动员的两倍。发病率和患病率统计数据不尽相同，究其原因在于大多数研究者在腹股沟损伤的研究方法、分类和定义等方面存在显著差别，这些差别模糊了腹股沟损伤的真实情况。鉴于此，最近召开的关于运动员腹股沟疼痛术语和定义的多哈协议会议提出了临床分类系统和统一运动员腹股沟损伤术语的建议。强有力的证据表明，腹股沟旧伤和内收肌疲劳是导致腹股沟二次损伤的风险因素，但踢腿和短跑与旧伤复发的关系却一直没有答案。尽管已经有大量成功的多模式治疗方案，足球比赛中发生腹股沟损伤风险仍让人十分担忧，这与临床上缺乏相关的腹股沟病理学或功能障碍相矛盾。

本文旨在提供更多信息，助力揭示腹股沟损伤的复杂性。我们就此仔细研究了荷兰女性和男性足球运动员腹股沟损伤的症状及其发生率和程度，并研究了新的风险因素及踢腿机理。我们开发了功能评估测试，并通过人工按摩治疗内收肌对早期的恢复运动进行了研究。

损伤负荷

在**第二章**，我们仔细研究了434名荷兰女性业余足球运动员损伤的患病率和复发情况，该人群从未被研究过。总体伤病率很高（93%），非伤停期间运动员的伤病率是伤停期间运动员的两倍。腹股沟损伤是运动员非伤停期间最常见的伤病（36%），其发病率是伤停期间发生腹股沟损伤（11%）的三倍。我们还发现，一半左右（52%）腹股沟受过伤的人群会在下一个季前赛中腹股沟再次受伤。腹股沟损伤持续时间越长，出现复发、成为慢性病及发展为严重腹股沟问题的风险越高（臀部和腹股沟结果评分，即HAGOS评分低）。

在**第三章**，我们研究了这类人群中的伤病关系。需要注意，腹股沟受伤的运动员在同一赛季承受其他伤病的概率是腹股沟没有损伤的运动员的两倍。在之前赛季承受的位于腹股沟、膝盖和踝关节的伤病与下一个季前赛的腹股沟损伤有关（比值比（OR）分别为9.6、4.6和2.1）。我们还发现因腹股沟损伤而伤停的运动员出现了最为严峻的腹股沟相关问题（HAGOS）。

第四章介绍了一项前瞻性研究，调查了190名荷兰男子职业足球运动员腹股沟损伤的发病率和风险因素。我们发现季赛内伤停期间腹股沟损伤发病率为11%，四分之一的男性运动员（24%）在季前赛中出现腹股沟相关症状和问题（HAGOS）的风险较高，两者的结果与女性运动员相似（**第二章和第三章**）。我们在该人群中发现的患病率和发病率均低于北欧和阿拉伯专业球队。这可以通过接触、地区、比赛风格、训练强度和气候条件的差异来解释。

这项研究的主要发现是，之前赛季因踝关节、膝关节、大腿和肩关节长期（中位数为9周）伤停是随后下一赛季因腹股沟损伤而伤停的重大风险因素（风险比为5.1; 95%CI 1.8-14.6）。有人曾提出，旧伤的后遗症会影响踢腿和跑步的生物力学，从而髋屈肌需要进行补偿性工作。这项研究的结果似乎符合这一假设。此外，我们还发现之前因腹股沟损伤两次或更多次伤停会增加在季前赛中承受更高程度腹股沟相关问题风险（OR 3.0; 95% CI=1.0-8.3)。有限的证据表明，髋关节ROM（运动范围）减少是腹股沟损伤的风险因素，但由于ROM测量精度低，因此充分估算个体的风险程度是不可能的。髋关节ROM筛查确实无法让我们确认存在后续腹股沟损伤风险的球员。出于此原因，我们不能建议俱乐部的医务人员在季前赛筛选中执行这些措施。

损伤机理

踢腿是最常见的足以引起腹股沟损伤的为防止受伤，建议分足球运动动作。析风险因素调节运动任务机制的生物力学。通常这些机制表明，快速运动节段在方形或共线关节角度下的减速可通过运动链传递机械能，从而有助于提高球速和精度。第5章介绍了一项调查经验丰富的足球运动员在用最大力量踢球时身体部分协调情况的研究。我们在四个特定时刻（关键点）确定了11个峰值节段速度来反映踢腿机制的力量转移。在腿部后摆期间，踢腿侧臀部和非踢腿侧肩部伸展同时进行，从而形成全身张力弧。强力张力弧引起臀部肌肉的爆炸性收缩带来高速度的踢腿运动（髋屈曲）。髋关节屈曲减速峰值（髋关节翻转）和与膝关节方角的骨盆后倾角峰值速度同时（关键点Kf90）同步。髋关节逆转是在撞击球之前，髋关节将其运动从屈曲转向伸展的现象。由于骨盆后倾导致髋部伸展，我们建议精确的骨盆正时可以诱导髋关节翻转，从而有效地将能量从大腿转移到小腿。

后摆运动的范围对于肌筋膜结构的预拉伸很重要，前向摆动的ROM是发展节段速度的必要条件。在**第六章**中，我们研究了身体部分的ROM和经验丰富的足球运动员在次最大和最大力量踢球期间臀部逆转的情况。与次最大力量踢球时相比，我们发现在最大力量踢球时的张力弧、膝关节屈曲和伸展、骨盆后倾和脊柱屈曲的运动轨迹都有所增大。张力弧的增大主要是髋关节伸展和脊柱旋转增加的结果（效应大小（ES）分别为1.1和1.6）。腰椎脊柱屈曲和骨盆后倾，在运动中是耦合运动，表现出运动轨迹的最大相对增加（分别为ES 3.2和2.2）。这些发现表明，张力弧和骨盆的灵活性对于球速的提高是必不可少的。髋关节逆转在最大力量踢球中存在，在次最大力量踢球中则不存在。

检查与治疗

可根据临床实体法（关于运动员腹股沟疼痛术语和定义的多哈协议会议）检查存在腹股沟损伤的运动员。然而，该会议并没有解释为什么像最大幅度踢腿和短跑这样的运动行为是最常引起腹股沟损伤。为更深入了解腹股沟损伤的机理，我们分析了这两种运动的具体生物力学现象。在**第七章**，我们开发了一种针对运动的模拟张力弧的被动ROM测试，并就那些经历过或没有经历过与内收肌相关的腹股沟损伤的业余和职业足球运动员的测试结果进行研究。根据此标准化测试程序，我们检查了髋关节伸展、内收、外展、外部和内部旋转的被动ROM，以及测量了张力弧的生物工作空间。我们总结了五个维度的ROM来计算总ROM分数。我们发现没有受伤的业余和职业运动员的优势腿和非优势腿的可靠参考值相似

（平均总ROM为188°）。受伤腿的具体运动ROM减少（平均总ROM 136°）。ROC曲线显示最佳的截点为17%不对称（32°），以此可准确区分受伤和未受伤的腿。这一发现的临床推断是受伤的运动员缺乏足够的特定运动热身，因此在踢腿时臀部运动速率过低。
第8章介绍了一项关于未受伤运动员和腹股沟损伤运动员主动骨盆倾斜的研究。我们开发了一套可靠的主动测试程序，在此过程中运动员必须进行主动骨盆前倾（“背部后仰”）和主动骨盆后倾（“背部放平”）。将两个骨盆运动的ROM总计为一个完整的主动骨盆倾斜评分。我们发现，未受伤运动员优势腿和非优势腿的参考值相似。同时，与未受伤侧相比，受伤侧的主动骨盆倾斜程度较低。由此，我们认为这种骨盆功能障碍在临床上具有相关性，因为有限的侧腹髋关节减速度阻碍了髋屈肌补偿性工作的有效力量流。从这个角度来看，恢复主动骨盆倾斜能力似乎须列在康复计划中。
充分证据表明，与广泛采用的积极锻炼法（18周）相比，包含人工按摩治疗在内的多模式治疗法能缩短复健时间（12周）。当康复计划制定完成并用于预定时期时，可能会出现不必要的治疗拖延。随后运动复健就会忽视早期症状的缓解。在我们的临床实践中，我们观察到当症状水平允许时，运动员往往会重回运动场。因此，第9章研究了内收肌相关腹股沟损伤运动员在偶然期间没有诊断记录的情况下人工按摩治疗内收肌后恢复运动的时间。内收肌人工按摩治疗技术包括在朝向耻骨的近端方向上做伸展按摩动作。在2周时82%及12周时88%的运动员报告说他们已恢复到伤前水平。应该承认的一点是，即使运动员重回运动场，他们中的大多数仍会承受大量与腹股沟相关的问题。这表明将重返运动场的时间这一因素作为治疗成功的指标并不合适。

结论

荷兰足球运动员发生腹股沟损伤的风险很高。特别是那些因腹股沟损伤而长期伤停的运动员似乎有复发和出现严重腹股沟相关问题的风险。荷兰女性业余运动员的腹股沟损伤发病率与荷兰男性专业运动员相当。非伤停期间发生腹股沟损伤的概率是伤停期间的三倍。之前因踝关节、膝盖、大腿和肩部损伤而长期伤停是随后腹股沟损伤的风险因素。旧伤的后遗症可能会调节踢腿的生物力学，这可以通过两项新开发的运动特定评估测试来评估。这些测试可靠地证明了腹股沟损伤运动员张力弧和主动骨盆运动的ROM降低。在踢腿时，这些带伤运动员可能无法将适当力量转移出去，这会导致髋屈肌的补偿性工作。在腹股沟损伤的治疗顺序中，通过人工按摩治疗内收肌恢复损伤机理和有针对性地干预、消除ROM张力弧、ROM骨盆倾斜及损伤后遗症似乎应占有一席之地。连续记录关于腹股沟症状和问题水平可以避免长期伤病或下一个季前赛中旧病复发。从该角度出发，使用髋关节ROM筛查来预防伤病并没有得到证实。

ADDENDUM

References

1. Werner J, Hägglund M, Waldén 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. doi:10.1136/bjsm.2009.066944.
2. 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. doi:10.1136/bjsports-2013-092263.
3. Thorborg K, Rathleff MS, Petersen P, Branci S, Hölmich 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 Sport.* 2015;27(1):107-114. doi:10.1111/sms.12623.
4. 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. doi:10.1136/bjsports-2014-094287.
5. 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. doi:10.1136/bjsports-2015-094869.
6. World Health Organization (WHO). 4th Edition of ICD-10. 2010.
7. Heerkens Y, Hirs W, M, De Kleijn-de Vrankrijker M, CD VR, Ten Napel H. Nederlandse WHO Collaborating Centre for the Family of International Classifications (68). Nederlandse Vertaling van de International Classification of Functioning , Disability and Health. *Bilthoven; RIVM.* 2002.
8. Van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Med.* 1992;14(2):82-99. doi:10.2165/00007256-199214020-00002.
9. Bahr R, Krosshaug T. Understanding injury mechanisms: a key component of preventing injuries in sport. *Br J Sports Med.* 2005;39(6):324-329. doi:10.1136/bjsm.2005.018341.
10. Holmich P, Renstrom PA. Long-standing groin pain in sportspeople falls into three primary patterns, a "clinical entity" approach: a prospective study of 207 patients. *Br J Sports Med.* 2007;41(4):247-252. doi:10.1136/bjsm.2006.033373.
11. Falvey EC, Franklyn-Miller A, McCrory PR. The groin triangle: a patho-anatomical approach to the diagnosis of chronic groin pain in athletes. *Br J Sports Med.* 2009;43(3):213-220. doi:10.1136/bjsm.2007.042259.
12. Schilders E, Bharam S, Golan E, et al. The pyramidalis–anterior pubic ligament–adductor longus complex (PLAC) and its role with adductor injuries: a new anatomical concept. *Knee Surgery, Sport Traumatol Arthrosc.* 2017;25(12):3969-3977. doi:10.1007/s00167-017-4688-2.
13. Robertson BA, Barker PJ, Fahrer M, Schache AG. The anatomy of the pubic region revisited: Implications for the pathogenesis and clinical management of chronic groin pain in athletes. *Sport Med.* 2009;39(3):225-234. doi:10.2165/00007256-200939030-00004.
14. Davis JA, Stringer MD, Woodley SJ. New insights into the proximal tendons of adductor longus, adductor brevis and gracilis. *Br J Sports Med.* 2012;46(12):871-876. doi:10.1136/bjsports-2011-090044.
15. Knox R. A system of human anatomy: on the basis of the "Traite d'anatomie descriptive". In: Cloquet MH, ed. 2nd ed. Edinburgh: MacLachlan and Stewart; 1831.
16. Bell J, Bell C. The anatomy of the human body. In: edn. Longman, Hurst R, Orme, eds. 4th ed. London. T. Cadell and W. Davies, Strand; 1816.
17. Strauss EJ, Campbell K, Bosco JA. Analysis of the cross-sectional area of the adductor longus tendon: a descriptive anatomic study. *Am J Sports Med.* 2007;35(6):996-999. doi:10.1177/0363546506298583.
18. Reiman MP, Thorborg K. Clinical examination and physical assessment of hip joint-related pain in athletes. *Int J Sports Phys Ther.* 2014;9(6):737-755. http://www.ncbi.nlm.nih.gov/pubmed/25383243.
19. Tijssen M, Van Cingel R, Willemsen L, De Visser E. Diagnostics of femoroacetabular impingement and labral pathology of the hip: A systematic review of the accuracy and validity of physical tests. *Arthrosc - J Arthrosc Relat Surg.* 2012;28(6):860-871. doi:10.1016/j.arthro.2011.12.004.
20. Hölmich P, Hölmich LR, Bjerg AM. Clinical examination of athletes with groin pain: an intraobserver and interobserver reliability study. *Br J Sports Med.* 2004;38(4):446-451. doi:10.1136/bjsm.2003.004754.
21. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Clin J Sport Med.* 2006;16(2):97-106. http://www.ncbi.nlm.nih.gov/pubmed/16603877.

22. Waldén M, Hägglund 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. doi:10.1136/bjsports-2015-094705.
23. Harøy J, Clarsen B, Thorborg K, Hölmich 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. doi:10.1177/0363546516687539.
24. 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. doi:10.1136/bjsports-2016-096619.
25. Dompier TP, Powell JW, Barron MJ, Moore MT. Time-loss and non-time-loss injuries in youth football players. *J Athl Train.* 42(3):395-402. http://www.ncbi.nlm.nih.gov/pubmed/18059996.
26. Powell JW, Dompier TP. Analysis of Injury Rates and Treatment Patterns for Time-Loss and Non-Time-Loss Injuries among Collegiate Student-Athletes. *J Athl Train.* 2004;39(1):56-70.
27. Clarsen B, Bahr R. Matching the choice of injury/illness definition to study setting, purpose and design: one size does not fit all! *Br J Sports Med.* 2014;48(7):510-512. doi:10.1136/bjsports-2013-093297.
28. Stubbe JH, van Beijsterveldt A-MMC, 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. doi:10.4085/1062-6050-49.3.64.
29. 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. doi:10.1136/bjsports-2016-097277.
30. Hägglund M, Waldén M, Ekstrand J. Injury incidence and distribution in elite football--a prospective study of the Danish and the Swedish top divisions. *Scand J Med Sci Sports.* 2005;15(1):21-28. doi:10.1111/j.1600-0838.2004.00395.x.
31. Orchard JW. Men at higher risk of groin injuries in elite team sports: A systematic review. *Br J Sports Med.* 2015;49(12):798-802. doi:10.1136/bjsports-2014-094272.
32. Delahunt E, Thorborg K, Khan KM, Robinson P, Hölmich P, Weir A. Minimum reporting standards for clinical research on groin pain in athletes. *Br J Sports Med.* 2015;49(12):775-781. doi:10.1136/bjsports-2015-094839.
33. Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. *Br J Sports Med.* 2011;45(7):553-558. doi:10.1136/bjsm.2009.060582.
34. 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. doi:10.1177/0363546510375544.
35. Hägglund M, Waldén 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. doi:10.1136/bjsm.2006.026609.
36. Thorborg K, Branci S, Stensbirk F, Jensen J, Hölmich 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. doi:10.1136/bjsports-2013-092607.
37. 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. doi:10.2519/jospt.2018.7883.
38. ellis E, Katis A. The relationship between isokinetic knee extension and flexion strength with soccer kick kinematics: An electromyographic evaluation. *J Sports Med Phys Fitness.* 2007;47:385-394. https://www.ncbi.nlm.nih.gov/pubmed/?term=The+relationship+between+isokinetic+knee+extension+and+flexion+strength+with+soccer+kick+kinematics%3A+An+electromyographic+evaluation.
39. Meeuwisse WH, Tyreman H, Hagel B, Emery C. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clin J Sport Med.* 2007;17(3):215-219. doi:10.1097/JSM.0b013e3180592a48.
40. Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? *Br J Sports Med.* 2016;50(5):273-280. doi:10.1136/bjsports-2015-095788.

41. Meeuwisse WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med.* 1994;4(3):166-170. doi:10.1097/00042752-199407000-00004
42. Toohey LA, Drew MK, Cook JL, Finch CF, Gaida JE. Is subsequent lower limb injury associated with previous injury? A systematic review and meta-analysis. *Br J Sports Med.* 2017;51(23):1670-1678. doi:10.1136/bjsports-2017-097500.
43. Verrall GM, Esterman A, Hewett TE. Analysis of the three most prevalent injuries in australian football demonstrates a season to season association between groin/hip/osteitis pubis injuries with acl knee injuries. *Asian J Sports Med.* 2014;5(3):e23072. doi:10.5812/asjsm.23072.
44. Verrall GM, Slavotinek JP, Barnes PG, Esterman A, Oakeshott RD, Spriggins AJ. Hip joint range of motion restriction precedes athletic chronic groin injury. *J Sci Med Sport.* 2007;10(6):463-466. doi:10.1016/j.jsams.2006.11.006.
45. Mosler AB, Agricola R, Weir A, Hölmich P, Crossley KM. Which factors differentiate athletes with hip/groin pain from those without? A systematic review with meta-analysis. *Br J Sports Med.* 2015;49(12):810. doi:10.1136/bjsports-2015-094602.
46. 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.* 2015;44(3):682-688. doi:10.1177/0363546515617747.
47. Serner A, Tol JL, Jomaah N, Weir A, Whiteley R, Thorborg K, Robinson M, Hölmich P. Diagnosis of Acute Groin Injuries: A Prospective Study of 110 Athletes. *Am J Sports Med.* 2015;43(8):1857-1864. doi:10.1177/0363546515585123.
48. Tak I, Langhout R. Groin injury in soccer. *Aspeter Sport Med J.* 2014;3(TT4):272-277.
49. Whiting W, Zernicke R. Biomechanics of musculoskeletal injury. In: Human Kine. Champaign, IL; 1998.
50. McIntosh AS. Risk compensation, motivation, injuries, and biomechanics in competitive sport. *Br J Sports Med.* 2005;39(1):2-3. doi:10.1136/bjsm.2004.016188.
51. Burgess-Limerick R, Abernethy B, Neal RJ. Relative phase quantifies interjoint coordination. *J Biomech.* 1993;26(1):91-94. http://www.ncbi.nlm.nih.gov/pubmed/8423174.
52. Hamill J, van Emmerik RE, Heiderscheit BC, Li L. A dynamical systems approach to lower extremity running injuries. *Clin Biomech (Bristol, Avon).* 1999;14(5):297-308. http://www.ncbi.nlm.nih.gov/pubmed/10521606.
53. Scholz JP. Dynamic pattern theory--some implications for therapeutics. *Phys Ther.* 1990;70(12):827-843. doi:10.1093/ptj/70.12.827
54. Bizzi E, Cheung VCK. The neural origin of muscle synergies. *Front Comput Neurosci.* 2013;7(April):51. doi:10.3389/fncom.2013.00051.
55. Turvey MT. Coordination. *Am Psychol.* 1990;45(8):938-953. http://www.ncbi.nlm.nih.gov/pubmed/2221565.
56. Stergiou N, Jensen JL, Bates BT, Scholten SD, Tzetzis G. A dynamical systems investigation of lower extremity coordination during running over obstacles. *Clin Biomech* (Bristol, Avon). 2001;16(3):213-221. http://www.ncbi.nlm.nih.gov/pubmed/11240056.
57. Juárez D, Mallo J, De Subijana C, Navarro E. Kinematic analysis of kicking in young top-class soccer players. *J Sports Med Phys Fitness.* 2011;51(3):366-373. http://europepmc.org/abstract/med/21904274. Accessed December 28, 2014.
58. Dörge HC, Anderson TB, Sørensen H, Simonsen EB. Biomechanical differences in soccer kicking with the preferred and the non-preferred leg. *J Sports Sci.* 2002;20(4):293-299. doi:10.1080/026404102753576062.
59. Nunome H, Asai T, Ikegami Y, Sakurai S. Three-dimensional kinetic analysis of side-foot and instep soccer kicks. *Med Sci Sports Exerc.* 2002;34(12):2028-2036. doi:10.1249/01.MSS.0000039076.43492.EF.
60. Putnam CA. A segment interaction analysis of proximal-to-distal sequential segment motion patterns. *Med Sci Sport Exerc.* 1991;23(1):130-144. doi:10.1249/00005768-199101000-00019.
61. De Witt JK, Hinrichs RN. Mechanical factors associated with the development of high ball velocity during an instep soccer kick. *Sport Biomech.* 2012;11(3):382-390. doi:10.1080/14763141.2012.661757.

62. Huang L, Liu Y, Wei S, et al. Segment-interaction and its relevance to the control of movement during sprinting. *J Biomech.* 2013;46(12):2018-2023. doi:10.1016/j.jbiomech.2013.06.006.
63. Fregly BJ, Zajac FE. A state-space analysis of mechanical energy generation, absorption, and transfer during pedaling. *J Biomech.* 1996;29:81-90. doi:10.1016/0021-9290(95)00011-9.
64. Zajac FE, Neptune RR, Kautz SA. Biomechanics and muscle coordination of human walking. Part I: introduction to concepts, power transfer, dynamics and simulations. *Gait Posture.* 2002;16(3):215-232. doi:10.1016/S0966-6362(02)00069-3.
65. Naito K, Fukui Y, Maruyama T. Multijoint kinetic chain analysis of knee extension during the soccer instep kick. *Hum Mov Sci.* 2010;29(2):259-276. doi:10.1016/j.humov.2009.04.008.
66. Jones KE, Hamilton AFDC, Wolpert DM. Sources of signal-dependent noise during isometric force production. *J Neurophysiol.* 2002;88(3):1533-1544. doi:10.1152/jn.00985.2001.
67. Egan CD, Verheul MHG, Savelsbergh GJP. Effects of experience on the coordination of internally and externally timed soccer kicks. *J Mot Behav.* 2007;39(5):423-432. doi:10.3200/JMBR.39.5.423-432.
68. Graven-Nielsen T, Svensson P, Arendt-Nielsen L. Effects of experimental muscle pain on muscle activity and co-ordination during static and dynamic motor function. *Electroencephalogr Clin Neurophysiol - Electromyogr Mot Control.* 1997;105(2):156-164. doi:10.1016/S0924-980X(96)96554-6.
69. Hölmich P, Thorborg K, Dehlendorff C, Krogsgaard K, Gluud C. Incidence and clinical presentation of groin injuries in sub-elite male soccer. *Br J Sports Med.* 2013;48(16):1245-1250. doi:10.1136/bjsports-2013-092627.
70. Brophy RH, Backus SI, Pansy BS, Lyman S, Williams RJ. Lower extremity muscle activation and alignment during the soccer instep and side-foot kicks. *J Orthop Sports Phys Ther.* 2007;37(5):260-268. doi:10.2519/jospt.2007.2255.
71. Shan G, Westerhoff P. Full-body kinematic characteristics of the maximal instep soccer kick by male soccer players and parameters related to kick quality. *Sports Biomech.* 2005;4(1):59-72. http://www.tandfonline.com/doi/abs/10.1080/14763140508522852. Accessed January 14, 2015.
72. Bober T, Putnam C, Woodworth GG. Factors influencing the angular velocity of a human limb segment. *J Biomech.* 1987;20(5):511-521. doi:10.1016/0021-9290(87)90251-X.
73. Shan G. Influence of gender and experience on the maximal instep soccer kick. *Eur J Sport Sci.* 2009;9(2):107-114. doi:10.1080/17461390802594250.
74. Dörge HC, Andersen TB, Sørensen H, et al. EMG activity of the iliopsoas muscle and leg kinetics during the soccer place kick. *Scand J Med Sci Sports.* 1999;9:195-200. doi:10.1111/j.1600-0838.1999.tb00233.x.
75. Nunome H, Ikegami Y, Kozakai R, Apriantono T, Sano S. Segmental dynamics of soccer instep kicking with the preferred and non-preferred leg. *J Sports Sci.* 2006;24(5):529-541. doi:10.1080/02640410500298024.
76. Robertson D, Mosher P. Work and power of the leg muscles in soccer kicking. In: Winter D, Norman R, Wells R, Hayes K, Patla A, eds. Champaign, IL; 1985:533-538.
77. Lees A, Asai T, Andersen TB, Nunome H, Sterzing T. The biomechanics of kicking in soccer: A review. J Sports Sci. 2010;28(8):805-817. doi:10.1080/02640414.2010.481305.
78. Levanon J, Dapena J. Comparison of the kinematics of the full-instep and pass kicks in soccer. *Med Sci Sports Exerc.* 1998;30(6):917-927. doi:10.1097/00005768-199806000-00022.
79. Apriantono T, Nunome H, Ikegami Y, Sano S. The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. *J Sports Sci.* 2006;24(9):951-960. doi:10.1080/02640410500386050.
80. De Sa D, Hölmich P, Phillips M, et al. Athletic groin pain: A systematic review of surgical diagnoses, investigations and treatment. *Br J Sports Med.* 2016;50(19):1181-1186. doi:10.1136/bjsports-2015-095137.
81. Serner A, Van Eijck CH, Beumer BR, Hölmich P, Weir A, De Vos RJ. Study quality on groin injury management remains low: A systematic review on treatment of groin pain in athletes. *Br J Sports Med.* 2015;49(12):813. doi:10.1136/bjsports-2014-094256.
82. King E, Ward J, Small L, Falvey E, Franklyn-Miller A. Athletic groin pain: A systematic review and meta-analysis of surgical versus physical therapy rehabilitation outcomes. *Br J Sports Med.* 2015;49(22):1447-1451. doi:10.1136/bjsports-2014-093715.

83. Hölmich P, Uhrskou P, Ulnits L, et al. Effectiveness of active physical training as treatment for long- standing adductor-related groin pain in athletes: randomised trial. *Lancet.* 1999;353(9151):439-443. doi:10.1016/S0140-6736(98)03340-6.
84. Weir A, Jansen JACG, van de Port IGL, Van de Sande HBA, Tol JL, Backx FJG. Manual or exercise therapy for long-standing adductor-related groin pain: a randomised controlled clinical trial. *Man Ther.* 2011;16(2):148-154. doi:10.1016/j.math.2010.09.001.
85. Stegen J, Stubbe JH. Injuries in Female Football. Factsheet BIS/TNO. 2009:1-4.
86. Engström B, Johansson C, Törnkvist H. Soccer injuries among elite female players. *Am J Sports Med.* 19(4):372-375. doi:10.1177/036354659101900408.
87. Jacobson I, Tegner Y. Injuries among Swedish female elite football players: a prospective population study. *Scand J Med Sci Sports.* 2007;17(1):84-91. doi:10.1111/j.1600-0838.2006.00524.x.
88. Langhout R, Tak I, van Beijsterveldt A-M, Ricken M, Weir A, Barendrecht M, Kerkhoffs G, Stubbe J. 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. doi:10.2519/jospt.2018.7990.
89. Söderman K, Adolphson J, Lorentzon R, Alfredson H. Injuries in adolescent female players in European football: A prospective study over one outdoor soccer season. *Scand J Med Sci Sport.* 2001;11(5):299-304. doi:10.1034/j.1600-0838.2001.110508.x.
90. Patrick DL, Burke LB, Powers JH, et al. Patient-reported outcomes to support medical product labeling claims: FDA perspective. *Value Health.* 10 Suppl 2:S125-37. doi:10.1111/j.1524-4733.2007.00275.x.
91. Von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. *Int J Surg.* 2014;12(12):1495-1499. doi:10.1016/j.ijsu.2014.07.013.
92. Rae K, Orchard J. The Orchard Sports Injury Classification System (OSICS) version 10. *Clin J Sport Med.* 2007;17(3):201-204. doi:10.1097/JSM.0b013e318059b536.
93. Thorborg K, Hölmich P, Christensen R, Petersen J, Roos EM. The Copenhagen Hip and Groin Outcome Score (HAGOS): Development and validation according to the COSMIN checklist. *Br J Sports Med.* 2011;45(6):478-491. doi:10.1136/bjsm.2010.080937.
94. Dijkstra P, Pollock N, Chakraverty R, Alonso JM. Managing the health of the elite athlete: a new integrated performance health management and coaching model. *Br J Sports Med.* 2014;48(7):523-531. doi:10.1136/bjsports-2013-093222.
95. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA.* 2013;310(20):2191-2194. doi:10.1001/jama.2013.281053.
96. Wingfield K. Neuromuscular training to prevent knee injuries in adolescent female soccer players. *Clin J Sport Med.* 2013;23(5):407-408. doi:10.1097/01.jsm.0000433153.51313.6b.
97. Karlsson MK, Dahan R, Magnusson H, Nyquist F, Rosengren BE. Geschlechtsspezifische unterschiede von leistenschmerzen im fußball. *Dtsch Z Sportmed.* 2014;65(2):38-42. doi:10.5960/dzsm.2013.095.
98. Bahr R. No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. *Br J Sports Med.* 2009;43(13):966-972. doi:10.1136/bjsm.2009.066936.
99. Waldén M, Hägglund M, Orchard J, Kristenson K, Ekstrand J. Regional differences in injury incidence in European professional football. *Scand J Med Sci Sport.* 2013;23(4):424-430. doi:10.1111/j.1600-0838.2011.01409.x.
100. Östenberg A, Roos H. Injury risk factors in female European football. A prospective study of 123 players during one season. *Scand J Med Sci Sport.* 2000;10(5):279-285. doi:10.1034/j.1600-0838.2000.010005279.x.
101. Langhout R, Weir A, Litjes W, Gozeling M, Stubbe J, Kerkhoffs G, Tak I. Hip and groin injury is the most common non-time-loss injury in female amateur football. *Knee Surg Sports Traumatol Arthrosc.* 2018. doi:10.1007/s00167-018-4996-1 [Epub ahead of print]
102. Finch CF, Cook J, Kunstler BE, Akram M, Orchard J. Subsequent injuries are more common than injury recurrences: An analysis of 1 season of prospectively collected injuries in professional australian football. *Am J Sports Med.* 2017;45(8):1921-1927. doi:10.1177/0363546517691943.
103. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med.* 29(3):300-303. doi:10.1177/03635465010290030801.

104. Tak IJR, Langhout RFH, Groters S, Weir A, Stubbe JH, Kerkhoffs GMMJ. A new clinical test for measurement of lower limb specific range of motion in football players: Design, reliability and reference findings in non-injured players and those with long-standing adductor-related groin pain. *Phys Ther Sport.* 2017;23:67-74. doi:10.1016/j.ptsp.2016.07.007.
105. Langhout R, Weber M, Tak I, Lenssen T. Timing characteristics of body segments during the maximal instep kick in experienced football players. *J Sports Med Phys Fitness.* 2016;56(7-8):849-856. http://www.ncbi.nlm.nih.gov/pubmed/26129917.
106. Windt J, Gabbett TJ. How do training and competition workloads relate to injury? The workload-injury aetiology model. *Br J Sports Med.* 2017;51(5):428-435. doi:10.1136/bjsports-2016-096040.
107. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med.* 2009;32:5S-16S. doi:10.1177/0363546503258912.
108. Hägglund M, Waldén 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. doi:10.1177/0363546512470634.
109. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med.* 2011;39(6):1226-1232. doi:10.1177/0363546510395879.
110. 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. doi:10.1136/bjsports-2016-096278.
111. 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. doi:10.1016/j.jsams.2016.05.010.
112. Lea RD, Gerhardt JJ. Range-of-motion measurements. *J Bone Joint Surg Am.* 1995;77(5):784-798. http://www.ncbi.nlm.nih.gov/pubmed/7744906.
113. Nussbaumer S, Leunig M, Glatthorn JF, Stauffacher S, Gerber H, Maffiuletti N a. 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. doi:10.1186/1471-2474-11-194.
114. 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. https://www.ncbi.nlm.nih.gov/pubmed.21091412.
115. Drew MK, Lovell G, Palsson TS, Chiarelli PE, Osmotherly PG. Australian football players experiencing groin pain exhibit reduced subscale scores of Activities of Daily Living and Sport and Recreation on the HAGOS questionnaire: A case-control study. *Phys Ther Sport.* 2017;26:7-12. doi:10.1016/j.ptsp.2017.04.004.
116. Hawkins RD, Fuller CW. A prospective epidemiological study of injuries in four English professional football clubs. *Br J Sports Med.* 1999;33(3):196-203.
117. Bahr R. Why screening tests to predict injury do not work-and probably never will...: a critical review. *Br J Sports Med.* 2016;50(13):776-780. doi:10.1136/bjsports-2016-096256.
118. Langhout R, Tak I, van der Westen R, Lenssen T. Range of motion of body segments is larger during the maximal instep kick than during the submaximal instep kick in experienced football players. *J Sport Med Phys Fitness.* 2017;57(4):388-395. doi:10.23736/S0022-4707.16.06107-7.
119. Severin AC, Mellifont DB, Sayers MGL. Influence of previous groin pain on hip and pelvic instep kick kinematics. *Sci Med Footb.* 2017;1(1):80-85. doi:10.1080/02640414.2016.1221527.
120. Finch CF, Cook J. Categorising sports injuries in epidemiological studies: the subsequent injury categorisation (SIC) model to address multiple, recurrent and exacerbation of injuries. *Br J Sports Med.* 2014;48(17):1276-1280. doi:10.1136/bjsports-2012-091729.
121. Bahr R, Holme I. Risk factors for sports injuries,a methodological approach. *Br J Sports Med;* 2003;37(5):384-392. doi: 10.1136/bjsm.37.5.384
122. Lees A, Nolan L. The biomechanics of soccer: a review. *J Sports Sci.* 1998;16(3):211-234. doi:10.1080/026404198366740.
123. Andersen T, Dörge H, Thomsen F. Collisions in soccer kicking. *Sport Eng.* 2002;2:121-125. doi: 10.1046/j.1460-2687.1999.00015.x.
124. Asami T, Togashi H. Study on kicking in soccer. *J Phys Educ Hlth Sport Sci.* 1968;12:267-272.

125. Rahnama N, Reilly T, Lees A. Injury risk associated with playing actions during competitive soccer. *Br J Sports Med.* 2002;36:354-360. doi:10.1136/bjsm.36.5.354.
126. Verrall G, Slavotinek J, Fon G. Incidence of pubic bone marrow oedema in Australian rules football players: relation to groin pain. *Br J Sports Med.* 2001:28-33. http://bjsm.bmj.com/content/35/1/28.short. Accessed January 18, 2015.
127. Shan G, Zhang X. From 2D leg kinematics to 3D full-body biomechanics-the past , present and future of scientific analysis of maximal instep kick in soccer. *Sport Med Arthrosc Rehabil Ther Technol.* 2011;3(1):23. https://doi.org/10.1186/1758-2555-3-23.
128. Glazier P, Davids K, Bartlett RRM. Dynamical systems theory: A relevant framework for performance-oriented sports biomechanics research. *SportScience*. 2003;7(1997):1-8. http://www.sportsci.org/jour/03/psg.htm.
129. Lees A, Steward I, Rahnama N, Barton G. Lower limb function in the maximal instep kick in soccer. In: Reilly T, Atkinson G, eds. *Contemporary Sport, Leisure and Ergonomics*. Oxford: Routledge;2009:149-160. https://doi.org/10.1080/02640414.2010.481305.
130. Barfield W. Effects of selected kinematic and kinetic variables on instep kicking with dominant and nondominant limbs. *J Hum Mov Stud.* 1995;6(29):251-272. https://www.bisp-surf.de/Record/PU199608109643.
131. Zajac FE. Understanding muscle coordination of the human leg with dynamical simulations. *J Biomech.* 2002;35(8):1011-1018. https://doi.org/10.1016/S0021-9290(02)00046-5simulations.http://www.ncbi.nlm.nih.gov/pubmed/12126660.
132. Naito K, Fukui Y, Maruyama T. Energy redistribution analysis of dynamic mechanisms of multi-body, multi-joint kinetic chain movement during soccer instep kicks. *Humov.* 2012;31(1):161-181. doi:10.1016/j.humov.2010.09.006.
133. Putnam CA. Sequential motions of body segments in striking and throwing skills: descriptions and explanations. *J Biomech*. 1993;26:125-135. http://www.sciencedirect.com/science/article/pii/002192909390084R. Accessed January 18, 2015.
134. Luthanen P. Kinematics and kinetics of maximal instep kicking in junior soccer players. In: Reilly T, Lees A, Davis A, Murphy W, eds. *Science and Football.* London: E & FN Spon; 1988:143-148.
135. Zajac F, Neptune R, Kautz S. Biomechanics and muscle coordination of human walking: part II: lessons from dynamical simulations and clinical implications. *Gait Posture.* 2003;17. http://www.sciencedirect.com/science/article/pii/S0966636202000693. Accessed January 18, 2015.
136. Ross JR, Nepple JJ, Philippon MJ, Kelly BT, Larson CM, Bedi A. Effect of changes in pelvic tilt on range of motion to impingement and radiographic parameters of acetabular morphologic characteristics. *Am J Sports Med.* 2014;42(10):2402-2409. doi:10.1177/0363546514541229.
137. Schache AG, Blanch PD, Murphy AT. Relation of anterior pelvic tilt during running to clinical and kinematic measures of hip extension. *Br J Sports Med.* 2000;34(4):279-283. doi:10.1136/bjsm.34.4.279.
138. ellis E, Katis A. The relationship between isokinetic knee extension and flexion strength with soccer kick kinematics: An electromyographic evaluation. *J Sports Med Phys Fitness.* 2007;47:385-394. https://www.ncbi.nlm.nih.govpubmed/?term=The+relationship+between+isokinetic+knee+extension+and+flexion+strength+with+soccer+kick+kinematics%3A+An+electromyographic+evaluation.
139. Katis A, Giannadakis E, Kannas T. Mechanisms that influence accuracy of the soccer kick. *J Electromyogr Kinesiol.* 2013.;23(1):125-131. doi:10.1016/j.jelekin.2012.08.020.
140. Andersen TB, Dörge HC. The influence of speed of approach and accuracy constraint on the maximal speed of the ball in soccer kicking. *Scand J Med Sci Sports.* 2011;21(1):79-84. doi:10.1111/j.1600-0838.2009.01024.x.
141. Masuda K, Kikuhara N, Demura S, Katsuta S, Yamanaka K. Relationship between muscle strength in various isokinetic movements and kick performance among soccer players. *J Sports Med Phys Fitness.* 2005;45(1):44-52. doi:10.1016/j.jconhyd.2010.08.009.
142. Young W, Clothier P, Otago L, Bruce L, Liddell D. Acute effects of static stretching on hip flexor and quadriceps flexibility, range of motion and foot speed in kicking a football. *J Sci Med Sport*. 2004;7(1):23-31. doi:10.1016/S1440-2440(04)80040-9.

143. Charnock BL, Lewis CL, Garrett WE, Queen RM. Adductor longus mechanics during the maximal effort soccer kick. *Sport Biomech.* 2009;8(3):223-234. doi:10.1080/14763140903229500.
144. Ibrahim A, Murrell G, Knapman P. Adductor strain and hip range of movement in male professional soccer players. *J Orthop Surg (Hong Kong).* 2007;15(1):46-49. https://doi.org/10.1177/230949900701500111.
145. Verrall GM, Hamilton IA, Slavotinek JP, et al. Hip joint range of motion reduction in sports-related chronic groin injury diagnosed as pubic bone stress injury. *J Sci Med Sport.* 2005;8(1):77-84. http://www.ncbi.nlm.nih.gov/pubmed/15887904.
146. Tak IJR, Langhout RFH. Groin injury in soccer. Steps towards a sport-specific approach. From hypothesis to physical examination and treatment. *Aspetar Sport Med J.* 2014;6:272-277.
147. Zernicke R, Roberts E. Lower extremity forces and torques during systematic variation of non-weight bearing motion. *Med Sci Sport.* 1978;10:21-26. http://europepmc.org/abstract/MED/672547.
148. Cavagna GA. Storage and utilization of elastic energy in skeletal muscle. Exerc Sport Sci Rev. 1977;5:89-129. http://www.ncbi.nlm.nih.gov/pubmed/99306.
149. Kapandji I. The Physiology of the Joints: The Lower Limb Volume Two. 6th ed. London: Elsevier Health Sciences; 2010.
150. Schache AG, Blanch P, Rath D, Wrigley T, Bennell K. Three-dimensional angular kinematics of the lumbar spine and pelvis during running. *Hum Mov Sci.* 2002;21(2):273-293. http://www.ncbi.nlm.nih.gov/pubmed/12167303.
151. Geraci MC. Overuse injuries of the hip and pelvis. *J Back Musculoskelet Rehabil.* 1996;6(1):5-19. doi:10.3233/BMR-1996-6103.
152. Watson A. Sports injuries in footballers related to defects of posture and body mechanics. *J Sports Med Phys Fitness.* 1995;35:289-294. https://www.ncbi.nlm.nih.gov/pubmed/8776077.
153. Kellis E, Katis A, Gissis I. Knee biomechanics of the support leg in soccer kicks from three angles of approach. *Med Sci Sports Exerc.* 2004;36(6):1017-1028. https://www.ncbi.nlm.nih.gov/pubmed/15179172.
154. Dallinga JM, Benjaminse A, Lemmink K a PM. Which screening tools can predict injury to the lower extremities in team sports?: a systematic review. *Sports Med.* 2012;42(9):791-815. doi:10.2165/11632730-000000000-00000.
155. Williams JG. Limitation of hip joint movement as a factor in traumatic osteitis pubis. *Br J Sports Med.* 1978;12(3):129-133. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1859670/.
156. Birmingham PM, Kelly BT, Jacobs R, McGrady L, Wang M. The effect of dynamic femoroacetabular impingement on pubic symphysis motion: a cadaveric study. *Am J Sports Med.* 2012;40(5):1113-1118. doi:10.1177/0363546512437723.
157. 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. doi:10.1177/0363546512441328.
158. Hegedus EJ, Stern B, Reiman MP, Tarara D, Wright A a. A suggested model for physical examination and conservative treatment of athletic pubalgia. *Phys Ther Sport.* 2013;14(1):3-16. doi:10.1016/j.ptsp.2012.04.002.
159. Holmich P. Goin pain in football players: A systematic diagnostic approach. *Aspetar Sport Med J.* 2013;2(TT1):192-196.
160. Tak IJR, Weir A, Langhout RFH. Clinical biomechanics of the soccer instep kick in relation to groin pain. Flemish/Dutch *J Sport Medine Sport Sci.* 2012;1(1):18-26 [Dutch].
161. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977;33(1):159-174. https://www.ncbi.nlm.nih.gov/pubmed/843571.
162. Van der Roer N, Ostelo RWJG, Bekkering GE, van Tulder MW, de Vet HCW. Minimal clinically important change for pain intensity, functional status, and general health status in patients with nonspecific low back pain. *Spine (Phila Pa 1976)*. 2006;31(5):578-582. doi:10.1097/01.brs.0000201293.57439.47.
163. Herrington L, Rivett N, Munro S. The relationship between patella position and length of the iliotibial band as assessed using Ober's test. *Man Ther.* 2006;11(3):182-186. doi:10.1016/j.math.2006.06.008.

164. 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. doi:10.1136/bjsm.2008.055749.
165. Manning C, Hudson Z. Comparison of hip joint range of motion in professional youth and senior team footballers with age-matched controls: an indication of early degenerative change? *Phys Ther Sport.* 2009;10(1):25-29. doi:10.1016/j.ptsp.2008.11.005.
166. Brophy RH, Chiaia TA, Maschi R, et al. the core and hip in soccer athletes compared by gender. *Int J Sport Med.* 2009;30:663-667. doi:10.1055/s-0029-1225328.
167. Wodecki P, Guigui P, Hanotel MC, Cardinne L, Deburge A. [Sagittal alignment of the spine: comparison between soccer players and subjects without sports activities]. *Rev Chir Orthop Reparatrice Appar Mot.* 2002;88(4):328-336. https://www.ncbi.nlm.nih.gov/pubmed/12124531.
168. 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. doi:10.1016/j.jsams.2013.04.008.
169. Rambani R, Hackney R. Loss of range of motion of the hip joint: a hypothesis for etiology of sports hernia. *Muscles Ligaments Tendons J.* 2015;5(1):29-32. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4396673/.
170. Schache AG, Bennell KL, Blanch PD, Wrigley T V. The coordinated movement of the lumbo – pelvic – hip complex during running : a literature review. *Gait Posture.* 1999;10:30-47. https://www.ncbi.nlm.nih.gov/pubmed/10469939.
171. Bittencourt NFN, Meeuwisse WH, Mendonça LD, Nettel-Aguirre A, Ocarino JM, Fonseca ST. Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition—narrative review and new concept. *Br J Sports Med.* 2016;50(21):1309-1314. doi:10.1136/bjsports-2015-095850.
172. Gokeler A, Verhagen E, Hirschmann MT. Let us rethink research for ACL injuries: a call for a more complex scientific approach. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(5):1303-1304. doi:10.1007/s00167-018-4886-6.
173. Sun Y, Wei S, Zhong Y, Fu W, Li L, Liu Y. How joint torques affect hamstring injury risk in sprinting swing-stance transition. *Med Sci Sports Exerc.* 2015;47(2):373-380. doi:10.1249/MSS.0000000000000404.
174. Inoue K, Nunome H, Sterzing T, Shinkai H, Ikegami Y. Dynamics of the support leg in soccer instep kicking. *J Sports Sci.* 2014;32(11):1023-1032. doi:10.1080/02640414.2014.886126.
175. Ross JR, Nepple JJ, Philippon MJ, Kelly BT, Larson CM, Bedi A. Effect of changes in pelvic tilt on range of motion to impingement and radiographic parameters of acetabular morphologic characteristics. *Am J Sports Med.* 2014;42(10):2402-2409. doi:10.1177/0363546514541229.
176. Briggs KK, Lysholm J, Tegner Y, Rodkey WG, Kocher MS, Steadman JR. The reliability, validity, and responsiveness of the Lysholm score and Tegner activity scale for anterior cruciate ligament injuries of the knee: 25 years later. *Am J Sports Med.* 2009;37(5):890-897. doi:10.1177/0363546508330143.
177. Chaudhari A, McKenzie C, Pan X, Oñate J. Lumbopelvic control and days missed because of injury in professional baseball pitchers. *Am J Sports Med.* 2014;42(11):2734-2740. doi:10.1177/0363546514545861.
178. Chaudhari AMW, Yedimenko J, Jamison ST, McNally M, McKenzie C, Onate J. Validation of a novel clinical tool to measure pelvic tilt. *Gait Clin Mov Anal Soc Annu Meet.* 2013:3.
179. Mann RV. The mechanics of sprinting and hurdling. 2011th ed. (Mann RV, ed.). Las Vegas: Createspace (independent publishing)/Amazon; 2011.
180. Cohen J. A power primer. *Psychol Bull.* 1992;112(1):155. https://www.ncbi.nlm.nih.gov/pubmed/19565683.
181. Janse van Rensburg L, Dare M, Louw Q, et al. Pelvic and hip kinematics during single-leg drop-landing are altered in sports participants with long-standing groin pain: A cross-sectional study. *Phys Ther Sport.* 2017;26:20-26. doi:10.1016/j.ptsp.2017.05.003.
182. FranklynMiller A, Richter C, King E, et al. Athletic groin pain (part 2): a prospective cohort study on the biomechanical evaluation of change of direction identifies three clusters of movement patterns. *Br J Sport Med.* 2016;43(13):10361040. doi:10.1136/bjsm.2009.066944.
183. Trigt B Van, Schallig W, Graaff E Van Der. Knee Angle and Stride Length in Association with Ball Speed in Youth Baseball Pitchers. *Sport J.* 2018;6(2):1-10. doi:10.3390/sports6020051.

184. Hamner SR, Seth A, Delp SL. Muscle contributions to propulsion and support during running. *J Biomech.* 2010;43(14):2709-2716. doi:10.1016/j.jbiomech.2010.06.025.
185. Weir A, Veger SAS, Van de Sande HBA, Bakker EWP, de Jonge S, Tol JL. A manual therapy technique for chronic adductor-related groin pain in athletes: a case series. *Scand J Med Sci Sports.* 2009;19(5):616-620. doi:10.1111/j.1600-0838.2008.00841.x.
186. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res.* 1985;(198):43-49. https://www.ncbi.nlm.nih.gov/pubmed/4028566.
187. Herr KA, Spratt K, Mobily PR, Richardson G. Pain intensity assessment in older adults: use of experimental pain to compare psychometric properties and usability of selected pain scales with younger adults. *Clin J Pain.* 2004;20(4):207-219. https://www.ncbi.nlm.nih.gov/pubmed/15218405.
188. Salaffi F, Stancati A, Silvestri CA, Ciapetti A, Grassi W. Minimal clinically important changes in chronic musculoskeletal pain intensity measured on a numerical rating scale. *Eur J Pain*. 2004;8(4):283-291. doi:10.1016/j.ejpain.2003.09.004.
189. Beaton DE, Bombardier C, Guillemin F, Ferraz MB. Guidelines for the process of cross-cultural adaptation of self-report measures. *Spine (Phila Pa 1976)*. 2000;25(24):3186-3191. https://www.ncbi.nlm.nih.gov/pubmed/11124735.
190. Kapron AL, Aoki SK, Peters CL, Anderson AE. In-vivo hip arthrokinematics during supine clinical exams: Application to the study of femoroacetabular impingement. *J Biomech.* 2015;48(11):2879-2886. doi:10.1016/j.jbiomech.2015.04.022.
191. Jansen J, Weir A, Dénis R, Mens J, Backx F, Stam H. Resting thickness of transversus abdominis is decreased in athletes with longstanding adduction-related groin pain. *Man Ther.* 2010;15(2):200-205. doi:10.1016/j.math.2009.11.001.
192. Kamper SJ, Ostelo RWJG, Knol DL, Maher CG, de Vet HCW, Hancock MJ. Global Perceived Effect scales provided reliable assessments of health transition in people with musculoskeletal disorders, but ratings are strongly influenced by current status. *J Clin Epidemiol.* 2010;63(7):760-766.e1. doi:10.1016/j.jclinepi.2009.09.009.
193. Hägg O, Fritzell P, Nordwall A, Swedish Lumbar Spine Study Group. The clinical importance of changes in outcome scores after treatment for chronic low back pain. *Eur Spine J.* 2003;12(1):12-20. doi:10.1007/s00586-002-0464-0.
194. Bland M. *An Introduction to Medical Statistics.* 4th ed. Oxford, UK: Oxford University Press; 2015.
195. Weir A, Jansen J, van Keulen J, Mens J, Backx F, Stam H. Short and mid-term results of a comprehensive treatment program for longstanding adductor-related groin pain in athletes: a case series. *Phys Ther Sport.* 2010;11(3):99-103. doi:10.1016/j.ptsp.2010.06.006.
196. Reiman MP, Thorborg K, Goode AP, Cook CE, Weir A, Hölmich P. Diagnostic Accuracy of Imaging Modalities and Injection Techniques for the Diagnosis of Femoroacetabular Impingement/Labral Tear: A Systematic Review With Meta-analysis. *Am J Sports Med.* 2017;45(11):2665-2677. doi:10.1177/0363546516686960.
197. Thorborg K, Branci S, Nielsen MP, Langelund MT, Hölmich P. Copenhagen five-second squeeze: a valid indicator of sports-related hip and groin function. *Br J Sports Med.* 2017;51(7):594-599. doi:10.1136/bjsports-2016-096675.
198. 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):1-6. doi:10.1016/j.ptsp.2016.07.002.
199. Finstad K. Response interpolation and scale sensitivity: Evidence against 5-point scales. *J Usability Stud.* 2010;5(3):104-110. https://www.semanticscholar.org/paper/Response-Interpolation-and-Scale-Sensitivity-%3A-Finstad/f8b27873043cf56f158d013c6175996475a6509d.
200. Moore NJ, Bhumbra GS, Foster JD, Beato M. Synaptic connectivity between Renshaw cells and motoneurons in the recurrent inhibitory circuit of the spinal cord. *J Neurosci.* 2015;35(40):13673-13686. doi:10.1523/JNEUROSCI.2541-15.2015.
201. Drew MK, Lovell G, Palsson TS, Chiarelli PE, Osmotherly PG. Do Australian Football players have sensitive groins? Players with current groin pain exhibit mechanical hyperalgesia of the adductor tendon. *J Sci Med Sport.* 2016;19(10):784-788. doi:10.1016/j.jsams.2015.12.516.

202. Moseley GL, Butler DS. Fifteen Years of Explaining Pain: The Past, Present, and Future. *J Pain.* 2015;16(9):807-813. doi:10.1016/j.jpain.2015.05.005.

203. Kemp JL, Makdissi M, Schache AG, Pritchard MG, Pollard TCB, Crossley KM. Hip chondropathy at arthroscopy: prevalence and relationship to labral pathology, femoroacetabular impingement and patient-reported outcomes. *Br J Sports Med.* 2014;48(14):1102-1107. doi:10.1136/bjsports-2013-093312.

204. Jacobson I, Tegner Y. Injuries among female football players - With special emphasis on regional differences. *Adv Physiother.* 2006;8(2):66-74. doi:10.1080/14038190600621706.

205. Emery CA, Meeuwisse WH. Risk factors for groin injuries in hockey. *Med Sci Sports Exerc.* 2001;33(9):1423-1433. http://www.ncbi.nlm.nih.gov/pubmed/11528328.

206. Zheng QJ, Zhu HP, Yu AB. Finite element analysis of the rolling friction of a viscous particle on a rigid plane. *Powder Technol.* 2011;207(1-3):401-406. doi:10.1016/j.powtec.2010.11.026.

207. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic Risk Factors for Hamstring Injuries Among Male Soccer Players. *Am J Sports Med.* 2010;38(6):1147-1153. doi:10.1177/0363546509358381.

208. Forsdyke D, Gledhill A, Ardern C. Psychological readiness to return to sport: three key elements to help the practitioner decide whether the athlete is REALLY ready? *Br J Sports Med.* 2016. doi:10.1136/bjsports-2016-096770.

209. Steffen K, Myklebust G, Andersen TE, Holme I, Bahr R. Self-reported injury history and lower limb function as risk factors for injuries in female youth soccer. *Am J Sports Med.* 2008;36(4):700-708. doi:10.1177/0363546507311598.

210. Cowan SM, Schache AG, Brukner P, et al. Delayed onset of transversus abdominus in long-standing groin pain. *Med Sci Sports Exerc.* 2004;36(12):2040-2045. doi:10.1249/01.MSS.0000147587.81762.44.

211. Van Goeverden W, Langhout R, Barendrecht M and Tak I. Active pelvic tilt is reduced in athletes with groin injury; A case-controlled study. *Phys Ther Sport* 2019;36:14-21. doi:10.1016/j.ptsp.2018.12.011.

212. Tak I, Langhout R, Bertrand B, Barendrecht M, Stubbe J, Kerkhoffs G, Weir A. Manual therapy and early return to sport in football players with adductor-related groin pain: A prospective case series. *Physiother Theory Pract* 2018:11;1-10. doi:10.1080/09593985.2018.1531096 [Epub ahead of print]

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Rob Langhout, Adam Weir, Wendy Litjes and Igor Tak. The complexity of hip and groin injury in female amateur football; A survey study in 434 players in The Netherlands. Sport Geneesk. 2018;51(3):6-13 [Dutch]
There was no funding received fort his study. All authors declared there was no conflict of interest.

Rob Langhout, Igor Tak, Anne-Marie van Beijsterveldt, Martijn Ricken, Adam Weir, Maarten Barendrecht, Gino Kerkhoffs and Janine Stubbe. 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. doi:10.2519/jospt.2018.7990 [Epub 2018 May 23]
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Rob Langhout, Marvin Weber, Igor Tak and Ton Lenssen. Timing characteristics of body segments during the maximal instep kick in experienced football players. J Sports Med Phys Fitness. 2016;56(7-8):849-856. http://www.ncbi.nlm.nih.gov/pubmed/26129917 [Epub 2015 Jul 1]
There was no funding received fort his study. All authors declared there was no conflict of interest.

Rob Langhout, Igor Tak, Roelof van der Westen and Ton Lenssen. Range of motion of body segments is larger during the maximal instep kick than during the submaximal instep kick in experienced football players. J Sports Med Phys Fitness. 2017;57(4):388-395. doi:10.23736/S0022-4707.16.06107-7 [Epub 2016 Mar 30]
There was no funding received fort his study. All authors declared there was no conflict of interest.

Igor Tak, Rob Langhout, Sanne Groters, Adam Weir, Janine Stubbe and Gino Kerkhoffs. A new clinical test for measurement of lower limb specific range of motion in football players: Design, reliability and reference findings in non-injured players and those with long-standing adductor-related groin pain. Phys Ther Sport. 2017;23:67-74. doi:10.1016/j.ptsp.2016.07.007 [Epub 2016 Jul 31]
There was no funding received fort his study. All authors declared there was no conflict of interest.

Wouter van Goeverden, Rob Langhout, Maarten Barendrecht and Igor Tak. Active pelvic tilt is reduced in athletes with groin injury; A case-controlled study. Phys Ther Sport. 2019;36:14-21. doi:10.1016/j.ptsp.2018.12.011 [Epub 2018 Dec 26]
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Igor Tak, Rob Langhout, Bas Bertrand, Maarten Barendrecht, Janine Stubbe, Gino Kerkhoffs, Adam Weir. Manual therapy and early return to sport in football players with adductor-related groin pain: A prospective case series. Physiother Theory Pract. 2018:11;1-10. doi:10.1080/095 93985.2018.1531096 [Epub ahead of print]
There was no funding received fort his study. All authors declared there was no conflict of interest.

PhD Portfolio

Name:	Rob R. F. H. Langhout
PhD period:	Juli 2018-june 2019
Promotor:	Prof. dr. Gino M.M.J. Kerkhoffs
Co-promotores:	Dr. Janine H. Stubbe
	Dr. Igor J.R. Tak

Podium Presentations

Groin injury in sports. Invited speaker at Tweede Vlaamse Inter-Universitair Congres Sportkinesitherapie. Leuven (Belgium): 2019

Diagnostiek van liesblessures in voetbal. Invited speaker at Football Medical Symposium; Diagnostics of football injury. Koninklijke Nederlandse Voetbal Bond (KNVB). Zeist (The Netherlands): 2019

Diagnostiek van liespijn. Invited speaker at Symposium Canisius Wilhelmina Ziekenhuis (CWZ) Liesblessures. CWZ, Nijmegen (The Netherlands): 2019

Risk factors for groin injury and symptoms in elite level soccer players: a prospective cohort study in the Dutch professional leagues. Free paper at The Dutch Congres for Sports Medicine (VSG). Golden Tulip Hotel, Ermelo (The Netherlands): 2018

Groin injury is the most frequent non-timeloss injury in female amateur football; a survey study in 434 Dutch players. Free paper at The Dutch Congres for Sports Medicine (VSG). Golden Tulip Hotel, Ermelo (The Netherlands): 2018

Een biomechanische benadering van heup- en liesklachten bij sporters. Invited speaker at MSG Science Netwerk Fysiotherapie and Faculty of Behavioural and Movement Sciences Vrije Universiteit Amsterdam (The Netherlands): 2018

Hamstring mechanics during sprinting. Invited speaker at The Dutch Annual Scientific Congress for Sports Medicine (VSG). Golden Tulip Hotel, Ermelo (The Netherlands): 2016

Adductor-related groin pain. Invited speaker at GIZ Physio/Artze Fokus Tage Hufte/Leiste (incl. workshops), Vienna (Austria): 2016

Pelvic tilt; the key to a safe and efficient football kick? A biomechanical study to understand groin injury. Invited speaker at Sportärzte Woche, Gesellschaft für Interdisziplinäre Zusammenarbeit, Kaprun (Austria): 2015

Adductor mechanics during kicking in football players. Free paper at The Dutch Congress for Sports Medicine (VSG). Van der Valk Hotel, Eindhoven (The Netherlands): 2015

Hip reversal as safety mechanism during the maximal instep kick in football players. Free paper at the 1st World Conference at Groin Pain. Aspetar Excellence Auditorium. Aspetar Hospital, Doha (Qatar): 2014

Association between range of motion and ball velocity during the maximal instep kick. Free paper at The WFATT/ARTI/FSEM World Congress Hip, groin and hamstring; a complex triangle. The Helix, Dublin City University, Dublin (Ireland): 2014

Sport specific range of motion and its relation to long-standing adductor related groin pain. Invited speaker at Aspetar Groin Pain Conference (included workshops and visiting professional rounds). ASPETAR hospital, Doha (Qatar): 2013

Clinical biomechanics of the soccer kick and its relation to long-standing adductor related groin pain. Invited speaker at GIZ Physio Fokus Tag Hufte/Leiste (including workshops), Vienna (Austria): 2013

Sport-specific range of motion and groin pain in football. Free paper at The Dutch Congress for Sports Medicine (VSG). Golden Tulip Hotel, Ermelo (The Netherlands): 2012

Hip-Spine Dilemma. Invited speaker at 'In Duet' Congress, Jaarbeurs, Utrecht (The Netherlands): 2010

Hernia nucleus pulposos and lumbar instability. Invited speaker Hoytema Foundation, Enschede (The Netherlands): 2002

Lumbar instability and manual therapy. Invited speaker at the Dutch Association of Manual Therapy Congress (NVMT). Koningshof, Veldhoven (The Netherlands): 2002

Psychosocial factors and back pain. Invited speaker at the Dutch Association of Manual Therapy Congress (NVMT). Koningshof, Veldhoven (The Netherlands): 2001

Biomechanics and biochemics of the human intervertebral discs. Invited speaker at the International Federation of Orthopaedic Manual Therapy (IFOMPT) World Congress, Perth (Australia): 2000

Publications (peer reviewed)

Langhout R, Tak I. Including athlete's injury perception lowers the injury prevalence. A game changer in injury reporting? Knee Surg Sports Traumatol Arthrosc. 2019. Submitted

Otten R, Stam S, Langhout R, Weir A, Tak I. The effect of compression shorts on pain and performance in male football players with groin pain-A double blinded randomized controlled trial. Phys Ther Sport. 2019 [Epub ahead of print]

Van Goeverden W, Langhout R, Barendrecht M and Tak I. Active pelvic tilt is reduced in athletes with groin injury; a case-controlled study. Phys Ther Sport. 2019;36:14-21. doi:10.1016/j.ptsp.2018.12.011

Tak I, Langhout R, Bertrand B, Barendrecht M, Stubbe J, Kerkhoffs G, Weir A. Manual therapy and early return to sport in football players with adductor-related groin pain: A prospective case series. Physiother Theory Pract. 2018:11;1-10. doi:10.1080/09593985.2018.1531096 [Epub ahead of print]

Langhout R, Weir A, Litjes W, Gozeling M, Stubbe J, Kerkhoffs G and Tak I. Hip and groin injury is the most common non-time-loss injury in female amateur football. Knee Surg Sports Traumatol Arthrosc. 2018. doi: 10.1007/s00167-018-4996-1. [Epub ahead of print]

Langhout R, Weir A, Litjes W, Tak I. The complexity of hip and groin injury in female amateur football; A survey study in 434 players in The Netherlands. Sport Geneesk. 2018;51(3):6-13 [Dutch]

Langhout R, Tak I, Van Beijsterveldt AM, Ricken M, Weir A, Barendrecht M, Kerkhoffs G, Stubbe J. 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. doi: 10.2519/jospt.2018.7990 [Epub 2018 May 23]

Tak I, Engelaar L, Gouttebarge V, Barendrecht M, Van den Heuvel S, Kerkhoffs G, Langhout R, Stubbe J, Weir A. Infographic. Is lower hip range of motion a risk factor for groin pain in athletes? A systematic review with clinical applications. Br J Sports Med. 2018;52(16):1022-1023. doi: 10.1136/bjsports-2017-098535. Online Februari 15th 2018

Tak I. Infographic. Hip and groin pain in athletes: morphology, function and injury from a clinical perspective. Collaborators Weir A, Agricola R, Kerkhoffs G, Langhout R. Br J Sports Med. 2018;52(16):1024-1025. doi: 10.1136/bjsports-2017-098618 [Epub 2018 Jan 25]

Langhout R, Tak I, van der Westen R, Lenssen T. Range of motion of body segments is larger during the maximal instep kick than during the submaximal instep kick in experienced football players. J Sports Med Phys Fitness. 2017;57(4):388-395. doi:10.23736/S0022-4707.16.06107-7 [Epub 2016 Mar 30]

Tak I, Langhout R, Groters S, Weir A, Stubbe J, Kerkhoffs G. A new clinical test for measurement of lower limb specific range of motion in football players: Design, reliability and reference findings in non-injured players and those with long-standing adductor-related groin pain. Phys Ther Sport. 2017;23:67-74. doi:10.1016/j.ptsp.2016.07.007 [Epub 2016 Jul 31]

Tak I, Engelaar L, Gouttebarge V, Barendrecht M, Van den Heuvel S, Kerkhoffs G, Langhout R, Stubbe J, Weir A. 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. doi: 10.1136/bjsports-2016-096619 [Epub 2017 Apr 21]

Langhout R, Weber M, Tak I, Lenssen T. Timing characteristics of body segments during the maximal instep kick in experienced football players. J Sports Med Phys Fitness. 2016;56(7-8):849-856. http://www.ncbi.nlm.nih.gov/pubmed/26129917. [Epub 2015 Jul 1]

Tak I, Glasgow P, Langhout R, Weir R, Kerkhoffs G, Agricola R. Hip range of motion is lower in professional football players with hip and groin symptoms or previous injury, independent of cam deformity. Am J Sports Med. 2016 Mar;44(3):682-688. doi: 10.1177/0363546515617747. [Epub 2015 Dec 16]

Tak I, Weir A, Langhout R, Stubbe J, Kerkhoffs GMMJ, Agricola R. 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; May;49(9):630-634.
doi:10.1136/bjsports-2014-094130. [Epub 2015 Jan 7]

Tak I, Weir A, Langhout R. Clinical biomechanics of the soccer instep kick and the relation to groin injury; a review of literature. Flemish/Dutch J Sports Med Sports Sc. 2012;45(1):18-26 [Dutch]

Publications (book/journal chapter and other)

Tak I, Langhout R. Groin pain in athletes. InTouch Journal. Towcester: Organisation of Chartered Physiotherapists in Private Practice. 2017 Summer;156:12-20

Van Beijsterveldt A, Tak I, Langhout R, Stubbe J. Monaco abstracts 295: Risk factors for groin injuries in elite male soccer players. Br J Sports Med. 2017;51:400

Langhout R, Tak I, Glasgow P. Groin pain in athletes: A comprehensive sports physiotherapeutic approach. Sportphysiotherapie, Groin pain Issue. (Eds. Ophey M, Tak I.) Thieme Verlag [German]. 2016 May;64-71 [German]

Glasgow P, Tak I, Langhout R. Groin pain in athletes: Rehabilitation of a footballer with groin pain; Case report. Sportphysiotherapie, Groin pain Issue. (Eds. Ophey M, Tak I.) Thieme Verlag [German]. 2016;5:72-76 [German]

Tak I, Langhout R. Groin injury in soccer. Steps towards a sport-specific approach. From hypothesis to physical examination and treatment. Aspetar Sports Med J. 2014;3 (TT 4):136-141

Langhout R. Wingbermühle R. Discus intervertebralis. Manuele diagnostiek wervelkolom. (Ed. Van der El A). Manthel Rotterdam. 2000;82-92

Teaching

Lecturer Master Education Manual Therapy, SOMT University, Amersfoort, Münster and Kerpen (The Netherlands, Germany): 1991-current

Volunteer lecturer Dutch Institute of Allied Health Care (Nederlands Paramedisch Instituut, NPi), Amersfoort (The Netherlands): 1995-current

Liespijn bij sporters. Lecture at Universiteit of Antwerpen De Drie Eiken. Antwerpen (Belgium): 2019

Masterclass bewegingsketens. Nederlands Paramedisch instituut (NPi) Amerfoort (The Netherlands): 2018

Hip-spine syndrome in ADL and sports. Lecture Department of Rehabilitation Sciences
Faculty of Kinesiology and Rehabilitation Sciences University of Leuven (Belgium): 2019

Masterclass spinal manipulation. Invited lecture at Post Graduate Education KUL (incl. workshop). Catholic University Leuven (Belgium): 2006-2018

Masterclass liespijn. Nederlands Paramedisch instituut (NPi) Amerfoort (The Netherlands): 2016-current

Hip and groin pain in athletes. Symposium at Philips Stadium, PSV, Eindhoven (The Netherlands): 2018

Hip and groin pain in athletes; Fitting the evidence into a conceptual approach. Symposium at Philips Stadium, PSV Eindhoven (The Netherlands): 2017

Liespijn bij sporters. Invited lecture University of Brussels (Belgium): 2017

Liespijn bij sporters. Invited lecture University of Antwerp (Belgium): 2016

"Management of hip and groin pain in footballers: How we do it". Invited lecture for Arsenal FC medical staff: (incl. workshop); Arsenal FC training grounds, London (UK). 2016

Masterclass spinal manipulations. Invited lecture for Sports Institute of Northern Ireland (SINI)/ Ulster University (incl. workshop) Belfast (UK): 2016

Masterclass Sports physiotherapy: "from biomechanics to treatment in athletes with groin pain". Vienna (Austria): 2015

Masterclass Sports physiotherapy: from biomechanics to treatment in athletes with groin pain". Belfast (UK): 2014

Lumbar radicular syndrome and manual therapy. Graduation Symposium Jasper Den Boer. Radboud University Nijmegen (The Netherlands): 2008

Lecturer Master of Science in Sports Physical Therapy program by Dutch Institute of Allied Health Care (Nederlands Paramedisch Instituut) AVANS+; Sports and congress Centre Papendal, Arnhem (Netherlands): 2007-2017

Stenosis and physiotherapy. Free paper Symposium CWZ. Nijmegen (The Netherlands): 2007

Masterclass neck- and back pain. Invited lecture at Elisabeth Hospital, Willemstad (Curaçao, The Netherlands): 2006 and 2008

A-spezifische Rückenschmerz. Invited lecture at AOK Kleve (Germany): 2005

Guideline Aspecific low back- and neck pain. Invited lecture at PAOG. Radboud University, Nijmegen (The Netherlands): 2003 and 2006

Implementatie Standaard Cervicogene Duizeligheid in de manuele therapie. Nederlandse Vereninging voor Manuele Therapie (NVMT) Amersfoort (The Netherlands): 1991-1993

Supervising

Master of Science in Sports Physical Therapy; supervising students on their research projects. NPi/Avans+ (1 or 2 students yearly): 2012-2016

Master of Science in Movement Sciences; supervising students on their research projects. University of Amsterdam; Department Movement Science (1 student yearly): 2015-2016

Master of Science in Applied Sciences; supervising students on their research projects. The Hague University of Applied Sciences; Department Movement Science (1 student yearly): 2017-2018

Curriculum Vitae

Rob (Robertus, Franciscus Hendrik) Langhout was born in Nijmegen, The Netherlands, on November 17th, 1960. After graduating from the Atheneum at Canisius College in Nijmegen in 1980, he accomplished his compulsory military service in 1981 and graduated his Physiotherapy Bachelor in Nijmegen in 1985. He studied at the Master Education Manual Therapy (SOMT University) in Amersfoort and graduated in 1991. Since then he is lecturer at the SOMT University, Department Spinal Practice Manual Therapy and volunteer lecturer at the Dutch Institute of Allied Health Care (NPi) in Amersfoort since 1995. He worked as physiotherapist at the St. Maartenskliniek, Department Orthopaedics and Rheumatology from 1985 to 1995 and started working as co-owner and manual therapist at Physiotherapy Dukenburg Nijmegen from 1990 up to now.

Rob started his PhD on groin injury in football in 2018 at the AMC-UvA/Academic Center for Evidence-Based Sports Medicine (ACES), supervised by his promotor professor Gino Kerkhoffs and copromotores doctor Janine Stubbe and doctor Igor Tak. His groin project had already started years before in great conspiracy with his teammate Igor (Utrecht). Rob wrote a number of international papers in peer reviewed journals and spoke at (inter) national congresses.

His marriage with Nora Caerteling in 1995 (Nijmegen) brought them their fantastic children Linda (1996) and Tom (1998), both paranymphs at Rob's PhD graduation.

'DARE TO CHANGE A WINNING TEAM'

Dankwoord

Niet bewust van de gevolgen die het zou hebben werd ik in mijn praktijk vaak geconfronteerd met voetballers die op onverklaarbare wijze hun sport niet konden hervatten vanwege opspelende liesblessures. Hierdoor gegrepen heb ik getracht deze blessure beter te begrijpen hetgeen de start betekende van een langdurig liesproject. Ik ben dankbaar voor de geweldige hulp van alle mensen die me daarbij hebben geholpen en een aantal van hen wil ik in het bijzonder bedanken.

Prof. dr. Kerkhoffs, promotor. Beste Gino, ik dank je voor je vertrouwen en de mogelijkheid die je me hebt geboden om van een hobby een buitenpromotie te maken. Tijdens ons eerste gesprek gaf je me het laatste zetje om in een PhD traject te stappen. Ja, ik kon promoveren aan AMC-UvA/ACES en eigen ideeën en zelfstandigheid waren welkom. Bedankt je dat je mijn promotor wilde zijn en mede door de efficiënte samenwerking met Ellen Rolleman en Rosalie van de Sandt is het na anderhalf jaar zover. Ik heb veel van je geleerd als wetenschapper en als enkel/voet expert. Ik hoop in de toekomst nog intensief met je te mogen samenwerken.

Dr. Stubbe, co-promotor. Beste Janine, ik dank je dat je mijn co-promotor wilde zijn. Je hebt me onwijs goed geholpen, zowel bij het vervaardigen van ons GRIP-artikel als je tips & tricks bij het schrijven van mijn boekje. Onze bijeenkomsten waren altijd bijzonder leerzaam en gezellig en ik wens jou en je gezin met kleine Nora heel veel geluk.

Dr. Tak, co-promotor, vriend, collega, reisgenoot, duo docent, klankbord en voorbeeld. Igor, ik heb ontzettend veel aan je gehad. Wat hebben we samen veel kilometers en uren gemaakt op onze groin crusade. We ‘deden' veel voetballers in binnen- en buitenland, maakten samen de eerste (en tevens laatste) poster, schreven abstracts en artikelen, ontwikkelden bewegingssensoren (dank Fred Dijkstra en Maarten Gijssel), gaven trainingen en stonden op symposia in Nederland en buitenland, van sneeuwtop tot zandduin. Er zijn veel strategieën om kennis te vergaren en ik kan je verzekeren dat afkijken een hele goede is! In de slipstream van jouw promotie boetseerde ik die van mij. Bijzonder dankbaar ben ik voor je 24/7 stand-by functie; enorme problemen kon jij semi-arrogant decimeren tot praktische oplossingen waardoor ik snel weer verder kon. Overtuigd van onze missie hebben we samen heel wat barrières geslecht en daar altijd veel plezier aan beleefd. Ik ben trots dat we ons werk samen uitdragen in wetenschap, onderwijs, congressen, fysiotherapie praktijken, voetbalclubs en wie had van te voren kunnen bedenken dat we *beiden* zouden promoveren…
Ik hoop nog lang met je als vriend en professional te mogen optrekken en spoedig weer te toasten met vliegtuigbier.

Dr. Agricola. Beste Rintje, op jouw leeftijd al zoveel bereikt. Je doet me denken aan het Nederlands voetbal in zijn beste dagen; met de allerbesten trek je de wereld over en druk je je stempel. Ik heb veel respect voor je ontspannen en collegiale houding en heb inhoudelijk veel aan je te danken. Dankzij jou werden de congressen altijd erg gezellig! Bedankt dat je zitting wilde nemen in de promotiecommissie en we zullen elkaar nog vaak tegenkomen.

De overige leden van de promotiecommissie. Prof. dr. Zwerver, Prof. dr. Maas, Prof. dr. Nollet, Prof. dr. Oostra en Dr. Tol, ik wil u allen hartelijk bedanken voor uw deelname als opponent voor de verdediging van mijn proefschrift en bovendien voor de tijd en moeite die u hebt genomen om het zoveelste proefschrift door te nemen.

Dr. Weir. Beste Adam, nu ik je goed heb leren kennen vind ik het niet meer dan logisch dat je in Nottingham in Engeland opgroeide. Eens stal Robin daar van de rijken en verdeelde de rijkdom onder de armen. Jaren later is hij weer terug en vergaart kennis bij de Arabieren en deelt het belangeloos met de behoeftigen. Adam, je hebt voor mij veel wetenschappelijke drempels verlaagd, me geënthousiasmeerd met je klinische blik op liespijn en ik ben je ontzettend dankbaar voor je hulp met abstracts, artikelen, conferenties en altijd a.s.a.p. telefoontjes en mails beantwoorden. Door jou heb ik figuurlijk en letterlijk mijn grenzen verlegd en ben bekend geraakt met het Aspetar netwerk, kamelen en woestijnraces. Ik hoop dat we nog lang samen blijven 'liezen'. Thank you, Adam 'The Hood' Weir.

Prof. dr. Glasgow. Dear Phil, you were an indispensable link in our groin crusade. You surprised the world introducing pelvic decoupling as a central rehabilitation theme in targeting groin injury. How well does it fit in with kicking biomechanics, I can say now! As you used to say, together we have potential. Remember the evening drinking beer with Igor at Arsenal FC, laughing and speculating about the odds me finishing a PhD. This graduation now feels like an enormous hangover the day after, being graduated. I look forward reuniting soon in beautiful Northern Ireland and continue collaborating in future.

Prof. dr. Lenssen. Beste Ton, zonder dat we het allebei wisten startte mijn carrière als wetenschapper via Ed Waltjé bij jou in de kelders van Universiteit Maastricht. Ik ben je dankbaar voor je vertrouwen dat voetballers in jouw laboratorium ballen mochten trappen met een gemeten maximale snelheid van 121 km/u tussen peperdure camera's. Bedankt Roelof van der Westen en Marvin Weber dat ik jullie heb mogen lastig vallen met al mijn vragen. Ton, je moet soms moedeloos zijn geweest van mijn cowboy gedrag en ik waardeer het enorm dat je de teugels liet vieren en ze dan weer aanhaalde. Weet dat ik heel veel van je heb geleerd. Daarbij denk ik met veel plezier terug aan de avondjes bier drinken met jou en Ed in Kerpen na het lesgeven. Voor herhaling vatbaar!

GRoin Injury Prevention (GRIP) studie

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Voetbal fysiotherapeuten

Ik bedank alle fysiotherapeuten die wetenschappelijk onderzoek op hun club toestonden. In het bijzonder Bram Swinnen, Maarten Gozeling, Rob Ouderland, Mark Rekers, Martijn Smeets, Han Tijshen en atletiek expert Peter Eemers; doorgewinterde rotten met de voeten in de klei (of zand). Dank jullie voor je leerschool hoe je in het echie met blessures omgaat. Hoe pragmatisme en wetenschap toch samen kunnen gaan. Jan Kleinpenning. Beste Jan, de spier manipulatie die wij hebben mogen onderzoeken heb je zelf 'uitgevonden' en blijkt bijzonder effectief maar dat wist je al. Dank je voor je collegialiteit en ik hoop dat je nog lang doorgaat!

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Down Under

Dr. Schache and Dr. Verrall. It is a privilege knowing you both. Dear Anthony, thank you for always granting my requests for literature and our inspirational discussions on biomechanics. Dear Geoffrey, your injury mechanism hypotheses are challenging and your company at congresses (the bar) was always more than welcome. I sincerely hope catching up soon with you guys, whether up or down.

Lay-out

Joan Klooster, bedankt voor je deskundige kennis van sportvoeding, onze gezellige strandruns, strandkoffie en het geduld dat je samen met Maaike Navon had tijdens de shootings. Maaike, de foto's zijn prachtig! Dolly Lotthrinkx-van Breda, bedankt voor het drukken van mijn proefschrift en je adviezen op maat; het is mooier geworden dan ik had gehoopt.

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Manuele therapie SOMT

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Vakgroep neurofysiologie: Bedankt prof. dr. Rob Oostendorp, Leo Hagenaars(†) en Nol Bernards: vernieuwers van de fysiotherapie in Nederland. Beste Nol, elftalleider E1, docent fysiotherapie, docent manuele therapie, collega docent manuele therapie, narratief expert en dus verteldokter. Bedankt voor je vriendschap en de tijd en energie die je aan me besteedde. Ik heb ongelooflijk veel van je geleerd. Succes ouwe hap, het ga jullie goed.

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Fysiotherapie Dukenburg Nijmegen

Beste maten. Het is niet vanzelfsprekend dat je collega's je gang laten gaan. Lieve Lidwine, ik bedank je voor je luisterend oor en klankbord. Je houdt me met de voeten op aarde en ik kan me geen betere maat en collega wensen. Beste Occo, zonder jouw interesse, feedback en je aanstekelijke enthousiasme was het moeilijk deze weg te gaan. Ontzettend bedankt voor je hulp bij het overnemen van patiënten, hulp bij de onderzoeken met spelers en je wijze adviezen. Sanne, dank voor je onbaatzuchtige hulp met je expertise op het gebied van statistiek in den beginne. Alle andere collega's, Eric-Jan, Jan, Floor, Kim, Lucas, Irene, Illis, Robert, Ivan, Ashley, Elly, Yvonne, Michelle, Chris, Bas, Vince, Lidwine & Maarten, Liesbeth, Olga, Noud en Jolien: bedankt voor jullie support en vermaak tijdens de koffie! Ik ben blij met jullie en trots op onze praktijk. Jits(†), ik ben je dankbaar voor deze erfenis.

Cliënt

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Fysiotherapie Burg en van Riel

Jan, pionier en beste fysiotherapeut *ever* die zijn patiënten selectief kan l*llen. Bedankt voor je vriendschap en ongelooflijke hoeveelheid klinische expertise die ik van je heb geleerd heb en nog steeds toepas. De wandelingen met Jos Stolte, de wespendieven en de nachtzwaluw waren onvergetelijk! Ine, bedankt dat jij me als eerste adviseerde om manuele therapie te gaan studeren. Wees trots op jullie indrukwekkende carrière en ik hoop van harte dat het jullie gegund is te genieten.

St. Maartenskliniek Nijmegen, afdeling Orthopedie en Reuma

Bedankt Mart Bardoel(†), Leon 'Goof' Schoonhoven, Har Hendriks, Hilde Meijs, Vera van de Anker, Jan van de Braak, Els Kok-Truijens, Erna Veerman, Wilma Rutten, Marij Font Freide, Corrie Barends-Beeken voor de leerzame en gezellige orthopedie en reuma ervaringen. Mijn eerste werkplek en 1 om nooit te vergeten.

Van Stoof tot Thorn

Luuk en Yvonne, Sep en Jacqueline, Joep en Roeleke, Goof, Jan, Noor en alle kinderen. Al 18 jaar houden we het met elkaar vol met Oud en Nieuw naast de Thornse kathedraal. Zittend aan de secretaire in het opkamertje op de 1e verdieping heb ik al ontelbare keren de zon zien opkomen. Hier werd het eerste artikel over biomechanica geschreven en het laatste was dit proefschrift. Vrienden, dank jullie voor je warmte en support al die jaren. Het schrijven zit erop. Op naar een nieuwe locatie 2020?

Nora Caerteling, mijn vrouw
Lieve Noor. Toen wij elkaar leerden kennen was ik al een gepassioneerd manueel therapeut met veel werk doordeweeks en lesgeven in het weekend. Boeien, we waren verliefd! Twintig jaar later verschoof mijn aandacht naar voetbal en liesblessures en heb me daar vervolgens op gestort; een proces dat sluipend steeds meer tijd in beslag nam. Je trof mij 's morgens achter de laptop aan: onverstoorbaar, afwezig, ongeïnteresseerd, misschien wel manisch en met de vaat nog op de aanrecht. De lange duur van mijn groin crusade heeft een stempel op onze relatie gedrukt. Pas toen het woord 'promotie' viel ben ik me gaan beseffen dat ik veel quality-time aan ons gezin onttrokken heb. Lieve Noor, ik ben je dankbaar voor de werkbare modus en je begrip voor mijn mentale afwezigheid (Igor bellen, Igor bellen, Igor bellen, lezen, schrijven, grafieken analyseren-lijntjes kijken noemde jij dat) en fysieke afwezigheid (vliegen, spelers testen, praten met "slimme mensen"). Mooie Nora, ik ben blij dat ik klaar ben en dankbaar dat we het samen gered hebben. Motor rijden naar Corsica zullen we maar niet meer doen maar ik heb tussen de bedrijven door al heel wat ideeën gekregen over leuke toekomstbestemmingen: NORA EST!

Linda en Tom Langhout, mijn kinderen en paranimfen
Lieve Linda en Tom. Wat ben ik trots dat jullie mijn paranimfen zijn. Jullie eerste reactie op mijn verzoek hiertoe was oprecht spontaan: 'Wow, vet cool pap'. Weet dat ik me in de aanloop naar de verdediging enorm gesteund voelde dat jullie naast me zouden staan. Bedankt, vet coole kids. Ik merkte dat jullie ook trots op mij waren vanwege de 'promotie stuff' en dat heeft me heel goed gedaan. Linda, weet dat ik aan je dacht als ik op 't punt stond mijn laptop te vermorzelen: 'je maakt 't toch wel af hè pap'! Hoe gezellig was het om met jou een voetbalwedstrijd in Rome te zien (je stond je met name te vergapen aan de emotionele supporters) en samen met Stefan de catacomben van de St. Pieter te bewonderen. Tom, tegenpool van je zus, socioloog in spé, we hebben samen al veel ondernomen en je hebt gouden handen. Je was een uitstekende fysiotherapie-assistent op het trainingskamp van Lazio en ik heb genoten van onze bezoekjes aan de Spaanse stadions. Lieve kinderen, ik hou van zielsveel van jullie en hoop nog veel tripjes met jullie te maken. Ik denk 't wel!

Tom Langhout en Riet Langhout-de Kleijn, mijn ouders
Beste Pa en Ma. Jullie kennen het spreekwoord: wie niet sterk is moet slim zijn. En wie niet slim is moet volharden, zeg ik dan maar. Ik denk dat die laatste eigenschap me over de promotiestreep getrokken heeft. En van wie anders dan jullie beiden heb ik die eigenschap meegekregen. Jullie hebben altijd enorm je best gedaan om iets van je kinderen Harry, Rob en Karin te maken en vandaag is slechts 1 van de vele voorbeelden dat jullie dat gelukt is. Pa en Ma, ik ben dankbaar voor alles wat jullie voor ons gedaan hebben en ik ben ontzettend

trots dat mijn promotie vlak voor jullie ogen en die van broer Harry en zus Karin heeft mogen plaatsvinden. Ma, ik heb weer tijd dus we gaan gauw weer lunchen met een wijntje. Pa, met goed weer gaan we een hengeltje uitgooien bij de visvijvers in Appeltern. Ik hou van jullie!

Van proefschrift naar praktijk..

Stefan: Hoi Rob! Ik heb het afgelopen jaar niet zo lekker geschoten als deze twee weken! Wat had ik nu eigenlijk aan die rechterlies?

Rob: Geweldig Stefan! Waarschijnlijk bewoog je je bekken tijdens het schieten minder soepel waardoor je de neiging had je adductoren te gebruiken op balcontact. Daardoor werden ze overbelast.

Stefan: Goh, weet je ook waardoor dat is gekomen?

Rob: Nou, je hebt vorig jaar een meniscusoperatie aan je linkerknie gehad. Daar ben je toch wel een tijdje zoet mee geweest. Waarschijnlijk heeft de beperkte strekfunctie van je knie de actie van je standbeen beïnvloed waardoor je bekken slechter werd aangestuurd. Je bekken kantelt dan minder achterover en je adductoren rekken daardoor niet op tijdens balcontact maar worden juist ingeschakeld met schieten.

Stefan: Maar het is toch de bedoeling dat je met spierkracht de bal schiet?

Rob: Nee. Je schiet met de zwiep van je onderbeen en voet. Daarvoor is het nodig dat je lenig bent in je achterzwaai. In die fase is spierkracht wel belangrijk.

Stefan: Is de kans groot dat ik het terugkrijg?

Rob: Normaal gesproken wel want je hebt al 2 eerdere liesblessures en 1 knieblessure gehad. Maar ik denk dat als je de lenigheid van de achterzwaai en je bekken onderhoudt en je gaat de strekking van de knie trainen, je geen liesblessure meer hoeft te krijgen. Daar is alleen nog geen onderzoek naar gedaan.

Stefan: Heerlijk dat ik weer kan spelen, ik dacht echt dat ik een ernstige blessure had.

Rob: Met je adductoren was niets aan de hand. Hooguit verkrampten ze. De tuning van je lichaamsdelen tijdens schieten was waarschijnlijk ontregeld. Gelukkig kunnen we de sport specifieke lenigheid nu onderzoeken en hebben we een quick fix voor de adductoren. Wat de tuning betreft, daar zijn bewegingssensoren voor nodig, dat gaat te snel voor het blote oog.

Stefan: Fijn dat ik er zelf iets aan kan doen.

Rob: En ik ben blij dat ik het nu begrijp.

Eindelijk rust.