Risk factors for hamstring injuries in professional football players

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Risk factors for hamstring injuries in professional football players

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“Abandon the urge to simplify everything, to look for formulas and easy answers, and to begin to think multidimensionally, to glory in the mystery and paradoxes of life, not to be dismayed by the multitude of causes and consequences that are inherent in each experience — to appreciate the fact that life is complex.”

M. Scott Peck

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List of abbreviations

Ag	Silver Chloride
AgCl	Silver
AIISP	Aspetar Injury and Illness Surveillance Program
ASPREV	Aspetar Injury and Illness Prevention Program
AUC	Area Under the Curve
BF	Biceps Femoris
BMI	Body Mass Index
BW	Body Weight
CI	Confidence Interval
cm	centimeters
d	Cohen' d
D	Difference
db	decibel
DOI	Digital Object Identifier
e.g.	exempli gratia
EMG	electromyography
FIFA	Fédération International de Football Association
HR	Hazard Ratio
HSI	hamstring strain injury
H:Q	hamstrings : quadriceps
Hz	Hertz
IBM	International Business Machines Corporation
ICC	Intraclass correlation coefficient
i.e.	it est
Inc	Incorporated
IOC	International Olympic Committee
IRB	Institutional Review Board
kg	kilogram
Ltd	Limited

m	meters
ME	Measurement Error
MH	Medial Hamstrings
mm	millimeters
ms	milliseconds
n	sample size
N	Newton
Nm	Newton-meter
PHE	periodic health evaluation
OR	Odds Ratio
QSL	Qatar Stars League
p	probability
Pty	Proprietary company
r	correlation coefficient
RCT	Randomized Control Trial
ROC	Receiver Operating Characteristics
s	seconds
SD	Standard deviation
sEMG	Surface electromyography
SPSS	Statistical Packages for Social Sciences
STATA	Statistics and Data software
UEFA	Union of European Football Associations
UK	United Kingdom
USA	United States of America
V	version
vs	versus
WYSIATI	What You See Is All There Is
χ^2	Chi-square
yrs	years
°	degrees
%	percentage

Chapter 1

General introduction

EPIDEMIOLOGY

Hamstring injuries are common in sports that involve high speed running such as football (soccer), American football, Australian football, rugby and sprinting.[1–3] In elite football (soccer), muscle injuries represent 18% to 37% of all time loss injuries,[4–6] and hamstring muscle injuries have become the most common injury reported.[6] A team of 25 players might expect to see six hamstring injuries on average per season.[6,7] In addition, the recurrence of hamstring injury is also high, ranging from 16% to 60% across different sports.[2,5] More than half of all recurrent hamstring injuries occur within the first month after return to play.[8] What is of greater concern is that at the Union of European Football Associations (UEFA) Champions league level, representative of professional football, the injury rate has increased over the past decade by 2.3% annually.[9] In parallel, data from the English premier league demonstrate that high speed running demands have increased by as much as 30% to 35% in the past 13 years,[10] which may be a factor that at least partly explains the increase in injury rates we observe. Nevertheless, the burden of hamstring injury is considerable.

Hamstring injuries carry substantial financial implications for both the professional athlete and the team they represent. In elite football, the cost of a hamstring injury to a first team player can be up to €500,000 per month.[11] Little is known about hamstring injuries in the general population. A recent systematic review found that hamstring injuries are more common in males than in females, although the proportion of non-sporting injuries was significantly higher in females compared to males (25.9% female non-sporting injuries, vs 8.5% male non-sporting injuries).[12] Although it clearly impacts both professional athletes as well as the general population, in elite sport, and in particular football, the burden of hamstring injury is evident.[13]

ANATOMY, FUNCTION AND MECHANISM OF INJURY

The hamstring muscle group consists of the biceps femoris (long head and short head), semimembranosus and semitendinosus. These muscles originate from their proximal attachment to the ischial tuberosity, apart from the biceps femoris short head that originates from the lateral lip of the linea aspera along the lateral supracondylar ridge of the femur. The biceps femoris long head and semitendinosus share a common (conjoint) tendon at their origin. Both heads of the biceps femoris insert distally at the proximal head of the fibula, while the semitendinosus and semimembranosus attach through the pes anserinus at the antero-medial aspect of the tibia. The hamstring muscle group is bi-articular and acts as both hip extensor and knee flexor, excluding the biceps femoris short head that acts only as knee flexor and is seldom injured (Figure 1).

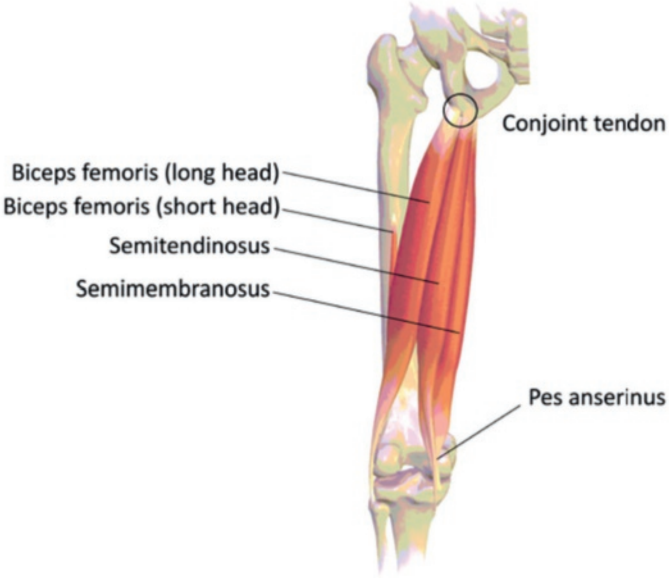

Figure 1 Anatomy of the hamstring muscles. *(Reproduced and adapted from Andrew Myerson www.anatomist.us with permission).*

Biomechanical studies demonstrate that the hamstrings are at greatest risk of injury during the terminal swing phase of high speed running,[14,15] as the biarticular hamstring muscle undergoes a stretch-shortening cycle in this phase.[16] The hamstrings remain active during the entire sprinting gait cycle, while peak activation is observed during the terminal swing and early stance phases.[16] During the terminal swing phase, the hamstrings contribute to decelerating the swinging leg; as the hip flexes and the knee extends the hamstrings are lengthening, performing much negative work to absorb energy.[15] It is also during the terminal swing phase that the hamstrings reach their maximal length.[14] Malliaropoulos et al suggested a combination of (1) peak hamstring musculotendinous stretch (significantly greater for biceps femoris) during the late swing phase, and (2) eccentric hamstring activity needed during this same phase of the gait cycle, resulting in (3) an active lengthening contraction during this phase for hamstring injury to occur.[17]

Other components to consider are the metabolic requirements and neuromuscular activity during repeated sprint running. During isokinetic testing, myoelectrical activity is reported to be markedly reduced in the biceps femoris compared to the medial hamstrings, particularly during eccentric force production, while concentric activity remains largely unchanged.[18] In addition, the synergistic muscle recruitment of the biceps femoris and semitendinosus muscles are altered after an eccentric fatigue protocol, indicating the biceps femoris compensates for the potential lack of endurance in the semitendinosus. [19] This recruitment pattern, observed as changes in metabolic activity when the muscles are fatigued, may increase the risk of hamstring injury in football players.[20] It might explain why hamstring injuries in football tend to occur during the latter stages of each half.[6]

It is still unclear whether hamstring injury is most often the result of a single traumatic event or due to the presence of accumulated microscopic muscle damage,[2,21] and the exact moment of injury is based on incidental evidence.[22] There exists some debate over whether muscle strain or the magnitude of eccentric force is the determining factor for hamstring injuries to occur, and therefore both muscle length, or the ability to elongate, and eccentric force production could be considered potential risk factors for injury. Opar et al[2] suggested that an inter-relationship may exist between muscle strain and eccentric force; injury may be avoided if low levels of muscle strain is coupled with high eccentric force. However, hamstring injuries are also observed at low eccentric load coupled with high muscle strain,[3,7] therefore, we must consider different mechanisms of hamstring injury.

High speed running is the most frequent injury mechanism seen in sports such as football, but another injury mechanism has been suggested that involve slow-speed stretching.[23] This injury mechanism occurs during activities such as stretching and dancing, when the hamstrings are lengthened with excessive hip flexion while the knee is extended. Unlike the explosive high-energy type injury we see in high-speed running, this type of injury occurs during movements to the limit of flexibility, or at least extreme lengthening of some musculotendinous units involved.[24] Rarely seen in football, this is more common in dancers or gymnasts exposed to slow or maximal muscle lengthening (i.e. high kicks) under eccentric load.[24] This type of injury more often involves the semimembranosus and the proximal musculotendinous junction, whereas the biceps femoris long head is more commonly injured during high-speed running type injuries. The stretching type injury also typically results in longer rehabilitation periods and delayed return to sport.[24] Therefore, the potential risk factors might be different if we consider the injury mechanism, possible muscle recruitment patterns, as well as metabolic activity profiles in a population of football players compared to gymnasts.

There has been some debate as to the classification and terminology used to describe hamstring injuries. Differentiation between contact and non-contact injuries, location, severity, neurogenic pain, and the involvement of the intramuscular tendon has been suggested, with poor consensus in the literature.[25–27]

INJURY PREVENTION

It has been over 30 years since van Mechelen et al described the "sequence of prevention" research model, creating a framework for injury prevention research.[28] The model suggests three steps: (1) identify the magnitude of the problem (incidence and severity), (2) ascertain the aetiological risk factors or injury mechanism responsible, and based on these findings (3) introduce a preventative measure to address the injury occurrence. Finally, the efficacy of the intervention is evaluated by repeating the first step.

The causation model proposed by Meeuwisse et al further developed our understanding of injury risk by accounting for the interaction of multiple risk factors, both intrinsic and extrinsic.[29] Bahr and Krosshaug expanded on the characteristics of the injury mechanism including the inciting event as a component of the causal pathway.[30] The causation model was later updated to capture the non-linearity of sports injury in the dynamic recursive model,[31] which allows for the potential of the inciting event to change the athlete's intrinsic risk factors and their predisposition to injury. This model moved beyond the simple identification of extrinsic and intrinsic factors that might be associated with injury towards understanding that these factors may mediate and moderate each other, and the outcome. Finch et al advanced the original injury prevention model further by addressing the issues related to implementation and integration of such interventions, and their effectiveness, through the Translating Research into Injury Prevention Practice (TRIPP) framework.[32] In this framework, two important steps were added before repeating step one – determining the ideal conditions to perform the preventative measure, and evaluating the effectiveness of the prevention programme in an implementation context. More recently, the complexity of sports injuries was captured in a conceptual model that applies predictive modelling for injury and prevention.[33] We are starting to appreciate the complexity of sports injury and, in particular hamstring injury, which may have many contributing factors.[34] An overview of the development of the injury prevention models is presented in Figure 2.

In any prevention model, the goal is the implementation of a preventative measure. A number of intervention studies have shown that hamstring injuries can be reduced through the introduction of specific prevention programmes.[35–37] These findings demonstrate that by introducing a specific measure targeting a potential risk factor, we might be able to protect the athlete from injury. To better design and plan these interventions, a vital step in all these models remains the identification of (risk) factors that may predispose the athlete to injury.

The largest and most comprehensive meta-analysis to date identified age, previous injury, and greater quadriceps strength as potential risk factors for hamstring injury.[38] However, it concludes that the tendency to assess variables in isolation may confound the true picture of risk for hamstring injury, as it remains a multifactorial problem.[38] Interactions between different risk factors may be overlooked and the influence of some factors may be exaggerated, leading to misinterpretations of their value and importance.

METHODOLOGICAL CONSIDERATIONS

It is important to differentiate the purpose of risk factor identification, i.e. explaining or predicting injury. Explanatory modelling is used for testing causal theory, where underlying factors are tested by certain variables that may lead to a specific outcome. Predictive modelling aims to apply a statistical model or data mining algorithm to predict future outcomes.[39] Both these approaches are important. To better understand the causation of hamstring injury, we must attempt to identify risk factors that can be addressed through preventative measures at a group level. Furthermore, we must aim to develope tests that may accurately and effectively identify individuals at high risk of injury, allowing us to tailor targeted intervention to these individuals, or a specific group of the population in question. This goal remains elusive.[40]

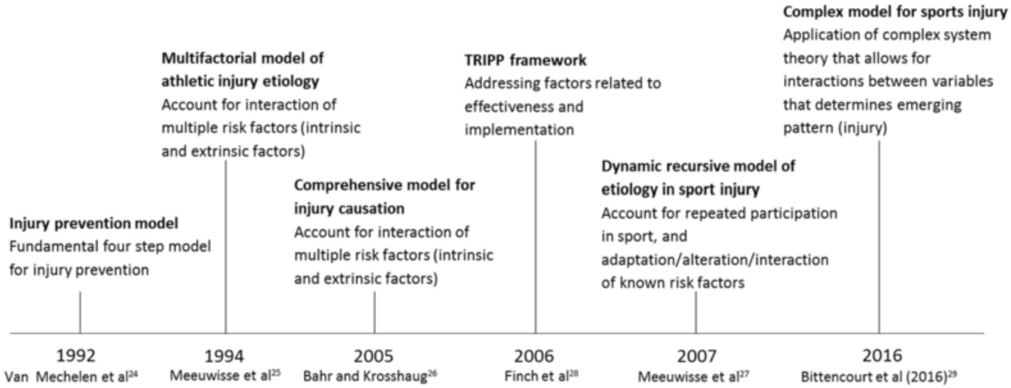

Figure 2 Temporal development of injury prevention models, with key characteristics for each model highlighted.

The preferred study design for risk factor analyses is a prospective cohort study, where the different candidate risk factors can be measured at baseline and the cohort followed prospectively to record injuries in a defined period of time.[41] Quality control is simplified and this design makes completeness possible to a high degree. The more advanced model to study risk of injury is the Cox proportional hazards regression model.[41] The advantage in this statistical approach is that exposure (time) becomes the main variable. As playing time may vary dramatically between individual players, this type of analysis is considered more robust. Importantly, it accounts for both confounding (when an association between two variables could be the effect of a third variable), and interaction (when two factors combine to produce a risk greater or lesser than anticipated).[41]

The main limitation to prospective cohort study design is sample size. It is suggested that 20–50 injury cases are needed to detect moderate to strong associations, whereas small to moderate associations would need about 200 injured subjects. The sample size may depend on the anticipated effect of the a candidate factor on injury risk, and most studies published on risk factors for hamstring injury are too small to detect small to moderate associations.[41] These methodological considerations are important to ensure appropriate statistical analyses and study design are used when investigating risk factors for hamstring injury.

RISK FACTORS FOR HAMSTRING INJURY

A number of modifiable and non-modifiable risk factors have been proposed for hamstring injury. In two large systematic reviews age, previous injury, ethnicity, strength deficits and imbalances, flexibility, neuromuscular control, limb dominance, playing position, and fatigue have all been investigated as candidate risk factors.[38,42]

Non-modifiable risk factors

Age has consistently been identified as a risk factor for injury. In the meta-analyses performed by Freckleton and Pizzari,[38] age was identified as a significant risk factor for injury, supported by multiple previous findings identifying age as a risk factor.[5,43–45] Importantly, in a number of multivariate regression analyses, age remains a significant factor, indicating that it is independently associated with risk of injury. It is therefore important to include age as a potential risk factor candidate, or consider age as a confounding factor in a multivariate analysis.

The most consistent risk factor for hamstring injury is previous injury.[5,38,42,43] In a large prospective cohort study, previous injury was associated with a seven-time increase in risk of hamstring injury.[43] A recent meta-analysis supported these findings across different studies for the odds ratio and relative risk calculated from the pooled data.[38] The strong association between previous injury and future hamstring injury requires some thoughtful interpretation. Are we merely returning the injured athlete to the same pre-injury status for risk of injury, never addressing the risk factors that could influence the primary injury occurrence? Or might it indicate a failed rehabilitation process, where the athlete is caught in a continuous cycle of injury and risk of re-injury? Nevertheless, much of the previous injury findings are limited by self-reported questionnaires, and therefore subject to recall bias. A robust analysis and reliable injury surveillance method is required.

Weak evidence have been found in support of other non-modifiable risk factors, such as weight, body mass index (BMI), ethnicity, playing position and limb dominance.[2,38,42]

Modifiable risk factors

Strength

Muscle strength, in particular quadriceps and hamstring strength, has been associated with hamstring injury, even though the evidence remains conflicting.[38,42,43,46,47] Muscle strength is typically measured through isokinetic dynamometry expressed as torque, and includes both concentric and eccentric modes of contraction at different velocities. Eccentric hamstring peak torque has been found associated with risk of injury.[48,49] However, in a large meta-analysis, increased quadriceps peak torque was the only modifiable risk factor associated with risk of hamstring injury.[38]

These findings indicate a potential inverse relationship as the hamstring muscle aims to act as a “breaking” force to the muscles flexing the hip and extending the knee during the terminal swing phase. Therefore, interactions between different muscle groups (quadriceps and hamstrings) and isokinetic strength characteristics, commonly expressed as the hamstring-to-quadriceps ratios, have also been associated with an increased risk of hamstring injury.[50,51] A more dynamic representation of strength has been suggested as an exploration of the strength ratios between the hamstrings and quadriceps muscle groups. The "dynamic control ratio" represents the net joint torque at different angles over the entire range of motion.[52] No prospective study has invesitgated this new interpretation of strength ratios.

Eccentric strengthening programmes have been used successfully to reduce the number of injuries in football over a specific season, using the Nordic hamstring exercise.[35,36,53] The Nordic hamstring exercise has been used previously to determine at-risk players by dichotomising the range of motion achieved during the test, where it was not identified as a risk factor for hamstring injury.[54] However, a novel device has been developed to measure force produced during the movement.[55] Eccentric strength as measured with this novel device has since been reported as a significant risk factor for hamstring injury,[56–58] and therefore offers a unique way of measuring eccentric strength while performing an exercise that is often used for injury prevention.

Although strength measures have been used in many hamstring risk factor studies, the season-to-season variability of isokinetic strength testing is unknown. Equally, the relationship between standard isokinetic muscle strength testing and eccentric strength testing using the novel Nordic hamstring exercise device has not yet been explored.

Flexibility

Prospective studies associating flexibility with risk of hamstring injury have produced contrasting results.[38,42] A recent investigation found no relationship between flexibility and hamstring injury,[59] yet previous investigations have found the opposite.[60,61] The evidence supporting the use of stretching exercises aimed at improving flexibility to prevent injury is limited.[62–64] Nevertheless, flexibility was the most routine injury risk screening test reported by the 32 teams participating in the FIFA 2014 World Cup in Brazil.[65] Flexibility testing is also perceived by European clubs to be important; 87% of elite clubs reported it as one of the three most commonly used injury screening tests.[66]

In a large systematic review, no association was found between various flexibility measures, including the slump test, lumbar spine flexion, lumbo-femoral ratio, straight leg raise or the sit-and-reach-test with risk for hamstring injury.[38] However, the active and passive knee extension tests, quadriceps flexibility and the dorsiflexion lunge test demonstrated mixed or contradicting results, hampered by small sample sizes and large heterogeneity between the studies included in the meta-analyses.[38,42] This relationship between flexibility and risk of hamstring injury is still poorly understood.

Neuromuscular function

Neuromuscular function, or neuromuscular control, are terms used interchangeably to describe motor output. It includes measures of force development, intrinsic muscle activity, balance and agility.[67,68] Retrospective studies have shown that rate of torque development and muscle activity deficits are present after hamstring injury.[68,69] These results indicate altered neuromuscular function after injury; however, it is not known whether these differences are the result of the injury, or demonstrate traits for athletes at risk of hamstring injury.

Persistent neuromuscular inhibition might be the result of inadequate rehabilitation, and predispose the athlete to re-injury.[70] Differences post-injury have been demonstrated in a number of different areas, including preferential eccentric strength weakness, muscle architecture, and changes in rate of torque development as well as muscle activity.[57,69–71] Retrospective studies have shown that significant bilateral differences in rate of torque development and muscle activity during isokinetic eccentric knee flexion are present after hamstring injury.[68,69] However, no prospective study has been performed to establish whether rate of torque development and the timing of muscle activity onset during isokinetic strength assessment might be identified as risk factors for hamstring injury.

AIMS AND OUTLINE OF THIS PROJECT

The research described in this thesis studied the causative nature as well as potential predictive risk factors for hamstring injury in professional male football players.

The purpose of this research project was to investigate the main risk factors for hamstring injury in a single-centre, adequately powered, prospective cohort study. The specific aims were to establish the relationship between hamstring injury risk and:

1. Strength, an established risk factor for hamstring injury, including both standard isokinetic dynamometry, as well as novel strength characteristics (dynamic control profile of the hamstring-to-quadriceps ratio) and the Nordic hamstring exercise test. In addition, to establish the season-to-season variability of isokinetic strength testing, as well as the relationship between isokinetic dynamometer muscle strength testing and eccentric strength testing using the Nordic hamstring exercise device.
2. Flexibility, specifically hip flexion range of motion using the active and passive knee extension test, and ankle dorsiflexion range of motion measured during the dorsiflexion lunge test.
3. The rate of torque development and onset of muscle activity characteristics during both concentric and eccentric modes of isokinetic strength testing.

We firstly investigated strength as one of the most commonly reported risk factors for hamstring injury in **Chapter 2** *Part one*. This investigation was performed over four seasons with a large sample size and a large number of injuries, allowing the detection of small to moderate associations. We explored the common variables of peak torque and the hamstring-to-quadriceps ratios calculated from isokinetic strength tests as potential risk factors.

We continue the investigation into strength in **Chapter 2** *Part two* using eccentric strength as measured during the Nordic hamstring exercise, in addition to the isokinetic testing. *Part two* also included the addition of two novel isokinetic strength test variables to the risk factor analysis - the dynamic control profile and the angle of crossover. The dynamic control profile represents the net joint torque (eccentric hamstrings to concentric quadriceps), and the "angle of crossover" was identified as the point where the net joint torque was equal to zero. In addition, we thoroughly explored previous injury as a risk factor for hamstring injury.

A key aspect of risk factor analysis that is commonly overlooked is the characteristics of the tests that are used to measure strength, and whether they are appropriate to use in risk factor analysis. Therefore, the stability of the isokinetic test variables over multiple seasons was assessed in **Chapter 3**. The season-to-season variability of isokinetic strength testing, as well as the influence of hamstring injury on the stability of the variable were investigated. Furthermore, the relationship between traditional isokinetic muscle strength testing and eccentric strength testing using the novel Nordic hamstring exercise device was investigated in this chapter.

Flexibility is seen as an important part of injury prevention in football. Stretching to improve flexibility is common practice in elite football teams, yet risk factor studies have not produced convincing evidence for flexibility as a risk factor for hamstring injury. As with strength, many studies have reported results from small cohorts, and with a small number of injuries included. In **Chapter 4** we examined the relationship between hamstring and ankle dorsiflexion range of motion with risk of hamstring injury in a large cohort including a substantial number of injuries.

Retrospective studies have identified rate of torque development and muscle activity as a risk factor for hamstring injury. The first prospective study to investigate these measures of intrinsic neuromuscular function as candidate risk factors for hamstring injury is presented in **Chapter 5**. The term neuromuscular function is wide-ranging, and is used to describe different aspects needed for optimal motor output. Although recognizing this interaction between central and peripheral mechanisms, risk factor studies have predominantly focused on specific intrinsic aspects of neuromuscular function. We investigated the association between the timing of hamstring muscle activity onset and rate of torque development during the early phase of isokinetic strength testing with risk of hamstring injury.

Finally, in **Chapter 6** we discuss the most important findings from these studies, together with the strengths and limitations of this project. The clinical implications of these results are discussed, as well as what we might expect from future research.

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Chapter 2
Part one

Hamstring and quadriceps isokinetic strength deficits are weak risk factors for hamstring strain injury
A 4-Year Cohort Study

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ABSTRACT

Background: A hamstring strain injury (HSI) has become the most common noncontact injury in soccer. Isokinetic muscle strength measurements are considered a risk factor for HSIs. However, underpowered studies with small sample sizes unable to determine small associations have led to inconclusive results regarding the role of isokinetic strength and strength testing in HSIs.

Purpose: To examine whether differences in isokinetic strength measures of knee flexion and extension represent risk factors for hamstring injury in a large cohort of professional soccer players in an adequately powered study design.

Study Design: Cohort study; Level of evidence, 2.

Methods: A total of 614 professional soccer players from 14 teams underwent isokinetic strength assessment during preseason screening. Testing consisted of concentric knee flexion and extension at 60 deg/s, 300 deg/s and eccentric knee extension at 60 deg/s. A clustered multiple logistic regression analysis was used to identify variables associated with the risk of HSIs. Receiver operating characteristic (ROC) curves were calculated to determine sensitivity and specificity.

Results: Of the 614 players, 190 suffered an HSI during the four seasons. Quadriceps concentric strength at 60 deg/s (odds ratio [OR], 1.41; 95% CI, 1.03 to 1.92; *P* = .03) and hamstrings eccentric strength at 60 deg/s (OR, 1.37; 95% CI, 1.01 to 1.85; *P* = .04) adjusted for bodyweight were independently associated with the risk of injuries. The absolute differences between the injured and uninjured players were 6.9 N·m and 9.1 N·m with small effect sizes ($d < 0.2$). The ROC analyses showed an area under the curve of 0.54 and 0.56 for quadriceps concentric strength and hamstring eccentric strength, respectively, indicating a failed combined sensitivity and specificity of the 2 strength variables identified in the logistic regression models.

Conclusion: This study identified small absolute strength differences and a wide overlap of the absolute strengths measurements at the group level. The small associations between lower hamstrings eccentric strength and lower quadriceps concentric strength with HSIs can only be considered as weak risk factors. The identification of these risk factors still does not allow the identification of individual players at risk. The use of isokinetic testing to determine the association between strength differences and HSIs is not supported.

INTRODUCTION

A hamstring strain injury (HSI)[1] has become the most common non-contact injury in elite male soccer,[30] and have increased over the past decade.[7,12,14,19] HSI represent 12 to 14% of all injuries in elite soccer[14,21,31] accounting for 37% of all muscle injuries sustained[14,18,30] resulting in a mean of 14 (1–128) competition days lost.[13] HSI recurrence remains substantial, ranging from 16 to 60%[7,8,14,18] across different sports.

Many risk factors for HSIs have been suggested, including non-modifiable factors such as age, previous injury and ethnicity, as well as modifiable factors such as strength, flexibility, and fatigue.[13,15,16,23] Muscle strength, in particular decreased hamstring strength, has been associated with HSIs, even though the evidence remains conflicting.[7,10,15,16,25] Interactions between different muscle groups (quadriceps and hamstrings) and strength characteristics (concentric/eccentric), expressed as hamstring-to-quadriceps (H:Q) ratio, have also been associated with an increased risk for HSIs.[1] A recent meta-analysis by Freckleton and Pizzari[16] identified age, previous HSIs, and increased quadriceps peak torque as risk factors for HSI. Strength variables such as hamstring peak torque, hamstring-to-quadriceps ratio and eccentric hamstring strength were not found to be associated with an increased risk for a primary or recurrent HSI. The authors concluded that these risk factors, including hamstring peak torque, require further research to adequately clarify their involvement due to small sample sizes, inconclusive results, or very few studies on their influence.[16]

To date, no adequately powered single-center study exists that investigates the relationship between isokinetic strength and HSI risk. We therefore aimed to examine whether isokinetic strength deficits of knee flexion and extension represent risk factors for HSIs in a large cohort of professional soccer players.

METHODS

Study design

Ethical approval for this study was obtained from the Shafallah Medical Genetics Centre (institutional review board project number 2012–020). All soccer teams (N = 14) eligible to compete in the Qatar Stars League (QSL) agreed to participate in the study, which covered 4 seasons (September 2010 to June 2014) with repeated measures of all players. The QSL is the highest level of elite competition in Qatar. Each player from the respective teams underwent an annual periodic health evaluation (PHE) at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar. This evaluation was performed during the pre-season period from May to September, with the official start of the season in September of each year.

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[1] Hamstring strain injury (HSI) is terminology used only in this chapter to describe hamstring injury, as published in the American Journal of Sports Medicine

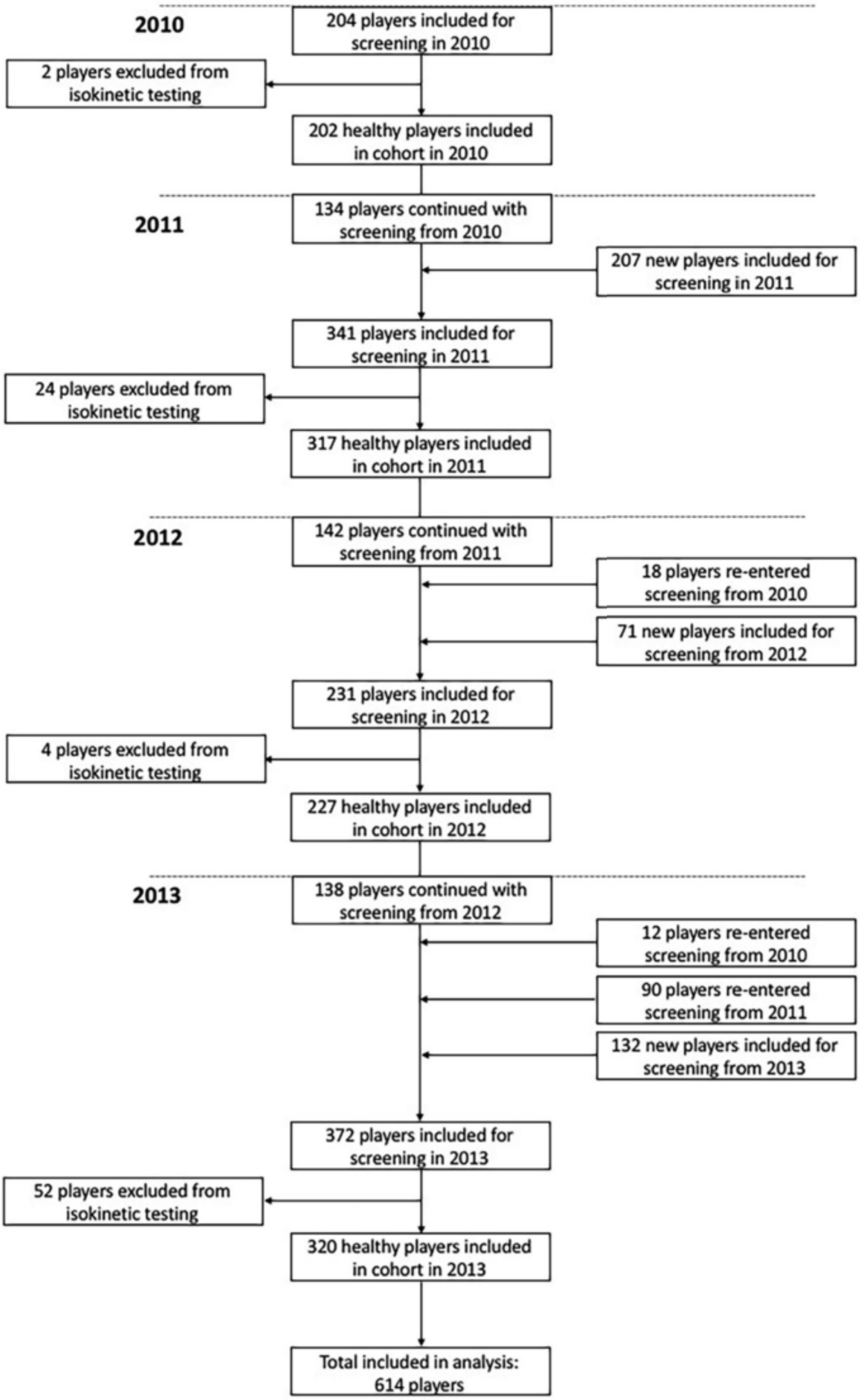

Figure 1 Flowchart demonstrating the movement of players and repeated measurements between different seasons.

As part of the musculoskeletal component of the PHE, all players that provided informed consent performed an isokinetic assessment of both lower limbs in the rehabilitation department of the hospital, measuring knee flexion and extension isokinetic strength. Players that did not consent or refused to perform the isokinetic assessment were excluded from the study.

Figure 1 depicts the inclusion methodology during the 4 study seasons. If a player was injured at the time of testing, all possible tests were still performed on the uninjured limb.

Experimental Procedure for Isokinetic Testing

Knee flexion and extension muscle strength were tested using an isokinetic dynamometer (Biodex Multi-joint System 3; Biodex Medical Systems Inc). After an explanation of the testing methodology, the player performed a self-selected 5–10 min warm up routine, consisting of either light running or cycling on a stationary exercise bike (Bike Forma, Technogym). Players tended to prefer cycling, but would select light running if the stationary bike was not available.

Before each isokinetic test, the player was instructed as to the mode and procedure of the specific test and allowed 3 practice repetitions. The order (ie, left, right) was randomized, which was then maintained for each of the 3 different testing modes and speeds for the particular participant. Each player was positioned on the dynamometer so that the hip was flexed to 90°, ensuring that the dynamometer and knee joint axes were aligned. Straps were fixed around the thigh, waist and trunk to minimize secondary joint movement.[26] During testing, vigorous verbal encouragement was provided by the assessors.[20,28]

Testing was composed of 3 different modes and speeds. First, the athletes were tested over 5 repetitions of concentric knee flexion and extension at 60 deg/s. This was followed by 10 repetitions of concentric knee flexion and extension at 300°/s. Finally, they performed five repetitions of eccentric knee extension at 60°/s. The highest peak torque value observed from all repetitions performed for each of the three different tests were recorded. Between each mode of testing a minimum of 60 seconds of rest was provided.

Several “mixed” strength ratios were examined. Knee extension (“quadriceps”) peak torque to knee flexion (“hamstring”) peak torque ratios were developed to investigate the relationship between the different modes and speeds of testing. This included quadriceps concentric 60 deg/s to hamstring concentric 60 deg/s, quadriceps concentric 300 deg/s to hamstring concentric 300 deg/s and quadriceps concentric 300 deg/s to hamstrings eccentric 60 deg/s.

Injury Surveillance

All teams participating in the Qatar Stars League (QSL) national soccer league are provided with medical services by the National Sports Medicine Programme, a division of Aspetar Orthopaedic and Sports Medicine Hospital. This centralized system with a focal point for the medical care of each club competing in the QSL allowed for the standardization of the ongoing injury surveillance performed at each of the clubs.[11] The managers and medical staff of all 14 first-division clubs from the QSL were invited and briefed about the details of the study.

An HSI was defined as acute pain in the posterior thigh that occurred during training or match play, and resulted in immediate termination of play and inability to participate in the next training session or match.[11] These injuries were confirmed through a clinical examination (identifying pain on palpation, pain with isometric contraction, and pain with muscle lengthening) by a sports medicine practitioner and/or team doctor. If indicated, the clinical diagnosis was supported by ultrasonography and magnetic resonance imaging at the study center. A recurrent injury was defined as an HSI that occurred in the same limb and during the same season as the initial injury[28].

The injury data were collected monthly, with regular communication with the responsible team physician/physical therapist to encourage timely and accurate reporting. At the conclusion of each season, all the data from the individual clubs were collated into a central database, and discrepancies were identified and followed up at the different clubs to be resolved.

To ensure all eligible injuries were included, a manual review of each of the participants' hospital file was carried out at the end of 2014 examining all available medical information regarding each season from 2010 to 2014. A season (with or without injury) was only included in the analyses if the player had performed an isokinetic screening measurement at the start of the same season.

Statistical Analyses

Univariate analyses (independent *t* tests) were performed between the injured and the uninjured players for the strength measurements. Injured limbs were compared to uninjured limbs among injured players and then to all uninjured limbs among the uninjured players. Absolute values (peak torque) were also adjusted for bodyweight as previously described.[5] A P value of < .05 was considered to be statistically significant. Effect size, which is the quantitative measure of the strength of an observed occurrence, was calculated and interpreted as small (0.2 to 0.3), medium (0.5) or large (> 0.8).[9]

Because of the consistency in our sample group, the repeated measures performed over the 4 seasons, as well as the fact that not every participant had the same number of measurements (ie, some participants would have test results including both limbs for each season, while other participants might only have been tested once), standard errors would have increased when using general estimating equations in a traditional logistic regression model. Therefore, we used a population-averaged logit model, performing a clustered multiple logistic regression analysis in STATA (version 11.0; Statacorp). Variables independently associated with HSIs among soccer players were determined from the univariate analyses.

We calculated receiver operating characteristic (ROC) curves to describe the sensitivity and specificity of the significant strength variables. The area under the curve (AUC) indicates how well the strength variables under consideration would discriminate between injured and uninjured players, and were interpreted as excellent (0.90–1), good (0.80–0.90), fair (0.70–0.80), poor (0.60–0.70) or fail (0.50–0.60).[2,22]

RESULTS

Participants

During the 4-year study period, 614 elite male soccer players (mean ± SD: age, 24.7 ± 4.7 years; height, 176.5 ± 6.7 cm; weight, 71.8 ± 9.1 kg; body mass index [BMI], 22.9 ± 2.0 kg/m^2) reported for screening and were considered for isokinetic testing. Those players who were unable to perform the test due to injury or did not consent to performing the test (n = 51, age, 26.5 ± 5.0 years; height, 176.6 ± 6.7 cm; weight, 73.8 ± 8.7 kg; BMI, 23.6 ± 1.8 kg/m^2) were excluded from the final analyses. The remaining 563 players performed a total of 2136 isokinetic test procedures (considering both limbs) over the 4 seasons.

In this cohort, 62% of players were of Arab origin, with minor ethnic representations from Africa (29%), Asia (4%), Europe (3%) and South America (2%). There were no differences in age or body composition between injured and uninjured groups. A history of HSIs was reported by 9.3% of the cohort, more commonly among the subsequently injured players than uninjured players (Table 1).

Playing position was documented in 4 categories: goalkeepers (n = 69), defenders (n = 195), midfielders (n = 202), and forwards (n = 97). Among the injured players, there were fewer goalkeepers (2.6%) than defenders (9.9%), forwards (9.0%), or midfielders (8.0%) ($P = .002$, χ^2) In this cohort, 19.9% of the players were dominant in the left limb, and 80.1% were dominant in the right limb, with no significant difference in injury risk between injured and uninjured players (Table 1).

New hamstring strain injuries

In total, 190 of the 614 players suffered a HSI during the 4 seasons, but 23 injured players were excluded from the analysis because they had not undergone isokinetic testing. Therefore, 167 players were included in the analyses (131 with first-time injuries and 36 with reinjuries). The overall injury rate was 8.3% per limb per season, with 5.4% in season 1, 7.3% in season 2, 11.7% in season 3 and 8.6% in season 4 ($P < .001$, χ^2).

Table 1 Characteristics of the injured and uninjured players (n=563)[a]

	Injured (n = 167)	**Uninjured (n = 396)**	***P* value**
Age, y	25.3 ± 4.9	24.7 ± 4.7	.09
Body mass, kg	71.3 ± 7.8	71.9 ± 9.1	.37
Body height, cm	176.6 ± 6.1	176.6 ± 6.7	.98
Body mass index, kg/m^2	22.9 ± 1.9	23.0 ± 2.0	.32
Previous HSIs, %	20.5	9.5	<.001
Player position, n, %			<.001
Goalkeeper	14 (8.4)	55 (13.9)	
Defender	55 (32.9)	140 (35.3)	
Midfielder	46 (27.5)	156 (39.4)	
Forward	52 (31.2)	45 (11.4)	
Limb dominance, n, %			.11
Left	29 (17.4)	83 (20.9)	
Right	138 (82.6)	313 (79.1)	

[a] Data are shown as mean ± SD unless otherwise indicated. HSI, hamstring strain injury.

Isokinetic strength measurements

The results of the univariate analyses are shown in Table 2. When comparing the injured limb to the uninjured limb among injured players considering all 4 seasons (n = 167), no strength differences were observed.

When comparing the injured limbs to the limbs of uninjured players of all 4 seasons (n = 1931), quadriceps concentric torque at 60 deg/s, hamstrings concentric torque at 60 deg/s and hamstring eccentric torque at 60 deg/s adjusted for bodyweight were lower in injured players, but with small effect sizes ($d < 0.2$). As shown in Figures 2 and 3, there was substantial population overlap in quadriceps and hamstring strength between the injured and uninjured groups.

Table 2 Univariate comparison of isokinetic strength testing between the injured and uninjured limbs in the injured players and all uninjured limbs in the uninjured players.

	Injured players					Uninjured players			
	Injured limb (n = 167)	Uninjured limb (n = 167)	*P* value[a]	Absolute difference	Effect Size (d)	Uninjured limbs (n = 1931)	*P* value[b]	Absolute difference	Effect Size (d)
Quadriceps									
Concentric at 60 deg/s	227.3 ± 39.9	231.7 ± 39.9	.31	4.4	0.11	234.2 ± 44.3	**.03**	6.9	0.17
– BW adjusted	320.6 ± 46.5	326. ± 47.2	.25	6.0	0.13	327.5 ± 51.5	.10	6.9	0.14
Concentric at 300 deg/s	133.7 ±26.3	133.1 ± 24.6	.85	-0.6	0.02	133.4 ± 26.0	.90	-0.3	0.01
– BW adjusted	188.5 ± 31.2	187.8 ± 28.9	.85	-0.7	0.02	186.3 ± 28.6	.35	-2.2	0.08
Hamstrings									
Concentric at 60 deg/s	122.9 ± 43.2	124.6 ± 24.9	.53	1.7	0.07	125.8 ± 25.1	.15	2.9	0.12
– BW adjusted	173.9 ± 27.7	175.2 ± 29.3	.68	1.3	0.05	175.7 ± 29.1	.43	1.8	0.07
Concentric at 300 deg/s	94.2 ± 19.4	94.2 ± 22.2	.99	0.0	0.00	95.9 ± 21.9	.35	1.7	0.08
– BW adjusted	132.5 ± 23.0	132.5 ± 26.4	.99	0.0	0.02	133.8 ± 25.9	.54	1.3	0.05
Eccentric at 60 deg/s	178.9 (±7.8	181.9 ± 40.5	.48	3.0	0.08	186.0 ± 41.1	**.03**	7.1	0.18
– BW adjusted	250.7 ± 43.6	255.4 ± 49.4	.37	4.7	0.00	259.8 ± 50.0	**.03**	9.1	0.19
Mixed ratios									
Quadriceps concentric at 60 deg/s to hamstrings concentric at 60 deg/s	1.89 ± 0.38	1.89 ± 0.33	.91	0.0	0.01	1.89 ± 0.31	.93	0.0	0.01
Quadriceps concentric at 300 deg/s to hamstrings concentric at 300 deg/s	1.45 ± 0.26	1.46 ± 0.24	.54	0.0	0.00	1.42 ± 0.25	.25	0.0	0.01
Quadriceps concentric at 300 deg/s to hamstrings eccentric at 60 deg/s	0.77 ± 0.17	0.75 ± 0.17	.77	0.0	0.07	0.74 ± 0.17	.06	0.0	0.16

Absolute values and values adjusted for body weight (BW) are shown in newton-meters as mean ± SD. Bolded P values indicate statistically significant difference between compared groups.

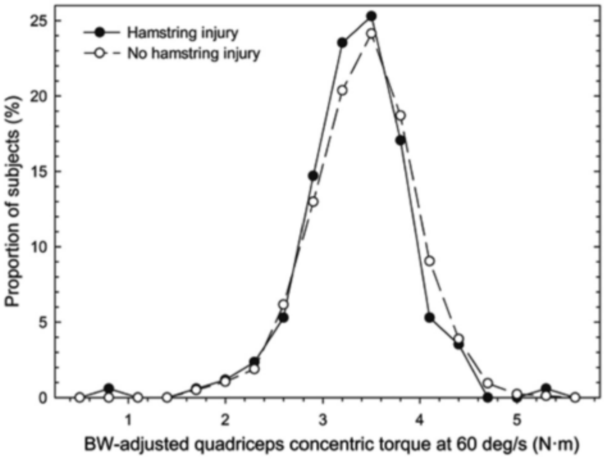

Figure 2 Distribution of isokinetic strength for quadriceps concentric at 60 deg/s in the injured vs uninjured groups. BW, body weight.

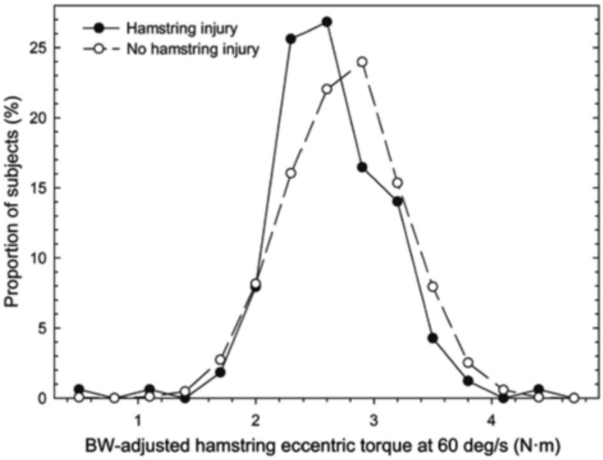

Figure 3 Distribution of isokinetic strength for hamstring eccentric at 60 deg/s in the injured vs uninjured groups. BW, body weight.

Logistic regression analysis (Marginal population-average logit model)

Age, weight, BMI, previous hamstring injuries, season, side (left or right limb), team, limb dominance, and position were tested as potential confounding variables using univariate population-average logit analysis. Previous injuries, season, and position were established as significant factors and included in the final regression model.

The parameter estimates of the multiple logistic regression analysis, expressed as odds ratios per 1-unit (N·m/kg) strength decrease are presented in Table 3. Quadriceps concentric strength at 60 deg/s adjusted for bodyweight and hamstrings eccentric at 60 deg/s adjusted for bodyweight were independently associated with risk of HSI. However, ROC analyses revealed an AUC of 0.54 and 0.56 for quadriceps concentric and hamstring eccentric strength, respectively, indicating a failed combined sensitivity and specificity of the two strength variables identified in the logistic regression models.

Table 3 Multiple logistic regression analysis demonstrating parameter estimates* (95% confidence intervals, CI) with all possible risk factors included (n = 565).

	Odds ratio	95% CI	*P* value
Quadriceps			
Concentric at 60 deg/s	1.01	1.00 to 1.01	0.06
– BW adjusted	1.41	1.03 to 1.92	***0.03***
Concentric 300 deg/s	1.01	1.00 to 1.01	0.97
– BW adjusted	0.91	0.53 to 1.79	0.87
Hamstrings			
Concentric at 60 deg/s	1.01	1.00 to 1.01	0.17
– BW adjusted	1.33	0.78 to 2.33	0.29
Concentric at 300 deg/s	1.01	1.00 to 1.01	0.20
– BW adjusted	1.33	0.78 to 2.33	0.29
Eccentric at 60 deg/s	1.01	1.00 to 1.01	0.12
– BW adjusted	**1.37**	**1.01 to 1.85**	***0.04***
Mixed Ratios			
Quadriceps concentric at 60 deg/s to hamstrings concentric at 60 deg/s	1.32	0.76 to 2.27	0.32
Quadriceps concentric at 60 deg/s to hamstrings eccentric at 60 deg/s	0.93	0.29 to 2.94	0.90
Quadriceps concentric at 300 deg/s to hamstrings concentric at 300 deg/s	0.68	0.36 to 1.32	0.26
Quadriceps concentric at 300 deg/s to hamstrings eccentric at 60 deg/s	0.68	0.31 to 1.52	0.35

* Odds ratio (OR) per one unit change adjusted for previous injury, season and position and accounting for clustering factors (player, left or right side, and team).

DISCUSSION

In this 4-year cohort study of 614 soccer players with 190 hamstring strain injuries, lower hamstrings eccentric torque and lower quadriceps concentric torque (adjusted for bodyweight) of the injured limb were independently associated with increased risk for HSIs. Small absolute differences in isokinetic measures between the injured and uninjured groups, together with the wide overlap shown in the strength distribution graphs (Figures 2 and 3), clearly illustrate that it would be difficult to distinguish between the groups clinically. ROC analyses further demonstrate that it is not possible to discriminate between injured and uninjured players based on the strength deficits identified.

Isokinetic strength deficits

Our finding of an association between lower hamstring eccentric isokinetic strength adjusted for body weight and the risk of HSIs is comparable with similar findings in the literature,[4,11,28,30] although different measurements of eccentric strength are utilized in these studies. Opar et al,[24] using a novel device measuring peak bilateral eccentric knee flexion force during performance of a Nordic hamstring curl, recently found lower eccentric strength to increase an athlete's risk of injuries substantially.

Previous studies have shown that it is possible to decrease the incidence of HSIs by modifying hamstring muscle strength through an intervention program,[4,10] reporting convincing results in reducing both first-time and recurrent HSIs.[3,27,29] These results are in agreement with our findings identifying eccentric hamstring strength as a risk factor for HSIs.

This study also showed lower quadriceps concentric strength adjusted for body weight as a risk factor for HSIs, which has not been described previously as an independent risk factor for HSIs. Previous prospective studies present conflicting results, which have led to different interpretations of the role of strength. A recent systematic review and meta-analysis[16] identified high concentric quadriceps strength as being a risk factor for HSIs, which is in contrast to our results. Furthermore, low concentric hamstring strength has been identified as a risk factor for HSIs,[25] but neither concentric nor eccentric strength were supported in the meta-analysis by Freckleton and Pizzari.[16]

H:Q Ratio not identified as a risk factor for HSIs

Interestingly, the present analysis did not identify hamstring-to-quadriceps (H:Q) ratio as a risk factor for HSIs, which supports similar findings in the meta-analysis by Freckleton and Pizzari.[16] The present study examined a number of candidate H:Q ratios and found no association with subsequent injury (Table 3). H:Q ratios as both conventional and dynamic[1] entities of mixed isokinetic strength have been identified previously as risk factors for HSIs, although there has been some debate over how these ratios are interpreted statistically.[5]

Croisier et al[10] described cut-off values for H:Q ratios together with existing pre-season strength imbalances, and found that HSIs were 4 to 5 times more probable in players classified as having a strength imbalance compared to players without strength imbalances.[10] This study was conducted on multiple sites, with players from different leagues, and used two different isokinetic testing devices. Inclusion criteria were hamstring injuries which caused more than 30 days of lost playing time. These methodological differences make comparisons with the present research difficult. Our findings casts serious doubt over whether H:Q ratios are as effective in risk factor identification as previously reported.

Strengths and Limitations

The identification of decreased isokinetic strength as a risk factor for HSIs is both supported and opposed by previous studies.[16,17,25] Perhaps the main reason for these inconsistencies are due to methodological shortcomings, such as sample size and number of injuries included. Bahr and Holme[6] suggested that 30–40 injury cases would be needed to detect strong to moderate associations and that more than 200 injury cases are needed to find small to moderate associations.[6] The large number of participants and injury cases represent a strength of the current study. Inconclusive results identified in the literature[16] due to sample size, weak methodological quality, or lack of power were overcome as our study design was able to identify small associations.

The present study was performed in a professional athlete setting, utilizing one isokinetic testing system with highly experienced assessors. We performed repeated measures of the same study population over a 4-year observation period, and while there was no systematic change, the year-to-year variability might limit our ability to detect an association between strength and injury risk. While the participants were professional athletes performing at a similar level as other national leagues around the world, we do not know whether factors related to ethnic background, training culture, or climate specific to the Middle East region played a role.

Limitations to our study results include no recording of exposure of the players included in the study. We also have to acknowledge inconsistencies in the injury surveillance process, particularly with regards to the first 2 seasons. There were unrecorded movement of players between different teams, as well as the possibility of misdiagnoses and injuries not being recorded. The retrospective chart review was only investigating injuries recorded in the medical file of the player at the hospital. Therefore, there is a risk of misclassification of players, that is, players suffering HSIs without these being recorded.

In our statistical model, we separated the left and right limbs of the players to allow for appropriate clustering, although we did control for side in the regression model. With our history-based definition of an HSI, we cannot confirm that false-positive HSIs were not included. We recommend clinical and imaging confirmation in future studies. We were also not informed about prevention intervention during the season and/or alterations of strength during the season. Although no systematic change was found in any of the strength variables over the four seasons, we cannot discount the possible random variance in strength within individual players during the study period.

Clinical Implications

The statistical power of our study enables us to identify small to moderate associations, as demonstrated by the results. They would suggest that players with lower quadriceps and hamstring strength are at greater risk for an HSI. However, when interpreting these results, we would urge restraint. Of the 12 strength variables we included in our analysis, only 2 were found to display a weak, albeit statistically significant, association with the risk of HSIs, with large CIs and small effect sizes between groups (Table 2). It should be clear from Figures 2 and 3 that it is impossible to distinguish these 2 groups clinically, as there is complete overlap between the injured and uninjured groups. The multifactorial nature of an HSI is well established[23] and strength training has been demonstrated as a successful intervention for both the prevention and rehabilitation of hamstring injuries, but the use of isokinetic quadriceps or hamstring strength testing to predict the risk of HSIs is not supported by our results.

CONCLUSION

This study identified lower hamstrings eccentric strength and lower quadriceps concentric strength when adjusted for bodyweight as risk factors weakly associated with HSIs. However, these findings have little clinical value, and the use of isokinetic testing in athlete screening to predict the risk of future HSIs must be reconsidered.

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Chapter 2

Part two

A comprehensive strength testing protocol offers no clinical value in predicting risk of hamstring injury:

a prospective cohort study of 413 professional football players

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ABSTRACT

Background: Hamstring injuries remain prevalent across a number of professional sports. In football, the incidence has even increased by 4% per year at the Champions League level over the last decade. The role of muscle strength or strength ratios and their association with risk of hamstring injury remain restricted by small sample sizes and inconclusive results.

Purpose: To identify risk factors for hamstring injury in professional football players in an adequately powered, prospective cohort study. Using both established (isokinetic) and novel (eccentric hamstring test device) measures of muscle strength, we aimed to investigate the relationship between these strength characteristics over the entire range of motion with risk of hamstring injury.

Methods: All teams (n = 18) eligible to compete in the premier football league in Qatar underwent a comprehensive strength assessment during their annual periodic health evaluation at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar. Variables included isokinetic strength, Nordic hamstring exercise strength, and dynamic hamstring: quadriceps ratios.

Results: Of the 413 players included (68.2% of all league players), 66 suffered a hamstring injury over the two seasons. Only isokinetic quadriceps concentric at 300°/s (adjusted for bodyweight) was associated with risk of hamstring injury when considered categorically. Age, body mass, and playing position were also associated with risk of hamstring injury. None of the other 23 strength variables examined were found to be associated with hamstring injury.

Conclusion: The clinical value of isolated strength testing is limited, and its use in musculoskeletal screening to predict future hamstring injury is unfounded.

INTRODUCTION

Hamstring injuries have remained prevalent across a number of professional sports.[1] In football, the incidence has even increased by 4% per year over the last decade at the Champions League level.[2] Recently, the complexity involved with the occurrence of injury has been highlighted,[3] but clinically meaningful risk factor identification remains an important part of the injury prevention model.[4] The most recent meta-analysis identified age, previous hamstring injury, and quadriceps strength as risk factors for a primary or recurrent hamstring injury.[5] Isokinetic muscle strength in particular has received much attention in the literature.[6–10] In addition, lower limb strength balance, typically expressed as hamstring-to-quadriceps (H:Q) strength ratio, has also been associated with an increased risk for hamstring injury, although the results have been inconsistent.[8,10–12] Alternative measures of eccentric muscle strength have been suggested[13] and recently a novel device was developed to objectively measure eccentric hamstring muscle strength when performing the Nordic hamstring exercise.[14]

The findings related to muscle strength or strength ratios and their association with risk of injury, remain restricted by small sample sizes and inconclusive results.[5] Further exploration of these strength ratios between hamstrings and quadriceps muscle groups have been suggested to include a more dynamic representation,[15] as well as the “dynamic control ratio” which represents the net joint torque at different angles over the entire range of motion.[16] However, this approach has not been investigated prospectively. Although the need for adequately powered studies with appropriate design were called for more than a decade ago,[17] few such prospective studies exist. Previous methodological limitations include inconsistency regarding injury surveillance, biased sampling of previous injury data, and a lack of recorded exposure for the athletes included.[18]

The purpose of this study was to identify risk factors for hamstring injury in professional football players in an adequately powered, prospective cohort study. Using both established (isokinetic) and novel (eccentric hamstring test device) measures of muscle strength, we aimed to investigate the relationship between these strength characteristics over the entire range of motion with risk of hamstring injury.

METHODS

Study design

All teams (n = 18) eligible to compete in the Qatar Stars League (QSL), the premier football league in Qatar, agreed to participate in the study, which covered two football seasons (September 2013 to May 2015). Each player from the respective teams underwent an annual periodic health evaluation (PHE) at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar. The PHE was performed from May to September, with the official start of the season in September of each year. If players performed PHE outside of this period and met the inclusion criteria, they were still included in the study.

All players over the age of 18 years and eligible to compete in the QSL, who had provided written consent and were able to perform the strength testing, were included. Players who were injured at the time of the PHE and therefore unable to perform the tests were excluded. If no isokinetic test was performed at the start of a season, or no exposure or injury surveillance data were recorded over an entire season, players were also excluded. Figure 1 depicts the inclusion methodology during the two study seasons.

Ethical approval was obtained from the Institutional Review Board, Anti-doping Laboratory, Qatar (IRB F2013000003).

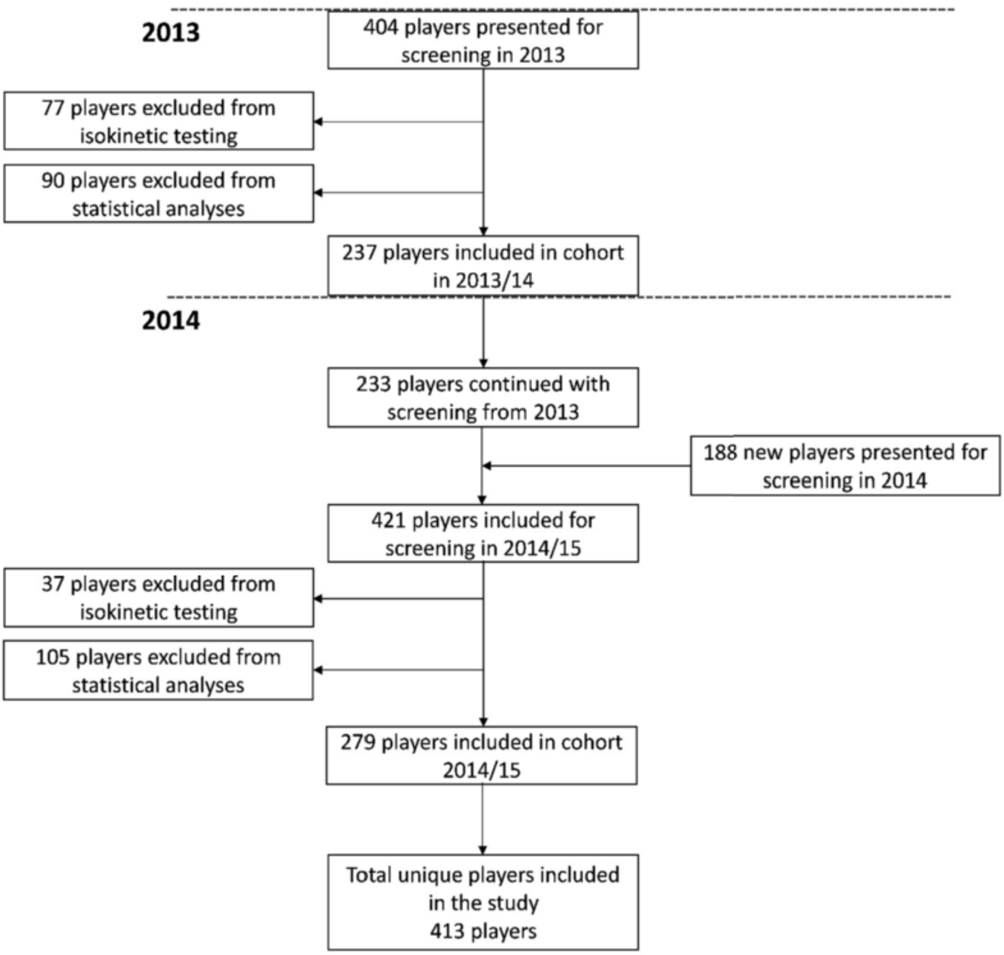

Figure 1 Flow chart demonstrating the movement of players and repeated measurements between different seasons.

Player information

All likely non-modifiable risk factors were considered. A history of previous hamstring injury in the past 12 months,[19,20] season, team, leg dominance, position, and ethnicity were recorded. Player height and weight were measured and body mass index (BMI) calculated during the PHE.

History of previous injury was self-reported at the time of screening and cross-checked with their hospital medical file for the entire cohort. To minimize recall bias and account for players not willing to reveal past injuries during screening, we also conducted a subgroup analysis including only players playing in the QSL during the previous seasons (2012 to 2014) and therefore were covered by our prospective injury surveillance.

Isokinetic strength testing

Knee flexion and extension muscle strength were tested using an isokinetic dynamometer (Biodex Multi-joint System 3, Biodex Medical Systems Inc. New York, USA). After an explanation of the testing methodology, the player performed a 5–10 min warm up routine, cycling on a stationary exercise bike (Bike Forma, Technogym®, Cesena, Italy).

The order (i.e. left, right) was randomized and maintained for each of the three different testing modes and speeds for each subject. All players completed the test procedure as previously described.[18]

First, the players were tested over five repetitions of concentric knee flexion and extension at 60°/s, followed by 10 repetitions of concentric knee flexion and extension at 300°/s. These test modes measures the concentric strength of the quadriceps (knee extension) and hamstring (knee flexion) muscles. Finally, players performed five repetitions of eccentric knee extension at 60°/s which measures the eccentric strength of the hamstring muscles. The highest peak torque value observed from all repetitions performed for each of the three different tests was recorded.

Dynamic control profile

The dynamic control profile represents the net joint torque (eccentric hamstrings to concentric quadriceps) over the entire range of motion during isokinetic testing.[16] The specific knee flexion angle where the quadriceps torque was greater than the eccentric hamstring torque was identified, and the torque-angle plots for eccentric hamstrings and concentric quadriceps were determined using a custom algorithm created in Labview (V7.0 National Instruments, Austin, Texas) and exported in Microsoft Excel® (Microsoft Office 2013, Redmond, Washington, USA).

The peak torque (Nm) measurements for concentric knee flexion and extension at 60°/s and eccentric knee extension at 60°/s were used to define the dynamic control profile. Concentric hamstrings to quadriceps (H:Q) ratio (concentric hamstrings divided by concentric quadriceps) and dynamic control ratios (eccentric hamstrings was divided by the concentric quadriceps) were calculated at angles of 30°, 40°, and 50°.

For each data point (angle), the torque value for concentric quadriceps was subtracted from the eccentric hamstrings. Consequently, the "angle of crossover" was identified as the point where the net joint torque was equal to zero.

Nordic hamstring exercise testing

Before the start of season two, players also performed one set of three maximal repetitions on a device specially designed to measure the Nordic hamstring exercise.[14] After completion of the isokinetic test, the players were tested in a kneeling position on a padded board, with both ankles secured immediately above the lateral malleolus by individual ankle braces. These braces were attached to uniaxial load cells (Delphi Measurement Pty Ltd, Gold Coast, Australia) with wireless data acquisition capabilities (Mantracourt Electronics Ltd, Farringdon, UK). The device has been described previously[14] and allows for separate measurements of each limb. The player was instructed to progressively lean forward at the slowest possible speed resisting the movement with both limbs while keeping the trunk and hips in a neutral position and the hands held across the chest. If the force output reached a distinct peak (indicative of maximal eccentric strength), followed by a rapid decline in force that occurred when the player could no longer resist the effects of gravity, a trial was deemed acceptable.

Injury surveillance

All participating QSL teams are provided with medical services by the National Sports Medicine Programme, a department with the Aspetar Orthopaedic and Sports Medicine Hospital. This centralized system with a focal point for the medical care of each club competing in the QSL allowed for standardization of the ongoing injury surveillance through the Aspetar Injury and Illness Surveillance Programme (AIISP).[21]

The AIISP includes prospective injury and exposure (minutes of training and match play) recording from all QSL teams. The injury data were collected monthly, with regular communication with the responsible team physician/physiotherapist to encourage timely and accurate reporting. Throughout the 2013 and 2014 season (July to May; 44 weeks), training and match exposure for each team were recorded by the team physician (or lead physiotherapist if no team physician was available). At the conclusion of each season, all the data from the individual clubs were collated into a central database, and discrepancies were identified and followed up at the different clubs to be resolved.

A hamstring injury was defined as acute pain in the posterior thigh that occurred during training or match play, and resulted in immediate termination of play and inability to participate in the next training session or match.[22] These injuries were confirmed through clinical examination (identifying pain on palpation, pain with isometric contraction and pain with muscle lengthening) by the club medical team. If indicated, the clinical diagnosis was supported by ultrasonography and magnetic resonance imaging at the study centre. A recurrent injury was defined as a hamstring injury that occurred in the same limb and within two months of the initial injury.[23]

Statistical analyses

Univariate analyses (independent *t* tests) were performed between the limbs of the injured and the uninjured players for the isokinetic strength test, Nordic hamstring exercise test, and dynamic control profile. Injured limbs were compared to uninjured limbs among injured players, and then to all uninjured limbs among the uninjured players.

Due to the consistency in our sample, the repeated measures performed over the two seasons, as well as the fact that not every player had the same number of measurements (i.e. some subjects would have test results including both limbs for both seasons, while other subjects might only have been tested once), standard errors would have increased when using general estimating equations in a traditional Cox regression model. Therefore we performed a univariate Cox regression analysis in STATA (version 11.0, College Station, Texas, USA) using the limb as the unit of analyses, adjusting for player identity as a cluster factor. Exposure was totaled as duration in hours for game and training combined from the start to the end of each season, or time to first injury. Variables independently associated with hamstring strain injury were determined from the univariate analyses. A *P* value of ≤ 0.05 was considered statistically significant. Effect size, which is the quantitative measure of the strength of an observed occurrence, was calculated and interpreted as small (0.2 to 0.3), medium (0.5) or large (> 0.8).[24]

Potential risk factors were treated as continuous and categorical variables. In the continuous analyses, all variables with *P* value ≤ 0.10 were considered further in a backward stepwise multivariate Cox regression analysis to evaluate potential predictor variables. Hazard ratios (HR) with 95% confidence intervals (CIs) are presented with exact *P* values, and *P* values of ≤ 0.05 were considered statistically significant.

For the categorical analyses, the limbs of players were grouped for isokinetic strength, Nordic hamstring exercise, and dynamic control profile. The HR and 95% confidence interval (95% CI) were calculated for the groups with the lowest (< 1 SD below the mean) and the highest (> 1 SD above the mean) values for each variable, respectively, with the intermediate group as the reference group.[25]

RESULTS

Players

During the two-season study period, 592 elite male soccer players (age 25.8 ± 4.8 yrs, height 177 ± 7 cm, weight 72.4 ± 9.3 kg, BMI 23.1 ± 2) reported for screening and were considered for isokinetic testing. Players who were unable to perform the test due to injury, did not provide consent, or had no exposure data recorded in either season (n = 179, age 25.3 ± 4.5 yrs, height 177 ± 7 cm, weight 73.5 ± 9.8 kg, BMI 23.4 ± 1.8), were excluded from the final analyses. The remaining 413 players performed a total of 1087 isokinetic test procedures (considering both limbs) over the two seasons.

New hamstring strain injuries

Over the two seasons, 413 unique players (68.2% of all QSL players) competed for 544 player seasons (132 players competed both seasons) (Figure 1). In total, 66 of the 413 players sustained 69 index hamstring injuries. The three players who had more than one injury were retained in the analyses (none of these injuries met the criteria for re-injury), and all injured players in season one had their previous injury status adjusted accordingly in season two.

Non strength-related risk factors

There were no differences in height, ethnicity, limb dominance, and body composition between injured and uninjured groups (Table 1). Previous hamstring injury was reported by 31% of the entire cohort (n = 413) with no significant difference between injured and uninjured players. Also in the subgroup of players with injury history based on injury surveillance during the previous season (n = 336), a history of previous injury did not represent an increased risk for new hamstring injury.

Univariate analyses identified age and position as potential risk factors for hamstring injury (Table 1). Goalkeepers were significantly less likely to sustain a hamstring injury than defenders, midfielders or forwards. When age was considered as a categorical variable, players in the younger age group (< 1 SD below the mean, 18 to 21 years) had a lower risk of injury than the intermediate age group (table 2). Players who weighed more (> 1 SD above the mean, 81.8 to 104.5 kg) were at lower risk of injury compared to the intermediate weight group (Table 2).

In the multivariate Cox regression analysis, age (HR 1.07 per one year increase in age, 95% CI 1.03 to 1.12) and position (HR 5.79 for outfield players vs goalkeepers, 95% CI 1.44 to 23.32) were retained from the univariate analyses and were significantly associated with hamstring injury risk.

Strength measurements as potential risk factors

The results of the univariate analyses are shown in tables 3 and 4 for isokinetic strength and Nordic hamstring exercise, respectively. Among injured players (n = 66), there were no differences in strength between the injured and uninjured limbs.

Table 1 Characteristics of injured (n = 66) and uninjured players (n = 347).

	Injured (n = 66)	**Uninjured (n = 347)**	***P* value**
Age, yrs	27.9 (4.3)	25.9 (4.9)	**0.002**
Weight, kg	72.2 (7.7)	72.6 (9.2)	0.86
Height, cm	175.8 (6.7)	176.8 (6.8)	0.30
Body mass index, kg/m^2	23.4 (1.9)	23.1 (2.0)	0.33
Previous Injury, n (%)	21 (31.8)	117 (30.9)	0.89
Player position, n (%)			**0.02**
Goalkeeper	1 (1.4)	44 (11.6)	
Defender	28 (42.4)	122 (32.3)	
Midfielder	25 (37.9.)	140 (37.0)	
Forward	12 (18.2)	72 (19.0)	
Limb dominance, n (%)			0.39
Left	16 (24.2)	71 (18.8)	
Right	50 (75.8)	307 (81.2)	
Ethnicity, n (%)			0.16
Arab	35 (53.0)	225 (59.5)	
Black	23 (34.8)	109 (28.8)	
Asian	2 (3.0)	9 (2.4)	
Caucasian	6 (9.1)	35 (9.3)	

Data are shown as mean values with SD or percentages.

Comparing injured limbs (n = 69) to the uninjured limbs (n = 1018), the parameter estimates of the univariate Cox regression analyses of the isokinetic strength test variables are presented in table 3, expressed as hazard ratios per one unit (1 Nm/kg) strength change. In the continuous analyses, none of the eleven strength variables were found to be significantly associated with an increased risk of hamstring injury (Table 3). The categorical analyses identified the greater strength group (> 1 SD above mean, 2.2–3.7 Nm/kg) for quadriceps concentric torque at 300°/s (normalized to bodyweight) as being at increased risk for injury (Table 2).

No significant differences were found for any of the Nordic hamstring exercise test variables between injured and uninjured limbs (Table 4).

When profiling dynamic control, no difference was observed in either the angle of cross over between the injured limbs (n = 56) uninjured limbs (n = 752) (injured limbs: 45° ± 8° (SD), uninjured limbs: 44° ± 7°), or in the dynamic control ratio (Figure 2).

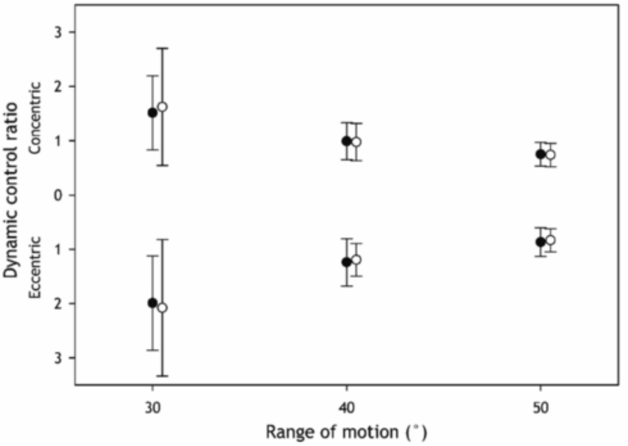

Figure 2 Dynamic control ratio at 30°, 40° and 50° for injured (closed symbols) and uninjured players (open symbols) throughout the test range of motion for the two test modes (concentric and eccentric). Data represent group means with standard deviations.

Table 2 Comparison between uninjured and injured players with potential risk factors treated as categorical variables using univariate cox regression analyses.[a]

	Risk as a categorical variable			
	>1 SD below the mean		**>1 SD above the mean**	
	HR (95% CI)	***P* value**	**HR (95% CI)**	***P* value**
Age, y	0.15 (0.04 to 0.61)	**0.008**	1.21 (0.72 to 2.03)	0.48
Weight, kg	0.95 (0.54 to 1.66)	0.90	0.39 (0.17 to 0.89)	**0.024**
Height, cm	0.93 (0.50 to 1.73)	0.81	0.64 (0.28 to 1.44)	0.28
Body mass index, kg/m^2	0.80 (0.41 to 1.54)	0.50	0.79 (0.42 to 1.49)	0.46
Quadriceps				
Concentric at 60°/s	0.82 (0.41 to 1.63)	0.57	1.00 (0.53 to 1.91)	0.10
– BW adjusted	1.10 (0.56 to 2.18)	0.78	1.46 (0.77 to 2.79)	0.25
Concentric at 300°/s	0.43 (0.17 to 1.13)	0.09	1.37 (0.81 to 2.34)	0.25
– BW adjusted	0.90 (0.43 to 1.90)	0.79	2.06 (1.21 to 3.51)	**0.008**

Table 2 *Continued*

	Risk as a categorical variable			
	>1 SD below the mean		**>1 SD above the mean**	
	HR (95% CI)	***P* value**	**HR (95% CI)**	***P* value**
Hamstrings				
Concentric at 60°/s	0.78 (0.37 to 1.67)	0.53	0.72 (0.35to 1.49)	0.38
– BW adjusted	0.92 (0.45 to 1.89)	0.82	0.88 (0.45 to 1.89)	0.71
Concentric at 300°/s	0.41 (0.14 to 1.18)	0.10	0.72 (0.37 to 1.40)	0.33
– BW adjusted	0.75 (0.33 to 1.69)	0.49	1.49 (0.82 to 2.70)	0.19
Eccentric at 60°/s	0.68 (0.34 to 1.38)	0.29	0.48 (0.21 to 1.14)	0.10
– BW adjusted	0.83 (0.42 to 1.64)	0.59	1.02 (0.52 to 2.03)	0.95
Hamstrings eccentric 60°/s to Quadriceps concentric 300°/s	0.85 (0.43 to 1.70)	0.66	0.70 (0.33 to 1.52)	0.37
Peak Force (N)	0.87 (0.30 to 2.50)	0.79	1.51 (0.43 to 3.06)	0.78
– BW adjusted (N/kg)	0.83 (0.29 to 2.39)	0.73	1.39 (0.57 to 2.39)	0.47
Peak Force Imbalance (N)	0.40 (0.54 to 2.99)	0.37	0.87 (0.25 to 2.99)	0.82
Average Force (N)	0.60 (0.18 to 1.96)	0.40	1.06 (0.42 to 2.68)	0.90
– BW adjusted (N/kg)	0.79 (0.28 to 2.28)	0.67	1.05 (0.41 to 2.66)	0.93
Angle of crossover	0.89 (0.42 to 1.89)	0.76	1.42 (0.70 to 2.89)	0.34
Dynamic Control Ratio	0.75 (0.29 to 1.95)	0.55	1.79 (0.91 to 3.51)	0.09
Dynamic Control Ratio at various degrees in ROM				
Concentric at 30°	0.95 (0.67 to 1.42)	0.71	1.43 (0.78 to 3.41)	0.44
Concentric at 40°	0.89 (0.56 to 1.31)	0.49	1.74 (0.91 to 2.98)	0.17
Concentric at 50°	1.60 (1.00 to 2.43)	0.50	1.81 (0.95 to 3.46)	0.07
Eccentric at 30°	1.16 (0.30 to 4.47)	0.83	1.78 (0.79 to 4.00)	0.16
Eccentric at 40°	0.90 (0.38 to 2.10)	0.80	1.32 (0.64 to 2.69)	0.45
Eccentric at 50°	0.71 (0.31 to 1.62)	0.41	1.38 (0.65 to 2.92)	0.40
Overall H:Q ratio	0.42 (0.57 to 3.08)	0.39	1.71 (0.80 to 3.66)	0.80

The hazrd ratio (HR; 95% confidence interval [CI]) was calculated for the group of players with the lowest (> 1 SD below the mean) and the highest (> 1 SD above mean) values for each variable, respectively, with the intermediate group of players as reference group.

Table 3 Univariate comparison of isokinetic strength tests between the injured and a) the uninjured limb in the injured players, b) all uninjured limbs in the uninjured players, and (c) Cox regression analysis demonstrating parameter estimates (95% confidence intervals, CI) for all isokinetic strength variables when comparing injured to uninjured limbs.

	Injured players					Uninjured players				Univariate Cox regression		
	Injured limb (n = 69)	Uninjured limb (n = 69)	Difference	95% CI	*P* value[a]	Uninjured limbs (n = 948)	Difference	95% CI	*P* value[b]	HR	95% CI	*P* value
Quadriceps												
Concentric at 60°/s	235.3 (46.3)	239.2 (46.7)	3.9	-12.1 to 19.9	0.62	234.0 (46.9)	-1.3	-13.0 to 10.4	0.81	1.00	1.00 to 1.01	0.96
– BW adjusted	3.28 (0.6)	3.34 (0.6)	0.06	-0.15 to 0.27	0.55	3.23 (0.6)	-0.05	-0.20 to 0.10	0.55	1.09	0.68 to 1.74	0.71
Concentric at 300°/s	139.3 (30.9)	134.2 (28.6)	-5.1	-15.4 to 5.2	0.32	134.9 (26.3)	-4.4	-11.1 to 2.3	0.25	1.01	1.00 to 1.02	0.17
– BW adjusted	1.93 (0.4)	1.86 (0.4)	-0.07	-0.21 to 0.07	0.28	1.86 (0.3)	-0.07	-0.15 to 0.01	0.13	2.05	0.96 to 4.37	0.06
Hamstrings												
Concentric at 60°/s	126.6 (23.9)	124.9 (25.8)	-1.7	-10.3 to 6.9	0.70	126.1 (27.8)	-0.5	-7.4 to 6.4	0.88	1.00	0.99 to 1.01	0.97
– BW adjusted	1.76 (0.3)	1.74 (0.3)	-0.02	-0.12 to 0.08	0.68	1.74 (0.3)	-0.02	-0.10 to 0.06	0.54	1.16	0.55 to 2.46	0.70
Concentric at 300°/s	97.6 (17.6)	94.8 (17.6)	-2.8	-8.9 to 3.3	0.35	96.5 (20.5)	-1.1	-6.2 to 4.0	0.63	1.00	0.99 to 1.01	0.60
– BW adjusted	1.36 (0.2)	1.32 (0.2)	-0.04	-0.1 to 0.03	0.34	1.33 (0.3)	-0.03	-0.10 to 0.04	0.35	1.62	0.60 to 4.34	0.34
Eccentric at 60°/s	206.3 (40.1)	203.1 (40.6)	-3.2	-17.1 to 10.7	0.65	203.2 (43.7)	-3.1	-14.0 to 7.8	0.55	1.00	1.00 to 1.01	0.48
– BW adjusted	2.86 (0.5)	2.82 (0.5)	-0.04	-0.21 to 0.13	0.65	2.80 (0.5)	0.98	0.94 to 1.02	0.32	1.30	0.81 to 2.11	0.28
H:Q Ratio (functional)												
Hamstrings eccentric 60°/s to Quadriceps concentric 300°/s	1.52 (0.3)	1.55 (0.3)	0.03	-0.07 to 0.13	0.49	1.53 (0.3)	0.01	-0.07 to 0.09	0.72	0.90	0.41 to 1.96	0.79

Absolute values and values adjusted for body weight (BW) are shown as mean force values in Newton-meter (Nm) with standard deviation (SD).

Table 4 Univariate comparison of Nordic hamstring exercise test results between the injured and a) the uninjured limb in the injured players, b) all uninjured limbs in the uninjured players, and (c) Cox regression analysis demonstrating parameter estimates (95% confidence intervals, CI) for all strength variables included when comparing injured to uninjured limbs. Absolute values and values adjusted for body weight (BW) are shown as mean force values in Newton(N) with standard deviation (SD).

	Injured players					**Uninjured players**				**Univariate Cox regression**		
	Injured limb n = 29)	**Uninjured limb (n = 29)**	**Difference**	**95% CI**	***P* value**[a]	**Uninjured limbs (n = 432)**	**Difference**	**95% CI**	***P* value**[b]	**HR**	**95% CI**	***P* value**[c]
Peak force (N)	312.1 (67.3)	302.1 (60.8)	-10.0	-43.74 to 23.74	0.55	299.1 (70.9)	-13.0	-31.29 to 5.29	0.32	1.00	0.98 to 1.01	0.36
– BW adjusted (N/kg)	4.45 (1.01)	4.37 (0.97)	-0.08	-0.60 to 0.44	0.75	4.20 (1.01)	-0.25	-0.51 to 0.01	0.20	1.25	0.88 to 1.76	0.21
Peak force imbalance (N)	30.8 (21.4)	34.8 (33.1)	4.0	-10.66 to 18.66	0.75	33.6 (29.8)	2.8	-4.7 to 10.29	0.59	1.00	0.98 to 1.01	0.50
Average force (N)	292.5 (64.5)	287.3 (62.7)	-5.2	-38.66 to 28.26	0.76	281.9 (68.7)	-10.6	-28.30 to 7.10	0.40	1.00	1.00 to 1.01	0.47
– BW adjusted (N/kg)	4.21 (0.98)	4.14 (0.97)	-0.07	-0.58 to 0.44	0.79	3.97 (0.98)	-0.24	-0.49 to 0.01	0.20	1.24	0.88 to 1.77	0.22

DISCUSSION

The main finding of this prospective two season cohort study of 413 football players, the largest to date, was that none of the 24 strength variables examined, differed between injured and healthy players. The only exception was that the group with the highest quadriceps concentric torque at 300°/s (> 1 SD above the mean) had an increased risk for hamstring injury. Age, body mass, and playing position (i.e. being a goalkeeper) were associated with injury risk.

Modifiable risk factors

The comparison of the strength measures between the injured and uninjured groups (Table 3 and 4) clearly demonstrate that it is not possible to distinguish between the groups clinically. In the categorical analyses, the greater strength group for concentric quadriceps strength at 300°/s (adjusted for bodyweight) was found to be significant (see table 2). Although our finding of a weak association with quadriceps strength is supported by the meta-analyses performed by Freckleton and Pizzari,[5] the small effect size of 0.2 and the fact that there was no group difference in strength indicates that this holds little clinical value. The smallest detectable difference for concentric quadriceps peak torque is reported between 11.9 and 20%,[26,27] and therefore the differences reported in this study are likely equivalent to test-retest variability. Comparison to previous findings is difficult, such as the testing protocol, inclusion criteria, duration of the follow-up period, and injury definition. It is however more striking that only one out of 24 strength variables evaluated (eleven isokinetic strength test, five Nordic hamstring exercise test, and eight dynamic control profile measures) was weakly associated with an increased risk of hamstring injury.

The Nordic hamstring exercise has received much attention in the literature and its value as a preventative tool is well established.[28] Further investigation has been done to examine the use of this exercise as a test to determine risk of hamstring injury, and initially no significant association was found between a simple visual assessment of test performance and hamstring injury risk.[13] Despite this, a novel device has recently been developed to accurately measure eccentric hamstring strength when performing this exercise.[14] Subsequent studies positively identified players with inferior eccentric strength as being at increased risk of hamstring injury,[29,30] while Bourne et al[31] found no increased risk with lower eccentric strength in rugby union players. These previous studies determined best fit cut-off values for eccentric hamstring strength, and assessed the risk of injury based on these in multivariate models. In the present study, we compared eccentric strength in the Nordic hamstring exercise test between injured and uninjured groups, and also assessed risk in the group with inferior performance. However, none of the variables related to the Nordic hamstring exercise test were found to be significantly associated with an increased risk for hamstring injury. We do not dispute that the Nordic hamstring exercise may be a useful injury prevention tool.[32,33] It may alter the influence of non-modifiable risk factors such as age or previous injury,[29] or lead to protective muscle architecture adaptations.[30,34] However, the present findings urge caution if the clinician attempts to relate the results of a standalone Nordic hamstring exercise test to individual risk for injury.[35]

The H:Q ratio as conventional and dynamic entities of mixed isokinetic strength have been identified previously as risk factors for hamstring injury,[7,8,11,36] with some debate over how these ratios are interpreted. Essentially, we should consider that scaling these data may not appropriately represent the lower and higher end of the range (i.e. the slope of the relationship between the two variables is not equal to one). Furthermore, when we divide two normally distributed variables, the resulting ratio is unlikely to be normally distributed itself.[37] Two large previous investigations have reported contradicting results, which make it difficult to determine whether these strength ratios are valuable or not.[8,18] Therefore, the dynamic control profile, as described by Graham-Smith et al,[16] was also included to explore the relationship between hamstring and quadriceps strength throughout the entire test range of motion.

No association was found between the dynamic H:Q ratio (knee flexion ("hamstring") eccentric peak torque at 60°/s to knee extension ("quadriceps") concentric peak torque at 300°/s) (Table 2), a finding supported by a previous meta-analysis.[5] Additionally, there was no difference in the dynamic control profile over the entire range of motion, or the angle of crossover. Figure 2 clearly demonstrates that the ratios for both the injured and uninjured players were indistinguishable. Although this dynamic ratio might be considered a valuable tool when interpreting isokinetic strength in previously injured players, it adds little value for the clinician to establish risk of hamstring injury for the individual. Our findings suggest that H:Q ratios in any form are ineffective in risk factor identification.

Mean body mass did not differ between groups, but players with greater body mass (> 1 SD above the mean, > 82 kg) did have a lower risk for a hamstring injury than the intermediate weight group. However, the absolute difference between the injured and uninjured players was less than 1 kg. This finding is therefore also not clinically useful and, as previously reported,[5,13,25] we would not consider body mass as an important risk factor for hamstring injury.

Non-modifiable risk factors

Age has consistently been identified as a risk factor for hamstring injury,[5,10,20,25,38] as in the current study, where we observed a 7% increased risk for hamstring injury per year added. The injury risk of the youngest group (< 22 yrs) was 85% less than the intermediate group, while we detected no difference in risk between the intermediate and the oldest group (Table 2). This supports the results of previous studies where fewer hamstring injuries were found in the younger age group.[39] Playing positions were retained in the multivariate analyses to investigate whether it might influence age, as goalkeepers were on average one year older than the other playing positions combined. It did not however change the risk for these players significantly, even though outfielders were five times more likely to get injured compared to goalkeepers.

Surprisingly, a history of previous injury was not found to be associated with risk of hamstring injury, although consistently identified as a risk factor in the literature.[5,40] This finding was further explored, attempting to reduce the risk of recall bias in self-reporting injuries (or unwillingness to disclose previous injuries), by analysing a subgroup of players where the previous injury status were known through detailed injury surveillance. Again, no significant association was found. In contrast, a retrospective investigation of the same league over previous seasons did identify previous injury as a risk factor.[18] To interpret these contrasting results, consider that two large randomized control trials were being conducted at the Aspetar Orthopaedic and Sports Medicine Hospital concurrent with this prospective study.[41] Both these studies incorporated a structured criteria based rehabilitation programme, including a large number of QSL players. The first RCT reported a low re-injury rate of 6%[23] compared to other football leagues.[42] A reduced risk in previously injured players has been reported before[43] due to the effect of successful intervention programmes. Our finding suggest a similar effect, where the introduction of systematic, criteria based rehabilitation programmes may have reduced the risk associated with previous injury.

Strengths and limitations

To detect strong to moderate associations in prospective cohort studies, it is suggested that 30-40 injury cases are needed, while for small to moderate associations to be detected, 200 injury cases are needed.[17] Importantly, even though this is one of the largest prospective study to date on risk factors for hamstring injury, we were not able to include enough cases to detect small associations, illustrating the difficulty in performing adequately powered investigations. However, the effect sizes calculated for each strength variable never exceeded 0.3, failing to reach clinical significance.

Intra-season variability in the repeated measures over the two-year observation period may have limited our ability to identify an association between strength and injury risk. Injury surveillance was carefully monitored during each season; however, we cannot discount that the clinical criteria used to confirm a hamstring injury may have involved other differential diagnoses.

All tests performed utilized the same isokinetic testing system with highly experienced assessors in a multinational, multi-language clinical setting for professional athletes. Although every effort was made to ensure players understood the test procedure and instructions, it is possible that some players did not comprehend the instructions fully. However, this reflects a “real world” scenario, increasing the external validity of the study.

We also acknowledge the homogeneity of our study population of professional male football players, which limits the generalization of these findings to other sports, age groups, or female players. Other factors such as training culture and possible prevention strategies within different teams, or climate specific to the Middle East region, could have influenced the results.

Clinical implications

It is clear that isolated strength variables, including the new test device for the Nordic hamstring exercise and a more comprehensive interpretation of strength ratios, have limited clinical application in identifying individual players at risk. Our continued pursuit of risk factor identification through performance tests seems incongruous. Muscle strength continues to form part of a multifactorial complex model that may lead to injury. However, our findings should urge the clinician to exercise caution and not translate the results of these commonly used screening tests into risk of injury for the individual player.

CONCLUSION

None of the other 24 strength-related variables were found to be associated with hamstring injury. Increased concentric quadriceps strength when adjusted for bodyweight was the only associated with hamstring injury when considered categorically, although the magnitude of this difference is likely too small to be clinically relevant. The use of strength measurements and different strength characteristics in musculoskeletal screening to predict future hamstring injury is unfounded.

What are the findings

- Isolated strength measurements cannot assist the clinician in predicting risk of hamstring injury.
- Functional and dynamic measures of isokinetic H:Q ratio are not useful in determining individual risk of injury.
- Age and playing position are non-modifiable risk factors associated with an increased risk of hamstring injury.
- Population-based risk of injury in previously injured players might be reduced by implementation of criteria based rehabilitation programmes .

What this study adds to existing knowledge

- Greater consideration might be given to the use of strength testing and strength ratios in identifying players at risk for hamstring injury.
- Muscle strength continues to be identified in the causation of hamstring injury and must be considered in prevention measures.
- The small association found with strength highlights again the multifactorial nature of hamstring injury.

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Chapter 3

Substantial interseason variability in isokinetic muscle strength testing and poor correlation with Nordic eccentric hamstring strength in professional male football players

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ABSTRACT

Background: In elite sport, the use of strength testing to establish muscle function and performance is common. Traditionally, isokinetic strength tests have been used, measuring torque during concentric and eccentric muscle action. A device that measures eccentric hamstring muscle strength while performing the Nordic hamstring exercise is now also frequently used.
The study aims to investigate the variability of isokinetic muscle strength over time, e.g. between seasons, and the relationship between isokinetic testing and the new Nordic hamstring exercise device.

Methods: All teams (n = 18) eligible to compete in the premier football league in Qatar underwent a comprehensive strength assessment during their periodic health evaluation at Aspetar Orthopaedic and Sports Medicine Hospital in Qatar. Isokinetic strength was investigated for measurement error, and correlated to Nordic hamstring exercise strength.

Results: Of the 529 players included, 288 players had repeated tests with one/two seasons between test occasions. Variability (measurement error) between test occasions was substantial, as demonstrated by the measurement error (approximately 25Nm, 15%), whether separated by one or two seasons. Considering hamstring injuries, the same pattern was observed among injured (n = 60) and uninjured (n = 228) players.
A poor correlation (r = 0.35) was observed between peak isokinetic hamstring eccentric torque and Nordic hamstring exercise peak force. The strength imbalance between limbs calculated for both test modes were not correlated (r = 0.037).

Conclusion: There is substantial intraindividual variability in all isokinetic test measures, whether separated by one or two seasons, irrespective of injury. Also, eccentric hamstring strength and limb-to-limb imbalance were poorly correlated between the isokinetic and Nordic hamstring exercise tests.

INTRODUCTION

In elite sport, the use of strength testing to establish muscle function and performance is common.[1,2] Most professional football teams perform periodic health evaluations (PHE) or screening procedures to identify athletes at risk, with a view to target injury prevention programmes to the profile of each player, or the entire team.[3] Muscle strength testing is believed to represent an important part of the PHE, to identify strength deficits and imbalances which can be addressed to decrease injury risk. A recent meta-analysis has shown that isokinetic strength testing has limited predictive value in determining future risk of hamstring strain injury.[4] Still, strength testing is one of the three most commonly used screening methods in professional football,[3] purportedly to determine the risk for various types of lower limb injuries, particularly to the thigh and knee.

Traditionally, isokinetic strength tests have been used, capable of measuring torque during both concentric and eccentric muscle action. A device specifically designed to measure eccentric muscle strength while performing the Nordic hamstring exercise has quickly gained popularity in elite sporting teams and sports medicine facilities. The Nordic hamstring exercise has been shown to effectively reduce the risk of hamstring injury,[5,6] the most common injury type in football.[7] Therefore, it seems intuitive that monitoring the force produced during this test might contribute to appropriately define muscle strength characteristics for football players.

Several studies have investigated the reliability of standard isokinetic strength measurements, reporting on test-retest reliability, as well as characterizing the minimal difference required between tests to be interpreted as a meaningful change.[8–10] In these studies, the test-retest measures are performed within one to seven days. However, the variability of isokinetic muscle strength over time, e.g. between seasons, has not been investigated, nor has the relationship between isokinetic testing and the new Nordic hamstring exercise device. It is common practice to conduct preseason screening, or single time point periodic health assessment that might include musculoskeletal strength testing.[3,11] Although one would expect that the tests between seasons would differ, the amount of variability that might be expected is unknown, and therefore makes the clinical interpretation of the data difficult.

Therefore, the aim of this study was twofold, (a) to describe the season-to-season variability of isokinetic strength testing in a group of professional male football players, and also determine the influence of hamstring injury on the stability of the variable; and (b) to investigate the relationship between isokinetic muscle strength testing and eccentric strength testing using the novel Nordic hamstring exercise device.

METHODS

Study design and participants

The analyses were performed on prospectively collected data from professional male football players as part of their annual PHE at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar. All teams (n = 18) eligible to compete in the Qatar Stars League (QSL), the highest level of competition in Qatar, agreed to participate in the study, with serial tests on all players from September 2010 to June 2014. As part of the musculoskeletal component of the PHE, players who provided informed consent performed a strength assessment of both lower limbs in the rehabilitation department at Aspetar. Players that did not consent or could not perform the strength assessment due to injury were excluded. Players who performed testing during consecutive seasons were identified for the current analyses, and grouped as players with one season and/or two seasons between tests.

Figure 1 depicts player inclusion. Ethical approval was obtained from the Institutional Review Board, Anti-doping Lab, Qatar (IRB project number 2012-020, IRB F2013000003).

Isokinetic strength testing

The same isokinetic strength battery was used for all tests. Knee flexion and extension strength were tested using an isokinetic dynamometer (Biodex Multi-joint System 3, Biodex Medical Systems Inc. New York, USA). After an explanation of the testing methodology, the player performed a 5–10 min warm up routine, consisting of either light running or cycling on a stationary exercise bike (Bike Forma, Technogym®, Cesena, Italy) at approximately 1 W/kg body weight, and familiarization with the test procedure. Each player was seated on the dynamometer so that the hip was flexed to 90°, ensuring that the dynamometer and knee joint angle were aligned. The trunk, waist and tested thigh were fixed with straps to minimize secondary joint movement. Range of motion was determined as 0 to 90°, with gravitational correction for each limb performed at 30° in the set range of motion. Vigorous verbal encouragement was provided by the assessors during the testing.[12]

Testing comprised of three different modes and speeds. Players were tested over five repetitions of concentric knee flexion and extension at 60°/s, followed by 10 repetitions of concentric knee flexion and extension at 300°/s. These test modes measure concentric strength of the quadriceps (knee extension) and hamstring (knee flexion) muscle groups. Subsequently, players performed five repetitions of eccentric knee extension at 60°/s to measure the eccentric strength of the hamstring muscle group. A 60 s rest period was observed between each set. The highest peak torque value observed from all repetitions performed for each of the three different tests was recorded.

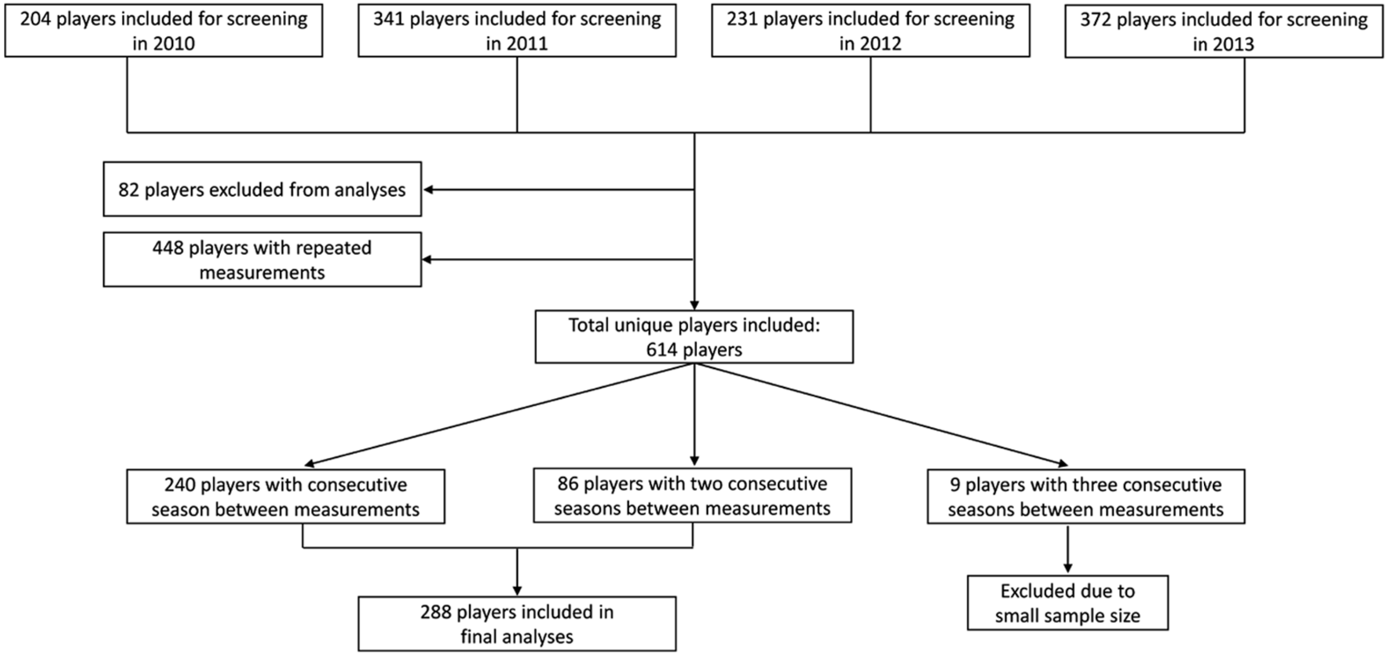

Figure 1 Flow chart demonstrating the inclusion of players over different seasons.

Nordic hamstring exercise testing

In 2014, the players also performed one set of three maximal repetitions on a device specifically designed to measure eccentric muscle strength while performing the Nordic hamstring exercise. The Nordic hamstring exercise was performed directly after the isokinetic testing, with at least three minutes between tests. The device allows for separate measurements of peak eccentric strength for each limb as described previously.[13] The players were tested in a kneeling position on a padded board, with both ankles secured immediately above the lateral malleolus by individual ankle braces. The player was instructed to keep the trunk and hips in a neutral position with his hands held across the chest, and then progressively lean forward at the slowest possible speed while resisting the movement with both limbs. The highest peak force measure was recorded, as well as the average of the peak force recorded for the three trials.

Injury surveillance

All participating QSL teams are provided with medical services by the National Sports Medicine Programme, a department within the Aspetar Orthopaedic and Sports Medicine Hospital. This centralized system, with a focal point for the medical care of each club competing in the QSL, allowed for standardization of the ongoing injury surveillance through the Aspetar Injury and Illness Surveillance Programme (AIISP).[11]

The AIISP includes prospective injury data collected monthly, with regular communication with the responsible team physician/physiotherapist to encourage timely and accurate reporting. At the conclusion of each season, all the data from the individual clubs were collated into a central database.

A hamstring injury was defined as acute pain in the posterior thigh that occurred during training or match play, and resulted in immediate termination of play and inability to participate in the next training session or match.[14] These injuries were confirmed through clinical examination (identifying pain on palpation, pain with isometric contraction and pain with muscle lengthening) by the club medical team.[15] If indicated, the clinical diagnosis was supported by ultrasonography and magnetic resonance imaging at the study centre.

Statistical analyses

Data were analysed with IBM SPSS statistics, V.21 (IBM Corp, Armonk, New York, USA), using each limb as the unit of analysis. Paired *t* test were used to assess whether there were systematic differences in the isokinetic strength variables between different test occasions (one and two seasons in between tests). The significance level was set at $P < 0.05$. The variability (random error) was assessed using a two way mixed model to determine the intraclass correlation coefficient ($ICC_{3,1}$) with 95% CI, as well as the measurement error. The measurement error was determined by calculating the difference between the standard deviation (SD) of the mean for the two test occasions divided by the square root of 2, presented as the mean error and also expressed as a percentage of the mean value. Effect size, which is the quantitative measure of the strength of an observed occurrence, was calculated and interpreted as small (> 0.2), medium (> 0.5) or large (> 0.8).[16] To describe the correlation between strength measured during the isokinetic and Nordic hamstring exercise, we calculated the Pearson correlation coefficient between the peak torque for isokinetic eccentric contraction at 60°/s and the peak force produced during the Nordic hamstring strength test. Data are presented as means with SD or 95% CI unless otherwise stated. The between-limb strength imbalance was correlated between left and right limbs as a percentage imbalance, using the right limb as the base measure.

RESULTS

Participants

Between 2010–2013, all elite male football players (n = 614) that reported for screening were considered for isokinetic testing. Of the 529 players included, 241 players did not have at least two consecutive test measurements. The final sample therefore included 288 players (age 25 ± 5 yrs, height 177 ± 7 cm, weight 71.5 ± 8.7 kg, BMI 22.9 ± 2.0) that performed the isokinetic test procedure on two occasions, 240 players with one season between measurements and 86 players with two consecutive seasons between measurements (Figure 1). Those players who were unable to perform the test due to injury, or did not consent to performing the test (n = 85, age 27 ± 5 yrs, height 177 ± 7cm, weight 73.8 ± 8.7 kg, BMI 23.6 ± 1.8), were excluded from the analyses. These players were significantly older and heavier ($P < 0.05$, Cohen's d of 0.4 and 0.2, respectively). Considering ethnicity, 64% of the players were Arabic, 30% black, 2% Asian, and 4% Caucasian. Playing position was documented in four categories, goalkeepers (n = 37), defenders (n = 98), midfielders (n = 108) and forwards (n = 45).

In 2014, 337 players (age 25.9 ± 5 years, height 176.7 ± 6.9 cm, weight 72.2 ± 9.2 kg, BMI 23.1 ± 2.1) performed Nordic hamstring exercise testing in addition to the isokinetic strength testing.

Interseason variability of the isokinetic tests

The mean time between measurements was 374 (226 to 560) days for players with one season between test occasions and 790 (551 to 867) days for players with two seasons between test occasions.

A significant increase in isokinetic strength measurements from the first to the second test was observed in both groups for some modes, with very small to small effect sizes (Table 1 and 2).

Variability (random error) between test occasions was substantial, as demonstrated by the large measurement error for all the contraction modes, whether separated by one or two seasons. The same pattern was observed among players not suffering from any hamstring injuries between tests (n = 228) as for those who did have one or more hamstring injuries (n = 60) (Table 1). The variability between two test occasions is illustrated for quadriceps concentric torque at 60°/s and hamstrings eccentric torque at 60°/s in Figures 2 and 3.

Table 1 Interseason comparison of isokinetic strength testing for players with one season between measurements (n = 240).

	Test 1 (mean ± SD) Nm	**Test 2 (mean ± SD) Nm**	**Difference test 2 to test 1 (mean, 95% CI) Nm**	**ICC (95% CI)**	**Effect size (d)**	***P* value**	**Measurement Error Nm (%)**
Quadriceps concentric at 60/s							
All	234.1 (42.5)	235.1 (45.4)	1.0 (-5.8 to 3.7)	0.71 (0.67 to 0.81)	0.02	0.72	24.5 (10.5)
Injured	227.0 (41.9)	235.9 (45.3)	8.9 (-8.3 to 26.0)	0.68 (0.51 to 0.96)	0.2	0.31	24.7 (10.9)
Uninjured	235.0 (42.5)	235.1 (45.5)	0.1 (-5.8 to 6.0)	0.69 (0.67 to 0.82)	0.02	0.98	24.4 (10.4)
Hamstrings concentric at 60/s							
All	123.7 (23.0)	128.6 (26.1)	4.9 (1.7 to 8.1)	0.63 (0.60 to 0.76)	0.2	**0.002**	15.7 (12.7)
Injured	121.3 (20.5)	127.1 (27.8)	5.8 (-3.7 to 15.5)	0.57 (0.46 to 1.09)	127	0.23	16.4 (13.6)
Uninjured	124.0 (42.5)	128.7 (25.9)	4.7 (1.5 to 8.1)	0.60 (0.59 to 0.76)	0.2	**0.005**	15.6 (12.6)
Quadriceps concentric at 300/s							
All	131.9 (24.6)	136.3 (26.8)	4.4 (1.9 to 6.9)	0.79 (0.78 to 0.90)	0.2	**0.01**	12.4 (9.4)
Injured	129.3 (23.7)	135.7 (27.8)	6.4 (-3.7 to 16.6)	0.75 (0.67 to 1.11)	0.3	0.21	13.0 (10.1)
Uninjured	132.2 (24.7)	136.4 (26.8)	4.2 (0.7 to 7.7)	0.78 (0.72 to 0.91)	0.2	0.02	12.3 (9.3)
Hamstrings concentric at 300/s							
All	93.9 (21.3)	98.6 (21.4)	4.7 (2.3 to 7.8)	0.56 (0.55 to 0.75)	0.2	**0.0003**	14.5 (15.4)
Injured	92.4 (21.2)	98.7 (20.5)	6.3 (-1.9 to 14.5)	0.66 (0.43 to 0.85)	0.3	0.13	12.2 (13.2)
Uninjured	94.1 (21.3)	98.6 (21.6)	4.5 (2.0 to 7.8)	0.55 (0.48 to 0.64)	0.2	**0.001**	14.8 (15.7)
Hamstrings eccentric at 60/s							
All	181.7 (37.0)	185.5 (39.5)	3.8 (-0.9 to 9.1)	0.52 (0.47 to 0.64)	0.1	0.1	26.6 (14.6)
Injured	176.4 (32.5)	170.4 (33.4)	5.8 (-7.3 to 19.4)	0.52 (0.25 to 0.78)	0.2	0.37	23.2 (13.2)
Uninjured	182.3 (37.4)	187.2 (39.8)	4.9 (-0.1 to 10.5)	0.52 (0.46 to 0.64)	0.1	0.05	26.9 (14.8)

*Mean ± SD for test 1 (season 1) and test 2 (season 2), mean interseason difference, measurement error (ME) from test 1 (season 1) to test 2 (season 2) are reported. ICC, intraclass correlation coefficient; Nm, Newton-meter; d, Cohen's d.

Table 2 Interseason characteristics of the isokinetic strength tests for players with two seasons between measurements (n = 86)*.

	Test 1 (mean ± SD) Nm	Test 2 (mean ± SD) Nm	Difference test 2 to test 1 (mean, 95% CI) Nm	ICC (95% CI)	Effect size (d)	*P* value	Measurement Error Nm (%)
Quadriceps concentric at 60/s							
All	225.2 (40.3)	238.5 (44.1)	13.3 (4.3 to 22.3)	0.69 (0.63 to 0.87)	0.3	**0.004**	23.8 (10.6)
Injured	215.1 (42.5)	220.9 (41.6)	5.8 (-35.2 to 47.8)	0.78 (0.22 to 1.31)	0.1	0.77	19.6 (9.1)
Uninjured	225.8 (40.3)	239.6 (44.2)	13.8 (4.5 to 23.0)	0.68 (0.62 to 0.87)	0.3	**0.003**	24.0 (10.6)
Hamstrings concentric at 60/s							
All	122.3 (22.8)	128.4 (22.1)	6.1 (0.9 to 11.1)	0.65 (0.51-0.74)	0.3	**0.01**	13.3 (10.9)
Injured	123.5 (20.1)	128.5 (16.8)	5.0 (-13.5 to 23.4)	0.50 (-0.23 to 1.1)	0.3	0.58	13.2 (10.7)
Uninjured	122.1 (23.0)	128.3 (22.4)	6.2 (0.6 to 11.5)	0.65 (0.52 to 0.75)	0.3	**0.02**	13.4 (10.9)
Quadriceps concentric at 300/s							
All	129.2 (25.7)	135.0 (26.5)	5.8 (0.3 to 11.4)	0.67 (0.58 to 0.81)	0.2	**0.04**	15.0 (11.6)
Injured	128.8 (33.9)	127.6 (20.4)	1.2 (-26.8 to 29.1)	0.40 (-0.25 to 0.73)	0.04	0.93	22.5 (17.5)
Uninjured	129.2 (25.3)	135.4 (26.8)	6.2 (0.5 to 12.0)	0.69 (0.61 to 0.85)	0.2	**0.03**	14.5 (11.2)
Hamstrings concentric at 300/s							
All	93.4 (20.8)	96.2 (20.6)	2.8 (-1.1 to 7.8)	0.53 (0.41-0.66)	0.1	0.14	14.1 (15.1)
Injured	94.8 (19.0)	97.1 (16.7)	2.3 (-15.6 to 20.1)	0.67 (0.01 to 1.17)	0.1	0.79	10.3 (10.9)
Uninjured	93.3 (21.0)	95.9 (20.9)	2.9 (-1.2 to 8.0)	0.53 (0.40 to 0.67)	0.1	0.15	14.3 (15.3)
Hamstrings eccentric at 60/s							
All	176.2 (38.0)	187.9 (38.9)	11.7 (5.3 to 21.7)	0.51 (0.39-0.65)	0.3	**0.001**	26.5 (15.0)
Injured	175.1 (37.5)	191.6 (48.5)	16.5 (-23.0 to 63.6)	0.43 (-0.63 to 1.79)	0.4	0.35	34.0 (19.4)
Uninjured	176.3 (38.1)	187.7 (38.4)	11.4 (4.6 to 21.5)	0.52 (o.39 to 0.65)	0.3	**0.002**	26.2 (14.9)

*Mean ± SD for test 1 (season 1) and test 2 (season 3), mean interseason difference, measurement error (ME) from test 1 (season 1) to test 2 (season 3) are reported. ICC, intraclass correlation coefficient; Nm, Newton-meter; d, Cohen's d.

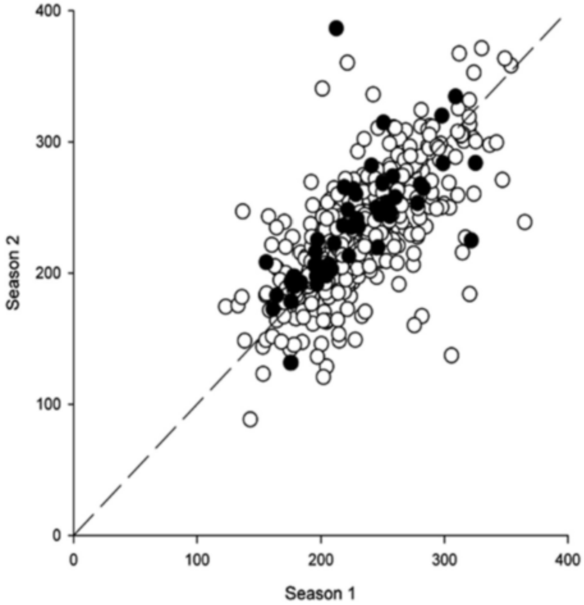

Figure 2 Scatter plot presenting the isokinetic quadriceps concentric torque @60°/s for injured (n = 51, closed symbols) and uninjured (n = 189, open symbols) for season 1 (test 1) and season 2 (test 2). The hatched line represents the identity line.

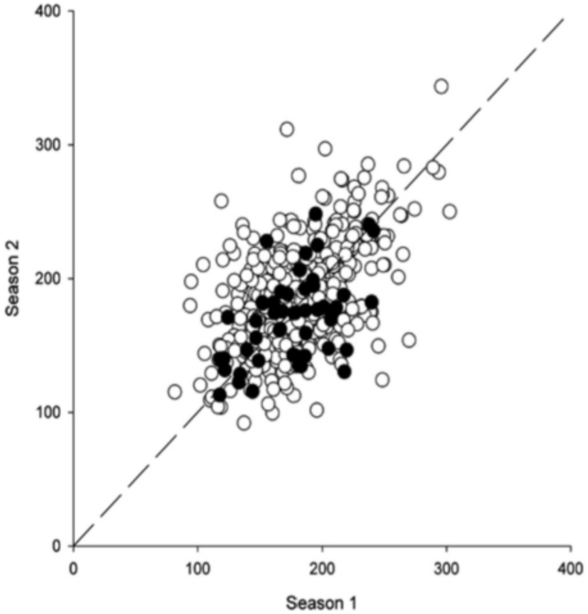

Figure 3 Scatter plot presenting the isokinetic hamstrings eccentric torque @60°/s for injured (n = 51, closed symbols) and uninjured (n = 189, open symbols) for season 1 (test 1) and season 2 (test 2). The hatched line represents the identity line.

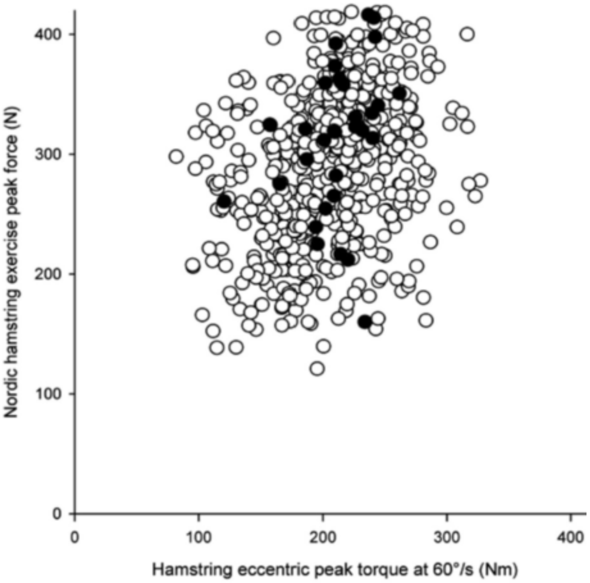

Figure 4 Scatter plot with correlation between isokinetic hamstring eccentric peak torque @ 60°/s and Nordic hamstring exercise peak force for injured (n=31, closed symbols) and uninjured (n = 306, open symbols).

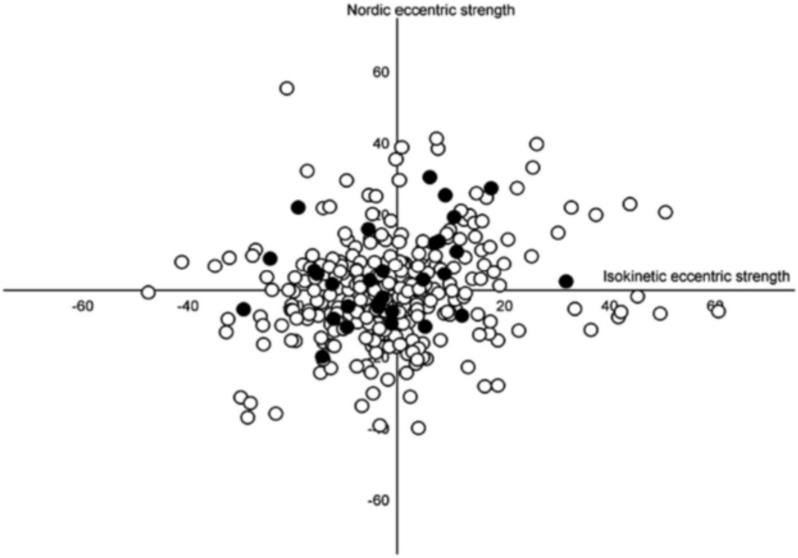

Figure 5 Scatter plot illustrating the correlation of between-limb imbalance (expressed as a percentage of left compared to right for isokinetic hamstring eccentric peak torque @ 60°/s (x-axis) and Nordic hamstring exercise peak force (y-axis) for injured (n = 31, closed symbols) and uninjured (n = 306, open symbols) players.

Relationship between isokinetic and Nordic hamstring exercise test

A poor correlation (r = 0.35) was observed between peak isokinetic hamstring eccentric torque @60°/s (Nm) (mean 207.7 ± 44.1, 82.0 to 348.4) and Nordic hamstring exercise peak force (N) (mean 298.6 ± 72.3, 121.0 to 502.5), as illustrated in figure 4. The mean imbalance between limbs was 23.0 ± 19.8 Nm for isokinetic strength and 28.7 ± 27.4 N for Nordic hamstring strength. The (percentage) strength imbalance between limbs (left compared to right) was calculated for both test modes, and they were not correlated (r = 0.037), as shown in Figure 5.

DISCUSSION

In this study of professional football players, substantial individual season-to-season variability was identified for isokinetic strength measurements, unrelated to any hamstring injury during the interval. Additionally, the results from standard (isokinetic) and novel (Nordic hamstring exercise) eccentric hamstring strength testing were poorly correlated.

Variability of isokinetic strength measurements

Isokinetic assessments are often used to establish strength profiles of athletes. The results are used for different purposes, such as performance training, return to sport and to determine risk of injury, particularly hamstring injuries.[1,2,12,17–24] However, there seems to be a discrepancy in the literature between intervention studies testing the effect of eccentric strength training on hamstring injury risk and prospective cohort studies examining the association between eccentric hamstring strength and the risk of injury. Several intervention studies have reported a reduction in hamstring injuries after implementing various strengthening regimes.[25,26] By far the largest effect has been demonstrated with the Nordic hamstring exercise. Three large intervention studies (two randomized and one non-randomized) have shown that injuries can be reduced by approximately 70% by implementing the Nordic hamstring exercise in a team's training regime.[17,27,28] The results from these intervention studies suggest that eccentric strength must represent a key risk factor for hamstring injuries. However, a recent meta-analysis[29] documents that prospective cohort studies have failed to consistently identify hamstring strength as a strong risk factor associated with injury.[12,26,30–33]

The large variability observed in this study might explain the apparent incongruity between intervention studies, consistently showing the positive effect of eccentric strengthening, and the lack of strong evidence to support this in prospective cohort studies. Prospective studies are based on a one-time baseline strength test, and with variability (measurement error) of approximately 25 Nm (15%) between strength tests separated by one season as observed in this study, it seems that large fluctuations in hamstring strength occur within seasons. This would make it difficult to identify any relationship between hamstring strength and injury risk, if such a relationship even exists.

An obvious question is how much of the observed variability is due to measurement error and how much is real. The reliability of standardized isokinetic testing has been reported previously, claiming high reproducibility if adequate calibration, gravity correction, and patient positioning were standardized.[8–10] In a previous study from our centre that matches the methods used in this present investigation, Otten et al reported on the reliability of isokinetic testing, utilizing the same isokinetic dynamometer, and with the same skilled assessors conducting the testing.[34] In this study, tests were performed on four occasions with a minimum of 48 h of rest between each testing session. Although the ICC for quadriceps and hamstrings peak torque was again interpreted as reliable (> 0.8), the standard error of the measurement was reported as 16.4 Nm and 10.5 Nm, respectively. The measurement errors in our study were 24.5 Nm and 15.7 Nm, suggesting an additional 50% variability in these two measures, or approximately 10% of the base measure. In other words, both studies identify substantial random error when performing these isokinetic tests, and it seems clear that this increases when tests are separated by one or two seasons.

A potential explanation for the variability observed is injuries incurred during the season, particularly hamstring injuries. However, the season-to-season variability observed was similar for uninjured and injured players across all the modes of testing. All the players were deemed fit to play at the time of testing, but it should be noted that we have only investigated the effect of hamstring injuries, not any other injuries between test occasions. However, as hamstring injuries are the most likely to affect hamstring strength, it seems highly unlikely that the variability observed is due to inter-test injuries.

Correlation of isokinetic torque and Nordic hamstring eccentric force

The Nordic hamstring exercise is today often used to measure hamstring strength, and determining risk of lower limb injury.[23,24,35] This is the first study to determine the correlation between the Nordic hamstring exercise and conventional isokinetic strength test using a dynamometer. Unexpectedly, we found a poor correlation between the Nordic hamstring exercise and isokinetic tests, as well as no correlation between the bilateral imbalances identified in either test.

These tests are biomechanically different, and muscle activation patterns will be different,[36,37] which may influence how well they correlate. Bourne et al reported that the Nordic hamstring exercise provides the largest stimulus for changes in biceps femoris fascicle length,[38] which might explain the effect of the intervention on reducing injury risk, since decreased fascicle length has been reported as a risk factor for hamstring injury.[24] Unfortunately, none of the intervention studies measure the effect of the intervention on muscle architecture, or any other factor, and we are therefore not able to identify the mechanism responsible for the preventative effect.

Although the effect of reducing risk of hamstring injury using the Nordic hamstring exercise has been well established,[5] when implemented as a screening tool, it has yielded mixed results.[19,21,23,24] Engebretsen et al found no significant association when it was used as a simple visual assessment of test performance.[21] Subsequent studies positively identified players with inferior eccentric strength (measured by a novel device) as being at increased risk of hamstring injury.[23,24] However, in a cohort of rugby players, between-limb imbalances and not eccentric strength was associated with the risk of hamstring injury.[19] The quantification of this exercise by Opar et al[13] provided the opportunity to test how well it compares to other forms of measuring strength, in particular isokinetic testing, which has been described as the gold standard of strength testing.[39] Although both tests are assumed to measure the same trait, eccentric force production, the low correlation suggests that they do not.

Importantly, there are two main differences between the test modes. Firstly, the position in which the two tests are performed have opposing features. For the isokinetic test, the strength is measured as the limb performs a unilateral movement in a seated position, with the hip in flexion. In contrast, the Nordic hamstring exercise test measures the strength of both limbs in a bilateral movement, with the player in a kneeling position and the hips extended. Secondly, the units of measurement are also different; isokinetic strength is measured as torque and Nordic hamstring strength as force. Perhaps these central differences can explain why we do not find any correlation between isokinetic and Nordic hamstring strength testing.

Even if the force and torque measurements do not correlate between test modes, one might expect any limb-to-limb strength imbalance to favour the same side using both devices; however, these did not correlate at all (Figure 5). One hypothesis to explain this is the bilateral deficit, the reduction in amount of force produced from bilateral movements compared to the sum of forces produced unilaterally by the left and right limbs when tested alone.[40,41] The Nordic hamstring test measures the imbalance when both legs are tested together, in contrast to the isokinetic test, where unilateral strength tested for each leg separately.

Strengths and Limitations

A major strength of this study is that all tests performed utilized the same isokinetic testing system with highly experienced assessors, and it was performed in a single clinical setting for professional athletes. This reflects a “real world” scenario and might contribute to the external validity of the study.

Limitations to this investigation includes no recording of exposure to football training and match play, specific strength training or interventions aimed at prevention across the different clubs. This study was performed in a multinational, multilingual setting, and while every effort was made to guarantee that players comprehended the test procedure and directions, it is possible that some players did not fully understand the instructions. In our clinical setting, a thorough familiarization procedure was not possible, and the change we observe between seasons may partly be due to a learning effect between the test sessions. We also acknowledge the homogeneity of our study population of professional male football players, which limits the generalization of these findings to other sports, age groups, or female players.

CONCLUSION

There is substantial intraindividual variability in all isokinetic test measures, whether separated by one or two seasons, and irrespective of injury. Also, eccentric hamstring strength and limb-to-limb imbalance were poorly correlated between the isokinetic and Nordic hamstring exercise test.

PERSPECTIVE

The use of strength testing to establish muscle function and performance in elite sport is common.[1,2] Muscle strength testing is believed to represent an important part of the PHE, identifying strength deficits and imbalances which can be addressed to decrease injury risk. Strength testing is one of the three most commonly used screening methods in professional football,[3] to determine the risk for various types of lower limb injuries, particularly to the thigh and knee. The large variability observed in this study might explain the apparent incongruity between intervention studies, consistently showing the positive effect of eccentric strengthening, and the lack of strong evidence to support this in prospective cohort studies. The variability (measurement error) of approximately 25 Nm (15%) between strength tests separated by one season as observed in this study, indicating that large fluctuations in hamstring strength occur within seasons, makes it difficult to identify any relationship between hamstring strength and injury risk. There is substantial intraindividual variability in all isokinetic test measures, whether separated by one or two seasons, and irrespective of injury. Eccentric hamstring strength and limb-to-limb imbalance were poorly correlated between the isokinetic and Nordic hamstring exercise test, indicating that these tests might measure different characteristics of strength.

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Chapter 4

Hamstring and ankle flexibility deficits are weak risk factors for hamstring injury in professional soccer players:

A prospective cohort study of 438 players including 78 injuries

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ABSTRACT

Background: Hamstring injuries remain a significant injury burden in sports such as soccer that involve high speed running. It has repeatedly been identified as the most common noncontact injury in elite male soccer, representing 12% of all injuries. As the incidence of hamstring injuries remains high, investigations are aimed at better understanding how to prevent hamstring injuries. Stretching to improve flexibility is a commonly used in elite level sport, but risk factor studies have reported contradicting results leading to unclear conclusions regarding flexibility as a risk factor for hamstring injury.

Hypothesis/Purpose: To investigate the association of lower limb flexibility with risk of hamstring injury in professional soccer players.

Study Design: Cohort study; Level of evidence, 2.

Methods: All teams (n = 18) eligible to compete in the premier soccer league in Qatar underwent a comprehensive musculoskeletal assessment during their annual periodic health evaluation at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar. Variables included passive knee extension and the ankle dorsiflexion lunge range of motion.

Results: A total of 438 unique players (72.4% of all QSL players) competed for 601 player seasons (148 players competed both seasons) and sustained 78 hamstring injuries. Passive knee extension range of motion (hazard ratio [HR], .97; 95% CI, 0.95 to 0.99; *P* = .008) and ankle dorsiflexion lunge range of motion (HR, .93; 95% CI, 0.88 to 0.99; *P* = 0.02) were independently associated with injury risk. The absolute difference between the injured and uninjured players were 1.8° and 1.4cm respectively, with very small effect sizes ($d < 0.2$). The receiver operating characteristics (ROC) curves analysis showed an area under the curve of 0.52 for passive knee extension and 0.61 for ankle dorsiflexion, indicating a failed to poor combined sensitivity and specificity of the two strength variables identified in the multivariate Cox regression analysis.

Conclusion: This study identified deficits in passive hamstring and ankle dorsiflexion range of motion as weak risk factors for hamstring injury. These findings have little clinical value in predicting future hamstring injury risk, and test results must therefore be interpreted cautiously in athletic screening.

INTRODUCTION

In elite soccer, hamstring injury is the most common non-contact injury reported.[17,25] The incidence of hamstring injuries remains high, and, at least at the Champions League level, even seems to rise.[18] Although there are prevention programs based on eccentric strength training indicating positive results,[3,35,46,49] the evidence supporting the use of stretching exercises aimed at improving flexibility to prevent injury is limited.[32,44,53] Nevertheless, flexibility was the most routine injury risk screening test reported by the 32 teams participating in the FIFA 2014 World Cup in Brazil.[30] Flexbility testing is also perceived by European clubs to be important; 87% of elite clubs reported it as one of the three most commonly used injury screening tests.[31] However, prospective studies examining the relationship between flexibility and injury risk have produced conflicting results.[28,50–52]

The most comprehensive meta-analysis to date identified high quadriceps muscle strength as the only modifiable risk factor to increase the risk of hamstring injury (together with the non-modifiable factors age and previous injury).[20] Another systematic review confirmed previous injury as a risk factor, yet found conflicting evidence for age and hamstring flexibility.[48]

No association was found between various flexibility measures, like the slump test, lumbar spine flexion, lumbo-femoral ratio, straight leg raise or the sit-and-reach-test with the risk for hamstring injury.[20] However, for the active and passive knee extension tests, quadriceps flexibility and the dorsiflexion lunge test there were mixed or contradicting results, hampered by small sample sizes and large heterogeneity between the studies included in the meta-analyses.[20,48] Thus, the relationship between flexibility and risk of hamstring injury is still poorly understood, and, to date, no adequately powered study exists investigating the relationship between flexibility and risk of hamstring injury.

The purpose of this study was therefore to examine the relationship between flexibility, measured as hamstring and ankle dorsiflexion range of motion, with risk of hamstring injury in a large cohort of professional soccer players.

METHODS

Study design

Ethical approval was obtained from the Institutional Review Board, Anti-doping Laboratory, Qatar (IRB F2013000003). This study covered two consecutive soccer seasons (September 2013 to May 2015) of the Qatar Stars League (QSL), the premier soccer league and highest level of competition in Qatar. All teams (n = 18) eligible to compete agreed to participate in the study. Each player from the respective teams underwent an annual periodic health evaluation (PHE) at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar. The PHE was performed from May to

September, with the official start of the season in September of each year. If players performed PHE outside of this period and met the inclusion criteria, they were still included in the study.
All players over the age of 18 years and eligible to compete in the QSL, who had provided written consent and were able to perform the testing, were included. Players who were injured at the time of the PHE and unable to perform the tests were excluded. If no musculoskeletal tests were performed at the start of a season, or no exposure or injury surveillance data were recorded over an entire season, players were also excluded. Figure 1 depicts the inclusion methodology during the two study seasons.

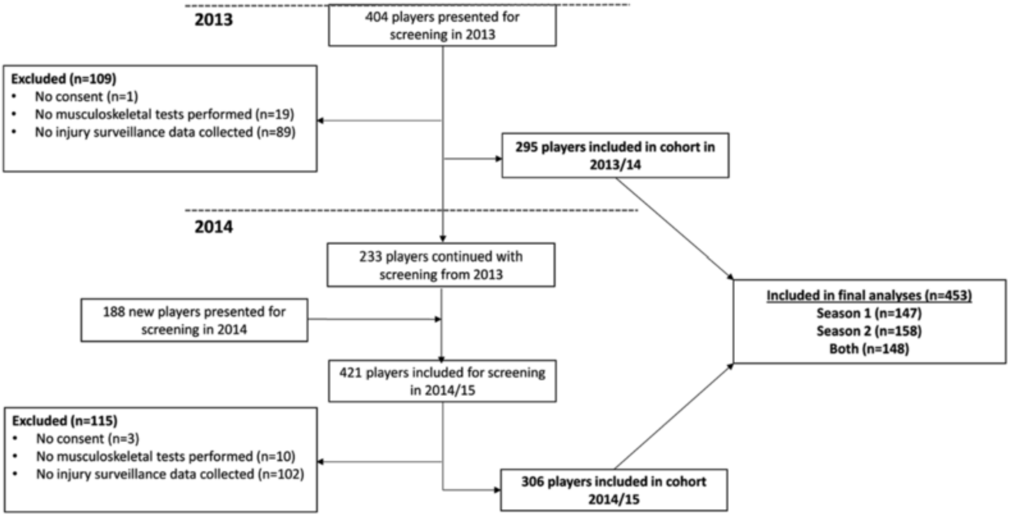

Figure 1 Flowchart demonstrating the movement of players and repeated measurements between different seasons.

Player information

Non-modifiable risk factors that were included for analysis were history of previous hamstring injury in the past 12 months, age, playing season, team, leg dominance, playing position, and ethnicity. Player height and weight were measured and body mass index (BMI) calculated during the PHE.

Flexibility tests

Active knee extension test

The active knee extension test was performed for both limbs with the player positioned in supine on an examination table and the tested hip flexed to 90°. A digital hand held inclinometer was positioned at the anterior tibial border halfway between the inferior pole of the patella and the line between the two malleoli.[36] The player was instructed to extend his knee until reaching maximal tolerable stretch of the hamstring muscle, while the examiner maintained the position of the thigh to the vertical by reading the inclinometer (90° ipsilateral hip flexion). At the end point of maximal tolerable stretch, the absolute knee angle was measured with the inclinometer on the tibia as read out by the tester. The active knee extension test have been found to be reliable.[43]

Passive knee extension test

The passive knee extension test was performed for both limbs in the same starting position as for the active test; the hip of the tested limb positioned in 90° flexion, while the contralateral leg remained flat on the examination table. The examiner extended the knee until reaching the maximal tolerable stretch of the hamstring muscle as indicated by the tested player, while maintaining the thigh to the vertical.[36] At the end point of the maximal tolerable stretch, the absolute knee angle was measured with the inclinometer on the tibia as read out by the tester. Excellent interrater reliability and good test-retest reliability have been found for this test.[23]

Dorsiflexion lunge test

A measuring tape (in cm) was placed on the floor with the start point (0 cm) aligned to the bottom corner of the wall. The player was instructed to stand facing the wall, positioning their foot so that the heel line and big toe were aligned on the tape measure on the floor.[9] They lunged forward so that their knee touched the wall. Players were allowed to hold onto the wall for balance during the test with the untested leg free to rest in a comfortable position. The player was instructed to lunge forward moving his ipsilateral knee into flexion and touch the wall while maintaining contact between the heel and the floor. The examiner observed the maximum distance where the player could maintain this position, measuring the distance from the wall to the big toe. The measure was repeated for both the left and right side. The inter- and intra-rater reliability for this test have been reported as excellent.[9]

Injury surveillance

All participating QSL teams were provided with medical services by the National Sports Medicine Programme, a department with the Aspetar Orthopaedic and Sports Medicine Hospital. This centralized system with a focal point for the medical care of each club competing in the QSL allowed for standardization of the ongoing injury surveillance through the Aspetar Injury and Illness Surveillance Programme (AIISP).[8]

The AIISP includes prospective injury and exposure (minutes of training and match play) recorded from all QSL teams. The injury data were collected monthly, with regular communication with the responsible team physician/physiotherapist to encourage timely and accurate reporting. Throughout the 2013 and 2014 season (July to May; 44 weeks), training and match exposure for each team were recorded by the team physician (or lead physiotherapist if no team physician was available). At the conclusion of each season, all the data from the individual clubs were collated into a central database, and discrepancies were identified and followed up at the different clubs to be resolved.

A hamstring injury was defined as acute pain in the posterior thigh that occurred during training or match play, and resulted in immediate termination of play and inability to participate in the next training session or match.[47] These injuries were confirmed through clinical examination (identifying pain on palpation, pain with isometric contraction and pain with muscle lengthening) by the club medical team. If indicated, the clinical diagnosis was supported by ultrasonography and magnetic resonance imaging at the study centre. A recurrent injury was defined as a hamstring injury that occurred in the same limb and within two months of the initial injury.[25]

Statistical analyses

The average of the flexibility measures, as determined by the active knee extension, passive knee extension and dorsiflexion range of motion tests, was compared between injured and uninjured players using independent *t* tests. Similar comparisons were made between the injured limb with the uninjured limb using paired *t* tests. Effect size, which is the quantitative measure of the strength of an observed occurrence, was calculated and interpreted as small (> 0.2), medium (> 0.5) or large (> 0.8).[13]

Due to the consistency in our sample, we modeled time to first hamstring injury following date of testing using Cox-regression analysis. Since our study included repeated measures performed over the two seasons, as well as the fact that not every player had the same number of measurements (i.e. some players would have test results including both limbs for both seasons, while other players might only have been tested once), standard errors would have increased when using general estimating equations in a traditional Cox regression model. Therefore, we performed a univariate Cox regression analysis using the limb as the unit of analysis, adjusting for player identity as a cluster factor (STATA (version 11.0, College Station, Texas, USA). Each individual player's exposure was computed as total duration in hours for matches and training combined from the start to the end of each season, or time to first injury. All variables with *P* value ≤ 0.10 in the univariate analysis were considered further in a backward stepwise multivariate Cox regression analysis to identify potential predictors. Hazard ratios (HR) with 95% confidence intervals (CIs) are presented with exact *P* values, and *P* values of ≤ 0.05 were considered statistically significant.

We calculated receiver operating characteristic (ROC) curves to describe the sensitivity and specificity of the significant flexibility variables. The area under the curve (AUC) indicates how well the strength variables under consideration would discriminate between injured and uninjured players, and were interpreted as excellent (≥ 0.90 to ≤ 1), good (≥ 0.80 to < 0.90), fair (≥ 0.70 to < 0.80), poor (≥ 0.60 to < 0.70) or fail (≥ 0.50 to < 0.60).[1,33]

RESULTS

Players

During the 2-season study period, 592 elite male soccer players (age, 25.8 ± 4.8 years; height, 177 ± 7 cm; weight, 72.4 ± 9.3 kg; body mass index [BMI], 23.1 ± 2.0 kg/m^2) reported for screening and were considered for musculoskeletal testing. Players who were unable to perform the test (n = 45), who did not provide consent (n = 4), or had no injury surveillance data recorded during the subsequent season (n = 105) were excluded from the final analyses (n = 154; age, 25.2 ± 4.7 years; height, 178 ± 9 cm; weight, 75.1 ± 9.8 kg; BMI 23.4 ± 1.9). In total, 438 unique players (72.4% of all QSL players) competed for 601 player seasons (148 players competed both seasons) (Figure 1).

New hamstring strain injuries

In total, 73 of the 438 players sustained 78 index hamstring injuries. The five players who had more than one injury were retained in the analyses; none of these injuries met the criteria for re-injury and all subsequent injuries were sustained in the second season. All players injured in season one had their previous injury status adjusted accordingly in season two.

Non-modifiable risk factors

There were no differences in height, ethnicity, limb dominance, and body composition between injured and uninjured groups (Table 1). Previous hamstring injury was reported by 30.1% of the entire cohort (n = 132) with no significant difference between injured and uninjured players.

Table 1 Characteristics of injured (n = 73) and uninjured players (n = 365)[a].

	Injured (n=73)	**Uninjured (n=365)**	***P* value**
Age, yrs	27.8 ± 4.1	26.2 ± 4.6	**.001**
Weight, kg	71.6 ± 7.5	72.7 ± 9.3	.15
Height, cm	175 ± 7	177 ± 7	.09
Body mass index, kg/m^2	23.3 ± 1.9	23.2 ± 2.0	.96
Previous injury, n (%)	26 (35.6)	106 (29.0)	.59
Player position, n (%)			**.02**
Goalkeeper	1 (1.4)	54 (11.9)	
Defender	29 (42.0)	144 (31.8)	
Midfielder	27 (39.1)	159 (35.1)	
Forward	12 (17.4)	96 (21.2)	
Limb dominance, n (%)			.55
Left	17 (23.3)	79 (21.6)	
Right	56 (76.7)	286 (78.4)	
Ethnicity, n (%)			.62
Arab	40 (54.8)	222 (61.0)	
Black	25 (34.2)	107 (29.3)	
Asian	2 (2.8)	6 (1.5)	
Caucasian	6 (8.2)	30 (8.2)	

[a] Data are shown as mean ± SD unless otherwise indicated. Chi-square analyses were used for categorical variables.

Univariate analyses identified age and position as potential risk factors for hamstring injury (Table 1). Goalkeepers were significantly less likely to sustain a hamstring injury than defenders, midfielders or forwards. The injured players were on average 18 months older than the uninjured players.

Range of motion tests as potential risk factors

The results from the univariate analysis are presented in table 2 for both the active and passive knee extension tests, as well as the dorsiflexion lunge test. Both the passive knee extension test and the dorsiflexion lunge test displayed a significant difference between the injured and uninjured groups. These effects were maintained when exposure was accounted for in the univariate Cox regression analysis (Table 2).

In the multivariate Cox regression analysis, both passive knee extension as well as the dorsiflexion lunge tests were retained from the univariate analyses and significantly associated with hamstring injury risk, with no influence of age and position (Table 3).

ROC analyses revealed an AUC of 0.52 and 0.61 for the passive knee extension test and dorsiflexion lunge test respectively, indicating a failed to poor combined sensitivity and specificity of the two strength variables identified in the Cox regression. The results for both variables were normally distributed, with complete overlap in the distribution of range of motion between the injured and uninjured groups for both passive knee extension range of motion and ankle dorsiflexion range of motion (Figures 2 and 3 respectively).

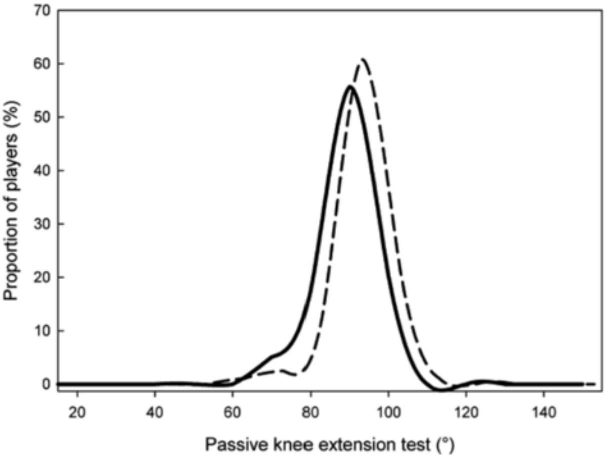

Figure 2 Distribution of passive knee extension test results (°) for the injured (solid line) vs uninjured (thatched line) groups.

Table 2 Univariate comparison of range of motion tests between the injured and a) the uninjured limb in the injured players, b) all uninjured limbs in the uninjured players, and (c) Cox regression analysis demonstrating parameter estimates (95% confidence intervals, CI) for all range of motion variables when comparing injured to uninjured limbs.

	Injured Players				**Uninjured Players**			**Univariate Cox regression**	
	Injured limb (n = 78)	**Uninjured limb (n = 78)**	**Difference (95% CI)**	***P* value**[a]	**Uninjured limbs (n = 1156)**	**Difference (95% CI)**	***P* value**[b]	**HR (95% CI)**	***P* value**[c]
Active knee extension test (°)	77.3 ± 9.3	77.1 ± 8.7	0.2 (-2.7 to 3.1)	.53	78.0 ± 9.7	0.7 (-1.5 to 2.9)	.52	0.99 (0.97 to 1.01)	.30
Passive knee extension test (°)	84.4 ± 7.2	84.5 ± 7.9	0.1 (-2.3 to 2.5)	.05	86.2 ± 7.6	1.8 (0.1 to 3.5)	**.04**	0.97 (0.95 to 1.00)	**.02**
Dorsiflexion Range of motion (cm)	9.8 ± 3.1	10.3 ± 2.9	0.5 (-0.5 to 1.5)	.34	11.2 ± 3.2	1.4 (0.7 to 2.1)	**.0003**	0.89 (0.84 to 0.95)	.0001

Absolute values for all measures are shown as mean ± SD. Bolded *P* values indicate statistically significant difference between compared groups. HR, Hazard ratio.

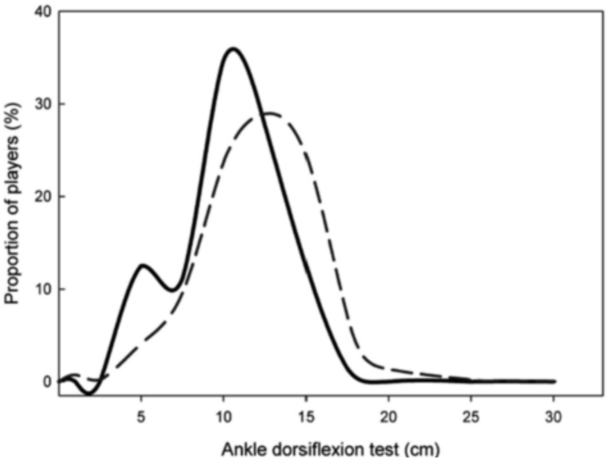

Figure 3 Distribution of the ankle dorsiflexion test results (cm) for the injured (solid line) vs uninjured (thatched line) groups.

Table 3 Multivariate Cox regression analysis demonstrating parameter estimates (95% confidence intervals, CI) for significant predictor variables for hamstring injuries.

	HR	95% CI	*P* value
Age	1.07	1.02 to 1.11	**.002**
Position (reference group: goalkeepers)			
Outfielders	5.09	1.29 to 20.07	**.02**
Passive knee extension test	0.97	0.95 to 0.99	**.008**
Ankle dorsiflexion test	0.93	0.88 to 0.99	**.02**

Bolded *P* values indicate statistically significant difference between compared groups. HR, Hazard ratio.

DISCUSSION

This 2-season prospective cohort study, with 438 players and 78 hamstring injuries the largest to date, identified significant albeit small associations between hamstring and ankle range of motion and risk of injury. This suggests that limited flexibility represents a weak risk factor for hamstring injuries, and may be considered a causal factor. The group differences in the range of motion measures between players who went on to suffer a hamstring injury and those who did not were small, and the wide overlap between groups clearly illustrate that it is not possible to use these tests in screening to identify whether a player is at risk of hamstring injury or not.

Hamstring range of motion

Flexibility is consistently described in the literature as the outcome of range of motion tests. Although factors such as joint mobility[22] and neural dynamics[41] might influence the findings of range of motion tests, the active and passive knee extension, straight leg raise, sit-and-reach, or lumbar spine flexion tests are interpreted to represent muscle flexibility.[50,53] Therefore we might consider how these different range of motion tests compare to each other when used to determine flexibility, and risk of hamstring injury.

Recently, range of motion measured by the sit-and-reach test was found not to be associated with risk of hamstring injury,[50] while range of motion measured by the straight leg raise test has been identified as a risk factor for hamstring injury.[52] A recent meta-analysis of available prospective cohort studies found no significant difference between injured and uninjured groups for the lumbar spine flexion, sit and reach test, and straight leg raise tests.[20] Similarly, the same meta-analysis did not identify active or passive knee extension as risk factors for hamstring injury.[20] However, there are two key elements that differentiate the active and passive knee extension tests from other measures of hamstring flexibility like the sit and reach, lumbar flexion and straight leg raise tests. The latter include (1) pelvic movement and/or (2) the knee being fixed in an extended position during the test. Due to the biarticular nature of the hamstrings, allowing the pelvis to move during the test and keeping the knee fixed might influence the resultant range of motion. The results from the knee extension test, where pelvic movement is constrained and motion occurs at the knee joint, might more accurately represent the flexibility of the hamstrings. Although the concurrent validity of these tests are poor, the knee extension test is recommended as the most valid and reliable measure for clinicians to use when the aim is to measure hamstring muscle length.[15]

The hamstrings are thought to be at greatest risk of injury during the terminal swing phase of high speed running,[39,27] as the biarticular hamstring muscle undergoes a stretch-shortening cycle in this phase of the stride cycle.[45] During the terminal swing phase, the hamstrings are lengthening, producing peak force and performing much negative work.[38] Greatest musculotendinous strain is produced during this phase, making the hamstrings susceptible to injury during the lengthening (eccentric) contraction.[12] Pelvic movement is necessary for high speed running, however, the amount of anterior tilt and hip flexion does not alter dramatically in the late swing phase.[14] Although the relationship between measures of flexibility and high speed running is unknown, the active and passive knee extension tests might represent a more valid test for hamstring flexibility in soccer players exposed to high speed running.

Active knee extension

Our results support previous findings that range of motion during active knee extension is not associated with risk of hamstring injury. The same test has been investigated for risk of re-injury and potential delayed return to sport.[16,28,51] De Vos et al did identified an independent association with the risk for re-injury. The active component might capture different aspects of apprehension or comfort with the movement, similar to Askling's H-test at return to sport.[5] It might reflect changes in the affected tissue that persist even when rehabilitation is completed.

Passive knee extension

Our results do challenge previous findings that fail to identify passive knee extension as a risk factor for hamstring injury.[4,19,37] There are potential reasons for the contrasting results. Although Engebretsen et al[19] did include a high number of hamstring injuries (n = 65), this represented a mix of acute and overuse hamstring injuries. Also, a small absolute difference between the groups (0.5°) and a large standard error of the mean (2.1°) were reported.[19] Arnason et al[4] included less than half the number of injuries compared to our study (n = 31). Interestingly, they found greater range of motion (by 3.4°) in the injured groups, again with a large standard error of the mean (2.1°). Rolls and George[37] investigated a cohort of youth soccer players, and in their small sample of only 15 injuries, they observed a difference of 4.4°, but with a standard deviation of 8.3° there is again the potential for a type II error. The inclusion of a large number of acute index injuries in our study allows for the identification of weaker associations between passive knee extension and hamstring injury than what have been possible in previous studies.

Ankle dorsiflexion range of motion

Gabbe et al found restricted ankle dorsiflexion range of motion on the lunge test to be independently associated with risk of hamstring injury,[21] albeit not so when adjusting for age and previous injury in a multivariate model. Our results, based on a greater number of injuries (78 vs. 31) confirm this and suggest that ankle dorsiflexion range of motion may represent a risk factor for hamstring injury. Adequate ankle dorsiflexion mobility is a necessary component for running.[11] Decreased ankle mobility changes the touchdown position of the foot during sprinting, reducing the horizontal force production.[10] As hamstring muscle activity is highly correlated with increased horizontal force production,[34] limited ankle dorsiflexion mobility might lead to increased work required from the hamstring muscle, predisposing it to injury.

The neuromuscular coordination of the posterior muscle chain has been proposed as a potential risk factor for hamstring injury.[40] Although empirical evidence to support the theory surrounding the function of the posterior kinetic chain is lacking, we might consider how knee extension and ankle dorsiflexion range of motion influence the overall flexibility of the posterior lower limb, and consequently, the conditions necessary for optimal neuromuscular function of the posterior kinetic chain.

Strengths and limitations

While 200 injury cases are needed to detect small to moderate associations between risk factors and injury, 30 to 40 injury cases are needed to detect strong to moderate associations in prospective cohort studies.[6] With 78 cases, this is as yet the largest prospective study investigating flexibility as a potential risk factor for acute hamstring injuries.

These findings suggest that flexibility, measured as hamstring and ankle range of motion, may be involved in the causation of hamstring injury. However, all of the effect sizes observed were small, too small to have any clinical importance.

All tests were performed by highly experienced assessors in a multinational, multilingual clinical setting for professional athletes. Although every effort was made to ensure players understood the test procedure and instructions, it is possible that some players did not comprehend the instructions fully. However, this is representative of current clinical practice, which increases the external validity of the study.

As with every prospective cohort study, we must consider that the once-off baseline test might not necessarily reflect the status of the player at the time of injury. We also acknowledge the homogeneity of our study population of professional male soccer players, which limits the generalizability of these findings to other sports, age groups or female players. Other factors such as training culture and possible prevention strategies within different teams, or climate specific to the Middle East region, could also have influenced the results.

Clinical implications

It is still common practice to include stretching exercises to prevent injury in elite level soccer.[29] Stretching improves the compliance of the musculotendinous unit,[53] and the ability to undergo the stretch-shortening cycle. However, basic science evidence documenting that improved compliance increases the ability to absorb energy is lacking.[42]

Currently there is no intervention study documenting that stretching reduces the risk of hamstring injury.[24,54] Although there are studies showing a reduction in injuries, these were done on military recruits aiming at reducing overuse injuries.[2,26] While two studies did find an effect on overuse injuries,[2,26] the findings cannot be extrapolated to elite soccer. In fact, a non-randomized intervention study found no effect of a program of warm-up stretching and additional flexibility training on the risk of hamstring injury in elite soccer.[3] Another investigation indicated that stretching might be useful as part of a warm up.[17] However, in this study the warm up programme also included running, calisthenics and skill exercises with the ball, and it is unclear which component of the warm up was responsible for the preventative effect.[42]

The passive knee extension and dorsiflexion lunge test cannot be used to predict who may be at risk of injury; there is no suitable cut-off point for either test which can differentiate between injured and uninjured legs. The results display wide overlap between injured and uninjured players (Figures 2 and 3), as demonstrated for other screening tests.[7] However, screening has been shown to be valuable in detecting ongoing musculoskeletal conditions,[8] and flexibility tests may be helpful to identify underlying injuries.

CONCLUSION

This study identified deficits in passive hamstring and ankle dorsiflexion range of motion as weak risk factors for hamstring injury. These findings have little clinical value in predicting future hamstring injury risk, and test results must therefore be interpreted cautiously in athletic screening.

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Chapter 5

No association between rate of torque development and onset of muscle activity with increased risk of hamstring injury in a prospective cohort study of elite football players

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ABSTRACT

Introduction: Hamstring injuries remain a significant injury burden in sports that involve high speed running. In elite male football, hamstring injury has repeatedly been identified as the most common noncontact injury, representing 12% of all injuries. As the incidence of hamstring injuries remains high, investigations are aimed at better understanding how to prevent hamstring injuries. Intrinsic risk factors such as strength have been investigated extensively in a cohort of professional football players; however, other intrinsic measures of neuromuscular function have not been studied in this cohort.
This study aims to investigate the association of rate of torque development and the timing of muscle activity onset, measured during the early phase of isokinetic strength testing, with risk of hamstring injury in professional football players in a prospective cohort study.

Methods: All teams (n = 18) eligible to compete in the premier football league in Qatar underwent a comprehensive strength assessment during their annual periodic health evaluation at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar. Variables included rate of torque development and timing of muscle activity onset.

Results: A total of 367 unique players (60.6% of all QSL players) competed for 514 player seasons (103 players competed both seasons) and sustained 65 hamstring injuries. There was no difference in the onset of muscle activity between the biceps femoris and medial hamstrings comparing the injured to uninjured players. For both onset of muscle activity and rate of torque development, there were no significant differences between any of the variables ($P > 0.05$), with very small to small effect size detected across all the different variables ($d < 0.3$).

Conclusion: Rate of torque development and onset of muscle activity was not associated with a risk of future hamstring injury. The use of these measures as part of a periodic health evaluation screening for risk of hamstring injury is unsupported.

INTRODUCTION

Hamstring injuries remain a significant injury burden in sports that involve high speed running.[1–3] In elite male football, hamstring injury has repeatedly been identified as the most common noncontact injury,[4,5] representing 12% of all injuries.[5] As the incidence of hamstring injuries remains high,[5,6] with serious financial implications,[3,5] investigations are aimed at better understanding how to prevent hamstring injuries. A key component to better understand injury risk and to develop targeted prevention programmes, is the identification of both intrinsic and extrinsic risk factors. Intrinsic risk factors such as strength and range of motion have been investigated extensively. Van Dyk et al[7] a reported that lower isokinetic concentric quadriceps strength and eccentric hamstring strength were associated with an increased risk of injury. Another investigation in the same cohort found that greater isokinetic concentric quadriceps strength was associated with hamstring injury risk. Therefore, the relationship between strength and risk of injury, albeit significant, is weak and offers little clinical value.[8,9,7,10] However, risk factors that have not been thoroughly investigated in the same cohort of players are intrinsic measures of neuromuscular function such as rate of torque development and the timing of muscle activity onset.

The term neuromuscular function is wide-ranging, and is used to describe different aspects needed for optimal motor output. Although recognizing that skilled motor performance (as is required in football) requires a feed-forward mechanism where information is continually fed into sensory-motor loops from peripheral to central neural networks,[11,12] previous risk factor studies, all of them retrospective, have predominantly focused on specific aspects of neuromuscular function, such as rate of force development and muscle activity.[13–17]

During high speed running, a primary role of the hamstring muscle group is active deceleration of the forward moving thigh and shank during the terminal swing phase.[14,15] This terminal swing phase is considered as the phase in the gait cycle where most of the hamstring injuries occur; high eccentric force contraction decelerating the limb with the hamstrings in a lengthened position.[3,14,15,18] Therefore, the ability to develop torque quickly and the appropriate timing of muscle activity may be important to protect the hamstring muscle during high speed running. The first study to provide experimental evidence for differences in rate of torque development and muscle activity with injury found significantly lower hamstring activation with the muscle in a lengthened position in previously injured athletes.[13] Opar et al identified an absolute deficit of 13% in muscle activity during eccentric activity, and a 22% difference in the rate of torque development during rapid force generation.[14,19] The conceptual role of neuromuscular inhibition in rehabilitation after hamstring injury has been described, suggesting that inhibition of the neural system after injury may lead to atrophy, muscle fascicle length shortening, preferential eccentric weakness, and ultimately, an increased risk of re-injury.[20]

As all results to date are from retrospective studies,[13,14,19,21] no adequately powered prospective study has investigated rate of torque development or the onset of muscle activity as potential risk factors for hamstring injury. Methodological limitations with previous studies also include self-reported injury data that may be subject to recall bias, and a lack of recorded exposure for the athletes included. [13,14,19]

The purpose of this study was therefore to investigate the association between the timing of hamstring muscle activity onset and the rate of torque development during the early phase of isokinetic strength testing, with risk of hamstring injury in professional football players in a prospective cohort study.

METHODS

Study design

A prospective cohort study was performed which covered two football seasons (September 2013 to May 2015), with players included in season 1, season 2, or both seasons. All teams (n = 18) eligible to compete in the Qatar Stars League (QSL), the premier football league in Qatar, agreed to participate in the study. Each player from the respective teams underwent an annual periodic health evaluation (PHE) at Aspetar Orthopaedic and Sports Medicine Hospital in Doha, Qatar. The PHE was performed from May to September, with the official start of the season in September of each year. However, if players performed PHE outside of this period and met the inclusion criteria, they were still included in the study.

All players over the age of 18 years and eligible to compete in the QSL, who had provided written consent, were uninjured at the time and able to perform the strength testing, were included. If no isokinetic test was performed at the start of a season, or no exposure or injury surveillance data were recorded over an entire season, players were excluded. Figure 1 depicts the inclusion methodology during the two study seasons.

Ethical approval was obtained from the Institutional Review Board, Anti-doping Lab, Qatar (IRB F2013000003).

Player information

Non-modifiable risk factors that were considered included a history of previous hamstring injury in the past 12 months, age, team, regular season, leg dominance, playing position, and ethnicity were recorded. We measured height and weight, and calculated body mass index (BMI). History of previous hamstring injury was self-reported at the time of screening and cross-checked with their hospital medical file.

Isokinetic strength testing with surface EMG measurement

Prior to the isokinetic strength test procedure described below, both limbs were prepared for surface electromyography (sEMG) measurement. Bipolar pre-gelled Ag/AgCl sEMG electrodes (Ambu Blue sensor T, Ambu A/S, Denmark; diameter 9 mm; interdistance electrode 30 mm) were used to record sEMG activity from the medial hamstrings and biceps femoris. After skin preparation via shaving, light abrasion, and sterilisation, electrodes were placed on the posterior thigh half way between the ischial tuberosity and tibial epicondyles.[14] Electrodes were placed on the muscle bellies that were identified via palpation during strong isometric knee flexion as per Surface Electromyography for Non-Invasive Assessment of Muscles (SENIAM) guidelines.[22] The reference electrode was placed on the lateral head of the right fibula. To minimise movement artifact from sEMG electrodes on the dynamometer seat, players were positioned on a custom made pad placed on top of the original seat, with two holes at the level of the posterior mid-thigh where the electrodes were placed.[14] Muscle activity via sEMG was recorded in the medial hamstrings and biceps femoris while the isokinetic test was performed.

Knee flexion and extension muscle strength were tested using an isokinetic dynamometer (Biodex Multi-joint System 3, Biodex Medical Systems Inc. New York, USA). After an explanation of the testing methodology, prior to the electrodes being affixed to the limb, the player performed a 5–10 min warm up routine, consisting of cycling on a stationary exercise bike at approximately 1 W/kg bodyweight (Bike Forma, Technogym®, Cesena, Italy), and familiarization with the test procedure. Each player was positioned on the dynamometer so that the hip was flexed to 90°, ensuring that the dynamometer and knee joint angle were aligned. The trunk, waist and tested thigh were fixed with straps to minimize secondary joint movement. Vigorous verbal encouragement was provided by the assessors during the testing.[7] Isokinetic testing comprised of three different modes and speeds, with the selection of speed and repetition based on the findings from previous meta-analyses.[8] The order (i.e. left, right) was randomized and maintained for each of the three different testing modes and speeds for each subject. First, the players were tested over five repetitions of concentric knee flexion and extension at 60°/s, followed by 10 repetitions of concentric knee flexion and extension at 300°/s. These test modes measure the concentric strength of the quadriceps (knee extension) and hamstring (knee flexion) muscles. Finally, players performed five repetitions of eccentric knee extension at 60°/s which measures the eccentric strength of the hamstring muscles.[9]

Dynamometer torque and lever position data were synchronously collected with sEMG data collected using commercially available hardware (Biopac MP35, systems Inc) and software (Acqknowledge 3.6.7, Biopac Systems Inc) operating at 1000 Hz (bandwidth 10–500 Hz, common mode rejection ratio > 115 dB at 60 Hz). Data were transferred to a personal computer for later analysis.

Data Analysis

Concentric and Eccentric Torque

The onset (start) and offset (end) points for each repetition during each contraction mode were automatically detected. Firstly, the raw torque data was smoothed at 3 Hz (low pass Butterworth digital filter) and the first derivative of the signal was determined, after which the maximum value (peak torque) for each repetition was determined through a peak detection method. For

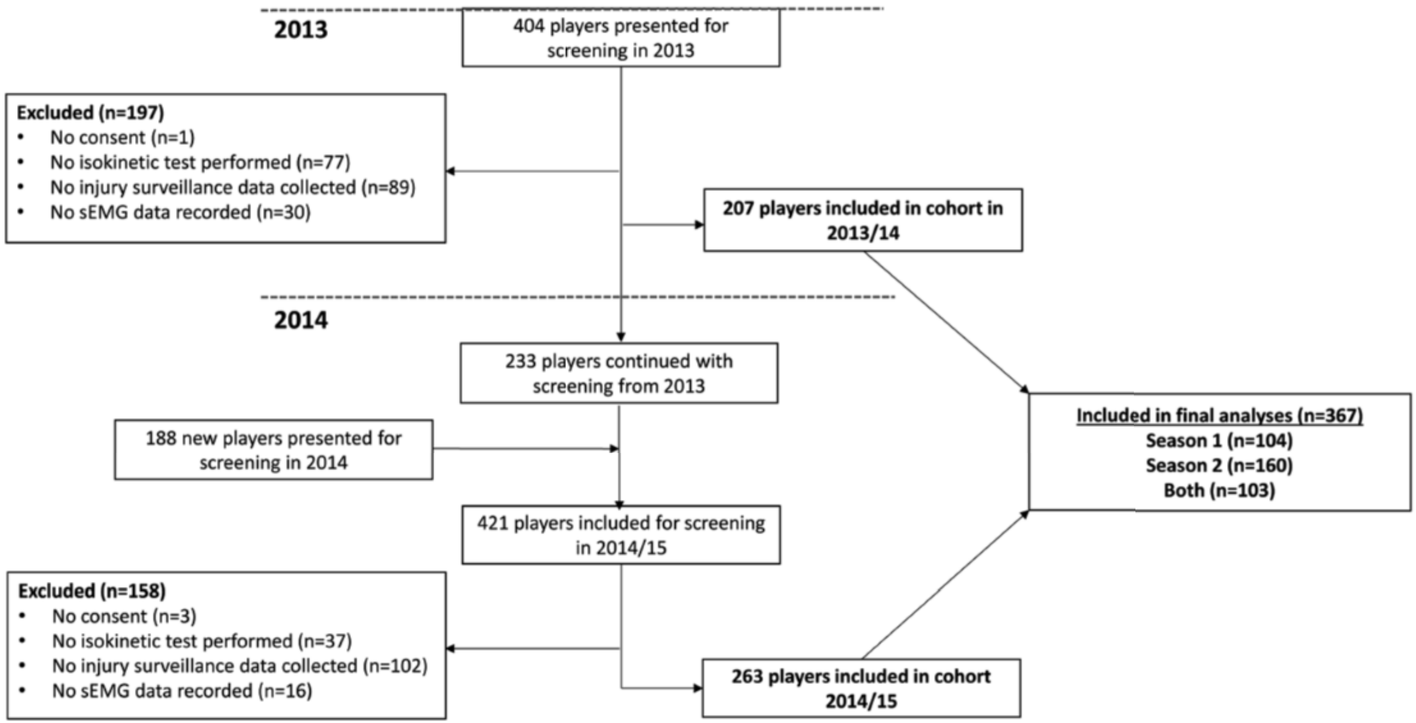

Figure 1 Flowchart demonstrating the movement of players and repeated measurements between different seasons.

concentric trials, once the peak was identified, the onset and offset points for each repetition were determined by searching through the raw torque data until values exceeding -3 Nm and 3 Nm were found (Figure 2).[14] For eccentric trials, the onset and offset points were identified for each repetition by searching from each repetition's peak both backwards (onset) and forwards (offset) until the points where the gradient was zero (Figure 3). The onset and offset points were then visually confirmed via comparison with the original torque signal.

Rate of torque development

For repetitions of both concentric and eccentric contraction modes, the rate of torque development was determined to be the mean of the average slope of the torque-time trace (Dtorque/Dtime) from the onset of contraction through until 30, 50, and 100 ms of the contraction.[14] The peak rate of torque development for each contraction across all repetitions was determined for further analyses.

Muscle activity (sEMG)

Raw sEMG data were demeaned, full-wave rectified and low-pass filtered at 4 Hz using a fourth-order dual pass Butterworth digital filter to form a linear envelope.[23] The onset of myoelectrical activity for each repetition was automatically determined to be when it rose three SD from the baseline sEMG activity.[24] While the computerized automatic detection method to determine onset was typically successful; when it was not, manual detection was implemented. Visual inspection was performed within the customized software programme for each onset determination to ensure accurate measurement.[25,26] The peak onset (measurement that displayed the earliest timing) as well as average onset from all the measurements as recorded during each isokinetic strength contraction were determined for medial hamstrings and biceps femoris. The above processes were all implemented using a customized software programme written in Labview V7.0 (National Instruments, Austin, Texas).

Injury surveillance

All participating QSL teams are provided with medical services by the National Sports Medicine Programme, a department with the Aspetar Orthopaedic and Sports Medicine Hospital. This centralized system with a focal point for the medical care of each club competing in the QSL allowed for standardization of the ongoing injury surveillance through the Aspetar Injury and Illness Surveillance Programme (AIISP).[27]

The AIISP includes prospective injury and exposure (minutes of training and match play) recording from all QSL teams. The injury data were collected monthly from the club, with regular communication with the responsible team physician/physiotherapist to encourage timely and accurate reporting. Throughout the 2013 and 2014 season (July to May; 44 weeks per season), training and match exposure for each team were recorded by the team physician (or lead physiotherapist if no team physician was available). At the conclusion of each season, all the data from the individual clubs were collated into a central database, and inconsistencies were identified and followed up to be resolved with club medical personnel.

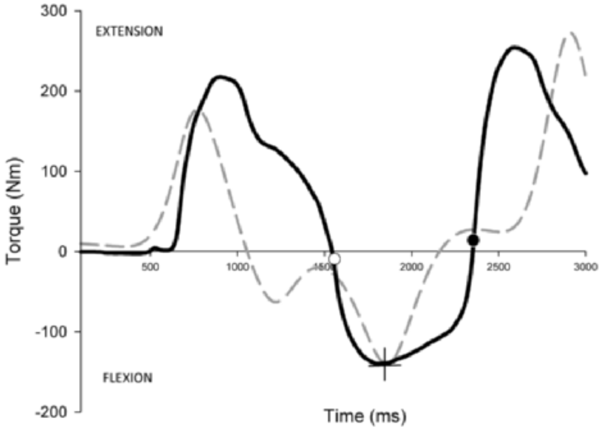

Figure 2 Concentric torque onset detection. The peak (indicated by cross) was detected from the 1st derivative (dashed line), and mapped onto the raw torque (solid line). The onset (open symbol) and offset (closed symbol) points were identified moving backwards (onset) and forwards (offset) for each repetition in the raw torque data until values exceeding -3 Nm and 3 Nm, respectively, was found.

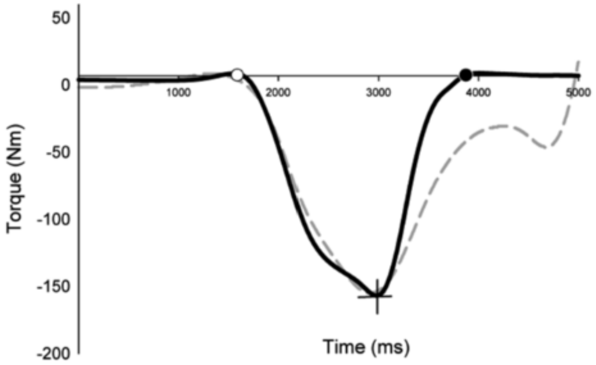

Figure 3 Eccentric torque onset detection. The peak (indicated by cross) was detected from the 1st derivative (dashed line), and mapped onto the raw torque (solid line). The onset (open symbol) and offset (closed symbol) points were identified moving backwards (onset) and forwards (offset) for each repetition in the raw torque data until the points where the gradient was zero.

A hamstring injury was defined as acute pain in the posterior thigh that occurred during training or match play, and resulted in immediate termination of play and inability to participate in the next training session or match.[4] These injuries were confirmed through follow-up clinical examination (identifying pain on palpation, pain with isometric contraction and pain with muscle lengthening) by the club medical staff, not more than three days post-injury. If indicated, the clinical diagnosis was supported by ultrasonography and/or magnetic resonance imaging at the study centre. A recurrent injury was defined as a hamstring injury that occurred in the same limb and within two months of the initial injury.[28]

Statistical analyses

For each player included, all repetitions for each isokinetic mode of contraction for both limbs (40 trials) were used in the statistical analyses, except if any repetition in a specific trial was found unusable due to the quality of the data. All repetitions for each mode of contraction were used to determine the average rate of torque development and onset of muscle activity, and this average, together with the peak effort within each set of repetitions were used in the analyses. Univariate analyses (independent t-tests) were performed between the limbs of the injured and the uninjured players for the sEMG and rate of torque development measures. Injured limbs were compared to uninjured limbs among injured players, and then to all uninjured limbs among the uninjured players. For categorical variables, a chi-square analysis was performed.

Due to the consistency in our sample, the repeated measures performed over the two seasons, as well as the fact that not every player had the same number of measurements (i.e. some subjects would have test results including both limbs for both seasons, while other subjects might only have been tested once), standard errors would have increased when using general estimating equations in a traditional Cox regression model. Therefore, we performed a clustered univariate Cox regression analysis in STATA (version 11.0, College Station, Texas, USA) using the limb as the unit of analyses, adjusting for the interdependence of the limbs by using the player as a cluster factor. Due to the skewness of the sEMG and rate of torque development measurements, the natural log transformation was used. Exposure was totaled as duration in hours for game and training combined from the start to the end of each season, or time to first injury. Variables independently associated with hamstring strain injury were determined from the univariate analyses. A *P* value of ≤ 0.05 was considered statistically significant. Effect size, which is the quantitative measure of the strength of an observed occurrence, was calculated and interpreted using thresholds as suggested by Cohen et al as small (> 0.2), medium (> 0.5), and large (> 0.8).[29]

RESULTS

Participants

During the two-season study period, 592 elite male soccer players (age 25.8 ± 4.8 yrs, height 177 ± 7 cm, weight 72.4 ± 9.3 kg, BMI 23.1 ± 2) reported for screening and were considered for isokinetic testing. Players who were unable to perform the test (n = 70), who did not provide consent (n=4), or had no injury surveillance data recorded during the subsequent season (n = 105) were excluded from the final analyses (n = 179, age 25.3 ± 4.5 yrs, height 177 ± 7 cm, weight 73.5 ± 9.8 kg, BMI 23.4 ± 1.8). Of the remaining 413 players, 46 did not have any sEMG measurements recorded, and were also excluded. In total, 367 unique players (60.6% of all QSL players) competed for 514 player seasons (103 players competed both seasons) (Figure 1). The only demographic difference between the injured and uninjured players were age and player position ($P < 0.05$) (Table 1).

New hamstring strain injuries

Overall, 62 of the 367 players sustained 65 index hamstring injuries. The three players who had more than one injury were retained in the analyses (none of these injuries met the criteria for re-injury).

Table 1 Characteristics of the injured (n = 62) and uninjured players (n = 305). Data are shown as mean values with SD or percentages.

	Injured (n=62)	**Uninjured (n=305)**	***P* value**
Age	27.8 (4.3)	26.1 (4.8)	**0.01**
Body mass (kg)	72.3 (7.8.)	72.3 (9.2)	0.94
Body height (m)	176 (7)	177 (6.8)	0.32
BMI	23.4 (1.9)	23.1 (1.9)	0.50
Previous hamstring injury (yes)	30.6%	29.2%	0.73
Player position (n)			**<0.01**
– Goalkeeper[a]	1 (1.6%)	33 (10.8%)	
– Defender	26 (41.9%)	94 (30.8%)	
– Midfielder	25 (40.3%)	119 (39.1%)	
– Forward	10 (16.2%)	59 (28.8%)	
Limb dominance (n)			0.36
– Left	15 (24.4%)	44 (14.4%)	
– Right	47 (75.6%)	261 (85.6%)	

[a] Comparator value used in Chi-square analysis for categorical variable.

Electromyography and rate of torque development measurements

Muscle activity (sEMG) was recorded for 367 players while performing a total of 1018 isokinetic test procedures (considering both limbs) over the two seasons. There was no difference in the onset of muscle activity between the medial hamstrings and biceps femoris (Table 2), or the rate of torque development (Table 3) for both the injured and uninjured players. The results of the univariate analyses are shown in Tables 2 and 3 for sEMG muscle onset and rate of torque development, respectively. Among injured players, comparing the injured to the uninjured limb (n = 62), no significant differences in the onset of muscle activation or rate of torque development were observed for any of the test modes.

Table 2 Timing of muscle activity onset in relation to isokinetic torque. Comparison of surface electromyography (sEMG) measurements between the injured and (a) the uninjured limb in the injured players, and (b) all uninjured limbs in the uninjured players. Absolute values for sEMG are displayed for medial hamstrings (MH) and biceps femoris (BF) in seconds as mean values with SD. [a]Paired *t* test, [b]unpaired *t* test.

	Injured players				**Uninjured players**		
	Injured limb (n = 65)	**Uninjured limb (n = 65)**	***P* value[a]**	**Effect Size (d)**	**Uninjured limbs (n = 963)**	***P* value[b]**	**Effect Size (d)**
Medial hamstrings							
Concentric @60°/s							
Peak onset sEMG	-0.167 (0.024)	-0.162 (0.031)	0.38	0.20	-0.172 (0.029)	0.42	0.17
Average onset sEMG	-0.147 (0.026)	-0.141 (0.034)	0.31	0.23	-0.149 (0.027)	0.52	0.09
Concentric @300°/s							
Peak onset sEMG	-0.172 (0.025)	-0.174 (0.024)	0.73	0.06	-0.177 (0.027)	0.28	0.19
Average onset sEMG	-0.150 (0.027)	-0.170 (0.036)	0.69	0.07	-0.152 (0.023)	0.82	0.08
Eccentric @60°/s							
Peak onset sEMG	-0.205 (0.053)	-0.201 (0.036)	0.68	0.07	-0.204 (0.047)	0.56	0.03
Average onset sEMG	-0.157 (0.050)	-0.155 (0.037)	0.85	0.03	-0.158 (0.041)	0.83	0.04
Biceps Femoris							
Concentric @60°/s							
Peak onset sEMG	-0.158 (0.038)	-0.152 (0.038)	0.42	0.16	-0.157(0.035)	0.71	0.02
Average onset sEMG	-0.132 (0.033)	-0.124 (0.037)	0.24	0.24	-0.132 (0.032)	0.96	0.01
Concentric @300°/s							
Peak onset sEMG	-0.166 (0.032)	-0.170 (0.036)	0.61	0.10	-0.167 (0.031)	0.80	0.01
Average onset sEMG	-0.142 (0.028)	-0.141 (0.030)	0.87	0.03	-0.141 (0.028)	0.68	0.05
Eccentric @60°/s							
Peak onset sEMG	-0.211 (0.052)	-0.207 (0.050)	0.67	0.08	-0.206 (0.047)	0.48	0.11
Average onset sEMG	-0.159 (0.041)	-0.157 (0.047)	0.84	0.05	-0.160 (0.040)	0.98	0.02

Table 3 Comparison of the rate of torque development measurements between the injured and (a) the uninjured limb in the injured players, and b) all uninjured limbs in the uninjured players. Absolute values for rate of torque development are displayed in Nm/s as mean values with SD. [a]Paired *t* test, [b]unpaired *t* test

	Injured Players				Uninjured players		
	Injured limb (n = 65)	Uninjured limb (n = 65)	*P* value[a]	Effect Size (d)	Uninjured limbs (n = 963)	*P* value[b]	Effect Size (d)
Concentric @60°/s							
30 ms	1019 (373)	1025 (463)	0.93	0.02	1058 (460)	0.53	0.08
50 ms	952 (333)	901 (385)	0.44	0.15	950 (391)	0.99	0.01
100 ms	864 (226)	815 (264)	0.29	0.22	864 (261)	0.83	0.01
Concentric @300°/s							
30 ms	1404 (432)	1388 (403)	0.83	0.03	1418 (389)	0.96	0.03
50 ms	961 (234)	914 (235)	0.28	0.20	949 (221)	0.56	0.05
100 ms	682 (173)	670 (202)	0.71	0.07	677 (173)	0.62	0.04
Eccentric @60°/s							
30 ms	355 (252)	357 (213)	0.97	0.01	377 (213)	0.33	0.10
50 ms	365 (246)	360 (207)	0.92	0.02	389.09 (207)	0.31	0.12
100 ms	342 (225)	325 (161)	0.66	0.07	374 (176)	0.20	0.18

Comparing the injured limbs to the limbs of uninjured players (n = 963), there were no significant differences between any of the variables *(P* > 0.05), with very small to small effect size detected across all the different variables (d < 0.3) (Table 2).

Cox regression analysis

Age, weight, body mass index, previous hamstring injury, season, side (left or right limb), team, limb dominance and player position were tested as potential confounding variables. The parameter estimates of the regression analyses are presented in table 4 and 5 expressed as hazard ratios. Age and player position were significantly associated with increased risk of injury, while the onset of muscle activation or rate of torque development were not during any of the different contraction modes.

Table 4 Univariate Cox regression analysis demonstrating parameter estimates (95% confidence intervals, CI) with all possible muscle onset sEMG variables for medial hamstrings (MH) and biceps femoris (BF) included (n = 367)

	Hazard Ratio	**95% CI**	***P* value**
Medial hamstrings			
Concentric @60°/s			
Peak onset sEMG	0.45	0.10 to 2.01	0.30
Average onset sEMG	0.59	0.24 to 1.46	0.25
Concentric @300°/s			
Peak onset sEMG	0.63	0.34 to 1.18	0.15
Average onset sEMG	0.79	0.37 to 1.71	0.55
Eccentric @60°/s			
Peak onset sEMG	1.15	0.32 to 4.06	0.83
Average onset sEMG	0.71	0.30 to 1.67	0.43
Biceps femoris			
Concentric @60°/s			
Peak onset sEMG	1.36	0.42 to 4.40	0.61
Average onset sEMG	0.93	0.42 to 2.08	0.86
Concentric @300°/s			
Peak onset sEMG	1.10	0.31 to 3.86	0.89
Average onset sEMG	1.20	0.39 to 3.72	0.75
Eccentric @60°/s			
Peak onset sEMG	1.40	0.48 to 4.13	0.54
Average onset sEMG	0.88	0.42 to 1.83	0.73

Table 5 Univariate Cox regression analysis demonstrating parameter estimates (95% confidence intervals, CI) with all peak rate of torque development variables for each of the different isokinetic contraction modes (n = 367).

	Hazard Ratio	**95% CI**	***P* value**
Concentric @60°/s			
30 ms	0.85	0.50 to 1.43	0.54
50 ms	0.98	0.56 to 1.74	0.96
100 ms	0.94	0.48 to 1.84	0.85
Concentric @300°/s			
30 ms	0.84	0.35 to 2.06	0.71
50 ms	1.32	0.41 to 4.26	0.64
100 ms	1.23	0.45 to 3.38	0.68
Eccentric @60°/s			
30 ms	0.68	0.38 to 1.23	0.20
50 ms	0.64	0.34 to 1.18	0.15
100 ms	0.54	0.30 to 1.03	0.06

DISCUSSION

Neither rate of torque development nor onset of muscle activity during concentric and eccentric isokinetic contractions were found to be associated with risk of hamstring injury in this study.

Strength variables have been investigated thoroughly in the same cohort of players, where quadriceps strength was the only significant, albeit weak, risk factor identified. To complement these findings, this is the first large prospective cohort study to examine the association between rate of torque development and the onset of muscle activity with risk of hamstring injury. Previous work have examined these measures when players have returned to sport after hamstring injury, suggesting that changes persist for a prolonged period after injury, or that rehabilitation may have been inadequate.[19] However, the current investigation examined these aspects in healthy players while performing isokinetic strength tests in an elite football screening environment.

Rate of torque development

Rate of torque development is important for all athletes participating in sports that require explosive muscle action.[30] In particular, the demands of high speed running during football requires rapid deceleration of the limb during the terminal swing phase. During this phase, the amount of biomechanical load is greatest, with the largest peak musculotendinous strain in the biceps femoris.[15] Therefore, the ability to generate torque during this rapid deceleration in order to counter the applied load is of great importance. Although many studies have examined the rate of torque development in performance testing, these investigations mainly focus on isometric contractions,[31,32] or the effect of either concentric or eccentric training on muscle strength and mass,[33] mainly in healthy individuals. The development of force during rapid concentric and eccentric movement has been largely overlooked.

Concentric muscle action

We were able to investigate the rates of force development for isokinetic concentric muscle action at 60°/s and 300°/s in 367 healthy professional football players. Our results indicate higher rates of torque development in the concentric contraction modes compared to eccentric contractions at 60°/s, although no differences were observed between injured or uninjured players, neither in the concentric nor eccentric modes. We might consider that because the concentric contractions represent a transition from knee extension to knee flexion, the resultant rate of torque development will artificially be higher, compared to the eccentric contraction which starts from rest.

A decline in the rate of torque development from 30 to 100 ms was observed, supported by previous findings.[,30,34] Although variability between individual players might lead to different rates of torque development, the decline we observed would suggest that the majority of force development occurs early in the movement. However, the concentric action was not isolated, and we urge caution when interpreting this result.

Eccentric muscle action

There was no difference between injured and uninjured limbs for rate of torque development during anticipated eccentric contractions at any of the time intervals in the present study. Contrary to previous findings,[14] we observed little to no change in the rate of torque development over the 100 ms period.

Most explosive sporting activities such as running or jumping involve stretch-shortening cycle movements where a concentric muscle action is preceded by an eccentrically stretched muscle-tendon complex.[12] In football, a key feature of hamstring muscle function is the ability to generate rapid force at the terminal swing phase during high speed running.[3] This rapid deceleration of the hip (flexion) and knee (extension) is imperative to maintain function of the limb during explosive action. During this phase of the stride cycle, the hamstrings (with exception of the biceps femoris short head) produce the greatest musculotendinous strain, peak force, and perform negative (eccentric) work.[35] The ability to rapidly develop force is important because of the limited time available for deceleration (~100 ms),[36] which prevents the development of peak torque.[37]

The only previous study to investigate the relationship between rate of torque development during anticipated eccentric contraction @60°/s and hamstring injury found lesser rates of torque development at 50 ms and 100 ms in previously injured players.[14] Since the methodology in this study was similar to ours, the results in our study would suggest that the difference in rate of torque development identified in a previous study [14] is a result of the hamstring injury, and not present prior to injury.

Onset of muscle activity

We found no association between the onset of muscle activity and risk of hamstring injury for any of the contraction modes. Furthermore, no significant difference was observed between the onset of muscle activity of the medial hamstrings and biceps femoris. The myoelectrical activity during the early phase of the contraction onset has been shown to have a positive relationship with rate of torque development,[30,31] and the initial onset of muscle activity might therefore influence the rate of torque development. However, our findings indicate no difference in the onset of muscle activity between injured and uninjured players, or between the different hamstring muscles. Sole et al reported the onset of both the biceps femoris and medial hamstrings were shown to be earlier among previously injured players, highlighting differences in the muscle activity after injury.[21]

Although the present investigation did not measure the amplitude of myoelectrical activity, previous investigations have found significant differences in muscle activity of previously injured hamstring muscles. Indeed, Sole et al demonstrated significantly lesser biceps femoris myoelectrical activity in the lengthened range of eccentric contraction.[13] This was confirmed by another retrospective study where the myoelectrical activity in the biceps femoris was decreased at 100 ms after the onset of the eccentric contraction.[19] In this study, the myoelectrical activity at 60°/s in the biceps femoris was significantly lower in the previously injured limbs during anticipated eccentric contractions.[19]

Other prospective investigations profiling the muscle activity patterns of the trunk and lower limb have identified associations with the risk of hamstring injury in football players.[17,38,39] These studies suggest that other components such as muscle recruitment patterns between the biceps femoris and medial hamstrings, or activation profiles of different muscles such as the erector spinae and gluteus medius during sprinting, might be related to hamstring injury.[39] However, the present investigation does not provide any evidence that the timing of muscle activity onset during isokinetic contractions, either concentrically or eccentrically, is associated with an increased risk of injury.

Strengths and limitations

It has been proposed that 30 to 40 injury cases are needed to detect strong to moderate associations between risk factors and injury in prospective cohort studies, while 200 injury cases are needed to detect small to moderate associations.[40] With 65 cases, this is the largest prospective study to date on rate of torque development and the onset of muscle activity as risk factors for hamstring injury, yet it was insufficient to detect small associations. However, it should be noted that none of the effect sizes calculated for these variables exceeded 0.3, failing to reach clinical importance.

As with the investigation by Opar et al[14] we acknowledge that the lag between the dynamometer lever arm and the onset of torque development limits our ability to accurately measure muscle activity onset. Given the short time frame over which rate of torque development and myoelectrical onset are analysed, the actual contraction is quasi-isometric.[14] However, evidence suggests that the brain plans and programmes eccentric tasks differently from concentric tasks.[41] Greater cortical signal for eccentric muscle contraction suggests that brain activity differs when planning movement strategy for eccentric movement compared to concentric movement, reflected in the measurement of myoelectrical activity.[41]

The use of isokinetic dynamometry at 60°/s and 300°/s to assess the rate of torque development might be influenced by other factors, in particular fatigue during 10 repetitions at high speed of concentric action. Also, the results from seated isokinetic dynamometry strength testing do not reflect the functional demands placed on the hamstrings during sport specific activity such as high speed running or direction changes,[14] urging caution when translating these findings to the clinical setting.

All tests performed utilized the same isokinetic testing system with highly experienced assessors in a multinational, multi-language clinical setting for professional athletes. Although every effort was made to ensure players understood the test procedure and instructions, it is possible that some players did not comprehend the instructions fully. Intra-season variability in the repeated measures over the two-year observation period may have limited our ability to identify an association between rate of torque development and the onset of muscle activity with injury risk. We must consider that a once-off test at a specific time point in the season does not necessarily reflect the actual status of the player at the time of injury.

In addition, even though every effort was made in the data analysis to account for variability, we accept that there may be a large amount of "noise" in the data. The larger inter-electrode distance of the electrodes used in this study (30 mm) compared to previous investigations (25 mm) may increase the risk of signal contamination from adjacent muscles. However, this is representative of current clinical practice.

We also acknowledge the homogeneity of our study population of professional male football players, which limits the generalization of these findings to other sports, age groups, or female players. Other factors such as training culture and possible prevention strategies within different teams, or climate specific to the Middle East region, could have influenced the results.

Clinical implications

The results of this investigation indicate that the previous findings of lower rates of torque development, as well as reduced biceps femoris activation during maximal eccentric contractions, are more likely the result of changes in response to injury. Previously injured hamstring muscles (in particular biceps femoris) have a reduced ability to generate torque with anticipated eccentric movements.[19] This holds important consequences for rehabilitation and risk of recurrent injury. Although it is not possible to determine the muscle activity or rate of torque development of the hamstring muscle at the precise moment of injury, interestingly, we did not find any association between these measures with risk of future hamstring injury.

So called "neuromuscular training" programmes to improve function and performance have been investigated,[42–44] particularly aimed at preventing knee and ankle injuries. The effectiveness of such programmes to prevent injuries in football has been established, showing a preventative effect across all injuries types.[42,45] Although our study did not find any deficits in the specific elements of neuromuscular function prior to hamstring injury, these programmes might address different components of the neural system, which might prove to be effective.

CONCLUSION

Rate of torque development and onset of muscle activity was not associated with a risk of future hamstring injury. Our results provide insights previously unknown into the causal relationship between rate of torque development and the onset of muscle activity with risk of hamstring injury. The use of these measures as part of a periodic health evaluation is unsupported.

PERSPECTIVE

Rate of torque development and onset of muscle activity has been found retrospectively associated with risk of hamstring injury, but these measures has not been studied prospectively. Other studies have found global aspects of muscle activity, such as proximal activation and synergistic activity in the lower limb muscles, associated with risk of injury. In our results, rate of torque development and onset of muscle activity do not represent risk factors for hamstring injury.

Our findings would suggest that deficits observed in rate of torque development and muscle activation is the consequence rather than the cause of hamstring injury. This holds specific implications for rehabilitation. Adequate rehabilitation for players with hamstring injuries might consider adressing components such as rate of torque development and muscle activation, as neuromuscular inhibition may persist for a long period after return to play. It is also clear from these results that once-off testing during the season is not valuable in identifying athletes at risk of hamstring injury.

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Chapter 6

General discussion

Sections within this discussion have been published as editorials

Prevention forecast: cloudy with a chance of injury

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There is strength in numbers for muscle injuries:
it is time to establish an international collaborative registry

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Hamstring injuries represent a substantial injury burden in football,[1] and the most common non-contact muscle injury overall.[2] It has been demonstrated that player availability impact negatively on team success,[3–5] and therefore the prevention of hamstring injuries have received much attention in the literature, as well as on the field.[6–8] However, injury prevention efforts have not reduced the number of injuries at elite level. Incidence patterns in the UEFA Champions League have demonstrated a steady increase of 2.3% in the hamstring injury rate per year.[9] These results are worrying, considering that investigations identifying risk factors associated with these injuries have been plentiful.[10–12] Unfortunately, these studies continue to provide contrasting conclusions, often directly contradicting each other's findings. This is evident in systematic reviews and meta-analyses that do not provide substantial evidence for any specific modifiable risk factor.[10–12]

Despite these inconsistencies, a number of intervention studies have shown to be effective at reducing hamstring injuries; the greatest effect found in studies focused on eccentric strengthening.[6,7,13] Although not specifically aimed at hamstring injuries, we observe similar success where the intervention was aimed at neuromuscular function and improving flexibility.[3,14,15] This creates a curious paradox. Although there are perceptions and beliefs around these prevention strategies that pose serious barriers to implementation,[16,17] there seems to be a "disconnect" between the identification of risk factors associated with hamstring injury, and the results of injury prevention studies. Therefore, the identification of risk factors associated with hamstring injury in a methodologically sound, high-quality study was needed to further understand how these risk factors are associated with hamstring injury, and how we might improve our injury prevention efforts.

This project aimed at identifying risk factors for hamstring injuries in a cohort of professional football players. Traditional risk factors such as strength and flexibility were included, together with novel measures of strength and a dynamic profile of strength characteristics. The variability and relationship between standard and novel strength measurements were also investigated. Furthermore, we included neuromuscular risk factors that have not been studied prospectively.

In this discussion, we contemplate the main findings of these studies, in light of their strengths and limitations. We consider what clinical implications these findings might hold for every day practice, and make recommendations for future research.

Non-modifiable risk factors – playing position, ethnicity, age and previous injury

Predictably, goalkeepers are much less likely to sustain a hamstring injury when compared to outfielders. High speed running is considered the predominant hamstring injury mechanism involved in football, and outfielders are naturally required to do much more running compared to goalkeepers.[18,19] This supports the unsurprising finding in our study of lower risk of hamstring injury in goalkeepers. All other positions were similar in the risk of hamstring injury, with no significant difference between midfielders, forwards or defenders.

The role of ethnicity and how it may impact injury risk is still poorly understood.[20] Bahr suggests that to develop good screening tests, the second step after risk factors are established is to validate these tests in different athlete cohorts.[1] This would include athletes from different ethnic origin. The studies in this thesis represent the first large investigation on risk factors for hamstring injury in the Arabic peninsula, and therefore includes a predominantly Arab cohort (60% of players). However, our investigation also included representations of players from other ethnic backgrounds, and we did not find ethnicity to be associated with an increased risk of hamstring injury.

Age was identified as a risk factor for hamstring injury in our studies. It is not clear why older players are at greater risk of injury. Some theories that offer an explanation for increased age as a risk factor have been promoted, such as loss of muscle mass leading to decreased strength, and changes in muscle structure. This is an unlikely reason in our study population, where the mean difference between the injured and uninjured players was only 18 months. Arnason et al did not find a mediating effect of previous injury on age, confirming an independent relationship between age and risk of hamstring injury.[21] However, in a separate investigation, the associated risk of increased age with hamstring injury was mitigated by improvements in eccentric strength,[22] suggesting that the interaction between these different modifiable and non-modifiable risk factors are important.

A history of previous injury is consistently identified as a risk factor for hamstring injury.[11,12,21,23] Hamilton et al explores two potential theories to explain the relationship between previous injury and subsequent injury.[24] Firstly, a causal relationship exists between previous injury and future risk of injury, most likely due to inadequate rehabilitation. This might lead to incomplete healing, weakness of the previously injured tissue, and other possible functional movement or even psychological factors that persist after return to sport.[24] Alternatively, a “noncausal marker” theory is proposed, where previous injury is simply a marker for other factors that would cause an individual to be at greater risk of injury.[24] Supposedly then, certain individuals might be at greater risk of injury due to behaviour, or other injury-prone characteristics (training, playing position, psychological, etc.). This would suggest that confounding bias is present when a history of previous injury is examined as a potential risk factor.

In our investigation, a history of previous injury was found to be a risk factor in our first study, where we looked at strength variables over a four year period. However, it was not found to be associated with risk of hamstring injury in any of the subsequent studies which included the two seasons following the first study. In an attempt to reduce the risk of recall bias in self-reporting injuries (or unwillingness to disclose previous injuries), we analysed a subgroup of players where the previous injury status was known through detailed injury surveillance. Again, no association was found.

To interpret these contrasting results, let us consider the context of this investigation. Two large randomized control trials (RCT) were being conducted at the Aspetar Orthopaedic and Sports Medicine Hospital concurrent to this prospective study. Both these studies incorporated a structured criteria-based rehabilitation programme, including a large number of QSL players. While the second RCT is still ongoing, the first RCT reported a re-injury rate of 6%,[25,26] which is low compared to other football leagues.[27] If we consider previous injury a "noncausal marker" for other predisposing factors, present in certain individuals that might lead to injury, our finding suggest that the introduction of a systematic, criteria based rehabilitation programme may have reduced the risk associated with previous injury by addressing some of these factors. Alternatively, if we assume that a causal relationship exists between previous injury and hamstring injury, the player may have received adequate rehabilitation, including optimal loading and criteria-based progression to address predisposing risk factors.[28,29] Either way, it seems that the rehabilitation programme might have mitigated the risk of hamstring injury associated with previous injury. This study did not aim to measure the effect of a rehabilitation programme for hamstring injuries on the risk of subsequent injury. However, in this cohort, with the study centre being the focal point of care for the entire football league, it seems a plausible explanation. Such an effect has also been observed in volleyball, where the association between previous injury and ankle sprains was no longer identified after the implementation of a structured rehabilitation programme.[30]

Modifiable risk factors – strength, flexibility, and neuromuscular function

In a large meta-analysis quadriceps strength was the only modifiable risk factor associated with risk of hamstring injury.[12] In addition to strength, a recent systematic review reported conflicting evidence for flexibility as a risk factor for hamstring injury.[11] Previous retrospective investigations have found deficiencies in neuromuscular function after hamstring injury; in particular, altered rate of torque development and muscle activity during eccentric contraction.[31,32] These factors, representing intrinsic neuromuscular function, have never been studied prospectively, and the role of these factors in either the cause or the consequence of hamstring injury was undefined. In football, we observe prevention strategies aimed at addressing these risk factors, despite the limited evidence from systematic reviews that these risk factors are associated with increased risk of hamstring injury.

Traditional and novel strength measurements

Isokinetic dynamometer strength testing is still considered a reliable measure of determining the strength profile of individual players.[33] At the elite level, coaches and medical staff rely heavily on isokinetic testing, often making recommendations for training or rehabilitation based on the results of these tests.[17,34,35] Previous prospective studies have investigated a host of measures derived from these tests, including peak torque, both as an absolute value and normalized to bodyweight, leading to contradicting results.[12]

We performed a comprehensive isokinetic strength assessment, including both concentric and eccentric contraction modes at different speeds. A significant association was found between lower concentric quadriceps and eccentric hamstring strength, normalized to bodyweight, at slow speed. The second strength investigation, accounting for exposure, confirmed the results from previous meta-analysis,[12] where greater quadriceps strength was associated with an increased risk of hamstring injury.

Previously, concentric and eccentric isokinetic hamstring strength measures have yielded mixed results.[36–38] In contrast to previous findings,[37] our study identified lower peak eccentric hamstring torque as a risk factor for hamstring injury. Retrospective case control studies have also identified significant differences in eccentric strength when comparing previously injured to uninjured players.[38] However, these investigations included small samples, with a small number of hamstring injuries. Most other investigations include eccentric hamstring peak torque as part of a strength imbalance protocol, where arbitrary cut-off points were used, or hamstring-to-quadriceps (H:Q) ratios were calculated.[39,40]

Greater quadriceps strength has consistently been identified as a risk factor for hamstring injury.[10,12,40] Considering the hamstring injury mechanism during high speed running, where the hamstrings have to act as a “breaking force” to the hip flexors and quadriceps extending the knee and shank, greater quadriceps strength might require greater eccentric action from the hamstrings, thereby increasing the risk of injury. The findings in both our studies indicate that there is a relationship, albeit weak, between quadriceps strength and risk of hamstring injury.

In addition to peak strength measures, different strength ratios have received much attention in the literature, in particular the H:Q ratio.[12,39–41] Interestingly, we did not identify the H:Q ratio as a risk factor for hamstring injury, supported by similar findings in the meta-analysis by Freckleton and Pizzari. A number of candidate H:Q ratios, both conventional and dynamic entities of mixed isokinetic strength, had no association with subsequent injury.

Investigations of strength ratios have found contradictory results.[39,42–44] Croisier et al described cut-off values for H:Q ratios, together with existing pre-season strength imbalances, and found hamstring injury were 4 to 5 times more likely in players classified as having a strength imbalance compared to players without strength imbalances.[39] This study was conducted on multiple sites, with players from different leagues, and used two different isokinetic testing devices. Inclusion criteria were hamstring injuries which caused more than 30 days of lost playing time. In comparison, our study was able to overcome some of these methodological limitations, where the same experienced assessors used the same isokinetic device over the entire study period, with repeated measurements on the majority of players that participate in the premier football league in Qatar. Injuries were included if they met the criteria for hamstring injury, regardless of the time to return to play. Where the previous investigation only included 35 injuries, a combined number of 256 hamstring injuries were included in our two studies , improving the power of these investigations to identify true associations.[45]

There has been some debate over how these ratios are interpreted statistically.[46] A ratio is based on the assumption that the slope of the relationship between the logarithmically-transformed numerator and denominator is one. If this assumption is violated, then the ratio will scale inaccurately at the lower and higher ends of the range measured, leading to errors in interpretation. Also, when normally distributed variables are divided by each other, it is unlikely that the resulting ratio is normally distributed itself.[46]

The dynamic control ratio, which interprets the functional H:Q ratio at different angles during the movement, as well as the angle of crossover, were also not identified as risk factors for hamstring injury in our study. Although both these variables have retrospectively been associated with increased risk of hamstring injury, we cannot confirm this finding prospectively. Since no association was found between a number of different strength ratios and risk of hamstring injury, we question whether H:Q ratios in any form are as effective in risk factor identification as previously purported.

The Nordic hamstring exercise, performed as a screening test, was also included in our study as a potential risk factor for hamstring injury. Previously, when the Nordic hamstring exercise were dichotomized into a pass/fail result based on range of motion, it was not identified as a risk factor for injury.[47] With the subsequent development of a novel testing device, the eccentric force produced during the test was made measureable.[48] The novel test device has been used in preseason Nordic hamstring exercise strength assessments in football and Australian football, with these studies reporting players with lower eccentric strength during the Nordic hamstring exercise being more likely to suffer a hamstring injury.[22,49] In these studies, other potential effect modifiers such as previous injury, age and biceps femoris fascicle length were included in a multifactorial model, but did not markedly improve the association between limb strength imbalances with risk of hamstring injury.[50] However, considering that these studies identified increased risk of injury with eccentric strength measured during the Nordic hamstring exercise, it highlights the importance of validating these risk factors in different cohorts.[50] In our study population, this association was not identified.

We were only able to include 32 injuries for this analysis over a single season, and therefore our results have the same methodological limitations as many other investigations. Similar to the analysis of isokinetic strength measures, it would be necessary to continue analysing the Nordic hamstring exercise test over multiple seasons with repeated measures to better understand its relationship with risk of hamstring injury.

The use of the Nordic hamstring exercise in intervention programmes has been successful, and we do not contest that the Nordic hamstring exercise may be a useful tool to the clinician, despite observing no significant association with hamstring injury in our study. In fact, it has arguably been shown as the most effective intervention tool to reduce the incidence of hamstring injuries in football.[6,7,21] In this clinical context, performing the Nordic hamstring exercise as a screening test to determine a baseline for the implementation of a specific intervention programme might still be considered useful. However, our investigation did not identify eccentric hamstring strength measured during the Nordic hamstring exercise as a risk factor for hamstring injury.

Additionally, we investigated the relationship between standard isokinetic strength testing and the Nordic hamstring exercise. The correlation between these tests was poor, both as absolute values of torque and force, as well as the limb-to-limb strength difference. There are clear differences in the characteristics between these two tests. Isokinetic testing is performed with the hip in flexion, and the knee extending at a fixed velocity with the player in a seated position. The Nordic hamstring exercise is executed from an upright kneeling start position, the hip in extension, and the player self-determining the lowering of the body while performing the test. Furthermore, isokinetic strength is measured as torque and Nordic hamstring strength as force. Torque is the moment produced by force in relation to the axis of movement, defined as the rate of change in angular momentum. The load cells used in the Nordic hamstring test device measure the linear force produced during the motion. These differences might make it difficult to compare these tests results. One would, however, expect that both tests would equally identify eccentric strength differences between limbs, but the correlation for between-limb difference was poor. Another possible explanation for this finding is the bilateral deficit. The bilateral deficit has been described as the reduction in maximal voluntary strength induced by simultaneous bilateral exertion as compared with unilateral exertion.[51] During bilateral exercise, both force and electromyography are reduced, and lower symmetrical outcomes are observed. The Nordic hamstring test measures the imbalance during a bilateral test, in contrast to the isokinetic test, where unilateral strength is measured for each leg separately. It is suggested that this bilateral deficit might be the result of cortical influence, changing the motor output of the exercise. In bilateral exercises, maximal excitation from the motor cortex can be obtained without contralateral cortical suppression.[51] This phenomenon possibly explains why we found poor association between the bilateral Nordic hamstring exercise and the unilateral isokinetic strength tests.

Flexibility of the posterior thigh and ankle

Two studies have reported a significant association between hamstring flexibility and injury, measured with the supine straight leg raise test.[15,52] In contrast, studies that measured flexibility using the active and passive knee extension test did report an association.[21,43,47] The sit-and-reach test has also been used to determine hamstring flexibility, with no association between hamstring flexibility and risk of hamstring injury.[53] Measures other than the hamstring posterior thigh tests that determine flexibility have also been suggested as potential risk factors.[54,55] The dorsiflexion lunge test, measuring ankle range of motion, has been investigated previously.[54] A recent meta-analysis reported conflicting evidence for the ankle dorsiflexion lunge test.[12] In our investigation both passive knee extension and ankle dorsiflexion range of motion demonstrated a significant association with increased risk of hamstring injury. Interestingly, both these tests represent range of motion changes in the posterior kinetic chain.

The conceptual framework of a kinetic chain originates in the area of mechanical engineering, where rigid overlapping segments are connected via pin joints, whereby movement produced at one joint affects movement at another joint in the kinetic link.[56] This theory was extrapolated to include analysis of human movement, proposing that extremities be thought of as rigid overlapping segments in series, and the kinetic chain as a "combination of successively arranged joints constituting a complex motor unit."[57] In a complex motor unit such as the lumbo-pelvic-hip complex, consisting of the lumbo-pelvic and lower limb segments, the structures that interface the overlapping joints such as fascia, muscle, tendons and ligaments also contribute to the kinetic chain. Therefore, to achieve the desired motor output, the actions of these structures interacting with a number of articulations are likely to be appurtenant to neuromuscular control.[59] In a controlled open kinetic chain it is implied that all the articulations can produce the required conditions of defined and predictable motion.[58,59] The neuromuscular coordination of the posterior muscle chain (hamstrings, gluteus maximus, and lumbar erector spinae) has been proposed as a potential risk factor for hamstring injury.[60] Although empirical evidence to support the theory surrounding the function of the posterior kinetic chain is lacking, we might consider how knee extension and ankle dorsiflexion range of motion influence the overall flexibility of the posterior lower limb, and consequently, the conditions necessary for optimal neuromuscular function of the posterior kinetic chain.

The relationship between intrinsic neuromuscular function and risk of hamstring injury

It is difficult to encapsulate all the components necessary for optimal neuromuscular function in one single test, or even a combination of variables. Recent investigations into the lumbo-pelvic-hip complex suggest that the neuromuscular coordination in the posterior kinetic chain influences the risk of hamstring injury in male football players.[61] This suggests a protective effect if the global musculature is addressed in terms of neuromuscular function.[60,61] In our investigation of intrinsic neuromuscular function, neither rate of torque development nor the onset of muscle activity for any of the concentric or eccentric quadriceps and hamstring isokinetic modes of testing were associated with risk of hamstring injury. Our results suggest that previous findings of differences in rate of torque development and muscle activity[32] are most likely the consequence of the injury, and that both these variables may be altered post-injury. Previous findings suggest that insufficient capacity to generate force (altered rate of torque development) and delayed muscle activity during the early phase of the movement may represent a reduction in 'early neural drive', indicating altered neuromuscular function.[31,62] These differences post-injury might be expected to influence the stimulus needed to induce muscle hypertrophy and sarcomerogenesis, predominantly during eccentric contraction, needed for adequate rehabilitation.[31] It is important to acknowledge that our results, similar to this previous retrospective study, only represent one aspect of intrinsic neuromuscular function.

Fyfe et al has suggested a conceptual framework where neuromuscular inhibition persists after hamstring injury, therefore sabotaging the rehabilitation process, leading to several maladaptations, poor outcomes and elevated risk of re-injury.[63] General consensus regarding return to play criteria after hamstring injury do not include an assessment of neuromuscular function.[7,64] In fact, due to the difficulty in defining and assessing neuromuscular function, it was specifically excluded from one of the consensus statements.[65] In our study, we do not identify rate of torque development or the onset of muscle activity as risk factors for hamstring injury; however, previous studies demonstrate these measures of intrinsic neuromuscular function were altered post-injury.[32] Importantly, it raises two questions – are we addressing the neuromuscular function appropriately in our rehabilitation? And secondly, should the player that has suffered a hamstring injury continue to receive training focused on resolving the neuromuscular inhibition even after return to play?

The most popular preventative exercises used by elite football teams are aimed at addressing eccentric strength, and neuromuscular function through balance/proprioception and core workouts.[17] In addition, stretching has become a central part of any professional team's warm up routine.[3,8] The aim of these stretching programmes are to reduce the risk of injury by addressing flexibility. Flexibility is also reported as the most common screening test used by professional teams.[17] Since it is not possible to determine a suitable cut-off to identify high risk players in our study, it would be impossible to identify a specific subgroup of players to receive the intervention. Or indeed, if we do, we would be excluding a large proportion of players that get injured from receiving the intervention.[50] Our results provides further support for group-based interventions, since we cannot identify individuals or high risk subgroups within our population. However, the significant association, albeit weak, suggest a causal relationship between these factors and hamstring injury. A recent systematic review has shown that eccentric training can improve flexibility,[66] evidence that we might be able to affect one variable by addressing another.

The relationship of strength, flexibility and neuromuscular control with risk of hamstring injury as discussed here highlights the importance of a multifactorial model for hamstring injury prevention.[67]

Practical implications – translating statistical significance into clinical meaningfulness

A wealth of risk factor studies and systematic reviews have delivered contrasting findings. The inconsistency in the results are likely due to methodological shortcomings in many studies. In our studies, we were able to include an adequate sample size, with a large number of injuries. Although no formal sample size calculations were performed to determine whether the studies have adequate power, we were able to follow the methodological recommendations set out by Bahr and Holme.[45] The authors suggest that 30–40 injury cases would be needed to detect strong to moderate associations, while it is suggested that 200 injury cases are needed to find small to moderate associations. This is based on calculations for a Cox regression model, without adjusting for other factors, and considering the injury frequency, distribution, and that the uninjured players will on average be exposed to football (training and match play) during 90% of the season.[45] As is pointed out, it is difficult to determine what a significant clinical difference should be, since the relationship between a risk factor and the frequency of that injury type is usually uncertain. However, we aimed to identify not only strong but also potentially small to moderate associations, and were able to include over 400 subjects, and 70–190 injury cases. Previous cohort studies were only able to detect strong relationships. Due to small cohorts and/or proportion of injury cases, interpreting a negative finding might lead to type 2 error (overlooking a true effect).[45] In our studies, we overcome this limitation, and we are confident that the negative findings reported are true, and not the result of type 2 error.

Other methodological difficulties were overcome in our studies by performing a standardized testing protocol utilizing the same isokinetic testing system with highly experienced assessors in a multinational, multi-language clinical setting for professional athletes. The Aspetar Injury and Illness Surveillance Programme (AIISP)[68] also allowed for greater consistency and reliable collection of the injury data.

Regardless of the statistical significance in any of our findings, we observe small absolute differences between the injured and uninjured groups, together with small effect sizes reported for strength, flexibility and neuromuscular function. These findings indicate limited clinical value in using standard isokinetic strength testing and flexibility measures to identify at-risk players. Although our findings indicate that strength and flexibility are likely to be small components in the causative pathway of hamstring injury, these isolated risk factors are poor predictive factors for hamstring injury, confirmed by the large overlap seen on the distribution curves of injured and uninjured players (Figure 1).

To illustrate the clinical interpretation of our results, let us consider one of the findings identifying eccentric strength as a risk factor. The first study reported that lower eccentric hamstring peak torque (normalized to bodyweight) was significantly associated with an approximate 40% increased risk of injury. To put this finding into perspective, we must consider the base rate of the injury. The base rate refers to the incidence of hamstring injury in a football population, in other words, what are the odds of having a hamstring injury anyway? In this study population it is reported as 11%.[5] Now consider the eccentric hamstring strength test result, eccentric strengthening being one of the most commonly used prevention exercises.[17] An odds ratio of 1.37 applied to the base rate would increase the risk from 11.1% to 14.6% (Figure 2).

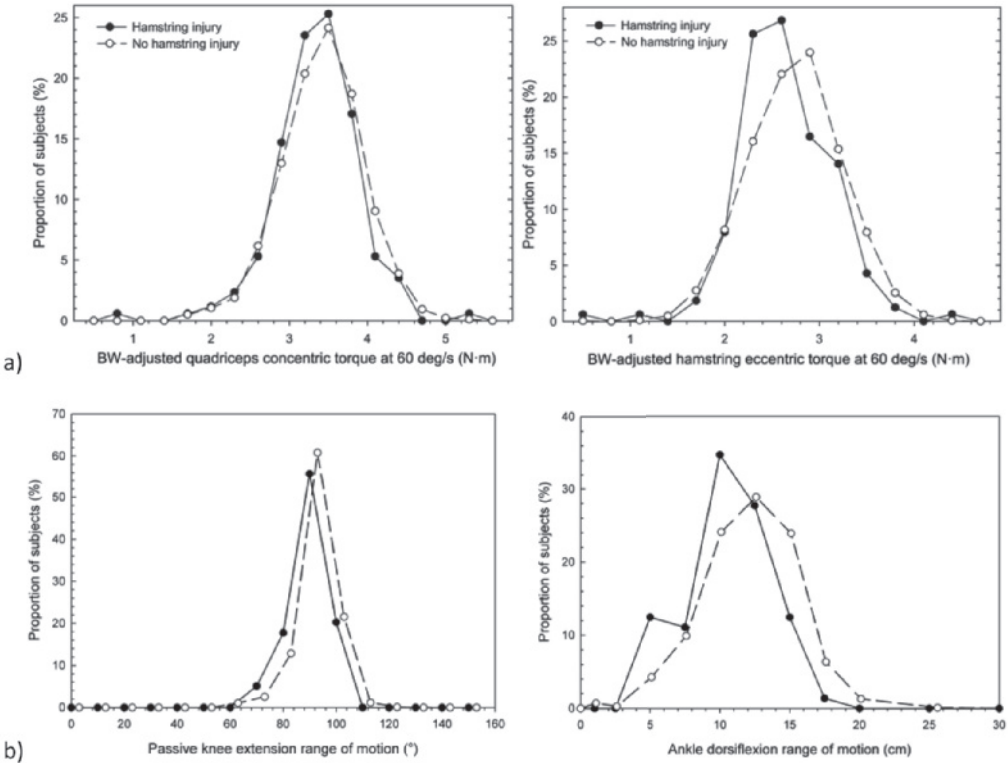

Figure 1 Distribution of injured (closed symbols) and uninjured players (open symbols) for significant variables a) strength and b)flexibility.

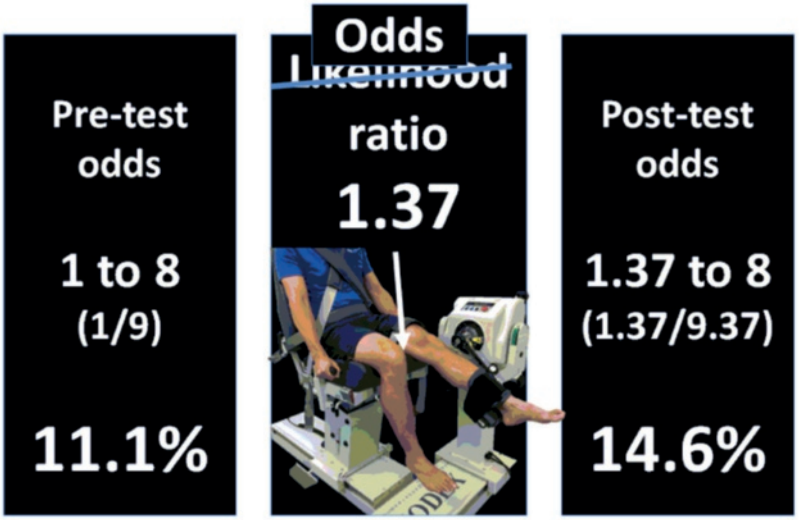

Figure 2 An illustration of how to apply a specific odds ratio to the base rate of an injury to better interpret the clinical value of the finding.

Although this change would need to be considered within the context of a specific player, it may be argued that this difference is clinically meaningless, even if statistically significant. It is highly unlikely that the change from 11.1% to 14.6% (still 85.4% likely to remain uninjured) will lead to a change in practice for the clinician.

A potential reason for the overemphasis of statistically significant differences is the way we have misinterpreted p-values in modern medicine, and specifically in sports medicine.[69] Although p-values are useful to determine probability in hypothesis testing, they are not valuable in assigning clinical meaning to a finding. And we quickly assign the "importance" of a particular finding based almost entirely on this one statistic. As Ziliak and McCloskey point out, statistical significance is not the same as clinical significance.[70] In isolation, the p-value finding is meaningless, and do not convey the importance of relationships. The meaning of the difference between groups will depend on the context for a particular problem, not the p-value alone.

To better understand if these significant risk factors hold any clinical value, we must consider the effect size and potential absolute difference observed in these strength variables. For eccentric hamstring strength, an effect size of less than 0.2 is reported, interpreted as very small to small. The absolute difference between the injured and uninjured players was less than 5 Nm torque (2%). With the large amount of variability for this isokinetic test observed between different seasons (15%), it is clear that the observed difference would fall within the normal variation we find for this measurement of strength. This limits our ability to make meaningful clinical deductions from these findings, in particular when assigning individual risk of injury to a player.

Furthermore, we might consider the contrast within our own results. In the first cohort, we reported lower concentric quadriceps strength as a significant risk factor for hamstring injury. In the second cohort we reported that greater concentric quadriceps strength at 300°/s was associated with hamstring injury when categorized into strong (two standard deviations above the mean) and weak (two standard deviations below the mean) groups; players with stronger quadriceps being twice as likely to suffer a hamstring injury. So in these studies, performed in two similar player populations with exactly the same methodology and design, greater and lesser quadriceps strength were both associated with risk of hamstring injury. Usually, when faced with such findings, we find plausible statistical or clinical arguments to justify the results. But perhaps we need to consider our decision making process, and a lack of acceptance of the uncertainty in these findings.[71] We fall victim to a common human decision making bias that Nobel laureate Daniel Kahneman describes as "what you see is all there is" (WYSIATI).[72] The basis of WYSIATI is that the availability heuristic influences decision making around frequency and probability.[73,74] We form knee jerk impressions and judgments from the information available to us, and ignore other facts that should be considered to make more holistic decisions. It is only when we account for the availability heuristic in light of our contradicting strength results that we can see what meaning these findings truly represent. Confounding factors such as age and previous injury were accounted for in both studies, yet these opposing results suggest that we have not accounted for how the different variables might influence, or even alter, the direct effect of another variable. Perhaps both greater and lesser quadriceps strength can be associated with risk of injury, depending on the mediating or moderating effect of other variables, and the interaction between them.

When screening tests are performed in the clinical setting, we interpret the information based on guidelines usually developed specific to the particular team or organization, and recommendations are made to the player or the team regarding specific findings. If an individual player acts on these recommendations, the results from such actions might very well mitigate the risk identified in the screening, and we would not be able to find the association with injury in a prospective follow-up of that player. However, we know that compliance with prevention exercises is low.[16] To date, no prospective trial has been performed to establish the effect of intervention on purely those individuals with identified risk factors from specific screening tests, and how that might influence their risk of injury.

Injury prediction vs. risk factor identification

In 2009, the International Olympic Committee (IOC) released a consensus statement regarding the use of periodic health evaluations (PHE), commonly referred to as "screening." It suggested PHE's to be set up as research projects, and called for future research to perform large-scale population-based studies to "evaluate the components of history and examination that can be used to identify athletes at risk, intervene, and change outcome."[75] In agreement with this recommendation, the Aspetar Sports Injury and Illness Prevention Programme (ASPREV) was initiated in November 2012 at the Aspetar Orthopaedic and Sports Medicine hospital in Doha, Qatar. As part of this programme, a comprehensive periodic health evaluation (PHE) was performed for every football player that participated in the Qatar Stars League, the highest level of football in Qatar. The PHE included cardiovascular, haematological, dental, medical history review, and an expanded musculoskeletal examination. Concurrently, this large prospective cohort study was conducted to investigate risk factors that may lead to hamstring injuries in professional football players.

The purpose of any screening strategy is the early detection of pathology or disease (usually in a symptom free population) to allow appropriate and early intervention which hopefully leads to prevention of the pathology, and reduces the morbidity and mortality.[50] In sports medicine, we have adopted this strategy from general medicine, aimed at addressing risk factors to prevent injury. But it seems the interpretation of risk identification has been "lost in translation" in sports medicine. The purpose of the PHE is indeed to identify risk factors present in individuals that may allow early targeted intervention, and prevent injury. However, the significant group findings (associations that might explain some component of the causative nature of these injuries) cannot be directly translated as individual risk (predictive power to ascertain which players might go on to have an injury or not). A clear differentiation between these two purposes is needed.

In a literature search conducted recently, of the 55 studies reporting “prediction” and “injury”, only 35% reported statistical modelling that reflect predictive analyses.[76] Association refers to studies that investigate whether a relationship exists between a variable (such as strength) and a particular outcome that might occur (such as hamstring injury). This association might then be explanatory, and provide some insight into the potentially causative nature of the outcome. Prediction refers to the ability to positively identify those athletes that will go on to sustain a particular outcome (hamstring injury) with a certain level of accuracy. Although 100% accuracy is unlikely, the expectation would be to provide a specific measurement or test with an acceptable level of accuracy able to identify at-risk athletes, and make specific recommendations based on the results of such a test.

The idea of risk as a continuous measure disguises the concept of risk as applied to the individual. The mean risk for a group indicates the proportion of individuals for whom sufficient causal risk factors are present (explanatory), where the actual risk for the individual is a matter of whether or not a sufficient risk factor will lead to injury (predictive).[77] The application of some intermediate value of risk to an individual is only a means of estimating the individual’s risk by the mean risk of many other presumably similar individuals. Risk of injury for the individual can therefore be viewed as a probability statement about the likelihood of a sufficient risk factor for injury existing within the appropriate time frame.

Is screening a waste of time?

The results of our risk factor analyses for hamstring injuries do not stand alone. Together with this project, co-investigations at the Aspetar Orthopaedic and Sports Medicine Hospital also aimed to determine whether PHEs are useful to identify risk factors for hip and groin injury, as well as the predictive value of functional movement screening (FMS).[78,79] Overall, none of these studies provided any screening test with high predictive value, and cannot identify players at high risk of injury successfully. The large variability we identified between seasons in tests results, together with similar distribution of injured and uninjured players emphasize the lack of clinical utility in the current tests used to screen for risk of injury.

However, significant group findings of certain variables associated with increased risk of injury were identified. These findings might assist in how we design our prevention programmes, specifically which factors to include in a multifactorial injury prevention model.

Although such primary prevention interventions are best delivered at a group level, targeted individual PHEs still has a role to play. Instead of trying to predict future injury, the PHE should focus on early identification of current health problems (sometimes called secondary prevention)[68] and assessing the status of ‘old’ injuries to prevent their recurrence (tertiary prevention).[80] Results of the PHE must then lead to some form of follow-up action for the individual player. Screening without action is simply data collection and that has no value for the player.[80] In addition, the PHE can be a valuable opportunity to perform baseline testing, review medication and supplement use, establish trust between the practitioner and the athlete and, in some cases, satisfy medico-legal requirements.[51,76] The information collected is ideally shared among the various members of the management team as permitted and appropriate. Management of the players is ideally executed by an integrated healthcare team in a shared decision making process.[81] The aim is to improve the health and performance of the player.

A complex and temporal problem

Prospective cohort studies are aimed at identifying certain risk factors associated with injury, thus "explaining" the injury by identifying its cause. Rothman attempts to elucidate the "gap between metaphysical notions of cause and basic epidemiologic parameters."[77] A cause is an inciting event – either in isolation or in conjunction with other events – that initiates or allows a sequence of events that results in an effect (i.e. hamstring injury). A cause which inevitably produces an effect is described as sufficient. Our findings suggest that both strength and flexibility are components in a larger sufficient cause of hamstring injury. However, as is the case with most causes of interest in healthcare, the cause of hamstring injury is made up of different components to be sufficient, although they are not sufficient in isolation.[77] And most often, by removing one of the components, the cause becomes insufficient to produce the event (injury). Therefore, identification of all the components needed to produce a sufficient cause for hamstring injury is unnecessary for injury prevention, as the intervention aimed at altering one component might reduce the combined effect of the other components, preventing the injury from occurring. We find evidence of this in our simple prevention programmes, able to dramatically reduce hamstring injuries, although focused on just one component of the causal model.

Complexity

In the studies presented in this thesis, the largest prospective risk factor study on hamstring injury performed to date, every effort was made to fulfil recommendations from previous work. This included a larger sample size and sufficient number of injuries, appropriate statistical approaches, comprehensive and reliable injury surveillance, standardized and reliable measurements, and consistency in data collection. Yet we still observe significant risk factors demonstrating small effects, large overlap between injured and uninjured players, contradictory results and poor stability of the variable between seasons. This indicates that future research might need to consider something else, beyond pure methodological considerations - an appreciation of complexity.

Complex systems are dynamic, open systems with inherent non-linearity and unpredictability that exhibit self-organization from a large number of interacting individual components to form an emergent behaviour (not derivable for the sum of the activity of these components alone).[71] Our traditional screening prevention models include the assumption that we are dealing with a static, non-dynamic closed system. As with all prospective risk factor studies, we also assume that a single time point measurement of strength is reflective of the strength of the player at the time of injury, which is increasingly unlikely the further the injury happens from the assessment. Our models, even multivariate models accounting for exposure, include predictors that are too refined and restrictive to translate to the "real world" setting.[82] We are lacking an appreciation for how these predictors might be altered or interact with each other in a dynamic system.

An example of complexity is found in beehives. Healthy beehives with many different elements (thousands of bees) produce highly functional, ordered patterns. They may consist of up to 70,000 bees; if you remove a few hundred, or even the queen bee, the system would merely adapt – other workers would take over the tasks of the missing bees, or the hive would breed a new queen.[83]

Similar to beehives, athletes also have a multitude of different agents (previous injury, age, technique, playing style, motivation, strength, neuromuscular control, emotional health) acting and interacting to form the emergence of injury. Our lack of appreciation in sports injuries for how this dynamic system with its many different agents interact and emerge is apparent. A deeper understanding of the injury phenomenon have been suggested in numerous models, yet transition into clinical research has not always followed such recommendations.

A complex systems approach has been suggested to better reflect the dynamic nature of sports injuries.[84] This approach would require investigations of interactions between different (risk) factors, and how these interactions might influence, or even alter each other to form different emergent patterns of injury. The interaction between different variables are evident in the "simple" task of riding a bicycle. Explaining how bicycles stay upright requires about 25 mathematical variables. But even after altering a key factor needed for balance and motion (such as the gyroscopic force of the wheel) that would technically make them unrideable, it remains stable and on track.[85] This is due to an understanding of the interaction of the various parts, as well as the complex action of the human riders to intuitively keep the bicycle stable and upright. These systems are robust and can easily adapt to change, but when the balance between order and disorder is disrupted, it fails. We might be able to understand these emergences better by applying appropriate predictive modelling, which accounts for how a specific variable might change through interaction and over time, allowing for a more real-world interpretation of how such a variable is associated with risk of injury.

Temporality

Clinically, it is likely that the strength of players will change in response to team training and individual strengthening regimens. Risk factors are time-based and we observe substantial temporal variability. In our study, as in all prospective risk factor studies, the risk factor identification was determined during a screening examination at baseline, and the players were followed for the subsequent season. Unfortunately, we do not monitor how the factors we measure change over time, and therefore our analyses are based on the assumption that our screening results are "frozen-in-time", and are representative of that factor at the time of injury. The investigation into the stability of these tests support our clinical intuition, demonstrating that the isokinetic strength measurements display substantial variability between two seasons. It provides motivation to move away from isolated time-point testing towards continuous monitoring of these risk factors, allowing the clinician to identify changes in these risk factors, and how these changes might be associated with risk of injury. The template for this type of monitoring has been provided in overuse injuries focused around injury burden rather than time loss due to injury,[86] yet the hypothesis of monitoring risk factors as an alternative to once-off screening has not been investigated. As injury risk is influenced by workload,[87] we might expect that strength and other factors would be affected. However, we have yet to establish a better understanding of the interactions between these factors, and how these factors may respond to fluctuations in applied load over time.

Uncertainty and contradiction are ingrained in complex systems, and some things will remain unknowable.[71] However, by moving away from a list of risk factors towards developing risk profiles similar to "fingerprinting", we might be able to better manage the emergence of sports injuries, and protect our athletes.

LIMITATIONS

The PHEs were conducted between May and September of each year. Although accounted for in the Cox regression model, we might consider how players may present differently at the beginning of the season compared to four months later.

Although every effort was made to ensure players understood the test procedure and instructions, it is possible that some players did not comprehend the instructions fully. The clinical setting does not allow a thorough familiarization process. Therefore, we acknowledge that the performance of these tests in a clinical setting may have influenced the results. However, this reflects a "real world" scenario. If teams were to implement these tests in their daily practice, it would be reproducible.

The substantial variability we observe between seasons might be explained by different underlying mechanisms, such as muscle architecture changes in response to training, workload, strength training during the season, familiarization with the test procedure, and/or player's improving their competitive level of play. Although many such changes would likely result in changes in the variables that were measured, we were unable to account for these different factors in our analyses.

Another important limitation, as with many prospective studies, is that exposure only considers time, and not the amount of high speed running or other measures of workload for individual players. In light of the strong relationships that have been established between hamstring injury risk and exposure to repeated high speed running,[88–90] it is important to acknowledge this limitation in our investigation.

Injury surveillance was carefully monitored during each season, and the majority of injuries included in this study were confirmed through imaging. However, we cannot discount that the clinical criteria used to confirm a hamstring injury may have involved other differential diagnoses.

We also acknowledge that sub-analysis of these injuries according to location and/or severity may have yielded different results. However, if we were to subgroup these injuries, we would severely hamper the power of the analysis. For regression analysis using 6 or more variables, an absolute minimum of 10 participants per predictor variable is required.[91] Tabachnick and Fidell demonstrated that 50 participants is needed per factor.[92] Guide samples sizes from this work suggest 50 as very poor, 100 as poor, 200 as fair, 300 as good, 500 as very good, and 1000 as excellent. Even though our study represents the largest prospective cohort study to date, small injury subgroups would have been underpowered.

The analysis of previous injury only accounted for hamstring injury, made possible through comprehensive review of the medical records for each player, and subsequent improvement in our surveillance programmes. However, we do not control for any other previous injury in any of our investigations, nor do we exclude players that suffered injuries other than hamstring injury during the study period. Whether other previous injuries would represent a significant association with risk of injury is not known in our study. The need for better understanding of how injury status might lead to subsequent injuries have been highlighted through two different subsequent injury models.[93,94] Furthermore, players with previous ACL-reconstruction demonstrate a higher risk of hamstring injury.[95,96] Considering the low incidence of ACL injuries in our cohort, it is unlikely that this would have had a substantial influence. However, other lower limb injury may have resulted in changes of the variables included in the analyses, and influenced their relationship with risk of hamstring injury.

WHAT THESE FINDINGS ADD TO OUR CLINICAL PRACTICE

To assist the clinician with translating the findings of this study into clinical practice, we have summarized the important findings of this thesis in table 1. The three key points are:

1. Strength and Flexibility are weak risk factors for hamstring injuries, and continue to form a small but important part of the causal pathway. Multi-faceted prevention programmes should include both these components to be successful in the prevention of hamstring injuries.
2. Rate of torque development and the onset of muscle activity is not identified as risk factors for hamstring injury. In contrast, previous findings demonstrate these components of intrinsic neuromuscular function were altered post-injury. In light of both our findings and previous results, clinicians should focus on returning the player to full function during the rehabilitation of hamstring injuries, which may include specific targeted intervention even after return to play.
3. Our common strength and flexibility tests have poor predictive value, and do not possess the characteristics needed to successfully identify individual players at greater risk of hamstring injury. This is evident in the large amount of variability between seasons, and poor sensitivity and specificity demonstrated for these measurements. The wide overlap in distribution of strength between the injured and uninjured players demonstrate the difficulty in identifying a

subgroup of at-risk players that might benefit from targeted intervention. It is recommended that prevention programs be implemented at a group level.

Table 1 Translation of key research findings from this thesis into clinical practice.

What we found	How it might change what we do
Previous injury is not a risk factor for hamstring injury	If we perform criteria-based progressive rehabilitation programmes, we might decrease the risk of re-injury.
Isokinetic strength and flexibility tests have poor predictive value	Association is not prediction, and we cannot identify appropriate cut-off values to determine which players are at increased risk of injury.
A substantial amount of interseason variability is found for strength measures	Isolated once-off screening holds little clinical value. Small changes don't tell us much. Consider the minimal detectable difference when interpreting results.
Rate of torque development and muscle activity onset are not associated with increased risk of hamstring injury	This would suggest that previous findings indicating differences in these factors after injury may reflect neuromuscular inhibition. Rehabilitation efforts should aim at restoring full function, and should continue after the player has returned to play.
Eccentric strength measured during the Nordic hamstring exercise and isokinetic dynamometry do not correlate	You cannot trade one test for another. The amount of imbalance found during isokinetic testing might be different than that found during the Nordic hamstring exercise, and should be interpreted with care. The measurement tool should fit the intervention used.
In large cohort studies, we identify small effect sizes and absolute differences for strength, flexibility, and rate of torque development.	We overestimate the clinical utility of these findings. Injury prevention should be implemented at a group level.

ADVICE FOR FUTURE RESEARCH

We continue to utilize performance tests when we assess risk of injury. Perhaps we need to consider what elements of the inciting event we could recreate in a safe way to test risk patterns and behaviour. This would include factors such as fatigue, dual cognitive tasks, and sport specific movements. Unfortunately, many sports medicine research groups continue to work in isolation and aim to answer similar research questions; answers that are ultimately published as separate small studies. The clinical application of the results and the inconsistencies that appear among studies make it difficult for clinicians to determine the appropriate course of evidence based practice. A concerted effort is needed to establish a number of (large) well-planned sequential investigations. This calls for a shared collaboration between institutions and research groups to perform collective data analyses and combine the results of individual projects. Ideally, information regarding the mechanism, clinical presentation and treatment of the injury, as well as data on outcome measures such as return to play or recurrence rate are shared. This integration of information might lead to bigger datasets and enable more accurate modelling that may advance our prevention and rehabilitation efforts.[97]

There is strength in numbers. Similar projects have led to remarkable achievements in general medicine. Data collection on malaria mortality has been challenging and are relatively sparse in sub-Saharan Africa. An ensemble of different microsimulation data models (leveraging data collation and the relationships between different metrics) was developed and used together with high resolution population maps. This approach led to greater understanding of the clinical incidence and how to direct prevention efforts.[98] We could achieve similar results in sports medicine.

It will require collaboration between sporting organizations, their affiliated teams, researchers and practitioners to allow for the appropriate scientific and clinical veracity needed to make meaningful conclusions. It is time to leverage our collective strength and share our resources. Only the implementation of such joint data analytics will truly advance the management and prevention of hamstring injury, and indeed all sports injuries.

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Chapter 7

Summary

Nederlandstalige samevatting
(summary in Dutch)

Summary

Hamstring injury is one of the most common sports injuries, and the most common non-contact injury in professional football. Although we have many studies that have investigated risk factors for hamstring injuries, these studies have reported contradicting results, and there is poor consensus in the literature regarding the relationship between these risk factors and hamstring injury. The burden of hamstring injury in professional football, as well the financial cost associated with these injuries, are substantial. This thesis aimed to contribute to better understanding the risk of hamstring injury by investigating both traditional and novel risk factors in a methodologically sound, well designed prospective cohort including a large number of injuries.

In **Chapter1**, an introduction of the work of this thesis is given, consisting of the epidemiology, functional anatomy, mechanism of injury, important methodological considerations, and risk factors associated with risk of hamstring injury in professional football.

In **Chapter 2**, we investigated isokinetic strength as a risk factor for hamstring injury, consisting of traditional isokinetic strength variables that is reported in *Part one*, and novel measures of strength characteristics and strength ratios in *Part two*. The first investigation included 614 players and 190 injuries in the investigation, found decreased concentric quadriceps and eccentric hamstring strength to be associated with an increased risk of hamstring injury. The second part also included the new dynamic control profile and the angle of crossover, but found only the category of players with greater quadriceps strength twice as likely to suffer a hamstring injury. This investigation also included eccentric strength while performing the Nordic hamstring exercise as measured by a novel testing device, which was not identified as a risk factor for injury. Interestingly, an in-depth analysis of previous injury never conducted before did not identify previous injury as a risk factor for hamstring injury, contrary to previous findings. Our results indicate that there is a small association between strength and risk of hamstring injury. The findings to not support strength ratios, such as the popular H:Q ratio, both as previously reported functional ratios and a new dynamic interpretation, as a risk factor for injury.

Isokinetic strength testing continues to be a popular measurement tool in professional football. We investigated the interseason variability of these tests in **Chapter3**. The results demonstrate that a large amount of variability exists between seasons, and that this variability must be taken into account when we interpret follow-up strength test results. When comparing these isokinetic test results, the change might reflect the normal variation we observe for these measurements, which is not impacted by injury.

Furthermore, we found that the correlation between isokinetic test results and the novel device measuring eccentric Nordic hamstring exercise strength is poor. It seems the Nordic hamstring device and isokinetic dynamometry are measuring different aspects of eccentric strength, explained by the characteristics unique to the different types of strength testing. The between limb strength imbalance is also not correlated, and clinicians must decide carefully on the type of testing used, and interpret these results according to the test performed.

In **Chapter 4**, we explore flexibility as a risk factor for injury. Despite inconclusive evidence from previous studies, stretching programmes to address flexibility remain popular in professional football teams. Our results indicate that limited range of motion for both the passive knee extension and ankle dorsiflexion lunge tests are risk factors associated with hamstring injury. Both these measures represent different components of the posterior kinetic chain, and it indicates the importance of the overall flexibility of the lower limb. Practitioners might continue to consider the addition of stretching to improve flexibility as part of a multifactorial injury prevention programme.

Intrinsic neuromuscular function as a risk factor for hamstring injury is assessed in **Chapter 5**. Previous retrospective studies identified delays in rate of torque development and muscle activity during the early part of eccentric movement that persist after injury. This might be linked to neuromuscular inhibition that is not adequately addressed during rehabilitation. Our study does not identify either rate of torque development or the the timing of muscle activity onset during the early phase of both concentric and eccentric isokinetic movement as a risk factor for hamstring injury. This would suggest that these differences in intrinsic neuromuscular function are the consequence rather than the cause of hamstring injury.

In **Chapter 6** we reflect on the main findings of this thesis, and the clinical meaningfulness of the observed results is discussed. Although our findings indicate that strength and flexibility have poor predictive value, they form a small but important part of the causative pathway. Multifactorial prevention programmes should include both these components to be successful in the prevention of hamstring injuries.

This investigation was conducted in one of the largest sample sizes of football players to date, with a large number of injuries included, yet we do not overcome the restrictions in our current methodological approach. To better understand risk of injury, and improve our prevention efforts, we must focus on developing more complex models, able to measure and account for the interaction between different factors, and how they might mediate or moderate the eventual outcome of hamstring injury. This will require collaborations across different fields of expertise, such as mathematics and data analytics, as well as a united effort between research and clinical practice. It is time to leverage our collective strength and shared resources to advance the management of hamstring injuries.

Nederlandstalige samenvatting

Hamstring letsels zijn het meest voorkomende sportletsel en het meest voorkomende niet-contact letsel in voetbal. Ondanks het bestaan van verschillende studies die risicofactoren voor hamstrings onderzoeken, zijn er tegenstrijdige resultaten tussen deze studies en is er geen consensus in de literatuur omtrent de verhouding tussen risicofactoren en hamstrings letsels. Hamstring letsels brengen een grote impact met zich mee binnen een club en dit zowel sportief als financieel. Het doel van dit doctoraat is om een beter inzicht te verkrijgen in het oplopen van hamstring letsels bij voetbalspelers en dit door zowel traditionele als nieuwe risicofactoren te onderzoeken in een goed opgezet prospectief onderzoek met een groot aantal hamstringletsels.

In **hoofdstuk 1** wordt in een inleiding het onderwerp van dit doctoraat gesitueerd. Het omvat epidemiology, functionele anatomie, letselmechanismen, belangrijke methodologische reflecties, en risicofactoren geassocieerd met hamstring blessures in het professionele voetbal.

In **hoofdstuk 2** werd isokinetische kracht als risicofactor van hamstring blessures onderzocht, met verscheidene traditionele isokinetische variabelen (deel 1), en nieuwe isokinetische variabelen (deel 2). In een eerste onderzoek werden 614 voetbalspelers en 190 hamstring blessures opgenomen. Deze studie stelde een associatie vast tussen een verminderde concentrisch Quadricepskracht en eccentrische hamstringskracht en hamstring letsels. In het tweede deel werden de nieuwe variabele ”angle of crossover” en dynamische controle onderzocht. Hier kon enkel bij de spelers met een verhoogde quadricepskracht een tweemaal verhoogde kans op hamstring blessures worden vastgesteld. In dit onderzoek werd de eccentrische hamstringkracht opgemeten tijdens de Nordic hamstring test, opgemeten via het recent ontwikkelde Nordic Board toestel. Opvallend was dat een voorgeschiedenis van een hamstring letsel in dit doctoraat niet als risicofactor voor een nieuw hamstringletsel werd geïdentificeerd. Onze resultaten tonen tevens een zwakke associatie aan tussen kracht en het ontstaan van hamstring letsels. Onze bevindingen konden de populaire H/Q ratio (zowel de frequent gerapporteerde traditionele H/Q ratio als de nieuwe dynamische interpretatie) niet als risicofactor identificeren voor een hamstring letsel.

Isokinetisch testen blijft zeer populair in professionele voetbalclubs. In dit werk onderzochten we de inter-seizoens variabiliteit van deze isokinetische tests in **hoofdstuk 3**. De resultaten tonen een zeer grote variabiliteit aan tussen de verschillende seizoenen, dewelke niet beïnvloed wordt door een kwetsuur. Deze variabiliteit dient zeker in rekening te worden gebracht bij de interpretatie van de isokinetische tests. Zo kan bij follow-up onderzoek het verschil tussen de resultaten mogelijks grotendeels verklaard worden door deze inter-seizoens variabiliteit.

Vervolgens konden we slechts een lage correlatie vaststellen tussen de isokinetische test resultaten en de resultaten bekomen via het Nordic hamstrings board toestel. Dit wijst erop dat beide toestellen een ander aspect van spierkracht meten. Ook het bilaterale krachtsverschil is tussen beide toestellen erg verschillend. Clinici moeten daarom goed overwegen wat getest moet worden, welk toestel hier best voor gebruikt wordt, en tenslotte de resultaten op een correcte manier interpreteren.

In **hoofdstuk 4** wordt lenigheid als risicofactor voor hamstring letsels onderzocht. Ondanks tegenstrijdige onderzoeksresultaten in de literatuur m.b.t. het belang van lenigheid in het oplopen van een hamstring letsel, is het gebruik van stretching wijd verspreid binnen het professionele voetbal. Onze resultaten tonen aan dat een verminderde lenigheid voor zowel de “passive knee extension test” als voor de enkel dorsiflexie test een verhoogde kans op een hamstring blessure betekent. Beide tests vertegenwoordigen twee verschillende componenten van de posterieure kinetische keten, en dit toont het belang aan van een goede lenigheid van het onderste lidmaat. Deze onderzoeksresultaten onderschrijven het belang van stretching als onderdeel van een multifactorieel preventieprogramma bij voetballers.

In **hoofdstuk 5** wordt de neuromusculaire functie onderzocht als risicofactor. Voorgaande retrospectieve studies observeerden een verlate “rate of torque development” en spieractiviteit in de proximale baan tijdens eccentrische activiteit van de hamstrings na een hamstring blessure. Dit wordt mogelijks veroorzaakt door een neuromusculaire inhibitie die niet voldoende behandeld werd tijdens de revalidatie. Onze onderzoeksresultaten tonen noch een afwijking in de rate of torque development, noch in de “onset” van spieractiviteit aan in de proximale baan tijdens eccentrische of concentrische activiteit van de hamstrings als risicofactor voor een hamstring kwetsuur. Dit suggereert dat deze veranderingen in intrinsieke neuromusculaire functie eerder een gevolg van een hamstring letsel zijn, dan wel de oorzaak ervan.

In **hoofdstuk 6** wordt gereflecteerd over de belangrijkste bevindingen van dit doctoraat en de klinische gevolgen ervan. Ondanks de geobserveerde kleine associatie tussen kracht en lenigheid en het ontstaan van hamstring blessures, vormen deze beide toch een mineur, maar belangrijk deel van het onstaansmechanisme van hamstring kwetsuren. Multifactoriële preventie programma’s dienen deze beide componenten dus te bevatten.

Dit onderzoek werd uitgevoerd in een van de grootste cohortes van voetbalspelers tot op heden, met een groot aantal hamstring blessures. Ondanks dit gegeven blijven er belangrijke restricties in dit soort onderzoek. Om een belangrijke stap voorwaarts te zetten m.b.t. het inzicht en preventie van sportblessures dienen we over te schakelen naar het gebruik van meer complexe modellen. Deze modellen bieden het grote voordeel dat zij de mogelijkheid hebben om de interactie tussen de verschillende factoren in rekening te brengen. Het gebruik van deze complexe modellen zal samenwerking over de verschillende disciplines noodzakelijk maken, zoals de toepassing van wiskundige predictieve modellen, maar ook de samenwerking tussen onderzoekers en clinici.

Appendices

Acknowledgements

Curriculum Vitae

PhD Portfolio Summary

List of Publications

Acknowledgements

I am deeply grateful to many individuals and institutions that have made my journey possible, and contributed to its success.

Firstly, my deepest appreciation to the Aspetar Orthopaedic and Sports Medicine hospital in Doha, Qatar, for supporting clinical research, and in particular, the Rehabilitation department. This project would also not be possible without the support from our colleagues in the Screening department, and the many clinicians in the National sports medicine programme. Indeed, I am grateful to all my colleagues at Aspetar, both past and present, for their support and many shared moments of reflection that helped to sustain my efforts, and make this project a success.

My promotor, Professor Dr. Erik Witvrouw, who stands central to the realization of this PhD. Erik, your first advice to me was “Kiezen is verliezen.” And although there was perhaps a fair helping of good fortune, I can only say thank you for the choice that allowed us to work together over the past five years. Your unique approach is evident in how you conduct research, but also life in general. I am eternally grateful for all the wonderful memories shared in Qatar, and I hope that this special collaboration will continue for many years to come.

A special thank you also to my co-promotor, Professor Dr. Roald Bahr. Your attention to detail, high standards, and inexorable quest for excellence is contagious, and have fostered in me the desire to get it right, and get it done. The mentorship, guidance, and thoughtful tempering of my eager-young-investigator ambition have been invaluable to my development as a researcher.

To the members of my PhD committee, Professor Dr. Evert Verhagen, and Professor Dr. Damien van Tiggelen. I appreciate your patience and understanding, and always delivering such valuable input and guidance whenever it was required. Thank you.

I am thankful to the members of my examination board, Professor Dr. Dirk Cambier, Professor Dr. Jan Victor, Dr. Ruth Verrelst and Dr. Joke Schuermans from the faculty at Ghent University, as well as Dr. Hans Tol from Amsterdam Medical Centre and Dr. David Opar from the Australian Catholic University in Melbourne. The attentive, critical appraisal of my thesis have created much interesting debate and raised some important questions, and the work is better for it.

To Arnhild Bakken and Andrea Mosler, my partners in screening, thank you. I am indebted to you for the hard work in making such large contributions to this project while completing your own, and the many long days and conversations to ensure these projects are performed to the best of our abilities. I humbly submit that we succeeded.

I am grateful to my incredible family for their continuous love and support, even when we are far apart. What a privilege to have you all in my life. And the many friends, both old and new, with whom we have made such beautiful memories during this journey, thank you. Lastly, to my wife Eulogy, for her enduring care and encouragement. I am grateful for every day we get to share this incredible thing called life.

Curriculum Vitae

Nicol van Dyk | Physiotherapist and Clinical Researcher
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Professional Profile

Sports physiotherapist with ten years' experience working in elite team and athlete environments. Clinical researcher with a special interest in injury prevention, and great appreciation for integrated healthcare, evidence based medicine and pain management. Enthusiastic about advances in technology and the role of social media in disseminating scientific evidence and research knowledge to the broader community.

Career Summary

2013 – present Aspetar Orthpaedic and Sports Medicine Hospital, Doha Qatar
Physiotherapist

- Sports physiotherapist in Rehabilitation department, involved with care of elite and amateur athletes, as well as general musculoskeletal injuries
- Post-graduate researcher investigating risk factors for hamstring injuries in professional football players
- Musculoskeletal screening coordinator during annual periodic health evaluation of football players

2010–2012 Sport Science Institute of South Africa, Cape Town, South Africa
Physiotherapist

- Clinical physiotherapist involved in post-operative rehabilitation and elite athlete care
- Associate at the Sport Science Physiotherapy Centre
- Chief Physiotherapist at the Hamilton Rugby Club in Cape Town, South Africa
- Physiotherapist to Disney-on-Ice during performances in Cape Town
- Assistant physiotherapist to Argentina during opening match of Rugby Championship
- Member of medical team to the Western Cape regional team competing at the South African youth games in Polekwane, South Africa

2007–2009 Private Practice Tania Prinsloo Physiotherapy, Windhoek/Grootfontein, Namibia Physiotherapist

- Clinical physiotherapist in outpatient orthopaedic and musculoskeletal physiotherapy practice
- Physiotherapist to the Namibian National Cricket Team

2003–2006 Professional activities while completing BSc Physiotherapy degree

- Physiotherapist to various rugby clubs competing in the Western Province Super League Victorians Rugby team (1st division); Belhar Rugby Club (3rd division)
- Member of the Cape Epic Mountain Bike Race Recovery team
- Physiotherapist to Giants gymnastics club in Cape Town
- Tournament Physiotherapist at the SARFU University Rugby Competition held at Stellenbosch University(student with supervision), and at the Craven Week U/18 Rugby Festival held in Wellington (with referral supervision)

Education and qualifications

- BSc in Physiotherapy, Stellenbosch University, 2005
- MSc in Physiotherapy(Orthopaedic and Manipulative therapy), Stellenbosch University, 2010
- PhD in Health Sciences, Ghent University, 2018

Courses and Workshops attended

2003–2006

- Advanced Strapping Workshop - *A Hughes*
- Soft Tissue Disorders - *I Diener*
- Dry Needling(Module 1 & 2) – *S Stavrou*
- Cervical Manipulation - *D Reid*
- Bone and Joint Decade 2010 Symposium - Durban

2007–2012

- Sport Injuries and Management - *C Smith*
- Western Cape OMT Group Symposium, Cape Town - Lumbar and Pelvic Manipulation - *D Reid*
- Build the Complete Athlete - *R Sutton*
- 4th Clinical Sports Medicine Conference 2010
- Shoulder Workshop with *J Gray*
- Multi-directional Shoulder Instability - *M Magerey*
- Joint Approaches Course - *I Diener*
- Explain Pain- *L Moseley*

2013–2017

- McConnell Concept - *A Albasini*
- Lower Quarter Neurodynamics - *M Schacklock*
- Shoulder Biomechanics & Rehab - A Cools *B Kibler*
- Muscle Chain Approach - *Erik van Tendeloo*
- Kinetic control lower limb - *Koen Schoenmeesters*
- Muscle strengthening - *B Mackie & J Brosseau*
- Shoulder tendinopathyb - *J Lewi*s
- Strength Training - *K Chamari*
- Comfort&Safety in management cervical spine - *D Reid*
- Ankle Course - *C Bleakley*
- Treatment of Cartilage injuries in the knee - *B Wondrasch*
- Statistics in Sports Medicine - *A Farooq*
- Assessment/Treatment of Ligament injuries of the knee - *L Snyder-Mackler*
- Shoulder management course- *J Lewis*
- Interprofessional Sport & Exercise Medicine Workshops
- 1st AFC Team Physiotherapist Course - Aspetar
- Aspetar Knee Specialization Course - *Erik Witvrouw*
- Clinical Reasoning - *Phil Glasgow*

Professional Memberships and positions

- Accredited member of the South African Sports Medicine Association (SASMA)
- Member of the South African Society of Physiotherapy (SASP)
- Member of the World Congress of Physical Therapy (WCPT)
- Associate editor of the British Journal of Sports Medicine (BJSM)

PhD Portfolio Summary

Phd Training

(Inter)national conferences - attendance

IOC World Conference Prevention of Injury and Illness in Sport - *Monaco*	2014
Training and competing in the heat - *Doha, Qatar*	2014
1st World Conference on Groin Pain in athletes - *Doha, Qatar*	2014
Conference of New Sports Medicine Concepts in Handball - *Doha, Qatar*	2015
ISOKINETIC Football Medicine Strategies for Player Care - *London, UK*	2015
Sports Medicine Australia Conference - *Goldcoast, Australia*	2015
5th AFC Medical Conference - *New Dehli, India*	2015
ISAKOS FIFA Aspetar Challenges in Football Injuries - *Doha, Qatar*	2016
ISOKINETIC Football Medicine Strategies Return to play - *London, UK*	2016
1st GCC Aspetar Sports Medicine Conference - *Doha, Qatar*	2016
Aspetar-ACSM Symposium - New Developments in Sports Medicine - *Doha, Qatar*	2016
34th FIMS World Congress of Sports Medicine - *Ljubljana, Slovenia*	2016
IOC World Conference Prevention of Injury and Illness in Sport, *Monaco*	2017
Salzburger-Sport-Physio-Symposium, *Salzburg, Austria*	2017
World Congress of Physical Therapy - *Cape Town, South Africa*	2017
2nd World Conference of Sports Physical Therapy, *Belfast, Northern Ireland*	2017

(Inter)national conferences - presentations

Rehabilitation of hamstring injuries 2015
Conference of New Sports Medicine Concepts in Handball - *Doha, Qatar*
(invited workshop presenter)

Muscle strength imbalances and hamstring strain injuries – are we moving forward? 2015
ISOKINETIC Football medicine strategies for player care - *London, UK*
Abstract - Oral presentation

Symposium Hamstring strain injury - structural and functional considerations for prevention, rehabilitation, and return to play 2015
Workshop Criteria based rehabilitation of hamstring injuries
Sports Medicine Australia Conference - *Goldcoast, Australia*
Invited speaker and workshop presenter

Pre-Conference Course Sports Physiotherapy 2015
The role of strengthening in prevention and treatment of hamstring strain injuries
5th AFC Medical Conference - *New Dehli, India*
Invited speaker and workshop presenter

Predictive factors for hamstring injuries 2016
ISAKOS FIFA Aspetar Challenges in Football Injuries - *Doha, Qatar*
Invited speaker

Substantial interseason variability in isokinetic strength in professional football 2016
ISOKINETIC Football Medicine Strategies Return to play - *London, UK*
Abstract - Oral presentation

Hamstring injury - PRP or just load it? 2016
Aspetar-ACSM Symposium - New Developments in Sports Medicine - *Doha, Qatar*
Invited speaker

What are the risk factors for hamstring injuries and can we prevent them 2016
34th FIMS World Congress of Sports Medicine - *Ljubljana, Slovenia*
Invited workshop presenter

Symposium Screening for muscle strength - the Aspetar experience 2017
Workshop Risky business - can screening help to make quality return to play decisions
Workshop To screen or not to screen - Musculoskeletal screening tests that make sense
IOC World Conference Prevention of Injury and Illness in Sport, *Monaco*
Invited speaker

Hamstring muscle injury risk factors and prevention 2017
Return to sport after hamstring injury in soccer (football)
Hamstring injury - criteria based rehabilitation
Salzburger-Sport-Physio-Symposium, *Salzburg, Austria*
Invited speaker and workshop presenter

Optimal loading for muscle 2017
2nd World Conference of Sports Physical Therapy, Optimal Load in Sport, *Belfast N. Ireland*
Invited speaker

Teaching

Neuromuscular control in hamstring strain injuries - the chicken or the egg? 2015
Aspetar Rehabilitation department eduction programme lecture

Nordbord - Nordic hamstring device 2015
Aspetar Rehabilitation department eduction programme lecture

Risk factors, criteria based rehabilitation and return to play for hamstring injury 2016
Online workshop with Australian Catholic University, online

Hamstring strength, training 'sweet spot' and shared decision making #researchinreallife 2016
Aspetar Tuesday morning scientific lecture

Pain management in athletes 2016
Aspetar/ACSM Interprofessional Sport and Exercise Medicine Education workshop, Doha, Qatar

Hamstring muscle injuries 2016
IOC Diploma in Sports Physical Therapies, online

Muscle Injuries 2017
Aspetar Rehabilitation department Education Programme, Doha, Qatar
Rotational group sessions

Hamstring workshop, Nimi, Oslo, Norway 2017
Full day workshop

Risky business - preventing hamstring injuries in elite football 2017
Visiting Professional - Bournemouth FC, Bournemouth, UK

Hamstring muscle injuries 2017
Donegal Physiotherapy and Performance centre, Letterkenny, Ireland
Evening workshop

Other

Blogs

BJSM Blog: A sacrum too far - Tiger Woods 2015

BJSM Blog: Criteria based rehabilitation protocol - hamstrings 2015

Podcast

Eccentric hamstring exercises - they work in practice but not in theory?
BJSM host with guest David Opar 2015

What makes a happy hip? Understanding FAI, arthroscopy and treatment outcomes
BJSM host with guest Joanna Kemp 2015

Exercise interventions to prevent sports injuries - what you need to know
BJSM host with guests Lars Bo Andersen and Jeppe Bo Lauersen 2015

Criteria based return to play. Psychological readiness. How? Whose call?
BJSM host with guest Clare Ardern 2016

Which 3 on-field football scenarios precede ACL rupture? Dr. Markus Walden has video proof
BJSM host with guest Markus Waldén 2016

What are the odds? Understanding risk and uncertainty
BJSM host with guest Rod Whiteley 2017

Stop swimming upstream - a new model for swimmer's shoulder
BJSM host with guests Craig Boetcher and Andrew Delbridge 2017

Additional activities

Hamstrings: Recovery, rehabilitation, reasoning
Clinical Edge Online conference presenter 2016

Aspetar hamstring rehabilitation protocol (freely available online)
Videos and brochure with developed in Aspetar Rehabilitation department 2017
(Rod Whiteley, Arnlaug Wangensteen, Philipp Jacobsen, Patrice Muxart,
Marketing department) Aspetar

There are many good reasons to screen your athletes, but predicting future injury is not one of them. van Dyk, N, Bakken A, Targett S, Bahr, R.
Aspetar Sports Medicine Journal, Vol 6 Targeted Topic 12, 2017 2017

List of Publications

Whiteley R, **van Dyk N**, Wangensteen A. and Hansen C. Clinical implications from daily physiotherapy examination of 131 acute hamstring injuries and their association with running speed and rehabilitation progression. *Br J Sports Med* 2017; Published Online First: 30 October 2016. doi: 10.1136/bjsports-2017-097616

van Dyk N, Bahr R, Burnett AF, Whiteley R, Bakken A, Mosler A, Farooq A, and Witvrouw E. A comprehensive strength testing protocol offers no clinical value in predicting risk of hamstring injury: a prospective cohort study of 413 professional football players. *Br J Sports Med* 2017;pp. bjsports-2017.

van Dyk, N. and Clarsen, B. Prevention forecast: cloudy with a chance of injury. *Br J Sports Med* 2017; 51:1646-1647.

van Dyk, N., van der Made, A.D., Timmins, R.G., Opar, D.A. and Tol, J.L. There is strength in numbers for muscle injuries: it is time to establish an international collaborative registry. *Br J Sports Med* 2017; Published Online First: 05 May 2017. doi: 10.1136/bjsports-2016-097318

van Dyk N, Wangensteen A. and Whiteley R. Zurück auf den Rasen. *Sportphysio*, 2017; *5*(01), pp.22-30.

van Dyk N, Bahr R, Whiteley R, Tol JL, Kumar BD, Hamilton B, Farooq A, and Witvrouw E. Hamstring and quadriceps isokinetic strength deficits are weak risk factors for hamstring strain injuries: a 4-year cohort study. *Am J Sports Med*, 2017; *44*(7), pp.1789-1795.

Dijkstra HP, **van Dyk N**, and Schumacher YO. Can I tell you something? I'm doping…….." *Br J Sports Med* 2016; 50: 510-511.

Witvrouw E, **van Dyk N**, and Whiteley R. Zerrungen der ischiokruralen Muskulatur: Ätiologie und Konsequenzen für die Prävention. *Sportphysio*, 2014; *2*(02), pp.69-75.