UNIVERSITY OF COPENHAGEN
FACULTY OF HEALTH AND MEDICAL SCIENCES

SPORTS ORTHOPEDIC RESEARCH CENTER – COPENHAGEN (SORC-C)
ARTHROSCOPIC CENTER, DEPARTMENT OF ORTHOPEDIC SURGERY,
COPENHAGEN UNIVERSITY HOSPITAL, AMAGER-HVIDOVRE, HVIDOVRE, DENMARK



PhD Thesis

Mathias Fabricius Nielsen

Radiographic Findings, Muscle Function, Pain Sensitivity, and Psychological Factors in Athletes with Long-Standing Groin Pain

Supervisor: Kristian Thorborg
Co-supervisors: Per Hölmich & Lasse Ishøi

This thesis has been submitted to the Graduate School of Health and Medical Sciences, University of Copenhagen 8th October 2025

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“Not everything that can be counted counts and not everything that counts can be counted.”
Albert Einstein

Table of Contents

ABBREVIATIONS 10
LIST OF TABLES 11
LIST OF FIGURES 12
PREFACE 13
LIST OF STUDIES 15
THESIS IN SHORT FORM 17
ENGLISH SUMMARY 18
DANISH SUMMARY/DANSK RESUMÉ 19

CHAPTER 1 – INTRODUCTION 22
Introduction 23
Groin Pain in Male Football Players 23
Terminology and Classification of Groin Pain in Male Athletes 26
Diagnostic Imaging of Athletes with Long-Standing Groin Pain 29
Pubic-Related Radiographic Findings in Athletes with Long-Standing Groin Pain 29
Why the pubic symphysis and adjacent bones? 31
Hip-related Radiographic Findings in Athletes with Long-Standing Groin Pain 32
Assessment of Athletes with Long-Standing Groin Pain 34
Pain Location 34
Pain intensity 35
Disability 35
Muscle Function in Athletes with Long-Standing Groin Pain 35
Hip Muscle Strength Assessment 37
Management of Male Athletes with Long-Standing Groin Pain 38
Applying Pain Science to Long-Standing Groin Pain in Athletes 39
Quantitative Sensory Testing 41
Psychological Factors in Athletes with Long-Standing Groin Pain 42

AIM OF THE THESIS 44

CHAPTER 2 – STUDY I & II 45
METHODS 46
Study design and setting 47
Participants 48
Radiographic examination procedure 48
Radiological evaluation procedure 49
Pubic-related radiographic findings and parameters 50

Pubic symphysis radiographic severity score 54
Hip-related radiographic findings and parameters 55
Clinical examination and classification of clinical entities 55
The Copenhagen 5-Second Squeeze Test 56
The Copenhagen Hip and Groin Outcome Score 56
Descriptive questionnaire 57
Sample size considerations 57
Statistics 57
RESULTS 59
Study I Participants 59
Intra-rater reliability of Pubic-Related Radiographic Findings 61
Inter-rater reliability of Pubic-Related Radiographic Findings 63
Reliability of Hip-Related Radiographic Findings 65
Study II Participants 65
Prevalence of Pubic-Related Radiographic Findings 67
Pubic Symphysis Radiographic Severity Scores 67
5SST, HAGOS and Pubic-Related Radiographic Findings 67
CONCLUSIONS 69

CHAPTER 3 – STUDY III 70
METHODS 72
Design and setting 72
Participants 72
Muscle Function Assessment 72
Procedure for bilateral long-lever hip adduction squeeze testing 72
The handheld dynamometer setup 72
The ForceFrame setup 74
Provoked groin pain 74
Data collection 74
Statistics 75
RESULTS 76
Participants 76
Hip Adduction Squeeze Strength 76
Provoked Groin Pain 78
CONCLUSION 78

CHAPTER 4 – STUDY IV 79
METHODS 81
Design and Procedures 81
Participants 81

Radiological and Clinical Examination 82
Athlete characteristics 82
The Copenhagen Hip and Groin Outcome Score 82
Pain sensitivity 83
Pressure pain thresholds. 83
Pain detection and tolerance thresholds 85
Temporal summation of pain 86
Conditioned pain modulation 86
Pain intensity 86
Pain distribution 86
Psychological factors 87
Muscle function 87
Sample size consideration 88
Statistics 88
RESULTS 89
Participants 89
Pain distribution 91
Pain sensitivity 92
Psychological factors 95
Muscle function 95
CONCLUSION 97

CHAPTER 5 – DISCUSSION 98
Discussion Part One – Radiographic Findings 99
Reliability of pubic-related radiographic findings 99
Reliability of hip-joint related radiographic findings 100
Pubic-related radiographic findings in athletes with Long-Standing groin pain 101
Radiographic Findings – Future Research 103
Discussion Part Two – Muscle Function, Pain Sensitivity, and Psychological Factors 104
Muscle Function 104
Handheld Dynamometer or ForceFrame for hip adduction squeeze testing 104
Maximal and explosive strength in athletes with Long-Standing groin pain 105
Muscle Function - Future research 106
Pain Sensitivity in Athletes with Long-Standing Groin Pain 106
Hyperalgesia in Athletes with Long-Standing Adductor-related Groin Pain 107
Modulatory Pain Mechanisms in Athletes with Long-Standing Adductor-related Groin Pain 108
Pain Distribution in Athletes with Long-Standing Groin Pain 108
Psychological Factors in Athletes with Long-Standing Groin Pain 109
Pain sensitivity & Psychological factors - Future research 110

Methodological considerations **110**
Radiographic Limitations 111
Muscle Function Limitations 111
Pain Sensitivity and Psychological Factor Limitations 112

CHAPTER 6 – CONCLUSIONS **113**

CHAPTER 7 – PERSPECTIVES **115**

ACKNOWLEDGEMENTS **118**

REFERENCES **121**

APPENDIX **134**
STUDY I **134**
STUDY II **193**
STUDY III **247**
STUDY IV **277**

Abbreviations

IOC	International Olympic Committee
AP	Anteroposterior
MRI	Magnetic Resonance Imaging
CT	Computer Tomography
PSRS	Pubic Symphysis Radiographic Severity
PJSW	Pubic Joint Space Width
AA	Alpha Angle
AI	Acetabular Index Angle
COS	Crossover Sign
HJSW	Hip Joint Space Width
ISS	Ischial Spine Sign
LCEA	Lateral Center-Edge Angle
PWS	Posterior Wall Sign
5SST	Copenhagen Five Second Squeeze Test
HHD	Handheld Dynamometer
RFD	Rate of Force Development
RTD	Rate of Torque Development
QST	Quantitative Sensory Testing
PPT	Pressure Pain Threshold
PDT	Pain Detection Threshold
PTT	Pain Tolerance Threshold
TSP	Temporal Summation of Pain
CPM	Conditioned Pain Modulation
NRS	Numerical Rating Scale
VAS	Visual Analog Scale
HAGOS	Copenhagen Hip and Groin Outcome Score
ADL	Activities of Daily Living
Sport/Rec	Sport and Recreation function
PA	Participation in Physical Activity
QoL	Quality of Life
PCS	Pain Catastrophizing Scale
ICC	Intraclass Correlation Coefficient
CI	Confidence Interval
MDC	Minimal Detectable Change
LOA	Limits of Agreement
SD	Standard Deviation
SEM	Standard error of measurement

List of Tables

Table 1 Classification of clinical entities based on symptoms and examination findings.....26
Table 2 Pubic Symphysis Radiographic Severity Score.....55
Table 3 Classification of clinical entities based on pain provocation tests.....56
Table 4 Descriptive data of athletes in Study I. 59
Table 5 Intra-rater reliability of radiographic pubic-related parameters.....62
Table 6 Inter-rater reliability of radiographic pubic-related parameters.....64
Table 7 Descriptive data for athletes in Study II 66
Table 8 Muscle Function Assessment Stations.....74
Table 9 Descriptive data of athletes in Study III. 76
Table 10 Hip adduction squeeze strength (Nm/Kg) assessed with the HHD and ForceFrame. 77
Table 11 Descriptive characteristics of athletes in Study IV. 90

List of Figures

Figure 1 Classification of groin pain.....28
Figure 2 Example of an anteroposterior pelvic view radiograph of a male athlete. 29
Figure 3 An anteroposterior radiographic of a male athlete with long-standing groin pain.....31
Figure 4 Proposed pathophysiology of stress fractures 32
Figure 5 Pain distribution in athletes with long-standing groin pain. 35
Figure 6 Long-lever hip adduction squeeze testing with a HHD (A) and the ForceFrame (B).....38
Figure 7 Flow for Study I and Study II.....47
Figure 8 Patient positioning for the AP pelvic view radiograph.....49
Figure 9A to 9F Pubic-related radiographic findings. 54
Figure 10 Participant flow in Study I and Study II.....60
Figure 11 Prevalence of pubic-related radiographic findings.....68
Figure 12 “The 5SST setup” 73
Figure 13 ”The ForceFrame long-lever squeeze test setup” 74
Figure 14 Bland-Altman plot of absolute difference in hip adduction strength 77
Figure 15 Frequency of reported groin pain intensities 78
Figure 16 Pain sensitivity test sequence. 83
Figure 17 Sites for PPT measurements.....84
Figure 18 Example of PPT measurement 84
Figure 19 Example of computer-controlled cuff algometry test setup. 85
Figure 20 Participant flow for Study IV. 89
Figure 21 HAGOS Scores for symptomatic and asymptomatic athletes. 91
Figure 22 Overlay drawings of usual groin pain during sport activity. 92
Figure 23 Pressure pain thresholds on the index side 93
Figure 24 Pressure pain thresholds on the secondary side.....94
Figure 25 Muscle function with maximal isometric torque and rate of torque development.....96

Preface

This **PhD** was conducted at the **Sports Orthopedic Research Center – Copenhagen (SORC-C), Arthroscopic Center, Department of Orthopedic Surgery, Copenhagen University Hospital, Amager-Hvidovre**, Hvidovre, Denmark, from **April 1st, 2021, to October 8th, 2025,**

The thesis brings together…

… data from several cohorts of athletes with groin pain and asymptomatic healthy athletes studied at **SORC-C** between **2010-2012, 2020-2021** and **2021-2024**. Although collected at different time points, combining these datasets in this thesis allowed us to conduct a **unique** and **comprehensive** study on **longstanding groin pain in male athletes**.

In my **MSc Thesis**, supervised by **Kristian Thorborg**, we investigated the link between clinical pain provocation tests, pain intensity, and disability in athletes with longstanding groin pain. The findings of that study suggested two possible contributors to longstanding groin pain: pathoanatomical findings and changes in the sensitivity of the central nervous system. These two ideas became the backbone of this **PhD Thesis** and helped shape the included studies.

In **Studies I** and **III**, we examined the reliability and validity of the methods applied in **Studies II** and **IV**. Together, **Studies I** and **II** focused on conventional **radiographic examinations** to examine the clinical relevance of **pathoanatomical findings of the pubic symphysis joint** in athletes with longstanding groin pain. **Studies III** and **IV** focused on **hip muscle strength, provoked groin pain, pain sensitivity,** and **psychological factors** to explore the **plasticity** and **sensitivity** of the **central nervous system** in **athletes with longstanding groin pain**. Together, these studies aimed to provide **new insights** into the potential **drivers of longstanding groin pain** and how **athletes with longstanding groin pain are characterized**.

My journey towards this PhD began in 2016, when I…

… was an ambitious physiotherapy student interested in long-standing pain in athletes and eager to prove myself. I wrote an email to **Professor Kristian Thorborg**, my main supervisor, asking how I could become involved in research. Then, in **2017** I joined SORC-C as a pre-graduate researcher and outcome assessor on the *SExSI-Trial*, a large randomized controlled study led by **Mikkel Bek Clausen and supervised by Kristian Thorborg.** This scholarship ended with the successful defense of my bachelor's thesis in **2018**.

Then, I was officially caught in the research web, as I continued to work at **SORC-C** as research assistant for **Professor Per Hölmich**, before stating my **MSc in Physiotherapy** at the **University of Southern Denmark (SDU)** in the summer of **2018**. Throughout my studies, I maintained my connection with **SORC-C**, contributing to data collection and co-authoring my first research papers. During my studies, I was also accepted into the *Talent Track program,* which allowed aspiring researchers to be part of the Research Unit **Musculoskeletal Function and Physiotherapy (FOF)** at **SDU.** Under the mentorship of **Professor Jonas Thorlund**, this program not only helped me improve my research skills, knowledge about working as a researcher, and professional network, but also earned me the **Best Scientific Poster award at the Scandinavian Sports Medicine Congress 2020**.

It was also during this period that **Kristian** floated the possibility of doing a **PhD** at **SORC-C**, blending my interest in longstanding pain with hip and groin expertise from **Per Hölmich, Lasse Ishøi,** and **himself**. In **2020**, we laid the foundation for the **PhD** when I spent my second stint as a pre-graduate- researcher at **SORC-C**, and we designed **Study IV** as my **MSc Thesis; however,** as the study was postponed due to the covid-19 pandemic, it later turned out to be one of the main studies of this **PhD** (**Study IV**).

During the **PhD** period, on **September 10, 2022**, my fiancée **Anne Julie** and I welcomed our first child, Freja. Paternity leave resulted in **the extension** of my official PhD period. Fatherhood has brought me immense joy and a new perspective on my life and values. Unfortunately, during my paternity leave, I also encountered depression, resulting in sick leave and several months of gradually returning to work. With support from my family, friends, and supervisors, I returned to a four-day workweek in February 2024 and completed the project.

My journey towards this **PhD Thesis** has been **long**, incredibly **demanding**, **enriching**, and **transformative**, as you can read below. I am very **happy** with the included work, and I am extremely **proud** to have been able to finish the thesis under the circumstances.

I hope this thesis and work will **push the boundaries of sports physiotherapy** just a little further and **inspire clinicians** and **researchers** to incorporate contemporary pain science when dealing with longstanding pain in athletes.

Mathias Fabricius Nielsen
Copenhagen, 2025.

List of Studies

STUDY I

Intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in 86 male athletes with and without hip/groin pain

Mathias Fabricius Nielsen, Per Hölmich, Sonia Branci, Trine Torfing, Lasse Ishøi, Michael Bachmann Nielsen & Kristian Thorborg.

Status: Ready for submission

STUDY II

Pubic-related radiographic findings in football players with long-standing groin pain, and in asymptomatic controls – Are they clinically relevant?

Mathias Fabricius Nielsen, Per Hölmich, Sonia Branci, Trine Torfing, Lasse Ishøi, Michael Bachmann Nielsen & Kristian Thorborg.

Status: Published in peer-reviewed journal (https://doi.org/10.1111/sms.70068)

STUDY III

Hip adduction strength and provoked groin pain: A comparison of long-lever squeeze testing using the ForceFrame and the Copenhagen 5-Second-Squeeze test

Mathias Fabricius Nielsen, Kristian Thorborg, Kasper Krommes, Kasper B. Thornton, Per Hölmich, Juan J. J. Penalver & Lasse Ishøi

Status: Published in peer-reviewed journal (https://doi.org/10.1016/j.ptsp.2022.02.002)

STUDY IV

Pain sensitivity, psychological factors, and muscle function in male athletes with long-standing groin pain and matched controls

Mathias Fabricius Nielsen, Lasse Ishøi, Mikkel Bek Clausen, Carsten Juhl, Shellie Boudreau, Thomas Graven-Nielsen, Per Hölmich, & Kristian Thorborg

Status: Ready for submission

Additional Research Work

Part of the following scientific papers:

- **Nielsen MF**, Ishøi L, Juhl C, Hölmich P, Thorborg K. *Pain provocation tests and clinical entities in male football players with long-standing groin pain are associated with pain intensity and disability. Musculoskeletal Science and Practice. 2023. doi:10.1016/j.msksp.2023.102719*
- Ishøi L., Kraemer O., Thorborg K., **Nielsen MF.,** Hölmich P. *Muscle- and tendon-related palpation pain in patients with femoroacetabular impingement syndrome is associated with worse patient-reported outcome before and 12-months after hip arthroscopy. Submitted to Journal of Hip Preservation Surgery. 2025.*
- Krommes K., Jørgensen A.B., Thorborg K., Christensen L., **Nielsen MF.,** Hölmich P. *Long-term knee health in adults with a history of adolescent Osgood-Schlatter: A national cohort study of patients from secondary care in Denmark 1977-2020. Sports Medicine. 2025.*
- Ishøi L., Thorborg K., Kallemose T., Kemp JL., Reiman MP., **Nielsen MF**., Hölmich P. *Stratified care in hip arthroscopy: can we predict successful and unsuccessful outcomes? Development and external temporal validation of multivariable prediction models. British Journal of Sports Medicine. March 31, 2023. doi:10.1136/bjsports-2022-105534*
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- Ishøi, L., Krommes, K., **Nielsen MF**., Thornton, K. B., Hölmich, P., Aagaard, P., Penalver, J., & Thorborg, K. (2021). *Hamstring and Quadriceps Muscle Strength in Youth to Senior Elite Soccer: A Cross-Sectional Study Including 125 Players. International Journal of Sports Physiology and Performance, 1–7. doi:10.1123/ijspp.2020-0713*
- Ishøi, L., Aagaard, P., Nielsen, M.F., Thornton, K.B., Krommes, K.K., Hölmich, P., Thorborg, K., (2019). *The Influence of Hamstring Muscle Peak Torque and Rate of Torque Development for Sprinting Performance in Football Players: A Cross-Sectional Study. International Journal of Sports Physiology and Performance 14, 665–673.*

Thesis in Short Form

STUDY	AIMS	METHODS	RESULTS	CONCLUSION
I	To investigate the relative and absolute intra- and inter-rater reliability of pubic-related radiographic findings and hip-related radiographic parameters in male athletes with and without hip and groin pain.	AP and cross-table lateral radiographs from 46 footballers with hip/groin pain and 40 asymptomatic athletes were independently rated by two blinded radiologists (11- and 31-years' experience). One radiologist repeated ratings after 8 weeks. Pubic-related findings included bone lucency, proliferation, fragmentation, sclerosis, and pubic joint space width (PJSW). Hip-related findings included alpha angle (AA), lateral center-edge angle (LCEA), acetabular index angle (AIA), hip joint space width (HJSW), ischial spine sign, cross-over sign, and posterior wall sign. Relative reliability was estimated with Cohen's κ and intraclass correlation coefficients (ICC); absolute reliability with percentage agreement, standard error of measurement (SEM), and minimal detectable change (MDC).	Relative and absolute, intra- and inter-rater reliability was fair to substantial across pubic-related bone lucency (intra-rater κ: 0.60, overall agreement: 82%; inter-rater κ: 0.45, overall agreement: 80%), proliferation (0.49, 75%; 0.42, 70%), fragmentation (0.49, 93%; 0.30, 89%), sclerosis (0.63, 84%; 0.34, 64%) and PJSW (ICC: 0.76, SEM: 0.5, MDC: 1.5; 0.72, 0.6, 1.6). Relative reliability was slight–substantial for AA (intra-rater ICC: 0.74; inter-rater ICC: 0.17), but moderate–almost perfect for remaining hip-related findings (intra-rater ICC/κ: 0.51–0.81; inter-rater ICC/κ: 0.53–0.86). Absolute reliability indicated significant variability in AA (SEM: 5–12°, MDC: 15–33°), LCEA (SEM: 3°, MDC: 8°), AIA (SEM: 2°, MDC: 7°), while overall agreement was 75–93% across ischial spine sign, cross-over sign, and posterior wall sign.	Most pubic-related findings showed intra- and inter-rater reliability that support their use in group-level and research, preferably by a single rater. Most hip-related findings show reliability supporting their use in group-level and research. However, caution is warranted when applying cut-offs for individual clinical decision-making.
II	To compare the prevalence of pubic-related radiographic findings between male football players with long-standing groin pain, asymptomatic male football players and asymptomatic male non-football athletes.	Anteroposterior pelvic radiographs of 39 male football players with long-standing groin pain, 18 asymptomatic male football players, and 20 asymptomatic male non-football athletes were evaluated by two radiologists. Presence/absence of the pubic-related radiographic findings: bone lucency, proliferation, sclerosis, fragmentation, and joint space width (JSW, millimeters) were agreed upon during consensus meetings. The consensus-dataset was used for analyses. Groups were compared using $\chi 2$-tests and one-way analysis of variance.	For football players with long-standing groin pain, asymptomatic football players, and asymptomatic non-football athletes the prevalence's were, respectively: bone lucency: 87%, 83% and 40%, proliferation: 67%, 61%, and 25%, sclerosis: 64%, 50% and 15%, and fragmentations: 15%, 6% and 0%, while the mean JSW was 3mm, 3 mm, and 3mm. There were no differences between symptomatic and asymptomatic football players in any findings ($p \geq 0.39$). Bone lucency, proliferation, and sclerosis were more frequent in football players than non-football athletes ($p < 0.002$).	Pubic-related radiographic findings are not associated with long-standing groin pain. But pubic-related radiographic findings are more common in male football players than in male non-football athletes.
III	To compare long-lever bilateral hip adduction squeeze testing using a handheld dynamometer (HHD) setup and the ForceFrame for measures of hip adductor strength and provoked groin pain.	We recruited healthy elite male football players (n=83, mean age; 16 ±2.7 years) from U13, U14, U15, U17, U19 and senior teams from a Danish professional football club and academy. Maximum isometric hip adduction strength (Nm/kg) and provoked groin pain (0-10) was assessed with the ForceFrame and a HHD, in a randomized order. Strength were compared using a paired t-test and Bland-Altman plots with 95% limits of agreement. Pain was compared with a Wilcoxon signed rank test.	Hip adduction strength was a 16% higher in the HHD setup than in the ForceFrame, and there were wide limits of agreement between methods. In the HHD setup, more players reported groin pain, and the groin pain was more intense.	The ForceFrame and the HHD setups are not interchangeable for measures of hip strength and provoked groin pain.
IV	To compare pain sensitivity, psychological factors, and muscle function between 20 male athletes with adductor-related groin pain for ≥ 12 weeks and 20 gender, age and sports-matched asymptomatic athletes.	Pressure pain thresholds (PPT) were measured at the adductor longus muscle and its origin, the iliopsoas tendon, the pubic bone, the gluteus maximus, the pubic symphysis, and the elbow. Pain detection thresholds (PDT), pain tolerance thresholds (PTT), temporal summation of pain (TSP), and conditioned pain modulation (CPM) were assessed at the lower leg using cuff-pressure algometry. Pain catastrophizing, fear of movement, pain self-efficacy, depression, anxiety, stress, loneliness, and sleep were evaluated with 13 brief questions. A HHD was used with long-lever bilateral hip adduction squeeze and hip abduction press tests to measure maximal strength (Nm/kg) and explosive strength (rate of torque development [RTD, Nm/s/kg] at 0–100 milliseconds [RTD_{100}] and 0–200 milliseconds intervals [RTD_{200}]). Groups were compared using unpaired t-tests with effect sizes as Cohen's d.	Athletes with long-standing groin pain had significantly lower PPTs across all sites from the pubic symphysis (-70 kPa [-116 to -25], Cohen's $d = 1.0$) to the gluteus maximus (-152 kPa [-255 to -50], $d = -0.9$), as well as lower PDTs -6.5 kPa (-12.5 to -0.6, $d = -0.71$). But there were no differences in PTT, TSP, and CPM. Athletes with long-standing groin pain reported higher pain catastrophizing ($p < 0.00$), fear of movement ($p \leq 0.02$), depression ($p \leq 0.04$), and lower pain self-efficacy ($p \leq 0.02$). There were no differences in anxiety, stress, loneliness, and sleep. Athletes with long-standing groin pain were significantly weaker for adduction RTD_{200}: -2.5 (95%CI: -4.5 to -0.6, $d = 0.84$), abduction RTD_{100}: -2.3 (-4.0 to -0.7, $d = 0.91$), and abduction RTD_{200}: -1.0 (-2.0 to -0.1, $d = 0.68$).	Male athletes with long-standing adductor-related groin pain display widespread mechanical hyperalgesia, greater psychological distress, and reduced explosive hip strength compared to asymptomatic matched athletes.

English Summary

Introduction

The 2017 International Olympic Committee consensus on pain in athletes highlights the importance of integrating the biopsychosocial model and modern pain neuroscience into the assessment and management of athletes. However, the current approach to male athletes with long-standing groin pain relies heavily on a biomedical model that focuses on anatomical structure and physical function. This thesis attempts to bridge this gap in two parts. Studies I and II focused on the Aspetar pubic symphysis radiographic scoring protocol, a novel method that allows a standardized evaluation of the pubic bone and symphysis joint on radiographs. Studies III and IV focused on hip muscle function, groin pain, pain sensitivity, and psychological factors. This included deciding the method for hip muscle function assessment and exploring novel factors that could be relevant for understanding and future treatment of athletes with long-standing, groin pain.

Aims

The overall purpose of this thesis was to improve knowledge related to radiographic findings, muscle function, pain sensitivity, and psychological factors in male athletes with long-standing groin pain.

Methods

Four studies were included in this thesis. Study I was a reliability study involving 86 athletes with and without groin pain. The relative and absolute intra- and inter-rater reliability of the Aspetar protocol and commonly used hip joint radiographic parameters were derived from evaluations by two experienced radiologists. Study II was a cross-sectional study of 39 male football players with long-standing groin pain, 18 asymptomatic football players, and 20 asymptomatic non-football athletes. Consensus scores from the radiologists were used to determine and compare the prevalence of pubic-related radiographic findings between the three groups. Study III was a method agreement study involving 83 healthy elite male football players. Bilateral hip adductor squeeze testing with a Handheld Dynamometer (HHD) and The ForceFrame were compared for measures of strength and provoked groin pain. Study IV was a cross-sectional study of 20 athletes with long-standing adductor-related groin pain and 20 sex-, age-, and sports-matched asymptomatic athletes. Study IV explored differences between groups in pressure pain thresholds (PPT), pain detection thresholds (PDT), pain tolerance threshold, temporal summation of pain, conditioned pain modulation, pain catastrophizing, fear of movement, pain self-efficacy, depression, anxiety, stress, loneliness, sleep, and hip adduction and abduction maximal and explosive strength.

Results

In Study I, pubic-related radiographic findings showed moderate to substantial relative intra-rater reliability and fair to substantial relative inter-rater reliability. Hip-related radiographic findings showed slight to almost perfect relative intra- and inter-rater reliability, although their absolute reliabilities were often poor. In Study II, pubic-related radiographic findings for football players with long-standing groin pain, asymptomatic football players, and asymptomatic non-football athletes were as follows: bone lucency was observed in 87%, 83%, and 40%, respectively; proliferation in 67%, 61%, and 25%, respectively; sclerosis in 64%, 50%, and 15%, respectively; and fragmentation in 15%, 6%, and 0%, respectively, with a mean pubic joint space width of 3 mm across all groups. The prevalence was not significantly different between football players with and without groin pain; however, it was significantly higher in football players than in non-football athletes. In Study III, there was a systematic bias and wide limits of agreement for hip adduction strength between the HHD and ForceFrame setups, and the HHD setup provoked higher groin pain intensities. In Study IV, athletes with long-standing groin pain showed lower PPTs throughout the symptomatic hip/groin region and contralateral elbow, lower PDT at the lower leg, elevated levels of pain catastrophizing, fear of movement, and depressive symptoms, reduced pain self-efficacy, and deficits in explosive hip strength.

Conclusions

Study I showed that pubic- and hip-related radiographic findings have sufficient reliability for research and group assessment; however, caution is advised when applying these findings clinically. Study II showed that pubic-related radiographic findings are not associated with long-standing groin pain, although they are more common in male football players than in non-football athletes. Study III showed that the HHD and ForceFrame setups are not interchangeable and lack agreement for measuring hip adductor strength and provoking groin pain. Study IV showed that male athletes with long-standing adductor-related groin pain have widespread mechanical hyperalgesia and affected pain catastrophizing, fear of movement, depressive symptoms, pain self-efficacy, and reduced explosive hip adduction and abduction strength.

Perspective

The findings of this thesis underscore the complexity of athletes with long-standing groin pain, emphasizing the need to consider multiple biopsychosocial factors to fully understand the condition and its impact on athletes. Hopefully, this thesis will inspire future assessment and management strategies to incorporate a biopsychosocial and individualized approach to athletes with long-standing groin pain.

Danish Summary/Dansk Resumé

Introduktion

I en række konsensus artikler fra 2017 fremhævede den internationale olympiske komité at vurdering og behandling af atleter bør være baseret på en biopsykosocial model og moderne viden om smerter. Den nuværende tilgang til mandlige atleter med langvarige lyskesmerter er dog i høj grad forankret i en biomedicinsk model med fokus på anatomi og fysiske funktionsnedsættelser. I to dele prøver denne afhandling at bygge bro fra nuværende til en mere biopsykosocial forståelse af atleter med langvarige lyskesmerter. Studie I og II fokuserer på en ny standardiseret metode til at evaluere pubis knoglerne og symfyseleddet på røntgenbilleder. Studie III og IV fokuserer på muskelfunktion, fremprovokerede lyskesmerter, smerteføls omhed og psykologiske faktorer. Dette omfattede en undersøgelse af metoden til at måle hoftemuskelfunktion og en udforskning af nye faktorer, der kunne være relevante for forståelse og fremtidig behandling af atleter med langvarige lyskesmerter.

Formål

Det overordnede formål er at forbedre viden relateret til radiografiske fund, muskelfunktion, smerteføls omhed og psykologiske faktorer hos mandlige atleter med langvarige lyskesmerter.

Metoder

Fire studier er inkluderet i denne afhandling. Studie I er et reliabilitetsstudie med 86 atleter med og uden lyskesmerter. Relativ og absolut intra- og inter-rater reliabilitet af pubis-relaterede røntgen fund og hyppigt anvendte hofte-relaterede røntgen fund blev beregnet ud fra vurderinger udført af to erfarne radiologer. Studie II var et tværsnitsstudie af 39 mandlige fodboldspillere med langvarige lyskesmerter, 18 asymptomatiske fodboldspillere og 20 asymptomatiske ikke-fodboldatleter. Konsensus-vurderinger fra radiologerne blev brugt til at bestemme og sammenligne prævalensen af pubis-relaterede røntgen fund mellem de tre grupper. Studie III var et metode-overensstemmelsesstudie med 83 raske elite mandlige fodboldspillere. Et håndholdt dynamometer (HHD) og The ForceFrame blev sammenlignet på målinger af styrke og provokeret lyskesmerter under bilateral hofte adduktion squeeze test. Studie IV var et tværsnitsstudie af 20 mandlige atleter med langvarige adduktor-relaterede lyskesmerter og 20 asymptomatiske atleter matchet med køn, alder og sport. Studie IV undersøgte forskelle mellem grupper i tryksmertetærskler (PPT), smertedetektionstærskel (PDT), smertetolerancetærskel, temporal summation af smerte, konditioneret smertemodulation, smertekatastrofering, frygt for bevægelse, smerte self-efficacy, depression, angst, stress, ensomhed, søvn samt maksimal og eksplosiv hofte adduktion og -abduktions styrke.

Resultater

Studie I viser at de pubis-relaterede røntgen fund havde moderat til substantiel relativ intra-rater reliabilitet og fair til substantiel inter-rater relativ reliabilitet. Hofte-relaterede røntgen fund viste lav til næsten perfekt relativ intra- og inter-rater reliabilitet, men den absolutte reliabilitet var ofte dårlig. Studie II viser at forekomsten af pubis-relaterede radiologiske fund for fodboldspillere med langvarige lyskesmerter, asymptomatiske fodboldspillere og asymptomatiske ikke-fodbold atleter som følger: knoglegennemsigtighed blev observeret i hhv. 87 %, 83 % og 40 %; proliferation i hhv. 67 %, 61 % og 25 %; sklerose i hhv. 64 %, 50 % og 15 %; og fragmentering i hhv. 15 %, 6 % og 0 %, og den gennemsnitlige ledlinje afstand var 3 mm på tværs af alle grupper. Der var ingen statistiske forskelle mellem fodboldspillere med og uden lyskesmerter, men de pubis-relaterede fund var signifikant mere almindelige hos fodboldspillere end hos ikke-fodbold atleter. Studie III viser at der for hofte adduktion styrke er systematisk bias og brede limits of agreement mellem HHD og ForceFrame, og at lyskesmerter er hyppigere og mere intense ved målinger med HHD. Studie IV viser at atleter med langvarige adduktor-relaterede lyskesmerter havde lavere PPT-målinger i hele den symptomatiske lyske region og den kontralaterale albue samt lavere PDT på underbenet. De havde også højere niveauer af katastrofetanker om smerte, frygt for bevægelse, depressive symptomer, og reduceret tro på egen evne til at håndtere smerte samt eksplosiv hofte-styrke.

Konklusioner

Studie I viser at pubis- og hofte-relaterede røntgenfund har tilstrækkelig reliabilitet til brug i forskning og gruppe undersøgelser; dog bør der udvises forsigtighed ved klinisk anvendelse af disse fund. Studie II viser Pubis-relaterede røntgenfund er ikke associerede med langvarige lyskesmerter, men de forekommer hyppigere hos mandlige fodboldspillere end hos ikke-fodboldatleter. Studie III viser at der er dårlig overensstemmelse mellem HHD- og ForceFrame-metoderne for målinger af bilateral hofte adduktion squeeze styrke og provokerede lyskesmerter. Studie IV viser at mandlige atleter med langvarige adduktor-relaterede lyskesmerter har udbredt mekanisk hyperalgesi, og påvirkede psykologiske faktorer samt reduceret eksplosiv hofte adduktions- og abduktionsstyrke.

Perspektiver

Denne afhandling understreger kompleksiteten hos atleter med langvarige lyskesmerter og fremhæver behovet for at inddrage flere biopsykosociale faktorer for at kunne forstå og forbedre behandlingen af smerterne. Forhåbentlig vil denne afhandling inspirere fremtidige undersøgelses- og behandlingsstrategier til at inkorporerer en mere biopsykosocial og individualiseret tilgang til atleter med langvarige lyskesmerter.

Chapter 1 – Introduction

Introduction

Groin pain is common in male football players.[1–3] Symptoms often develop gradually,[4,5] allowing athletes to continue playing despite discomfort and reduced performance.[1,2] In most cases, groin pain resolve within 1–4 weeks,[3–5] but in approximately 20–30% the pain become long-standing, lasting up to 11 months.[6–8] At this point, athletes typically report reduced participation in football,[7–9] substantial deficits in physical- and sports-related function,[10,11] and reduced quality of life.[3,6,8,11]

An evidence-based approach to athletes with long-standing groin pain begins with a thorough clinical examination, supported by diagnostic imaging when indicated.[12–14] Based on clinical findings, groin pain is classified into clinical entities as adductor-, iliopsoas-, inguinal-, pubic-, and hip joint-related groin pain.[12,13] The recommended first-line imaging modality is plain radiography[15,16] as it is accessible and allows for rapid evaluation of bony changes,[15,16] and serious pathology in the pelvis. [14,15] The bony changes are used to subclassify hip joint-related groin pain (i.e., femoroacetabular impingement syndrome) based on established parameters such as alpha angle and lateral center edge angle.[13,15,16] Establishing both relative and absolute reliability data of using these parameters is therefore essential for the diagnostic work-up.[17,18] Relative reliability is important for the risk of misclassification), while absolute reliability tells how much confidence to place in an individual measurement.[19] Despite their recommended use,[13,15,16] many hip-related radiographic parameters still lack absolute reliability data in athletic populations.[20,21] In addition to the hip joint, the new Aspetar Pubic Symphysis Radiographic Scoring Protocol enables standardized scoring pubic-related radiographic findings in male athletes.[22] However, the Aspetar protocols reliability have not yet been investigated outside the development study, and the clinical relevance in athletes with and without long-standing groin pain remain to be established.[22]

Assessment and improvement of physical function is also included in an evidence-based approach to help reduce disability and return athletes to sports.[14,23] Athletes with long-standing groin pain often report difficulties with hip-dependent movements (running, kicking, change of direction)[3,6,8] and demonstrate objective deficits in hip muscle strength.[10,11,24,25] Maximal isometric hip adduction and abduction strength can be measured quickly and reliably using hip adduction squeeze and hip abduction press testing with a handheld dynamometer (HHD)[26,27] or portable fixed-frame devices (e.g., ForceFrame; VALD Performance, Australia).[28,29] Testing with both these devices also enables capturing provoked pain intensity during squeeze/press testing,[30,31] which helps to screen groin-related disability[27,31] and condition irritability.[8,23] However, the agreement between the HHD and ForceFrame for measures of hip strength and proved groin pain from bilateral long-lever hip

adduction squeeze testing has not yet been examined and should be established before these devices are used interchangeably.

Targeted exercise can restore physical function and hip muscle strength in these athletes,[32,33] however, gains in maximal strength explain only a small proportion of improvement in self-reported function,[24] suggesting contributions of other important factors.[24] In addition to maximal strength, squeeze/press testing with HHD or ForceFrame can quantify explosive strength expressed as rate of force/torque development (RFD/RTD).[26,28] Explosive strength is a key determinant of sports performance and rapid movement,[34] and may be an important component for improving function in athletes with long-standing groin pain.[26] Yet, explosive strength has not been studied in this population.[26]

In addition to restoring physical function and muscle strength, the management of long-standing groin pain aims to reduce disability, alleviate pain, and facilitate return to sport (RTS).[14,23] First-line treatment primarily targets the identified clinical entities of groin pain and physical deficits using progressive strength, balance, and coordination exercises, with adjuncts such as manual or shockwave therapy.[35–42] Across trials, 50–95% of athletes return to sport within approximately 2–4 months, while 5–50% do not return and/or do not become pain-free.[35,36,39,41,42] Importantly, RTS is not synonymous with full recovery[23] as significant groin-related disability and physical deficits are common even after RTS.[24,38,41,43–45] Athletes continue to report awareness, difficulties, restrictions, and negative mood due to their groin problem, they modify their lifestyle to avoid specific aggravating activities, and they also report reduced ability to participate in sport at their desired level and duration.[24,38,41,43–45] These findings suggest that complete recovery with normalized disability, restored function, and full RTS at the desired performance level may require addressing other factors.[24] From contemporary pain science,[46] these factors could be more neural-driven components such as pain mechanisms, psychological factors (emotions, behaviour, mood), and explosive muscle strength, that are not yet routinely assessed and targeted in the current evidence-based approach to long-standing groin pain.

In 2017, the International Olympic Committee (IOC) advocated for a biopsychosocial model of pain in sports medicine and physiotherapy.[46–48] From contemporary pain neuroscience, the IOC expert group emphasized that long-standing pain arises from interactions among neurophysiological, biological, psychological, and contextual factors rather than solely from structural pathology.[47] In addition to identifying pathology and physical impairments,[47] they recommended classifying pain mechanisms (nociceptive, neuropathic, nociplastic) and evaluating psychological factors to support athlete-centered management.[47,48] Therefore, advancing knowledge of pain mechanisms and psychological factors in athletes with long-standing groin pain is essential to progress the approach to long-standing groin pain.

Pain mechanisms are classified from history, clinical findings, and quantitative sensory testing (QST).[49,50] QST provides a standardized framework for assessing sensory and nociceptive function, including pressure pain threshold (PPT), pain detection and tolerance thresholds, temporal summation of pain (TSP), and conditioned pain modulation (CPM).[51,52] QST variables are used as psychophysical evidence of facilitated or inhibited pain mechanisms such as widespread reduced PPTs that indicate widespread mechanical hyperalgesia[51,52] a key signs of nociplastic pain.[49] In long-standing musculoskeletal pain, QST has been used to phenotype patients,[53,54] and to predict treatment outcomes,[55–57] though findings are variable.[58] QST has also been applied in healthy athletes[59,60] and in athletes with long-standing musculoskeletal pain such as Achilles and patellar tendinopathy.[61–63] However, only one study has examined QST in athletes with groin pain,[64] identifying hyperalgesia (reduced PPT) at the adductor longus tendon as a key factor explaining pain across clinical entities in male Australian football players.[64]

Psychological factors are essential to pain perception[65] and influence rehabilitation after injury and pain.[66] Although variations occur, fear of movement,[67–69] pain catastrophizing[69,70] and self-efficacy[69,71] have been associated with and are predictive of pain intensity and disability in long-standing musculoskeletal conditions.[67–71] Specific psychological constructs are rarely assessed in athletes with long-standing groin pain, despite low scores on the Copenhagen hip and groin outcome score (HAGOS)[72] subscales pain and quality of life, which include single items on fear-avoidance, negative mood, and sleep disturbance.[72] A single study of athletes with long-standing adductor- and/or pubic-related groin pain reported elevated pain catastrophizing that decreased after nonsurgical rehabilitation.[41] A second study of patients with long-standing mixed hip and groin pain found that higher psychological distress was more common in patients than in controls, and the level of distress was associated with worse pain and more symptoms.[73] Similar findings have been reported in several studies of patients with hip joint–related groin pain undergoing hip arthroscopy. These patients often have elevated pain catastrophizing,[74–78] fear of movement/kinesiophobia,[75–79] low self-efficacy,[77,78] depression,[77,78,80] anxiety,[77,78,80] and poor mental health.[81,82] Importantly, higher levels of these psychological factors are associated with worse pain,[74,77] disability,[77,80,82] function[82] and treatment outcomes.[74–76,78,81,82]

This thesis explores novel aspects of radiographic findings, muscle function (including explosive strength), pain sensitivity, and psychological factors to provide a more comprehensive biopsychosocial characterization of athletes with long-standing groin pain and to identify new potential drivers of persistent symptoms.

Groin Pain in Male Football Players

Football is a popular sport[83] that promotes physical activity and health,[84] yet injuries and pain are common.[85] Groin pain is one of the most frequent complaints in male football players.[85,86] Groin pain in football is usually reported as either an overuse injury with gradual onset or as an acute injury with a specific inciting event.[4,5,87] Seasonal prevalence estimates of groin pain range from 6–59% depending on surveillance methods.[1–5,88–95] Using athlete-reported data, the weekly prevalence of groin pain is between 7–32% across cohorts,[1,2,96] and during the pre-season 32–77% of players report symptoms.[97,98] Despite groin pain, many athletes are able to continue playing football,[1,2] which is reflected in epidemiological data of time-loss groin pain/injuries that have a seasonal prevalence of 6–22%,[1,4,5,93,94] a weekly prevalence of 0–3%,[1] an incidence of 0.2–4.0 per 1,000 exposure-hours,[1,2,4,5,86,87,94] and a burden of 9–24 days lost per 1000 hours.[1,5,93] Time-loss groin injuries generate a median 97 days lost per season per club[93] and roughly 2–9 injuries occur per team per season.[2,5,87,99] Risk factors for groin pain include previous groin injury,[4,90,100,101] reduced hip/groin-related disability at pre-season,[3,102] reduced hip adduction strength,[101,103,104] limited hip abduction/external rotation,[5,100] higher age[4,90] and BMI,[91,100] sport-specific training exposure,[101] and football team context.[105] Groin pain also affects athletes in other sports like rugby,[106] Gaelic football,[107] Australian football,[108] ice hockey,[109] and field hockey,[110] though often at lower rates.

Groin pain persisting for more than six weeks is commonly defined as *long-standing groin pain*.[111] The prevalence of long-standing groin pain is 4–27% among male football players[3,88,91,112,113] which corresponds to 22–31% of male football players with groin pain.[3,88,91,112,113] Although long-standing groin pain only affects a subgroup of players,[3,88,91,112,113] it has a major impact on the physical function, sports participation, and quality of life for these athletes,[11,24,114] which worsen with longer duration of pain and symptoms.[3]

Terminology and Classification of Groin Pain in Male Athletes

Assessing athletes with long-standing groin pain can be challenging and complex[12] due to the region's overlapping anatomical structures (Figure 1)[115] and historically inconsistent terminology,[9] with up to 33 diagnostic labels applied to similar presentations of groin pain.[9] To address this, three different expert groups have proposed consensus-based terminology and classification systems for groin pain in athletes.[12,116,117] The terminology proposed in the Doha Agreement by Weir et al.[12] is the most widely used system among experts and clinicians.[118] Recently, an ESSKA-EHPA-ESMA consensus report[13] combined the Doha terminology with terminology on hip-related pain proposed by the International Hip-related Pain Research Network (IHiPRN).[16] Accordingly, this thesis adopts the combined Doha/IHiPRN/ESSKA terminology. In this framework, the groin have been defined *as "the*

junctional area between the torso and the anterior and medial thigh"[13] and groin pain in athletes is grouped into three main categories: 1) defined clinical entities of groin pain, 2) hip joint-related groin pain, and 3) other causes of groin pain (Table 1, Figure 1).[12,13] The defined clinical entities are adductor-, iliopsoas-, inguinal-, and pubic-related groin pain (Table 1, Figure 1).[12,13] The classifications are based on subjective history, pain location, pain provocation tests, and diagnostic imaging, when indicated and available.[6,119,120] Although these classifications are rather clear, using this classification system is not without uncertainty,[6,119,120] as the reliability of classifying clinical entities ranges from slight to substantial.[6,119,120]

Table 1 Classification of clinical entities based on symptoms and examination findings. Adapted from Weir et al.12 British Journal of Sports Medicine. 2015;49(12):768-774. License: CC BY-NC 4.0

Classification	Definition
Adductor-related groin pain	Adductor tenderness† and pain on resisted adduction testing
Iliopsoas-related groin pain	Iliopsoas Tenderness.†
Inguinal-related groin pain	Pain in the inguinal canal region and tenderness† of the inguinal canal. No palpable inguinal hernia present.
Pubic-related groin pain	Local tenderness† of the pubic symphysis and immediately adjacent bone.
Hip joint-related groin pain - Femoroacetabular impingement syndrome (FAIS) - Acetabular dysplasia and/or hip instability - Conditions with or without a distinct osseous morphology	Clinical suspicion that the hip joint is the source of groin pain, either through history (e.g. mechanical symptoms of locking or catching) and/or clinical examination (e.g. painful and limited range of motion of the hip). See Reiman et al. for definitions of subclassifications.[13,16,121]
Other causes for groin pain - Inguinal/femoral hernia, post hernioplasty pain, nerve entrapment, referred pain, apophysitis or avulsion fracture - Stress fracture, other hip joint diagnoses, inguinal lymphadenopathy, intra-abdominal abnormality, gynecological conditions, spondyloarthropathies, tumors	Clinical suspicion of symptoms or a diagnosis that cannot be classified into one of the previous mentioned entities.

† Tenderness is defined as "discomfort or pain when the area is palpated, and the athlete recognizes this to be their specific injury pain".[12]

In team-based studies of male football players with groin pain 52–85% present with adductor-related groin pain,[4,5,87,89,94,95,122] 4–32% with iliopsoas-,[4,5,87,94,95,122] 4–19% with inguinal-,[4,5,87,89,94,122] and 3–29% with pubic-related groin pain,[5,87,89,94,95,122] while hip joint-related and other causes of groin pain account for ~4% and ~18%, respectively.[87,94] In secondary care-based studies of athletes, from multiple sports, with long-standing groin pain, 22–74% present with adductor-related groin pain,[6,8,123–125] 6–89% with iliopsoas-related,[6,8,123–125] 2–78% with inguinal-related,[6,8,123–125] 4–24% with pubic-related,[6,8,123–125] 7–45% with hip joint-related groin pain[6,123,124] and 10-20% with other causes of groin pain.[6,123] Furthermore, across settings 35–38% of athletes with groin pain report bilateral symptoms,[36,44,126–129] and 13–44% are classified with multiple entities,[5,122–125,130,131] with up to 21–24 unique combinations of entities.[6,8,123,124]

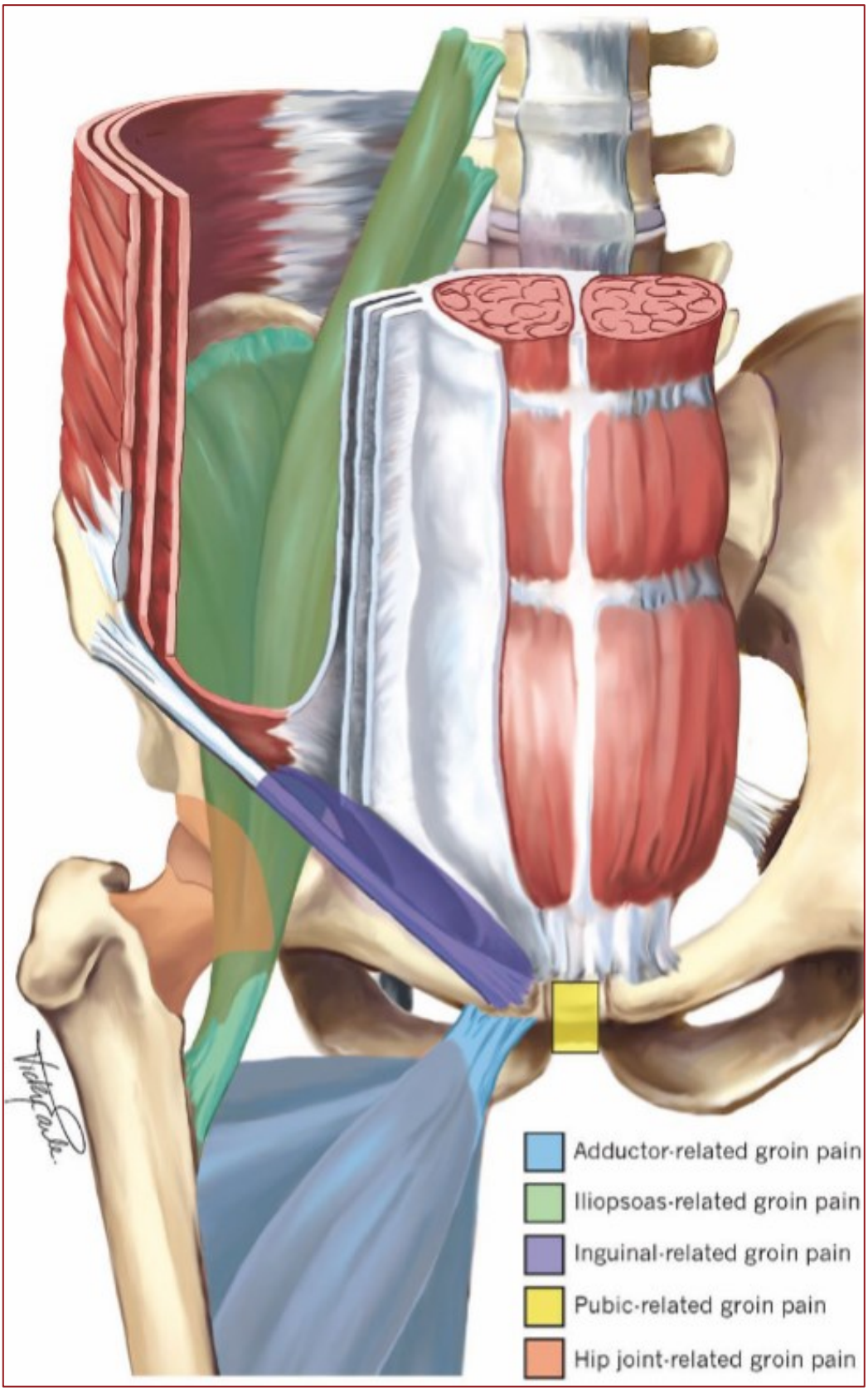


Figure 1 Classification of groin pain. From the A Formal Consensus on Hip and Groin Pain in Physically Active Adults by ESSKA-EHPA-ESMA.[13] Source: *https://cdn.ymaws.com/www.esska.org/resource/resmgr/docs/consensus_projects/2024_groin_complete_report.pdf*

Diagnostic Imaging of Athletes with Long-Standing Groin Pain

Diagnostic imaging, such as conventional radiographs, ultrasound, computer tomography (CT), and magnetic resonance imaging (MRI) can be used in the diagnostic work-up of athletes with long-standing groin pain.[14–16] Imaging are first used to rule out serious pathology, and other causes of groin pain,[14] before identifying subclassifications of hip joint-related groin pain.[15,16] Radiographs are first-line modality due to wide access, low cost and minimal radiation dose.[15,16] Radiographs provide a quick overall visualization the pelvis and hips.[15,16] Radiographs are static, two-dimensional images generated by passing x-ray beams through the body (Figure 2). [132] These x-rays are absorbed differently by bodily tissues with high-density structures like bone absorbing high amounts of x-rays generating high contrast (light/white) shades while x-rays pass more easily through low-density structures like soft-tissues generating low contrast (darker) shades (Figure 2).[132]



Figure 2 Example of an anteroposterior pelvic view radiograph of a male athlete.

Standard radiographs for athletes with long-standing groin pain include anteroposterior pelvic (AP) and lateral hip views.[15,16] These views allow the classification of hip joint-related groin pain based on specific parameters (e.g., lateral center edge angle (LCEA) and alpha angle),[15,16] while also visualizing the pubic symphysis and adjacent bone (Figure 2).[22] In healthy adult males, the pubic symphysis has smooth cortical margins and a joint space width of 4–7 mm.[133] Several pubic-related

radiographic findings such as erosions, proliferation, and sclerosis have been described as common in long-standing adductor- and pubic-related groin pain.[134–146] However, the clinical relevance of these findings remains uncertain as methods and findings are heterogeneous and not always clearly reported.[134–146] Martens et al.[147] suggested that the findings are adaptations to sports-related biomechanical stress rather than being pathognomonic to groin pain.[147] Accordingly, the occurrence of pubic-related radiographic findings may depend on sports type and level (football, hockey, etc.).[147–149] Studies that apply transparent methods and include sport-matched controls are needed to advance the understanding of the relationship between pubic-related radiographic findings and long-standing groin pain.

Pubic-Related Radiographic Findings in Athletes with Long-Standing Groin Pain

Pubic-related radiographic findings in male athletes with long-standing groin pain include sclerosis,[134,135,137–143,145,150] erosions/resorption,[135,137–143,145] cysts,[135,139] abnormal joint space,[134,138,140,143,145] irregular cortical margins,[134,135,139–143,150] bony proliferation/osteophytes ("beaking"),[135,137,139,143] and fragmentation/avulsion.[134,142] See Figure 3 for an example of pubic-related radiographic findings. Sclerosis appear as focal whitening compared to surrounding bone, indicating areas of increased density from excess bone formation.[22] Erosions appear as focal irregularities (darker areas) in cortical and trabecular bone, reflecting excessive bone resorption compared to bone formation.[22] Cysts appear as rounded subchondral/trabecular lucency outlined by a sclerotic line, indicating either joint fluid intrusion, or excess bone resorption.[22] Proliferation/osteophytes appear as abnormal bone formation at joint surfaces and margins,[22] reflecting specific sites with increased bone formation.[22] Fragmentation appear as loose bone pieces visible in pubic joint space, reflecting pubic apophysis maturation, fractures, and attrition.[22] Abnormal pubic joint space width appears as widening or narrowing, reflecting excessive marginal erosions and/or proliferation.[151]

Studies have reported that pubic-related radiographic findings are seen in 47–100% of athletes with adductor- and/or pubic-related groin pain,[135,136,138,139,142,145,150] whereas, athletes with inguinal-related groin pain rarely present with such radiographic findings.[39,152,153] Interestingly, pubic-related radiographic findings have also been identified in 30–85% of asymptomatic controls,[22,135,136,142] although controls also have been described with normal radiographs.[145] Across studies with athletes with adductor- and/or pubic-related groin pain,[134,136,143,145,150] the prevalence rates for pubic-related findings varies greatly between findings from 5% for avulsion fragmentation[134] to 88% for sclerosis.[143] These divergent results challenges an association between pubic-related radiographic findings and groin pain,[147,154] however, the results could be influenced by sampling, selection of controls, and inconsistent radiographic methodology.[22,154]

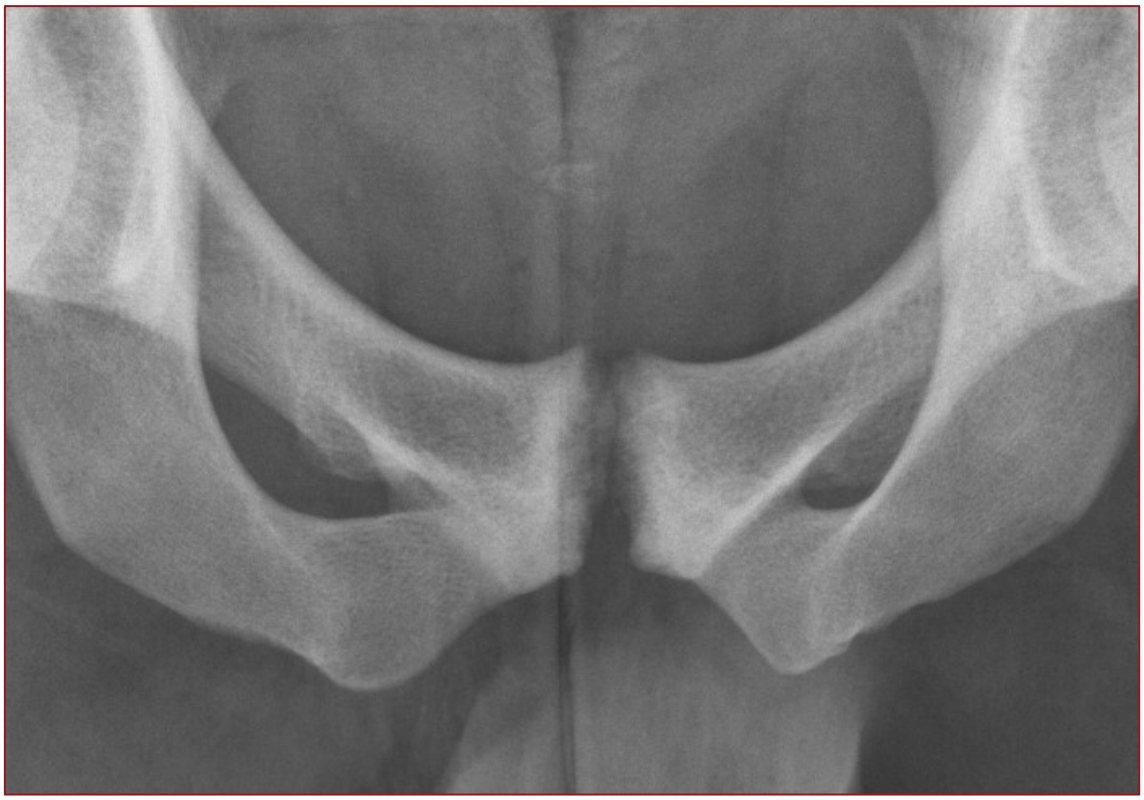


Figure 3 An anteroposterior radiographic of a male athlete with long-standing groin pain and bilateral findings of erosion-like configurations, bony proliferation ("beaking"), sclerosis and a joint space width of 1 mm.

The Aspetar pubic symphysis radiographic scoring protocol[22] was developed to address methodological heterogeneity, with standardized definitions for five main pubic-related radiographic findings: bone lucency (including erosions and cysts), bone proliferation, sclerosis, fragmentation, and joint space width, and ten subclassifications.[22] The main findings showed moderate to good relative intra- and inter-rater reliability in asymptomatic male elite football players,[22] with prevalence rates of 13–65% across findings.[22] However, the Aspetar protocol has not been applied in other settings, and its clinical relevance remains unknown. Reliability may change when other radiologists use the protocol in athletes with and without groin pain, as reliability depends on the sample (biological variability, error by the subject), instrumentation (equipment, procedures), and error by the raters.[18] Therefore, establishing the reliability of the protocol in a different setting with independent radiologists and athletes with and without groin pain should precede studies on the prevalence and associations with pain and disability.[17,18] These studies will help understand the relevance of pubic-related radiographic findings and may help improve the diagnosis and understanding of long-standing groin pain in athletes.

Why the pubic symphysis and adjacent bones?

The pubic symphysis joint is a fibrocartilaginous joint uniting the pubic bones.[133] The joint consists of a fibrocartilaginous disk,[133] as well as strong superior, inferior, anterior, and posterior pubic ligaments,[133] which allow minimal rotation (~1°) and translation (~2 mm).[133,155] The pubic symphysis and pubic bones are pivotal for absorbing and distributing shear, tensile, and compressive forces on the anterior pelvis during movements.[156,157] This role as a mechanical force and stress intersection makes the pubic-related structures prone to overload and microtears that may develop into pain problems if athletes have insufficient time and ability to recover (Figure 4).[158,159] This is especially relevant for football, where kicking and cutting movements rely on high activity of the hip adductor muscles[160,161] which then transfer stress to the pubic bones.

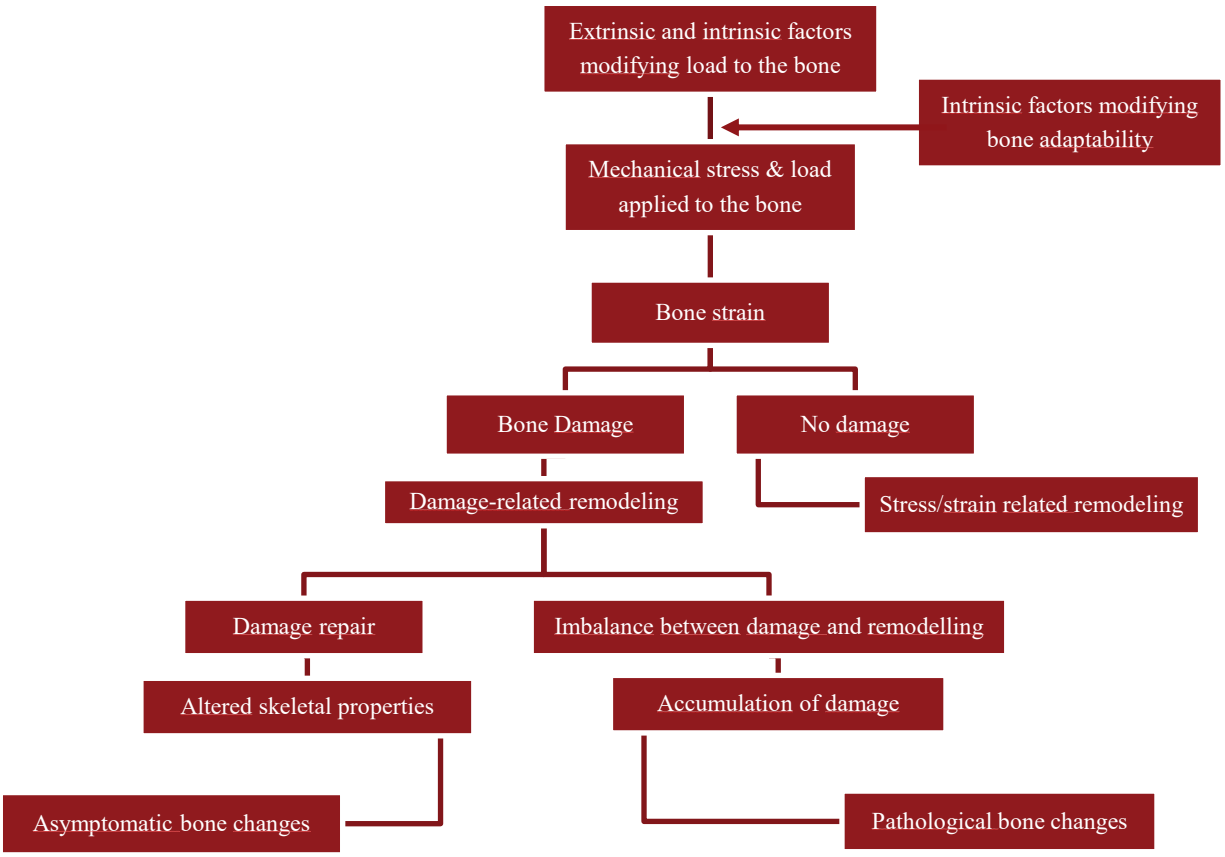


Figure 4 Proposed pathophysiology of stress fractures. Adapted from ***Figure 1.*** *Proposed pathophysiology of stress fractures* by Warden et al.[158] *Current Osteoporosis Reports 2006, 4:103–109* and Warden et al.[159] *Journal of Orthopaedic & Sports Physical Therapy* 2014

When bones undergo regular mechanical loading and stress, they respond by increasing load tolerance to resist applied forces.[162] Following repetitive strain, bones may develop microdamage, which initiates targeted bone remodeling, where osteoclasts remove damaged tissues (bone resorption) before osteoblasts replace the resorbed bone with osteoid (bone formation).[162] The bone remodeling process is time- and strain-dependent, taking several weeks or months for new bone to mineralize,[162] and

further strain may cause damage accumulation faster than bone generation (Figure 4).[158,159,162] This microdamage and bone remodeling process is currently the most likely explanation for pubic-related radiographic findings;[163] however, this explanation still needs further study in athletes with long-standing groin pain.

Hip-related Radiographic Findings in Athletes with Long-Standing Groin Pain

Hip-related radiographic parameters and findings are routinely used in the diagnostic work-up for athletes with long-standing groin pain.[15,16] Continuous parameters such as the alpha angle, lateral center edge angle (LCEA), acetabular index angle (AI), hip joint space width, as well as categorical findings such as ischial spine sign, posterior wall sign, and crossover sign are all used to help sub-classify hip joint-related groin pain (e.g., FAIS, hip dysplasia) and are defined in detail by experts in the Lisbon agreement papers.[15,20,164] Accordingly, establishing both relative and absolute reliability for these parameters and findings is essential.[17,18]

Despite the recommended and widespread use of hip-related radiographic findings,[15,20,164] detailed reports of both relative and absolute reliability in athletic populations are lacking.[20,21] Athletes often show higher prevalence of certain radiographic findings than non-athletes,[16,165] which can influence reliability through prevalence effects and between-subjects variability.[166,167] In a systematic review of 43 studies of patients with pre-arthritic hips undergoing hip arthroscopy, intra- and inter-rater reliability for common hip-related parameters ranged widely (ICC/κ from -0.08 to 0.987), absolute reliability metrics were not included and seldom reported, while physical activity characteristics of the samples were poorly described.[21] Nine previous studies have reported relative intra- and/or inter-rater reliability metrics for hip-related radiographic findings in athletes.[168–176] Across these studies, the ICC/κ varied from 0.59–0.93 for AA,[168–176] 0.63–0.95 for LCEA,[168,169,171,173–175] 0.76–0.81 for AIA,[173–175] 0.59–0.86 for COS,[173–176] while it was unclear for HJSW,[173] PWS,[173] and ISS.[173] Contrary to reporting guidelines,[177] none of the studies reported absolute reliability metrics, and often reported reliability briefly with incomplete methods and details[168–176] and only used smaller sub-samples (n = 15 to 50).[168–172,174,176] Thus, a detailed investigation of relative and absolute reliability for commonly used hip-related radiographic parameters and findings in athletes is still needed.

Assessment of Athletes with Long-Standing Groin Pain

Assessing athletes with long-standing groin pain should follow a standardized and systematic approach[14,119] due to the complex nature of the region's overlapping anatomical structures (Figure 1),[115] and the multiple other musculoskeletal and non-musculoskeletal conditions that may cause groin pain (Table 1).[12,179] Based on the history,[12,14] symptoms,[12,14] pain location,[12,14] clinical examination,[6,119,120] diagnostic imaging,[14,16] patient-reported outcome measures,[14] as well as physical and sport-related function and performance measurements,[14,23] clinicians and researchers are able to classify groin pain into clinical entities[12] and thoroughly map out disability.[14]

The typical athlete with long-standing groin pain is a male football player aged 18–40 years,[9] though groin pain and problems also occur in female and youth athletes.[7,123,180] The history often include a gradual onset of pain,[6,114,123] that is aggravated by movements (sprinting, cutting, kicking),[136] and have persisted for up to 11 months or longer.[6,7,9,44,123] In addition to experiencing pain, athletes may also experience burning, dull/aching, throbbing, tingling, electric, stabbing and numbness;[7] however these sensations seem highly variable and individual.[7] In the clinical examination, athletes with long-standing groin pain may present with many positive pain provocation tests (range 2–23)[8] and a subgroup of athletes may present with multiple clinical entities of groin pain,[6,8,123] pain in multiple locations from resistance and stretching testing,[119,120] bilateral groin pain,[7,8] and more widespread pain distribution,[7] which seem related to more severe pain and disability.[7,8]

Pain Location

Pain location is used to classify the clinical entities of groin pain (Table 1, Figure 1).[12] The distribution and location of long-standing groin pain have primarily been described with reference to body regions,[72] until Serner et al.[7] used digital pain drawings to visualize long-standing groin pain in 167 athletes.[7] The distribution of pain showed significant variation,[7] from focal areas (e.g., adductor longus insertion) to a triangular pattern spanning from the anterior superior iliac spine to the linea alba, pubic symphysis, and medial femoral condyle (Figure 5).[7] Most athletes seemed able to pinpoint a rather precise location of their groin pain,[7]. Others experienced diffuse and more widespread pain throughout the groin region,[7] which was related to multiple clinical entities,[7] and increased with pain intensity.[7] Highlighting the challenge of classifying severe long-standing groin pain.

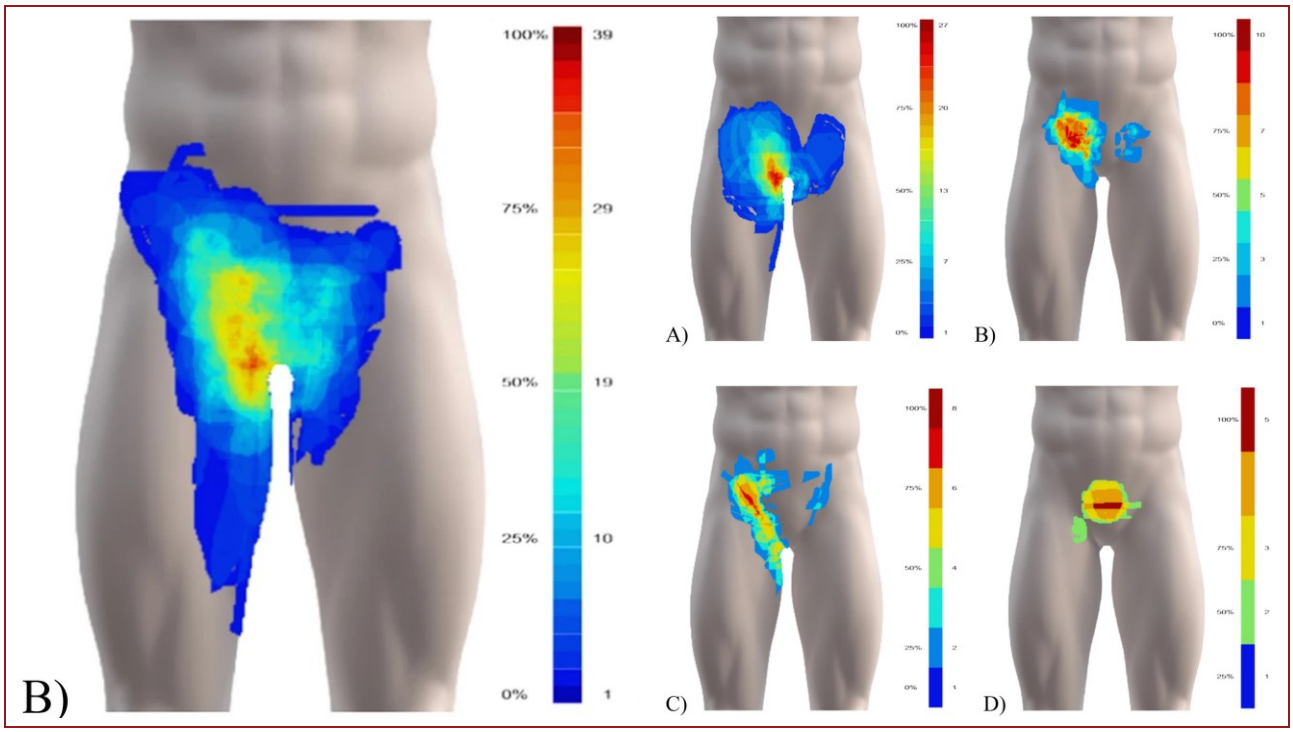


Figure 5 Pain distribution in athletes with long-standing groin pain. Adapted from "Figure 2 Pain map overlays from patients with (A) one (N = 88), (B) two (N = 64), and (C) three (N = 15) clinical entities of groin pain…." and "Figure 3 Pain map overlays of: (A) adductor- (N = 39), (B) inguinal- (N = 24), (C) iliopsoas- (N = 18), and (D) pubic-related (N = 7) …." in Serner et al.[7] Scientific Reports 12, 9789 (2022). Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1038/s41598-022-13847-1

Pain intensity

Groin pain at rest is uncommon and intensity rarely reported or low,[181] while pain intensity ranges from 5–8 on the a numerical rating scale when anchored to defined periods/activities (e.g., worst pain during previous week; during/after sports).[8,42,112,122] Another option is the Copenhagen 5-Second Squeeze Test (5SST)[31] which reliably measures intensity (0–10) of provoked groin pain following a maximal long-lever hip adduction squeeze test for five seconds (Figure 6).[27,31] Athletes with long-standing groin pain may report pain intensity ranging from 3–9 with the 5SST.[8,32,33,114,122] The 5SST is considered highly relevant for both athletes and clinicians[31] as athletes can generate high bilateral hip adductor forces[27,182] that generates high biomechanical stress which may mimic the stress from sports-related movements.[160,161] Additionally, the 5SST correlate negatively with groin-related disability,[31] hip adduction/abduction strength,[27] and positively with number of positive pain provocation tests,[8] and number of clinical entities.[8]

Disability

Pain location and intensity are not the only concerns for athletes with long-standing groin pain as they also experience moderate to severe disability.[114] Disability is a biopsychosocial construct which includes impairments, activity limitations and participation restrictions that an individual experience in relation to their contextual factors (environmental and personal factors).[183] Disability of athletes with

long-standing groin pain can be assessed with hip and/or groin specific patient-reported outcome measures (PROM) such as the Copenhagen Hip and Groin Outcome Score (HAGOS),[72] the international hip outcome tool-33 (iHOT-33)[184] and iHOT-12.[185] Of these HAGOS is recommended for athletes without hip joint-related groin pain due to superior content validity and clinimetric properties.[186,187] HAGOS was designed to reflect disability across three health dimensions: impairment, activity limitation, and participation restriction,[183] and can therefore be considered a biopsychosocial measure of both the athletes experienced and actual hip- and groin-related limitations.[72] HAGOS consists of 37 items scored on a five-point Likert scale (0–4) across six subscales (Pain, Symptoms, Physical Function in Daily Living [ADL], Physical Function in Sport and Recreation [Sport], Participation in Physical Activities [PA], and Quality of Life [QoL]) which each are reported as normalized scores from 0 (extreme symptoms) to 100 (no symptoms).[72] A recent validation of HAGOS using modern test theory led to a revised scoring of five subscales based 30-items.[188] In healthy male football players, the reference centiles for the HAGOS subscale scores are 80–100 for Pain, 64–100 for Symptoms, 80–100 for ADL, 72–100 for Sport, 75–100 for PA, and 75–100 for QoL.[189] Athletes with long-standing groin pain typically score significantly lower across all HAGOS subscales, although there are large variation between studies and settings.[8,24,44,119,120,122,148,190–193] Studies with athletes with long-standing groin pain report HAGOS scores range between: 58–88 for Pain, 50–79 for Symptoms, 58–94 for ADL, 28–72 for Sport, 0–75 for PA and 26–64 for QoL.[8,24,44,119,120,122,148,190–193]

Muscle Function in Athletes with Long-Standing Groin Pain

Assessing and restoring hip muscle function is especially important for athletes with long-standing groin pain to help reduce their overall level of disability.[14,23] Athletes with long-standing groin pain often have both self-reported and objectively measured reductions in physical and sport-related function and performance.[8,32,33] In movement laboratories they may also show altered biomechanics.[194–198] While during a clinical assessment they may display lower eccentric hip adduction strength,[114] isometric hip adduction squeeze strength,[10,11,192,199] and isometric hip adduction and abduction strength.[10,11,25,194,200] Importantly, many of sports-related movements and activation of the hip adductor muscles are often what aggravates groin pain,[89,136] which highlight a complex relationship[201] where movements provoke pain,[8] and pain generates changes and difficulties with movements.[194]

Maximal isometric and eccentric hip strength is often studied in athletes with groin pain,[10] and can be improved with targeted hip strengthening exercises.[32,33] However, improvements in maximal strength may only explain a small part of the improvement in self-reported physical function,[24] which suggests that other factors could also be important.[24] Maximal muscle strength is the peak force a muscle produces under specific conditions,[34] and the output may depend on full recruitment and

sustained muscle activation over a longer time (up to 5 seconds).[202,203] Explosive strength is another strength component than maximal strength, which could be an important target in the management of athletes with long-standing groin pain.[26] Explosive strength relates to changes in force from 0-50 milliseconds, 0-100 milliseconds, and 0-200 milliseconds and it is highly dependent on efficient neurophysiological mechanisms (i.e., motor unit recruitment, neural drive, reflexes, inhibition, coordination).[34,204] Sports performance and rapid movements are considered especially dependent on explosive strength,[34] as sports movements occur much faster than the time needed to achieve maximal force.[34,205] Explosive strength may be reduced even more than maximal isometric strength in long-standing pain conditions,[206] which could be due to a combination of explosive strength being more sensitive to nociceptive input and neural inhibition as well as cortical inhibition from fear of the explosive movements aggravating pain.[34,206,207] Whether explosive strength is impaired in athletes with long-standing groin pain remains uncertain.

Hip Muscle Strength Assessment

Hip muscle strength can be assessed using several devices (manual resistance, sphygmomanometer, HHD, fixed-frame dynamometer, isokinetic dynamometer),[208–211] with multiple setups (uni- or bilateral; long- or short-lever; in seated, standing, side-lying, or supine; with/without hip abduction and flexion; with/without belt-fixation of the device and/or athlete).[26,208–213] Manual resistance lacks objectivity,[214] sphygmomanometers have ceiling/validity issues,[211] and isokinetic dynamometers are expensive and completely stationary.[208] The accessibility, portability, and versatility of HHD and fixed-frame dynamometers makes them preferred in many clinical, sports, and research settings.[31,209,211]

Bilateral hip adduction squeeze testing is widely used to both evaluate hip adduction strength (Figure 6)[104] and classify adductor-related groin pain (Figure 1, Table 1).[119,215] Squeeze testing can be performed as a *long-lever* test with straight legs and resistance at the ankles, or as a *short-lever* test with hips and knees flexed and resistance at the knees.[209] The long-lever setup allows for quick, reliable maximal isometric[27,209] and explosive hip adduction and abduction strength[26] and provoked groin pain intensity measurements (See Pain intensity).[27,31] Hip adduction squeeze strength measured with a HHD from the long-lever setup correlate with provoked groin pain intensity,[27] self-reported disability,[27] and it is a risk factor for new events of groin pain in male football players.[90]

Fixed-frame dynamometers (e.g., ForceFrame) enable quick and reliable assessment of uni- and bilateral isometric and explosive hip strength (Figure 6).[28,29] The ForceFrame has been proposed as the gold standard for monitoring hip adductor strength in athletes;[211] however, it remains uncertain whether squeeze testing in the ForceFrame generates valid measures of provoked pain intensity. The ForceFrame has been validated against an HHD for hip adduction strength,[216] but this study compared

unilateral strength measures from a bilateral long-lever squeeze test in the ForceFrame and a unilateral long-lever hip adduction test with an HHD, which are not interchangeable tests because of differences in muscle EMG, strength output, and risk factor value.[217] Furthermore, differences in hip positioning (neutral vs. 10-15° hip abduction) when squeeze testing with fixed-frame dynamometers[28,29,216,217] and an HHD[26,27] may influence measurements.[218] Therefore, agreement between the ForceFrame and HHD should be established for bilateral long-lever hip adduction squeeze testing before substituting devices interchangeably.

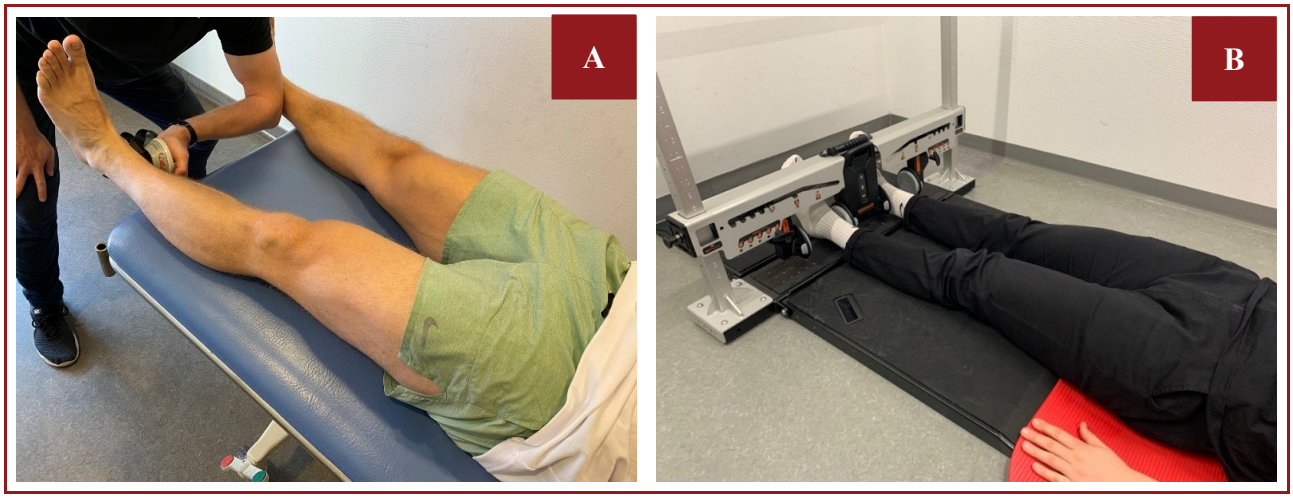


Figure 6 Long-lever hip adduction squeeze testing with a HHD (A) and the ForceFrame (B)

Management of Male Athletes with Long-Standing Groin Pain

First-line, evidence-based management of athletes with long-standing groin pain focuses on reducing disability, alleviating pain, restoring physical function, and returning athletes to sport and performance through load modification and progressive strength, balance, coordination, and endurance exercises targeting identified clinical entities of groin pain and physical impairments and optional adjunct therapies.[9,35–42] In addition to exercises, management may also include optional adjunct components such as manual therapy (mobilization, trigger point, myofascial techniques, muscle tonus release, spinal manipulation therapy, lymphatic drainage, taping, massage),[35,40–42] electrophysical modalities (extracorporeal shock wave therapy,[41] TECAR therapy,[38] transcutaneous electrical nerve stimulation [35]), intratissue percutaneous electrolysis,[37] stretching,[35,40–42] heat packs,[35,42], and warm baths[42].

Between 50-79% of athletes with long-standing adductor-related groin pain may return to sport after a median 18 weeks (range: 13-26 weeks)[36,42] following an active exercise program consisting of exercises that provide high activation of the adductor muscles[219,220] performed for 90-minute training sessions during three to seven times per week[36,42] Compared to this exercise program, a multi-modal

manual therapy treatment approach followed by structured running program may return 50% of athletes with long-standing adductor-related groin pain to sport within 13 weeks.[42] In athletes with long-standing adductor and/or pubic-related groin pain, an intensive 3-phase rehabilitation program with several modalities can reduce pain intensity, disability and pain catastrophizing after 3 months and return 95% of athletes to sport after 10 and 14 weeks, with a faster return if extracorporeal shock wave therapy is used as adjunct therapy.[41] In athletes with long-standing inguinal-related groin pain a superior pain relief can be achieved after 8 weeks of an active exercise program in addition to adjunct therapies compared to only adjunct therapies, however, only 65% of athletes return to sport without groin pain despite the active approach and pain relief.[35] Another option for athletes with long-standing inguinal-related groin pain is surgical treatment which for 90% of athletes can provide complete pain relief and return them to sport after 3 months and provide higher satisfaction with treatment after 12 months, compared to an active exercise program that only returns 27% to sport after 3 months.[39]

Across trials, 50–95% of athletes return to sport within approximately 2–4 months, while 5–50% do not return to sport or become clinically pain free.[35,36,39,41,42] Importantly, return to sport is not synonymous with full recovery as significant groin-related disability and physical deficits are common.[23,24,38,41,43,44] After returning to sport, athletes still report awareness, difficulties, and restrictions with or due to their groin problem and reduced ability to participate in sport at their desired performance level and duration.[23,24,43–45] They are also likely to modify their lifestyle to avoid specific activities and experience that groin pain affects their mood negatively.[23,24,43–45]

Taken together, these results from clinical trials and cohort studies suggest that achieving complete recovery with normalized disability, restored function, and full return to sport at the desired performance level may require targeting additional factors not routinely addressed by current management strategies,[35,36,41,42] for example, pain mechanisms, psychological factors (emotions, behavior, mood), and explosive muscle strength.

Applying Pain Science to Long-Standing Groin Pain in Athletes

The IOC advocates a biopsychosocial model of pain in sports medicine, emphasizing that "*injury may occur without pain, and pain may present without evidence of injury*"[47] and that pain emerges from complex interactions between neurophysiological, biological, psychological and contextual factors.[46–48] The IOC also supports athlete-centered management addressing all factors contributing to pain, including pathophysiology, physical impairments and psychosocial factors.[46–48] This aligns with the revised IASP definition of pain:[65] *"Pain is an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage."*[65]

Evidence-based assessment and management of athletes with long-standing groin pain acknowledge that a single consistent pathoanatomical source of nociception and pain in athletes with long-standing groin pain has not been identified.[12,14,23] The occurrence of pathoanatomical findings is highly heterogeneous across studies and clinical entities of groin pain, making it difficult to infer the clinical relevance of identifying pathoanatomical findings. Across the clinical entities, studies reported findings of musculotendinous strains,[221] tendinopathy,[140] enthesopathy,[191,222,223] nerve entrapment,[224] abdominal wall weakness,[224,225] avulsion injuries,[221] apophysitis,[180] pubic bone marrow oedema,[148,163,221] pubic symphysis disc protrusion,[148] bone spur,[226] peritendinitis[221] and symphyseal joint degeneration and/or capsulotendinous injury.[139,140] These highly variable pathoanatomical findings support a new perspective on long-standing groin pain as a sports-related pain condition,[227] where pain is not clearly related to tissue injuries and knowledge about pain mechanisms (nociceptive, neuropathic or nociplastic pain) and psychological factors may help to improve management.[47,48]

Nociplastic pain reflect altered nociception without clear ongoing tissue damage or nerve lesion.[50] Altered nociception may to arise from acute or continuous intense noxious stimuli that initiates peripheral and central sensitization and/or poor function of the descending pain modulatory system.[228,229] Clinically, a hypothesis of altered nociception is formed by features identified through subjective history, physical examination, questionnaires, pain duration, pain location, and quantitative sensory testing (QST).[49,50] Clinical characteristics of altered nociception can vary greatly between and within patient groups,[50,58] why it is highlighted that altered pain sensitivity exist on a dynamic continuum.[50] The proposed clinical characteristics include pain for 3 months or more;[49] regional rather than discrete distribution of pain including widespread and multiple pain sites;[49] there are no signs of nociceptive or neuropathic pain being entirely responsible for the pain;[49] history of pain hypersensitivity;[49] presence of comorbidities (sleep disturbance, fatigue, cognitive problems, sensitivity to sounds, light, or odors);[49] and clinical presence of evoked pain hypersensitivity in the region of pain.[49] Patients may also present with referred pain, facilitated temporal summation of pain (TSP); and impaired conditioned pain modulation (CPM).[228,230]

The IOC consensus on pain in athletes[47] suggested that sport-related pain likely starts as predominantly nociceptive pain but may shift toward nociplastic or mixed pain (nociceptive and nociplastic) if the pain and symptoms persist beyond normal tissue healing time.[47] In male athletes with long-standing groin pain, several characteristics remind of the proposed features of altered nociception: pain duration for months to years;[7–9,119] bilateral symptoms and multiple painful sites;[4,5,7,8,36] regional pain;[7] region-wide mechanical hypersensitivity;[8] and hyperalgesia at the adductor longus tendon as the main factor explaining groin pain across different clinical entities of groin pain.[64] Furthermore, multiple clinical entities and bilateral symptoms are linked to greater pain intensity,[8] worse disability,[8]

larger pain area,[7] higher time-loss from sport,[4,5] and worse treatment outcome.[36] Higher numbers of positive provocation tests correlate with higher pain intensity and disability,[8] suggesting altered mechanical pain sensitivity.[8] Similarly, a higher number of clinical entities makes it more difficult to classify clinical entities,[6] while single pain provocation tests often provoke pain in multiple sites and may provoke pain in asymptomatic areas.[119,120] Pain may spread and refer to the whole hip and groin region,[7] with different painful qualities,[7] and a larger pain area in more severe cases.[7] Altogether, these characteristics suggest that exploring pain mechanisms in athletes with long-standing groin pain could advance assessment and management aligned with the IOC consensus papers and contemporary pain science

Quantitative Sensory Testing

QST is a standardized psychophysical approach for assessing sensory and nociceptive function.[51,52] Stimuli such as blunt pressure, pinprick pressure, cold, heat, vibration, and touch are applied at local (at a painful site), regional, and remote (distant from painful site) body regions to evaluate function of small and large afferents (e.g., A-δ and C fibers) in skin and deeper tissues, including muscle.[51,52] These stimuli generate a range of stimulus-specific detection and tolerance thresholds,[51,52] and dynamic responses such as temporal summation of pain (TSP)[231] and conditioned pain modulation (CPM).[232] QST was initially developed for patients with neuropathic pain[51] but it has been widely used for studying pain sensitivity and mechanisms in patients with chronic musculoskeletal pain.[52,230] Pressure-based measurements, such as pressure pain thresholds (PPTs),[231] are often used to reliably quantify mechanical deep tissue pain sensitivity[231] in musculoskeletal pain,[230] as mechanical pressure is non-invasive stimuli that mimics pain from muscles, tendons, and bones.[228] Reduced PPTs locally in a painful site is usually interpreted as local mechanical hyperalgesia while widespread mechanical hyperalgesia is indicated by reduced PPTs in non-painful sites distant to a painful site, or reduced PPTs at multiple painful sites throughout the body.[228,230] Local and widespread hyperalgesia indicate altered pain sensitivity driven by peripheral and/or central pain mechanisms, respectively.[228,230] Pressure-based stimuli can also reliably evaluate TSP and CPM,[231,232] which are considered surrogate measures for the total effect of the central pro- and antinociceptive pain mechanisms.[228,230] TSP is assessed as the increase in perceived pain during a series of identical or progressive stimuli,[231] which mimic the wind-up phenomenon where repetitive peripheral nociceptive input increases the excitability of neurons in the dorsal horn.[228,230] CPM is assessed as the change in pain detection threshold with/without a conditioning painful stimulus applied in parallel or series with a test-stimuli,[232] and considered a proxy of the total effect of the descending pain modulatory system.[228,230]

QST have been widely used to explore pain sensitivity in various long-standing musculoskeletal pain conditions,[228,230] to characterize patients,[53,54] as well as predict treatment outcomes,[55–57] although findings show high variability.[58] QST have also been used in physical active populations with long-standing pain such as tendinopathy,[61–63] and healthy athletes[59,60] Populations with tendinopathies consistently show localized hyperalgesia at the painful site, compared to pain-free controls,[62,63] while there are divergent findings for widespread hyperalgesia between upper- and lower-limb tendinopathies[62,63] and a recent meta-analysis found no results of impaired CPM in athletes with lower-limb tendinopathies.[61] In healthy athletes, pain thresholds and tolerances tend to be higher than non-athletes,[59,60] suggesting that athletes can tolerate more/higher noxious/nociceptive stimuli before experiencing pain.[59,60]

Psychological Factors in Athletes with Long-Standing Groin Pain

Psychological factors are essential for the perception and modulation of pain.[46,48,65] Some of the most commonly assessed psychological factors in populations with long-standing musculoskeletal pain similar to groin pain are depression, anxiety, emotional distress, stress, mental health, fear of movement/kinesiophobia, catastrophizing, and self-efficacy factors.[233] Across populations with long-standing musculoskeletal pain, psychological factors such as fear of movement,[67–69] pain catastrophizing[69,70] and self-efficacy[69,71] have been associated with and predictive of pain intensity, and disability.[67–71] Besides a relationship with pain, psychological factors are also important for athletes in the sense that these factors are known to be associated with how athletes return to sport.[66]

First-line, evidence-based assessment and management of athletes with long-standing groin pain traditionally focuses on classifying groin pain, pain, disability, physical function, and returning athletes to sport and performance.[14,23] While these approaches are important, specific psychological factors are rarely evaluated systematically in these athletes, despite significant reductions in disability measures such as the HAGOS[72] and iHOT-33[184], which contain single items/questions on fear-avoidance behavior, sleep disturbances, negative mood, and frustration.[72,184] From these PROMs, it is clear that both before and after management, athletes with long-standing groin pain may adapt their lifestyle to avoid specific activities that aggravate their groin pain, they may experience negative mood because of their groin pain, and they may experience sleep disturbances because of their groin pain.[24,38,43–45] One study investigated psychological factors specifically in athletes with long-standing groin pain related to defined clinical entities.[41] In this randomized controlled trial,[41] athletes with adductor- and/or pubic-related groin pain demonstrated elevated levels of pain catastrophizing that decreased to normative levels over 3 and 12 months following nonsurgical rehabilitation, underscoring the potential clinical relevance of psychological factors in management.[41] In a cross-sectional

study of patients with long-standing hip and groin pain, Pålsson et al.[73] found that higher psychological distress was more frequent in patients than in healthy controls and distress levels were associated with self-reported pain and symptoms.[73] In a similar population, patients with hip joint-related groin pain undergoing hip arthroscopy, psychological factors have been widely studied. These patients may present with pain catastrophizing,[74–78] fear of movement/kinesiophobia,[75–79] low self-efficacy,[77,78] depression,[77,78,80] anxiety,[77,78,80] and poor mental health.[81,82] Higher levels of these psychological factors are associated with worse pain,[74,77] disability,[77,80,82] function[82] and treatment outcomes.[74–76,78,81,82]

Overall, there is still a significant gap in the knowledge of the psychological factors in athletes with long-standing groin pain. Further mapping of the psychological factors in these athletes is therefore warranted. Such knowledge may help in understanding long-standing groin pain, inform prognosis, and support the development of interventions that target both physical and psychological contributors to pain.

Aim of the Thesis

The overall aim of this PhD thesis was to explore novel aspects of radiographic findings, muscle function, pain sensitivity and psychological factors in male athletes with long-standing groin pain. This was obtained through the following study objectives:

OBJECTIVES

STUDY I

1) To investigate the relative and absolute intra- and inter-rater reliability of hip joint- and pubic-related radiographic parameters in male athletes with and without hip and groin pain.

STUDY II

1) To compare pubic-related radiographic findings across symptomatic male football players with groin pain, asymptomatic male football players and asymptomatic male non-football athletes.

2) To explore whether the total number of pubic-related radiographic findings is associated with groin pain, groin pain intensity, and disability.

3) To explore the influence of individual pubic-related radiographic finding on groin pain intensity and disability in symptomatic football players.

STUDY III

1) To compare long-lever squeeze testing using the ForceFrame and a handheld dynamometer for assessment of hip adductor squeeze strength and provoked groin pain.

STUDY IV

1) To compare measures of pain sensitivity, psychological factors, and muscle function between male athletes with long-standing adductor-related groin pain and sex, age, sports-matched asymptomatic athletes.

Chapter 2 – Study I & II

STUDY I

Intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in 86 male athletes with and without hip/groin pain

Mathias Fabricius Nielsen, Per Hölmich, Sonia Branci, Trine Torfing,
Lasse Ishøi, Michael Bachmann Nielsen, Kristian Thorborg.

STUDY II

Pubic-related radiographic findings in male football players with long-standing groin pain, and asymptomatic controls – Are they clinically relevant?

Mathias Fabricius Nielsen, Per Hölmich, Sonia Branci, Trine Torfing,
Lasse Ishøi, Michael Bachmann Nielsen, Kristian Thorborg.

Plain AP and lateral hip radiographs serve as the first-line imaging modality for athletes with long-standing hip and/or groin pain,[15] due to their accessibility and ability to quickly provide an overall visualization of the pelvis and hips.[13,15] From these radiographs, well-defined hip-related parameters and findings (e.g., LCEA, alpha angle) are recommended by experts to classify hip joint-related groin pain.[13,15] However, the certainty of these classifications may be negatively impacted by poor reliability.[18] It is therefore essential to establish both relative and absolute reliability data of these parameters in the settings where they are used.[17,18] Currently, absolute reliability of hip-related parameters is still unclear in athletic populations.[21]

The AP radiograph also visualize the pubic symphysis and adjacent bone.[22] which can be evaluated using the Aspetar Pubic Symphysis Radiographic Scoring Protocol.[22] In pain-free, male elite football players, the relative intra- and inter-rater reliability of the Aspetar protocol range from slight to substantial,[22] and before Study II the clinical relevance of findings scored with the protocol was still unknown.[22] The reliability of the Aspetar protocol is influenced by only including healthy elite athletes,[166] and using the same radiologists for both developing the protocol and rating radiographs for the reliability analyses.[22] Therefore, the reliability of the Aspetar protocol need further investigation beyond the development study, by independent radiologist and in athletes with and without long-standing groin pain, and the clinical relevance also needs to be established.[17,18]

First, Study I established the relative and absolute intra- and inter-rater reliability of the pubic-related radiographic findings from the Aspetar protocol,[234] as well as commonly used hip joint-related radiographic findings.[234] Then, Study II determined the prevalence of the pubic-related radiographic findings and compared them between athletes with and without long-standing groin pain.[235]

The aims of Study I were to assess relative and absolute intra- and inter-rater reliability of 1) pubic-related radiographic findings scored with the Aspetar protocol;[234] and 2) hip-related radiographic findings scored with currently used methods.[234]

The aims of Study II[235] was to 1) compare the prevalence of pubic-related radiographic findings between male football players with long-standing groin pain, asymptomatic male football players and asymptomatic male non-football athletes;[235] 2) explore associations between the total number of pubic-related radiographic findings and groin pain presence, pain intensity, and disability;[235] and 3) explore how individual pubic-related radiographic finding influence groin pain intensity and disability in football players with long-standing groin pain.[235]

METHODS

Study design and setting

Study I[234] and II[235] originate from a single project aimed at re-evaluating clinical data and diagnostic imaging from a large project on hip and groin pain in male football players conducted in 2010-2012 (H-2-2010-127).[3,148] The 2012 Project surveyed 700 football players about hip and groin pain,[3,31,189] and athletes with hip and/or groin pain could self-refer to an extensive assessment at an orthopedic department, at a public hospital.[8,114,148,236,237] The assessment included a clinical examination, radiographic examinations and magnetic resonance imaging as well as assessment of muscle strength and range of motion.[8,114,148,236,237] The 2012 project also recruited male football players and male non-football athletes without hip and groin pain.[114,148] Participants gave informed consent when they were included in the 2012 project.[8,114,148,236,237] Study I[234] and II[235] were approved by the Danish National Committee on Health Research Ethics (NVK 2117722), and conducted per the Declaration of Helsinki[238] with data management approved by the Capital Region of Denmark Data Agency (P-2021-497).[234,235]

Study I was a reliability study that pooled radiographs of athletes with and without groin pain.[234] Study II was an explorative cross-sectional study that compared male football players with long-standing groin pain, asymptomatic male football players and asymptomatic male non-football athletes.[235] From the 2012 project, study I[234] and II[235] included data from the questionnaires, clinical examinations, 5SST, and HAGOS, while radiographs were accessed in the Agfa IMPAX Client (Agfa-Gevaert Group, Belgium) to generate new data (Figure 7).[234,235]

The following sections describe the participants, radiographic examination procedure and findings, radiographic severity score, clinical examination, 5SST, HAGOS, and descriptive questionnaire.

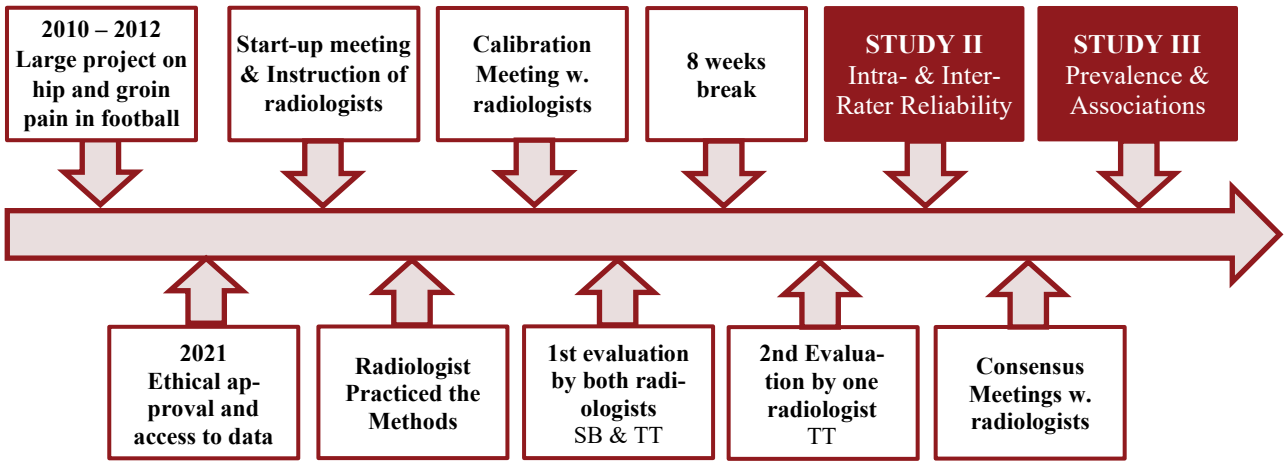


Figure 7 Flow for Study I and Study II

Participants

Studies I and II included male football players with groin pain, asymptomatic male football players, and asymptomatic male non-football athletes.[234,235] The inclusion criteria for symptomatic football players varied slightly between the studies. The three groups were matched by sex, age, and athletic exposure.[234,235] Having two asymptomatic groups, one matched by sport, allowed to determine whether football influenced any differences between symptomatic and asymptomatic groups.[148,235] The 2012 project recruited symptomatic and asymptomatic football players from a pool of 700 male senior players (18+ years) from 40 sub-elite football clubs (tier 2-5) in Denmark.[3,31,189] While asymptomatic non-football athletes were recruited from sports clubs, educational institutions, and fitness centers.[148,235] The inclusion and exclusion criteria were assessed during clinical examinations, irrespective of self-reported symptoms.[235]

The inclusion criteria were as follows.

Symptomatic football players

Study I: Male, ≥ 18 years old, participating in 2-4 weekly football sessions, and experiencing groin pain during football or running.[234]

Study II: In addition to the above, players had to report groin pain lasting ≥ 6 weeks.[235]

Asymptomatic football players (both studies)

Male, ≥ 18 years old, participating in 2-4 weekly football sessions, with no hip or groin pain in the past year.[234,235]

Asymptomatic non-football athletes (both studies)

Male, ≥ 18 years old, participating in 2-4 weekly training sessions, had no hip or groin pain in the past year, had not played football regularly in the past 10 years, and did not practice handball, rugby, ice hockey or similar sports.[234,235]

The exclusion criteria were as follows.

Systemic disorders, obesity, depression, alcohol or drug abuse, and other conditions that may cause groin pain or referred groin pain e.g. infection, low back pain, inguinal hernia.[234,235]

Radiographic examination procedure

In 2010-2012, each player underwent a conventional radiographic examination of the hip and pelvis, which included one AP pelvic radiograph and one cross-table lateral hip radiograph per hip, each with a radiation dose of 0.5 to 0.75 mSv.[234,235] Details of player positioning for the AP radiograph are provided below and are illustrated in Figure 8. The cross-table lateral hip positioning is described in the supplementary material, as this view was used exclusively for assessing the hip joint.

Positioning for AP Radiographs

The players stood with their weight evenly distributed, feet hip-width apart, and legs internally rotated by 15°, with toes almost touching (Figure 8).[234,235] The buttocks contacted the film, the pelvis kept a nearly neutral inclination, and the body was symmetrically placed in front of the x-ray beam.[234,235]



Figure 8 Patient positioning for the AP pelvic view radiograph. Reproduced from https://knoglebogen.dk/ Sources: https://knoglebogen.dk/e/6 and https://knoglebogen.dk/e/87

Radiological evaluation procedure

The radiographs were evaluated by two experienced musculoskeletal radiologists, Sonia Branci (SB), with 11 years of experience and Trine Torfing (TT) with 31 years of experience.[234,235]Although neither had prior experience with the Aspetar pubic symphysis radiographic scoring protocol, both had experience in evaluating hip-related radiographic findings.[234,235] To standardize the evaluations, the radiologists underwent through training in both the Aspetar protocol and the hip-related radiographic findings (Figure 7, Figure 1 in Study I).[234,235] Training consisted of instructions by Per Hölmich (PH), orthopedic surgeon specialized in hip and groin pain and senior author of the Aspetar protocol.[22] Under supervision by PH, SB, and TT then practiced the methods using 10 randomly selected radiographs from patients seen by PH in the outpatient clinic.[234] This was followed by practice on 10 study sample radiographs and a calibration meeting to reach a consensus on scoring methods.[234]

Evaluations were conducted independently, in randomized sequences, blinded to prior data and collected using a standardized case report form in REDCap.[234,235] Initial evaluations of pubic-related radiographic findings and dichotomous hip joint-related radiographic findings was performed from June 1-30, 2022.[234] Eight weeks later, TT performed a second evaluation from August 15-29, 2022.[234]

Afterwards three consensus meetings were held to resolve disagreements and to establish a final consensus-based dataset.[234,235] Due to technical issues the continuous hip joint-related radiographic findings were evaluated later, between November 25, 2022, to December 15, 2023.[234] A detailed overview of the radiographic evaluation process is included in the Study I manuscript.[234]

Radiographs were excluded based on image quality and patient positioning without further criteria being applied. AP radiographs were excluded from the pubic symphysis scoring if gonad shields covered the symphysis or inferior pubic rami[234,235] and from hip joint scoring if pelvic tilt showed a pubic symphysis-to-sacrococcygeal distance of less than 25 mm or more than 55 mm.[234,235]

Intra-rater reliability was based on TT's first and second evaluations,[234] while inter-rater reliability was assessed using the first evaluations from TT and SB,[234] to minimize practice effect bias.[21] The consensus dataset was used to determine the prevalence of findings and explore associations with long-standing groin pain, pain intensity and disability.[235]

Pubic-related radiographic findings and parameters

The Aspetar pubic symphysis scoring protocol provides standardized definitions for evaluating radiographic findings at the pubic symphysis joint on AP radiographs of male athletes.[22] It includes five main findings (bone lucency, proliferation, fragmentation, sclerosis, and pubic joint space width) with ten subclassifications (Figure 9A–9F).[22] All definitions are summarized below:

Pubic-related radiographic findings defined in the Aspetar Pubic Symphysis Scoring Protocol.[22]

Bone lucency (Figure 9A): *"A clear area of decreased attenuation compared to the surrounding bone, which corresponds to an erosion-like configuration and/or cyst.[22]"*

Erosion-like configuration (ELC): *"Irregularities of the cortical bone surface, potentially accompanied by loss of the adjacent trabecular bone.[22]"*

ELC was subclassified as follows:

Superior/Central ELC*: "ELC at the superior two thirds of the joint surface.[22]"*

Inferior ELC: *"ELC at the lower third of the joint surface – If the entire lower half was considered to have an erosion-like configuration, both of the above were scored as positive[22]"*

Cysts: "*Areas of bone lucency with a sclerotic rim inside the trabecular bone compartment, without accompanying cortical bone surface irregularity.[22]"*

Proliferation (Figure 9B): *"Clear osteophyte outgrowths at the joint margins or within the articular space.[22]"*

Proliferation was subclassified as follows:

Superior proliferation*: "This can be considered "bone spurs" or classified as "pubic beaking" when bilateral. Well rounded (smooth) bumps at the superior aspect, even if asymmetrical in size,*

were not considered proliferation. For superior proliferation, the "sharpness" of the superior bone corner angle was used for assistance with angles higher than 90 deg. (obtuse angle) considered "rounded" and scored negative/absent, whereas angles lower than 90 deg. (acute angle) were considered "sharp" and scored as positive/present.[22]"

Central proliferation*: "Proliferation at the central portion of the articular space.*[22]"

Inferior proliferation*: "Similar considerations as superior proliferation.*[22]"

Fragmentations (Figure 9C): "*Clear loose fragment(s) within the symphyseal joint space, or at the inferior medial margin of the pubic bone.*[22]"

Fragmentation was subclassified as follows:

Central fragmentation*: "Clear loose fragment(s) within the symphyseal joint space.*[22]"

Inferior fragmentation*: "Clear loose fragment(s) at the inferior medial margin of the pubic bone.*[22]"

Sclerosis (Figure 9D): *"A clear area of increased attenuation of the subchondral bone compared to the surrounding bone, corresponding to an area of increased bone density.*[22]"

Pubic joint space width (PJSW, Figure 9E): *"Symphyseal joint space measured in millimeters at the narrowest point of the joint surfaces.*[22]"

Pubic joint space width was subclassified as follows:

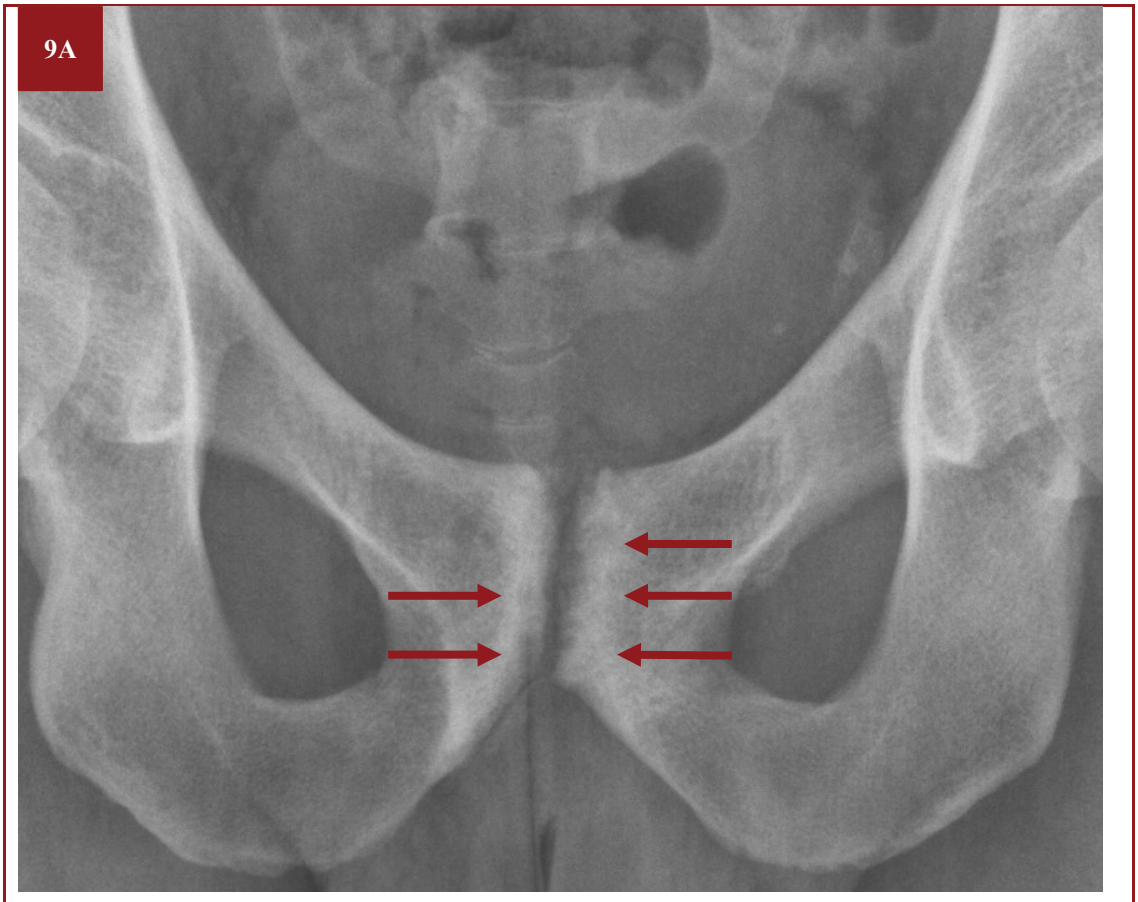
Narrow Joint Space Width*: "... if measured to less than 3mm.*[22]"

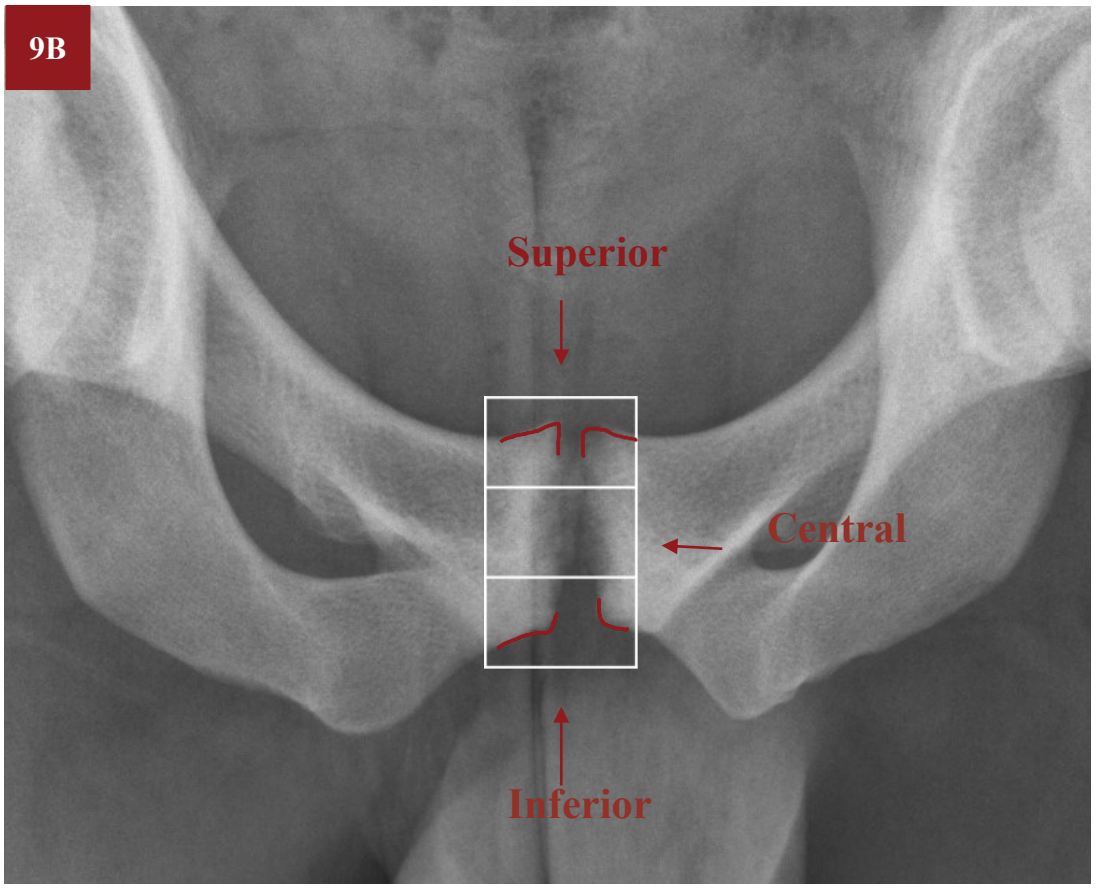
Findings were scored dichotomously as either absent or present, except for PJSW, which was measured in millimeters and rounded to nearest 0.5 mm.[234,235] Findings were scored as present only if they were clearly visible;[234,235] otherwise, they were scored as absent.[234,235] In cases of uncertainty, findings were scored as absent.[234,235] For the main findings that included subclassifications, radiologists scored only the subclassifications, as they determine the presence of the main findings.[234,235] The main findings were derived from the subclassifications using the following rules:[234,235]

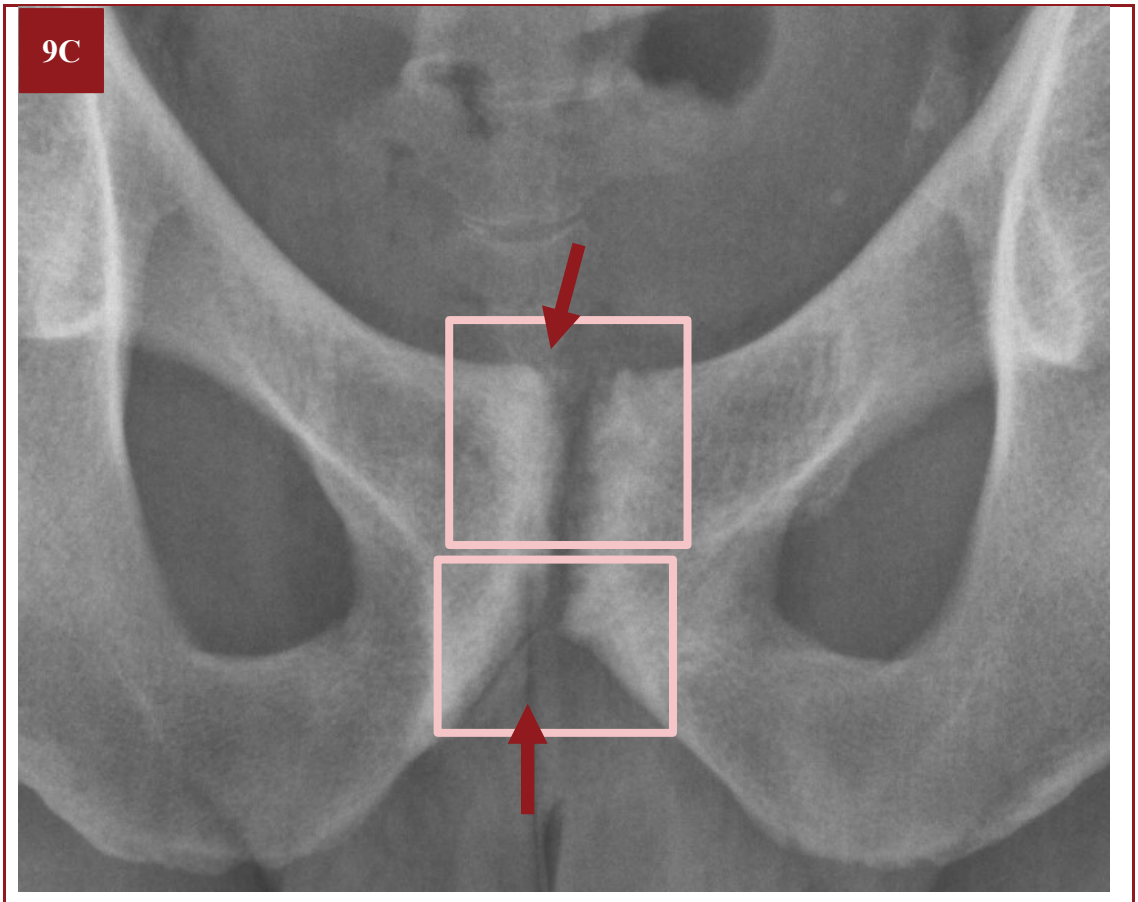
1) If any of the subclassifications are present, the main finding is present.

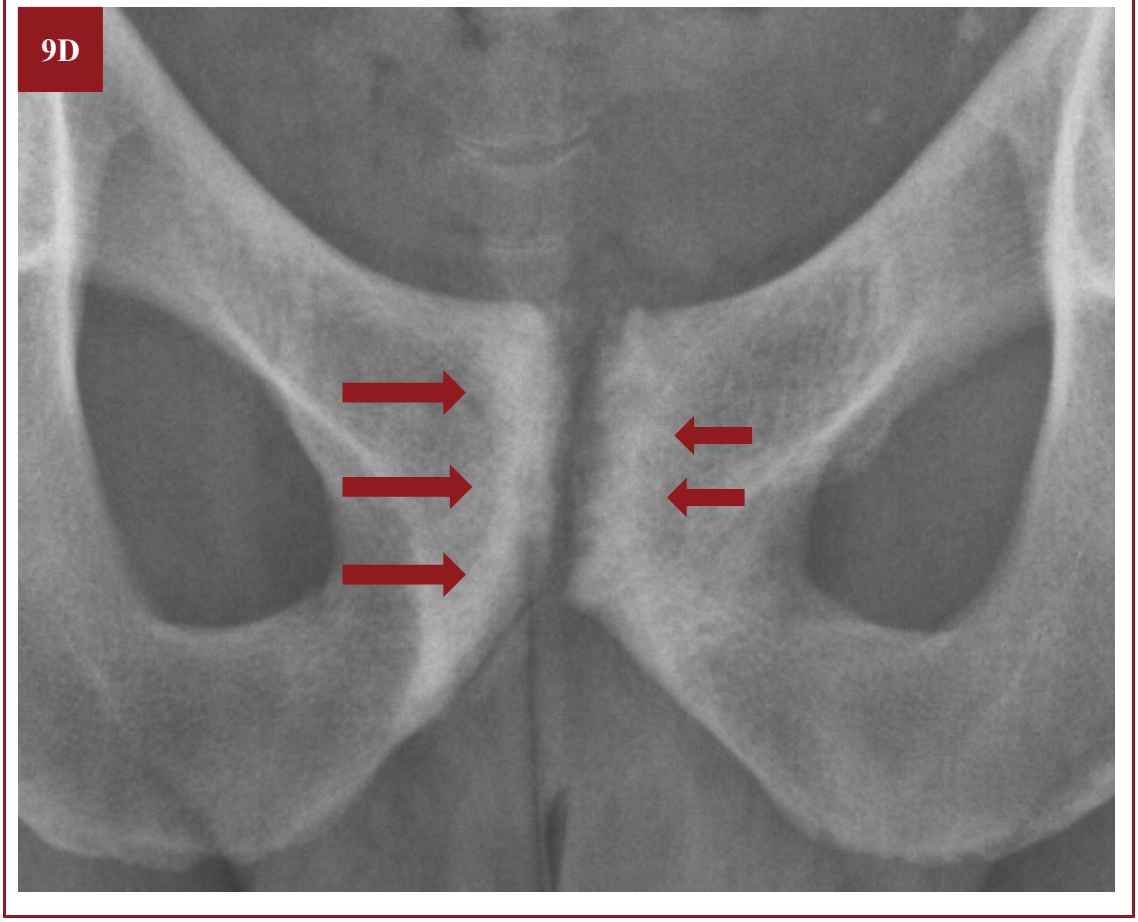
2) If all subclassifications are absent, the main finding is absent.

3) If all subclassifications are missing, or there is a mix of absent and missing subclassifications without any positive subclassifications, the main finding is missing.


9A


9B
Superior
Central
Inferior


9C


9D

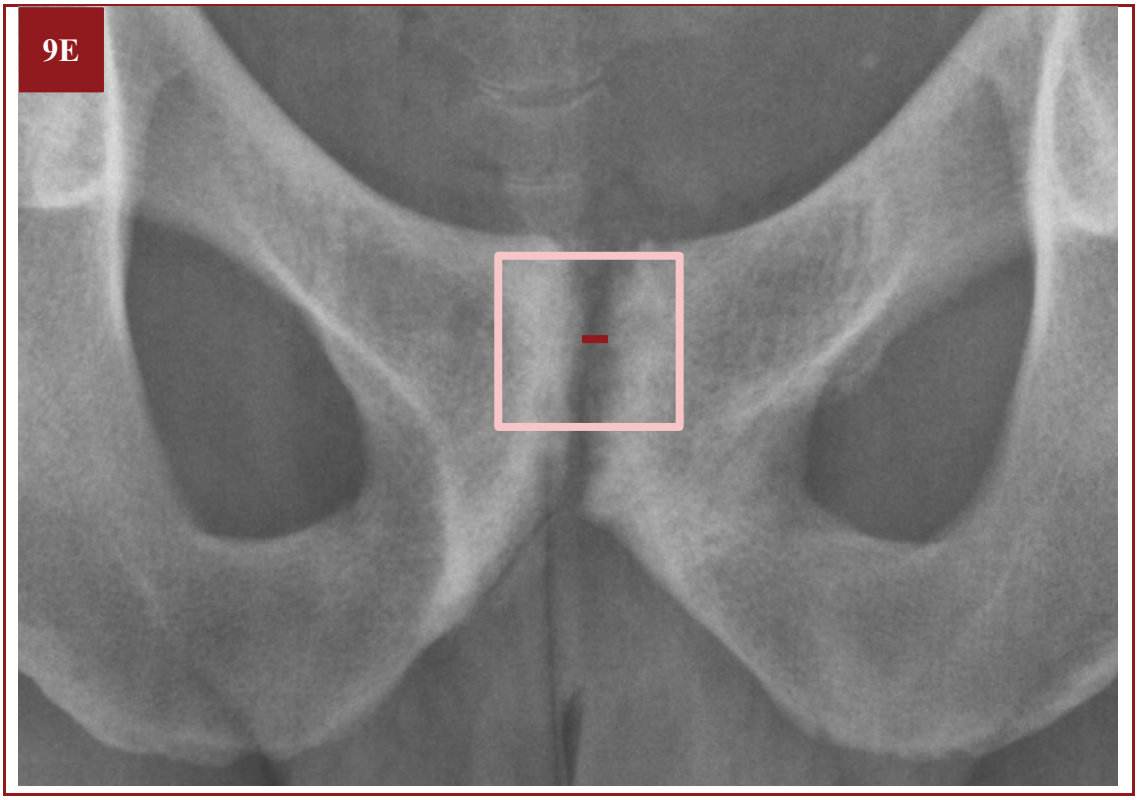


Figure 9A to 9F Pubic-related radiographic findings. 9A Bone lucency. 9B Proliferation. 9C Fragmentation. 9D Sclerosis. 9E Pubic Joint Space Width. Adapted from "Figure 2 Pubic-related radiographic findings as described by Serner et al[25]" by Nielsen et al.[235] *Scandinavian Journal of Medicine & Science in Sports*. 2025; 35: e70068. Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1111/sms.70068

Pubic symphysis radiographic severity score

In Study II, four versions of the Pubic Symphysis Radiographic Severity (PSRS) Score were developed to summarize the overall extent of radiographic findings[235] which may offer greater clinical value than using individual findings in isolation, similar to the grading scale by Besjakov et al.[135] We constructed the PSRS Scores by aggregating dichotomous data across four levels: individual, side, main location, and subclassification.[235] This resulted in four summary scores that reflected varying levels of detail, such as individual-level main findings versus side-level subclassification findings (Table 2).[235] The narrow pubic joint space was included only in PSRS scores 1 and 3, as PJSW (the parent finding) was only assessed at the individual level. The PSRS Scores were used exclusively in Study II.[235]

Table 2 Pubic Symphysis Radiographic Severity Score. Adapted from "Figure 2 Pubic-related radiographic findings as described by Serner et al[25]" by Nielsen et al.[235] *Scandinavian Journal of Medicine & Science in Sports*. 2025; 35: e70068. Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1111/sms.70068

Version	Assessment level	Included Findings	Range
PSRS Score 1	Each main finding assessed on a person level.	Bone lucency (0-1) Proliferation (0-1) Fragmentation (0-1) Sclerosis (0-1) Narrow joint space (0-1).	0-5
PSRS Score 2	Each main finding assessed on a side level, that is left and right in total.	Bone lucency (0-2) Proliferation (0-2) Fragmentation (0-2) Sclerosis (0-2)	0-8
PSRS Score 3	Each subclassification finding assessed on a person level.	Superior/central ELC (0-1) Inferior ELC (0-1) Cysts (0-1) Superior proliferation (0-1) Central proliferation (0-1) Inferior proliferation (0-1) Central fragmentation (0-1) Inferior fragmentation (0-1) Sclerosis (0-1) Narrow joint space (0-1)	0-10
PSRS Score 4	Each subclassification finding assessed on a side level, that is left and right in total.	Superior/central ELC (0-2) Inferior ELC (0-2) Cysts (0-2) Superior proliferation (0-2) Central proliferation (0-2) Inferior proliferation (0-2) Central fragmentation (0-2) Inferior fragmentation (0-2) Sclerosis (0-2)	0-18

Hip-related radiographic findings and parameters

The radiologists evaluated the alpha angle (AA) on cross-table lateral hip (CTLH) radiographs, whereas the lateral center-edge angle (LCEA), acetabular index angle (AI), ischial spine sign (ISS), posterior wall sign (PWS), crossover sign (COS), and hip joint space width (HJSW) were assessed on AP radiographs.[234,235] These hip-related findings were evaluated based on current clinical practice[234,235] and in accordance with the Lisbon agreement on femoroacetabular impingement imaging from the European Society of Musculoskeletal Radiology.[15,20,164] Athletes were classified with cam morphology, pincer morphology, borderline hip dysplasia, and hip dysplasia based on AA, LCAE, AI, ISS, PWS and COS.[15,20,164] Detailed descriptions can be found in Study I manuscript and supplementary materials.[234] Study I assessed the relative and absolute intra- and inter-rater reliability of the hip-related findings and parameters,[234] while they were used as descriptive variables in Study II.[235]

Clinical examination and classification of clinical entities

A bilateral clinical examination was conducted by Kristian Thorborg, a physiotherapist with a decade of expertise in hip/groin pain.[235] The examination followed the framework established by Hölmich et al.[239] and included palpation, resisted muscle tests, stretching, and orthopedic tests (Study II Table S1).[8,235] These tests were performed as pain provocation tests and deemed positive only if they elicited "known" and "recognizable" groin pain associated with football and running, either during or after testing.[8,235] Pain that did not align with the athlete's familiar symptoms was considered as negative.[8,235] Based on the 2012 clinical examination data, football players with long-standing groin pain were retrospectively classified with clinical entities of groin pain using the 2015 Doha Classification system (Table 3).[8,12,235] Classifying clinical entities strictly from pain provocation tests data has fair to substantial relative inter-rater reliability: Adductor-related: $\kappa = 0.49$, Iliopsoas-related: $\kappa = 0.73$, Inguinal-related: $\kappa = 0.48$, Pubic-related: $\kappa = 0.23$.[6]

Table 3 Classification of clinical entities based on pain provocation tests. Adapted from "*Table 2 Clinical entities of groin pain according to the 2015 Doha agreement*" by Nielsen et al.[8] Musculoskeletal Science and Practice 63 (2023) 102719 Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) https://doi.org/10.1111/sms.70068

Clinical Entity	Pain provocation tests
Adductor-related groin pain	A positive adductor longus palpation OR gracilis palpation AND a positive squeeze test with 0° hip flexion
Iliopsoas-related groin pain	A positive suprainguinal or infrainguinal Psoas palpation
Inguinal-related groin pain	A positive conjoint tendon palpation or external inguinal ring palpation
Pubic-related groin pain	A positive symphysis palpation
Hip joint-related groin pain	Not classified.
Other causes for groin pain	Not classified.

† Tenderness is "discomfort or pain when the area is palpated, and the athlete recognizes this to be their specific injury pain".[12]

The Copenhagen 5-Second Squeeze Test

The 5SST was used to evaluate provoked groin pain intensity on a verbal numerical rating scale (NRS) from 0 ("no pain") to 10 ("worst pain imaginable"), as described above.[31] Players lay supine with straight legs, toes pointing upward, and hips at 0° flexion (Figure 6A).[31] An assessor placed a forearm between the player's ankles, and the player performed a maximal bilateral long-lever hip adduction squeeze against the forearm for five seconds.[31] The 5SST has almost perfect relative test-retest reliability (CCC 0.90).[31]

The Copenhagen Hip and Groin Outcome Score

HAGOS was used to assess patient-reported hip and groin-related disability from 0 (extreme symptoms) to 100 (no symptoms) across the subscales Pain, Symptoms, ADL, Sport, PA and QoL,[72] as described above. Based on a recent construct validation of HAGOS using modern test theory,[188] both Study I and II used the revised HAGOS scores, while the original HAGOS scores are in the supplementary materials.[235]

Descriptive questionnaire

A paper-based descriptive questionnaire collected data on athletes' name, social-security number, age (years), height (cm), body mass (kg), preferred kicking leg (right/left), football participation status (playing/not-playing), weekly hours and sessions of football or sport training.[235] The questionnaire also included questions on symptom duration (months), pain location (right side, left side, or bilaterally) and the worst pain in the previous week, measured using a NRS as above.[235]

Sample size considerations

In the 2012 project, 88 athletes underwent clinical examinations with 86 completed radiological assessments corresponding to 86 symphysis joints and 172 pubic bones.[234] In Serner et al.,[22] the relative inter-rater reliability ranged from $\kappa = 0.18$ to $\kappa = 0.67$, with prevalence rates between 2% and 61%.[22] Based on these estimates, assuming all radiographs were of acceptable quality and no bias between the radiologists,[240] a sample size of 86 athletes was sufficient to detect significant kappa values, with lower confidence interval bounds ranging from 0.02 to 0.50.[234]

For study II, the 88 athletes included 47 symptomatic football players, 20 asymptomatic football players and 21 asymptomatic non-football athletes, assuming complete datasets and acceptable radiographs.[235] This sample size allowed for the detection of a 30% difference in prevalence between the groups, representing a moderate to large effect size (Cohen's $h = 0.75$).[235] This calculation was conducted using the "pwr" R-packed, a χ^2-test, an $\alpha = 0.05$ and a power = 0.80.[235]

Statistics

Statistical analyses were performed using R version 4.3.0 and RStudio 2022.12.0+353. Descriptive statistics were used to summarize athlete characteristics.[241] Study I used data from the radiologist evaluations,[234] whereas Study II used a dataset generated from consensus meetings (Figure 7).[235]

For dichotomous radiographic findings the relative reliability was assessed using unweighted Cohen Kappa (κ),[166] the prevalence index (PI)[166] and bias index (BI).[166] Absolute reliability was expressed as overall, positive, and negative agreement, with prevalence estimated as total true positive ratings.[22,166] For continuous radiographic findings the relative reliability was assessed using intraclass

correlation coefficients (ICC) from single measurement, absolute agreement, and two-way random-effects models (ICC 2.1).[242] Absolute reliability was expressed as standard error of measurement (SEM),[19] SEM %, minimal detectable change (MDC),[19] the individual- and group-level MDC (MDC_{Ind} and MDC_{Group}),[19] and by inspecting Bland-Altman plots with 95% Limits of Agreement (LOA).[243] κ and ICC values were interpreted as poor (<0.00), slight (0.00-0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80) and almost perfect (0.81-1.00).[244]

Between-group comparisons of pubic-related findings used data from individual-level findings, with sensitivity analysis comparing right-sided, left-sided, and symptomatic findings.[235] Groups were compared using χ^2-tests and estimation of odds ratios with 95% confidence intervals.[241] PJSW and PSRS Scores were compared using one-way analysis of variance (ANOVA) with Tukey's test.[241] In football players with groin pain, the PSRS Scores relationship with 5SST and HAGOS were investigated using LOESS curves and Spearman's correlation coefficients (ρ), interpreted as negligible (0.0–0.10), weak (0.10–0.39), moderate (0.40–0.69), strong (0.70–0.89), or very strong (0.90–1.00).[245] Multivariate linear regression was used to explore associations between main pubic-related radiographic findings and the 5SST or HAGOS subscales.[241] In Study II, the primary conclusions were based on raw p-values. Adjusted p-values[246] were also reported to address the risk of Type-1 error.

RESULTS

Study I Participants

We evaluated the radiographs of 86 athletes (Table 4 and Figure 10). Up to 38 athletes had excluded or missing data across the radiographic findings and parameters. For pubic-related findings, 248 (10%) of the 2494 data points were excluded or missing. Five anteroposterior radiographs were excluded: four due to gonad shields obscuring the pubic joint/inferior pubic rami and one due to improper positioning. Data points were missing due to unspecified reasons (n = 77), missing subclassification data (n = 14), unclear pubic joint lines (n = 4), gonad shield coverage (n = 3), overlaying structures (n = 3), and rotation of the pelvis or underexposure of the radiograph (n = 2). Details of the excluded hip-related radiographic data can be found in Study I, Supplementary File Section 4. Missing data.

Table 4 Descriptive data of athletes in Study I.

	All	Symptomatic football players	Asymptomatic football players	Non-football athletes
N	86	45	20	21
Age, years	24.3 (3.88)	24.3 (3.03)	23.0 (2.62)	25.7 (5.80)
Height, centimeters	181 (5.69)	181 (5.74)	181 (5.30)	181 (6.18)
Body mass, kilograms	78.2 (7.16)	77.1 (6.87)	78.5 (6.04)	80.3 (8.47)
BMI, kg/m^2	23.8 (1.92)	23.4 (1.42)	24.0 (1.63)	24.4 (2.80)
Training hours/week	6.0 (4.5 to 7.5)	6.0 (4.5 to 6.0)	6.0 (4.5 to 6.0)	7.5 (4.5 to 9.0)
Training sessions/week	4.0 (3.0 to 4.0)	4.0 (3.0 to 4.0)	4.0 (3.0 to 4.0)	3.0 (3.0 to 3.0)
HAGOS Pain	93.8 (84.4 to 100)	84.4 (68.8 to 93.8)	100 (98.4 to 100)	100 (100 to 100)
HAGOS Symptoms	79.2 (62.5 to 95.8)	66.7 (50.0 to 75.0)	91.7 (83.3 to 100)	95.8 (87.5 to 100)
HAGOS ADL	93.8 (81.3 to 100)	81.3 (62.5 to 93.8)	100 (100 to 100)	100 (100 to 100)
HAGOS Sport/Rec	70.8 (45.8 to 100)	50.0 (37.5 to 62.5)	100 (91.7 to 100)	100 (100 to 100)
HAGOS Participation	75.0 (37.5 to 100)	37.5 (12.5 to 62.5)	100 (100 to 100)	100 (100 to 100)
HAGOS QOL	81.3 (43.8 to 100)	50.0 (31.3 to 68.8)	100 (96.9 to 100)	100 (100 to 100)

Data are presented as mean (SD). †= Median [interquartile range]

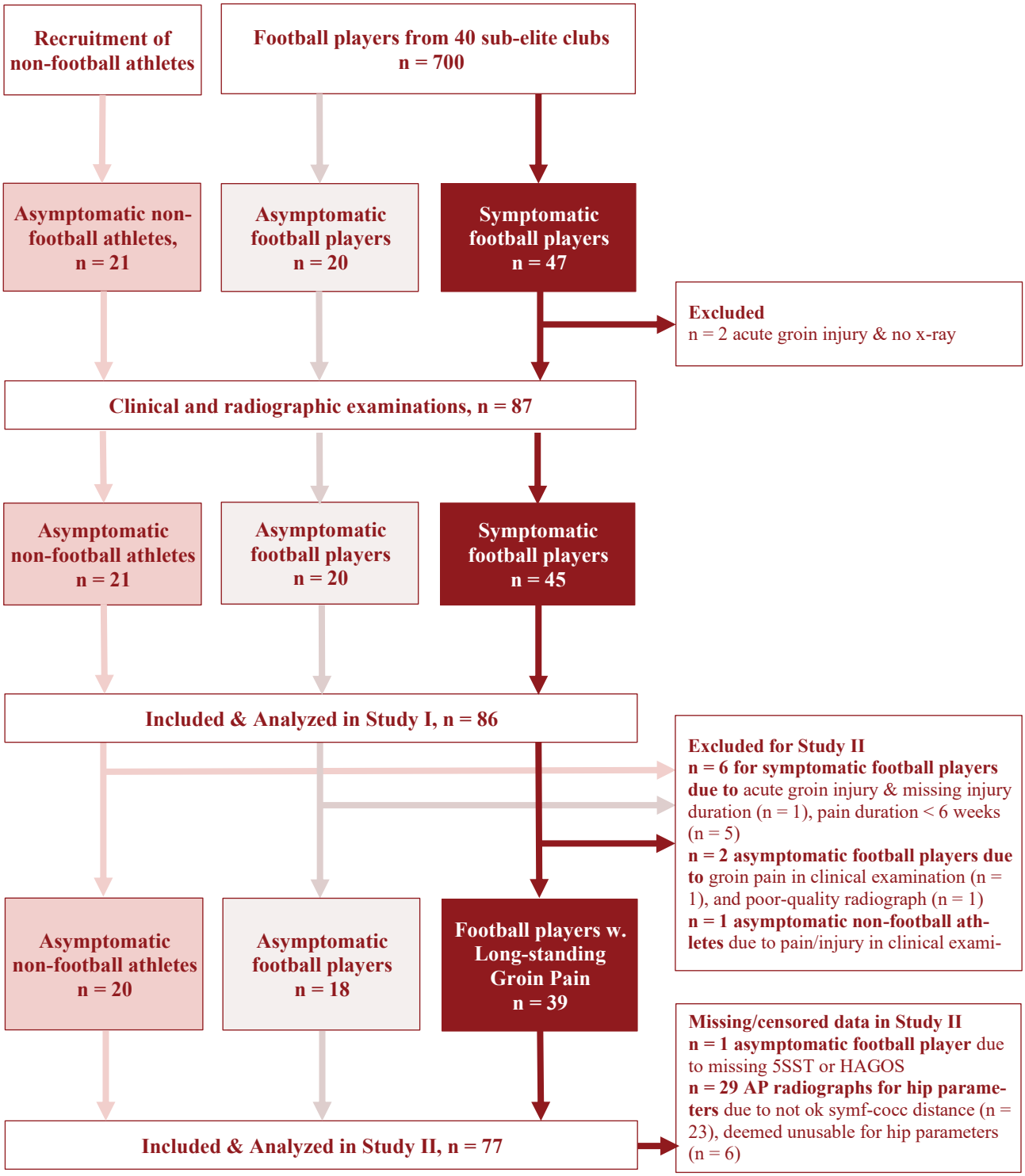


Figure 10 Participant flow in Study I and Study II

Intra-rater reliability of Pubic-Related Radiographic Findings

The relative intra-rater reliability for the main findings varied from moderate for proliferation (κ = 0.49) and fragmentation to substantial for bone lucency, sclerosis, and PJSW (κ = 0.60–0.63 and ICC = 0.76). For subclassifications, the relative intra-rater reliability ranged from slight for cysts (κ = 0.18) to substantial for ELC, superior/central ELC, superior proliferation, central fragmentation, and narrow joint space width (κ = 0.63–0.75). The prevalence index was high (close to 1) for cysts, central proliferation, fragmentation (main and subclassifications), and narrow joint space. The bias index was low (close to zero) for all the findings. For absolute reliability, the overall agreement was high (≥ 75%) across the findings; however, in eight of 14 findings, the negative agreement exceeded the positive agreement. For PJSW, the absolute reliability showed an SEM% of 16% and MDC% of 43% for individuals and 5% for groups. Bland-Altman plots are provided in Study I Appendix Figure 5a–9b. The intra-rater reliability statistics are presented in Table 5.

Table 5 Intra-rater reliability of radiographic pubic-related parameters.

	n	κ (95% CI)	Interpretation	Overall Agreement	Positive Agreement	Negative Agreement	Prevalence	PI	Bias Index
Bone lucency	163	0.60 (0.45, 0.75)	Substantial	82%	87%	73%	58%	0.34	0.10
ELC	164	0.63 (0.49, 0.78)	Substantial	83%	87%	76%	55%	0.28	0.11
Superior/central ELC	161	0.75 (0.60, 0.91)	Substantial	88%	88%	87%	46%	0.04	0.02
Inferior ELC	163	0.58 (0.43, 0.73)	Moderate	79%	79%	78%	40%	0.02	0.12
Cysts	159	0.18 (0.03, 0.33)	Slight	79%	30%	88%	4%	-0.70	0.07
Proliferation	161	0.49 (0.34, 0.65)	Moderate	75%	76%	73%	40%	0.05	0.09
Superior	161	0.71 (0.56, 0.86)	Substantial	86%	82%	89%	31%	-0.24	0.07
Central	160	0.56 (0.41, 0.71)	Moderate	92%	61%	95%	6%	-0.79	0.03
Inferior	160	0.41 (0.26, 0.57)	Moderate	76%	58%	83%	16%	-0.44	0.01
Fragmentation	162	0.49 (0.33, 0.64)	Moderate	93%	52%	96%	4%	-0.86	-0.01
Central	166	0.69 (0.54, 0.84)	Substantial	97%	71%	98%	4%	-0.90	-0.01
Inferior	162	-	-	95%	0%	97%	0%	-0.95	0.01
Sclerosis	162	0.63 (0.48, 0.78)	Substantial	84%	75%	88%	23%	-0.37	0.05
Narrow joint space†	80	0.61 (0.40, 0.83)	Substantial	86%	70%	91%	16%	-0.54	0.04

	n	ICC (95% CI)	Interpretation	Rating 1 Mean (SD)	Rater 2 Mean (SD)	Mean Diff (95% CI)	SEM (SEM%)	MDC	MDC % Indi / Group
Pubic joint space width (mm)¤	83	0.76 (0.68, 0.83)	Substantial	3.4 (1.2)	3.4 (1.0)	0.0 (-0.2, 0.2)	0.5 (16)	1.5	43 / 5

ELC = Erosion-like Configuration n = total number of sides with full data, †For narrow joint space n = number of participants with data, CI = confidence interval, prevalence = total number of true positive ratings, PI = prevalence index, ICC = Intra-class correlation, SD = Standard deviation, SEM = standard error of measurement, MDC = minimal detectable change.

Inter-rater reliability of Pubic-Related Radiographic Findings

The relative inter-rater reliability for the main findings varied from fair for sclerosis ($\kappa = 0.34$) to substantial for PJSW (ICC = 0.72). For subclassifications, inter-rater reliability ranged from slight for cysts ($\kappa = 0.07$) to substantial for superior/central ELC and narrow pubic joint space ($\kappa = 0.62 – 0.72$). The overall agreement was high (≥75%) for 10 of the 14 findings, with negative agreement exceeding positive agreement for eight of the 14 findings. The prevalence index was high for fragmentation (main and subclassifications), as well as central and inferior proliferation. The bias index suggested inter-rater bias for cysts and sclerosis. For the PJSW, absolute inter-rater reliability showed an SEM% of 17% and an MDC% of 46% for individuals and 5% for groups. Inter-rater reliability statistics are presented in Table 6

Table 6 Inter-rater reliability of radiographic pubic-related parameters.

	n	κ (95% CI)	Interpretation	Overall Agreement	Positive Agreement	Negative Agreement	Prevalence	PI	Bias Index
Bone lucency	163	0.45 (0.30, 0.60)	Moderate	80%	87%	58%	66%	0.52	0.06
ELC	165	0.50 (0.35, 0.65)	Moderate	79%	85%	65%	61%	0.42	0.02
Superior/central ELC	163	0.62 (0.46, 0.77)	Substantial	81%	83%	79%	45%	0.10	0.02
Inferior ELC	164	0.53 (0.38, 0.69)	Moderate	77%	81%	72%	48%	0.19	0.05
Cysts	159	0.07 (-0.03, 0.17)	Slight	45%	34%	53%	14%	-0.18	0.46
Proliferation	165	0.42 (0.27, 0.56)	Moderate	70%	70%	71%	34%	-0.02	-0.15
Superior	165	0.53 (0.39, 0.68)	Moderate	79%	68%	84%	23%	-0.33	-0.14
Central	164	0.26 (0.12, 0.40)	Fair	79%	37%	88%	6%	-0.67	0.10
Inferior	165	0.11 (0.01, 0.20)	Slight	73%	18%	84%	3%	-0.67	-0.24
Fragmentation	167	0.30 (0.15, 0.45)	Fair	89%	36%	94%	3%	-0.83	0.02
Central	168	0.39 (0.24, 0.54)	Fair	93%	42%	97%	2%	-0.89	0.02
Inferior	167	0.31 (0.16, 0.46)	Fair	95%	33%	98%	1%	-0.93	0.00
Sclerosis	166	0.34 (0.22, 0.47)	Fair	64%	63%	65%	31%	-0.02	0.31
Narrow joint space†	52	0.72 (0.45, 0.99)	Substantial	88%	80%	92%	23%	-0.42	0.08

	n	ICC (95% CI)	Interpretation	Rating 1 Mean (SD)	Rater 2 Mean (SD)	Mean Diff (95% CI)	SEM (SEM%)	MDC	MDC % Indi / Group
Pubic joint space width (mm)¤	81	0.72 (0.62, 0.80)	Substantial	3.3 (1.0)	3.4 (1.2)	0.0 (-0.2, 0.1)	0.6 (17)	1.6	46 / 5

ELC = Erosion-like Configuration n = total number of sides with full data, †For narrow joint space n = number of participants with data, CI = confidence interval, prevalence = total number of true positive ratings, PI = prevalence index, ICC = Intra-class correlation, SD = Standard deviation, SEM = standard error of measurement, MDC = minimal detectable change.

Reliability of Hip-Related Radiographic Findings

Relative and absolute intra-rater reliability for the hip-related radiographic findings were as follows: AA showed an ICC of 0.74 (95% CI: 0.6-0.8, MDC = 15°), LCEA showed an ICC of 0.78 (95% CI: 0.7-0.9, MDC = 8°), AI showed an ICC of 0.69 (95% CI: 0.6-0.8, MDC = 7°), HJSW showed an ICC of 0.73 (95% CI: 0.6-0.8, MDC = 1 mm), COS showed a κ of 0.51 (95% CI: 0.3-0.7, overall agreement = 75%), ISS showed a κ of 0.81 (95% CI: 0.6-1.0, overall agreement = 90%), and PWS had a κ of 0.65 (95% CI: 0.5-0.8, overall agreement = 82%). See Table 2 in Study I for more details.

Relative and absolute inter-rater reliability results were as follows: AA showed an ICC of 0.17 (95% CI: -0.1 to 0.4, MDC = 33°), LCEA showed an ICC of 0.77 (95% CI: 0.6-0.9, MDC = 8°), AI showed an ICC of 0.73 (95% CI: 0.6-0.8, MDC = 7°), HJSW showed an ICC of 0.71 (95% CI: 0.6-0.8, MDC = 1 mm), COS showed a κ of 0.53 (95% CI: 0.4-0.7, overall agreement = 76%), ISS showed a κ of 0.86 (95% CI: 0.7-1.0, overall agreement = 93%), and PWS showed a κ of 0.66 (95% CI: 0.5-0.9, overall agreement = 84%). See Table 3 in Study I for more details.

Study II Participants

Of the 88 athletes, 77 had complete clinical and radiographic data for inclusion in Study II (Figure 10 and Table 7). As reported in Study II, among non-football athletes, sports participation was as follows: fitness (n = 8), running (n = 5), martial arts (n = 3), cycling (n = 1), parkour (n = 1), kayaking (n = 1), and basketball (n = 1). Symptomatic football players experienced groin pain for a median of 10 months (IQR: 5-36) and were diagnosed with a median of three (IQR: 2–4) clinical entities of groin pain. As reported in Study II, the prevalence of clinical entities was as follows: iliopsoas-related groin pain, 79%; adductor-related groin pain, 67%; inguinal-related groin pain, 61%; and pubic-related groin pain, 13%.

Table 7 Descriptive data for athletes in Study II. Adapted from "Table 2 Descriptive Data" by Nielsen et al.[235] *Scandinavian Journal of Medicine & Science in Sports*. 2025; 35: e70068Copyright via "CC-BY 4.0" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1111/sms.70068

	SYMPTOMATIC FOOTBALL PLAYERS	ASYMPTOMATIC FOOTBALL PLAYERS	ASYMPTOMATIC NON-FOOTBALL ATHLETES
n	39	18	20
Age, *years*	24.5 (3.2)	23.1 (2.7)	25.9 (5.9)
Height, *cm*	181.9 (5.7)	181.0 (4.6)	181.9 (5.8)
Weight, *kg*	77.9 (6.6)	79.1 (6.0)	80.3 (8.7)
Body Mass Index	23.5 (1.4)	24.2 (1.5)	24.3 (2.8)
Training hours pr week	5.6 (1.6)	5.6 (1.0)	7.5 (2.9)
Training sessions pr week, *median (IQR)*	4 (3-4)	4 (3-4)	3 (3-3)
Kicking Leg, right, n (%)	29 (74%)	13 (81)	18 (95)
Symptomatic side *Right / Left, n*	16 / 7	-	-
Bilateral, n(%)	14 (36%)	-	-
Pain in preceding week, *median (IQR*	8 (6-9)	0.0 (0-0)	0.0 (0-0)
5SST, *median (IQR*	5 (4-8)	0.0 (0-0)	0.0 (0-0)
HAGOS Pain, *median (IQR*	84.4 (67.2-90.6)	100.0 (96.9-100)	100.0 (100-100)
HAGOS Symptoms, *median (IQR*	62.5 (50.0-72.9)	91.7 (83.3-100)	95.8 (90.6-100)
HAGOS ADL, *median (IQR*	81.2 (62.5-87.5)	100.0 (100-100)	100.0 (100-100)
HAGOS Sport, *median (IQR*	45.8 (33.3-62.5)	100.0 (91.7-100)	100.0 (100-100)
HAGOS PA, *median (IQR*	37.5 (18.8-62.5)	100.0 (100-100)	100.0 (100-100)
HAGOS QoL, *median (IQR*	43.8 (28.1-56.2)	100.0 (93.8-100)	100.0 (100-100)
Hip-related Radiographic Findings	***Right***	***Left***	***Right***	***Left***	***Right***	***Left***
Alpha Angle	53.2 (12.6)	54.9 (10.7)	52.4 (12.6)	51.8 (12.0)	48.3 (10.5)	48.5 (11.0)
Cam morphology, n (%)	9 (23)	10 (26)	3 (17)	5 (28)	2 (10)	3 (15)
Lateral Center Edge Angle	29.8 (5.4)	30.0 (5.5)	26.9 (6.6)	28.4 (9.2)	30.2 (6.3)	30.9 (4.8)
Acetabular Index Angle	6.90 (4.4)	5.66 (4.8)	8.94 (3.6)	8.60 (4.9)	7.05 (3.8)	4.9 (3.8)
Pincer Morphology, n (%)	2 (8)	1 (4)	1 (10)	1 (10)	1 (7)	0 (0)
Borderline Hip Dysplasia, n (%)	5 (21)	5 (21)	6 (60)	3 (33)	5 (33)	1 (7)
Hip Dysplasia, n (%)	1 (4)	1 (4)	2 (20)	3 (30)	1 (7)	0 (0)
Hip joint space width, mm	5.3 (1.0)	5.1 (1.1)	4.9 (1.1)	4.7 (1.3)	5.2 (0.9)	5.3 (0.9)
Cross-Over sign, n (%)	12 (50)	14 (58)	4 (40)	6 (60)	7 (47)	7 (47)
Ischial Spine Sign, n (%)	15 (63)	14 (58)	4 (40)	6 (60)	8 (53)	9 (60)
Posterior Wall Sign, n (%)	17 (71)	19 (79)	5 (50)	6 (60)	9 (60)	8 (53)

Missing/censored data: Asymptomatic football players, n = 1, Reason: no clinical examination, 5SST or HAGOS, n for the Hip-related Radiographic Findings: for anteroposterior images: symptomatic football players n = 24, asymptomatic football n = 10, asymptomatic non-football n = 15.

Prevalence of Pubic-Related Radiographic Findings

Figure 11 illustrates the prevalence of pubic-related radiographic findings in the three groups. Significant differences were observed among the groups due to the low prevalence among the asymptomatic non-football athletes, whereas no significant differences were found between football players with and without long-standing groin pain (Figure 11). The findings were consistent across all sensitivity and post-hoc analyses (Table A2, Tables A7–A9 in Study II).

Pubic Symphysis Radiographic Severity Scores

Comparing PSRS Scores between groups showed similar results. There were no differences in PSRS Scores between symptomatic and asymptomatic football players, but asymptomatic non-football athletes had significantly lower scores (Table A3 in Study II). For symptomatic football players, the PSRS Score 1 (0-5) was negatively correlated with HAGOS Pain and HAGOS QoL. However, when moving from PSRS Score 1 (range: 0-5) to PSRS Score 4 (range: 0-18) these correlations diminished (Table A4, Figure A1 to Figure A16 in Study II).

5SST, HAGOS and Pubic-Related Radiographic Findings

The presence of bone lucency and narrow pubic joint space was negatively associated with the 5SST (Table A5 in Study II), while the presence of sclerosis was negatively associated with HAGOS Pain and HAGOS ADL (Table A6 in Study II).

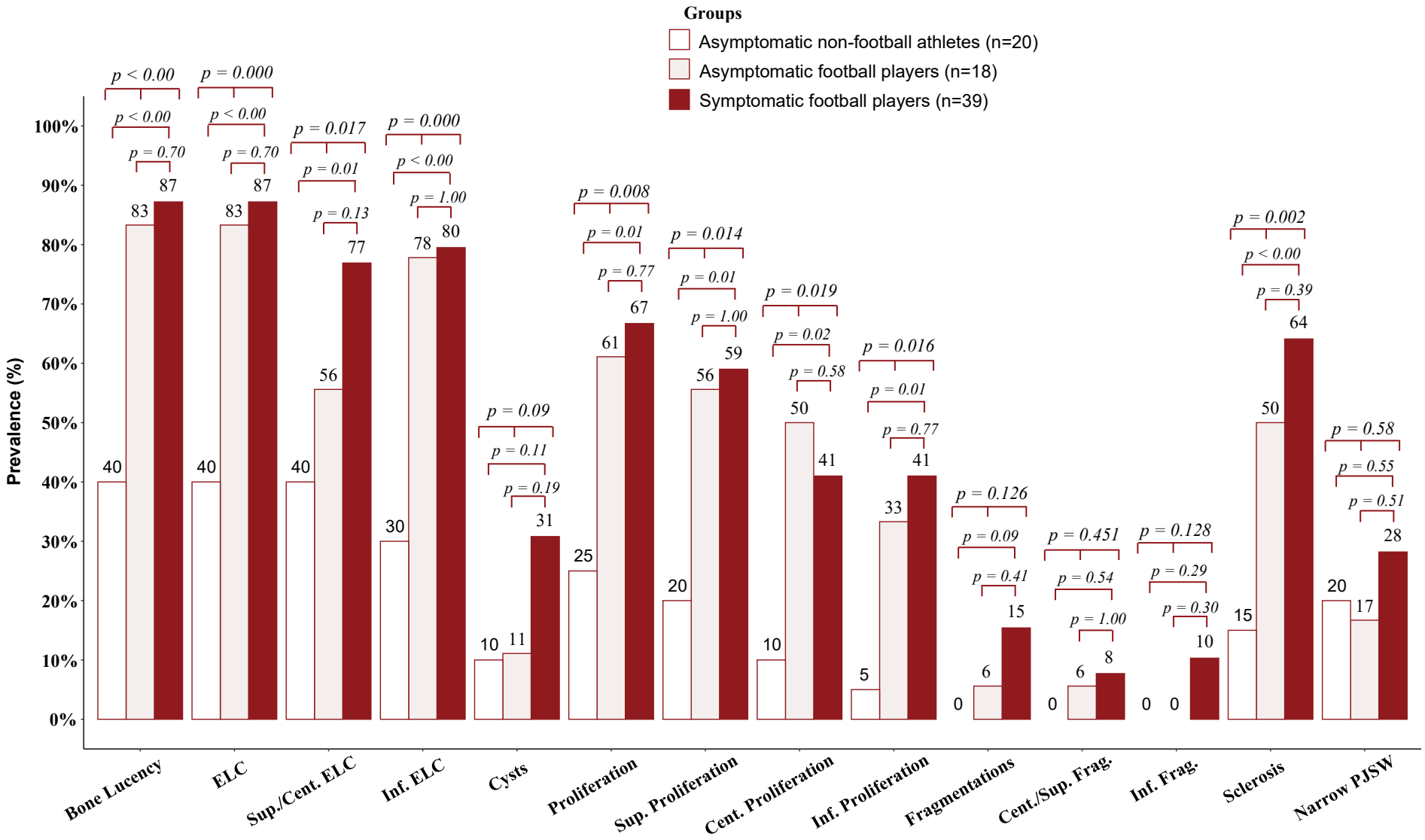


Figure 11 Prevalence of pubic-related radiographic findings. P-values are from χ2-tests across all three groups. ELC = Erosion-Like Configuration, Sup. = Superior, Cent. = Central, Inf. = Inferior, PJSW = Pubic Joint Space Width. Adapted from "Figure 3 Prevalence of pubic-related radiographic findings" by Nielsen et al.[235] Scandinavian Journal of Medicine & Science in Sports. 2025; 35: e70068. Copyright via "CC-BY 4.0" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1111/sms.70068

CONCLUSIONS

In Study I, the five main pubic-related radiographic findings scored using the Aspetar protocol demonstrated moderate to substantial relative intra-rater reliability and fair to substantial relative inter-rater reliability. The subclassifications showed slight to substantial relative reliability for both intra- and inter-rater assessments. For both main findings and subclassifications, positive agreement was generally lower than negative agreement. Moreover, hip joint-related radiographic findings showed moderate to almost perfect relative intra- and inter-rater reliability, whereas the alpha angle showed poor relative inter-rater reliability. For hip-related findings, large standard errors of measurement and minimal detectable changes indicated poor absolute reliability for the alpha angle, lateral center-edge angle, and acetabular index angle.

In Study II, pubic-related radiographic findings were more common in male football players than in non-football athletes; however, the radiographic findings were not associated with long-standing groin pain. Among symptomatic football players, the total extent of radiographic findings did not consistently correlate with provoked groin pain intensity or disability; however, bone lucency and narrow pubic joint space may be negatively associated with the 5SST, while sclerosis may be negatively associated with HAGOS Pain and HAGOS ADL.

Chapter 3 – Study III

Hip adduction strength and provoked groin pain: a comparison of long-lever squeeze testing using the ForceFrame and the Copenhagen 5-Second-Squeeze Test

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In an evidence-based approach to athletes with long-standing groin it is important to assess, monitor and improve muscle function[14,23] as these athletes usually have deficits in hip muscle strength,[10,11] and self-reported difficulties with hip dependent movements such as running, kicking, and change of direction.[3,44]

Bilateral long-lever hip adduction "squeeze" and hip abduction "press" tests using a handheld dynamometer (HHD) are reliable for evaluating hip adduction and abduction strength.[26,27,247] The ForceFrame is a portable fixed-frame device that can also provide rapid and reliable assessment of hip adduction and abduction strength.[28,29,211] Hip adduction squeeze testing with both devices can also provide measures of provoked groin pain intensity[30,31] which can be used to screen groin-related disability[27,31] and tissue irritability.[8,23] However, there is a key procedural distinction between testing with an HHD and the ForceFrame, which may impact the interchangeability of the two devices. When using the HHD, the athletes' hips are positioned at approximately 10–15° of abduction as the examiner places a forearm and the HHD between the ankles.[26,27] In contrast, the athletes have a near-neutral hip abduction angle in the ForceFrame.[217] This biomechanical variation may influence test outcomes[218] and, consequently, the interchangeability of the two methods for assessing strength and provoked groin pain intensity. Understanding whether these devices produce comparable results is important for choosing assessment methods in both research and clinical settings.

Therefore, the objective of Study III was to compare long-lever squeeze testing using the HHD and the ForceFrame setup in terms of hip adduction strength and provoked groin pain.[182]

METHODS

Design and setting

Study III was a cross-sectional study of healthy male football players from a Danish professional football club and academy.[182] Data were collected during routine pre-season physical assessments in February 2020 and January 2021 as part of a larger prospective data collection focused on evaluating muscle function.[182,247,248] This study specifically utilized hip muscle function data.

The study was approved by the Scientific Ethics Committees for the Capital Region of Denmark (ID: 19026064) and was conducted in accordance with the Declaration of Helsinki.[238] Informed consent to participate was given by all players and football club staff, including coaches, health professionals, and the technical director at the initiation of the larger data collection.[182,247,248]

Participants

Elite male football players from the U13, U14, U15, U17, U19, and Senior teams of a Danish professional club and academy were recruited.[182] To be included, players needed to be cleared by club and academy staff for full pre-season training and available for hip adductor strength testing.[182]

Muscle Function Assessment

Hip muscle function was expressed as hip adduction strength and provoked groin pain intensity as measured with a HHD and the ForceFrame using bilateral long-lever hip adduction squeeze testing.[182] Hip adduction strength was quantified as peak isometric torque normalized to body mass (Nm/Kg), calculated as: Force (Newton) * lever arm length (meter) / body mass (kilogram).[209] Lever arm length was measured from the anterior superior iliac spine (ASIS) to 1) 5 cm proximal of the edge of the medial malleoli, for the HHD setup[27,209] and 2) the center of the medial malleoli for the ForceFrame setup.[182] Provoked groin pain intensity was quantified as the highest reported pain intensity (NRS 0–10) across all trials.[31] Players reporting NRS>0, and NRS>2 were counted.[31]

Procedure for bilateral long-lever hip adduction squeeze testing

In both the HHD and ForceFrame setups, players were given standardized instructions on the correct testing form and technique.[182] Each test began with a warm-up trial at roughly 50% of their perceived maximum effort, followed by a 60-second break, during which feedback on the form was provided if necessary.[247] Players then executed two valid trials at 100% perceived maximum effort, with a 60-second rest interval between them.[247] Each 100% trial was initiated and encouraged with the command "Three–Two–One–Go–Push–Push–Push–Push–And–Stop,"[247] while players continuously

squeezed their legs together for five seconds against either the HHD and assessor's forearm[247] or the ForceFrame. Trials were discarded if players exhibited excessive hip or knee extension/flexion or failed to maintain the contraction for five seconds.[247] In such cases, an additional 100% trial was performed.

The handheld dynamometer setup

Players lay supine on an examination bed with their hips at 0° flexion, knees extended, toes pointing upward, and hands gripping the sides of the bed.[247] The assessor positioned their dominant forearm and an HHD between the player's ankles, establishing a distance of ~35 cm (Figure 12), which resulted in ~10–15° of bilateral hip abduction.[247] The HHD was a Hoggan MicroFET2 (Scientific L.L.C., Salt Lake City, USA), which recorded force (N) at 100 Hz.[249] The highest peak force from two valid 100% trials was used to calculate the peak isometric torque normalized to body mass (Nm/Kg).[247]

Two physiotherapists administered the HHD testing (one in February 2020 and the other in January 2021); each was trained by the senior author and had six months of experience with the method.[182] This setup has excellent relative inter-tester (ICC = 0.95) and intra-tester (ICC = 0.90-0.98) reliability for bilateral long-lever hip adduction squeeze strength.[27,209,247] Without a HHD this setup has excellent relative test-retest reliability for provoked groin pain intensity (CCC = 0.90).[31]



Figure 12 "The 5SST setup" by Nielsen et al.[182] Physical Therapy in Sport. 2022;55:28-36. Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1016/j.ptsp.2022.02.002

The ForceFrame setup

Players lay supine on a training mat with their hips at 0° flexion, knees extended, toes pointing upward, head resting on the mat, and arms on their sides.[102,216] They position both medial malleoli against the two inner ForceFrame dynamometers,[216] which are separated by approximately 0.17 m, resulting in a nearly neutral hip abduction angle (Figure 13).[102,216] The ForceFrame recorded force (N) from both inner dynamometers at 100 Hz. From each valid 100% trial, the average peak force of both inner dynamometers was calculated, and the highest average peak force was used to calculate the peak isometric torque normalized to body mass (Nm/Kg).[182]

The ForceFrame was administered by the primary author, MFN, a physiotherapist with three years of experience using the ForceFrame.[182] The ForceFrame demonstrates excellent relative reliability for bilateral hip adduction squeeze strength using a short-lever setup (ICC: 0.90–0.92).[28,211]

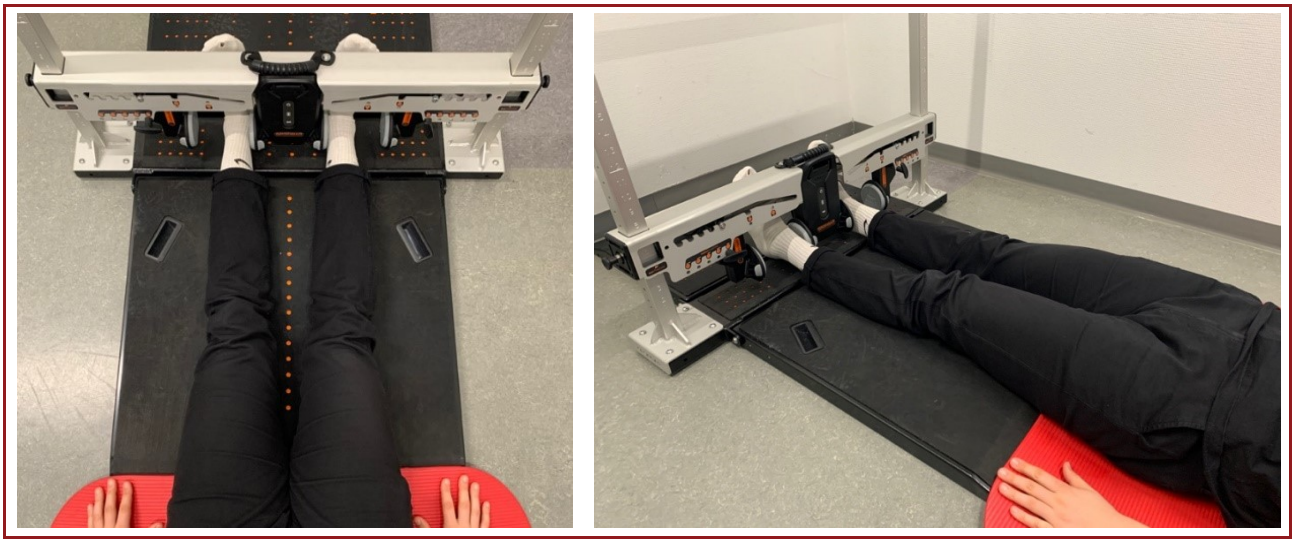


Figure 13 "The ForceFrame long-lever squeeze test setup" by Nielsen et al.[182] Physical Therapy in Sport. 2022;55:28-36. Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1016/j.ptsp.2022.02.002

Provoked groin pain

After each 100% squeeze test, the provoked groin pain intensity was assessed using an NRS from 0–10, corresponding to the 5SST[27,31], as described in Chapter 1. This was done with the standardized prompt: *"On a scale from 0 to 10, with 0 being no pain and 10 being the worst pain imaginable, how much pain did you feel in the groin area during the test?"*

Data collection

The players were assessed in groups of 5-8 players.[182] They began with a general warm-up, such as stationary biking for 5-15 minutes, under staff supervision before moving on to muscle function assessment, which was managed by five physiotherapists at five different stations (Table 8).[182,248] The

allocation to assessment station was based on convenience, as randomization was not feasible due to the pragmatic setup with specific time constraints.[182] The HHD and ForceFrame assessments were separated by knee muscle function assessments,[182] thus the sequence was *Station 1 → Station 2 or 5 → Station 3 → Station 4 → Station 2 or 5.*

Table 8 Muscle Function Assessment Stations

Station	
1	Measurement of leg length and body mass followed by allocation to station 2 or 5.
2	Hip muscle function using an HHD.
3	Knee extension muscle function using an HHD.
4	Knee flexion muscle function using an HHD.
5	Hip muscle function using the ForceFrame.

Statistics

Descriptive statistics were used to present athlete characteristics.[241] The HHD and ForceFrame were compared using a four-step approach. First, correlations were evaluated using scatterplots and Pearson's correlation coefficient for strength and Kendall's Tau for pain intensity.[241,250] Correlation coefficients were interpreted as negligible (0.0-0.09), weak (0.10-0.39), moderate (0.40-0.69), strong (0.70-0.89) and very strong (0.90-1.00).[245] Second, systematic bias between methods was evaluated by comparing strength with a paired t-test and pain intensity with a Wilcoxon signed-rank test.[18,241] Third, agreement was examined with Bland-Altman plots with 95% limits of agreement (LOA) for absolute and percentage differences in strength.[243] Agreement was considered acceptable if the 95% LOA fell within ±15% from the mean difference based on the MDC for hip adduction squeeze strength (3.6 to 13.7%)[209] and a study considering a change of >15% as clinically meaningful.[251] Fourth, the proportion of players reporting provoked groin pain (NRS > 0) and provoked groin pain intensity > 2 were compared between methods using Fisher's exact test.[241] All analyses used an alpha level of 0.05, and were performed in SPSS (v. 23, IBM Corporation, New York, USA) and Stata (Stata IC v. 16, Stata Corporation, USA).

RESULTS

Participants

We included data from 83 male football players from the U13, U14, U15, U17, U19, and senior teams. Table 9 presents the characteristics of the included players.

Table 9 Descriptive data of athletes in Study III. Adapted from "Table 1 Descriptive data of included players" by Nielsen et al.[182] Physical Therapy in Sport. 2022;55:28-36. Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1016/j.ptsp.2022.02.002

	All	U13	U14	U15	U17	U19	Senior
N	83	7	12	12	15	18	19
Age, years	16.0 (2.7)	12 (0.8)	13 (0.43)	14.3 (0.6)	15.6 (0.72)	17.2 (0.79)	19.5 (1.8)
Height, cm	174.7 (10.0)	160.1 (10.4)	163.5 (5.9)	172.9 (5.9)	179.8 (7.2)	179.9 (7.0)	179.3 (7.4)
Mass, kg	66.5 (13.0)	45.2 (9.8)	52.7 (8.1)	59.7 (5.2)	71.4 (7.3)	74.7 (7.4)	75.9 (8.3)
BMI	21.6 (2.5)	17.2 (1.5)	19.6 (2.1)	19.9 (1.2)	22.0 (1.2)	23.9 (1.2)	23.6 (2.24)
Dominant leg, left/right	18 / 65	1 / 6	2 / 10	5 / 7	3 / 12	3 / 15	4 / 15
Previous groin injury†	19 / 64	3 / 4	4 / 8	3 / 9	2 / 13	4 / 14	3 / 16

†Previous groin injury within the last 6 months

Hip Adduction Squeeze Strength

Hip adduction strength (Nm/Kg) showed a strong correlation ($r = 0.73$, $p < 0.000$) between the HHD and ForceFrame setups. Players produced significantly higher strength values with the HHD than with the ForceFrame (mean diff: 16.5%, 95% CI: 20% to 13%, Table 10). The Bland-Altman plot (Figure 14) indicated poor agreement with large variations in data points and LOA ranging from -46% to 14%. Overall, 47 players (57%) exhibited strength values that were ≥15% higher in the HHD setup.

Table 10 Hip adduction squeeze strength (Nm/Kg) assessed with the HHD and ForceFrame. Adapted from "Table 2 Hip adduction strength (Nm/Kg) assessed with the ForceFrame and the 5SST" by Nielsen et al.[182] Physical Therapy in Sport. 2022;55:28-36. Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1016/j.ptsp.2022.02.002

	ForceFrame	HHD	ForceFrame vs HHD		
Team	Mean (SD)	Mean (SD)	Mean diff. (95% CI)	p-value	Cohens *d*
All (n=83)	2.62 (0.53)	3.09 (0.63)	-0.47 (-0.57 to -0.38)	< 0.000	-2.182
U13 (n = 7)	2.41 (0.54)	2.40 (0.37)	-0.003 (-0.3 to 0.3)	0.982	0.019
U14 (n=12)	2.23 (0.39)	2.71 (0.43)	-0.48 (-0.71 to -0.25)	0.0008	-2.771
U15 (n=12)	2.46 (0.53)	2.73 (0.77)	-0.27 (-0.54 to 0.00)	0.0501	-1.327
U17 (n=15)	2.90 (0,44)	3.44 (0.25)	-0.54 (-0.76 to -0.32)	0.0001	-2.776
U19 (n=18)	2.91 (0.47)	3.38 (0.62)	-0.47 (-0.70 to -0.24)	0.0005	-2.078
Senior (n=19)	2.55 (0.54)	3.28 (0.55)	-.72 (-.89 to -.55)	< 0.000	-4.151

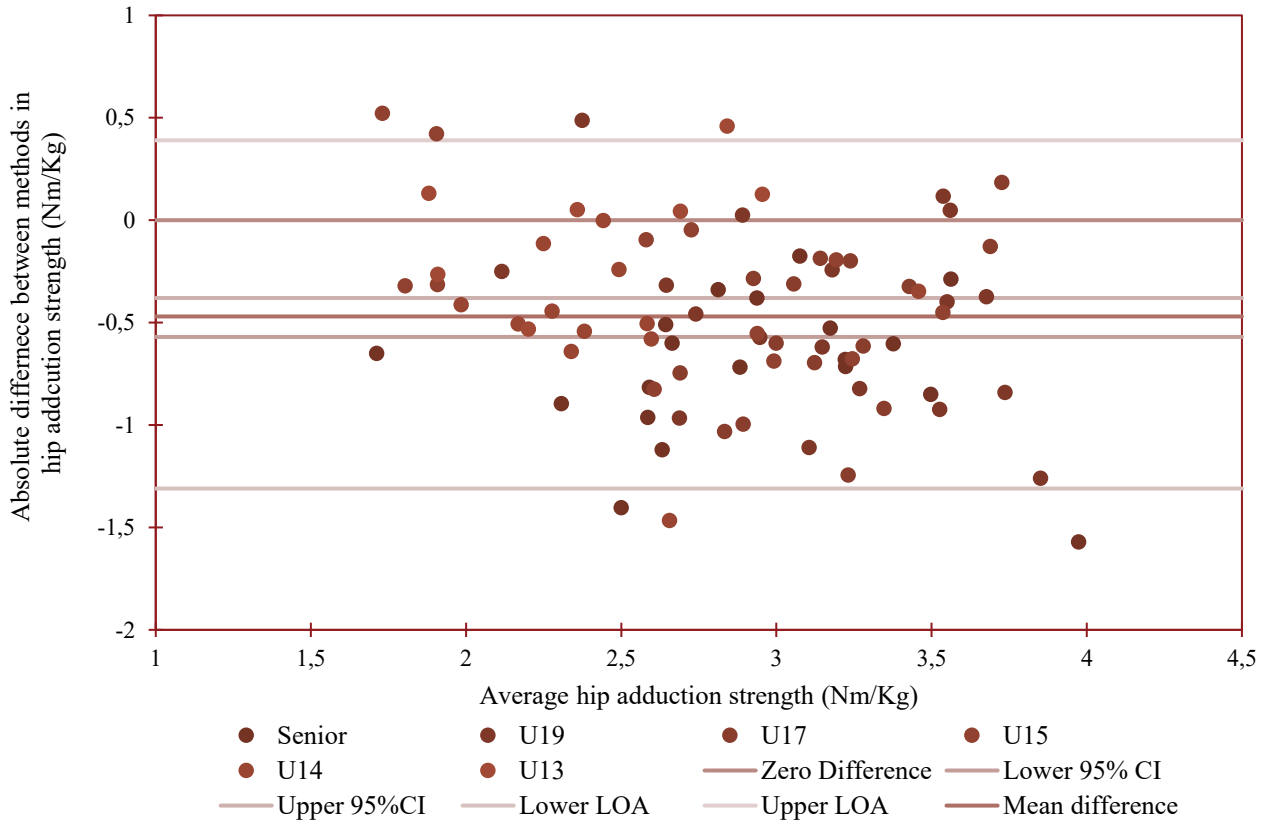


Figure 14 Bland-Altman plot of absolute difference in hip adduction strength (Nm/Kg) between methods and average hip adduction strength (Nm/Kg) between methods. Adapted from "Fig. 4. Bland-Altman plots of (A) absolute torque-to-body mass ratio (Nm/Kg) and (B) percentage (%) difference between methods for hip adduction strength (Nm/Kg)." by Nielsen et al.[182] Physical Therapy in Sport. 2022;55:28-36. Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1016/j.ptsp.2022.02.002

Provoked Groin Pain

The intensity of groin pain showed a moderate correlation between the HHD and ForceFrame (Kendall's Tau = 0.40). With the HHD, a greater number of players reported groin pain (n (%), HHD: 51 (61%) vs. n = 22 (27%), p = 0.005, Figure 15), and more players reported groin pain with NRS > 2 (n (%), HHD: 29 (35%) vs. ForceFrame: 14 (17%), p < 0.001, Figure 15). Additionally, the intensity of groin pain was significantly higher with the HHD (median (IQR), HHD: 1 (0-3) vs. ForceFrame: 0 (0-1), p < 0.000). Furthermore, 32 (61%) players reported groin pain during HHD but not during ForceFrame testing, and 18 (35%) reported pain intensity above 2 during HHD testing but less than 2 during ForceFrame testing.

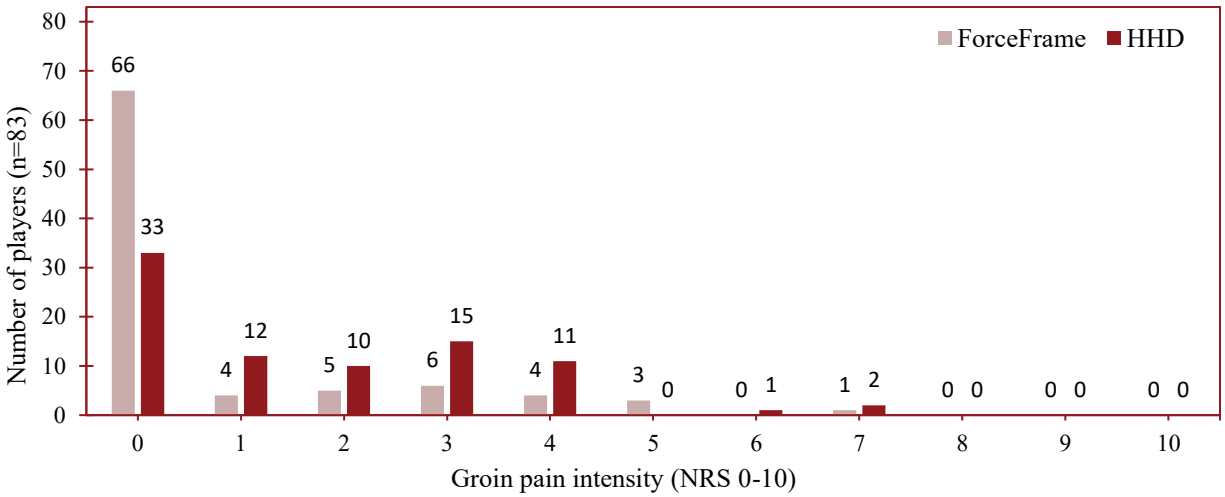


Figure 15 Frequency of reported groin pain intensities. Adapted from "Fig. 5. Frequency of each provoked groin pain intensity level among all players (n = 83)" by Nielsen et al.[182] Physical Therapy in Sport. 2022;55:28-36. Copyright via "CC-BY" license (https://creativecommons.org/licenses/by/4.0) Source: https://doi.org/10.1016/j.ptsp.2022.02.002

CONCLUSION

Study III found that bilateral long-lever hip adduction squeeze testing with a handheld dynamometer is not interchangeable with a ForceFrame for measuring hip adduction strength and intensity of provoked groin pain.

Chapter 4 – Study IV

Pain sensitivity, psychological factors, and muscle function in male athletes with longstanding groin pain and matched asymptomatic athletes – Which factors are affected?

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Shellie Boudreau, Thomas Graven-Nielsen, Per Hölmich, Kristian Thorborg.

First-line management of athletes with long-standing groin pain aims to reduce disability, alleviate pain, restore physical function, and return athletes to sport and performance with exercise-based rehabilitation programs.[14,23] Across trials, 50–95% of athletes return to sport within approximately 2–4 months, while 5–50% do not return to sport or become clinically pain free.[35,36,41,42] Furthermore, return to sport is not synonymous with complete reduction of disability, as athletes still report significant deficits in their physical function, ability to participate in sports, and quality of life, despite having returned to sport.[23,24,41,43,44] This indicates that additional factors, not routinely addressed and targeted by current evidence-based strategies, may play an important role in maintaining groin pain and disability.

In 2017, a series of IOC consensus papers emphasized that long-standing pain arises from the interactions of neurophysiological, psychological, biological, and contextual factors.[46–48] Among several factors, they suggested assessing pain mechanisms (nociceptive, neuropathic, and nociplastic pain) and psychological factors to improve pain management in athletes.[47,48] The complex and biopsychosocial nature of pain has gained increased recognition in research on long-standing hip and groin pain.[8,252–255] However, pain mechanisms and psychological factors remain poorly studied in athletes with long-standing groin pain. A single study has identified local hyperalgesia at the adductor longus tendon as a significant factor contributing to groin pain.[64] Similarly, one other study has measured a distinct psychological factor,[41] showing that athletes with long-standing pubic-related groin pain exhibited elevated levels of pain catastrophizing.[41]

Explosive strength is another novel factor that has not yet been examined in athletes with long-standing groin pain. Explosive strength is an important determinant of sports performance and rapid movements,[34] and is highly reliant on efficient neurophysiological mechanisms (i.e., motor unit recruitment, neural drive, reflexes, inhibition, and coordination).[34,204] Athletes with long-standing groin pain show reduced eccentric hip adduction strength,[114] which also depends heavily on neurophysiological mechanisms[206] and therefore suggests that explosive strength could also be reduced.

More knowledge of pain sensitivity, psychological factors, and neural aspects of muscle function in athletes with long-standing groin pain may help understand the condition and improve management so that more athletes can return to sports with better function and less disability. Study IV aimed to compare pain sensitivity, psychological factors, and muscle function between athletes with long-standing adductor-related groin pain and matched asymptomatic athletes.

METHODS

Design and Procedures

Study IV was a cross-sectional case-control study of male athletes with long-standing adductor-related groin pain and asymptomatic athletes matched for sex, age (±1–2 years), and sport type. The study was conducted at the Sports Orthopedic Research Center, Copenhagen, at the Copenhagen University Hospital Amager-Hvidovre, from November 2021 to April 2024. Informed consent was obtained during the first visit. As compensation for study participation, symptomatic athletes received a treatment consultation, while asymptomatic athletes received 300 Danish Krone (DKK). The study was approved by the Scientific Ethics Committees for the Capital Region of Denmark (H-20055130) and conducted in accordance with the Declaration of Helsinki.[238]

The athletes underwent telephone and in-person screening, clinical and radiographic examinations, and an experimental testing session. The experimental session assessed descriptive characteristics, HAGOS, psychological factors, pain intensity, pain distribution, pain sensitivity, and muscle function (Table S1, Study IV). Data were collected using paper forms and were later entered into a REDCap database. A male physiotherapist (MFN) with five years of experience conducted screenings and experimental testing for all athletes, as well as clinical examinations for asymptomatic athletes. An orthopedic surgeon specializing in groin pain (PH) examined the symptomatic athletes. The athletes were instructed to avoid pain medication before the visits, and standardized test instructions were used to minimize bias caused by the words in the instruction. Further details are in Study IV.

Participants

Athletes were recruited from Zealand and the Capital Region of Denmark through networks, social media platforms such as Instagram and Facebook, and emails sent to football clubs.

The inclusion criteria were as follows

Symptomatic athletes**:** Males aged 18–35 years, fluent in Danish, with ≥3 months of groin pain during sports, ≥3 hours of weekly sports activity or reduced sports activity due to groin pain, and adductor-related groin pain classified during the clinical examination.

Asymptomatic athletes**:** Males aged 18–35 years, fluent in Danish, no hip and groin pain or musculoskeletal injuries/pain within the past 3 months.

The exclusion criteria were as follows

Symptomatic athletes: hip joint-related groin pain (a positive FADIR test and a positive diagnostic hip injection),[121] hip dysplasia (LCEA of < 20°), hip osteoarthritis (HJSW < 3 mm), Perthes' disease,

slipped capital femoral epiphysis, avascular necrosis, acetabular fracture, hip dislocation, femoral neck fracture, stress fracture, referred pain from the facet or sacroiliac joints, previous hip surgery, other serious pathology, competing diseases, or a reduced activity level for reasons unrelated to groin pain.

Asymptomatic athletes: any groin pain during the 5SST, and all the exclusion criteria listed above were applied.

Radiological and Clinical Examination

Symptomatic athletes underwent standardized radiographic examinations, consistent with Studies I and II, except that cross-table lateral hip radiographs were obtained only for the symptomatic side. Asymptomatic athletes did not undergo radiographic examination. Radiographs were used by the PH in the clinical examination to evaluate the eligibility criteria and classify groin pain. Radiographs were evaluated by a radiologist,[235] and the findings were included as descriptive data.

Symptomatic athletes also underwent a standardized bilateral clinical examination to verify eligibility and classify groin pain.[8,12] This examination followed the approach of Hölmich et al.,[125,239] as in Studies I and II.[235] During the examination, the orthopedic surgeon classified athletes with clinical entities of groin pain according to the Doha agreement criteria (Figure 1, Table 1).[12] For athletes with suspected hip joint–related groin pain and a positive FADIR test, an ultrasound-guided intra-articular anesthetic injection was used to confirm or refute a classification of hip joint–related groin pain.[121] Asymptomatic athletes underwent a similar clinical examination (excluding palpation) to verify eligibility.

Athlete characteristics

A self-developed questionnaire was used to collect data on age, symptom duration, injury mechanism, previous treatment, sport type and participation level, pain medication use, and educational level. Body mass (kg) and height (cm) were measured using a digital body weight scale and stadiometer, respectively, to calculate the body mass index (BMI).

The Copenhagen Hip and Groin Outcome Score

The revised HAGOS scores[72,188] was used to assess self-reported hip- and groin-related disability in symptomatic and asymptomatic athletes, consistently with Studies I & II.[235]

Pain sensitivity

Pain sensitivity was assessed with a pressure-based QST protocol[256] (Figure 16) that included pressure pain threshold (PPT) assessed with a handheld algometer,[231] as well as pain detection thresholds (PDT),[231] pain tolerance thresholds (PTT),[231] temporal summation of pain (TSP)[231] and conditioned pain modulation (CPM)[232] assessed with a computer-controlled cuff-pressure algometer.[231,232]

To standardize the assessments, each leg was designated as either the index or secondary side. For symptomatic athletes, the index side was the most painful, whereas the secondary side was the least painful or pain-free. For asymptomatic athletes, side designation was randomized with no consideration of the dominant side.

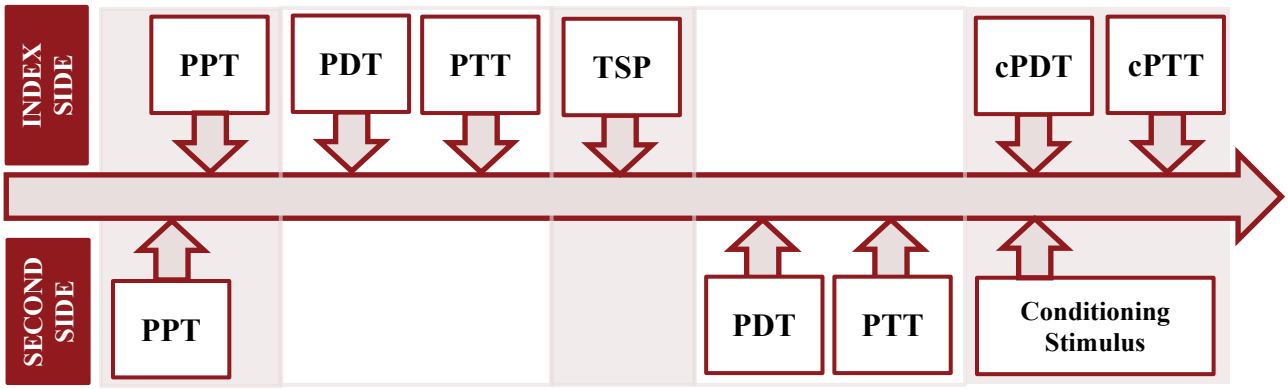


Figure 16 Pain sensitivity test sequence.

Pressure pain thresholds.

The PPT was measured at 12 anatomical sites (Figure 17) using a handheld pressure algometer equipped with a 1 cm² tip and a hand-held button (Somedic, Sweden, Figure 18).[231] The Elbow site was only assessed on the secondary side. The Pubic Symphysis site was assessed only once because of its central location. All other sites were assessed on both sides. The secondary side was always assessed before the index side (Figure 16). Two measurements were performed at each site, and the average was used for analysis.[231] PPT was recorded by applying pressure perpendicular to the skin at a constant rate of 30 kPa/s (Figure 18).[231] Athletes pressed a handheld button when the sensation transitioned from pressure to pain.[231] PPT was the amount of applied pressure (kPa) when the button was pressed.[231] A maximum of 1000 kPa was set as a safety limit. The relative test-retest reliability of PPTs assessed with handheld algometry range from an ICC of 0.87 to 0.89.[231]

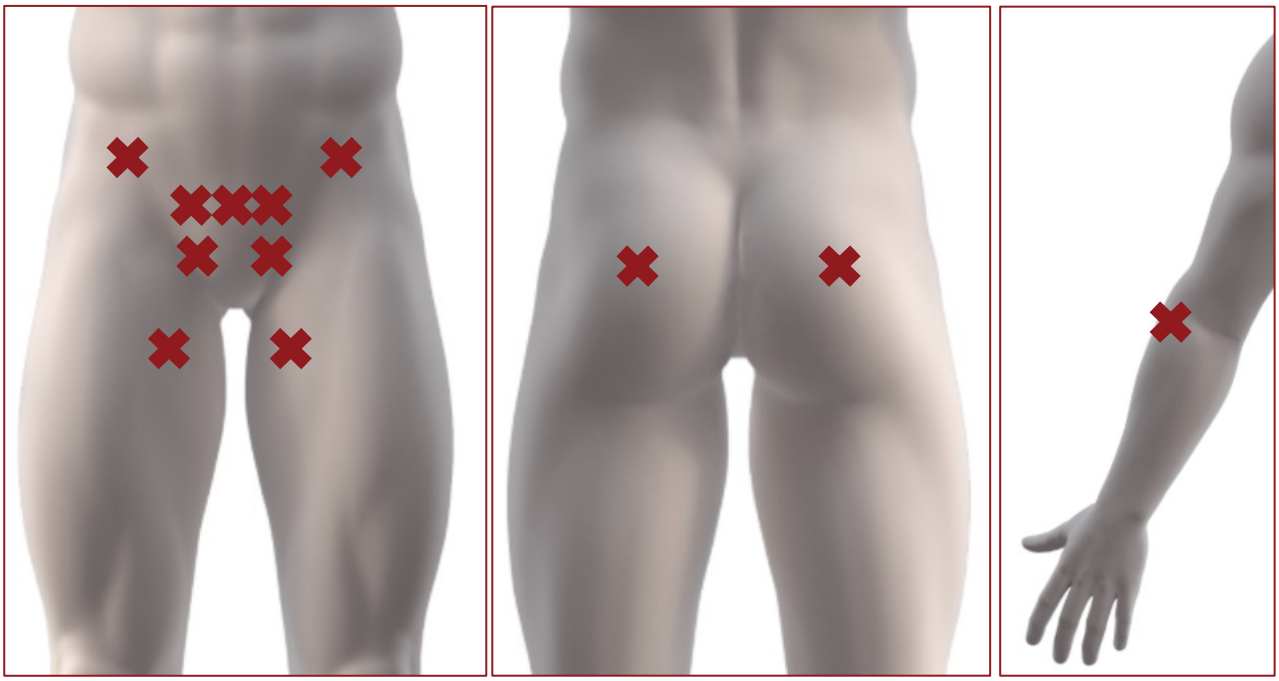


Figure 17 Sites for PPT measurements. Adductor longus muscle belly (Add longus), adductor longus muscle origin (Add Longus Origin), iliopsoas tendon (Iliopsoas), pubic bone (Pubic Bone), pubic symphysis joint (Pubic Symphysis), gluteus maximus (Glut Max), and lateral elbow epicondyle (Elbow).



Figure 18 Example of PPT measurement

Pain detection and tolerance thresholds

A computer-controlled cuff-pressure algometer (Nocitech and Aalborg University, Denmark) was used to measure PDT, PTT, TSP, and CPM.[231,232] The cuff algometer consisted of a computer connected to two 13-cm wide tourniquet cuffs, an air-compressor, and an electronic visual analog scale (VAS) with a red termination button for cuff-pressure release (Figure 19).[231,232] The PDT and PTT were measured at the lower leg with the cuff algometer.[231] The two cuffs were placed around each lower leg five centimeters distal to the tibial tubercle.[231] The index side was assessed before the secondary side, as illustrated in Figure 16. To record PDT and PTT, the cuff pressure was increased at a rate of 1 kPa/s, ranging from 0 kPa to a maximum of 100 kPa.[231] During this ramp-up, athletes continuously rated their pain intensity by sliding a button on an electronic VAS, from 0 ("no pain") to 10 ("worst imaginable pain").[231] Athletes were instructed to press a termination button when the pain became intolerable[231] or reached a VAS = 10. The PDT was the cuff pressure (kPa) when pain intensity reached a VAS = 1 while PTT was the cuff pressure (kPa) when the athlete terminated the cuff pressure or maximum pressure (100 kPa) was reached.[231] The VAS score at PTT was recorded to capture pain intensity at tolerance threshold (PTT-pain).[231] Assessment of PDT and PTT at the leg using a cuff algometer have substantial to almost perfect relative test-retest reliability (ICC range: 0.74-0.87).[231]



Figure 19 Example of computer-controlled cuff algometry test setup.

Temporal summation of pain

The TSP protocol consisted of ten painful pressure stimuli applied to the lower leg on the index side of the body. [231] For each stimulus, the cuff pressure was increased rapidly over 2 s to the pressure corresponding to the PTT for the index leg, followed by a one-second deflation to a nonpainful pressure (5 kPa).[231] Pain intensity was rated for each stimulus without resetting between stimuli.[231] VAS scores were recorded for all ten stimuli.[231] For the analysis, the means of stimuli 1–4 (VAS-1) and stimuli 8–10 (VAS-2) were calculated, with the TSP effect defined as VAS-2 minus VAS-1. [231] Assessment of TSP using this approach have moderate relative test-retest reliability (ICC: 0.6).[231]

Conditioned pain modulation

The CPM protocol consisted of two simultaneous pressure stimuli applied to both lower legs.[232] On the index side, cuff pressure was increased at a constant rate of one kPa/s, from 0 kPa to a maximum of 100 kPa.[232] On the secondary side, the cuff induced a conditioning stimulus by rapidly inflating to a constant pressure corresponding to 75% of the PTT for the secondary side.[232] Pain intensity was rated as previously but only for the index side.[232] From the CPM protocol, the PDT, PTT and PTT-pain were re-assessed as cPDT, cPTT and cPTT-pain.[232] For the analyses, the CPM effect was the absolute difference (CPM_{abs}) in PDT and PTT on the index side.[232] Assessment of CPM using this approach has moderate to almost perfect relative test-retest reliability (ICC range: 0.53-0.75).[232]

Pain intensity

Symptomatic athletes reported the intensity of their current groin pain at rest as well as their worst, least, and average groin pain over the past week, using verbal prompts from the assessor.[257] All ratings were recorded using a verbal NRS ranging from 0 “no pain” to 10 “worst pain imaginable.”[257]

Pain distribution

Symptomatic athletes used a high-resolution digital 2D body chart in Navigate Pain (Aglance Solutions, Aalborg, Denmark) to report the distribution of usual groin pain during sports.[7] The app was accessed via Google Chrome on an Apple iPad (6th generation) using an Apple Pencil (Apple Inc., USA). The body charts displayed front, back, and side views, with a zoom feature to enhance drawing precision.[7] Athletes received standardized instructions and began by drawing on the front view, followed by any additional views they considered relevant. They could also draw pain outside the groin area if it contributed to their pain experience.

Pain distributions for symptomatic athletes were visualized by two pain drawing overlays showing cumulative pain areas.[7] One overlay included areas marked by at least one athlete, whereas the other

overlay included areas marked by at least two athletes.[7] The overlays were created by "normalizing" the drawings such that the right side represented the most painful side, and the left side represented the least painful side.[7] Digital pain drawings using the Navigate Pain app are valid and reliable compared to paper-based drawings.[258]

Psychological factors

Psychological factors were assessed using 13 brief questions, most of which were designed and validated for patients in primary care or patients with severe musculoskeletal pain.[259,260] The questions addressed pain beliefs, including pain catastrophizing (2-items), fear of movement (2-items), pain self-efficacy (2-items), as well as mental health including depression (2-items), anxiety (1-item), stress (1-item), loneliness (1-item), and sleep (2-items).[259,260] Items were scored on a scale from 0 (not affected) to 10 (highly affected),[259,260] except for one sleep item that evaluated average weekly sleep hours and pain self-efficacy items,[261] which were rated from 0 to 6, with 0 representing the worst score.[261] The pain self-efficacy items were combined into a total score ranging from 0 to 12,[261] with a score of 8 or higher indicating desirable pain self-efficacy.[261]

Muscle function

Muscle function was evaluated by assessing maximal strength, explosive strength, and provoked groin pain intensity. In accordance with Study III,[31] we used a bilateral long-lever hip adduction squeeze test with a HHD (MicroFET2, Hoggan, Scientific L.L.C., Salt Lake City, USA),[26,209] which enabled measurement of maximal strength concomitantly with explosive strength.[26] Maximal strength was expressed as normalized peak torque (Nm/Kg), while explosive strength was expressed as normalized rate of torque development (RTD, Nm/s/kg) over two intervals: 0–100 milliseconds (RTD_{100}) and 0–200 milliseconds (RTD_{200}).[26] Compared to Study III, minor adjustments were applied to the HHD setup and test procedure to measure explosive strength and hip abduction strength.[26,27] Athletes performed a warm-up consisting of one 50% effort trial and one 100% effort trial, followed by three 100% maximum-effort trials.[26] Instructions emphasized executing each test "as fast and hard as possible, " while maintaining maximum contraction for five seconds.[26] For hip abduction strength, a rigid belt was used to provide resistance at the ankles and fixate the HHD 5cm proximal to the lateral malleoli.[26,27] The belt was adjusted so the hip abduction angle was the same as during adduction testing.[26,27]

The highest strength and pain intensity values from the three valid trials was used in the analyses.[26] The relative intra-tester reliability is substantial to almost perfect for peak isometric strength (hip

adduction ICC = 0.92; abduction ICC = 0.97), RTD_{100} (adduction ICC = 0.62; abduction ICC = 0.76) and RTD_{200} (adduction ICC = 0.86; abduction ICC = 0.83).[26]

Sample size consideration

An exploratory approach was applied to identify variables and between-group differences that may be important for future research.[262] Previous studies comparing PPT measurements between individuals with chronic pain and pain-free controls have reported large to very large effect sizes (Cohen's $d > 1.2$).[263] The sample size was set to detect large effect sizes for PPT at the adductor longus origin while remaining feasible. A minimum of 20 symptomatic and 20 asymptomatic athletes (total N = 40) was necessary to detect an effect size of Cohen's $d > 0.9$ based on a two-tailed unpaired t-test, with α of 0.05 and power of 0.80.[264]

Statistics

Statistical analyses were conducted using R version 4.3.0 and RStudio 2022.12.0+353. Descriptive statistics were used to summarize athlete characteristics.[241] The pain sensitivity and muscle function variables were compared between groups using two-tailed unpaired t-tests with effect sizes expressed as Cohen's *d*.[241,264] The psychological factors were compared using Wilcoxon rank-sum tests, with effect sizes expressed as rank-biserial correlation (*r)*.[241] The primary conclusions were drawn from effect sizes and unadjusted p-values, while Benjamini-Hochberg adjusted p-values were provided to address risk of Type-1 error.[246] Effect sizes were interpreted as small (0.2), moderate (0.5) and large (0.8).[264] Pain sensitivity variables were analyzed according to index and secondary side. On the secondary side, symptomatic athletes were further sub-grouped based on unilateral or bilateral groin pain. For PPT measurements, a sensitivity analysis was performed using a mixed ANOVA model, with group as the between-subject factor, PPT site as the within-subject factor, and their interaction term. For post-hoc estimations, Greenhouse–Geisser and Huynh–Feldt corrections were applied.[241]

RESULTS

Participants

Before experimental testing, 72 symptomatic and 37 asymptomatic athletes were screened, with 20 from each group included and completing the testing (Figure 20). Symptomatic athletes were excluded primarily because of the absence of adductor-related groin pain (n = 12) and hip joint-related groin pain (n = 10). The descriptive characteristics are shown in Table 11.

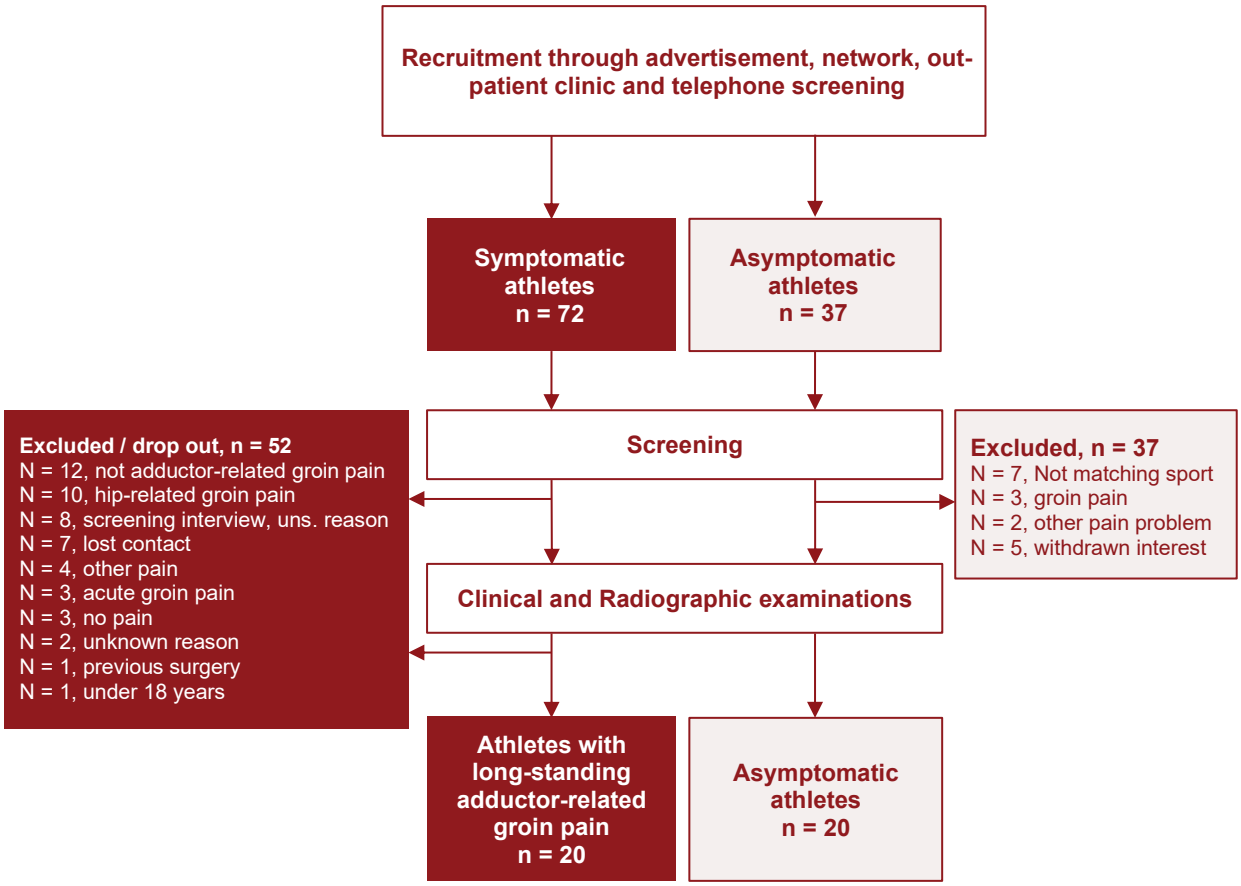


Figure 20 Participant flow for Study IV.

Table 11 Descriptive characteristics of athletes in Study IV.

Characteristics	Symptomatic athletes	Asymptomatic athletes
Age, *years, mean (SD)*	26.6 (5.6)	25.7 (4.3)
Height, *cm, mean (SD)*	180.9 (7.8)	183.5 (5.0)
Weight, *kg, mean (SD)*	77 (10)	81 (8)
BMI, *mean (SD)*	23.30 (1.88)	24.16 (2.83)
Sport, *hours per week, mean (SD)*	6.50 (3.11)	6.87 (3.29)
Sport type		
Football, *n (%)*	18 (90%)	18 (90%)
Volleyball, *n (%)*	1 (5%)	1 (5%)
Climbing, *n (%)*	1 (5%)	1 (5%)
Sport level		
Elite, *n (%)*	3 (16%)	2 (10%)
Competition, *n (%)*	10 (53%)	8 (40%)
Leisure activity, *n (%)*	6 (32%)	10 (50%)
Dominant leg		
Left, *n (%)*	2 (10%)	4 (20%)
Right, *n (%)*	18 (90%)	16 (80%)
Previous groin pain, *n (%)*		7 (35%)
Injury mechanism		
Acute after specific situation, *n (%)*	7 (35%)	4 (57%)
Gradual after specific situation, *n (%)*	6 (30%)	2 (29%)
Gradual and unspecific, *n (%)*	7 (35%)	1 (14%)
Previously treated for current groin pain, *n (%)*	13 (65%)	
Previously treated for previous groin pain, *n (%)*		2 (29%)
Type of treatment for current/previous groin pain		
Physiotherapy, unspecified, *n (%)*	7 (35%)	2 (1%)
Chiropractor, *n (%)*	1 (5%)	-
Massage, *n (%)*	3 (20%)	-
Exercises, *n (%)*	3 (20%)	-
Body SDS, *n (%)*	1 (5%)	-

In the symptomatic group, 65% (n = 13) experienced unilateral groin pain, predominantly on the right (n = 9). Of the seven athletes with bilateral groin pain, six reported that the right side was more painful. The duration of symptoms was long, with a median of 51 weeks (IQR: 26–175), and symptomatic athletes reported severe disability (Figure 21). Groin pain intensity in the week preceding testing varied, with the worst pain at 6.5 (IQR: 5–7), the least at 0.0 (0–1), and the average at 3.0 (2–4). At the time of testing, the pain intensity at rest was 2.5 (0–3). Three symptomatic athletes (15%) used pain medication (paracetamol, n = 3; ibuprofen, n = 2) at a median frequency of 3 days/week (range, 2–4).

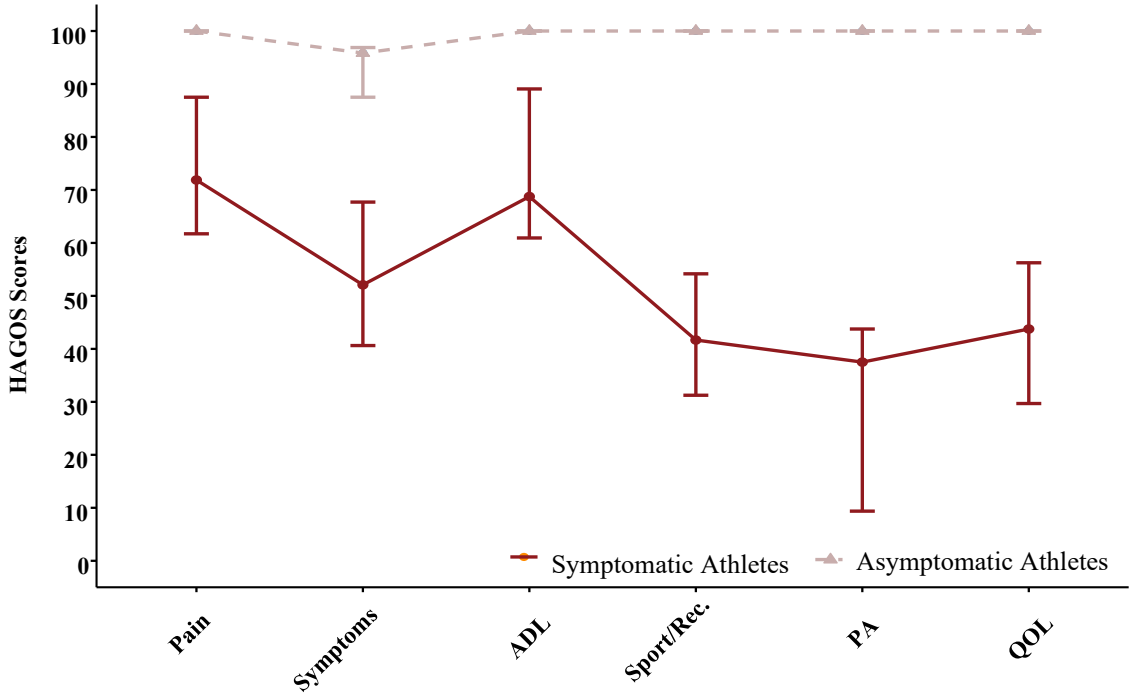


Figure 21 HAGOS Scores for symptomatic and asymptomatic athletes.

In addition to adductor-related groin pain, symptomatic athletes were also classified with iliopsoas-related (70%, 14/20), inguinal-related (37%, 7/20), and pubic-related groin pain (20%, 4/20). On average, the symptomatic athletes had three (± 2) clinical entities of groin pain. The side-specific classifications are presented in Table A1 in Study IV. The symptomatic athletes presented with the following pubic-related radiographic findings: bone lucency (65%, 13/20), proliferation (60%, 12/20), sclerosis (10%, 2/20), narrow pubic joint space (45%, 9/20), and a pubic joint space width of 3 mm (± 1). Symptomatic athletes presented with the following hip-related radiographic findings: cam morphology (25%, 5/20), pincer morphology (5%, 1/20), and borderline dysplasia (30%, 6/20). Further clinical and radiographic details are presented in Table A1 in Study IV.

Pain distribution

Most symptomatic athletes experienced pain in an area corresponding to the origin of the adductor muscles and the hip crease, although there was a large variation in pain distribution (Figure 22). Additionally, pain was symmetrically distributed between the sides for all athletes with bilateral groin pain, and some athletes marked pain areas in the lateral hip and buttocks (n = 3), lower back (n = 1), hamstring area (n = 1), and left knee (n = 1).

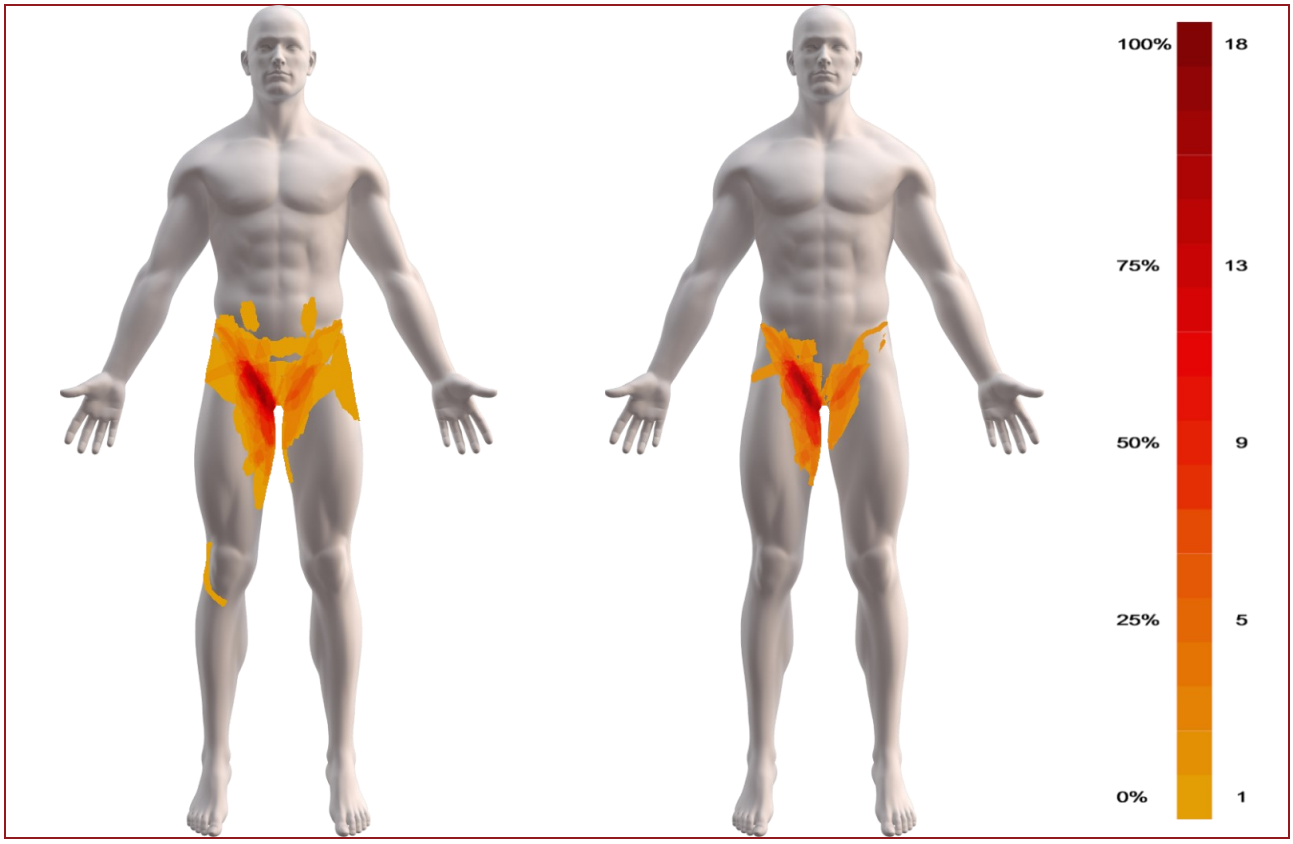


Figure 22 Overlay drawings of usual groin pain during sport activity. Left drawing illustrates all areas drawn by minimum one symptomatic athlete. Right drawing illustrates areas drawn by minimum two symptomatic athletes.

Pain sensitivity

Symptomatic athletes displayed significantly lower PPTs across all sites on the index side (Figure 23), with effect sizes ranging from *Cohen's d* = 0.73 (95% CI: 0.1-1.4) at the elbow to *d* = 1.2 (95% CI: 0.5-1.9) at the pubic symphysis. On the secondary side, athletes with unilateral groin pain showed significantly lower PPT only at the gluteus maximus (*d* = 0.9, 95% CI: 0.1-1.6), whereas those with bilateral groin pain showed significantly lower PPTs at all sites except the adductor longus origin (*d* = 1.3, 95% CI: -0.3 to 2.2) (Figure 24).

Symptomatic athletes also showed lower PDT on the index side (d = 0.7, 95% CI: 0.1-1.4), along with higher PTT-pain (d = 0.8, 95% CI: 0.2-1.5), and cPTT-pain (d = 0.8, 95% CI: 0.1-1.5). On the secondary side, athletes with unilateral groin pain showed lower PDT (d = 1.0, 95% CI: 0.3-1.7), and higher PTT-pain (d = 1.0, 95% CI: 0.3-1.7), while athletes with bilateral groin pain showed higher PTT-pain (d = 1.0, 95% CI: 0.3-1.7). No significant group differences were observed in the PTT, TSP, and CPM variables. Further details are provided in Table 2 in Study IV

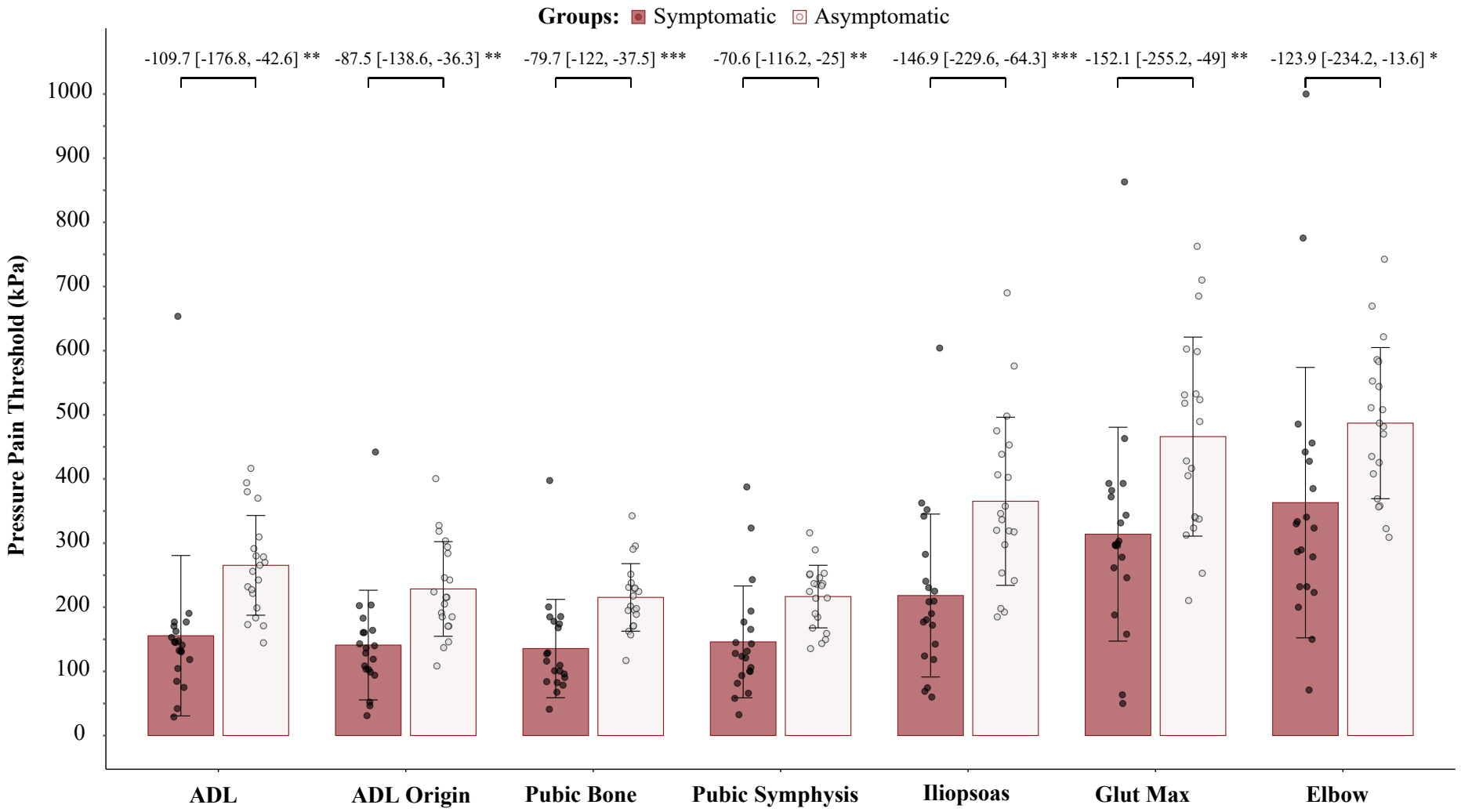


Figure 23 Pressure pain thresholds on the index side. Bars are means. Error bars are standard deviations. Dots are individual data points. Brackets indicate between group comparison with mean difference (95% confidence interval). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

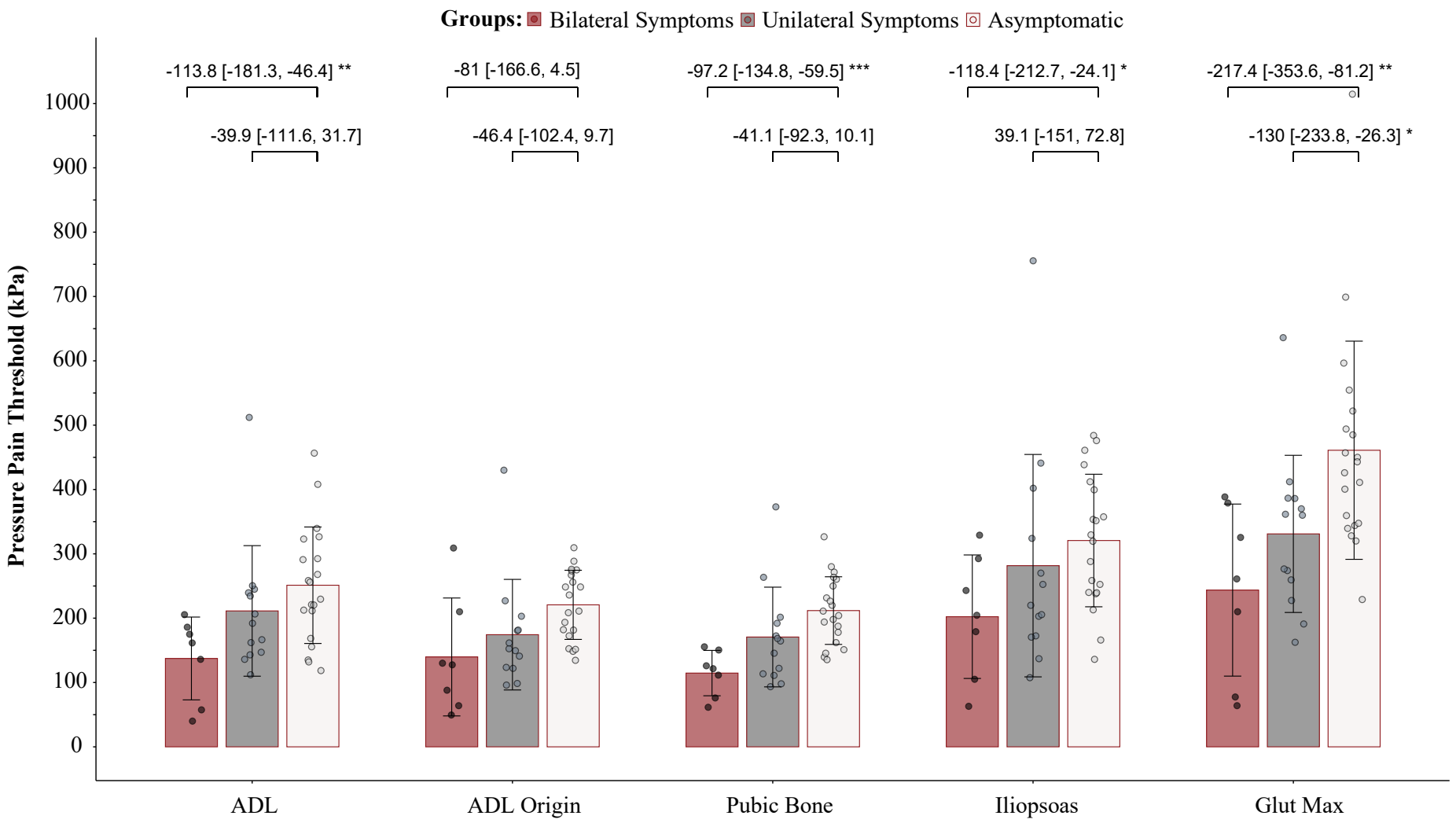


Figure 24 Pressure pain thresholds on the secondary side. Bars are means. Error bars are standard deviations. Dots are individual data points. Brackets indicate between group comparison with mean difference (95% confidence interval). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Psychological factors

Symptomatic athletes scored significantly higher on both pain catastrophizing items ($r \geq 0.56$, $p < 0.00$), both fear of movement items ($r \geq 0.41$, $p \leq 0.02$), both pain self-efficacy items and the total score ($r \geq 0.37$, $p \leq 0.02$), and both depression items ($r \geq 0.32$, $p \leq 0.04$) (Table 3 in Study IV). However, no significant differences were observed between the groups, and the effect sizes were small to negligible for anxiety, stress, loneliness, sleep duration, and sleep quality.

Muscle function

Symptomatic athletes had significantly lower explosive strength in adduction RTD_{200} (*Cohen's d* = 0.84, 95% CI: 0.2-1.5), abduction RTD_{100} (d = 0.92, 95% CI: 0.3-1.6), and abduction RTD_{200} (d = 0.68, 95% CI: 0.04-1.3) (Figure 25). Despite small to large effect sizes in adduction RTD_{100} (d = 0.55, 95% CI: -0.08 to 1.2), adduction peak torque (d = 0.36, 95% CI: -0.3 to 1.0), and abduction peak torque (d = 0.62, 95% CI: -0.02 to 1.3), the differences were not statistically significant.

Symptomatic athletes reported severe provoked groin pain from hip adduction testing (median: 7.0, IQR: 4.0 to 8.0) and mild groin pain from hip abduction testing (median: 2.5, IQR: 0.8 to 5.0). In contrast, asymptomatic athletes did not report pain during testing.

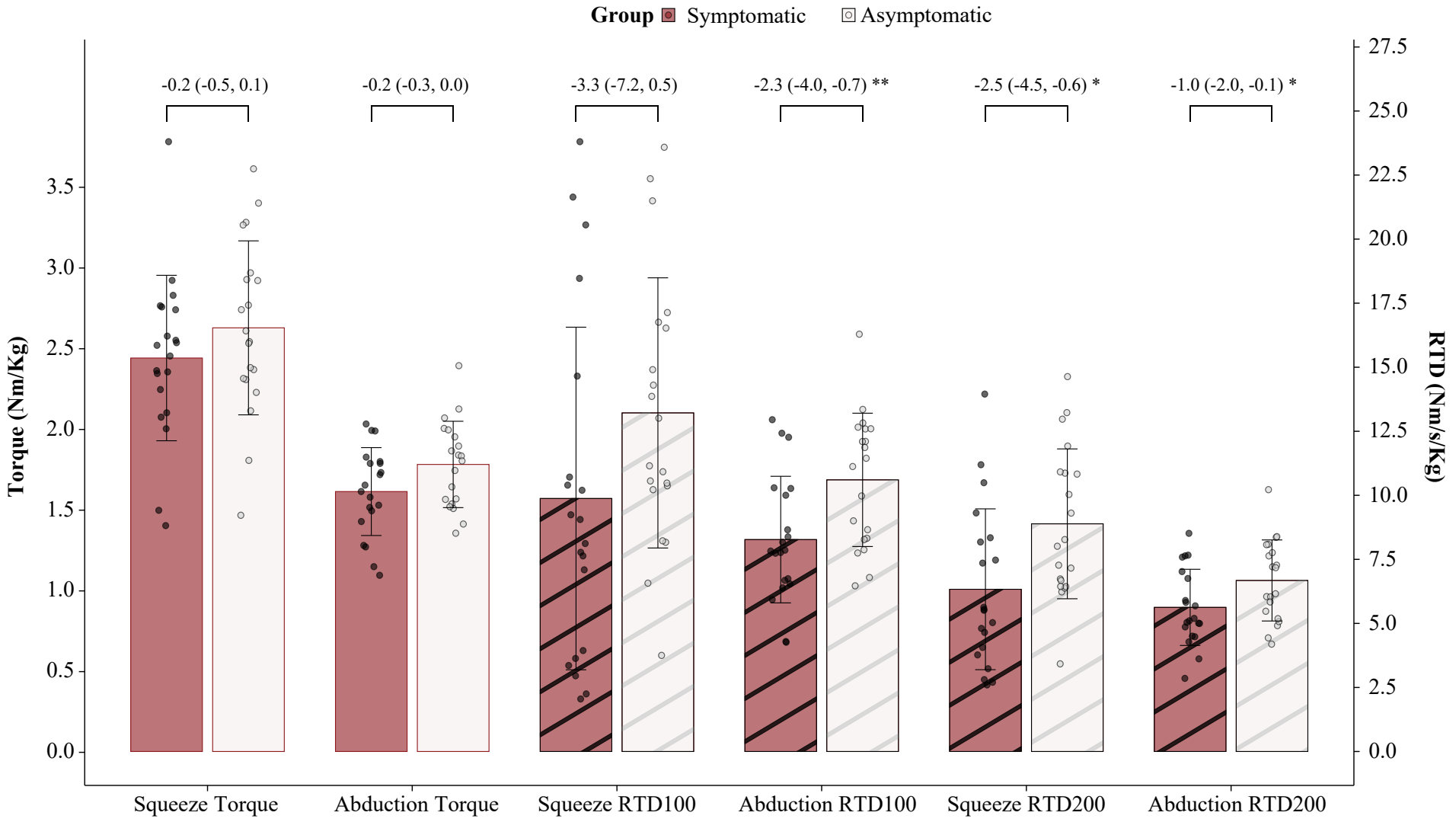


Figure 25 Muscle function with maximal isometric torque on left y-axis and rate of torque development on right y-axis. Bars are means. Error bars are standard deviations. Dots are individual data points. Full color bars are maximal torque. Pattern bars are rate of torque. Brackets indicate between group comparison with mean difference (95% confidence interval). * $p < 0.05$, ** $p < 0.01$

CONCLUSION

Study IV found that male athletes with long-standing adductor-related groin pain had affected pain sensitivity, psychological factors, and muscle function compared to matched asymptomatic athletes. Pain sensitivity was altered in the whole groin region, buttocks, elbow, and lower leg, as shown by widespread reductions in the pressure pain threshold. Psychologically, they tended to have heightened levels of pain catastrophizing, fear of movement, and depressive symptoms, and reduced pain self-efficacy. Their muscle function was also reduced, as they exhibited significant deficits in explosive hip adduction and abduction strength.

Chapter 5 – Discussion

This PhD thesis aimed to provide a more comprehensive biopsychosocial understanding of male athletes with long-standing groin pain by exploring novel aspects of radiographic findings, muscle function, pain sensitivity, and psychological factors. The discussion addresses the PhD thesis in two parts: the first part focuses on radiographic findings (Studies I and II), while the second part focuses on muscle function (Studies III and IV), pain sensitivity, and psychological factors (Study IV). The two sections are followed by methodological considerations.

Discussion Part One – Radiographic Findings

Radiographs remain the first-line imaging modality for assessing athletes with long-standing groin pain.[14,15] Establishing both relative and absolute reliability of radiographic findings and parameters across settings is therefore essential to understand how measurement errors may impact radiographic findings and clinical decision-making.[17,18] In 2021, the Aspetar Pubic Symphysis Radiographic Scoring protocol provided clear definitions for scoring the pubic symphysis joint on radiographs.[22] The protocol showed moderate to almost perfect intra-rater and fair to substantial relative inter-rater reliability in pain-free male professional football players,[22] but the clinical relevance remained unknown.[22] This thesis included the first studies applying the Aspetar protocol in another setting and in athletes with groin pain.[235] First, the intra- and inter-rater reliabilities of the Aspetar protocol were established based on radiographs of 86 Danish male athletes with and without groin pain evaluated by two radiologists (Study I).[234] Then, the clinical relevance of the Aspetar protocol was evaluated by comparing the prevalence of pubic-related radiographic findings among 39 male football players with long-standing groin pain, 18 asymptomatic male football players, and 20 asymptomatic non-football athletes (Study II).[235]

Reliability of Pubic-Related Radiographic Findings

For the main pubic-related radiographic findings (bone lucency, proliferation, fragmentation, sclerosis and joint-space width) the relative intra-rater reliability was moderate-to-substantial (κ and ICC range: 0.49-0.76), and the relative inter-rater reliability was fair-to-substantial (κ and ICC range: 0.34-0.72).[234] Relative reliability was substantial for superior/central ELC (κ: 0.75 & 0.62) and joint-space width (ICC: 0.76 & 0.72) but poor for cysts (κ: 0.18 & 0.07).[234] The absolute reliability for most findings, showed that positive agreement often was lower than negative agreement.[234]

These findings align with Serner et al.[22] and a recent conference abstract by Hanff et al.[265] Except for fragmentations and cysts, the confidence intervals for all findings overlapped between Study I and Serner et al.,[22] indicating that the true relative reliability may be within the combined confidence intervals.[234] Hanff et al.[265] reported relative inter-rater reliability as fair to almost perfect across

findings (κ: 0.37-0.93), however they did not report absolute reliability statistics.[265] Both Study I[234] and Serner et al.[22] reported lower positive than negative agreement,[22] indicating that it is easier to score absent than present findings. This was also highlighted by radiologists in Study I mentioning that scoring "normal" or "very abnormal" pubic joints was straightforward, while joints with minor changes caused uncertainty.[234]

Variations in reliability can be attributed to rater bias,[166,266] prevalence bias,[166,266] protocol training/experience,[267] radiograph quality,[268] and sample characteristics (biological variation).[18] In Study I,[234] the bias index for cysts, sclerosis, and inferior proliferation indicates that an unequal distribution of positive ratings may have inflated relative inter-rater reliability,[166] while the prevalence index for cysts suggests that a low prevalence reduced reliability.[166] Age and maturation may have influenced scoring of fragmentations,[22] erosions,[22] and cysts[22] as the pubic bone fully ossifies between ages 16-25.[133,269] Future studies should incorporate assessment of pubic bone maturation using methods like the Maturing Adolescent Pubic Symphysis (MAPS) classification,[269] as maturation status is a potential risk factors for pubic apophysitis[270], which have gained increased attention as a pathology underlying groin pain.[180]

Collectively, studies now show that radiologists can effectively learn and apply the Aspetar protocol with fair to substantial relative reliability in scoring the main pubic-related radiographic findings.[22,234,265] This may be acceptable for research and group-level assessments,[266] although higher reliability always is still warranted to minimize the probability of false positive/negative findings.[19,266,271] The variation in reliability also shows that multiple findings are influenced by measurement error to such a degree that they should be interpreted with caution, disregarded or that the protocol needs improvement.[266]

Reliability of Hip-Joint Related Radiographic Findings

Study I also established the relative and absolute reliability of hip-related radiographic findings and parameters commonly used to diagnose and classify hip joint-related groin pain in athletes.[15] These parameters showed moderate to almost perfect relative intra-rater reliability and slight to almost perfect relative inter-rater reliability.[234] However, absolute reliability was questionable as indicated by large values for SEM%, MDC% and systematic bias for alpha angle, lateral center edge angle, acetabular index angle, and hip joint space width.[234]

The relative intra- and inter-rater reliability for most hip-related findings were slightly lower than the relative reliability obtained in previous studies of athletes[168–176] and patients with pre-arthritic hips.[21] Most outstanding was the very poor relative inter-rater reliability for alpha angle (ICC = 0.17), which

indicates that there would be a very high probability of misclassifying cam morphology (alpha angle ≥ 60°) when substituting one radiologist with another. The alpha angle have shown good to almost perfect relative reliability on AP radiographs using semi-automated measurements,[168,169] and automated measurements with AI-software,[272] despite potential influence of pelvic tilt and rotation.[268] This indicate that the cross-table lateral hip view may not be ideal,[273] and that alpha angle reliability could be improved by combining AI-assisted procedures[272] with other radiographic views.[164]

No absolute reliability data have been reported in previous studies of athletes[168–176] and absolute reliability is rarely included in studies of patients with pre-arthritic hip-related pain.[21,274] Absolute reliability was considered questionable for the alpha angle, LCEA, and Acetabular Index angle, as these findings may vary by 10–36% from one measurement occasion to the next, even though the radiologist does not change. Furthermore, across those three findings, changes need to exceed 29–100% before they can be attributed to true changes and not measurement error. As an example, the alpha angle MDCs (15° and 33°) greatly exceed the 3.3° to 7.5° changes in alpha angle at one year after hip arthroscopy,[275] which questions whether these small changes are actually true or due to measurement error.

The hip-related radiographic findings and parameters showed relative reliability, which may be acceptable for research and group-level assessments,[266] particularly when assessed by a single radiologist. However, the absolute reliability statistics (systematic bias, large SEM, and large MDC) warrant caution when using these parameters to classify cam, pincer, and hip dysplasia in male athletes with and without groin pain.

Pubic-Related Radiographic Findings in Athletes with Long-Standing Groin Pain

The prevalence of the five main pubic-related findings was similar between football players with and without long-standing groin pain (differences: 4-14%, $p > 0.39$).[235] Non-football athletes showed lower rates of bone lucency, proliferation, sclerosis, and subclassifications than football players (differences: 15-49%, $p < 0.05$).[235] Central/superior ELC and cysts were more common in football players with groin pain than in those without, with absolute prevalence differences of +21% and +20%, respectively.[235] Although not statistically significant, these differences were large and suggest the potential clinical relevance of central/superior ELC and cysts.[235] However, the reliability results[234] indicated that differences of ±10-20 percentage points could be due to measurement error. Study II summarized pubic-related radiographic findings into four versions of a Pubic Symphysis Radiographic Severity Score.[235] Non-football athletes showed lower PSRS scores than football players but no differences existed between football players with and without long-standing groin pain.[235] This

suggests that PSRS scores cannot discriminate between athletes with and without groin pain and have limited clinical relevance.[235] Despite these results, pubic-related radiographic findings may still help understand and explain pain intensity and disability in male athletes with long-standing groin pain.[46] Study II explored whether pubic-related radiographic findings could explain pain intensity and disability in athletes with long-standing groin pain.[235] The PSRS Score version 1 showed weak negative correlations with HAGOS Pain and QoL,[235] which diminished with adjusted p-values and increased data ranges in PSRS Scores 2, 3, and 4.[235] This indicated that the correlations for PSRS Score 1 were potentially false positives.[276] Within symptomatic athletes, bone lucency and joint space narrowing were associated with lower provoked groin pain intensity (5SST), while sclerosis correlated with 20 points reductions in HAGOS Pain and ADL.[235] This reduction exceeds the MIC for HAGOS Pain (9.7 points) and ADL (11.8 points), suggesting that sclerosis could represent an important pain mechanism; however, these associations may also be explained by factors such as symptom duration, cumulative load, age, or recovery.[158] Given the wide confidence intervals, multiple statistical tests, and limited sample sizes, these exploratory analyses should be considered preliminary.

Erosions/resorption,[135,137–143,145] cysts,[135,139], proliferation (osteophyte formation),[135,137,139,143] sclerosis,[134,135,137–143,145,150] irregular cortical margins,[134,135,139–143,150] and changes in the joint space (narrowing and widening)[134,138,140,143,145] have been described as common features of adductor- and/or pubic-related groin pain. Across studies with athletes with adductor- and/or pubic-related groin pain, the prevalence rates for pubic-related findings varies greatly between findings from 5% for abnormal joint space width to 88% for irregular cortical margins.[134,136,138,143,145,150] However, for each specific findings their individual associations with the groin pain, pain intensity and disability are rarely reported.[134–146] Pubic-related radiographic findings have been reported in 47–100% of athletes with adductor- and/or pubic-related groin pain,[135,136,138,139,142,145,150] and in 0% to 85% of asymptomatic controls.[22,135,136,142,145]

A handful of studies have evaluated pubic-related radiographic findings using the Aspetar protocol.[22,234,235,265,277] Hanff et al.[265] found a higher cyst prevalence (17% vs. 5%; P = 0.029) among 184 high-impact athletes with hip/groin pain compared to 55 pain-free athletes;[265] however, the severity of pubic findings was not associated with hip/groin pain.[265] Serner et al.[22] found pubic-related radiographic findings ranging from 1% to 65% among professional male football players in Qatar.[22] Comparing the findings of Serner et al. 22 to symptomatic athletes in Study II[235] suggests that bone lucency (22% difference), proliferation (51% difference), and sclerosis (24% difference) may be related to long-standing groin pain. However, this does not match the prevalence of asymptomatic football players in Study II[235] and symptomatic athletes in Study IV.[277] Across Studies II,[235] IV,[277] and Serner

et al.[22] the following patterns emerged: bone lucency was common among Danish sub-elite football players regardless of groin pain;[235] Proliferation was uncommon in the professional football players from Qatar;[22] Fragmentation was rare in all three cohorts (0-15%);[22,235,277] In Danish recreational athletes with groin pain, sclerosis was uncommon and narrow pubic joint space was seen in almost half (45%).[277]

Collectively, the large variation in the existing literature, the findings of Study II[235] and the above-mentioned patterns support that pubic-related radiographic findings represent adaptations to long-term repetitive biomechanical stress from football and sports rather than long-standing groin pain as previously suggested.[147,148] In this case, the pubic-related radiographic findings may provide an illustration of how the pubic bone tolerates and adapts to repetitive strain, similar to bone stress injury pathophysiology as described by Warden et al.[158,159] Accordingly, the higher prevalence in subelite football players[235] suggests that the professional players from the Qatar cohort[22] react better to the stress from football. Following Warden et al.[158,159] this could be explained by professional athletes having better opportunity to manage factors that influence how much load goes into the pubic bone, and how well the bone responds to the load, such as muscle strength and endurance, movement biomechanics, training surfaces, training load and recovery management, genetics, diet, and nutrition.[158,159] At this point, pubic-related radiographic findings are not clinically relevant as single findings or summarized in a score, as neither show clear and robust associations with long-standing groin pain, pain intensity, and disability.[235]

Radiographic Findings – Future Research

Future research may find that pubic-related findings are clinically relevant if the reliability is improved and used in larger cross-sectional and prospective case-control studies. Reliability may be improved by using AI software to assist radiographic evaluations,[272] increasing the understanding of the influence of patient positioning on reliability,[268] or by redefining or omitting pubic-related findings with poor reliability. Larger samples will allow for the detection of smaller differences,[264] while prospective studies will allow for the investigation of the progression of pubic-related radiographic findings and their association with new episodes of groin pain, treatment outcomes, and changes in pain severity and disability. Pubic-related MRI findings (e.g., symphysis disc protrusion, severe pubic bone marrow oedema, secondary cleft sign, capsule/aponeurosis junction tears and oedema) have been associated with long-standing groin pain in athletes.[148,191,278] Using radiographs to evaluate the pubic-symphysis joint could be a valuable alternative to MRI,[22] although MRI is considered a superior imaging modality.[164]

Discussion Part Two – Muscle Function, Pain Sensitivity, and Psychological Factors

Part Two of the thesis shifts the focus from radiographic findings to investigating new aspects of muscle function (Studies III and IV), pain sensitivity, and psychological factors (Study IV).

Muscle Function

Muscle function is essential when assessing and managing athletes with long-standing groin pain,[14,23] as they may show deficits in maximal hip adductor strength.[10,11] However, improving maximal hip muscle strength may only explain a small part of self-reported physical function,[24] suggesting that other determinants of physical function may be important for these athletes.[24] Explosive strength is an important factor for sports performance and rapid movements.[34] However, explosive hip strength has not yet been investigated in athletes with long-standing groin pain.[26] Both maximal and explosive hip strength can be assessed with hip adduction "squeeze" and hip abduction "press" testing using an HHD or a ForceFrame; however, these devices have not been compared.

In this thesis, Study III compared maximal hip adduction strength and provoked groin pain intensity assessed with long-lever hip adduction squeeze testing using an HHD and a ForceFrame. Subsequently, the results guided the device selection for comparing maximal and explosive hip muscle strength between athletes with and without long-standing groin pain in Study IV.

Handheld Dynamometer or ForceFrame for hip adduction squeeze testing

Peak isometric hip adduction squeeze strength correlated strongly between HHD and ForceFrame,[182] although it was 16% lower with ForceFrame,[182] and limits of agreement exceeded the pre-specified acceptable level at ±15%.[182] Groin pain intensity showed moderate correlation between setups,[182] but HHD provoked higher pain intensity in more players.[182]

A likely explanation for these findings is the setup differences.[182] The hip abduction angle was ~15° with the HHD and ~0° with the ForceFrame, as shown by ankle distances of 35 cm and 17 cm, respectively.[182] A biomechanical study showed increased unilateral hip adduction torque at 10° and 20° hip abduction angles compared to neutral.[218] The slightly increased hip abduction angle may optimize force generation by improving the torque–angle relationship and force–length relationship for the hip adductor muscles.[279,280] This increased force production creates larger mechanical stress on muscles, tendons, entheses, pubic bones, and pubic symphysis joint,[279] making the test more likely to trigger nociception and provoke groin pain.

Hip adduction strength from bilateral short- and long-lever hip adduction squeeze testing using the ForceFrame has previously been compared to unilateral long-lever testing using a HHD[216]; however,

this study did not compare provoked groin pain.[216] Strength showed a moderate correlation between the setups,[216] but systematic bias, Bland-Altman plots, and limits of agreement were not evaluated.[216] A recent study found that bilateral hip testing in the ForceFrame produced higher force and adductor longus EMG activity compared to unilateral hip testing,[217] which in turn showed increased contralateral external abdominal oblique muscle EMG activity.[217] This study concluded that uni- and bilateral isometric hip tests are not interchangeable.[217] Accordingly, unilateral testing could reflect combined hip and abdominal strength and cross-body coordination, while bilateral tests to a larger degree may reflect the total hip add- & abduction capacity in terms of strength and tissue mechanical stress tolerance. Since Study III,[182] the ForceFrame[281] and GroinMate[282] now allow bilateral long-lever squeeze testing at 10–15° hip abduction in fixed-frame dynamometers.[281,282] These updated assessor-independent fixed-frame devices may enhance testing efficiency with outputs similar to those of the HHD setup. Furthermore, new reliability studies[211,282] indicate that the pre-specified acceptable LOA at ±15%[209,251] might have been too narrow as MDC can reach up to 22%.[211,282]

The HHD and ForceFrame are not interchangeable, as they showed different results for hip adduction squeeze strength and provoked groin pain. Given that the strength and pain outputs were higher with the HHD setup, we chose the HHD for Study IV.

Maximal and explosive strength in athletes with long-standing groin pain

Male athletes with long-standing adductor-related groin pain had 29%, 16%, and 22% lower hip adduction RTD200, abduction RTD200, and abduction RTD100, respectively, compared with sex-, age-, and sport-matched asymptomatic athletes.[277] Maximal adduction and abduction strength and adduction RTD_{100} showed small and moderate non-significant differences, respectively.[277] Only symptomatic athletes reported groin pain during the tests.[277] Importantly, differences in RTD_{200} exceeded the SEM (12%) and MDC (7.5%),[26] whereas differences in RTD_{100} were close to the SEM (adduction: 25%, abduction: 17%) and MDC (adduction: 16%, abduction: 11%)[26] and the RTD_{100} differences are therefore at risk of being explained by measurement error.[26]

Previous studies have shown that athletes with long-standing groin pain may have significant deficits in unilateral maximal eccentric hip adduction strength,[114] and unilateral maximal isometric hip adduction and abduction strength.[24,25,283] Deficits have also been observed in bilateral maximal isometric hip adduction squeeze strength,[10,11] although this is only when a short-lever squeeze test with neutral hip abduction angle have been used.[10,11]

Study IV is the first study that have compared explosive strength from hip adductor squeeze and abductor press testing between athletes with and without long-standing groin pain.[277] Similar deficits

in explosive strength during hip flexion and extension have been observed in patients with hip-joint related groin pain before[284] and after hip arthroscopy.[285] Together, these findings support that long-standing pain in the hip and groin region have a negative impact on explosive muscle strength and central neurophysiological mechanisms as also seen in long-standing upper limb/shoulder pain[206,207] and knee osteoarthritis.[286] In line with findings from upper limb/shoulder pain,[206,207] explosive strength showed larger deficits than maximal strength[277] which could be explained by neural inhibition activated by the acute provocation of intense groin pain during testing.[206,287] In rest athletes with long-standing groin pain rarely experience pain[181,277] while during the explosive testing the rapid and forceful hip adduction muscle contractions generates a high amount of biomechanical stress that would initiate an intense barrage of nociceptive stimuli from the groin tissues to the spinal cord[201,228] especially with a presence of mechanical hyperalgesia in the groin.[8,64,277] In contrast, contractions at a slower speed would reduce the peak biomechanical stress and thereby reduce the likelihood of initiating nociception.[228] Slower contraction may also improve the activation of painful muscles and compensatory synergist muscles[206] that together would allow to generate near normal maximal strength within 5 seconds despite reduction of explosive strength.[202,203,206] Finally, it has been argued that cortical inhibition, from fear avoidance, could be a more important and potent determinant of explosive strength than neural inhibition in long-standing musculoskeletal pain.[206,207] Supporting this, reduced explosive strength and increased fear of movement in slaughterhouse workers with chronic upper limb pain[207] In line with this, Study IV also showed increased levels of fear of movement and pain catastrophizing in addition to the reductions in explosive hip muscle strength in the athletes with long-standing groin pain.[277]

Muscle Function - Future research

It is important for researchers to know that athlete positioning for long-lever hip adduction squeeze testing influences strength and pain output, and long-standing groin pain is associated with reductions in explosive hip strength. Future research should examine hip muscle function and pressure pain thresholds in larger samples to better understand the relationship between mechanical pain sensitivity and strength output. Incorporating psychological profiling and pubic radiographic findings into a combined model could also help improve our understanding of strength deficits and provoked groin pain. Explosive strength should be studied prospectively to understand its relationship with groin pain onset, transition to long-standing pain, pain severity, disability, performance measures, psychological profiles, and return to sports.

Pain Sensitivity in Athletes with Long-Standing Groin Pain

Assessment of athletes with long-standing groin pain often includes pain intensity, location, quality, clinical tests and movements that provoke pain.[14,23] Athletes often present with long pain duration (up to 11 months),[9] high pain intensity (NRS ≥ 7),[8,114] bilateral pain,[7,8,36] multiple painful sites,[7,123] regional pain,[7] region-wide mechanical hypersensitivity,[8] and poor response to current first-line evidence-based treatment.[36,42] Similar characteristics are also seen in other severe long-standing pain conditions[230] that often are classified with altered nociceptive function.[228,230]

Study IV investigated nociceptive function in athletes with long-standing groin pain to determine whether these athletes are characterized by altered nociceptive function.

Hyperalgesia in Athletes with Long-Standing Adductor-related Groin Pain

In Study IV, male athletes with long-standing adductor-related groin pain showed moderate to large reductions in PPTs and PDTs, indicating widespread mechanical hyperalgesia from leg to arm.[277] Widespread mechanical hyperalgesia is considered an essential indicator of altered nociception,[49] and pain mechanisms such as peripheral and central sensitization.[228,230]

One previous study used PPT to study athletes with groin pain.[64] In Australian football players with groin pain, mechanical hyperalgesia at the adductor longus tendon was a significant factor in pain, irrespective of the clinical entity.[64] The study measured PPT at the tibialis anterior but found no remote hyperalgesia.[64] Several factors may explain the discrepancies with Study IV. First, they defined hyperalgesia as >10% asymmetry in PPT between sides within each athlete,[64] rather than comparing athletes with groin pain to healthy controls.[64] This approach was novel, but has not been adopted elsewhere.[263] Second, pain severity has been suggested as a driver of altered nociceptive function;[229] however, no pain severity measures were reported by Drew et al.[64] In Study IV, athletes had a median pain duration of 52 weeks, pain intensity of 6.7, bilateral pain (n = 7), and reduced HAGOS scores.[277]

The current findings[277] indicate that long-standing groin pain may have a different pain sensitivity profile than other lower-limb pain conditions in athletes,[62,63] as two meta-analyses show that athletes with lower-limb tendinopathies only have hyperalgesia at their primary pain site.[62,63] One explanation for this could be that long-standing groin pain might be a pelvic overload syndrome,[288,289] where groin pain may develop from a combination of high tissue loads and poor movement biomechanics.[288,289] During running, kicking, and change of directions, several muscles act upon the pelvis in combination,[289] and groin pain then causes unaffected surrounding muscles to compensate and thereby overloading multiple structures in combination.[44,289] When multiple structures are mechanically

overloaded, nociceptive stimuli may become facilitated by spatial summation of pain along with peripheral and central sensitization of the T12–L5 spinal segments.[228,230] Thereby creating a vicious cycle where the altered pain mechanisms amplify and help to maintain groin pain.[228,229] This could explain the widespread hyperalgesia in the hip and groin region observed in Study IV,[277] and clinical pain provocation tests and multiple clinical entities are related to pain severity and disability in athletes with long-standing groin pain.[8] However, segmental sensitization does not explain the observation of decreased PPTs at the elbow,[277] which suggest higher spinal segment sensitization that could have developed over time due to cranial spreading of sensitization.[256]

Modulatory Pain Mechanisms in Athletes with Long-Standing Adductor-related Groin Pain

Male athletes with long-standing adductor-related groin pain showed no difference in TSP and CPM compared with controls, suggesting sufficient pronociceptive and antinociceptive modulatory pain mechanisms.[277]

Modulatory pain mechanisms have not been previously assessed in athletes with long-standing groin pain. A study of 51 patients with hip joint-related groin pain undergoing hip arthroscopy assessed TSP using Von Frey filaments on the third finger.[290] They identified a facilitated pain response in 41% of patients, who showed less improvement after surgery compared to the rest.[290] Von Frey filaments primarily activates cutaneous nerves,[51] making them less suitable for assessing conditions characterized by deep tissue pain.[256] The computer-controlled cuff algometer stimulates both skin and muscle tissues and replicate pain from deeper tissues more accurately.[231,232] Pain severity also varied between studies.[290] Patients with facilitated TSP had a mean pain duration of 31 months and moderate pain at rest (mean VAS 4.4),[290] whereas the athletes with groin pain in Study IV had pain for 52 weeks and almost no pain at rest. The rich mechanoreceptor and nociceptor innervation of the hip joint[291] may be a stronger driver of nociceptive stimuli than the muscles, tendons, entheses and pubic symphysis joint.[133] Unlike Jochimsen et al.[290], Study IV included athletes, who have higher pain thresholds and tolerances than non-athletes.[59,60] Still, the current results align with two recent meta-analysis showing normal pain modulation in athletes with lower-limb tendinopathies.[61,63]

Pain Distribution in Athletes with Long-Standing Groin Pain

Male athletes with long-standing adductor-related groin pain experienced pain at the origin of the adductor muscles, hip crease, inguinal canal, lower abdomen and up to the anterior superior iliac spine, but there are large variations in the distribution.[277] These findings align with a triangular pattern observed in 167 athletes with long-standing groin pain[7] and the distributions of experimentally induced adductor-related groin pain.[292] Athletes with multiple clinical entities have a larger and more

widespread pain distribution.[7] In Study IV,[277] most athletes had multiple entities and some marked pain in four locations outside the groin.[277] While Serner et al.[7] found symmetrical pain in 48% of bilateral cases,[7] all seven bilateral cases in Study IV showed symmetrical pain.[277] These findings highlight that for most of the athletes their primary nociception site is the adductor longus muscle/tendon complex.[277] However, the widespread and symmetrical bilateral pain distributions provide additional support of some athletes with long-standing groin pain having altered nociceptive function and segmental central sensitization.[256,293]

Overall, the findings of widespread hyperalgesia and a large pain distribution suggest that athletes with long-standing groin pain may present with altered peripheral and central nociceptive function, distorting the local tissue capacity. These findings are novel and could be important for improving the assessment and management of long-standing groin pain.

Psychological Factors in Athletes with Long-Standing Groin Pain

The IOC consensus papers advocate an increased focus on psychological factors in athletes with pain,[47,48] as pain is influenced by cognitive-affective and emotion-behavioral factors.[65,69] Targeting psychological factors is considered important for the rehabilitation of athletes following an injury.[47,66] However, less is known about how psychological factors impact pain and disability in athletes with long-standing groin pain, as psychological factors are rarely assessed or targeted during management.

In Study IV,[277] athletes with long-standing adductor-related groin pain reported small to moderately higher scores than matched controls on questions about pain catastrophizing, fear of movement, depression symptoms, and lower scores for pain self-efficacy.[277] Scores for questions about anxiety, stress, loneliness, and sleep quality did not differ between groups.[277] Across the brief questions, the symptomatic athletes seemed to score lower than populations with severe long-standing pain conditions, such as widespread pain, spinal pain, and extremity pain.[260] One previous study have measured a distinct psychological factor in athletes with long-standing groin pain.[41] In a randomized controlled trial, 44 athletes with long-standing pubic-related groin pain showed a mean score of 22 (range: 5-42) on the Pain Catastrophizing Scale at baseline before treatment.[41] This mean PCS score was higher than reference values for healthy individuals (PCS ≈ 15),[294] and was gradually reduced to a mean of 10 over 1, 3, and 12 months with non-surgical treatment.[41] In line with the current results, another study by Pålsson et al.[73] found that patients with long-standing hip and groin pain more frequently displayed higher psychological distress than healthy controls and that distress levels were associated with self-reported pain and symptoms.[73] Whether pain, symptoms and disability are associated with the psychological factors in our sample is unclear, although it is not unlikely.

The current findings are in line with studies of patients with hip-joint related groin pain undergoing hip arthroscopy who can also present with low self-efficacy,[77,78] as well as increased fear of movement/kinesiophobia,[75–79] pain catastrophizing,[74–78] and depression.[77,78,80] Importantly, these specific psychological factors are also associated with worse pain, disability, function and treatment outcomes in these patients with hip-joint related groin pain.[74–80]

Although psychological factors have not yet been assessed regularly in athletes with long-standing groin pain, it is important for clinicians and researchers to know that it is not uncommon for these athletes to experience negative emotions, and pain-beliefs.[277] Furthermore, as there are no specific psychological measurements validated for athletes with groin pain, it is also important to know that the widely used HAGOS[72] and/or iHOT scores[184] are associated with fear of movement/kinesiophobia,[77,79] pain catastrophizing,[77,78] pain self-efficacy[77,78] and psychological readiness to return to sport,[295] although in patients with hip joint-related groin pain.[79,295] Thus, during a consultation, clinicians and researchers can use HAGOS and iHOT and their single items as the basis for a conversation about the psychological aspects of pain and being injured.[227,255] These findings support the importance of including psychological factors such as pain catastrophizing, fear of movement, depression, and pain self-efficacy into the assessment and management of athletes with long-standing groin pain.

Pain sensitivity & Psychological factors - Future research

Future longitudinal studies should investigate how pain sensitivity and psychological factors influence pain, disability, function, and treatment outcomes of long-standing groin pain in athletes. In parallel, qualitative studies are needed to understand the lived experience of long-standing groin pain. While emerging pain research areas such as genetics, epigenetics, cortical function, the neuro-immune system, inflammatory markers, may further advance understanding of the condition.[228]

Methodological considerations

This thesis has methodological limitations that should be acknowledged when interpreting its findings. Studies I and III used reliability and agreement designs, which depend on raters, equipment, procedures, and participants.[18] Studies II and IV used cross-sectional case–control designs, which cannot establish causal associations but can be used for hypothesis-generation.[241] The modest and fixed sample sizes in Studies I, II, and IV increased the risk of type-II error.[241] Whereas, multiple statistical tests increased Type-I error risk in Studies II and IV,[276] which therefore reported both raw and Benjamini–Hochberg-adjusted p-values to control the false-discovery rate.[246]

Sampling may have influenced the between-group differences and generalizability. Studies I and II re-evaluated radiographs from 2010-2012.[234,235] Using existing radiographs is ethically preferable to avoid exposing asymptomatic athletes to radiation. However, changes in training, sports medicine, and imaging technology over the past decade may limit the generalizability of our findings to modern athletic populations. Symptomatic athletes who self-referred to Studies I, II, and IV potentially over-represented severe cases. Recruiting asymptomatic athletes was difficult in Studies I and II,[148,234,235] which is why Study IV facilitated this recruitment with monetary compensation.[277] Study III included only healthy footballers from one academy/club, which facilitated same-day testing of a large sample.[182] However, including athletes with groin pain may show better agreement between devices if their overall strength output is lower. In Studies II and IV,[234,235] asymptomatic athletes were matched by sex, age, and sport,[234,235] while Study IV did not match for training amount, competition level, or weekly load.[277] In Study IV,[277] one-third of asymptomatic athletes reported previous groin pain, and two-thirds of symptomatic athletes were in treatment.[277] Finally, the focus on young adult men restricts applying the results directly to women, adolescent athletes, and non-sporting populations.

Radiographic Limitations

Radiographs visualize a three-dimensional pelvis in two-dimensions, why patient-positioning and pelvic rotation may influence results.[268] Radiographs were obtained by multiple radiographers in an outpatient clinic, reflecting non-study setting, although potentially increasing measurement errors.[234,235] The radiologists reflect target users; however, additional radiologists would have strengthened the study.[21] Radiographs were not anonymized;[234,235] therefore, recall bias could not be excluded despite randomized sequences and an 8-week interval between the evaluations.[234,235] For pubic-related findings, the only quality criterion was pubic symphysis visibility as the influence of other quality factors remains unknown.[234,235] For hip-related findings, no standard quality criteria were applied to cross-table lateral hip radiographs, potentially affecting the alpha angle reliability.[234,235] In Study II,[235] consensus readings do not reflect single-reader clinical practice and remain susceptible to bias

from "group-thinking, senior-junior influence, and wrong assumptions.[267] The proposed PSRS Scores were arbitrary aggregations of findings.[235] Thus, weighting and combining findings based on larger datasets and factor analyses may yield a more robust data-driven score.[235]

Muscle Function Limitations

Assessments in Study III were completed on the same day to reduce day-to-day variance.[182] Randomization of assessment order was not feasible due to time-constraints, instead players were alternately allocated between devices to mitigate fatigue effects.[182] Hip-abduction angle was not directly measured with a goniometer but inferred from distance between ankles (HHD: ~35 cm, ForceFrame: ~17 cm).[182] Assessors used standardized instructions and were blinded to the alternate device to minimize observer bias.[182] In Study IV, assessing explosive and maximal muscle strength at the same time may have influenced results,[34] as these strength components may be better measured with separate testing protocols with different repetitions, time under tensions, and instructions.[34] Although athletes were fixated with rigid belts during HHD testing in Study IV,[34] using a fixed frame device with 15° abduction angle may have improved stability, and reduced variance.[282]

Pain Sensitivity and Psychological Factor Limitations

All experimental assessments in Study IV were performed by a single unblinded assessor, increasing the risk of observer bias. Handheld algometry was assessor-dependent, while questionnaires,[72] cuff algometry,[231,232] HHD, and digital pain drawings[258] were mainly assessor-independent.[277] The cuff-algometer may show ceiling effects for PTT, TSP, and CPM due to the pressure limit at 100kPa. Finally, there is a risk of underreporting of psychological factors in athletes due to lack of validation of the brief psychological screening questions, which were designed and validated for screening of psychological conditions in general practice and secondary care.[259–261]

Chapter 6 – Conclusions

This thesis advances our understanding of radiographic findings, muscle function, pain sensitivity, and psychological factors in male athletes with long-standing groin pain.

Pubic and hip radiographic findings were suitable for group-level and research assessments based on moderate to almost perfect relative intra-rater reliability and slight to almost perfect relative inter-rater reliability. However, absolute intra- and inter-rater reliability measures indicate that caution is required in individual-level assessments and clinical decisions.

At this point, pubic radiographic findings show limited clinical relevance, as they are equally common in male football players with and without long-standing groin pain, but less common in asymptomatic non-football athletes. Among symptomatic football players, the number of pubic-related findings was not associated with pain intensity or disability, although bone lucency and narrow pubic joint space showed weak negative associations with pain intensity, and sclerosis showed a moderate negative association with disability.

Both an HHD and a ForceFrame can be used with bilateral long-lever hip adduction squeeze testing to assess hip adduction strength and provoke groin pain. However, the measurements differed significantly, likely due to differences in the hip abduction angle during testing, indicating that the HHD and ForceFrame are not interchangeable. When the HHD was used to explore muscle function differences between athletes with and without long-standing adductor-related groin pain, symptomatic athletes showed large reductions in explosive hip adduction and abduction strength but only a small non-significant reduction in maximal strength. These findings indicate clinically relevant deficits in muscle function, particularly explosive strength.

Male athletes with long-standing adductor-related groin pain showed reduced pressure pain thresholds but similar temporal summation of pain and conditioned pain modulation compared with asymptomatic athletes. This indicates widespread pressure hyperalgesia and sensitization of peripheral and central pain mechanisms, but no alteration in descending modulatory mechanisms. Symptomatic athletes reported higher pain catastrophizing, fear of movement, and depressive symptoms and lower pain self-efficacy, but showed no differences in anxiety, stress, loneliness, and sleep. This indicates alterations in the supraspinal regions that regulate pain, affect cognitive control, emotion, and behavior.

Chapter 7 – Perspectives

This thesis shows that long-standing groin pain in male athletes is associated with a combination of biomechanical, neurophysiological, and psychological factors rather than clinical findings and radiographic abnormalities alone. These findings support a transition toward a more biopsychosocial approach to these athletes in both research and clinical practice, as suggested by experts in the IOC consensus papers.[46–48]

Currently, pubic-related radiographic findings offer limited clinical information about groin pain, pain intensity, and disability.[22,235,265] Considering the risk of misclassification (false-positive findings),[22,234] pubic-related findings should not be used to guide the diagnosis or treatment of individual athletes.[235] However, the Aspetar Pubic Symphysis Radiographic Scoring Protocol may still be employed in prospective cohort studies and registries, as more data may change the conclusion and help to better understand the development, significance, and potential consequences of these radiographic findings.

Although first-line diagnostic imaging for athletes with hip and/or groin pain primarily assesses hip-related radiographic parameters and findings,[15] the poor absolute reliability observed in Study I[234] raises concerns about the usefulness of specific cut-offs for the alpha angle,[15] lateral center-edge angle,[15] and acetabular index angle.[15] Caution is advised when using such radiographic parameters and cut-offs in individual clinical decision-making and classification of hip joint-related groin pain in athletes.

Bilateral long-lever hip adduction squeeze testing now has a wide range of applications: diagnosing acute and long-standing adductor-related groin pain;[119,215] identifying risk of future groin problems;[104] measuring provoked groin pain intensity,[31] screening hip and groin-related disability[27,31] and tissue sensitivity;[8] and measuring maximal (Study III)[27,182,209] and explosive hip adduction strength (Study IV).[249,277] Notably, Study III highlighted the importance of patient positioning during adduction squeeze testing.[182] A ~15° hip abduction angle increased both strength output and provoked groin pain intensity,[182] potentially improving the assessment of total hip adduction capacity and biomechanical stress tolerance.[182] Contrary, the lesser pain and discomfort during ForceFrame testing may facilitate regular monitoring of strength and groin pain.[30]

The Study IV finding of reduced explosive hip adduction and abduction strength in athletes with long-standing groin pain may suggest impaired central neuromuscular control[201] and highlights a potential target for future management strategies. These deficits may reflect difficulties with sprinting, kicking, and other high-velocity tasks as measured by HAGOS.[31] Consequently, rehabilitation should gradually expose athletes to high-load, high-speed exercises to restore a more complete physical capacity

in these athletes before they return to sport.[23,24] At the same time, clinicians must be aware that explosive movements could more easily stress the groin and provoke groin pain.[89] In the athlete's mind, this risk of injury and pain may be accompanied by maladaptive fear of movement and pain catastrophizing specifically related to explosive actions.[201,206] Such movement-specific psychological responses might explain why Study IV only identified small to moderate elevations in psychological factors in athletes with long-standing groin pain. Nevertheless, the observed elevated levels of fear of movement, pain catastrophizing, depressive symptoms and reduced pain self-efficacy highlights that clinicians should screen for psychological factors to know when to provide the necessary psychological support or refer to a psychologist.[47,48]

Widespread mechanical hyperalgesia, as identified in Study IV, may account for the difficulties in the clinical examination and classification of athletes with multiple clinical entities of groin pain.[6,8] In such athletes, clinicians should consider the number of provocation tests conducted, prioritizing the identification of the pain response that aligns most closely with the athlete's known and recognizable groin pain experienced during sports.[8] Additionally, when multiple clinical entities are identified and tissue irritability is high, it may be challenging for clinicians to decide whether the management strategy should focus on a specific entity[36] or address all entities simultaneously with comprehensive multi-entity exercise programs. For such athletes, a more general exercise approach that maintains physical activity and enhances hip strength without triggering pain may be more suitable,[24,44] particularly if targeted exercises exacerbate symptoms. Furthermore, it may also be relevant to include a specific focus on pain management,[41] providing pain relief,[23,47,227] and education on pain science and how to adjust exercise progressions based on symptoms and flare-ups.[23]

In broader terms, altered pain sensitivity, negative pain beliefs, and poor mental health may be addressed by combining well-established progressive strength training principles[36,42] with athlete-centered strategies that align with contemporary pain neuroscience.[48,227] This may include adding a focus on patient empowerment through empathetic communication, pain education, graded activities, shared decision-making, and psychological support.[48,227,296] Incorporating these principles may improve clinical outcomes and reduce disability by addressing multiple biopsychosocial factors contributing to groin pain. With this approach, it can be hypothesized that even athletes with severe long-standing groin pain may achieve a sustainable return to sport that allows them to stay on the pitch and maintain long-term health.

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Appendix

STUDY I

Intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in 86 male athletes with and without hip/groin pain

Authors: Mathias Fabricius Nielsen, Per Hölmich, Sonia Branci, Trine Torfing, Lasse Ishøi, Michael Bachmann Nielsen & Kristian Thorborg.

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Title page

Title

Intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in 86 male athletes with and without hip/groin pain

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Ethics approval statement

This study has been approved by the Danish National Committee on Health Research Ethics (NVK 2117722) and the Capitol Region Data agency (P-2021-497). It includes data and radiographs collected in larger epidemiological project on hip and/or groin pain (ethical approval reference: H-2-2010-127, data approval reference: 2011-41-5964).

Patient consent statement

Participants provided written informed consent when included in a previous larger epidemiological project on hip and/or groin pain (ethical approval reference: H-2-2010-127, data approval reference: 2011-41-5964). The Danish National Committee on Health Research Ethics deemed that participants were not required to update their informed consent for this new project (NVK 2117722).

Conflict of interest statement

All other authors declare they have no conflicts of interest.

Authorship statement
The first author is the lead and corresponding author. Contributions to the paper are described using the CRediT taxonomy by Brand, A., Allen, L., Altman, M., Hlava, M., & Scott, J. (2015).:
Conceptualization: MFN, PH, and KT; Methodology: MFN, PH, SB, TT, LI, MBN, and KT; Formal Analysis: MFN; Investigation: MFN, PH, SB, TT, MBN, and KT; Resources: PH, SB, TT, MBN, and KT; Data Curation: MFN; Writing – Original Draft: MFN and KT; Writing – Review and Editing manuscript: MFN, PH, SB, TT, LI, MBN, and KT; Visualization: MFN; Supervision: PH, LI, and KT; Project Administration: MFN, PH, and KT; Funding Acquisition: MFN, PH, LI, and KT.

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1 **TITLE**

2 Intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in 86 male athletes with

3 and without hip/groin pain

ABSTRACT

Anteroposterior (AP) pelvic and lateral hip radiographs are the first-line diagnostic imaging used for athletes with longstanding hip/groin pain. Reliable radiographic parameters are essential for research and clinical decision-making; however, relative and absolute reliability data for these procedures are lacking.

This study investigated relative and absolute intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in male athletes.

AP and cross-table lateral radiographs from 46 footballers with hip/groin pain and 40 asymptomatic athletes were independently rated by two blinded radiologists. Hip-related parameters included alpha angle, lateral center-edge angle, acetabular index angle, hip joint space width, ischial spine sign, cross-over sign, and posterior wall sign. Pubic-related parameters included bone lucency, proliferation, fragmentation, sclerosis, and pubic joint space width. Relative reliability was quantified using intraclass correlation coefficients (ICC) and Cohen's κ; absolute reliability with minimal detectable change (MDC) and overall agreement.

Relative reliability for hip-related parameters ranged from ICC: 0.69–0.78 and κ: 0.51–0.81 for intra-rater, and ICC: 0.17–0.77 and κ 0.53–0.86 for inter-rater reliability. Relative reliability for pubic-related parameters ranged from κ: 0.49-0.63 (intra-rater) and κ: 0.34-0.45 (inter-rater). Absolute reliability for hip-related parameters ranged from MDC: 7.2°–14.7° (intra-rater) and 6.5°–33.1° (inter-rater). For pubic-related parameters, overall agreement were 82%–93% (intra-rater) and 64%–89% (inter-rater).

Most hip- and pubic-related radiographic parameters showed relative intra- and inter-rater reliability sufficient for use in group-level and research. However, absolute reliability shows considerable variability for hip-related parameters, which warrants caution when using radiographic measurements and cutoffs for individual clinical decision-making.

Keywords: Reliability, X-ray, Radiography,

INTRODUCTION

Anteroposterior pelvic and lateral hip radiographs are the first-line imaging modalities in the diagnostic work-up of athletes with longstanding hip and groin pain[1–3], as they allow for the evaluation of hip joint morphology, pelvic rotation, and changes in the pubic symphysis and adjacent bone[4].

Hip-related parameters, such as the Alpha Angle, Lateral Center-Edge Angle (LCEA), Acetabular Index Angle, Hip Joint Space Width, and the Ischial Spine (ISS), Posterior Wall (PWS), and Cross-Over Signs (COS), are recommended by consensus to assist in defining, classifying, and diagnosing hip-related groin pain (e.g., femoroacetabular impingement syndrome, acetabular dysplasia, and/or hip instability)[1,3,5]. As these radiographic parameters directly influence both research findings and clinical decision-making for athletes with longstanding hip and groin pain[1,6], it is important that these parameters and procedures are supported by sufficient relative and absolute reliability data from the settings and populations in which they are used[7–9].

Despite the widespread use of hip-related parameters,[3,5,10] relative reliability has typically only been briefly reported in athletes with incomplete details[11–19], and absolute reliability data from athletic populations have not yet been scrutinized[11–20]. In particular, absolute reliability is important for clinicians and researchers, as it is used to evaluate how much trust and certainty that clinicians can place in their individual radiographic measurements by quantifying the amount of measurement variability associated with this procedure[8,9,21]. Thus, both relative and absolute reliability of hip-related radiographic parameters in athletes requires further investigation.

The new Aspetar pubic symphysis radiographic scoring protocol[4] provide a clear and systematic method for determining the presence of radiographic changes of the pubic symphysis and adjacent bone in male athletes.[4] The protocol includes five main parameters (Bone Lucency, Proliferation, Fragmentation, Sclerosis, Pubic joint space width) with 10 subclassifications[4]. Despite fair to almost perfect relative reliability for the main parameters in asymptomatic athletes[4], the reliability of the Aspetar protocol when used in athletes with and without hip and groin pain and by other radiologists remains unclear.

Therefore, the primary aim of this study was to investigate the relative and absolute intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in male athletes with and without hip and groin pain.

MATERIALS AND METHODS

Study design

This study is based on data and radiographs from a large epidemiological project on hip and groin pain among male football players[ ]. In this project, football players with hip and/or groin pain, asymptomatic football players, and asymptomatic male non-football athletes were recruited to undergo clinical examination[ ], radiographic examination[ ], magnetic resonance imaging[ ], and muscle strength assessments[ ] at an orthopedic department in a public hospital. All participants provided written informed consent prior to inclusion, and the previous project was approved by the National Committee on Health Research Ethics (H-2-2010-127) and the Data Protection Agency (2011-41-5964).

This study was conducted as an intra- and inter-rater reliability study of radiological evaluations conducted from June 2022 to April 2023 by two radiologists. All radiographs were retrospectively reviewed as they were collected from 2010 to 2012 as part of the original project on hip and groin pain among male football players[ ]. The reliability study was approved by the National Committee on Health Research Ethics (NVK 2117722) and the Data Agency (P-2021-497). Reporting followed the guidelines for reliability and agreement studies[8] and best practices for radiographic parameter reliability studies[20]. Figure 1 illustrates the study timeline.

INSERT FIGURE 1 HERE

Participants

This study included football players with hip and groin pain, asymptomatic football players, and asymptomatic male non-football athletes to obtain a sample that represented a broad spectrum of athletes who may present routinely at a clinical sports medicine practice[31].

Male football players were recruited from a pool of 700 subelite (tier 2-5) senior players (≥18 years) who participated in a survey on hip and groin pain in . Symptomatic football players participated in 2-4 weekly football sessions and experienced hip and groin pain during football or running. Asymptomatic players met the same criteria but had no hip or groin pain in the previous year. Asymptomatic male non-football athletes were recruited from sports clubs, educational institutions and fitness centers. They were ≥18 years, trained 2-4 times per week, had no hip or groin pain in the past year, had not played football regularly for 10

years, and did not participate in sports associated with hip and groin pain. The exclusion criteria were systemic disorders, obesity, depression, alcohol or drug abuse, and other conditions that may cause hip and groin pain.

Data collection

All participants underwent conventional hip and pelvic radiography in 2011-2012 according to clinical practice in the outpatient clinic at the Orthopedic Department of a public hospital. This included a cross-table lateral hip view of each hip and a standing anteroposterior pelvic view. As all radiographs were collected in 2011-2012, we were unable to include a 45° Dunn view as recommended in 2020-21 by the Lisbon agreement on femoroacetabular impingement imaging[3,5,10]. Patient positioning is described in the Supplementary File.

Radiographs were accessed using the Agfa IMPAX Client Bundle 5 (Agfa-Gevaert Group, Belgium) and mediCAD (MediCAD Hectec GmbH, Germany). In accordance with clinical practice in our outpatient clinic and department, MediCAD was specifically used to measure the Alpha Angle, LCEA, Acetabular Index And Hip Joint Space. The remaining parameters were rated directly using the Agfa IMPAX Client Bundle 5. However, as the radiologists were delayed access to mediCAD, the parameters, including the Alpha Angle, LCEA, Acetabular Index And Hip Joint Space, were measured 21 weeks after the pubic-related parameters, ISS, PWS, and COS (Figure 1). During data collection, Rater 2 identified a technical error in the mediCAD software. The vertical reference lines were not calibrated correctly according to the radiographic orientation when measuring LCEA. To ensure correct measurements of LCEA, the entire procedure of placing reference lines was adjusted to account for the technical error; however, this resulted in Rater 1 having to re-measure the LCEA on 57 radiographs. To ensure radiographic quality, each radiologist screened for pelvic tilt, excluding radiographs in which the sacrococcygeal joint-to-pubic rim distance was <25 mm or >55 mm. Radiographs were excluded if the gonad shields covered key structures or if the radiologists judged that poor positioning/quality compromised the evaluation of hip- or pubic-related parameters.

Two musculoskeletal radiologists ([redacted]) with 11 and 31 years of experience, respectively, independently rated the radiographs in a random order, blinded to the prior data. After an 8-weeks washout, a second reading was performed by Rater 1 ([redacted]). Rater 2 ([redacted]) did not perform a second reading for intra-rater reliability, as this was not included in the study protocol, similar to multiple previous studies using a single rater for intra-rater analyses[4,11–14,16–19]. Intra-rater reliability was calculated from the repeated ratings by

Rater 1, while inter-rater reliability was based on the first ratings from both raters to mitigate practice-effect bias [20].

Neither radiologist had prior experience with the Aspetar protocol but were trained and calibrated in the protocol by [redacted], [redacted] of the Aspetar pubic symphysis radiographic scoring protocol[4]. Ratings were collected using REDCap[32].

Radiographic parameters

Hip-related parameters.

Each hip was evaluated for the alpha angle, lateral center-edge angle, acetabular index angle, ischial spine sign, posterior wall sign, crossover sign, and hip joint space width, following the Lisbon agreement on femoroacetabular impingement imaging (Figures 2A-2F)[3,5,10]. The ischial spine sign, posterior wall sign, and crossover sign were rated as either absent or present. The alpha angle, lateral center-edge angle, acetabular index angle, and hip joint space width were measured in degrees or millimeters, respectively. Parameters were rated as present only if clearly observable; otherwise, they were rated as absent.

INSERT FIGURES 2A-2F HERE.

Pubic-related parameters

The pubic symphysis and adjacent bones were evaluated using the Aspetar pubic symphysis scoring protocol[4] (Figure 3A-3E). All parameters were rated as either absent or present, except for pubic joint space width, which was measured in millimeters (nearest whole number). Parameters were rated as present only if clearly observable; otherwise, they were rated as absent. For bone lucency, erosion-like configuration, proliferation, and fragmentation, only their subclassifications were rated, which were then used to determine the absence/presence of the main parameters (Appendix Figure 4). A pubic joint space width of <3 mm was classified as being narrow.

INSERT FIGURES 3A-3E HERE.

Sample size consideration

A total of 86 athletes underwent radiography in the epidemiological project (H-2-2010-127). If all radiographs were of sufficient quality, 172 hips and pubic bones were available. For hip-related parameters, this sample size allowed the detection of statistically significant intraclass correlation coefficients (ICC) ≥ 0.26

and kappa values with lower confidence intervals of 0.07-0.26, using a two-sided test and assuming no examiner bias[33]. Sample size estimations for the pubic-related parameters are provided in the Appendix.

Statistical methods

Relative reliability describes the degree to which individuals maintain their position in a sample over repeated measurements[8,9,21] and provides an indication of how well a measurement can be used to differentiate between individuals or groups[8,9,21]. Relative reliability for continuous parameters was quantified as ICC(2,1) using single measurements, absolute agreement, and two-way random-effects models[9,34]. For continuous parameters with systematic bias between ratings and raters, we performed post-hoc analyses that quantified the relative reliability in a scenario where systematic bias could be adjusted for using the ICC(3.1) from single measurement, consistency, and two-way mixed-effects models[34]. The systematic bias between ratings and raters was evaluated using paired t-tests. Relative reliability for dichotomous parameters was quantified as unweighted Cohen's Kappa (κ) with 95% confidence intervals (95% CI) from 1000 bootstrap samples[35]. For the κ estimates, the prevalence effect on the κ was evaluated using the prevalence index[35], and the effect of bias between raters on the κ was evaluated using the bias index[35]. Relative reliability was interpreted as poor (<0.00), slight (0.00-0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80) and almost perfect (0.81-1.00)[36].

Absolute reliability describes the degree to which repeated measurements vary for individuals and, therefore, the precision of repeated measurements[9,21,37]. The smaller the metrics for absolute reliability, the better the reliability[9,21,37]. Absolute reliability for continuous parameters was reported as the standard error of measurement (SEM), SEM %, minimal detectable change (MDC), $MDC\%_{individual}$, $MDC\%_{group}$, and Bland-Altman plots with 95% limits of agreement (see Appendix for formulas)[9,21,37]. The SEM is the within-subject standard deviation of repeated measurements[9,21,37]. The SEM% indicates the SEM relative to the scale of the measure[37]. The MDC indicates the minimum detectable change that exceeds the measurement error/variability[9,21,37]. The MDC% scales the MDC to the magnitude of the measure as the smallest change for an individual ($MDC\%_{individual}$) and the smallest sample mean change ($MDC\%_{group}$) [9,21,37]. Bland-Altman plots with 95% limits of agreement show the mean bias between two measurements and the span within which the difference between any two measurements on a new individual from this population is expected to lie.[21] Absolute reliability for dichotomous parameters was expressed with the

overall, positive, and negative percentage agreement[4,35], which indicates the degree to which overall, positive, and negative ratings are identical.

Analyses were performed in R version 4.3.0, using the packages SimplyAgree, epiR, BlandAltmanLeh, pwr v. 1.3-0, and kappaSize v. 1.2.

RESULTS

Participants

In total, radiographs of 86 athletes with 172 hips, 172 pubic bones, and 86 pubic symphyses were included. The sample characteristics are presented in Table 1. For intra-rater reliability metrics, the number of hips, pubic bones, and pubic symphyses with complete data ranged from 102–168, 159–166, and 80–83, respectively (Tables 2 and 4). For inter-rater reliability metrics, the number of hips, pubic bones, and pubic symphyses with complete data ranged from 96–170, 159–168, and 52–81, respectively (Tables 3 and 5). The detailed reasons for the missing data are presented in the Supplementary Files.

INSERT TABLE 1 HERE.

Hip-related radiographic parameters

The intra- and inter-rater reliability statistics for hip-related parameters are presented in Tables 2 and 3, respectively.

Relative reliability for hip-related parameters

Relative intra-rater reliability for Alpha Angle, LCEA, Acetabular Index, And Hip Joint Space were substantial, with ICCs ranging from 0.69–0.78, indicating stable parameters when groups are measured by a single radiologist. Small systematic biases were observed for the Alpha Angle and Hip Joint Space, but post-hoc ICC(3.1) analyses showed that these biases had little influence on the relative intra-rater reliability (Appendix Table A1). For the COS, ISS, and PWS, the κ values ranged from 0.51–0.81, reflecting moderate to almost perfect relative intra-rater reliability. The prevalence and bias indices were close to zero, indicating that the κ values were not influenced by prevalence effects or bias between ratings.

The relative inter-rater reliability for the Alpha Angle was slight (ICC = 0.17), suggesting that using different radiologists to measure this parameter may lead to inconsistent measurements, even at the group level. However, LCEA, Acetabular Index, and Hip Joint Space demonstrated substantial relative inter-rater

reliability (ICC = 0.71–0.77). The systematic bias was large for the Alpha Angle and small for the LCEA and Acetabular Index. Post-hoc ICC(3.1) analyses indicating that the bias influenced the relative inter-rater reliability for Alpha Angle, as the ICC increased to ICC = 0.39 (Appendix Table A2), whereas LCEA and Acetabular Index were less influenced of bias. For COS, ISS, and PWS, κ values ranged from 0.53–0.86, representing moderate to almost perfect relative inter-rater reliability, with only minor influence of prevalence or bias indices.

INSERT TABLE 2 HERE.

INSERT TABLE 3 HERE.

Absolute reliability for hip-related parameters

Absolute intra-rater reliability suggested small–moderate variability in the Alpha Angle, LCEA, Acetabular Index (SEM: 2.6°-5.3°), and Hip Joint Space (SEM: 0.5 mm) (Table 2). However, the SEM% values of 9%–36% showed that the measurement error constituted a large proportion of the measurement range for each parameter. The corresponding MDC values (7.2°-14.7°, and 1.3 mm) and $MDC\%_{individual}$ values (26%-100%) show that measurement variability strongly influences the individual values, limiting the certainty clinicians can place in these parameters when applied to the individual athlete. Bland–Altman plots (Appendix Figures 5a–8a) illustrate these patterns in detail. For COS, ISS, and PWS, the absolute intra-rater reliability was high (73%-90% agreement), supporting consistent ratings by the same rater.

Absolute inter-rater reliability showed a large measurement error for the Alpha Angle (SEM = 11.9°) and smaller measurement errors for LCEA, Acetabular Index (SEM: 2.4°-2.9°), and Hip Joint Space (SEM: 0.5 mm) (Table 3). However, SEM% values of 11%–34% showed considerable measurement variability across all four parameters. Bland–Altman plots (Appendix Figures 5b–8b) further illustrate the patterns of measurement variability. For COS, ISS, and PWS, the absolute inter-rater reliability remained high (72%-94% agreement), demonstrating consistent ratings between raters (Table 3).

Pubic-related radiographic parameters

The intra- and inter-rater reliability statistics for pubic-related parameters are presented in Tables 4 and 5, respectively.

Relative reliability for pubic-related parameters

Relative intra-rater reliability for the main pubic-related parameters ranged from moderate for proliferation and fragmentation (κ = 0.49) to substantial for bone lucency, sclerosis, and PJSW (κ = 0.60–0.63 and ICC = 0.76). For pubic-related subclassifications, relative intra-rater reliability varied widely, from slight for cysts (κ = 0.18) to substantial for ELC, superior proliferation, central fragmentation, and narrow joint space (κ = 0.63–0.75). The prevalence index was high (close to 1) for cysts, central proliferation, fragmentation (main and subclassifications), and narrow joint space, indicating that κ values for these findings were influenced by prevalence. The bias index was low (close to 0), indicating minimal systematic differences between the repeated ratings (Table 4).

The relative inter-rater reliability for the main findings ranged from fair for sclerosis (κ = 0.34) to substantial for PJSW (ICC = 0.72, Table 5). For subclassifications, the κ values ranged from slight for cysts (κ = 0.07) to substantial for superior/central ELC and narrow joint space (κ = 0.62–0.72). The prevalence index was again high for fragmentation (main and subclassifications) and central and inferior proliferation, suggesting that κ values are influenced by prevalence. The bias indices indicated systematic differences between the raters for cysts and sclerosis (Table 5).

INSERT TABLE 4 HERE.

INSERT TABLE 5 HERE.

Absolute reliability for pubic-related parameters

The absolute intra-rater reliability was high (75%-97% overall agreement) for most pubic-related parameters, supporting consistent ratings by the same rater (Table 4). However, for eight of the 14 parameters, negative agreement exceeded positive agreement, showing that the radiologist was more consistent in identifying the absence than the presence of pubic-related parameters. For the PJSW, absolute intra-rater reliability showed an SEM(%) of 0.5 mm(16%) and MDC($\%_{individual}$) of 1.5 mm(43%), indicating that individual-level ratings were influenced by measurement variability. The Bland-Altman plot for the PJSW is provided in Appendix Figures 9a.

Absolute inter-rater reliability was also high (≥75% overall agreement) for 10 of the 14 parameters (Table 5). However, the negative agreement exceeded the positive agreement in 8 of the 14 findings. For the PJSW, absolute inter-rater reliability showed an SEM(%) of 0.6 mm(17%) and an MDC($\%_{individual}$) of 1.6 mm(46%), again reflecting considerable variability at the individual measurement level. The Bland-Altman plot for the PJSW is provided in Appendix Figure 9b.

DISCUSSION

This study assessed the relative and absolute intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in male football players with and without hip/groin pain. To our knowledge, this is the first study to examine both forms of reliability for the alpha angle, lateral center-edge angle, acetabular index angle, crossover sign, ischial spine sign, posterior wall sign, and hip joint space width in male athletes. In addition, this is the first study to examine the reliability of the Aspetar pubic symphysis radiographic scoring protocol beyond its original development study [4]. In summary, hip- and pubic-related radiographic parameters showed relative intra- and inter-rater reliability that supports their use in research settings, whereas the absolute reliability of hip-related parameters warrants caution when using specific radiographic cut-off values for individual clinical decision-making. This is important as these measures can involve large measurement variability, especially when measured by different radiologists.

Relative Reliability of Hip-related Radiographic Parameters

Relative reliability describes the degree to which measures maintain their position in a sample over repeated measurements[8,9,21]. Relative reliability values ≥ 0.60 have been suggested as an acceptable level of reliability for research and group-level purposes[8].

The relative intra-rater reliability for the Alpha Angle (ICC = 0.74) was similar to that reported in five previous studies including athletes (ICC range: 0.59-0.93) [11–13,17,18]. Similarly, 18 of 21 studies on patients with pre-arthritic hips reported Alpha Angle ICCs above 0.61 [20]. Together with the present study's findings, this indicates that across populations and settings, the Alpha Angle can be measured with acceptable relative intra-rater reliability and thus can be used for group-level assessments and research [8,9]. In contrast, the relative inter-rater reliability for the Alpha Angle in the current study was clearly lower (ICC = 0.17) than recommended and previously reported in both athletes (ICC range: 0.71-0.93) [11–13,15–18] and patients with pre-arthritic hips [20]. However, limited and variable relative reliability for the Alpha Angle has also been highlighted by others, such as Carlisle et al. (inter-rater ICC: -0.08, 95% CI: -0.12, -0.019)[38], and it has also been mentioned as a real matter of concern in both the Lisbon agreement [3,5,10] and in a review by Carreira & Emmons[20]. The measurement error and variability associated with measuring the Alpha Angle may arise

from differences in placing the template circle on the femoral head and the reference line along the femoral neck [20]. Even minor misalignments can easily increase or decrease the Alpha Angle substantially, while a cranially placed or undersized template circle may also artificially increase the alpha angle [20]. In our study, the radiologists discussed the uncertainty in defining where the femoral head-neck junction extended beyond the template circle, particularly when cam morphology was clearly visible, but the Alpha Angle measurement was below the ≥60° cut-off. These difficulties were especially apparent when the femoral head was elongated, flattened, or the imaging quality was poor due to poor patient positioning or overlying structures. Such challenges are inherent to two-dimensional radiographic assessment, as cam morphology represents a three-dimensional deformity that is most pronounced at the anterosuperior femoral head–neck junction [39,40]; hence, clinicians and researchers should always be cautious and avoid over-reliance on radiographic cut-offs, as their reliability is far from perfect. Importantly, studies combining manually defined landmarks with semi-automated or automated measurements have reported good-to-almost-perfect reliability for the Alpha Angle on AP and 45° Dunn radiographs of athletes[11,12]. Therefore, similar automated procedures may enhance the relative reliability of Alpha Angle measurements on cross-table lateral hip radiographs in the future.

The relative intra- and inter-rater reliability for LCEA (ICC = 0.77-0.78) and Acetabular Index Angle (ICC = 0.69-0.73) were consistent with previous findings in both athletes (LCEA ICC range: 0.63-0.95[11,12,16–18], Acetabular Index ICC range: 0.76-0.81[16–18]) and patients with pre-arthritic hips (LCEA: ICC > 0.81 in 15/23 studies, Acetabular Index: ICC > 0.61 in 11/13 studies)[10,20]. Small systematic biases were observed between raters; however, these had negligible influence on reliability, as indicated by the post-hoc ICC(3.1) analyses. Compared with the relative reliability of the Alpha Angle measurements, these findings suggest that positioning a template circle on the femoral head is easier on the AP than on cross-table lateral views. Overall, the evidence for the relative reliability of LCEA and Acetabular Index indicates that both parameters can be measured with acceptable consistency for group-level and research purposes,[8,9] irrespective of whether they are performed by single or multiple radiologists.

The relative intra- and inter-rater reliability for the cross-over sign (COS; κ = 0.51-0.53) was slightly lower than that previously reported in athletes (κ = 0.59-0.86)[16–19] but higher than that in patients with pre-arthritic hips (κ > 0.41 in 9/11 studies)[20]. Similarly, the relative reliability for the ischial spine sign (ISS) and posterior wall sign (PWS) (κ = 0.65-0.86) was marginally better than that reported in most studies of patients with pre-arthritic hips (ISS: κ > 0.41 in 4/4 studies, PWS: > 0.61 in 4/5 studies) [20]. For all three

parameters, the prevalence and bias indices indicated that kappa was not influenced by prevalence effects or systematic rater bias. The generally favorable reliability observed in this study may reflect the consistent exclusion of radiographs with excessive pelvic tilt or rotation, factors known to affect these radiographic signs [41]. Collectively, these findings suggest that COS, ISS, and PWS can be measured with acceptable consistency for group-level analyses and research[8], irrespective of whether they are assessed by a single or multiple radiologists. However, additional studies on athletic populations are required to strengthen these conclusions.

Absolute Reliability of Hip-related Radiographic Parameters

Absolute reliability reflects the degree to which repeated measurements vary within individuals and, therefore, the precision of these measurements [9,21,37]. Its interpretation depends on the intended use and consequences at the individual level [8,9]. Importantly, absolute reliability metrics have not yet been reported in studies of athletes [11–19] and are rarely included in studies of patients with pre-arthritic hips [20,42].

In this study, both intra- and inter-rater absolute reliability showed considerable measurement variability for the Alpha Angle, Lateral Center-Edge Angle and Acetabular Index Angle. The SEM values ranged from 2.4°–1.9°, indicating noticeable imprecision in the single measurements of these parameters. The corresponding MDC values ranged from 6.5°–33.1°, indicating that the measurements can vary by this magnitude purely due to measurement error/variability when a single or multiple radiologists repeatedly assess the same radiographs.

Despite acceptable relative intra-rater reliability for the alpha angle (ICC = 0.74), these absolute reliability metrics imply that an individual athlete could be classified as having no cam (< 60°) at one rating and severe cam (> 78°)[43] at another, without any true anatomical change but solely due to measurement variability. To further illustrate this, we observed 106 disagreements between the measurements from the two radiologists when applying the ≥ 60° cut-off for cam morphology. As an example, a measured alpha angle of 63° would be classified as having cam morphology[5]; however, the SEMs of 5° and 12° imply that the plausible true alpha angle could be in the intervals 58°–68° (intra-rater) and 51°–75° (inter-rater). Furthermore, MDCs of 15° and 33° imply that repeated measurements of the same radiographs could produce measures anywhere between 48°–78° for the same rater, and 30°–96° for different raters. A similar consideration applies to the acetabular parameters. Values such as LCEA of 19° or an Acetabular index of 14° would indicate hip dysplasia;

however, given the observed SEM, the true LCEA and Acetabular index measurements could be anywhere in the intervals 16°-22° for LCEA and 11°-17° for Acetabular Index. The MDCs indicate that repeated measurements of LCEA and Acetabular index in a single athlete could range between 11°–27° and 7°–21°, respectively. These intervals highlight that the presence of clinically meaningful bony hip joint morphologies is highly uncertain for individual-level assessments. Thus, specific cut-offs, in the form of a single value, to classify cam morphology, pincer morphology, borderline dysplasia, or dysplasia, should be used with caution for individual clinical decision-making.

In contrast, for the crossover sign, ischial spine sign, and posterior wall sign, intra- and inter-rater absolute reliability was high for overall agreement (76%-93%) and balanced across positive and negative agreement, indicating that both the presence and absence of these parameters were identified consistently within and between radiologists. Accordingly, these parameters may be used with confidence for individual clinical decision-making; however, as they are sensitive to patient positioning [41], careful attention to standardized positioning and image quality remains essential.

Relative Reliability of Pubic-related Radiographic Parameters

The relative intra- and inter-rater reliability for superior/central ELC, proliferation (inter-rater), superior proliferation, central proliferation, inferior proliferation (intra-rater), central fragmentation, sclerosis, and narrow joint space width (intra-rater κ: 0.49-0.75, inter-rater κ: 0.26-0.72) were slightly higher than reported by Serner et al.[4]. While the relative reliability for bone lucency, ELC, inferior ELC, cysts, fragmentation, inferior fragmentation (intra-rater κ: 0.18-0.63, inter-rater κ: 0.07-0.53) were all slightly or substantially lower than reported by Serner et al.[4]. For all kappa values, except for fragmentations and intra-rater cysts, the 95% confidence intervals overlapped the confidence intervals of Serner et al.[4], suggesting that future studies are likely to observe similar relative reliability metrics.

In general, the differences with Serner et al.[4] may reflect several mechanisms, such as protocol learning, calibration and interpretation, rater bias, radiograph quality, and sample characteristics such as race, age, and environmental factors[44]. Lower κ values for cysts and inferior fragmentation can be explained by low prevalence, as indicated by the high prevalence indices[35], while the bias index for cysts, sclerosis, and inferior proliferation indicated that systematic bias between the radiologists influenced the inter-rater relative reliability and that the true relative reliability may be lower than observed [35]. Between-study differences in

fragmentations may reflect the potential presence of pubic apophysitis[45], anatomical variability[35,45,46], or variability in pubic apophyses closure[46], which fuse between ages 16-25[4,45]. Between-study differences in bone lucency, proliferation, and their subclassifications may be influenced by variability in patient positioning, as pelvic tilt/rotation can alter the projections of the cortical bone surface, thereby increasing the subjectivity of radiologists when changes are subtle. The radiologists feedback aligned with this, as clearly normal or abnormal pubic symphysis joints were straightforward to evaluate, whereas minor joint/bone changes increased uncertainty.

Taken together, this study highlights that experienced musculoskeletal radiologists can learn and apply the Aspetar pubic symphysis radiographic scoring protocol with reliability comparable to that of its development[4]. The moderate-to-substantial relative reliability for bone lucency, proliferation, fragmentation, sclerosis, and joint space width suggests that they can be evaluated with acceptable consistency for group-level analyses and research[8], particularly when assessed by a single radiologist.

Absolute Reliability of Pubic-related Radiographic Parameters

Absolute intra- and inter-rater reliability was high (≥75% overall agreement) for most pubic-related parameters. Overall agreement levels were generally lower than those reported by Serner et al.[4], however, we observed the same pattern of negative agreement exceeding positive agreement for most parameters (8/14 in this study, compared to 12/14 in Serner et al.[4]). This similarity across studies indicates that radiologists are more consistent in identifying the absence than the presence of pubic-related radiographic changes. Clinically, negative ratings can therefore be interpreted with greater confidence, whereas positive ratings may require further verification (e.g., second reader, standardized repeat view) before guiding individual-level decisions.

Strengths & limitations

This study aligns with nine of the 11 best-practice methods for radiographic parameter reliability studies[20]. Furthermore, including male athletes with and without hip and groin pain strengthens the study, as this sample clearly reflects the broad spectrum of athletes who may present routinely at a clinical sports medicine practice[28,31]. A notable limitation of this study is that only one rater performed a second reading of the radiographs. Although common in reliability studies,[20] as well as previous studies reporting the

reliability of hip and pubic-related radiographic parameters, this may limit generalizability, as individual interpretation may introduce bias. However, the radiographic procedures reflect real-world outpatient settings with radiologists of varying experience.

Radiographs were not anonymized, but randomized ordering and the 8-week interval between ratings minimized the risk of recall and memory bias[20]. Multiple technicians in a hospital outpatient clinic collected the radiographs, which may have contributed to cases of poor patient positioning or imaging quality. Further research should determine how patient positioning and single versus multiple technicians impact reliability[41].

No predefined quality criteria were used for the cross-table lateral radiographs, which may have led to the inclusion of low-quality radiographs and poor alpha angle reliability. Furthermore, the cross-table lateral view may not be ideal for measuring the alpha angle[39]. Most previous studies assess alpha angle on AP, 45° Dunn or Frog-Leg views,[11–19] and the Lisbon agreement on femoroacetabular impingement imaging from 2020[3] recommended the 45° Dunn view as the best radiographic for assessing alpha angle and cam morphology.[3] The 45° Dunn view may show a smaller discrepancy with MRI than the cross-table lateral view[47,48;] however, the agreement between the 45° Dunn view and MRI is only moderate (ICC 0.57.)[49]. Importantly, the choice of radiographic view impacts the size of the measured alpha angle, as the alpha angle is significantly higher (10°-20°) on the 45° Dunn view than on the cross-table lateral view[47,50]. However, the orthopedic surgeons in our outpatient clinic preferred in 2011-2012 and still prefer in 2022-2025 a cross-table lateral hip view for visualizing the femoral head-neck junction in athletes with suspected hip-related groin pain, which reflects that the 45° Dunn view is not unanimously accepted as the specific best choice of lateral hip view [3]. Furthermore, as all radiographs were collected in 2011-2012, we were not able to accommodate the 2020-21 Lisbon consensus recommendation of using a 45° Dunn view.[3]

Conclusion

Most hip- and pubic-related parameters demonstrated relative intra- and inter-rater reliability sufficient to support their use for group-level assessments and research purposes, particularly when interpreted by a single radiologist. However, absolute reliability analyses showed moderate to large variability in the measurements of the alpha angle, lateral center-edge angle, and acetabular index angle, highlighting the need for caution when applying specific cutoff values for these parameters in individual clinical decision-making. For most

pubic-related parameters, negative agreement exceeded positive agreement, suggesting that the absence of pubic-related parameters can be interpreted with greater confidence than the presence of pubic-related parameters.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used Paperpal 2,14,5 by Editage to trim the word count without loss of meaning as well as improve the grammar and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and took (s) full responsibility for the content of the publication.

Data availability: The data supporting the findings of this study are available upon request from the corresponding author. The data are not publicly available because of privacy or ethical restrictions.

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566

Table 1 Sample characteristics

	All (n = 86)	Symptomatic football players (n = 46)	Asymptomatic football players (n=19)	Non-football athletes (n=21)
N	86	46	19	21
Age, years	24.3 (3.88)	24.3 (3.03)	23.0 (2.62)	25.7 (5.80)
Height, centimeters	181 (5.69)	181 (5.74)	181 (5.30)	181 (6.18)
Body mass, kilograms	78.2 (7.16)	77.1 (6.87)	78.5 (6.04)	80.3 (8.47)
BMI, kg/m^2	23.8 (1.92)	23.4 (1.42)	24.0 (1.63)	24.4 (2.80)
Training hours/week	6.0 [4.5, 7.5]	6.0 [4.5, 6.0]	6.0 [4.5, 6.0]	7.5 [4.5, 9.0]
Training sessions/week	4.0 [3.0, 4.0]	4.0 [3.0, 4.0]	4.0 [3.0, 4.0]	3.0 [3.0, 3.0]
HAGOS†				
- Pain	93.8 [84.4, 100]	84.4 [68.8, 93.8]	100 [98.4, 100]	100 [100, 100]
- Symptoms	79.2 [62.5, 95.8]	66.7 [50.0, 75.0]	91.7 [83.3, 100]	95.8 [87.5, 100]
- ADL	93.8 [81.3, 100]	81.3 [62.5, 93.8]	100 [100, 100]	100 [100, 100]
- Sport	70.8 [45.8, 100]	50.0 [37.5, 62.5]	100 [91.7, 100]	100 [100, 100]
- Participation	75.0 [37.5, 100]	37.5 [12.5, 62.5]	100 [100, 100]	100 [100, 100]
- QoL	81.3 [43.8, 100]	50.0 [31.3, 68.8]	100 [96.9, 100]	100 [100, 100]

Data are presented as mean (SD). †= Median [interquartile range]

Table 2 Intra-rater reliability of hip-related parameters

Continuous parameters	n	ICC (2.1) (95% CI)	Interpretation	Rating 1 Mean (SD)	Rating 2 Mean (SD)	Mean Difference (95% CI)	SEM (SEM%)	MDC	MDC % Ind / Group
Alpha Angle (degrees)	168	0.74 (0.64, 0.81)	Substantial	51.2 (9.9)	50.1(10.8)	1.1 (0.2, 2.0)*	5.3 (10)	14.7	29 / 2
Lateral Center Edge Angle (degrees)	109	0.78 (0.68, 0.86)	Substantial	25.2 (6.1)	24.9 (6.1)	0.4 (-0.1, 0.9)	2.8 (11)	7.9	31 / 3
Acetabular index angle (degrees)	107	0.69 (0.56, 0.79)	Substantial	7.4 (4.8)	7.1 (4.7)	0.1 (-0.4, 0.6)	2.6 (36)	7.2	100 / 10
Hip joint space width (mm)	114	0.73 (0.60, 0.82)	Substantial	5.0 (0.9	4.8 (0.9)	0.2 (0.1, 0.3)*	0.5 (9)	1.3	26 / 2

Dichotomous parameters	n	Kappa (95% CI)	Interpretation	Overall Agreement	Positive Agreement	Negative Agreement	Prevalence Index	Bias Index
Cross-Over Sign (Y/N)	102	0.51 (0.32, 0.70)	Moderate	75%	73%	77%	-0.09	-0.07
Ischial Spine Sign (Y/N)	103	0.81 (0.61, 1.00)	Almost Perfect	90%	90%	90%	0.01	0.02
Posterior Wall Sign (Y/N)	102	0.65 (0.45, 0.84)	Substantial	82%	84%	81%	0.08	0.06

Y = yes, N = no, n = total number of hips with complete data, ICC = Intra-class correlation, CI = Confidence Interval, SD = Standard deviation, SEM = standard error of measurement, MDC = minimal detectable change, MDC%indi = MDC% at an individual level, MDC%group = MDC% at a group-level, * = statistically significant at $p \leq 0.05$, moderate = κ/ICC 0.41-0.60, substantial = κ/ICC 0.61-0.80, almost perfect = κ/ICC 0.81-1.00

Table 3 Inter-rater reliability of hip-related parameters

Continuous parameters	n	ICC (2.1) (95% CI)	Interpretation	Rater 1/ Mean (SD)	Rater 2 / Mean (SD)	Mean Difference (95% CI)	SEM (SEM%)	MDC	MDC % Ind / Group
Alpha Angle (degrees)	170	0.17 (-0.06, 0.38)	Slight	51.2 (9.9)	67.8 (10.3)	-16.6 (-18.4, -14.7)*	11.9 (20)	33.1	56 / 4
Lateral Center Edge Angle (degrees)	114	0.77 (0.63, 0.85)	Substantial	25.2 (6.1)	26.9 (5.6)	-1.5 (-2.0, -1.1)*	2.9 (11)	7.9	30 / 3
Acetabular index angle (degrees)	114	0.73 (0.60, 0.82)	Substantial	7.4 (4.8)	6.4 (4.2)	0.8 (0.3, 1.3)*	2.4 (34)	6.5	95 / 9
Hip joint space width (mm)	116	0.71 (0.57, 0.80)	Substantial	5.0 (0.9)	4.8 (1.1)	0.2 (0.1, 0.4)	0.5 (11)	1.5	31 / 3

Dichotomous parameters	n	Kappa (95% CI)	Interpretation	Overall Agreement	Positive Agreement	Negative Agreement	Prevalence Index	Bias Index
Cross-Over Sign (Y/N)	96	0.53 (0.35, 0.71)	Moderate	76%	79%	72%	0.16	0.22
Ischial Spine Sign (Y/N)	99	0.86 (0.66, 1.05)	Almost Perfect	93%	94%	92%	0.14	0.05
Posterior Wall Sign (Y/N)	98	0.66 (0.46, 0.85)	Substantial	84%	87%	78%	0.24	0.08

Y = yes, N = no, n = total number of hips with complete data, ICC = Intra-class correlation, CI = Confidence Interval, SD = Standard deviation, SEM = standard error of measurement, MDC = minimal detectable change, MDC%indi = MDC% at an individual level, MDC%group = MDC% at a group-level, * = statistically significant at $p \leq 0.05$, moderate = κ/ICC 0.41-0.60, substantial = κ/ICC 0.61-0.80, almost perfect = κ/ICC 0.81-1.00

Table 4 Intra-rater reliability of radiographic pubic-related parameters

Dichotomous parameters	n	Kappa (95% CI)	Interpretation	Overall Agreement	Positive Agreement	Negative Agreement	Prevalence Index	Bias Index
Bone lucency (Y/N)	163	0.60 (0.45, 0.75)	Substantial	82%	87%	73%	0.34	0.10
Erosion-like configuration (Y/N)	164	0.63 (0.49, 0.78)	Substantial	83%	87%	76%	0.28	0.11
ELC superior/central (Y/N)	161	0.75 (0.60, 0.91)	Substantial	88%	88%	87%	0.04	0.02
ELC inferior (Y/N)	163	0.58 (0.43, 0.73)	Moderate	79%	79%	78%	0.02	0.12
Cysts (Y/N)	159	0.18 (0.03, 0.33)	Slight	79%	30%	88%	-0.70	0.07
Proliferation (Y/N)	161	0.49 (0.34, 0.65)	Moderate	75%	76%	73%	0.05	0.09
Superior (Y/N)	161	0.71 (0.56, 0.86)	Substantial	86%	82%	89%	-0.24	0.07
Central (Y/N)	160	0.56 (0.41, 0.71)	Moderate	92%	61%	95%	-0.79	0.03
Inferior (Y/N)	160	0.41 (0.26, 0.57)	Moderate	76%	58%	83%	-0.44	0.01
Fragmentation (Y/N)	162	0.49 (0.33, 0.64)	Moderate	93%	52%	96%	-0.86	-0.01
Central (Y/N)	166	0.69 (0.54, 0.84)	Substantial	97%	71%	98%	-0.90	-0.01
Inferior (Y/N)	162	-	-	95%	0%	97%	-0.95	0.01
Sclerosis (Y/N)	162	0.63 (0.48, 0.78)	Substantial	84%	75%	88%	-0.37	0.05
Narrow joint space† (Y/N)	80	0.61 (0.40, 0.83)	Substantial	86%	70%	91%	-0.54	0.04

Continuous parameters	n	ICC (95% CI)	Interpretation	Rating 1 Mean (SD)	Rater 2 Mean (SD)	Mean Diff (95% CI)	SEM (SEM%)	MDC	MDC % Indi / Group
Pubic joint space width (mm) ¤	83	0.76 (0.68, 0.83)	Substantial	3.4 (1.2)	3.4 (1.0)	0.0 (-0.2, 0.2)	0.5 (16)	1.5	43 / 5

Y = yes, N = no, n = total number of pubic bones with complete data, κ = Cohen's Kappa, †For narrow joint space n = number of athletes with data, CI = confidence interval, ICC = Intra-class correlation, SD = Standard deviation, SEM = standard error of measurement, MDC = minimal detectable change, MDC%indi = MDC% at an individual level, MDC%group = MDC% at a group-level, Slight = κ/ICC 0.00-0.20, moderate = κ/ICC 0.41-0.60, substantial = κ/ICC 0.61-0.80.

Table 5 Inter-rater reliability of radiographic pubic-related parameters

Dichotomous parameters	**n**	**κ (95% CI)**	**Interpretation**	**Overall Agreement**	**Positive Agreement**	**Negative Agreement**	**Prevalence Index**	**Bias Index**
Bone lucency (Y/N)	163	0.45 (0.30, 0.60)	Moderate	80%	87%	58%	0.52	0.06
Erosion-like configuration (Y/N)	165	0.50 (0.35, 0.65)	Moderate	79%	85%	65%	0.42	0.02
ELC superior/central (Y/N)	163	0.62 (0.46, 0.77)	Substantial	81%	83%	79%	0.10	0.02
ELC inferior (Y/N)	164	0.53 (0.38, 0.69)	Moderate	77%	81%	72%	0.19	0.05
Cysts (Y/N)	159	0.07 (-0.03, 0.17)	Slight	45%	34%	53%	-0.18	0.46
Proliferation (Y/N)	165	0.42 (0.27, 0.56)	Moderate	70%	70%	71%	-0.02	-0.15
Superior (Y/N)	165	0.53 (0.39, 0.68)	Moderate	79%	68%	84%	-0.33	-0.14
Central (Y/N)	164	0.26 (0.12, 0.40)	Fair	79%	37%	88%	-0.67	0.10
Inferior (Y/N)	165	0.11 (0.01, 0.20)	Slight	73%	18%	84%	-0.67	-0.24
Fragmentation (Y/N)	167	0.30 (0.15, 0.45)	Fair	89%	36%	94%	-0.83	0.02
Central (Y/N)	168	0.39 (0.24, 0.54)	Fair	93%	42%	97%	-0.89	0.02
Inferior (Y/N)	167	0.31 (0.16, 0.46)	Fair	95%	33%	98%	-0.93	0.00
Sclerosis (Y/N)	166	0.34 (0.22, 0.47)	Fair	64%	63%	65%	-0.02	0.31
Narrow joint space† (Y/N)	52	0.72 (0.45, 0.99)	Substantial	88%	80%	92%	-0.42	0.08

Continuous parameters	**n**	**ICC (95% CI)**	**Interpretation**	**Rater 1 Mean (SD)**	**Rater 2 Mean (SD)**	**Mean Diff (95% CI)**	**SEM (SEM%)**	**MDC**	**MDC % Indi / Group**
Pubic joint space width (mm) ¤	81	0.72 (0.62, 0.80)	Substantial	3.3 (1.0)	3.4 (1.2)	0.0 (-0.2, 0.1)	0.6 (17)	1.6	46 / 5

Y = yes, N = no, n = total number of pubic bones with complete data, κ = Cohen's Kappa, †For narrow joint space n = number of athletes with data, CI = confidence interval, ICC = Intra-class correlation, SD = Standard deviation, SEM = standard error of measurement, MDC = minimal detectable change, MDC%indi = MDC% at an individual level, MDC%group = MDC% at a group-level, Slight = κ/ICC 0.00-0.20, fair = κ/ICC 0.21-0.40, moderate = κ/ICC 0.41-0.60, substantial = κ/ICC 0.61-0.80.

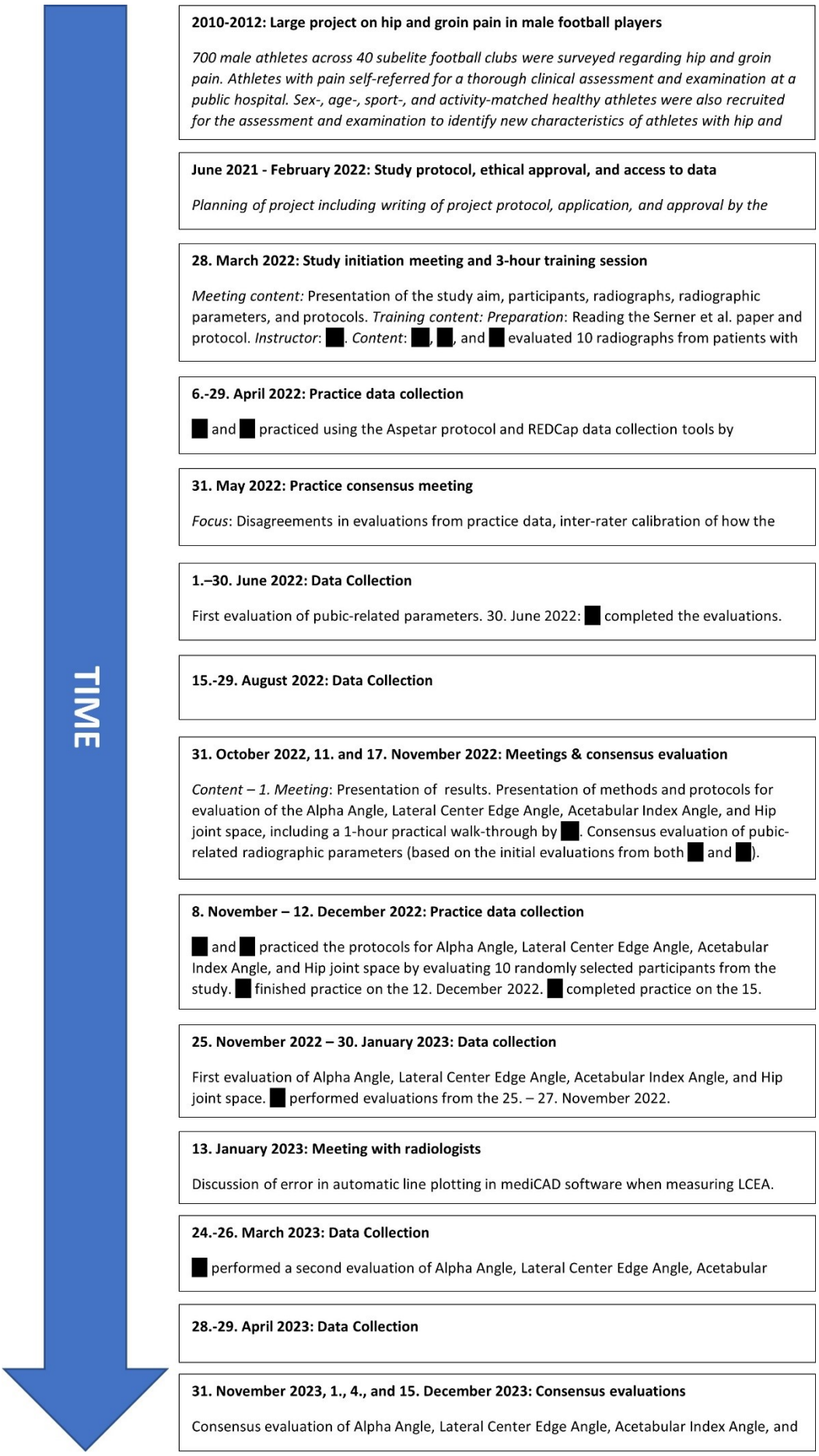
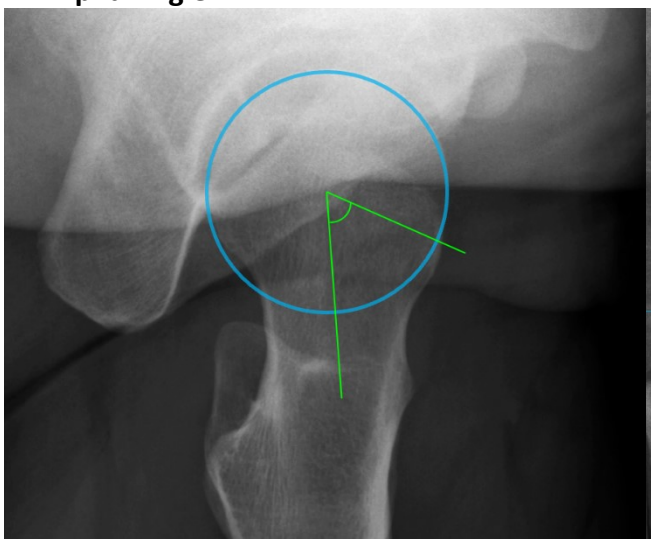
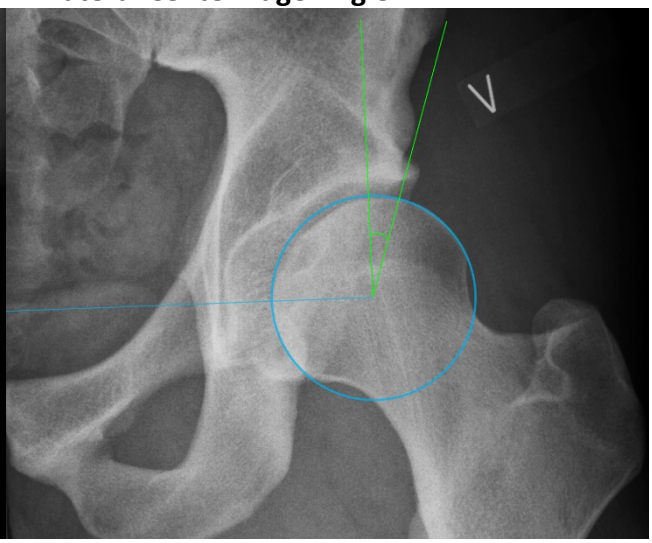


Figure 1 Project Timeline

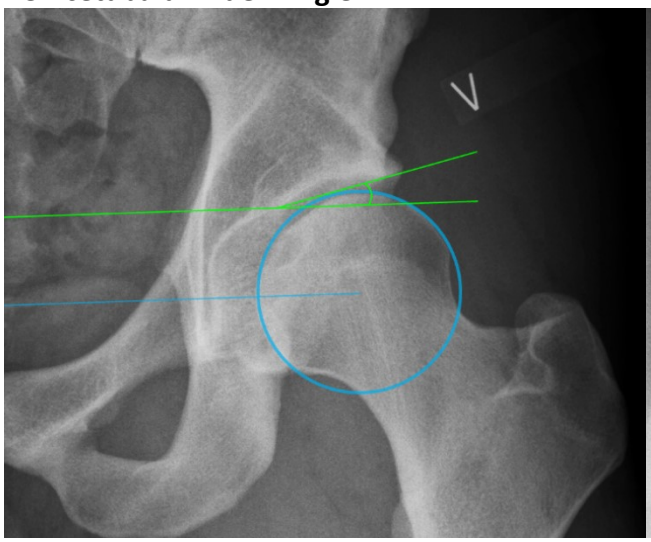
2A Alpha Angle



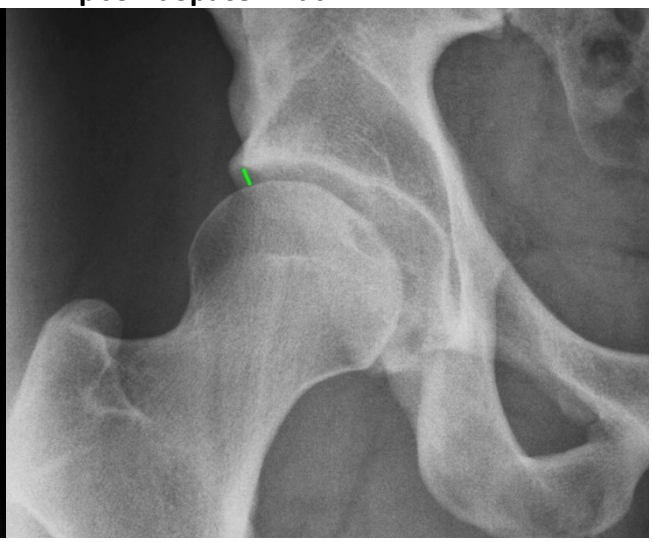
2B Lateral Center Edge Angle



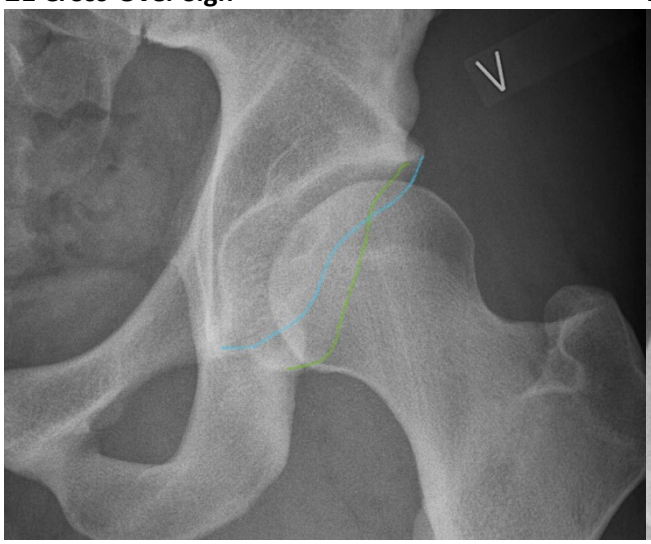
2C Acetabular Index Angle



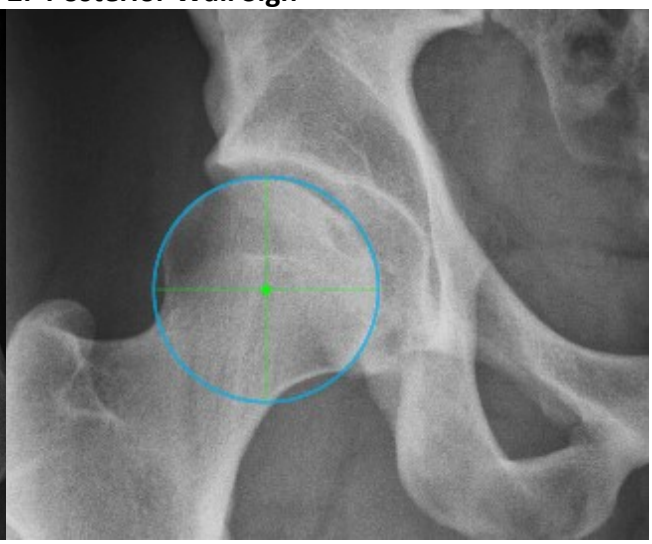
2D Hip Joint Space Width



2E Cross-Over Sign



2F Posterior Wall Sign



2G Ischial Spine Sign



Figure 2 Hip-related radiographic parameters as described in the Lisbon Agreement.[9–11] **2A: Alpha Angle. Definition:** The angle between 1) a line from the center of the femoral neck to the center of the femoral head, and 2) a line from the center of the femoral head to the point where the femoral head-neck junction extends beyond the margin of the circle[3]. **View**: Cross-table lateral hip. **Defines:** *Cam morphology* as alpha angle ≥ 60°[3]. **2B Lateral Center Edge Angle. Definition:** The angle between 1) a vertical line through the femoral head center and 2) a line between the femoral head center and the lateral sourcil of the acetabulum, as defined by Wiberg[3]. **View**: Anteroposterior. **Defines:** *Pincer morphology* as 1) a lateral center edge angle ≥ 40° OR 2) a lateral Center Edge angle ≥ 35° AND Acetabular index < 0° [3]. *Hip dysplasia* as 1) lateral center edge angle ≤ 25 **2C: Acetabular Index Angle. Definition:** The angle between a horizontal line and a line through the most medial point of the sclerotic zone of the acetabulum and the sourcil[3]. **View**: Anteroposterior. **Defines:** *Pincer morphology* as 2) a lateral Center Edge angle ≥ 35° AND Acetabular index < 0°[3]. *Hip dysplasia* as 2) acetabular index > 13°[3]. **2D Hip Joint Space Width. Definition:** The distance between the femoral head and the lateral sourcil at the acetabulum[3]. **View**: Anteroposterior. **Defines:** *Joint space narrowing* as hip joint space width < 3mm. **2E, Cross-over sign. Definition:** The anterior wall contour intersects and becomes lateral to the posterior wall contour[3]. **View**: Anteroposterior. **2F Posterior Wall Sign. Definition**: The posterior acetabular wall projection is medial to the femoral head center projection[3]. **View**: Anteroposterior. **2G, Ischial Spine sign. Definition:** The ischial spine is visible medially to the pelvic rim[3]. **View**: Anteroposterior. **2E, 2F and 2G Defines:** *Pincer morphology* as a positive Crossover sign AND posterior wall sign AND Ischial spine sign[3].

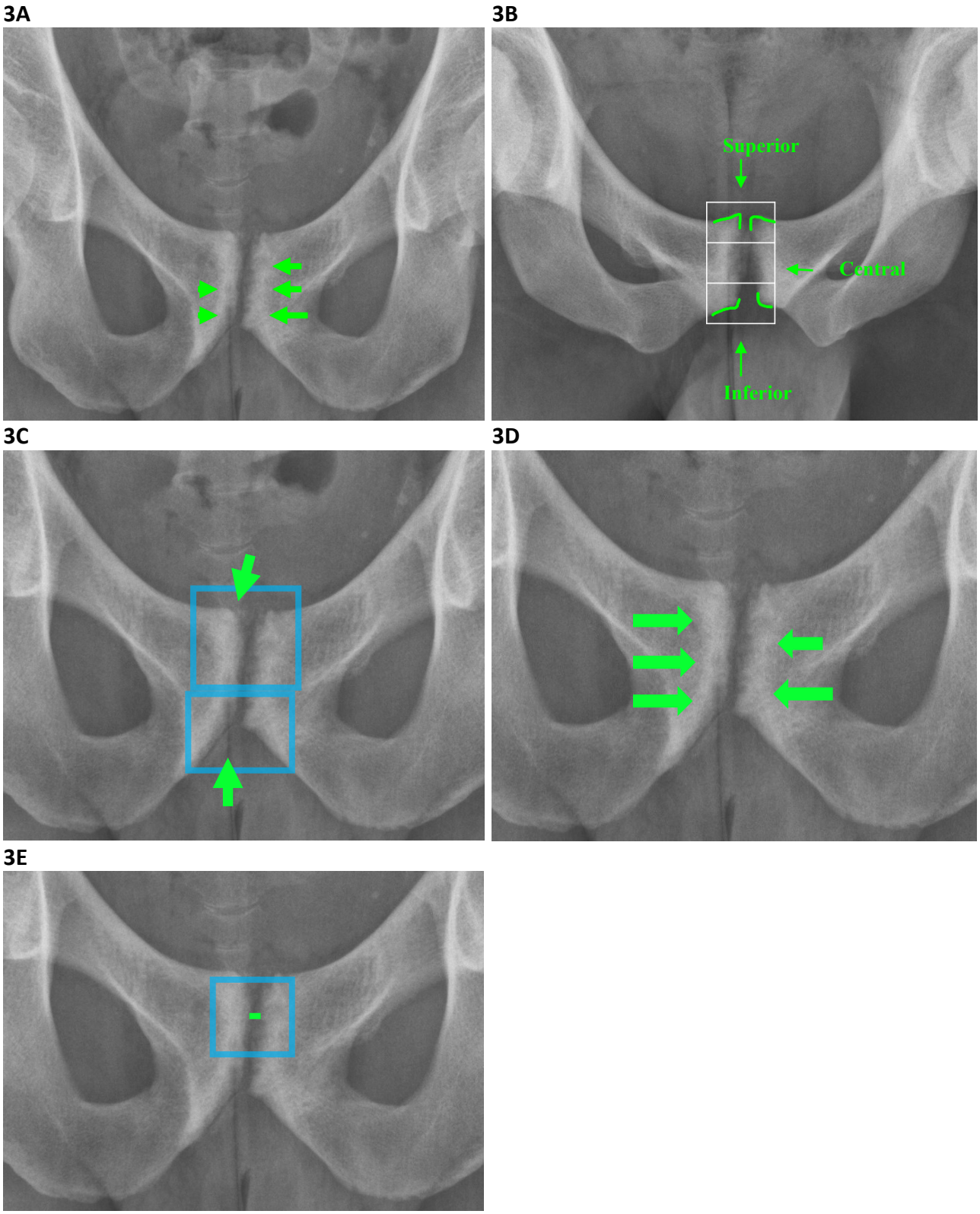


Figure 3 Pubic-related radiographic parameters as described by Serner et al[4] **3A: Bone lucency. Definition:** "A clear area of decreased attenuation compared to the surrounding bone, which corresponds to an erosion-like configuration and/or cyst."[4], **Subclassifications:** *Erosion-Like Configuration (ELC), Superior/Central ELC, Inferior ELC and Cysts.* **Definitions**: ***ELC***: "Irregularities of the cortical bone surface, potentially accompanied by loss of the adjacent trabecular bone."[4], ***Superior/Central ELC****:* ELC at the superior two thirds of the joint surface [4], ***Inferior ELC****:* ELC at the lower third of the joint surface - "If the entire lower half was considered to have an erosion-like configuration, both of the above were scored as positive"[4], ***Cysts***: "Areas of bone lucency with a sclerotic rim inside the trabecular bone compartment, without accompanying cortical bone surface irregularity." **3B Proliferation. Definition:** "Clear osteophyte outgrowths at the joint margins or within the articular space."[4], **Subclassifications:** *Superior, Central and Inferior Proliferation.* **Definitions**: ***Superior proliferation****:* "This can be considered "bone spurs" or classified

as “pubic beaking” when bilateral. Well rounded (smooth) bumps at the superior aspect, even if asymmetrical in size, were not considered proliferation. For superior proliferation, the “sharpness” of the superior bone corner angle was used for assistance with angles higher than 90 deg. (obtuse angle) considered “rounded” and scored negative/absent, whereas angles lower than 90 deg. (acute angle) were considered “sharp” and scored as positive/present."[4], ***Central proliferation****:* “Proliferation at the central portion of the articular space.”[4], ***Inferior proliferation****:* "Similar considerations as superior proliferation."[4]. **3C Fragmentation. Definition:** “Clear loose fragment(s) within the symphyseal joint space, or at the inferior medial margin of the pubic bone.”[4]**,** **Subclassifications**: *Central and inferior fragmentation.* **Definitions:** ***Central fragmentation****:* “Clear loose fragment(s) within the symphyseal joint space"[4], ***Inferior fragmentation***: “Clear loose fragment(s) at the inferior medial margin of the pubic bone.”[4]**.** **3D Sclerosis. Definition:** “A clear area of increased attenuation of the subchondral bone compared to the surrounding bone, corresponding to an area of increased bone density.”[4]. **3E Joint Space Width. Definition:** “Symphyseal joint space measured in millimeters at the narrowest point of the joint surfaces.”[4], **Subclassification:** *Narrow Joint Space Width*. **Definition**: ***Narrow Joint Space Width*****.** “ if measured to less than 3mm”[4]**.**

APPENDIX FILE

Intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in 86 male athletes

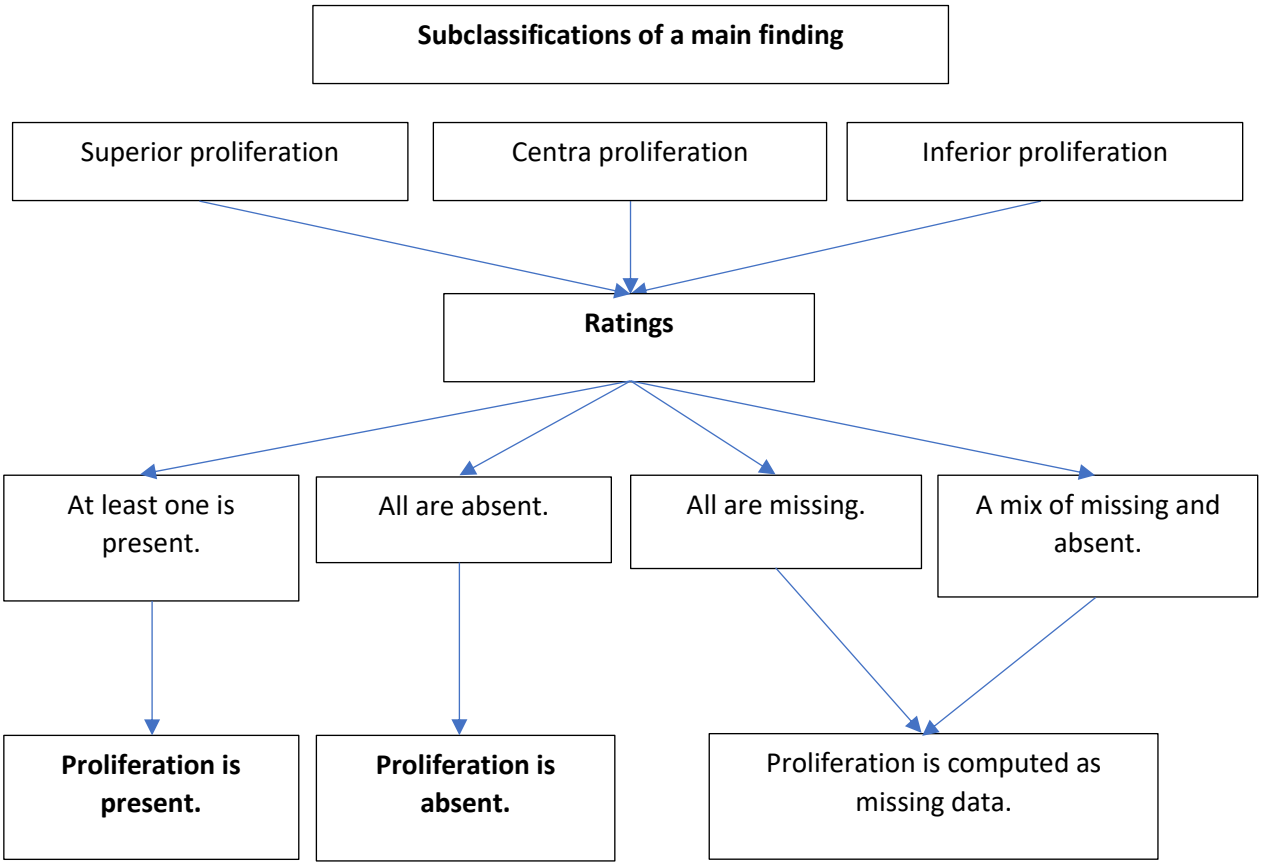
Content

- Data management of pubic-related parameters
- Sample size considerations for pubic-related parameters
- Formulas
- Descriptive data
- Results of post-hoc ICC (3.1) for consistency analyses
- Bland-Altman plots

Data management of pubic-related parameters

- If any of the subclassification variables are present, then the main finding variable is computed as present.
- If all the subclassification variables are absent, then the main finding variable is computed as absent.
- If all of the subclassification variables are missing, or there's a mix of absent subclassification variables and missing subclassification variables without any positive subclassification variables, then the main finding variable is computed as missing.

Figure 4. Illustration of the logical rules for computing pubic-related main findings



Sample size consideration for pubic-related parameters

We expected inter-rater kappa values from 0.18 to 0.67 and prevalence from 2% to 61% for scoring items related to the pubic bones/joint based on Serner et al.[1] and assumed that all radiographs were of adequate quality. Thus, fixed sample sizes of 86 pubic joints and 172 pubic bones allowed us to detect statistically significant kappa values with lower confidence intervals ranging from 0.02-0.50, when using a 2-sided test, and assuming no bias between examiners.[2] These estimations were performed in RStudio using the FixedNBinary function from the package kappaSize v. 1.2 [3].

Formulas

Overall agreement: $(\frac{a+d}{n})$

Positive agreement: $(\frac{2a}{2a+b+c})$

Negative agreement $(\frac{2d}{2d+b+c})$

Prevalence $(\frac{a}{n} \times 100)$

Prevalence index $(\frac{a-d}{n})$

Bias index $\frac{b-c}{n}$

Standard error of measurement (SEM): $SEM = SD_{pooled} \times \sqrt{1 - ICC}$

The relative SEM: $SEM\% = \frac{SEM}{mean_{pooled}} \times 100$

Minimal detectable change (MDC): $MDC = SEM \times 1{,}96 \times \sqrt{2}$

MDC % at the individual levels: $MDC_{indiv} = SEM\% \times 1{,}96 \times \sqrt{2}$

MDC % at the group levels: $MDC_{group} = \frac{SEM\% \times 1{,}96 \times \sqrt{2}}{\sqrt{n}})$

Descriptive data

Standardized paper questionnaires were used to collect descriptive data and the Copenhagen Hip and Groin Outcome Score (HAGOS)[4]. The descriptive data include age (years), height (centimeters, cm), body mass (kilograms, kg), body mass index (kg/m^2), self-reported training hours per week, number of weekly football training session and HAGOS scores. The HAGOS is a valid, reliable, and responsive patient-reported outcome measure of hip and groin-related disability that can be used for male athletes.[4,5] The HAGOS contains subscales of pain, symptoms, physical function in daily living (ADL), physical function in sport and recreation (sport), participation in physical activities (PA), and quality of life (QoL). Each subscale was summarized into a normalized score ranging from 0 (extreme symptoms) to 100 (no symptoms) [4]. The descriptive data are presented in Supplementary Table 1.

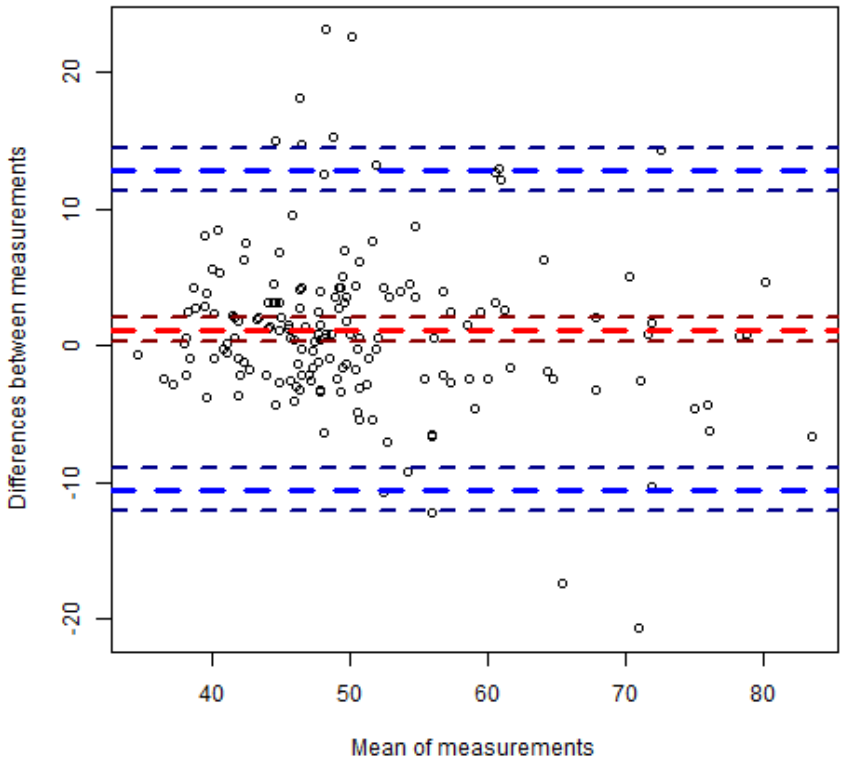
Table A1 Intra-rater reliability of radiographic hip-related measurements and findings using ICC (3.1) for consistency

Continuous measurements	n	ICC	(95% CI)	Interpretation	Rater 1 Mean (SD)	Rater 2 Mean (SD)	Mean Diff (95% CI)	SEM (SEM%)	MDC	MDC % Indi / Group
Alpha Angle	168	0.74	(0.65, 0.81)	Substantial	51.2 (9.9)	50.1(10.8)	1.1 (0.2, 2.0)*	5.3 (10)	14.6	29 / 3
Hip joint space width	114	0.74	(0.63, 0.83)	Substantial	5.0 (0.9	4.8 (0.9)	0.2 (0.1, 0.3)*	0.5 (9)	1.3	25 / 2

Table A2 Inter-rater reliability of radiographic hip-related measurements and findings using ICC (3.1) for consistency

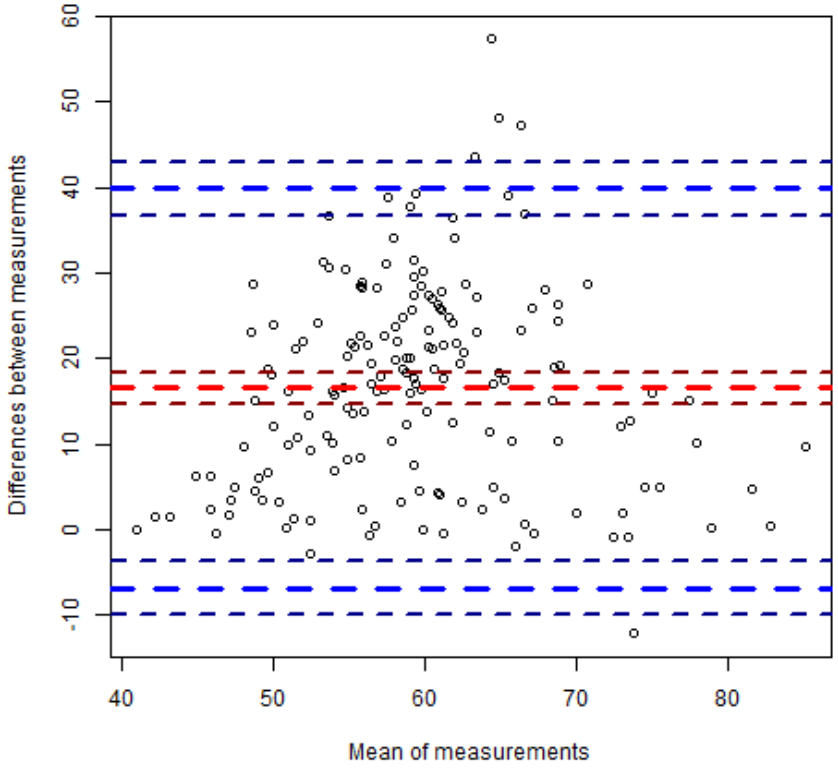
Continuous measurements	n	ICC	(95% CI)	Interpretation	Rater 1 Mean (SD)	Rater 2 Mean (SD)	Mean Diff (95% CI)	SEM (SEM%)	MDC	MDC % Indi / Group
Alpha Angle	170	0.39	(0.23. 0.53)	Fair	67.8 (10.3)	51.2 (9.9)	16.6 (14.7, 18.4)*	10.2 (17)	28.3	47 / 4
Lateral Center Edge Angle	114	0.79	(0.69. 0.86)	Substantial	26.9 (5.6)	25.2 (6.1)	1.5 (1.1, 2.0)*	2.7 (10)	7.5	29 / 3
Acetabular index angle	114	0.74	(0.62. 0.82)	Substantial	6.4 (4.2)	7.4 (4.8)	-0.8 (-1.3, -0.3)*	2.3 (34)	6.4	93 / 10

Figure 5a Bland-Altman plot of alpha angle intra-rater measurements



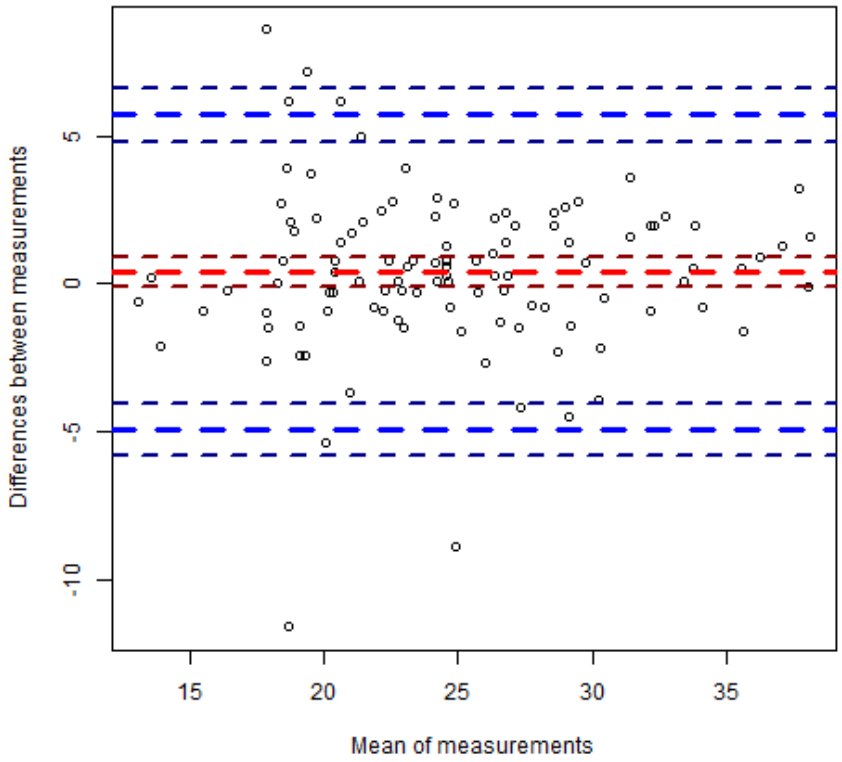
Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

Figure 5b Bland-Altman plot of alpha angle inter-rater measurements



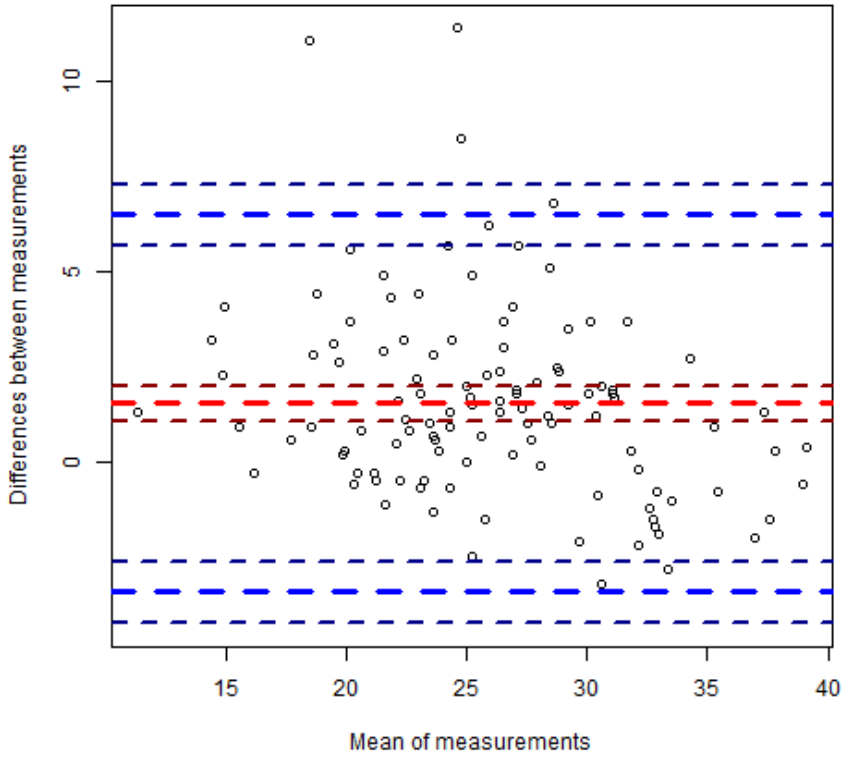
Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

Figure 6a Bland-Altman plot of lateral center edge angle intra-rater measurements



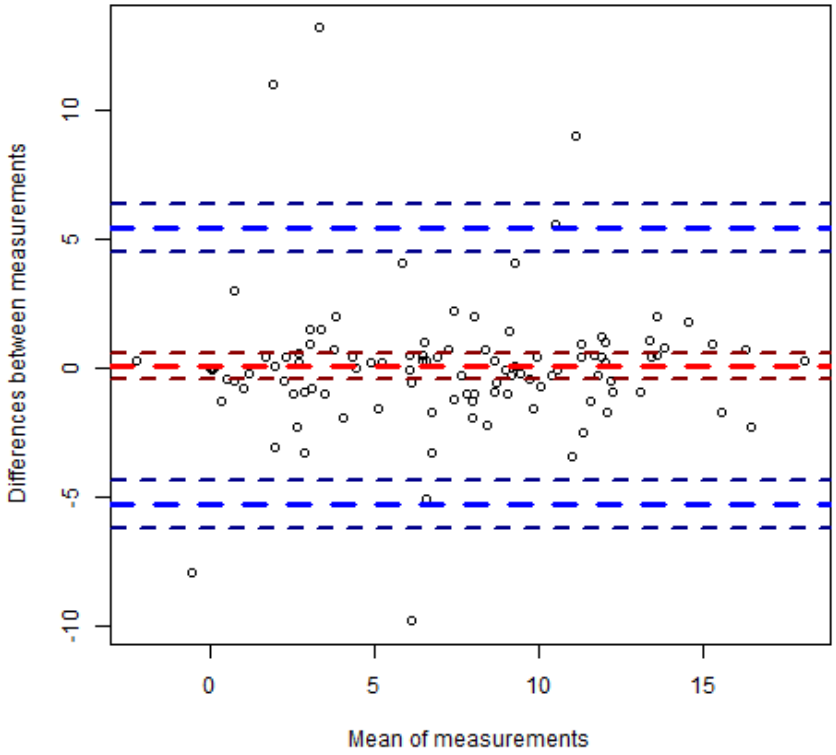
Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

Figure 6b Bland-Altman plot of lateral center edge angle inter-rater measurements



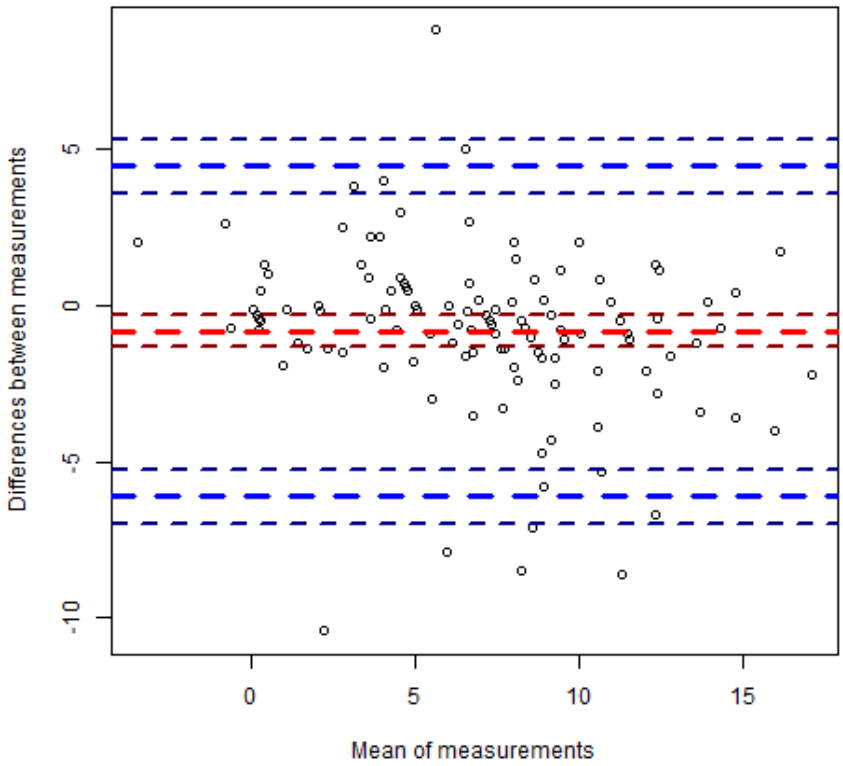
Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

Figure 7a Bland-Altman plot of acetabular index angle intra-rater measurements



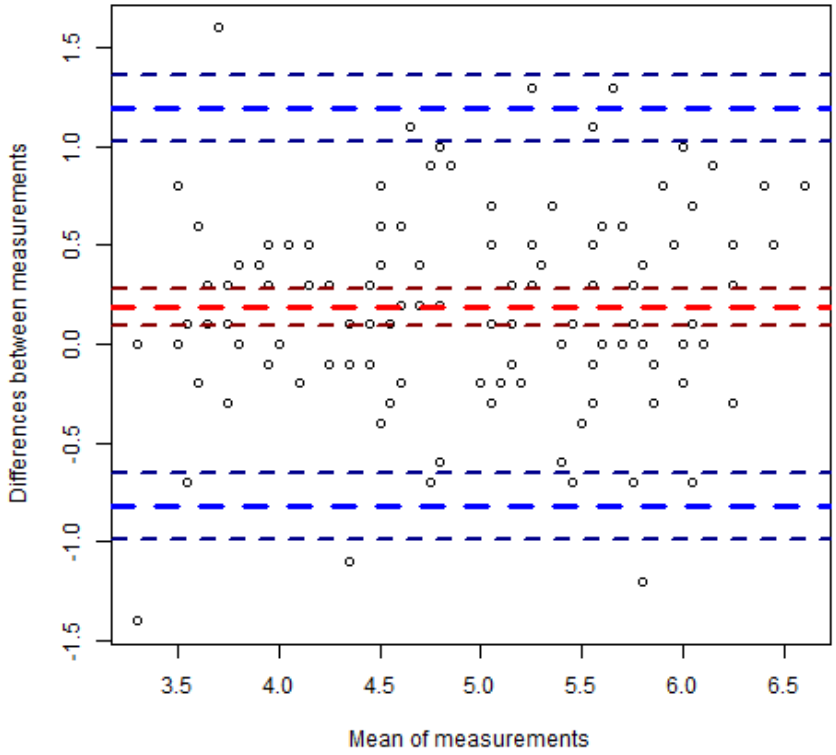
Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

Figure 7b Bland-Altman plot of Acetabular index angle inter-rater measurements



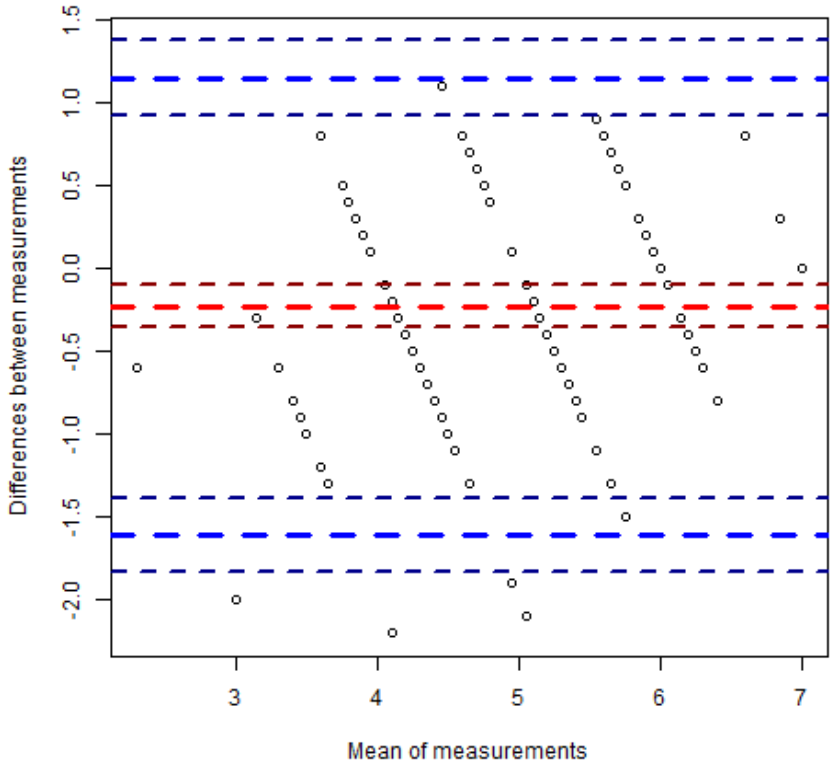
Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

Figure 8a Bland-Altman plot of hip joint space width intra-rater measurements:



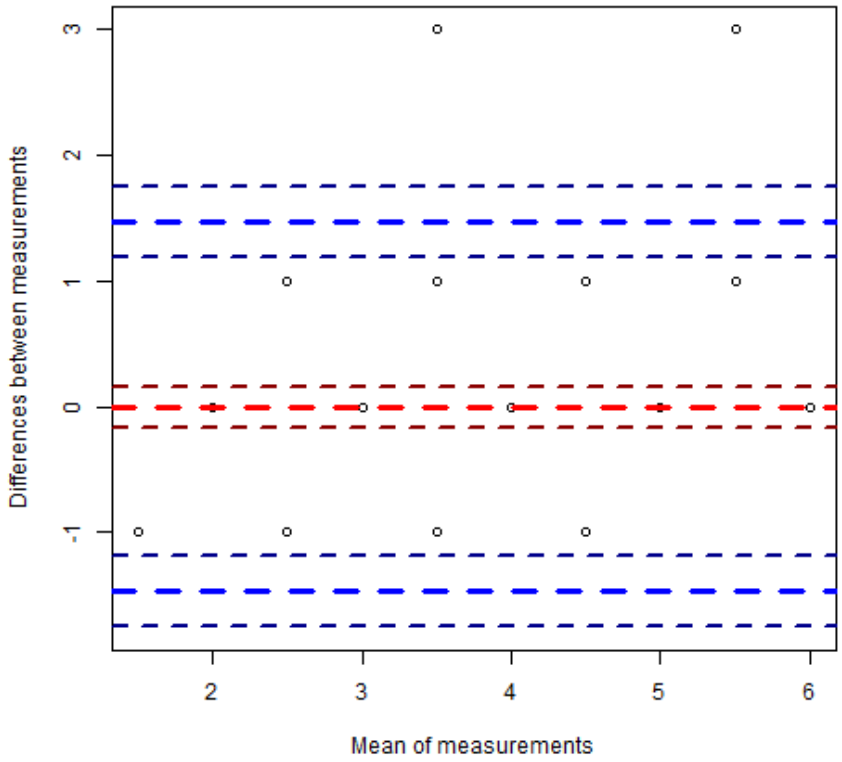
Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

Figure 8b Bland-Altman plot of hip joint space width inter-rater measurements



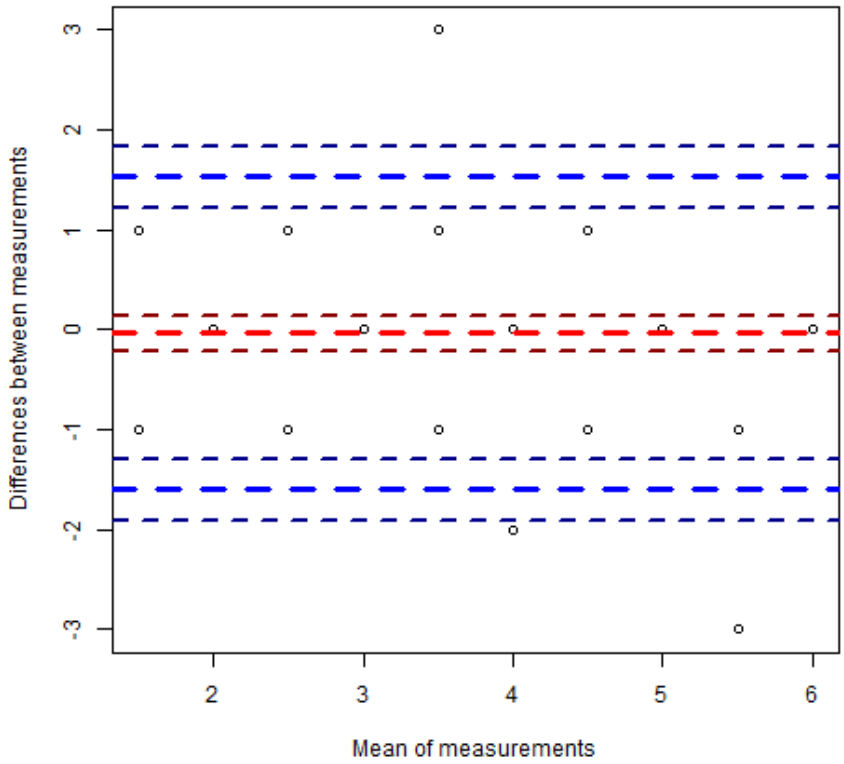
Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

Figure 9a Bland-Altman plot of pubic space width intra-rater measurements



Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

Figure 9b Bland-Altman plot of pubic space width inter-rater measurements



Red thick dotted line = mean difference, red thin dotted lines = upper and lower 95% confidence interval for the mean difference, large blue dotted lines = upper and lower 95% limits of agreement, blue thin dotted lines = upper and lower 95% confidence interval for 95% limits of agreement.

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1. Serner A, Arnaiz J, Mosler A, et al. Classifying radiographic changes of the pubic symphysis in male athletes: Development and reproducibility of a new scoring protocol. *Eur J Radiol*. 2021;134(109452):7. doi:https://doi.org/10.1016/j.ejrad.2020.109452

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SUPPLEMENTARY FILE

Intra- and inter-rater reliability of hip- and pubic-related radiographic parameters in 86 male athletes

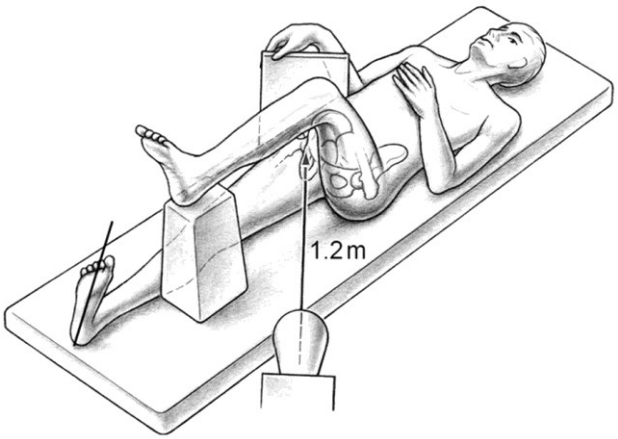
Content:

1. Radiographic Procedures
2. Picture examples of hip-related radiographic parameters
3. Picture examples of pubic-related radiographic parameters
4. Missing data

1. Radiographic Procedures

Cross-table Lateral Hip View.

Participants lay supine with the assessed leg internally rotated 15°. The contralateral hip was flexed and lifted out of the radiograph field. The beam was horizontal, angled at 45° towards the hip from the contralateral side (1.2 meters from the transmitter to the film). The black dot and arrow indicate the hip being radiographed.



Anteroposterior Pelvic View.

Participants stood with equal weight distribution, feet hip-width apart, legs internally rotated 15 ° and toes nearly touching. The buttocks were in contact with the film, the pelvis in a near-normal inclination and symmetrically centered in front of the beam.



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Sources: https://knoglebogen.dk/e/6 and https://knoglebogen.dk/e/87

2. Picture examples of hip-related radiographic parameters

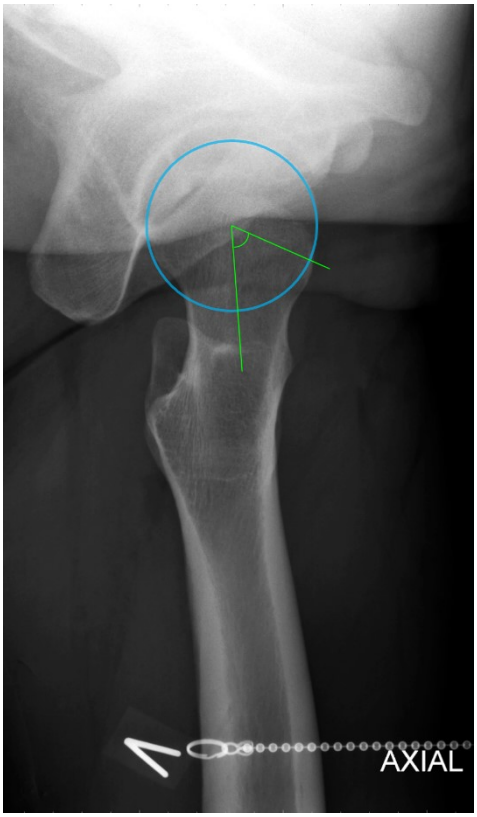
Cross-Table Lateral Hip View Radiograph

Participants were supine on an examination bed. The assessed leg was internally rotated 15°. The contralateral hip was flexed and lifted out of the radiograph field. The radiograph beam was horizontal and angled at 45° towards the assessed hip from the contralateral side (1.2 meters from the transmitter to the film).



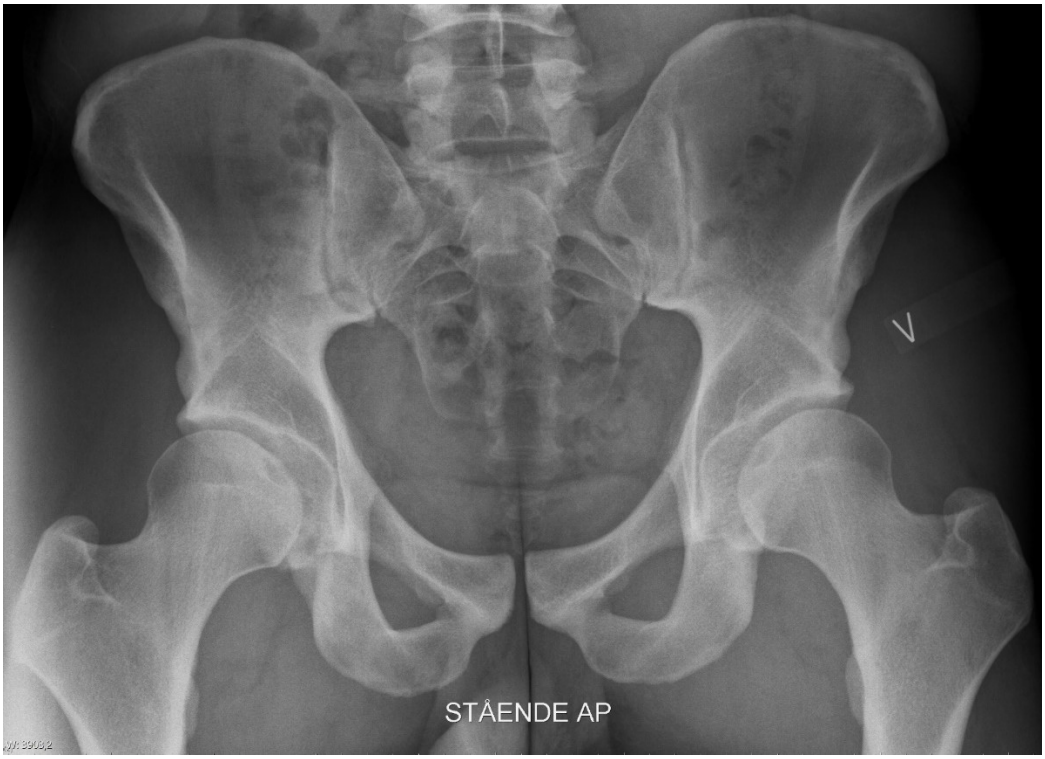
Alpha Angle

The angle between 1) a line from the center of the femoral neck to the center of the femoral head, and 2) a line from the center of the femoral head to the point where the femoral head-neck junction extends beyond the margin of the circle.[1]



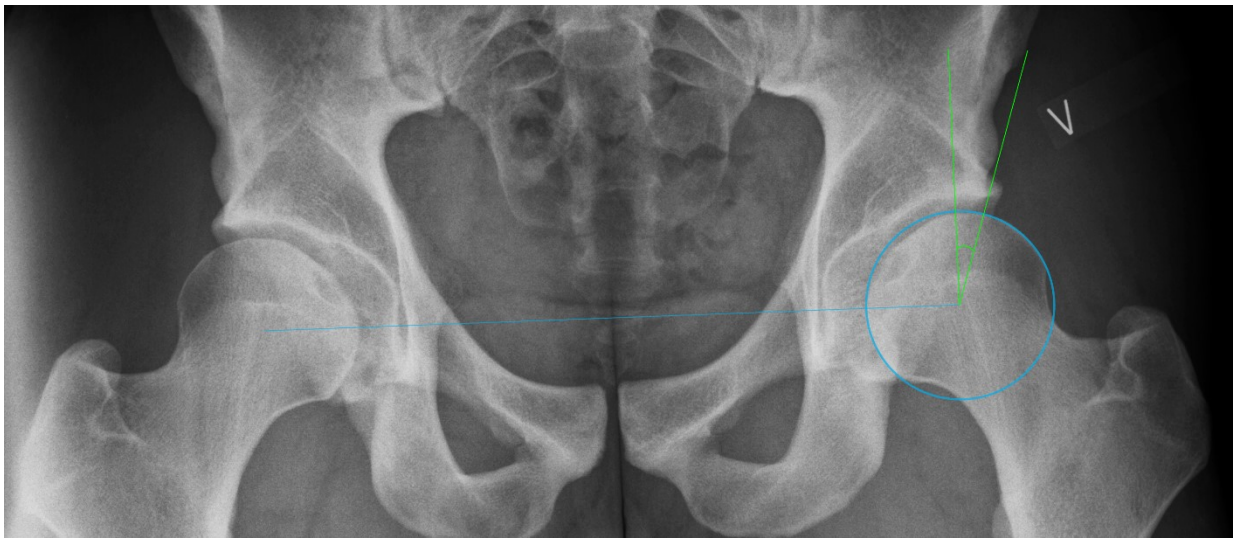
Anterior-Posterior Pelvic View Radiograph

Participants were standing with equal weight distribution on their legs, hip width distance between the feet, legs internally rotated 15 °, toes nearly touching each other. Participants were positioned with their buttocks in contact with the film, the pelvis in a near-normal inclination and symmetrically centered in front of the beam.



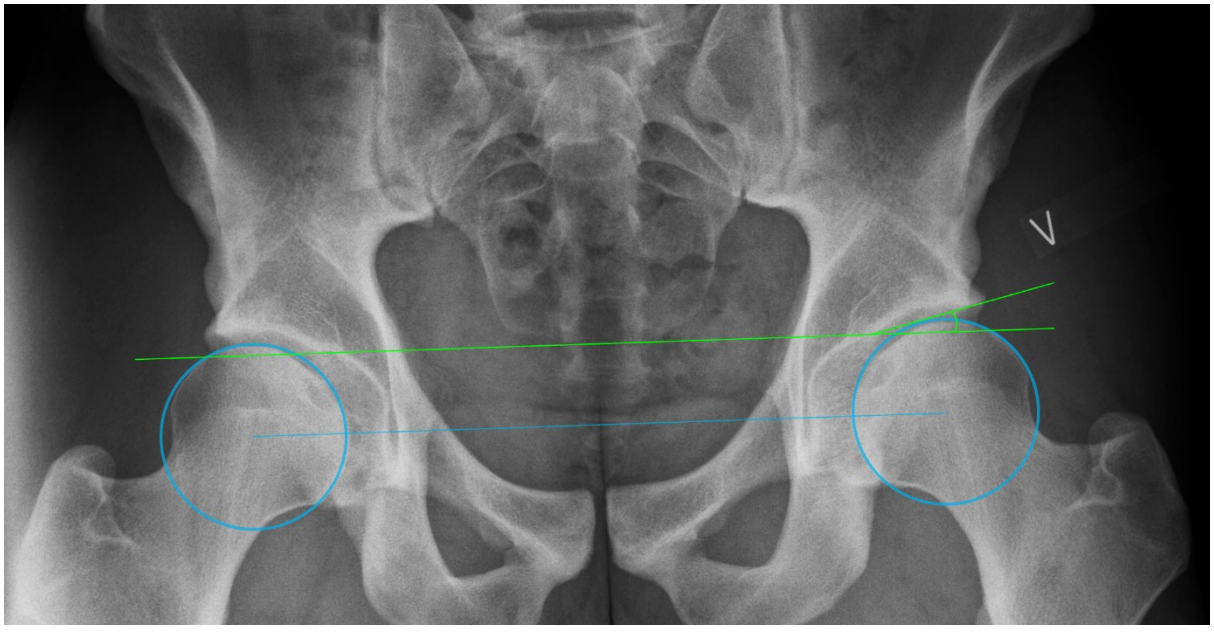
Lateral Center Edge Angle

The angle between 1) a vertical line through the femoral head center and 2) a line between the femoral head center and the lateral edge (the so-called sourcil) of the acetabulum, as defined by Wiberg.[1]



Acetabular Index Angle

The angle between a horizontal line and a line through the most medial point of the sclerotic zone of the acetabulum and the sourcil.[1]



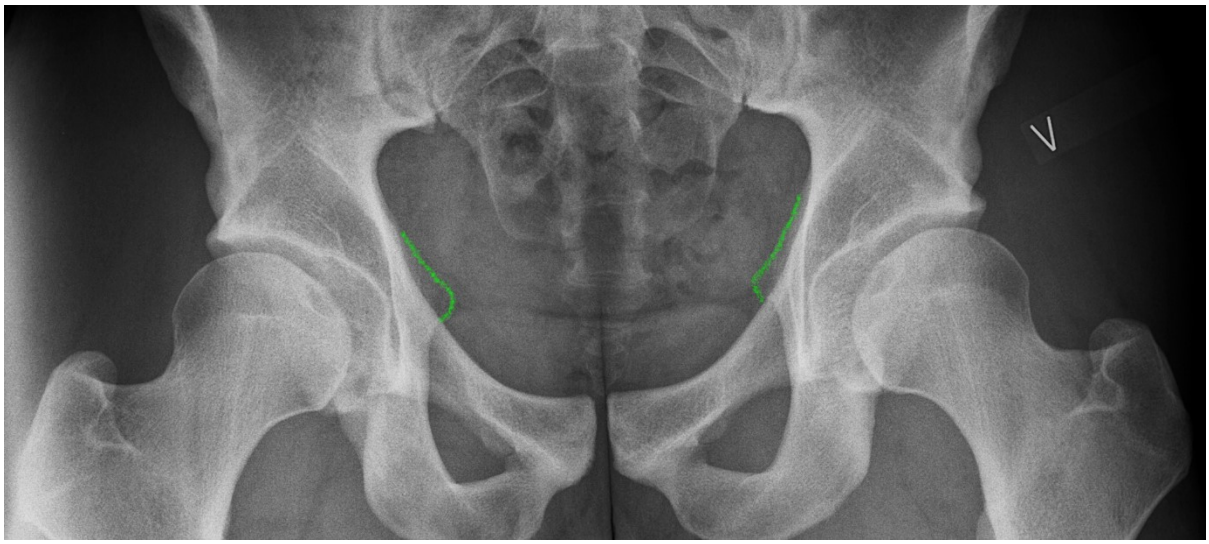
Cross-over sign

The contour of the anterior wall intersects and becomes lateral to the contour of the posterior wall.[1]



Ischial Spine sign

The projected triangular shape of the ischial spine protrudes and is visible medially to the pelvic rim.[1]



Posterior Wall Sign

The projection of the posterior acetabular wall is medial to the projection of the femoral head center.[1]



Hip Joint Space Width

The distance between the femoral head and the lateral sourcil at the acetabulum.[1]



3. Picture examples of pubic-related radiographic parameters

Bone Lucency

"A clear area of decreased attenuation compared to the surrounding bone, which corresponds to an erosion-like configuration and/or cyst."[2]

- **Erosion-Like configuration**

  Irregularities of the cortical bone surface, potentially accompanied by loss of the adjacent trabecular bone."[2]

  - **Superior/Central ELC**

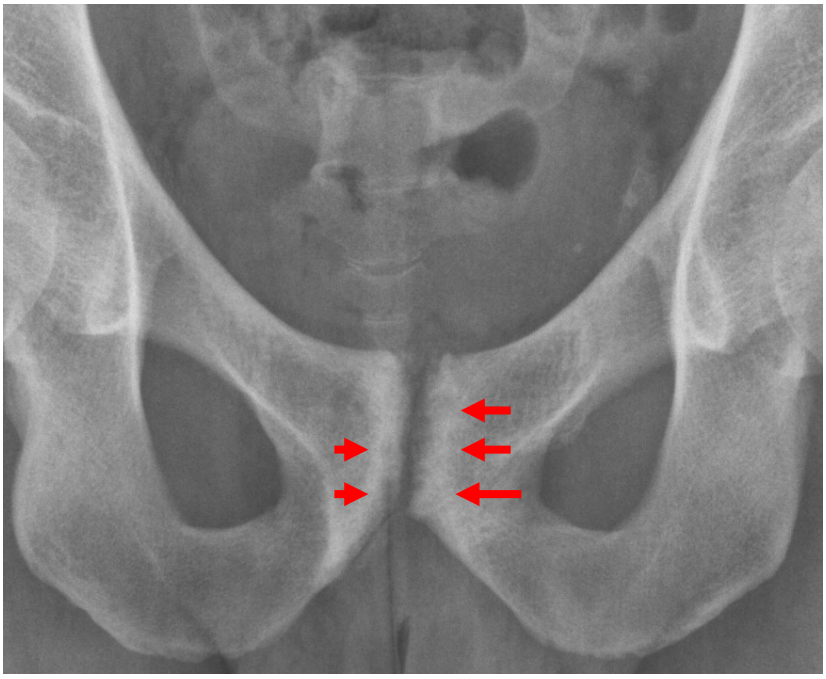
    ELC at the superior two thirds of the joint surface[2]

  - **Inferior ELC**

    ELC at the lower third of the joint surface - "If the entire lower half was considered to have an erosion-like configuration, both of the above were scored as positive"[2]

- **Cysts**

  "Areas of bone lucency with a sclerotic rim inside the trabecular bone compartment, without accompanying cortical bone surface irregularity." [2]



Proliferation

“Clear osteophyte outgrowths at the joint margins or within the articular space.”

- **Superior proliferation**

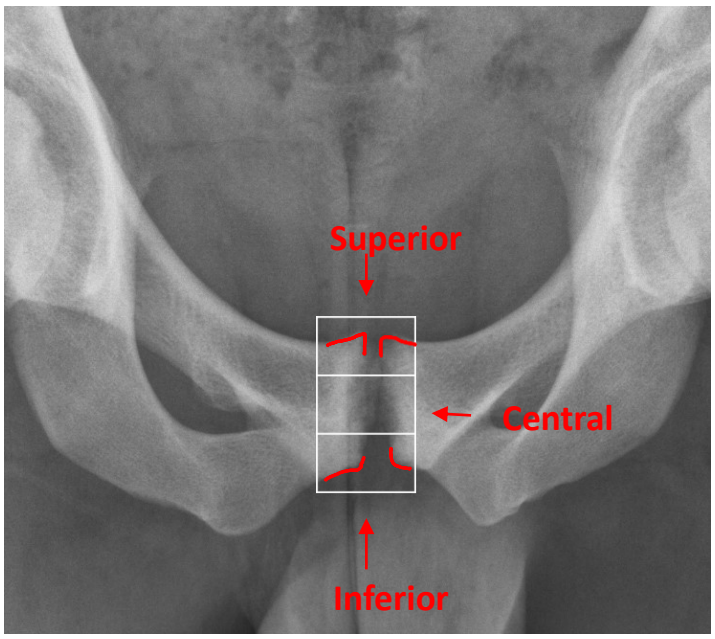
  “This can be considered “bone spurs” or classified as “pubic beaking” when bilateral. Well rounded (smooth) bumps at the superior aspect, even if asymmetrical in size, were not considered proliferation. For superior proliferation, the “sharpness” of the superior bone corner angle was used for assistance with angles higher than 90 deg. (obtuse angle) considered “rounded” and scored negative/absent, whereas angles lower than 90 deg. (acute angle) were considered “sharp” and scored as positive/present.”[2]

- **Central proliferation**

  “Proliferation at the central portion of the articular space.”[2]

- **Inferior proliferation**

  "Similar considerations as superior proliferation."[2]



Fragmentation

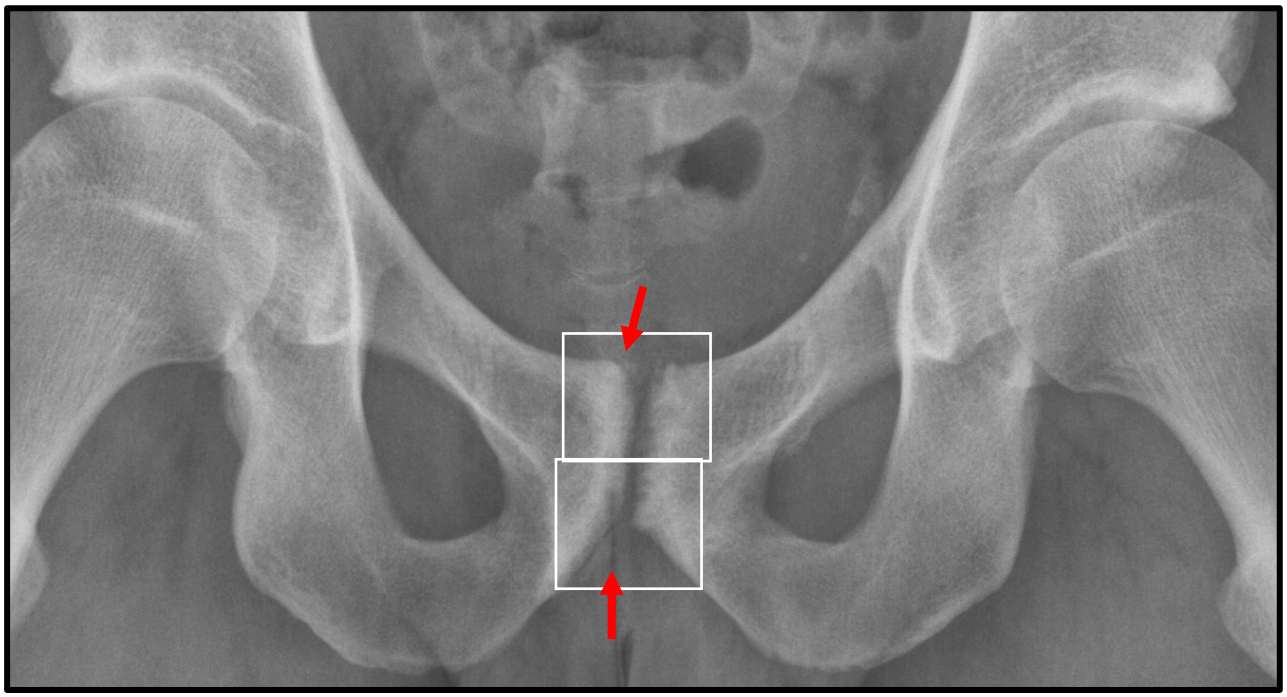
“Clear loose fragment(s) within the symphyseal joint space, or at the inferior medial margin of the pubic bone.” [2]

- **Central Fragmentation**

  “Clear loose fragment(s) within the symphyseal joint space"[2]

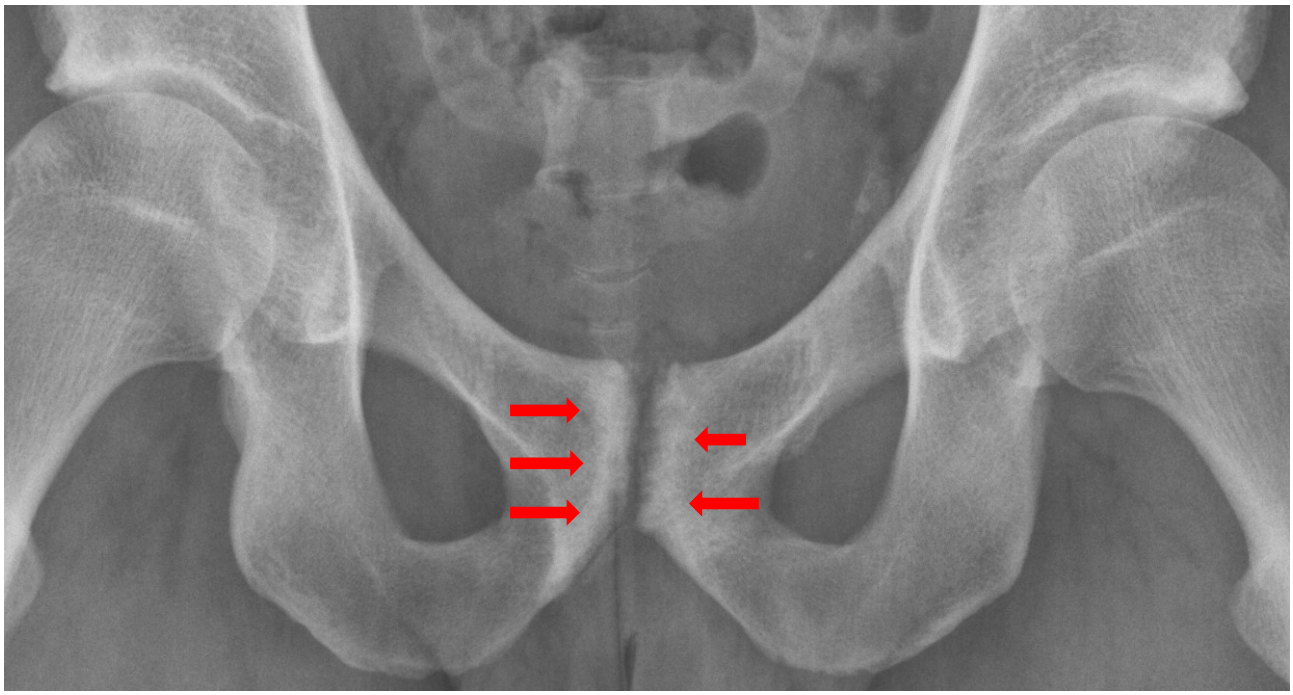
- **Inferior Fragmentation**

  “Clear loose fragment(s) at the inferior medial margin of the pubic bone.” [2]



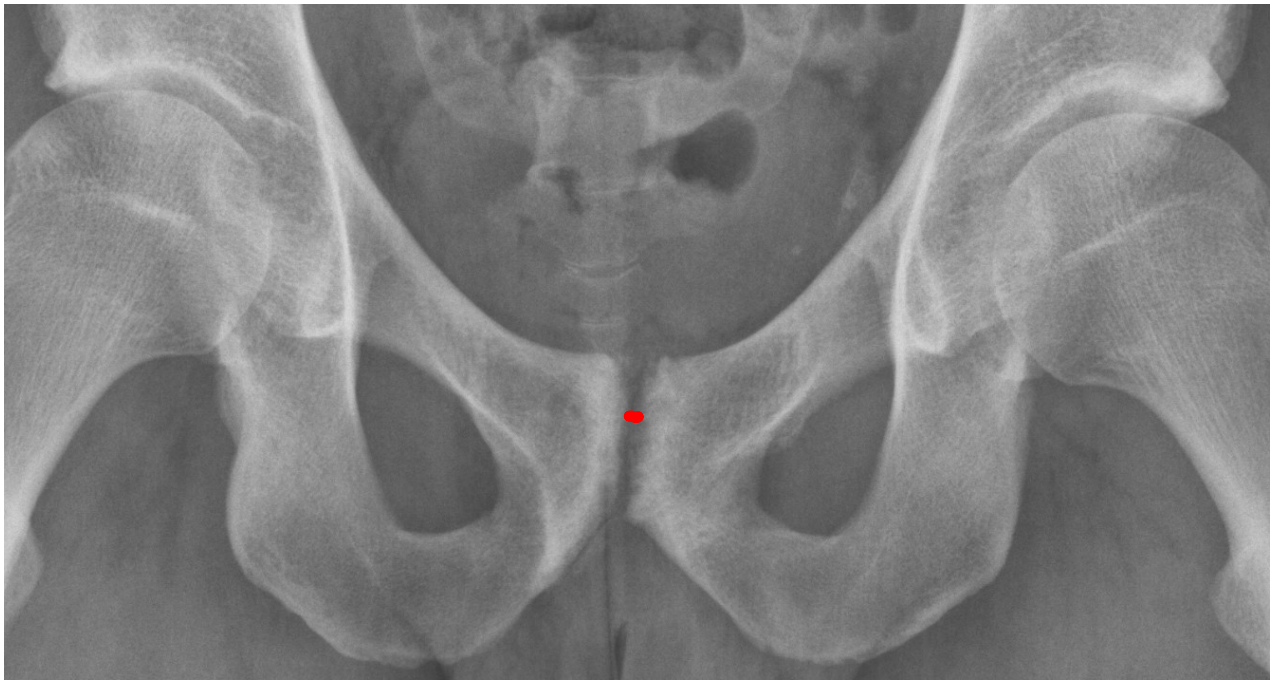
Sclerosis

"A clear area of increased attenuation of the subchondral bone compared to the surrounding bone, corresponding to an area of increased bone density." [2]



Pubic joint space width

"Symphyseal joint space measured in millimeters at the narrowest point of the joint surfaces." [2]



4. Missing data

An overview of excluded and missing data is available in the supplementary excel file. For the hip-related radiographic findings, a total of 895 (27%) data points out of 3268 potentially available data points were excluded and or missing. This was due to 84 anterior-posterior radiographs being excluded due to a too small or too large distance from the upper rim of the pubic bone/symphysis joint to the sacrococcygeal joint. Furthermore, 6 anterior-posterior radiographs were excluded due to subjective quality judgement by the radiologist. Additionally, 10 data points on included radiographs were missing due to faulty patient positioning judged by the radiologists, 8 data points were missing due to a technical error for one radiologist, 6 data points were missing without specified reason, 2 data points were missing due to underexposure. Also, 2 cross-table lateral hip radiographs were excluded due to missing side indication. For the pubic-related radiographic findings, a total of 248 (10%) data points out of 2494 potentially available data points were excluded or missing. This was due to 5 anterior-posterior radiographs being excluded due to gonad shields covered the symphysis joint or inferior rami of the pubic bone (n = 4) and faulty patient positioning judged by the radiologists (n = 1). Furthermore, 77 data points were missing without specified reason, 14 data points for main findings were missing due to missing data for the subclassifications, 4 data points were missing due to vague/unclear pubic joint lines, 3 data points were missing due to gonad shields coverage, 3 data points were missing due to overlay of other structures causing the pubic joint to be unclear, and 2 data points were missing due to rotation of the pelvis or underexposure of the radiograph.

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2. Serner A, Arnaiz J, Mosler A, et al. Classifying radiographic changes of the pubic symphysis in male athletes: Development and reproducibility of a new scoring protocol. *Eur J Radiol*. 2021;134(109452):7. doi:https://doi.org/10.1016/j.ejrad.2020.109452

STUDY II

Pubic-related radiographic findings in football players with long-standing groin pain, and in asymptomatic controls – Are they clinically relevant?

Authors: Mathias Fabricius Nielsen, Per Hölmich, Sonia Branci, Trine Torfing, Lasse Ishøi, Michael Bachmann Nielsen & Kristian Thorborg.

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ORIGINAL ARTICLE OPEN ACCESS

Pubic-Related Radiographic Findings in Male Football Players With Long-Standing Groin Pain, and Asymptomatic Controls — Are They Clinically Relevant?

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Keywords: athletes | football | groin pain | long-standing pain | pubic symphysis | radiographs

ABSTRACT

The Aspetar pubic symphysis radiographic scoring protocol is reliable in male football players, but its clinical significance is unclear. We investigated the prevalence of pubic-related radiographic findings and their association with groin pain and disability in male football players and asymptomatic controls. We included 39 symptomatic male football players with long-standing groin pain, 18 asymptomatic male football players, and 20 asymptomatic male non-football athletes. Standing anteroposterior pelvic radiographs were analyzed by two radiologists for pubic-related bone lucency, proliferation, sclerosis, fragmentation, and joint space width (JSW, millimeters). Findings were combined into a Pubic Symphysis Radiographic Severity Score (PSRS Score, 0–8). Groin pain and disability were measured using the Five-Second Squeeze Test (5SST, 0–10) and the Hip and Groin Outcome Score (HAGOS, 100–0). For symptomatic football players, asymptomatic football players, and asymptomatic non-football athletes, the pubic-related radiographic findings prevalence's were, respectively: bone lucency: 87%, 83%, and 40%; proliferation: 67%, 61%, and 25%; sclerosis: 64%, 50%, and 15%; and fragmentations: 15%, 6%, and 0%, while the mean JSW was 3 mm in all three groups. There were no differences between symptomatic and asymptomatic football players in any findings ($p \geq 0.39$). Bone lucency, proliferation, and sclerosis were more frequent in football players than non-football athletes ($p < 0.002$). PSRS Score showed poor correlation with 5SST and HAGOS. In conclusion, pubic-related radiographic findings are not associated with groin pain or disability. Pubic-related radiographic findings are more common in male football players than male non-football athletes.

1 | Introduction

Male athletes with long-standing groin pain often undergo anteroposterior pelvic and lateral hip radiographs to screen for serious pathology and classify hip joint-related groin pain based on bony morphology [1]. In addition to visualizing the hip joints, anteroposterior pelvic radiographs also display the pubic symphysis, which is considered a potential source of groin pain [2, 3]. In healthy adult males, the pubic symphysis typically has smooth, even, and well-defined joint surfaces and a joint space width of 4–7 mm [4–6].

At least 13 studies have suggested that the pubic symphysis in male athletes with groin pain frequently displays radiographical abnormalities, such as joint space widening or narrowing, bone irregularities, erosions, cysts, sclerosis, bony

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proliferation and/or osteophyte formation (beaking), fragmentation, and accentuation of the gracilis origin [7–17]. However, the prevalence of joint space widening or narrowing, bone irregularities, erosions, sclerosis, and accentuation of the gracilis origin varies between 5% and 83% in athletes with groin pain [9, 10, 18, 19], and 0% to 85% in asymptomatic controls [9, 18, 20–22], while no radiographical abnormalities are seen in 17% to 44% of athletes with groin pain [9, 10, 18, 19]. These highly variable findings may be attributed to substantial population heterogeneity within and between studies, inclusion of inappropriate control groups, and methods with unclear definitions of pubic-related radiographic findings [17, 20, 22]. Specifically, the prevalence of pubic-related radiographic findings may also be influenced by increasing age and high-impact load-bearing sports (football, hockey, etc.) as compared with technical and lower impact/load sports (running, martial arts, etc.) [5, 23, 24]. This emphasizes the need for clear definitions of radiographical findings, robust study methodology, and controlling for age and sport when studying the associations between pubic-related radiographic findings and groin pain.

The Aspetar pubic symphysis radiographic scoring protocol was recently developed to provide a detailed and reproducible scoring system for the pubic symphysis and adjacent bone with clear definitions of five main findings (bone lucency, proliferation, sclerosis, fragmentation, and joint space width) and ten subclassifications [22]. The protocol has moderate to good intra- and interrater reliability in healthy male football players [22], indicating an acceptable reliability for group-level assessments and research. Serner et al. reported that pubic-related radiographic findings were present in up to 65% of asymptomatic male football players [22], however, the prevalence in symptomatic football players with groin pain remains unknown. To understand the potential clinical relevance of radiographic findings scored using the Aspetar protocol, it is essential to first determine their associations with groin pain, pain intensity, and disability. Clarifying these associations might potentially benefit the diagnostic work-up of athletes with long-standing groin pain and improve the understanding of pathogenesis and mechanisms underlying groin pain.

The aim of this study was to investigate the associations between pubic-related radiographic findings and pain in male athletes with long-standing groin pain. The study had three specific objectives: (1) To compare pubic-related radiographic findings, from the Aspetar protocol, in symptomatic male football players with groin pain with asymptomatic male football players and asymptomatic male non-football athletes. (2) To explore whether the total number of pubic-related radiographic findings is associated with groin pain, groin pain intensity, and disability. (3) To explore the influence of individual pubic-related radiographic findings on groin pain intensity and disability in symptomatic football players.

2 | Methods

2.1 | Design

This is a cross-sectional case–control study based on retrospective clinical data and radiographic images collected in 2011–2012 as part of a larger epidemiological project on hip and/or groin pain (ethical reference: H-2-2010-127, data reference: 2011-41-5964) [24–26]. The epidemiological project was conducted in an orthopedic and a radiological outpatient clinic at a public university hospital in the Capital Region of Denmark. Participants provided written informed consent when included in the original project. In this study, new data were generated using the Aspetar pubic symphysis radiographic scoring protocol to reevaluate X-ray images. This study was approved by the Danish National Committee on Health Research Ethics (NVK 2117722) and the Capital Region Data agency (P-2021-497).

2.2 | Participants

Symptomatic and asymptomatic football players were recruited from a pool of 700 male senior players (18+ years) from 40 sub-elite football clubs (tier 2–5) in Denmark. Asymptomatic non-football athletes were recruited from sports clubs, educational institutions, and fitness centres. The symptomatic and asymptomatic participants were matched by age, sport, and athletic exposure to isolate the effect of sport and load as a potential confounder in the association between radiographic findings and groin pain. The participant flow is presented in Figure 1.

Symptomatic football players were male, ≥18 years old, participated in 2–4 weekly football sessions, and had self-reported groin pain during football or running with a duration of ≥6 weeks prior to the clinical examination. Asymptomatic football players met the same criteria but had no hip or groin pain in the past year. Asymptomatic non-football athletes were male, ≥18 years old, participated in 2–4 weekly training sessions, had no hip or groin pain in the past year, had not played football regularly in the past 10 years, and did not practice sports associated with groin pain (handball, rugby and ice hockey). Exclusion criteria for all groups were systemic disorders, obesity, depression, alcohol or drug abuse, and other conditions that may cause groin pain.

2.3 | Data Collection

From the original project, this study included data from a baseline questionnaire, the Copenhagen Five-Second-Squeeze Test (5SST), the Copenhagen Hip and Groin Outcome Score (HAGOS), a standardized clinical examination and one anteroposterior pelvic view radiograph, and a cross-table lateral view radiograph of each hip (see Supplementary File For Details).

2.3.1 | Radiographic Examination

All radiographs were accessed in Agfa IMPAX Client (Bundle 5) (Agfa-Gevaert Group, Belgium), and evaluated individually by two musculoskeletal radiologists, SB and TT, with 11 and 25 years of experience, respectively. They rated pubic- and hip-related radiographic findings using the Aspetar pubic symphysis radiographic scoring protocol, and commonly used methods for assessment of hip-related radiographic findings (see

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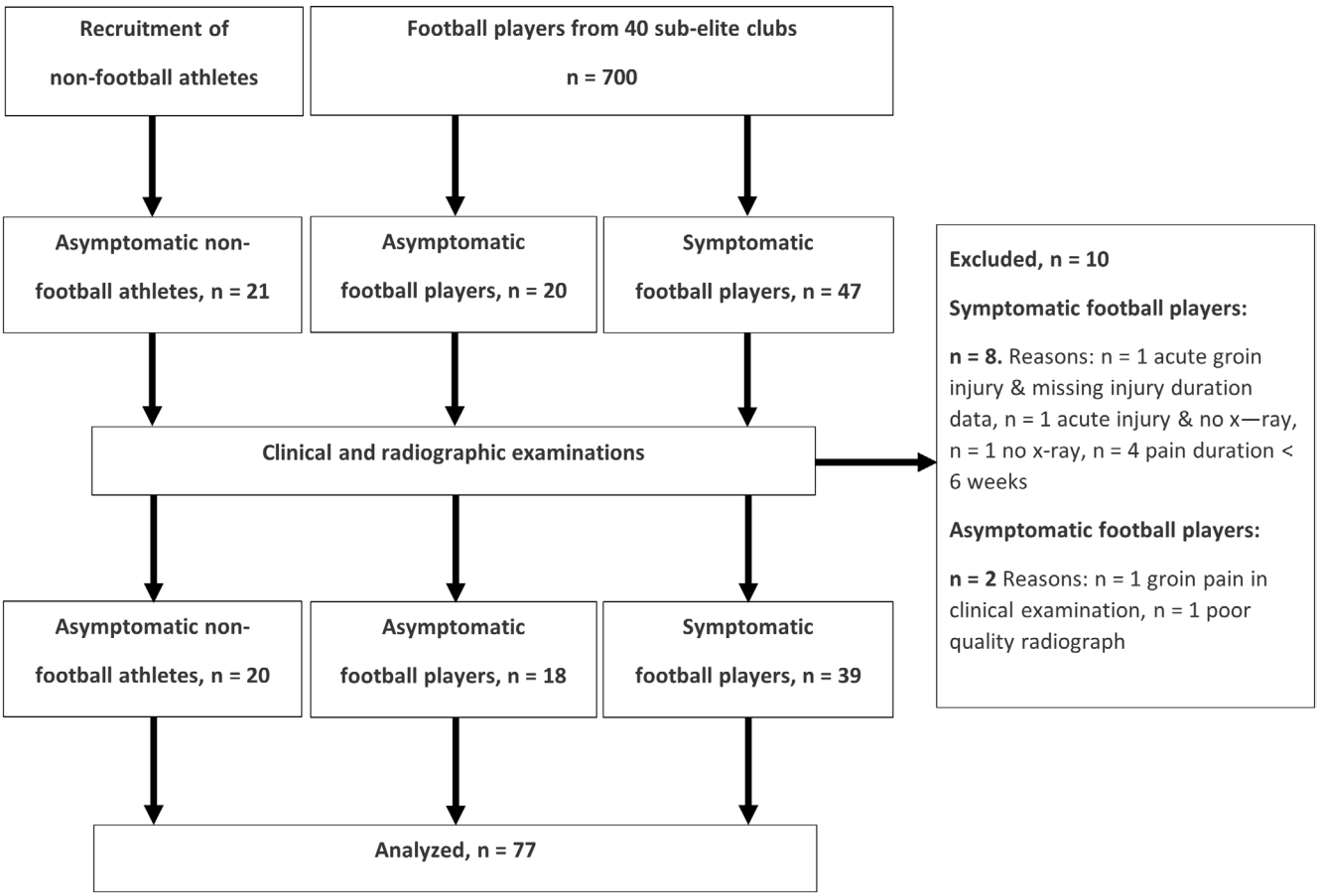


FIGURE 1 | Participant flow.

Supplementary File For Details). Following individual ratings, consensus meetings were held to resolve any disagreements and to establish a dataset of consensus-based ratings. This consensus dataset was used for all analyses in this study.

Pubic-related radiographic findings are illustrated and defined in Figure 2. Hip-related radiographic findings are included as descriptive variables and illustrated and defined in the Supplementary File. Findings were rated absent or present for both sides (right and left), except for pubic joint space width, which was measured in millimeters (nearest whole number), and narrow joint space (< 3 mm) which was measured once for each joint. Findings needed to be unmistakably present to be rated present. For pubic-related findings, the intra-and inter-rater reliability ranged from slight ($\kappa = 0.07$, ICC 2,1 = 0.17) to almost perfect ($\kappa = 0.86$, ICC 2,1 = 0.78) [27].

2.3.2 | Pubic Symphysis Radiographic Severity Score

To assess the extent of pubic-related findings, we combined the total number of dichotomous findings into a Pubic Symphysis Radiographic Severity Score (PSRS) for each participant. Four versions of the PSRS were developed to account for different levels of assessment: individual level, side level, main finding level, and subclassification level. All four versions of the PSRS Score are presented in Table 1. In the aggregated scores, equal weight was assigned to each finding. Consequently, narrow joint space was only included in the PSRS Scores at the individual level.

2.3.3 | Baseline Questionnaire

Before examinations participants completed a baseline questionnaire collecting information on age (years), height (centimeters), body mass (kilograms), preferred kicking leg (right/left), number of weekly football or sport training sessions and weekly training hours. For symptomatic football players, the questionnaire also included current football/sports participation status (playing/not-playing), duration of symptoms (months), symptom location (right/left/bilateral), and worst pain in the previous week, measured on a numeric pain rating scale (NRS) from 0, "no pain," to 10, "worst pain imaginable".

2.3.4 | The Copenhagen 5-Second Squeeze Test

The 5SST was used to assess self-reported groin-related pain intensity on a numeric rating scale from 0 "no pain" to 10 "worst pain imaginable" [28]. The 5SST was performed with athletes lying supine, with 0° hip flexion and straight legs on an examination bench. The forearm of the assessor was placed between the ankles of the athlete as resistance against bilateral hip adduction, and the arm was placed approximately 5 cm proximal to the medial malleoli, resulting in approx. 10°–15° hip abduction

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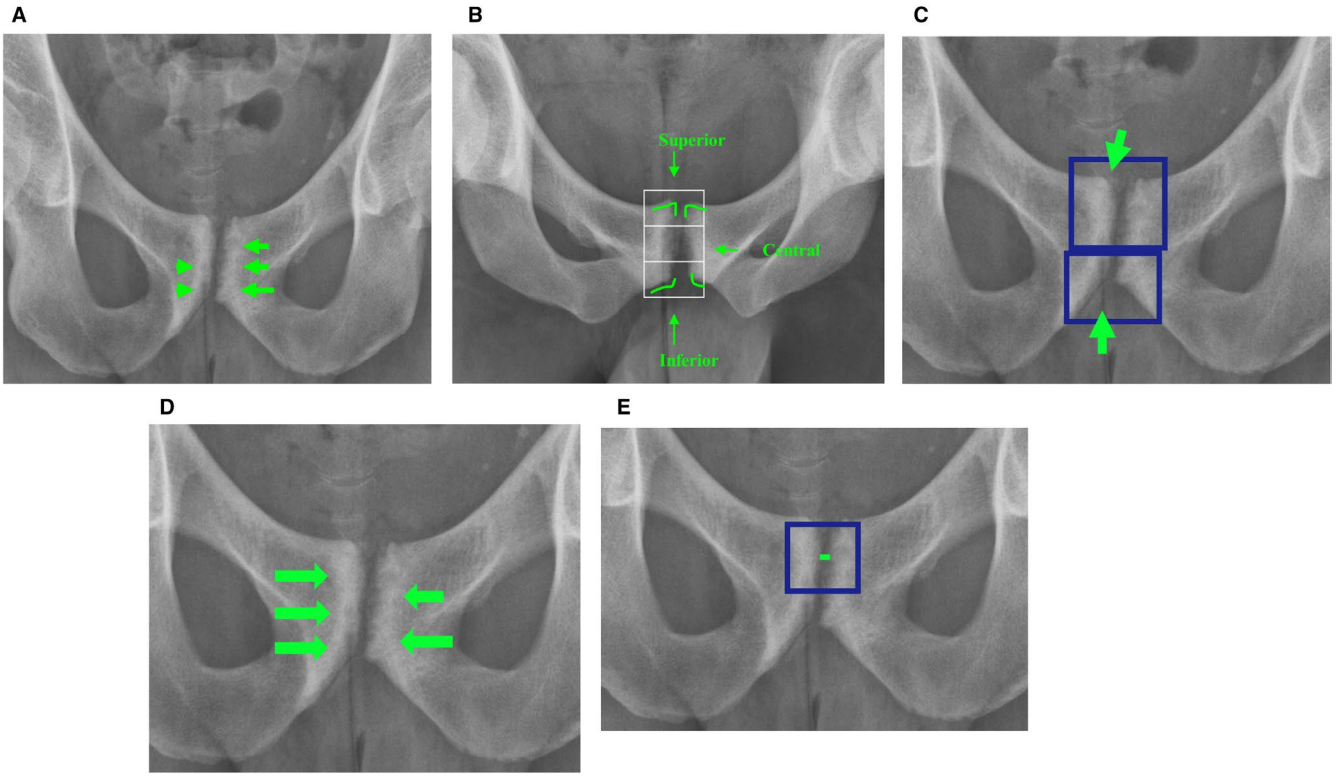


FIGURE 2 | Pubic-related radiographic findings as described by Serner et al. [22]. (A) Bone lucency. Definition: "A clear area of decreased attenuation compared to the surrounding bone, which corresponds to an erosion-like configuration and/or cyst." [22], Subclassifications: *Erosion-Like Configuration (ELC), Superior/Central ELC, Inferior ELC and Cysts*. Definitions: *ELC*: "Irregularities of the cortical bone surface, potentially accompanied by loss of the adjacent trabecular bone." [22], *Superior/Central ELC*: ELC at the superior two thirds of the joint surface [22], *Inferior ELC*: ELC at the lower third of the joint surface - "If the entire lower half was considered to have an erosion-like configuration, both of the above were scored as positive" [22], *Cysts*: "Areas of bone lucency with a sclerotic rim inside the trabecular bone compartment, without accompanying cortical bone surface irregularity." (B) Proliferation. Definition: "Clear osteophyte outgrowths at the joint margins or within the articular space." [22], Subclassifications: *Superior, Central and Inferior Proliferation*. Definitions: *Superior proliferation*: "This can be considered "bone spurs" or classified as "pubic beaking" when bilateral. Well rounded (smooth) bumps at the superior aspect, even if asymmetrical in size, were not considered proliferation. For superior proliferation, the "sharpness" of the superior bone corner angle was used for assistance with angles higher than 90 deg. (obtuse angle) considered "rounded" and scored negative/absent, whereas angles lower than 90 deg. (acute angle) were considered "sharp" and scored as positive/present." [22], *Central proliferation*: "Proliferation at the central portion of the articular space." [22], *Inferior proliferation*: "Similar considerations as superior proliferation." [22]. (C) Fragmentation. Definition: "Clear loose fragment(s) within the symphyseal joint space, or at the inferior medial margin of the pubic bone." [22], Subclassifications: *Central and inferior fragmentation*. Definitions: *Central fragmentation*: "Clear loose fragment(s) within the symphyseal joint space" [22], *Inferior fragmentation*: "Clear loose fragment(s) at the inferior medial margin of the pubic bone." [22]. (D) Sclerosis. Definition: "A clear area of increased attenuation of the subchondral bone compared to the surrounding bone, corresponding to an area of increased bone density." [22]. (E) Pubic Symphysis Joint Space Width. Definition: "Symphyseal joint space measured in millimeters at the narrowest point of the joint surfaces." [22], Subclassification: *Narrow Joint Space Width*. Definition: *Narrow Joint Space Width*. "if measured to less than 3mm" [22].

angle bilaterally (See Supplementary file for image of setup). Participants were instructed to perform a 5 s maximum and continuous bilateral isometric hip adduction squeeze with gradual increase in force production if necessary. The instruction was "3–2-1-Go-push-push-push-push-and-stop". This was followed by rating the intensity of evoked groin pain during or right after the test.

2.3.5 | The Copenhagen Hip and Groin Outcome Score

HAGOS was used to assess self-reported groin-related disability [29]. HAGOS includes 37 items on the subscales: pain, symptoms, physical function in daily living (ADL), physical function in sport and recreation (Sport), participation in physical activities (PA), and quality of life (QoL). Items are answered on a five-point Likert scale from 0 to 4. Subscales are normalized into a summary score ranging from 0 (extreme symptoms) to 100 (no symptoms) [29]. HAGOS is valid, reliable, and responsive in Danish [29]. HAGOS was recently validated using modern test theory, which resulted in revised HAGOS subscale scores utilizing only 30 items [30]. The revised HAGOS scores were used in this study. The original HAGOS scores are presented in the Appendix Table A1 to allow comparison with studies using the original version.

2.3.6 | Clinical Examination

All participants underwent a standardized bilateral clinical examination of the hip and groin regions in accordance with the

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TABLE 1 | Pubic symphysis radiographic severity (PSRS) score.

Version	Assessment level	Included findings	Score
PSRS Score 1	Each main finding assessed on a person level.	Bone lucency (0–1) Proliferation (0–1) Fragmentation (0–1) Sclerosis (0–1) Narrow joint space (0–1).	0–5
PSRS Score 2	Each main finding assessed on a side level, that is left and right in total.	Bone lucency (0–2) Proliferation (0–2) Fragmentation (0–2) Sclerosis (0–2)	0–8
PSRS Score 3	Each subclassification finding assessed on a person level.	Superior/central Erosion-Like Configuration (0–1) Inferior Erosion-Like Configuration (0–1) Cysts (0–1) Superior proliferation (0–1) Central proliferation (0–1) Inferior proliferation (0–1) Central fragmentation (0–1) Inferior fragmentation (0–1) Sclerosis (0–1) Narrow joint space (0–1)	0–10
PSRS Score 4	Each subclassification finding assessed on a side level, that is left and right in total.	Superior/central Erosion-Like Configuration (0–2) Inferior Erosion-Like Configuration (0–2) Cysts (0–2) Superior proliferation (0–2) Central proliferation (0–2) Inferior proliferation (0–2) Central fragmentation (0–2) Inferior fragmentation (0–2) Sclerosis (0–2)	0–18

framework by Hölmich et al. [31], which included palpation, manual resistance, or stretching tests. Tests were considered positive if they elicited known and recognizable groin pain. If discomfort but not known groin pain was reported, the test was rated negative. The symptomatic football players were classified with clinical entities of groin pain according to the Doha Classification system [3], based on the positive pain provocation tests. This approach has acceptable reliability [32]. Pain provocation tests and clinical entities of groin pain are described and defined in the Tables S1 and S2.

2.4 | Sample Size Considerations

A maximum of 88 participants underwent clinical and radiological examinations in the original project (H-2-2010-127). Assuming all participants had complete datasets and all radiographs were of adequate quality, this would result in a fixed sample size of 47 symptomatic football players, 20 asymptomatic football players, and 21 asymptomatic non-football athletes. Based on a X^2-test, an alpha level of 0.05, and a power of 0.80, this would allow for detecting a statistically significant difference of 34% between groups, corresponding to a moderate to large effect size (Cohens h = 0.75). Using the R package "pwr, we estimated that a fixed number of 48 symptomatic football players, an alpha level of 0.05, and a power of 0.80 would allow us to detect statistically significant correlation coefficients of at least 0.39.

2.5 | Statistical Analyses

Statistical analyses were performed in R version 4.3.0, RStudio 2022.12.0 + 353. Dichotomous pubic-related findings were analyzed and presented as categorical data. Pubic joint space width (mm), the 5SST, the HAGOS subscales, and the PSRS Scores were treated and presented as continuous variables.

Differences in pubic-related radiographic findings between groups were examined using X^2-tests and the "tableone" R-package. For pair-wise comparison between groups, odds ratios with 95% confidence intervals were estimated for each pubic-related radiographic finding using the "epitools" and "effectsize" R-packages. Differences in pubic joint space width and PSRS Scores between groups were investigated using the "multcomp" R-package to conduct a one-way analysis of variance (ANOVA) with a post hoc Tukey's test. For the primary between-group comparisons, pubic-related findings on an individual level, and not on the side-specific level, were used. However, a series of sensitivity analyses comparing only right-sided findings and left-sided findings between groups were also conducted, and only findings from sides with groin pain from symptomatic football players were analyzed.

For symptomatic football players, we explored the associations between PSRS Scores, 5SST, and HAGOS subscales using

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the "ggplot2" R-package to create scatter plots with Locally Estimated Scatterplot Smoothing (LOESS). We also used the "correlation" R-package to estimate Spearman's correlation coefficients with 95% confidence intervals. Correlation coefficients were interpreted as negligible (0.0–0.10), weak (0.10–0.39), moderate (0.40–0.69), strong (0.70–0.89), or very strong (0.90–1.00).

To explore the influence of the pubic-related radiographic findings on 5SST and HAGOS subscales in symptomatic football players, we constructed seven multivariate linear regression models using the "stats" R-package. In each model, the dependent variable was either the 5SST or a HAGOS subscale, and the independent variables were the five main pubic-related radiographic findings (bone lucency, proliferation, fragmentation, sclerosis, narrow joint space) at the individual level.

Conclusions from statistical analyses are based on unadjusted results to preserve the study's exploratory nature and avoid overlooking findings relevant for future research. However, as Type-1 error (false positives) was highlighted as a key limitation during peer review, we performed post hoc p value adjustments using the Benjamini–Hochberg approach [33]. The adjusted p values are included in Tables and the Appendix.

3 | Results

3.1 | Participants

Of 88 participants with available data, we included 39 symptomatic football players with long-standing groin pain, 18 asymptomatic football players, and 20 asymptomatic non-football athletes (Figure 1). Asymptomatic non-football athletes participated in fitness ($n=8$), running ($n=5$), martial arts ($n=3$), cycling ($n=1$), parkour ($n=1$), kayak ($n=1$), and basketball ($n=1$). Descriptive data are in Table 2.

3.2 | Pubic-Related Radiographic Findings

No significant differences were observed in pubic-related findings between symptomatic and asymptomatic football players (Table 3, Figure 3, and Appendix Table A9). The prevalence of cysts, fragmentation (including subclassifications), and a narrow pubic joint space did not differ across symptomatic football players, asymptomatic football players, and non-football athletes (Figure 3, Appendix Table A9). However, the prevalence of bone lucency, ELC (including subclassifications), proliferation (including subclassifications), and sclerosis differed significantly across all three groups (Figure 3, Appendix Table A9). To illustrate these findings, five different radiographs are visualized and described in Figure 4. Similar results were observed when symptomatic sides (right $n=32$, left $n=23$) were compared to asymptomatic athletes (Appendix Table A2).

3.3 | Pubic Symphysis Radiographic Severity Scores

No significant differences were observed in any of the four PSRS Scores between symptomatic and asymptomatic football players (Appendix Table A3). However, all four PSRS Scores were significantly higher in the symptomatic football players compared with asymptomatic non-football athletes (Appendix Table A3).

In symptomatic football players ($n=39$), the PSRS Score 1 (0–5) correlated significantly to HAGOS Pain (rho = −0.40, 95% CI: −0.64 to −0.09, $p=0.01$, adj. $p=0.08$, Appendix Figure A5) and HAGOS QoL (rho = −0.34, 95% CI: −0.60 to −0.01, $p=0.04$, adj. $p=0.13$, Appendix Figure A13), while the PSRS Score 2 (0–8) correlated significantly to HAGOS Pain (rho = −0.39, 95% CI: −0.63 to −0.07, $p=0.01$, adj. p = 0.08, Appendix Figure A6). All other correlations between PSRS Scores and 5SST and HAGOS subscales were negligible ($\rho=0.0$) to weak ($\rho \leq -028.$) and non-significant (p values = 0.08 to 0.75, Appendix Table A4 and Appendix Figures A1–A16).

3.4 | Influence of the Pubic-Related Radiographic Findings on 5SST and HAGOS

In the symptomatic football players ($n=39$), linear regression models for 5SST showed that bone lucency ($\beta=-3.9$, 95% CI: −7.0 to −0.8, $p=0.02$) and narrow pubic joint space ($\beta=-2.2$, 95% CI: −4.2 to −0.2, $p=0.04$) were associated with lower 5SST values, indicating lower groin pain intensity (Appendix Table A5).

In the models for HAGOS subscales, sclerosis was associated with lower HAGOS Pain ($\beta=-20.8$, 95% CI: −33.7 to −7.9, $p<0.00$) and HAGOS ADL values ($\beta=-20.6$, 95% CI: −38.2 to −2.9, $p=0.03$), indicating worse pain and impaired physical function in daily living (Appendix Table A6).

4 | Discussion

This is the first study to use the Aspetar pubic symphysis radiographic scoring protocol for evaluating the pubic symphysis joint in male football players with long-standing groin pain and asymptomatic controls. We found that the pubic-related findings had similar prevalence in symptomatic football players and asymptomatic football players. Most pubic-related findings (e.g., bone lucency, proliferation, and sclerosis) were more prevalent in male football players than in asymptomatic non-football athletes. The total number of radiographic findings (the Pubic Symphysis Radiographic Severity Score) was not associated with groin pain. In the group of symptomatic male football players, the PSRS Score showed a weak negative correlation to HAGOS Pain and HAGOS Quality of life, while bone lucency and joint space narrowing were associated with lower pain intensity, and sclerosis was associated with higher disability.

4.1 | Pubic-Related Radiographic Findings

Radiographic findings of erosion, cysts, bone proliferation, and sclerosis are common degenerative radiographic findings related to joint diseases. When these findings are present at the pubic symphysis joint and surrounding bone in male athletes with adductor and pubic-related groin pain, they have been interpreted as

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TABLE 2 | Descriptive data.

		Symptomatic football players		Asymptomatic football players		Asymptomatic non-football athletes	
n		39		18		20	
Age, years, mean (SD)		24.5 (3.2)		23.1 (2.7)		25.9 (5.9)	
Height, cm, mean (SD)		181.9 (5.7)		181.0 (4.6)		181.9 (5.8)	
Weight, kg, mean (SD)		77.9 (6.6)		79.1 (6.0)		80.3 (8.7)	
Body Mass Index, mean (SD)		23.5 (1.4)		24.2 (1.5)		24.3 (2.8)	
Training pr week, hours, mean (SD)		5.6 (1.6)		5.6 (1.0)		7.5 (2.9)	
Training pr week, sessions, median (IQR)		4 (3–4)		4 (3–4)		3 (3–3)	
Kicking Leg, right *n* (%)		29 (74%)		13 (81%)		18 (95%)	
Symptomatic side	*Right*, *n (%)*	16 (41%)		—		—	
	Left, *n* (%)	7 (18%)		—		—	
	Bilateral, *n* (%)	14 (36%)		—		—	
Long-standing groin pain, *n* (%)		39 (100%)		—		—	
Pain duration, months, median (IQR)		10 (5–36)					
Injury mechanism	*Acute*, *n* (%)	15 (39%)		—		—	
	Gradual, *n* (%)	24 (2%)		—		—	
Pain in preceding week, 0–10, median (IQR)		8 (6–9)		0 (0–0)		0 (0–0)	
5SST, 0–10, median (IQR)		5 (4–8)		0 (0–0)		0 (0–0)	
HAGOS, Revised							
Pain, median (IQR)		84 (67–91)		100 (97–100)		100 (100–100)	
Symptoms, median (IQR)		62 (50–73)		92 (83–100)		96 (91–100)	
ADL, median (IQR)		81 (62–87)		100 (100–100)		100 (100–100)	
Sport, median (IQR)		46 (33–62)		100 (92–100)		100 (100–100)	
PA, median (IQR)		37 (19–62)		100 (100–100)		100 (100–100)	
QoL, median (IQR)		44 (28–56)		100 (94–100)		100 (100–100)	
Clinical entities of groin pain		**Right**	**Left**				
Adductor-related groin pain, *n* (%)		19 (49%)	18 (46%)	—		—	
Iliopsoas-related groin pain, *n* (%)		20 (51%)	23 (59%)	—		—	
Inguinal-related groin pain, *n* (%)		18 (46%)	18 (46%)	—		—	
Pubic-related groin pain, *n* (%)		5 (13%)		—		—	
Total entities, median (IQR)		3 (2–4)		—		—	
Hip-related Radiographic Findings		**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
Alpha Angle, mean (SD)		53 (13)	55 (11)	52 (13)	52 (12)	48 (10)	49 (11)
Cam morphology, *n* (%)		9 (23%)	10 (26%)	3 (17%)	5 (28%)	2 (10%)	3 (15%)
Lateral Center Edge Angle, mean (SD)		30 (5)	30 (5)	27 (7)	28 (9)	30 (6)	31 (5)
Acetabular Index Angle, mean (SD)		7 (4)	6 (5)	9 (4)	9 (5)	7 (4)	5 (4)
Pincer Morphology, *n* (%)		2 (8%)	1 (4%)	1 (10%)	1 (10%)	1 (7%)	0 (0%)
Borderline Hip Dysplasia, *n* (%)		5 (21%)	5 (21%)	6 (60%)	3 (33%)	5 (33%)	1 (7%)

(Continues)

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TABLE 2 | (Continued)

	Symptomatic football players		Asymptomatic football players		Asymptomatic non-football athletes	
Hip Dysplasia, *n* (%)	1 (4%)	1 (4%)	2 (20%)	3 (30%)	1 (7%)	0 (0%)
Hip joint space width, mm, mean (SD)	5 (1)	5 (1)	5 (1)	5 (1)	5 (1)	5 (1)
Cross-Over sign, *n* (%)	12 (50%)	14 (58%)	4 (40%)	6 (60%)	7 (47%)	7 (47%)
Ischial Spine Sign, *n* (%)	15 (63%)	14 (58%)	4 (40%)	6 (60%)	8 (53%)	9 (60%)
Posterior Wall Sign, *n* (%)	17 (71%)	19 (79%)	5 (50%)	6 (60%)	9 (60%)	8 (53%)

Note: Missing/censored data: Asymptomatic football players, $n = 1$, Reason: no clinical examination, 5SST or HAGOS, *N* for the Hip-related Radiographic Findings: for anteroposterior images: symptomatic football players $n = 24$, asymptomatic football $n = 10$, asymptomatic non-football $n = 15$. Cam morphology: alpha angle > 60°. Pincer morphology: Lateral Center Edge Angle ≥ 40° OR (Lateral Center Edge Angle ≥ 35° AND Acetabular Index Angle < 0°). Borderline Hip Dysplasia: Lateral Center Edge Angle = 20° to 25°. Hip dysplasia: Lateral Center Edge Angle < 20° OR Acetabular Index Angle > 13°.

degenerative changes that may contribute to pain [2, 7–17]. The prevalence of each finding is rarely reported, but erosions, cysts, and sclerosis are often described as classical features of athletes with pubic and/or adductor-related groin pain [7–17]. These athletes are also described with joint space changes (narrowing and widening), which likely result from erosions [9, 10, 13, 20], or proliferations [22]. Fragmentations at the pubic symphysis are less frequently reported, but it has been suggested that fragmentations may represent specific conditions such as apophysitis or bone maturation status [22, 34].

With the Aspetar protocol, we used a clear and reliable method for assessing each of these radiographic findings independently, and with a higher level of detail and methodological rigor than ever before reported by previous studies. Importantly, this study included both asymptomatic football players and non-football athletes matched on age and physical activity level to the symptomatic athletes, which allows for determining whether pubic-related radiographic findings may be attributed to groin pain or playing football [24]. Between football players and non-football players, the absolute prevalence differences ranged between 8% and 50% and were statistically significant for 9 of the 15 main and subclassification findings. However, there were no statistically significant differences between football players with and without groin pain, despite rather clear differences for central/superior ELC (21%points), cysts (20%points), sclerosis (14% points), narrow pubic joint space (11% points) and fragmentations (9% points). These results suggest that many of the pubic-related radiographic findings, from the Aspetar protocol, may be attributed to playing football rather than groin pain. This assumption is in line with at least five studies that have also suggested that pubic-related radiographic findings are associated with sports activity rather than groin pain [23, 35–38].

It is important to note that 13 of 39 (33%) symptomatic players were not classified with adductor- or pubic-related groin pain. This raises a concern of false-negative findings (type two error) if the radiographic findings truly are pathognomonic for adductor- and pubic-related groin pain [2, 7–17]. To address this, we performed a post hoc analyses comparing the asymptomatic groups to the 26 symptomatic football players with adductor or pubic-related groin pain. This analysis produced similar results (Appendix Tables A7 and A8). To improve the understanding of pathogenesis and mechanisms underlying especially adductor- and pubic-related groin pain, future studies should explore other aspects of nociception and pain processing rather than focusing on specific radiological and surgical findings in the groin as the only factors contributing to long-standing groin pain.

4.2 | The Pubic Symphysis Radiographic Severity (PSRS) Score

The radiographic severity and progression of degenerative joint disease are often described with classification systems such as the Kellgren-Lawrence grade [39]. Inspired by this, we developed four versions of a cumulative PSRS Score, as a pragmatic approach to quantify the extent and severity of pubic-related radiographic findings. The results indicate that all versions of the PSRS score have limited value and clinical relevance. We found similar PSRS scores in symptomatic and asymptomatic players (see Figure 4), while in the symptomatic football players the PSRS Score correlated weakly to HAGOS Pain and QoL. However, the significant correlations diminished when the PSRS Score range increased from 0–5 to 0–18, and the *p* values were adjusted for false discovery rate. This suggests that the significant correlations should be interpreted with caution and confirmed by larger studies, as they are at risk of being random findings.

To improve the PSRS score and potentially enhance the relevance of a PSRS score in both research and clinical contexts, it may be beneficial to weight each finding independently or construct clusters of findings rather than applying an equal weight to all findings. This could be investigated further using methods such as principal component or factor analyses in data from larger samples. Another option could be to construct the PSRS score based on the findings with the largest differences between symptomatic and asymptomatic football players.

4.3 | Influence of Individual Pubic-Related Radiographic Findings on 5SST and HAGOS

When analyzing only the symptomatic players, sclerosis was associated with significantly worse scores on HAGOS Pain and ADL subscales. The football players with long-standing groin pain and sclerosis scored approximately 20 points lower on

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TABLE 3 | Pairwise comparison of pubic-related findings on person level.

Pubic-related findings	Symptomatic football ($n = 39$) vs. Asymptomatic football ($n = 18$)				Symptomatic football ($n = 39$) vs. Asymptomatic non-football ($n = 20$)				Asymptomatic football ($n = 18$) vs. Asymptomatic non-football ($n = 20$)			
	OR	(95% CI)	*p*	Adj. *p*	OR	(95% CI)	*p*	Adj. *p*	OR	(95% CI)	*p*	Adj. *p*
Bone Lucency	0.74	(0.12–5.38)	0.70	0.85	0.10	(0.02–0.42)	**< 0.00**	**< 0.00**	0.14	(0.02–0.73)	**0.01**	**0.04**
Erosion-Like Configuration	0.74	(0.12–5.38)	0.70	0.85	0.10	(0.02–0.42)	**< 0.00**	**< 0.00**	0.14	(0.02–0.73)	**0.01**	**0.04**
Superior/Central ELC	0.38	(0.10–1.47)	0.13	0.29	0.21	(0.05–0.74)	**0.01**	**0.03**	0.54	(0.12–2.31)	0.52	0.61
Inferior ELC	0.90	(0.20–4.81)	1.00	1.00	0.12	(0.03–0.44)	**< 0.00**	**< 0.00**	0.13	(0.02–0.64)	**< 0.00**	**0.04**
Cysts	0.29	(0.03–1.55)	0.19	0.40	0.26	(0.02–1.36)	0.11	0.28	0.89	(0.06–13.64)	1.00	1.00
Proliferation	0.79	(0.22–3.00)	0.77	0.86	0.17	(0.04–0.64)	**0.01**	**0.02**	0.22	(0.04–1.02)	0.05	0.08
Superior Proliferation	0.87	(0.25–3.16)	1.00	1.00	0.18	(0.04–0.69)	**0.01**	**0.02**	0.21	(0.04–1.01)	**0.04**	0.08
Central Proliferation	1.43	(0.40–5.11)	0.58	0.77	0.16	(0.02–0.85)	**0.02**	0.05	0.12	(0.01–0.74)	**0.01**	**0.04**
Inferior Proliferation	0.72	(0.18–2.63)	0.77	0.86	0.08	(0.00–0.60)	**0.01**	**0.02**	0.11	(0.00–1.09)	**0.04**	0.08
Fragmentations	0.33	(0.01–3.06)	0.41	0.68	0.00	(0.00–1.58)	0.09	0.24	0.00	(0.00–35.10)	0.47	0.61
Central Fragmentation	0.71	(0.01–9.61)	1.00	1.00	0.00	(0.00–4.73)	0.54	0.77	0.00	(0.00–35.10)	0.47	0.61
Inferior Fragmentation	0.00	(0.00–3.27)	0.30	0.55	0.00	(0.00–2.93)	0.29	0.55	—	—	—	—
Sclerosis	0.57	(0.16–2.03)	0.39	0.68	**0.10**	(0.02–0.44)	**< 0.00**	**< 0.00**	0.19	(0.03–0.99)	**0.04**	0.08
Narrow Pubic Joint Space	0.51	(0.08–2.38)	0.51	0.77	0.64	(0.13–2.65)	0.55	0.77	1.24	(0.18–9.94)	1.00	1.00
Pubic Joint Space, mean diff.	−0.3	(−1.0 to 0.5)	0.40	0.61	0.1	(−0.5 to 0.7)	0.75	0.75	0.3	(−1.0 to 0.4)	0.26	0.61

Note: Interpretation: A lower odds ratio indicates a higher risk of findings in the symptomatic group. Bold *p*-values are statistically significant.
Abbreviations: CI, confidence interval; OR, odds ratio.

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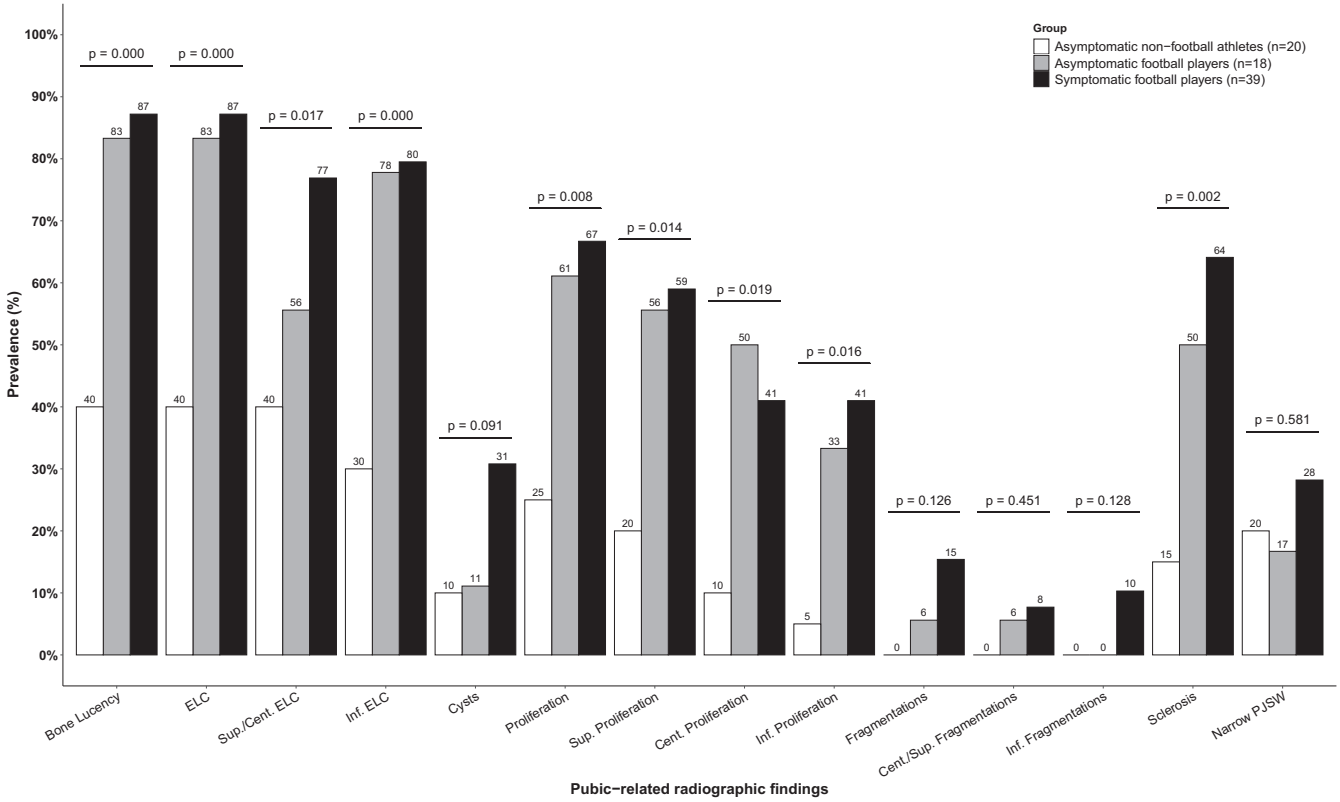


FIGURE 3 | Prevalence of pubic-related radiographic findings. *p* values are from χ^2-tests across all three groups. ELC = Erosion-Like Configuration.

HAGOS Pain and ADL compared to players without sclerosis. This difference exceeds the minimal important changes (MIC) thresholds for HAGOS Pain (9.7 points) and ADL subscales (11.8 points) [40], suggesting that sclerosis may be a clinically meaningful radiographic finding. Sclerosis may represent a specific mechanism or worsened state of groin pain, as it often presents at later stages of joint degeneration. These associations could therefore be influenced by age, duration of symptoms, and time spent participating in football.

The regression models showed that bony lucency and narrow joint space were associated with lower groin pain intensity as measured by the 5SST. This was an unexpected finding that contradicts the models for HAGOS subscales and the correlation between radiographic findings and HAGOS Pain. This discrepancy may stem from methodological limitations such as Type-1 and Type-2 errors, or the limited sample size. Alternatively, it can be speculated that bone lucency and narrow joint space reflect an earlier or later stage of groin pain, where the athletes and their pubic region are less sensitive to the mechanical forces during the 5SST.

4.4 | Limitations

The classification of groin pain relied solely on the clinical pain provocation tests [32]. Even though the flexion adduction internal rotation (FADIR) test can effectively screen for hip-joint related groin pain, relying only on clinical tests may result in underreporting of hip-joint related groin pain in symptomatic athletes with a positive FADIR test and radiographic cam, pincer, borderline dysplasia, or dysplasia.

All radiographs were taken in a public hospital by multiple technicians. This reflects a real-life clinic, although using a single technician may have reduced variation and error, as it is the technician's responsibility to secure satisfactory patient positioning. For the final dataset, we used consensus readings from two radiologists, with different levels of experience. This approach reduces the influence of individual skills and errors but limits generalizability, as single-rater readings are common in clinical practice. However, consensus readings are still at risk of error and bias due to lack of variability, influence of the senior radiologist on the junior radiologist, "group thinking" and application of wrong assumptions [41, 42].

The interpretation of fragmentations, erosions, and cysts may have been influenced by the maturation status of the pubic symphysis [34], as this is not accounted for by the Aspetar protocol [22]. Van Ovost et al. have developed the maturation of the adolescent pubic symphysis (MAPS) classification method [34], which may enhance the radiographic assessment of the pubic symphysis joint when added to the Aspetar protocol.

The fixed sample size limited the ability to detect potentially clinically meaningful differences. For example, detecting a 21% difference in superior/central ELC between two groups would have required at least 78 participants per group. The large number of statistical analyses increased the risk of false positive findings (Type 1 errors). As this was highlighted during peer review, we added adjusted *p* values post hoc to allow readers to evaluate the risk of type 1 error.

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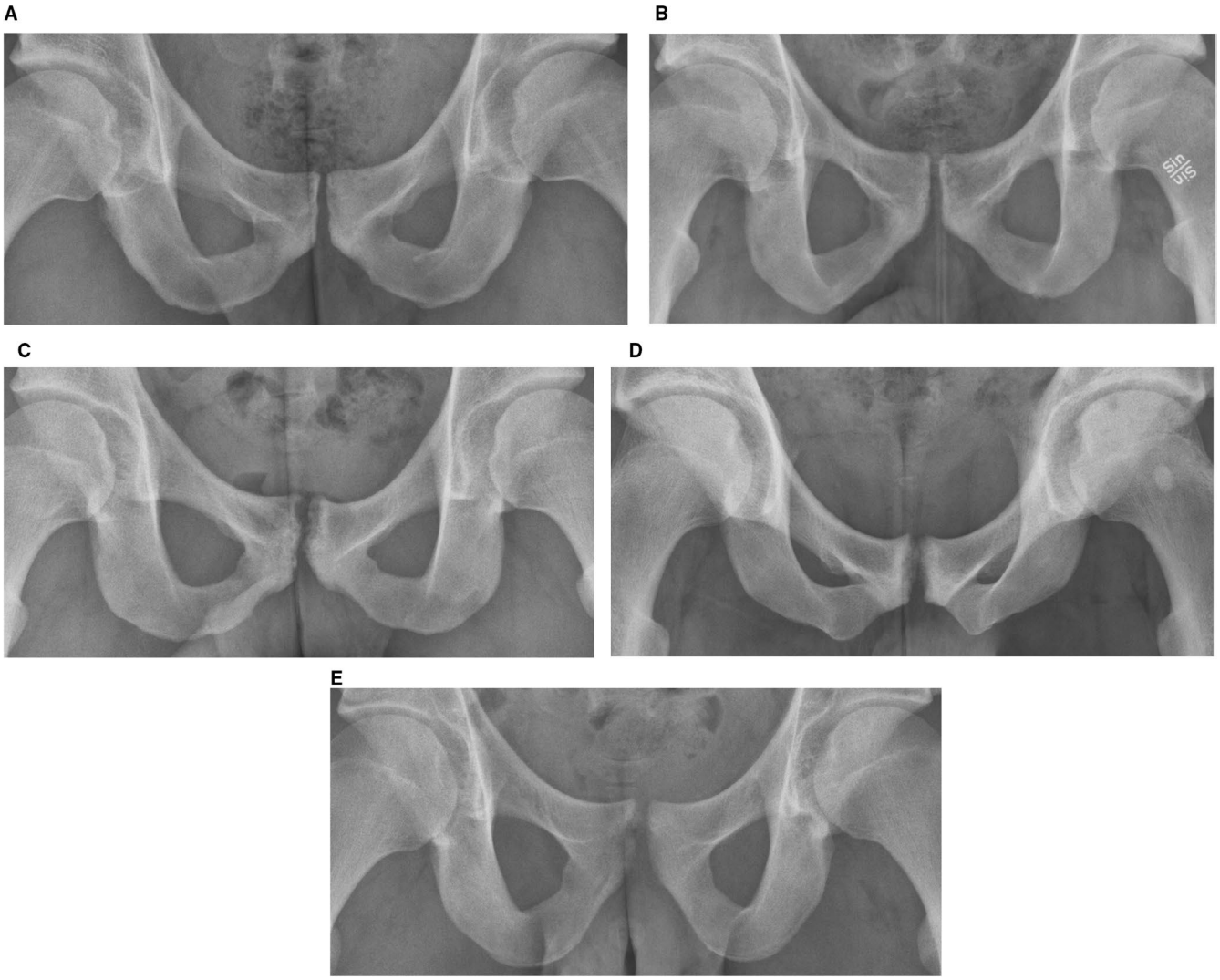


FIGURE 4 | Examples of anteroposterior radiographs of athletes with and without groin pain. (A) Symptomatic football player: 26 years, 178 cm, 72 kg, dominant leg: Right, bilateral groin pain, pain duration: 2 months, worst pain last week 8, 5SST: 8, HAGOS Pain 100, Symptoms 66.7, ADL 81.3, Sport 37.5, PA 25, QoL 75; Clinical Entities: Bilateral adductor-related, bilateral iliopsoas-related, bilateral inguinal-related, and pubic-related groin pain. Pubic-related radiographic findings total = 0 and JSW: 3 mm. (B) Symptomatic football player: 25 years, 182 cm, 75 kg, dominant leg: Right, right-sided groin pain, pain duration: 6 weeks, worst pain last week: 7, 5SST: 8, HAGOS Pain 78.1, Symptoms 54.2, ADL 68.8, Sport 42.7, PA 0.0, QoL 43.8; Clinical Entities: Right-sided adductor-related groin pain, right-sided inguinal-related groin pain. Pubic-related radiographic findings total = 0 and JSW: 4 mm. (C) Asymptomatic football player: 23 years, 180 cm, 79 kg, dominant leg: Right, HAGOS Pain 100, Symptoms 100, ADL 100, Sport 100, PA 100, QoL 100, Pubic-related radiographic findings total = 14: Bilateral bone lucency, ELC, central/superior ELC; right-sided cysts, bilateral proliferation, superior proliferation, central proliferation, inferior proliferation; bilateral sclerosis; JSW = 2 mm. (D) Symptomatic football player: 24 years, 188 cm, 80 kg, dominant leg: Right, bilateral groin pain, pain duration: 48 months, worst pain last week: 9, 5SST: 6, HAGOS Pain 37.5, Symptoms 29.2, ADL 31.3, Sport 29.2, PA 12.5, QoL 18.8; Clinical Entities: Bilateral adductor-related, bilateral iliopsoas-related, left inguinal-related, and pubic-related groin pain; Pubic-Related Radiographic Finding total = 13: Bilateral findings of Bone lucency, ELC, central/superior ELC, proliferation, superior proliferation, central proliferation, and sclerosis. Left sided inferior proliferation, fragmentation, inferior fragmentation. JSW 1 mm. (E) Asymptomatic non-football athlete: 19 years, 184 cm, 72 kg, dominant leg: Left, HAGOS Pain 100, Symptoms 100, ADL 100, Sport 100, PA 100, QoL 100, Pubic-related radiographic findings: Bilateral bone lucency, ELC, central/superior ELC; left-sided cysts, bilateral proliferation, superior proliferation; right-sided central proliferation, and JSW = 2 mm.

5 | Perspectives

While the Aspetar protocol is a reliable method for research and group-level assessments, pubic-related radiographic findings scored with the protocol and the cumulative PSRS Score have limited clinical relevance. The radiographic findings are common in male football players regardless of pain and do not add any valuable information about potential pathology in the pubic region.

At this point, radiographic examinations should be reserved for screening serious pathology, such as bony abnormalities,

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fractures, and sarcomas. Clinicians should be cautious if using pubic-related radiographic findings in the diagnostic workup of groin pain.

Larger cross-sectional and prospective cohort studies are still needed to confirm or refute these results, as findings from such studies may change the conclusion regarding the clinical relevance of the radiographic findings. This is particularly important for sclerosis, which showed a clinically relevant association with worse disability in the symptomatic football players with groin pain. The conclusion on clinical relevance may also be changed by future results about the progression of pubic-related radiographic findings over time in both female and male athletes, the association with groin pain incidence, and the response to treatment.

6 | Conclusion

In conclusion, pubic-related radiographic findings are not associated with groin pain or disability. Pubic-related radiographic findings are more common in male football players than in male non-football athletes.

Author Contributions

The first author is the lead and corresponding author. Contributions to the paper are described using the CRediT taxonomy by Brand A., Allen L., Altman M., Hlava M., and Scott J. (2015): conceptualization: M.F.N., P.H., and K.T.; methodology: M.F.N., P.H., S.B., T.T., L.I., M.B.N., and K.T.; formal analysis: M.F.N.; investigation: M.F.N., S.B., T.T., M.B.N., and K.T.; resources: P.H., S.B., T.T., M.B.N., and K.T.; data curation: M.F.N.; writing – original Draft: M.F.N. and K.T.; writing – review and editing manuscript: M.F.N., P.H., S.B., T.T., L.I., M.B.N., and K.T.; visualization: M.F.N.; supervision: PH, LI, and KT; project administration: M.F.N., P.H., and K.T.; funding acquisition: M.F.N., P.H., L.I., and K.T.

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Disclosure

Declaration of generative AI and AI-assisted technologies in the writing process: During the preparation of this work the author used ChatGPT by OpenAI to trim the wordcount without loss of meaning as well as improve the grammar and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Ethics Statement

This study has been approved by the Danish National Committee on Health Research Ethics (NVK 2117722) and the Capitol Region Data agency (P-2021-497). It includes data and radiographs collected in a larger epidemiological project on hip and/or groin pain (ethical approval reference: H-2-2010-127, data approval reference: 2011-41-5964).

Consent

Participants provided written informed consent when included in a previous larger epidemiological project on hip and/or groin pain (ethical approval reference: H-2-2010-127, data approval reference: 2011-41-5964). The Danish National Committee on Health Research Ethics deemed that participants were not required to update their informed consent for this new project (NVK 2117722).

Conflicts of Interest Statement

All authors declare they have no conflicts of interest. However, two authors (KT, PH) have conceived and published standardized clinical examinations of patients with long-standing hip and/or groin pain, the Copenhagen Hip and Groin Outcome Score (HAGOS) and the Copenhagen 5-s-squeeze test. One author (PH) has contributed to the conception and publication of the Aspetar pubic symphysis radiographic scoring protocol. These authors are, therefore, subject to confirmation bias and self-citation incentives.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Appendix file

Content

1. Descriptives data of HAGOS original version.
2. Pairwise comparison of pubic-related findings – side-specific level.
3. Pubic Symphysis Radiographic Severity Scores compared between groups.
4. Correlation coefficients for associations between Pubic Symphysis Radiographic Severity (PSRS) Scores and 5SST and HAGOS Subscales in the symptomatic football players (n=39)
5. Examples of scatterplots for associations between Pubic Symphysis Radiographic Severity (PSRS) Scores and 5SST and HAGOS Subscales in the symptomatic football players (n=39)
6. Linear regression models for associations between Pubic Symphysis Radiographic Severity (PSRS) Scores and 5SST and HAGOS Subscales in the symptomatic football players (n=39)
7. Post-hoc analyses including only symptomatic football players with adductor- or pubic-related groin pain
8. Post-hoc adjusted p-values for prevalence estimates.

1. Descriptives

TABLE A1 – Descriptive variables including original HAGOS, clinical entities and hip-related radiographic findings

	Symptomatic football players (n = 39)	Asymptomatic football players (n = 18)	Asymptomatic active athletes (n = 20)
HAGOS			
Pain, median (IQR)	75 (62-85)	100 (95-100)	100 (99-100)
Symptoms, median (IQR)	61 (50-71)	93 (82-96)	96 (89-100)
ADL, median (IQR)	80 (65-90)	100 (100-100)	100 (100-100)
Sport, median (IQR)	50 (34-62)	100 (94-100)	100 (100-100)
PA, median (IQR)	37 (19-62)	100 (100-100)	100 (100-100)
QoL, median (IQR)	40 (27-60)	100 (90-100)	100 (100-100)
Clinical entities of groin pain	**Individual level**		
Adductor-related groin pain, n (%)	26 (67%)	-	-
Iliopsoas-related groin pain, n (%)	31 (79%)	-	-
Inguinal-related groin pain, n (%)	24 (61%)	-	-
Pubic-related groin pain, n (%)	5 (13%)	-	-
Total entities, median (IQR)	2 (2-3)	-	-
Hip-related Radiographic Findings	**Individual level**	**Individual level**	**Individual level**
Alpha Angle, mean (SD)	54 (10)	52 (12)	48 (10)
Cam morphology, n (%)	12 (31%)	6 (33%)	4 (20%)
Lateral Center Edge Angle, mean (SD)	30 (5)	28 (8)	31 (5)
Acetabular Index Angle, mean (SD)	6 (4)	9 (4)	6 (4)
Pincer Morphology, n (%)	3 (12%)	1 (10%)	1 (7%)
Borderline Hip Dysplasia, n (%)	7 (29%)	4 (40%)	2 (13%)
Hip Dysplasia, n (%)	3 (12%)	4 (40%)	1 (7%)
Hip joint space width, mm, mean (SD)			
Cross-Over sign, n (%)	16 (67%)	6 (60%)	8 (53%)
Ischial Spine Sign, n (%)	19 (79%)	6 (60%)	11 (73%)
Posterior Wall Sign, n (%)	19 (79%)	7 (70%)	11 (73%)

2. Pairwise comparison of pubic-related findings – side-specific level

Table A2 Prevalence of pubic-related findings on side-level and pairwise comparison between groups

	Symptomatic football players, *painful sides*		**Asymptomatic football players**		**Asymptomatic non-football athletes** *n = 20*	
Pubic-related radiographic finding, n (%)	*Right, n =32*	*Left, n =23*	*Right, n = 18*	*Left, n = 18*	*Right, n = 20*	*Left, n = 20*
Bone Lucency	26 (81%)	18 (78%)	11 (61%)	12 (67%)	8 (40%)**	7 (35%)**
Erosion-Like Configuration	26 (81%)	18 (78%)	11 (61%)	12 (67%)	8 (40%)**	7 (35%)**
Superior/Central ELC	22 (69%)	16 (70%)	8 (44%)	10 (56%)	6 (30%)*	7 (35%)*
Inferior ELC	22 (69%)	16 (70%)	10 (56%)	11 (61%)	5 (25%)**	6 (30%)*
Cysts	5 (16%)	6 (26%)	2 (11%)	1 (6%)	0 (0%)	2 (10%)
Proliferation	17 (53%)	14 (61%)	11 (61%)	10 (56%)	4 (20%)*	4 (20%)*
Superior Proliferation	15 (47%)	11 (48%)	10 (56%)	7 (39%)	3 (15%)*	3 (15%)*
Central Proliferation	8 (25%)	7 (30%)	6 (33%)	5 (28%)	1 (5%)	1 (5%)
Inferior Proliferation	5 (16%)	4 (17%)	5 (28%)	4 (22%)	1 (5%)	0 (0%)
Fragmentations	2 (6%)	4 (17%)	0 (0%)	1 (6%)	0 (0%)	0 (0%)
Central Fragmentation	1 (3%)	2 (9%)	0 (0%)	1 (6%)	0 (0%)	0 (0%)
Inferior Fragmentation	2 (6%)	2 (9%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Sclerosis	17 (53%)	13 (57%)	8 (44%)	9 (50%)	2 (10%)**	3 (15%)*

**Statistically significantly different compared to symptomatic football players at a p <0.05 level*
***Statistically significantly different compared to symptomatic football players at a p <0.005 level*

3. Pubic Symphysis Radiographic Severity Scores between groups

Table A3 Between group comparisons of Pubic Symphysis Radiographic Severity (PSRS) Scores

	Symptomatic football players (n = 39)	Asymptomatic football players (n=17)	Asymptomatic non-football athletes (n=20)	Symptomatic football vs Asymptomatic football			Symptomatic football Vs Asymptomatic non-football			Asymptomatic football Vs Asymptomatic non-football		
PSRS Scores	***Mean (SD)***	***Mean (SD)***	***Mean (SD)***	**Diff *(95% CI)***	***p-value***	**Adj. P**	**Diff *(95% CI)***	***p-value***	**Adj. P**	**Diff *(95% CI)***	***p-value***	**Adj. P**
PSRS Score 1 (0-5)	2.6 (1.4)	2.2 (1.4)	1.0 (1.2)	0.4 (–0.5 to 1.4)	0.27	0.27	1.6 (0.7 to 2.5)	**< 0.00**	**< 0.00**	1.2 (0.1 to 2.2)	**0.009**	**0.01**
PSRS Score 2 (0-8)	4.1 (2.2)	3.4 (2.2)	1.4 (1.7)	0.7 (–0.9 to 2.2)	0.30	0.30	2.7 (1.4 to 4.0)	**< 0.00**	**< 0.00**	2.0 (0.5 to 3.6)	**0.003**	**0.004**
PSRS Score 3 (0-10)	4.4 (2.5)	3.6 (2.5)	1.5 (1.8)	0.8 (–0.9 to 2.6)	0.26	0.26	2.9 (1.5 to 4.3)	**< 0.00**	**< 0.00**	2.1 (0.3 to 3.8)	**0.007**	**0.01**
PSRS Score 4 (0-18)	6.4 (3.6)	5.4 (3.9)	2.0 (2.6)	–1.0 (–1.6 to 3.6)	0.37	0.37	4.4 (2.4 to 6.4)	**< 0.00**	**< 0.00**	3.4 (0.7 to 6.1)	**0.003**	**0.005**

PSRS = Pubic Symphysis Radiographic Severity, SD = standard deviation, CI = confidence interval, Adj. p = Benjamini-Hochberg adjusted p-values

4. Correlation coefficients

Table A4 Correlation coefficients for associations between Pubic Symphysis Radiographic Severity (PSRS) Scores and 5SST and HAGOS Subscales in the symptomatic football players (n=39)

	PSRS Score 1 (0-5)				PSRS Score 2 (0-8)				PSRS Score 3 (0-10)				PSRS Score 4 (0-18)			
	ρ	*(95% CI)*	*p-value*	*Ajd. p*	*ρ*	*(95% CI)*	*p-value*	*Ajd. p*	*ρ*	*(95% CI)*	*p-value*	*Ajd. p*	*ρ*	*(95% CI)*	*p-value*	*Ajd. p*
5-Second Squeeze Test	–0.10	(–0.41 to 0.23)	0.53	0.61	0.05	(–0.28 to 0.37)	0.75	0.85	–0.16	(–0.46 to 0.17)	0.33	0.78	–0.12	(–0.43 to 0.21)	0.46	0.80
HAGOS, Revised version																
Pain	**–0.40**	**(–0.64 to –0.09)**	**0.01**	0.08	**–0.39**	**(–0.63 to –0.07)**	**0.01**	0.10	–0.24	(–0.53 to 0.09)	0.14	0.48	–0.14	(–0.45 to 0.19)	0.39	0.80
Symptoms	–0.15	(–0.45 to 0.18)	0.36	0.50	–0.05	(–0.36 to 0.28)	0.78	0.85	0.00	(–0.33 to 0.32)	0.98	0.98	0.09	(–0.24 to 0.40)	0.57	0.80
ADL	–0.21	(–0.50 to 0.12)	0.20	0.47	–0.24	(–0.52 to 0.09)	0.14	0.32	–0.05	(–0.37 to 0.28)	0.75	0.98	–0.05	(–0.36 to 0.28)	0.78	0.91
SPORT	–0.17	(–0.47 to 0.16)	0.29	0.50	–0.17	(–0.47 to 0.16)	0.29	0.51	–0.05	(–0.37 to 0.28)	0.75	0.98	–0.01	(–0.33 to 0.32)	0.95	0.95
PA	–0.01	(–0.33 to 0.31)	0.95	0.95	0.03	(–0.30 to 0.35)	0.85	0.85	0.03	(–0.30 to 0.35)	0.87	0.98	0.12	(–0.21 to 0.43)	0.47	0.80
QoL	**–0.34**	**(–0.60 to –0.01)**	**0.04**	0.13	–0.28	(–0.56 to 0.05)	0.08	0.28	–0.28	(–0.55 to 0.05)	0.09	0.48	–0.19	(–0.49 to 0.14)	0.24	0.80

ρ = Spearmans Correlations Coefficients, 95% CI = 95% Confidence Interval, adj. p = Benjamini-Hocberg adjusted p-value

5. **Examples of scatterplots for associations between Pubic Symphysis Radiographic Severity (PSRS) Scores and 5SST and HAGOS Subscales in the symptomatic football players (n=39)**

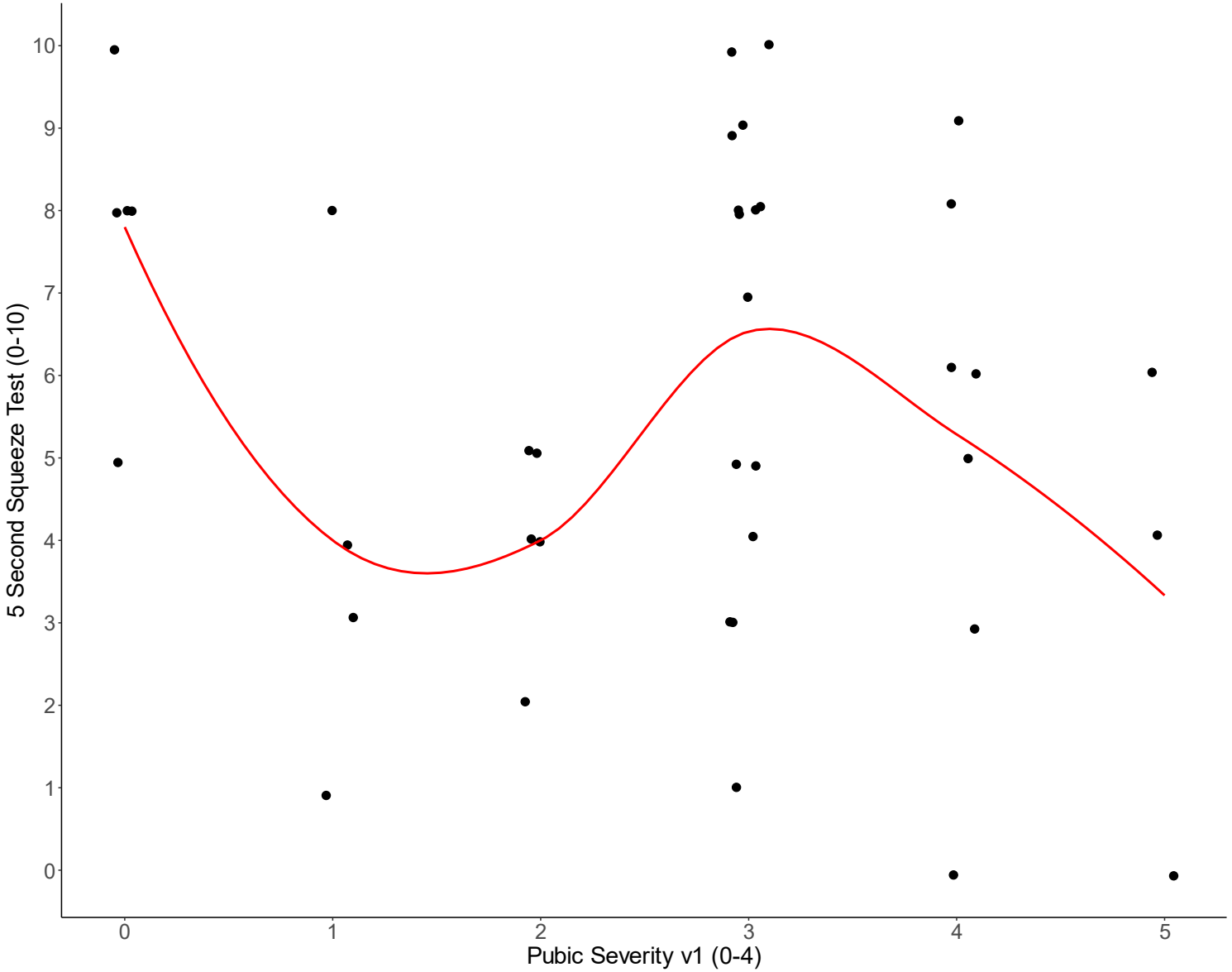


Figure A1 Scatterplot of 5-Second-Squeeze Test and PSRS Score 1 (0-5). *Red line is a LOESS curve.*

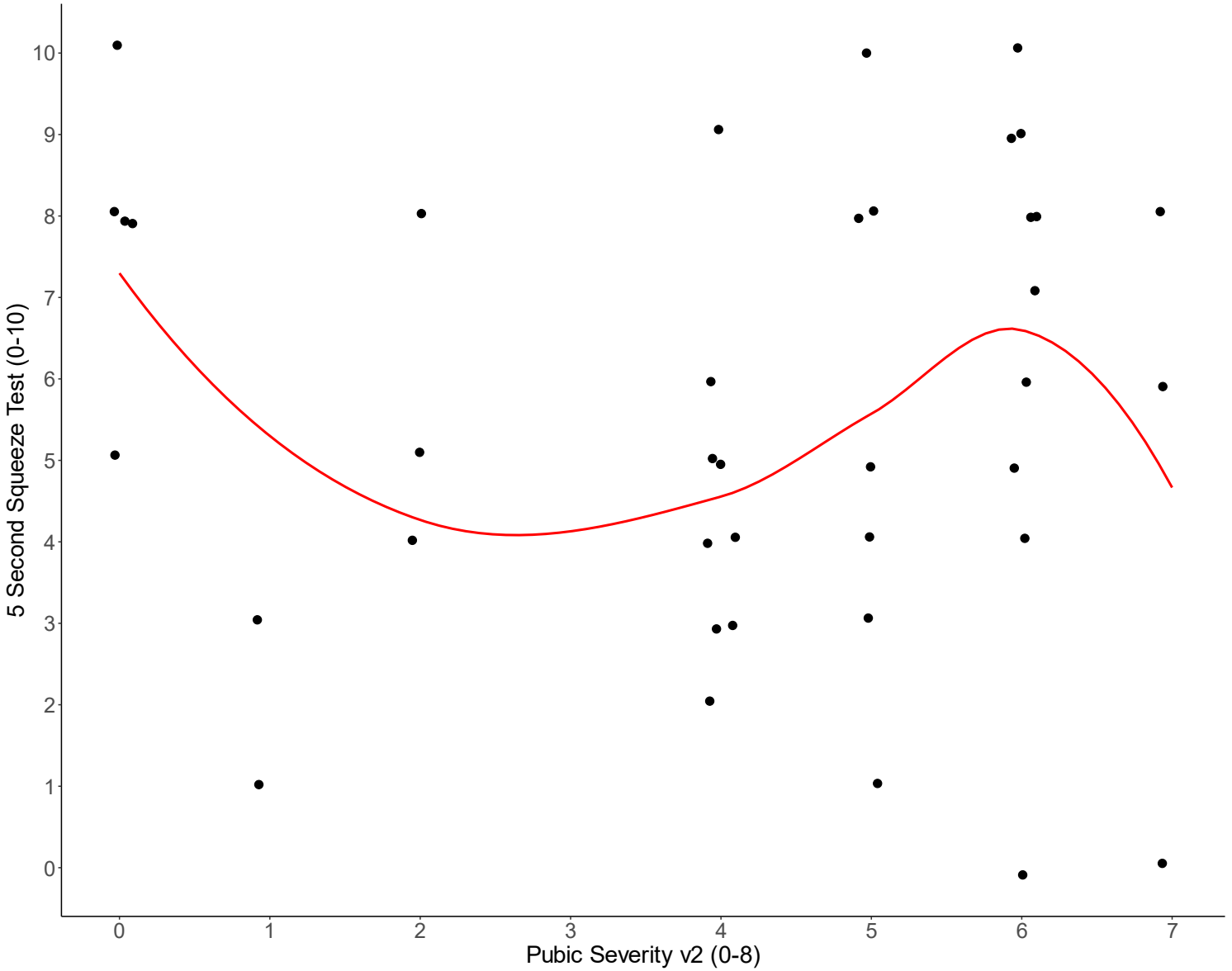


Figure A2 Scatterplot of 5-Second-Squeeze Test and PSRS Score 2 (0-8). *Red line is a LOESS curve.*

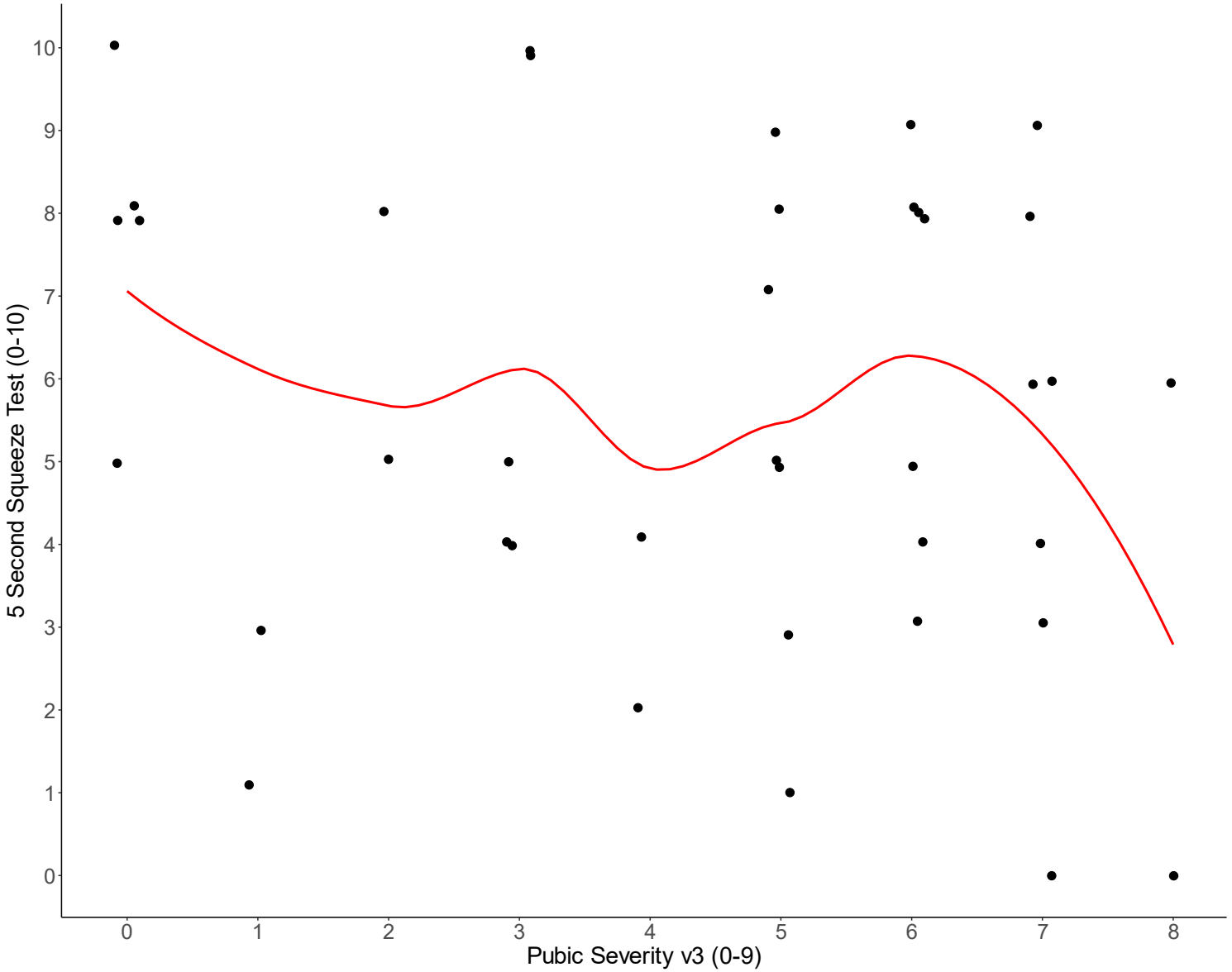


Figure A3 Scatterplot of 5-Second-Squeeze Test and PSRS Score 3 (0-10). *Red line is a LOESS curve.*

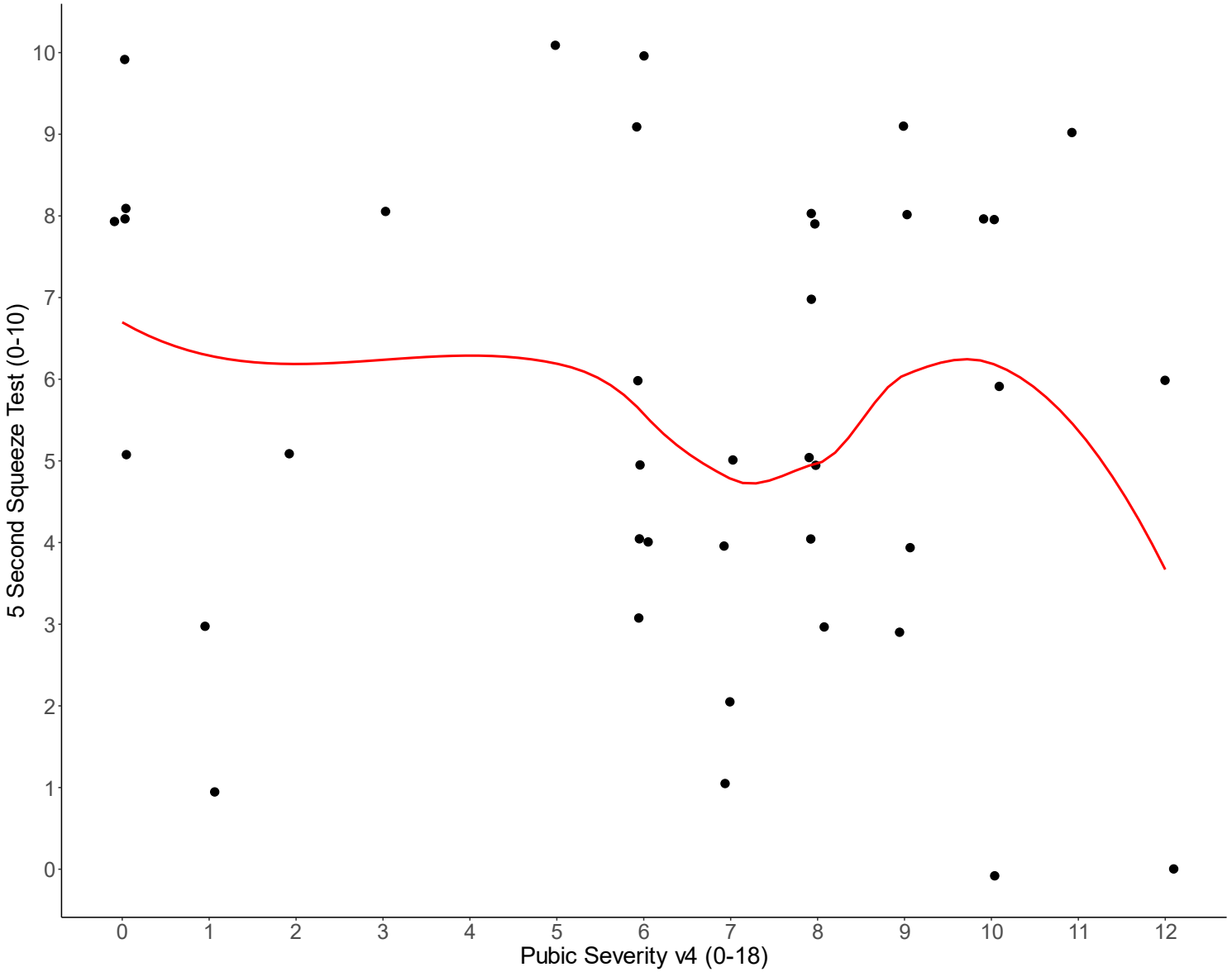


Figure A4 Scatterplot of 5-Second-Squeeze Test and PSRS Score 4 (0-18). *Red line is a LOESS curve.*

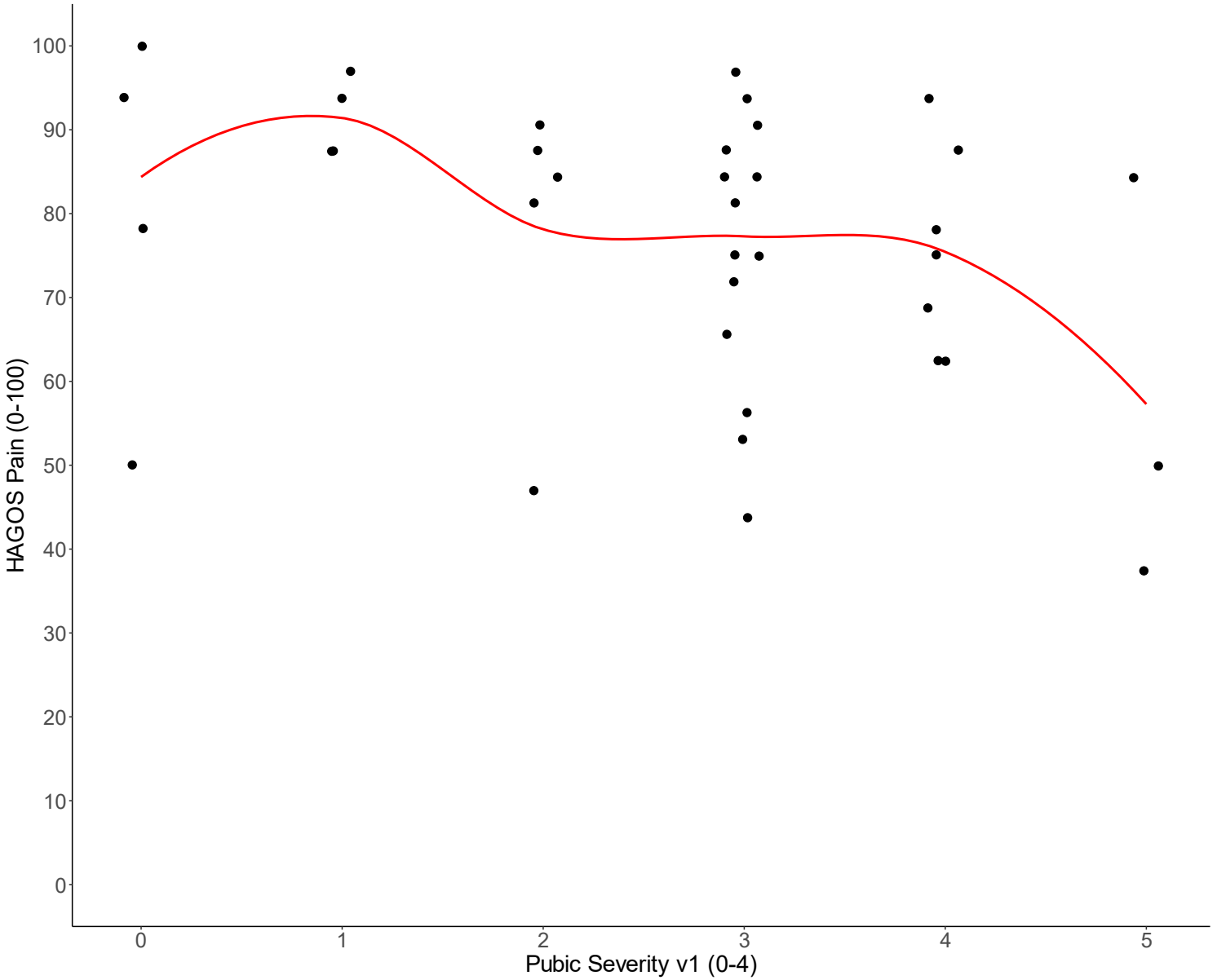


Figure A5 Scatterplot of HAGOS Pain and PSRS Score 1 (0-5). *Red line is a LOESS curve.*

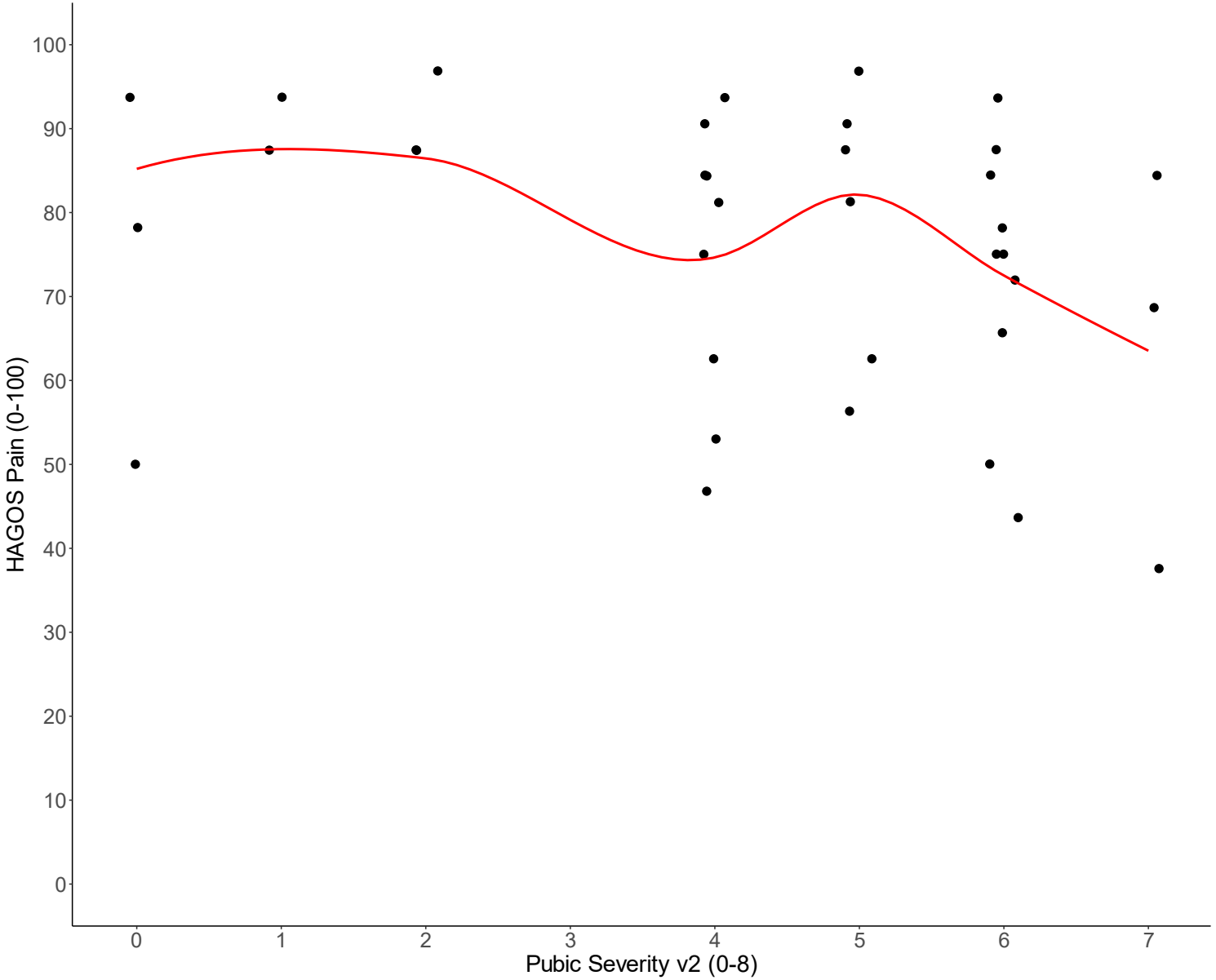


Figure A6 Scatterplot of HAGOS Pain and PSRS Score 2 (0-8). *Red line is a LOESS curve.*

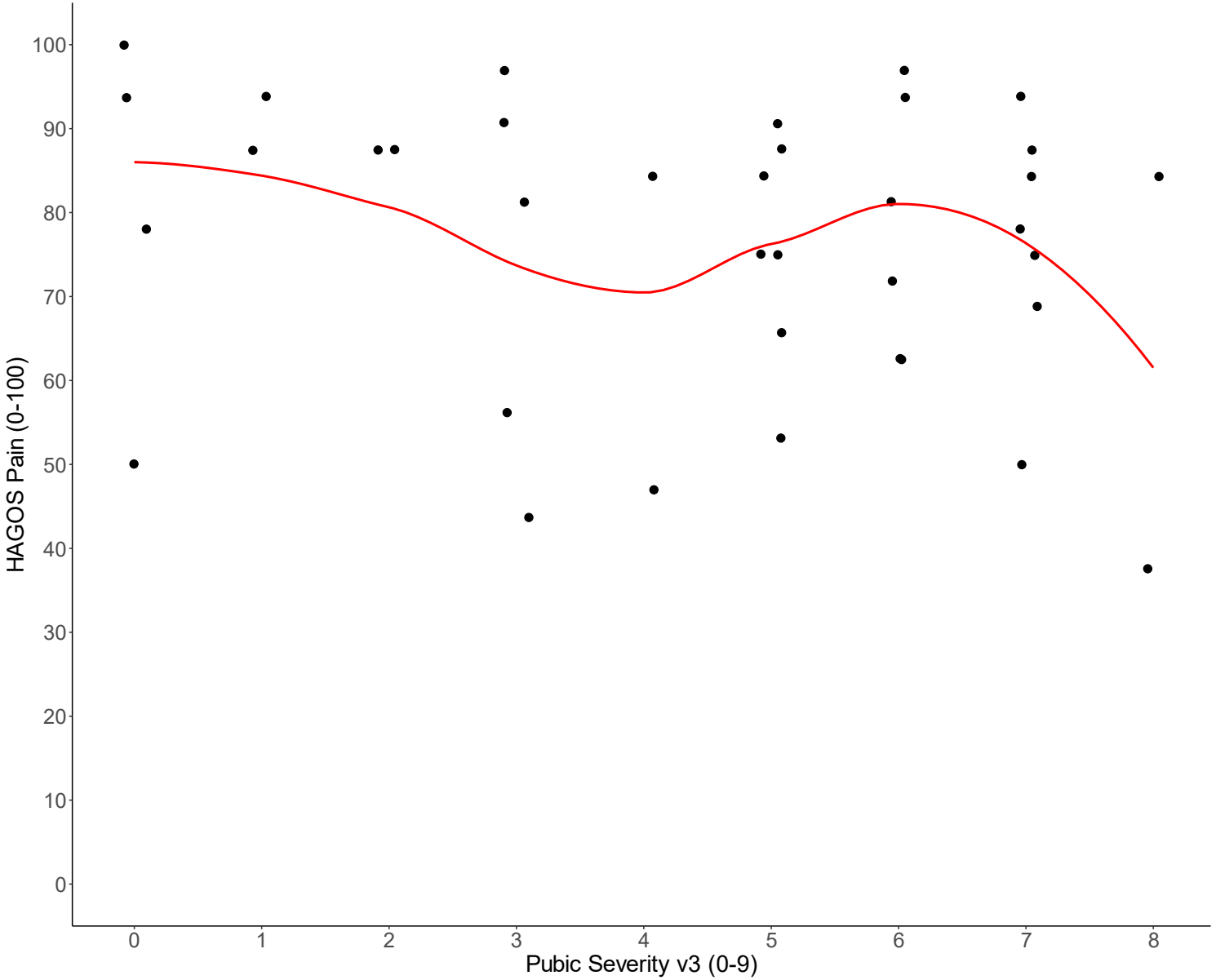


Figure A7 Scatterplot of HAGOS Pain and PSRS Score 3 (0-10). *Red line is a LOESS curve.*

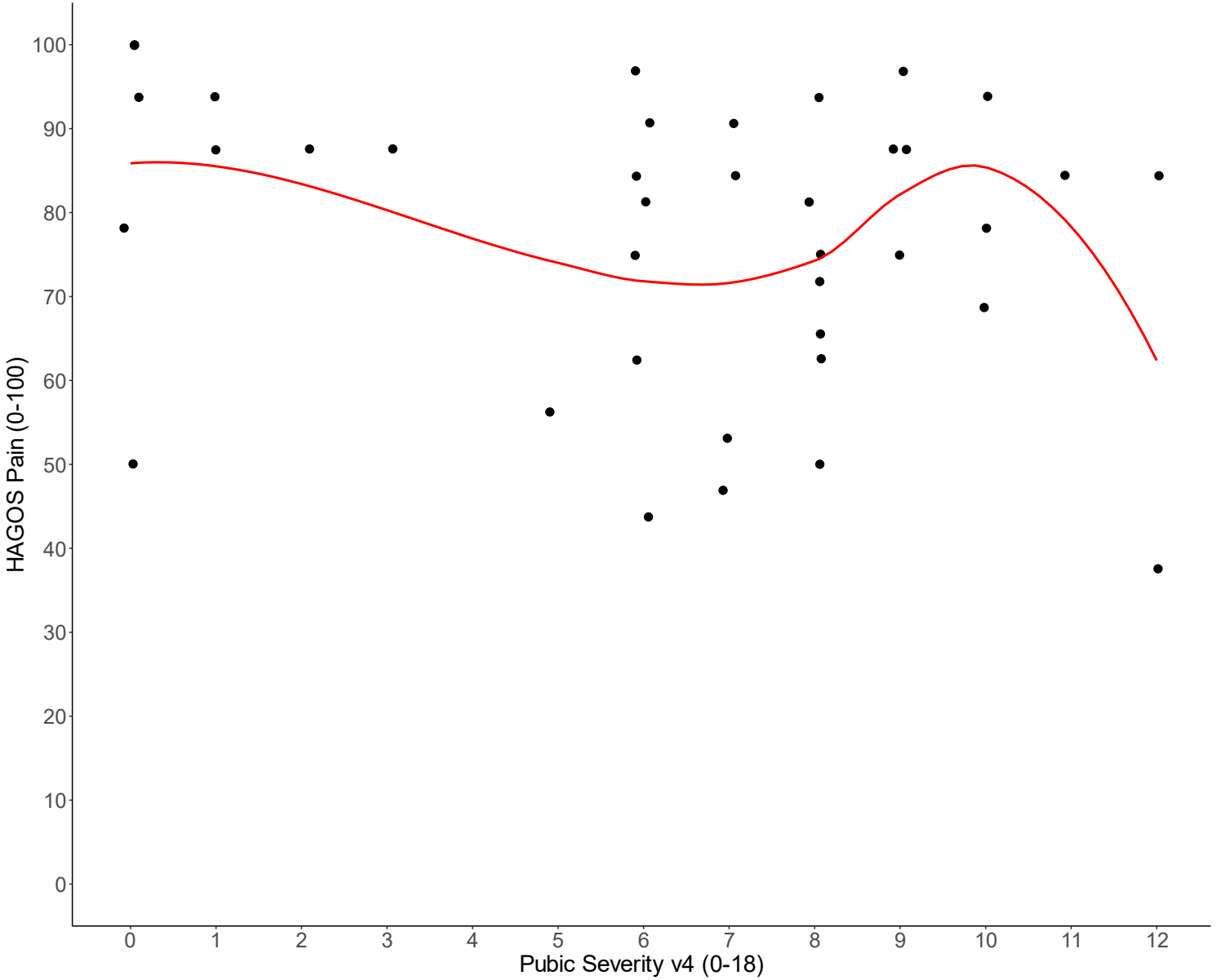


Figure A8 Scatterplot of HAGOS Pain and PSRS Score 4 (0-18). *Red line is a LOESS curve.*

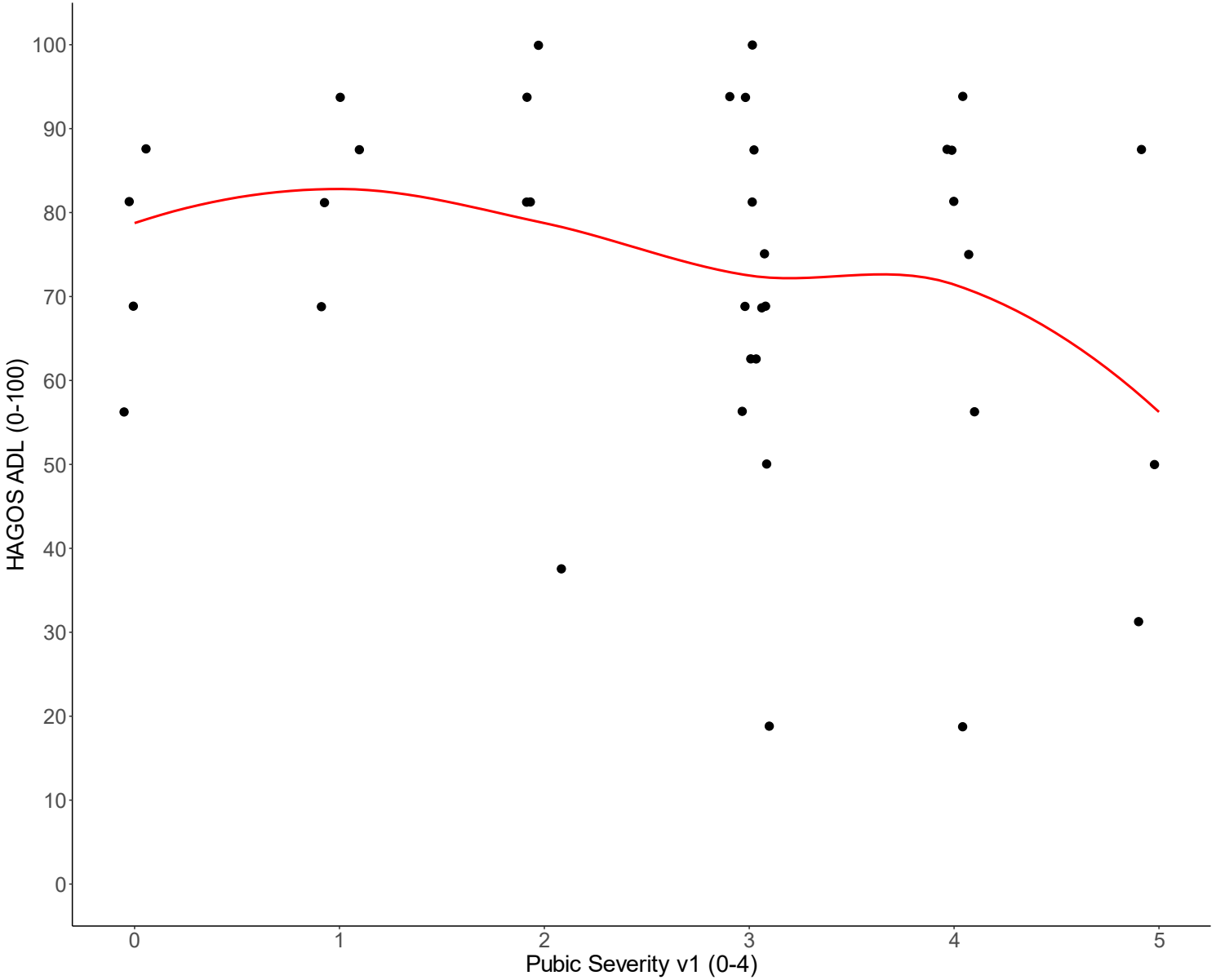


Figure A9 Scatterplot of HAGOS ADL and PSRS Score 1 (0-5). *Red line is a LOESS curve.*

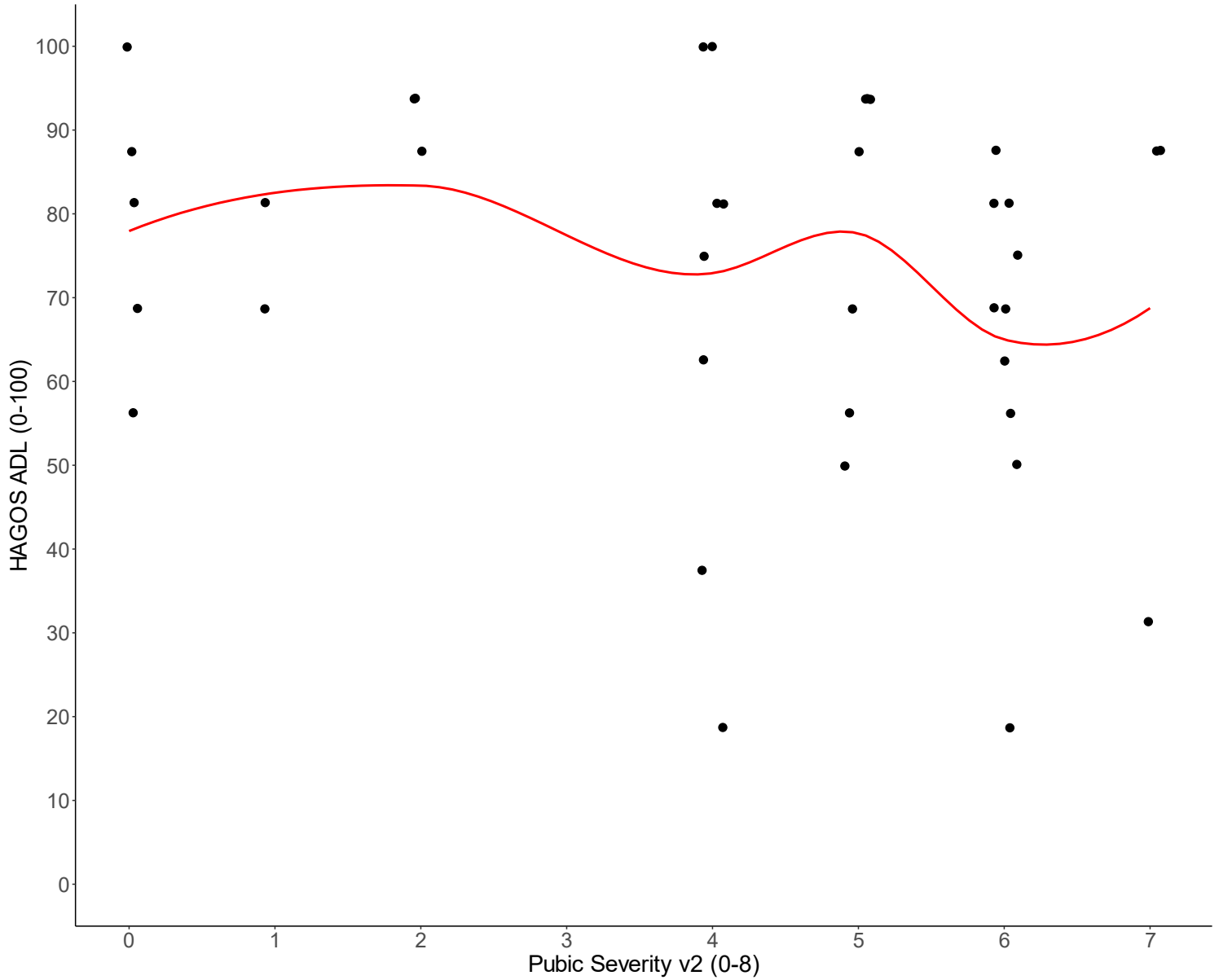


Figure A10 Scatterplot of HAGOS ADL and PSRS Score 2 (0-8). *Red line is a LOESS curve.*

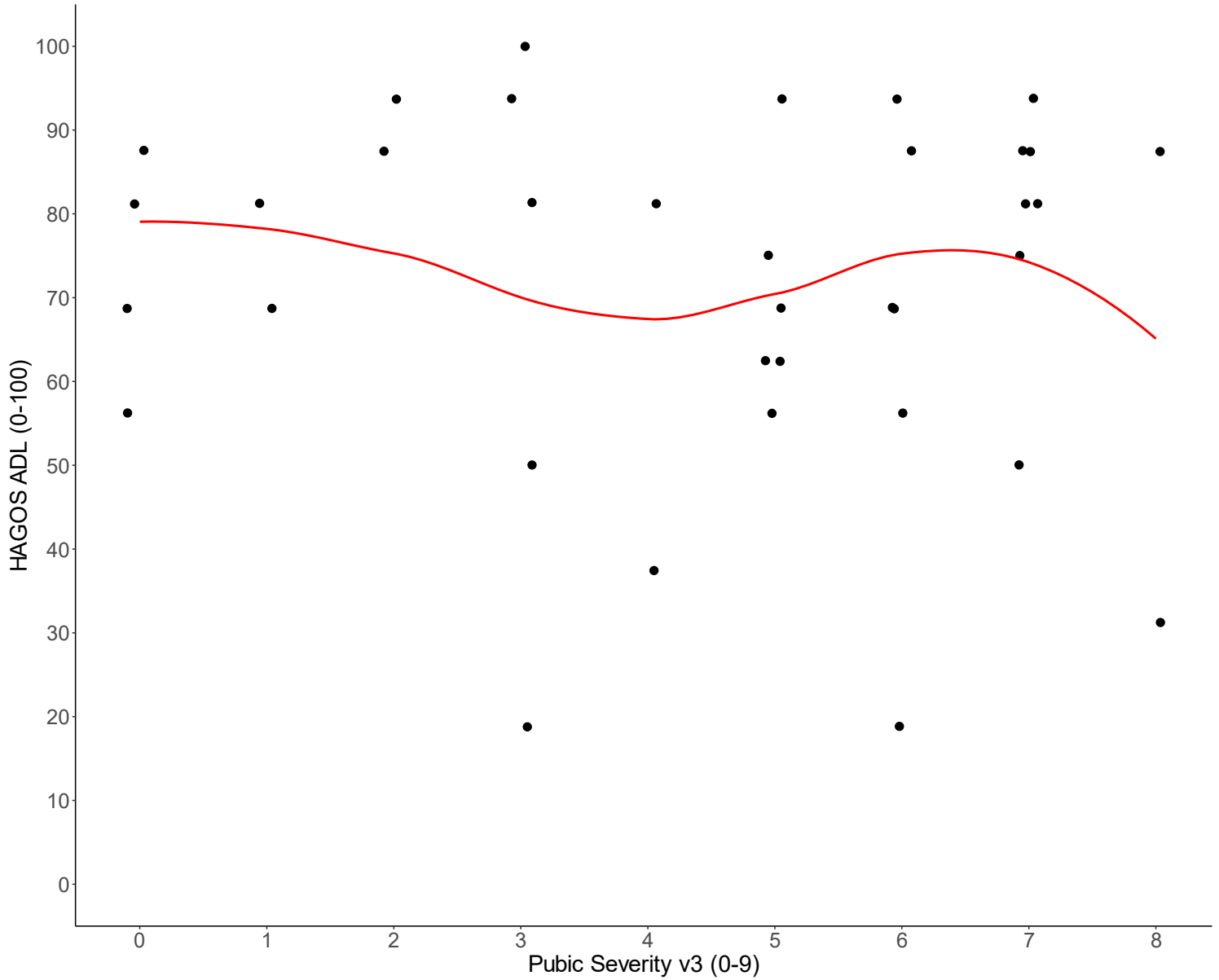


Figure A11 Scatterplot of HAGOS ADL and PSRS Score 3 (0-10). *Red line is a LOESS curve.*

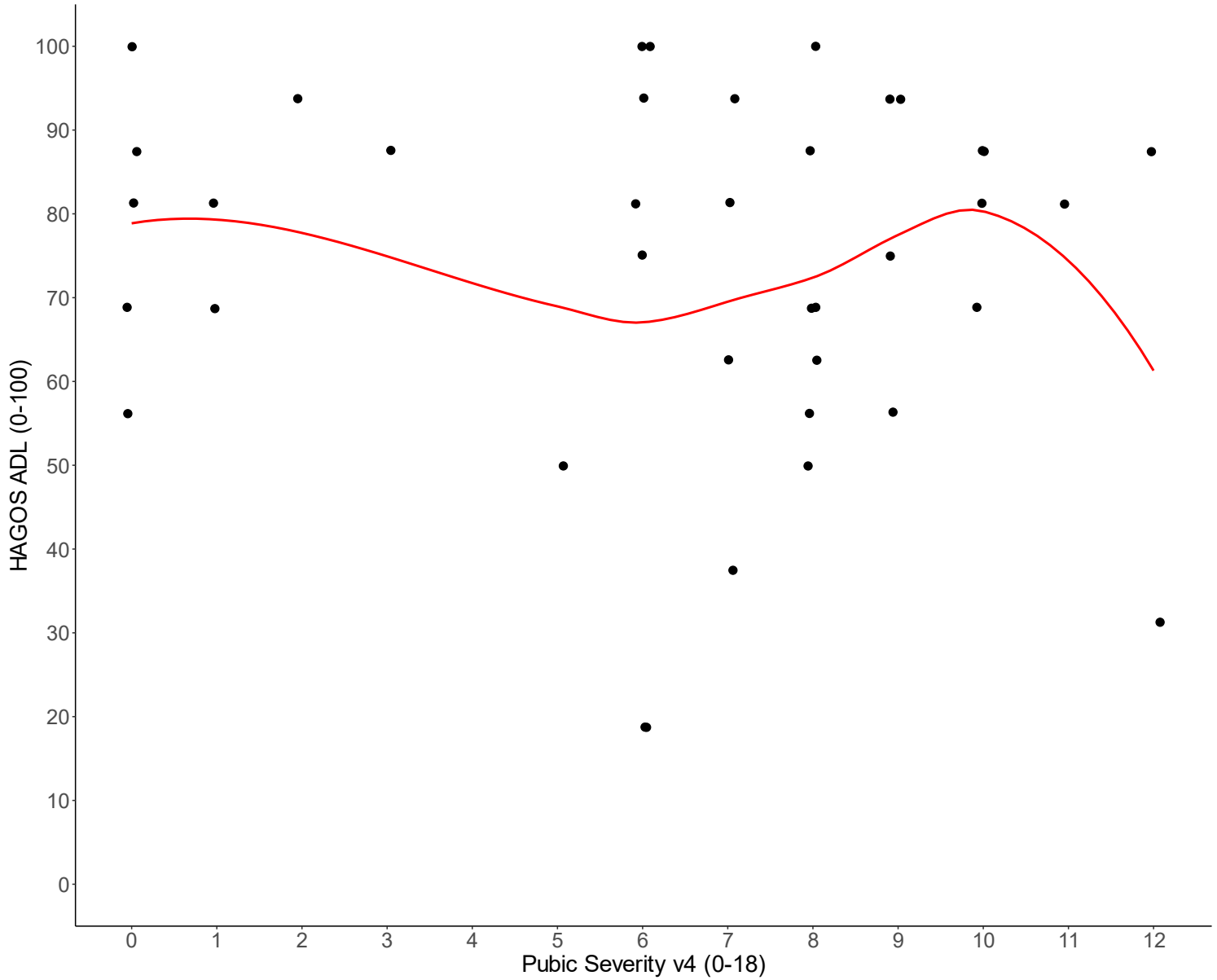


Figure A12 Scatterplot of HAGOS ADL and PSRS Score 4 (0-18). *Red line is a LOESS curve.*

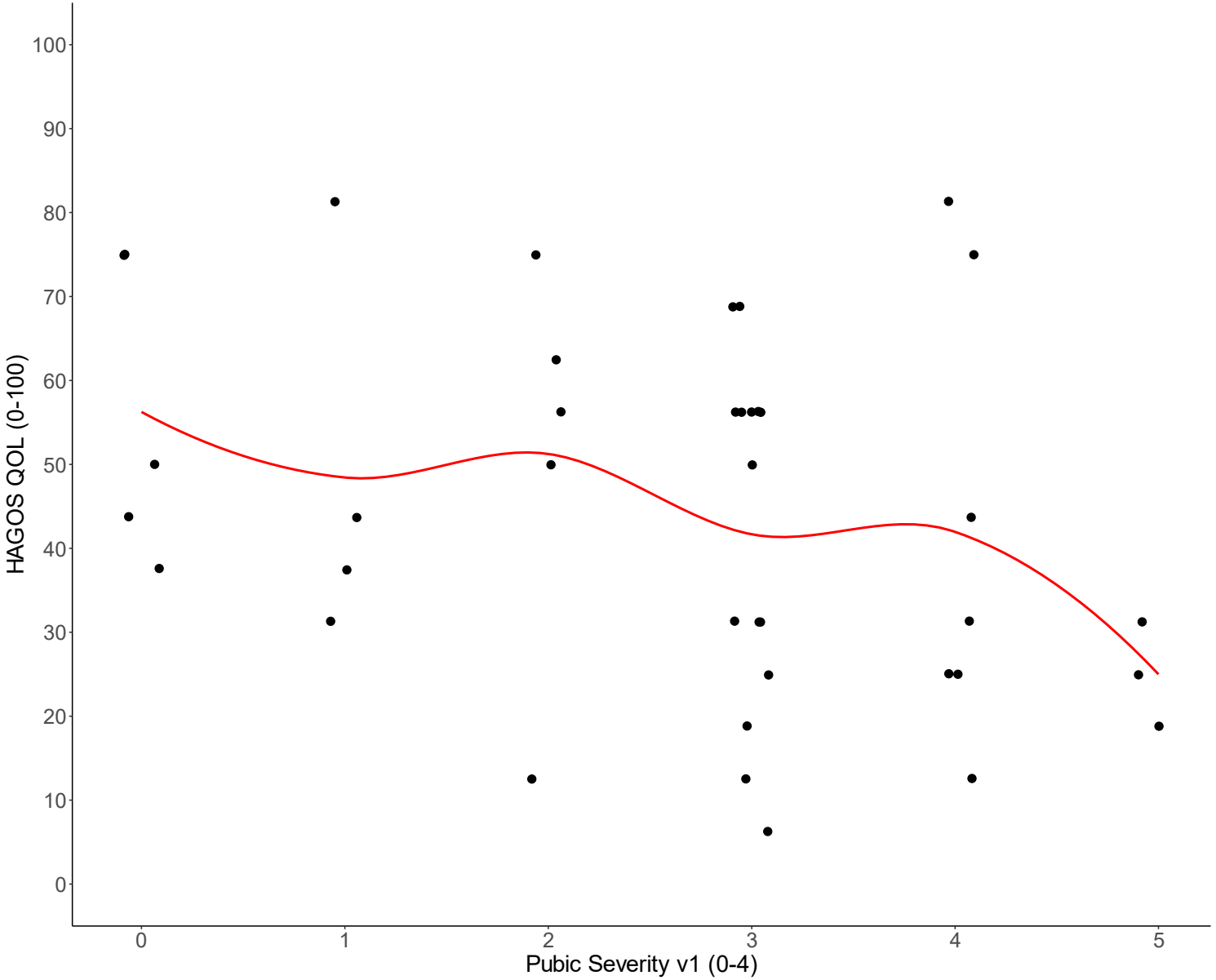


Figure A13 Scatterplots of HAGOS Quality of Life and PSRS Score 1 (0-5). *Red line is a LOESS curve.*

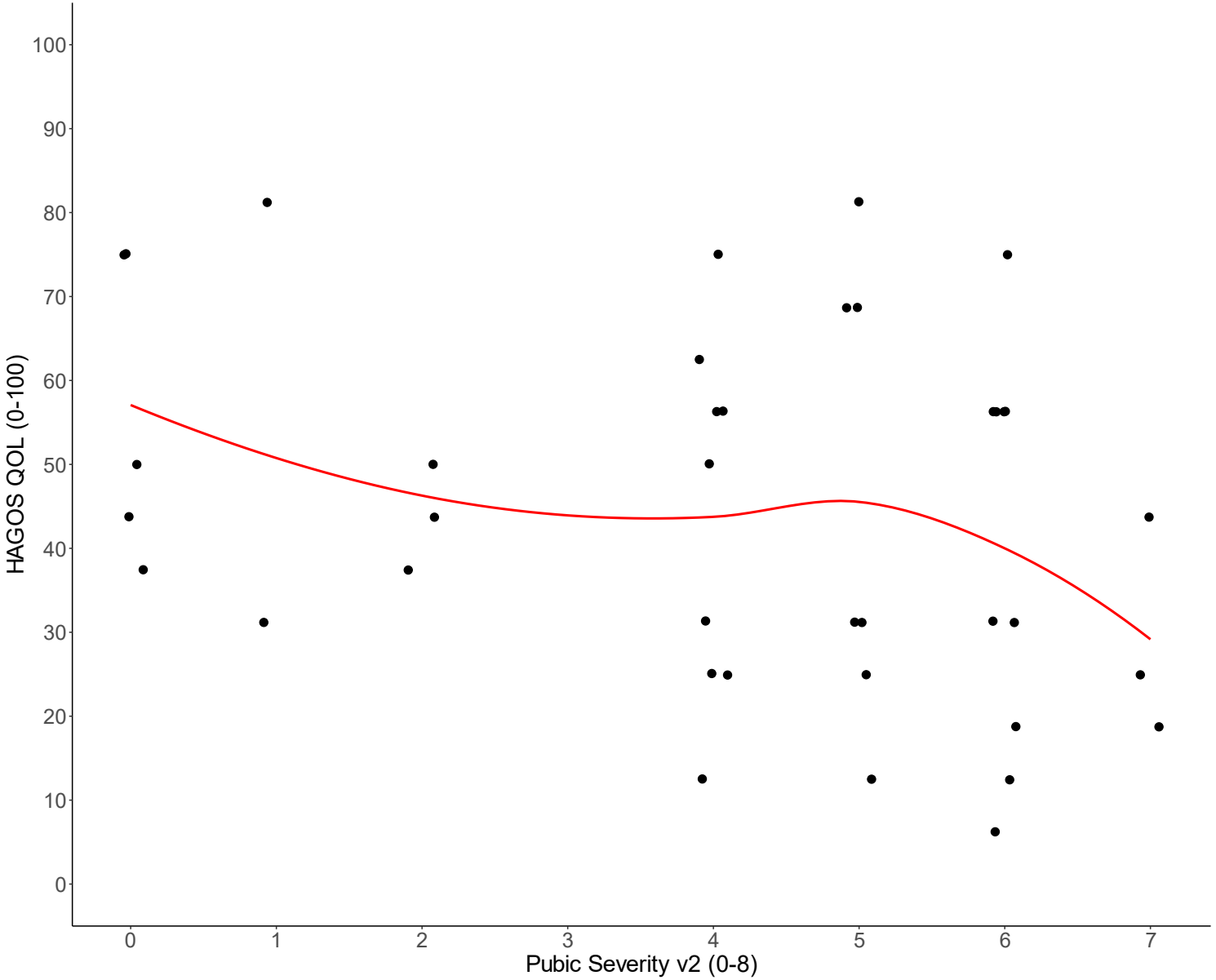


Figure A14 Scatterplots of HAGOS Quality of Life and PSRS Score 2 (0-8). *Red line is a LOESS curve.*

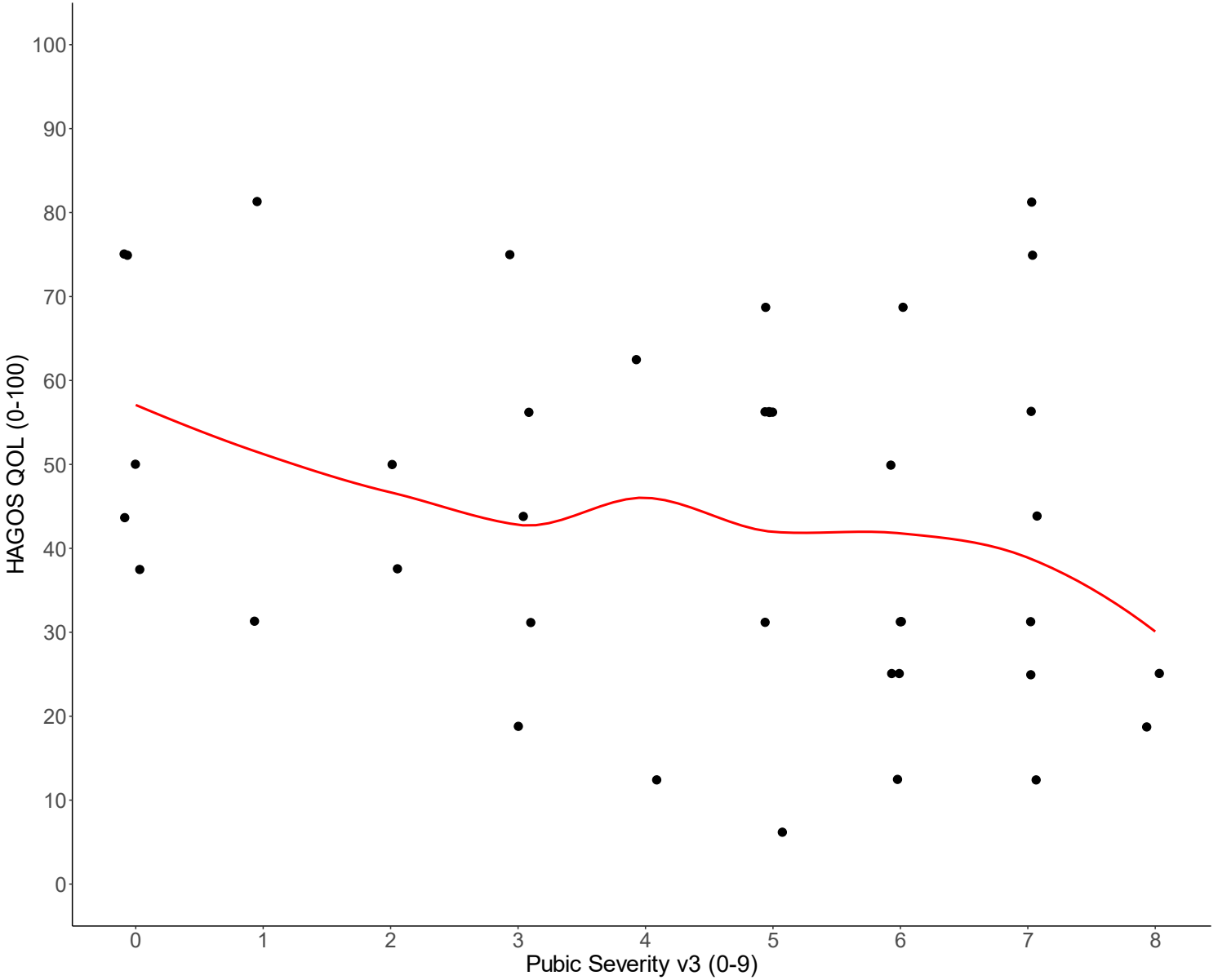


Figure A15 Scatterplots of HAGOS Quality of Life and PSRS Score 3 (0-10). *Red line is a LOESS curve.*

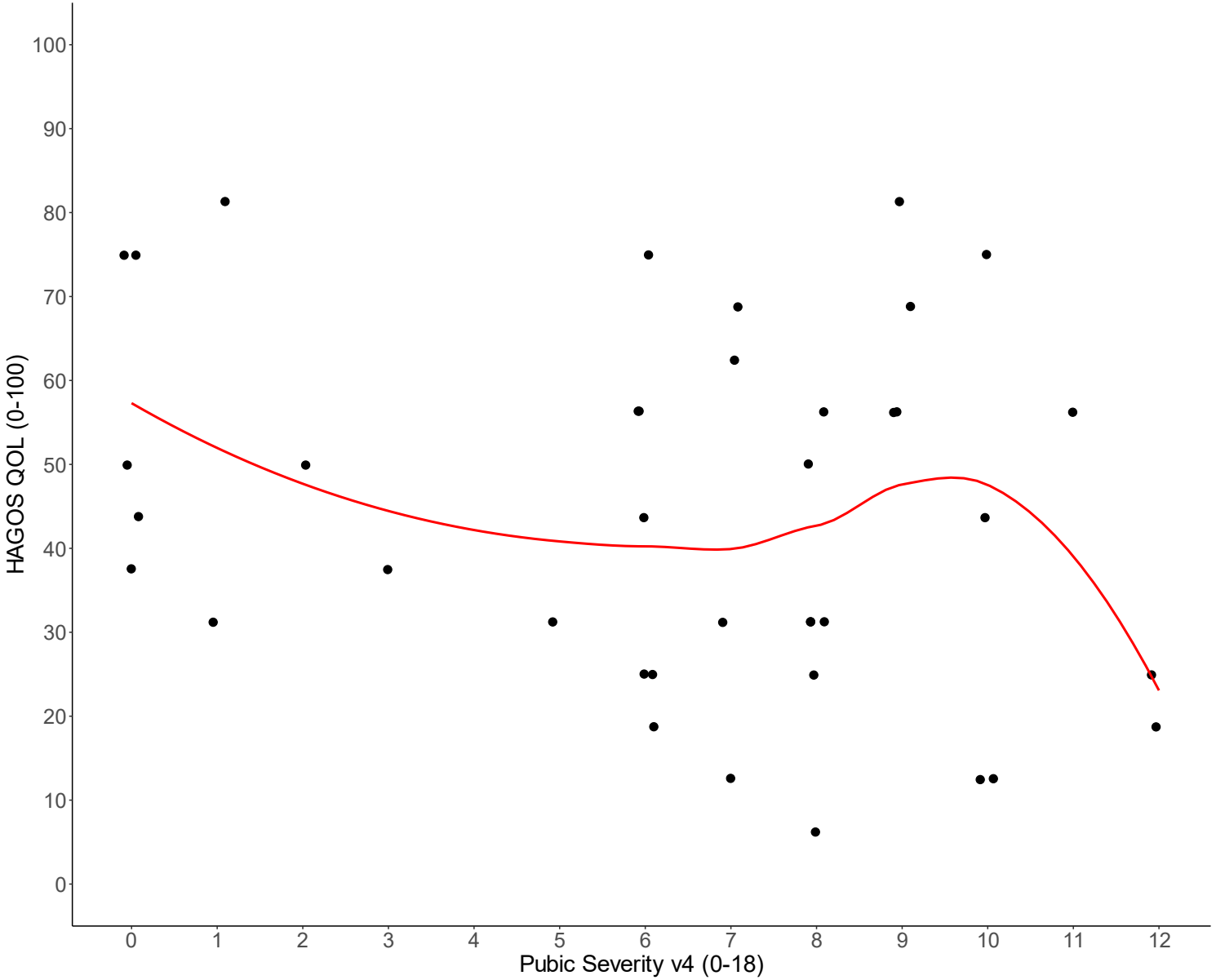


Figure A16 Scatterplots of HAGOS Quality of Life and PSRS Score 4 (0-18). *Red line is a LOESS curve.*

6. Linear regression models for associations between Pubic Symphysis Radiographic Severity (PSRS) Scores and 5SST and HAGOS Subscales in the symptomatic football players (n=39)

Table A5 Associations between Pubic Symphysis Radiographic Severity (PSRS) Scores and 5SST

	5SST			
	Coef.	*(95% CI)*	*p-value*	*adj. p*
Intercept	7.8	(5.5 to 10.1)	< 0.00	
Bone Lucency	**–3.9**	**(–7.0 to –0.8)**	**0.02**	0.12
Proliferation	2.3	(–0.0 to 4.5)	0.06	0.12
Fragmentation	0.3	(–2.2 to 2.7)	0.82	0.99
Sclerosis	0.5	(–1.7 to 2.6)	0.69	0.99
Narrow Pubic Joint space width	**–2.2**	**(–4.2 to –0.2)**	**0.04**	0.12

Coef. = beta coefficient, CI = confidence interval, adj. p = Benjamini-Hocberg adjusted p-value

Table A6 Associations between Pubic Symphysis Radiographic Severity (PSRS) Scores and HAGOS Subscales

	HAGOS Pain				HAGOS Symptoms				HAGOS ADL			
	Coef.	*(95% CI)*	*p-value*	*adj. p*	*Coef.*	*(95% CI)*	*p-value*	*adj. p*	*Coef.*	*(95% CI)*	*p-value*	*adj. p*
Intercept	84.4	(70.8 to 97.9)	< 0.00		59.2	(44.0 to 74.4)	<0.00		78.8	(60.2 to 97.3)	< 0.00	
Bone Lucency	5.4	(–13.0 to 23.8)	0.57	0.68	9.6	(–11.1 to 30.2)	0.37	0.53	6.1	(–19.0 to 31.3)	0.64	0.86
Proliferation	7.4	(–6.2 to 20.9)	0.29	0.59	6.1	(–9.1 to 21.2)	0.44	0.53	7.4	(–11.1 to 25.9)	0.44	0.86
Fragmentation	–11.1	(–25.5 to 3.4)	0.14	0.43	–9.0	(–25.2 to 7.3)	0.29	0.53	–8.3	(–28.2 to 11.5)	0.42	0.86
Sclerosis	**–20.8**	**(–33.7 to –7.9)**	**< 0.00**	**0.02**	–12.0	(–26.5 to 2.5)	0.11	0.53	**–20.6**	**(–38.2 to –2.9)**	**0.03**	0.17
Narrow Pubic Joint space width	–3.8	(–15.7 to 8.1)	0.53	0.68	–6.0	(–19.3 to 7.4)	0.39	0.53	–3.1	(–19.3 to 13.2)	0.72	0.86

Coef. = beta coefficient. CI = confidence interval. adj. p = Benjamini-Hocberg adjusted p-value

Table A6 continued

	HAGOS Sport				HAGOS PA				HAGOS QoL			
	Coef.	*(95% CI)*	*p-value*	*adj. p*	*Coef.*	*(95% CI)*	*p-value*	*adj. p*	*Coef.*	*(95% CI)*	*p-value*	*adj. p*
Intercept	45.0	(28.9 to 61.1)	< 0.00		37.5	(12.3 to 62.7)	< 0.00	0.04	56.3	(38.0 to 74.5)	< 0.00	
Bone Lucency	11.5	(–10.3 to 33.4)	0.31	0.61	–0.8	(–35.0 to 33.4)	0.96	0.96	–8.5	(–33.3 to 16.3)	0.51	1.00
Proliferation	5.9	(–10.1 to 22.0)	0.47	0.71	5.3	(–19.9 to 30.4)	0.68	0.96	0.1	(–18.1 to 18.3)	0.99	1.00
Fragmentation	–16.4	(–33.6 to 0.8)	0.07	0.21	–22.8	(–49.7 to 4.2)	0.11	0.32	–18.9	(–38.4 to 0.7)	0.07	0.40
Sclerosis	–14.8	(–30.1 to 0.5)	0.07	0.21	4.4	(–19.6 to 28.3)	0.72	0.96	–0.5	(–17.8 to 16.9)	0.96	1.00
Narrow Pubic Joint space width	2.5	(–11.6 to 16.6)	0.73	0.87	1.7	(–20.4 to 23.8)	0.88	0.96	–5.4	(–21.4 to 10.6)	0.51	1.00

7. Post-hoc analyses including only symptomatic football players with adductor- or pubic-related groin pain.

Table A7 Prevalence of pubic-related findings on side- and person level including only symptomatic football players with adductor- or pubic-related groin pain

	Symptomatic football players			Asymptomatic football players			Asymptomatic non-football athletes		
Pubic-related radiographic finding, n (%)	*Right, n = 26*	*Left, n = 26*	*Person, n = 26*	*Right, n = 18*	*Left, n = 18*	*Person, n = 18*	*Right, n = 20*	*Left, n = 20*	*Person, n = 20*
Bone Lucency	20 (77%)*	20 (77%)*	21 (81%)**	11 (61%)*	12 (67%)*	15 (83%)**	8 (40%)*	7 (35%)*	8 (40%)**
Erosion-Like Configuration	20 (77%)*	20 (77%)*	21 (81%)**	11 (61%)*	12 (67%)*	15 (83%)**	8 (40%)*	7 (35%)*	8 (40%)**
Superior/Central ELC	15 (58%)	18 (69%)	19 (73%)	8 (44%)	10 (56%)	10 (56%)	6 (30%)	7 (35%)	8 (40%)
Inferior ELC	17 (65%)*	19 (73%)*	20 (77%)**	10 (56%)*	11 (61%)*	14 (78%)**	5 (25%)*	6 (30%)*	6 (30%)**
Cysts	4 (15%)	7 (27%)	9 (35%)	2 (11%)	1 (6%)	2 (11%)	0 (0%)	2 (10%)	2 (10%)
Proliferation	14 (54%)*	14 (54%)*	16 (61%)*	11 (61%)*	10 (56%)*	11 (61%)*	4 (20%)*	4 (20%)*	5 (25%)*
Superior Proliferation	12 (46%)*	11 (42%)	14 (54%)*	10 (56%)*	7 (39%)	10 (56%)*	3 (15%)*	3 (15%)	4 (20%)*
Central Proliferation	4 (15%)	6 (23%)	9 (35%)*	6 (33%)	5 (28%)	9 (50%)*	1 (5%)	1 (5%)	2 (10%)*
Inferior Proliferation	5 (19%)	4 (15%)	9 (35%)*	5 (28%)	4 (22%)	6 (33%)*	1 (5%)	0 (0%)	1 (5%)*
Fragmentations	1 (4%)	2 (8%)	3 (11%)	0 (0%)	1 (6%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)
Central Fragmentation	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (6%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)
Inferior Fragmentation	1 (4%)	2 (8%)	3 (11%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Sclerosis	16 (61%)**	18 (69%)**	18 (69%)**	8 (44%)**	9 (50%)**	9 (50%)**	2 (10%)**	3 (15%)**	3 (15%)**
Pubic Joint Space width, mm, mean (SD)			3 (1)			3 (1)			3 (1)
Narrow pubic joint space width			6 (23)			3 (17)			4 (20)

**χ^2-test p-value < 0.05 indicating statistically significantly difference across all three groups.*
***χ^2-test p-value < 0.005 indicating statistically significantly difference across all three groups.*

Table A8 Pairwise comparison of pubic-related findings on person-level including only symptomatic football players with adductor- or pubic-related groin pain

	Symptomatic football players (n = 26) vs Asymptomatic football players (n=18)				Symptomatic football players (n = 26) vs Asymptomatic non-football athletes (n=20)			
Pubic-related findings	***OR***	***(95% CI)***	***p-value***	***Adj. p***	***OR***	***(95% CI)***	***p-value***	***Adj. p***
Bone Lucency	1.19	(0.19-8.83)	1.00	1.00	**0.17**	**(0.03-0.70)**	**0.01**	**0.04**
Erosion-Like Configuration	1.19	(0.19-8.83)	1.00	1.00	**0.17**	**(0.03-0.70)**	**0.01**	**0.04**
Superior/Central ELC	0.47	(0.11-1.97)	0.33	0.58	**0.25**	**(0.06-1.00)**	**0.04**	0.12
Inferior ELC	1.05	(0.20-6.04)	1.00	1.00	**0.14**	**(0.03-0.57)**	**< 0.00**	**0.03**
Cysts	0.24	(0.02-1.44)	0.15	0.39	0.22	(0.02-1.27)	0.08	0.23
Proliferation	0.98	(0.24-4.07)	1.00	1.00	**0.22**	**(0.05-0.87)**	**0.02**	0.10
Superior Proliferation	1.07	(0.27-4.26)	1.00	1.00	**0.22**	**(0.04-0.95)**	**0.03**	0.12
Central Proliferation	1.86	(0.47-7.65)	0.36	0.60	0.22	(0.02-1.27)	0.08	0.23
Inferior Proliferation	0.95	(0.21-3.97)	1.00	1.00	**0.10**	**(0.00-0.88)**	**0.03**	0.12
Fragmentations	0.46	(0.01-6.30)	0.63	0.93	0.00	(0.00-3.10)	0.25	0.48
Central Fragmentation	-	-	-	-	-	-	-	-
Inferior Fragmentation	0.00	(0.00-3.46)	0.26	0.48	0.00	(0.00-3.10)	0.25	0.48
Sclerosis	0.45	(0.11-1.83)	0.22	0.48	**0.08**	**(0.01-0.40)**	**< 0.00**	**0.01**
Narrow Pubic Joint Space	0.67	(0.09-3.80)	0.72	1.00	0.84	(0.15-4.26)	1.00	1.00

Interpretation: a lower odds ratio indicates a lower risk of findings in the asymptomatic group. OR = Odds ratio. CI = Confidence Interval.

8. Table with prevalence estimates, un- and adjusted p-values

Table A9 Pubic-related radiographic finding prevalences with un- and adjusted p-values for Chi² test across all groups.

	Symptomatic football players			**Asymptomatic football players**			**Asymptomatic non-football athletes**			**P-values from Chi2 test for prevalence differences across three groups**		
	Right n =	*Left n =*	*Person n = 39*	*Right n = 18*	*Left n = 18*	*Person n = 18*	*Right n = 20*	*Left n = 20*	*Person n = 20*	*Right p-value, adj. p*	*Left p-value, adj. p*	*Person p-value, adj. p*
Bone Lucency	33 (85%)	**30 (77%)**	**34 (87%)**	11 (61%)	**12 (67%)**	**15 (83%)**	8 (40%)	**7 (35%)**	**8 (40%)**	***0.002, 0.02***	***0.006, 0.02***	***0.0003, 0.002***
Erosion-Like Configuration	33 (85%)	**30 (77%)**	**34 (87%)**	11 (61%)	**12 (67%)**	**15 (83%)**	8 (40%)	**7 (35%)**	**8 (40%)**	***0.002, 0.02***	***0.006, 0.02***	***0.0003, 0.002***
Superior/Central ELC	26 (67%)	27 (69%)	**30 (77%)**	8 (44%)	10 (56%)	**10 (56%)**	6 (30%)	7 (35%)	**8 (40%)**	***0.022**, 0.05*	***0.042**, 0.08*	***0.0171, 0.03***
Inferior ELC	**27 (69%)**	26 (67%)	**31 (80%)**	**10 (56%)**	11 (61%)	**14 (78%)**	**5 (25%)**	6 (30%)	**6 (30%)**	***0.005, 0.02***	***0.024**, 0.05*	***0.0004, 0.002***
Cysts	5 (13%)	10 (26%)	12 (31%)	2 (11%)	1 (6%)	2 (11%)	0 (0%)	2 (10%)	2 (10%)	*0.253, 0.31*	*0.108, 0.16*	*0.0908, 0.14*
Proliferation	**22 (56%)**	22 (56%)	**26 (67%)**	**11 (61%)**	10 (56%)	**11 (61%)**	**4 (20%)**	4 (20%)	**5 (25%)**	***0.013, 0.04***	***0.021**, 0.05*	***0.0080, 0.02***
Superior Proliferation	**20 (51%)**	18 (46%)	**23 (59%)**	**10 (56%)**	7 (39%)	**10 (56%)**	**3 (15%)**	3 (15%)	**4 (20%)**	***0.013, 0.04***	*0.061, 0.10*	***0.0137, 0.03***
Central Proliferation	8 (20%)	12 (31%)	**16 (41%)**	6 (33%)	5 (28%)	**9 (50%)**	1 (5%)	1 (5%)	**2 (10%)**	*0.086, 0.13*	*0.076, 0.12*	***0.0193, 0.03***
Inferior Proliferation	6 (15%)	10 (26%)	**16 (41%)**	5 (28%)	4 (22%)	**6 (33%)**	1 (5%)	0 (0%)	**1 (5%)**	*0.154, 0.21*	***0.047**, 0.09*	***0.0156, 0.03***
Fragmentations	2 (5%)	5 (13%)	6 (15%)	0 (0%)	1 (6%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)	*0.368, 0.40*	*0.203, 0.26*	*0.1261, 0.16*
Central Fragmentation	1 (3%)	3 (8%)	3 (8%)	0 (0%)	1 (6%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)	*0.610, 0.61*	*0.451, 0.47*	*0.4505, 0.52*
Inferior Fragmentation	2 (5%)	2 (5%)	4 (10%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	*0.368, 0.40*	*0.368, 0.40*	*0.1280, 0.16*
Sclerosis	**23 (59%)**	**23 (60%)**	**25 (64%)**	**8 (44%)**	**9 (50%)**	**9 (50%)**	**2 (10%)**	**3 (15%)**	**3 (15%)**	***0.002, 0.02***	***0.005, 0.02***	***0.0017, 0.006***
Pubic Joint Space width, mm, mean (SD)	-	-	3 (1)	-	-	3 (1)	-	-	3 (1)			*0.5806, 0.62*
Narrow pubic joint space width	-	-	11 (28**%**)	-	-	3 (17**%**)	-	-	4 (20**%**)			*0.5534, 0.58*

Supplementary file

Content:

1. Description of radiographic procedure
2. Descriptive radiographic hip-related findings
3. The Copenhagen five-second squeeze test
4. Clinical examination pain provocation tests
5. Clinical entities of groin pain

1. Description of Radiographic Procedure

All participants underwent conventional radiographic examination of the hip and pelvis including a cross-table lateral hip view radiograph of each hip and a standing anteroposterior pelvic view radiograph (see the supplementary file for detailed description of patient positioning). Radiographs were accessed in the RIS/PACS system, Agfa IMPAX Client (Bundle 5) (Agfa-Gevaert Group, Belgium), and the surgical planning software mediCAD (MediCAD Hectec GmbH, Germany). Two musculoskeletal radiologists (SB and TT), with 11 and 25 years of experience in hip-related radiographic assessment, rated the radiographs independently and in random order, blinded to previously collected data. Both radiologists had no prior experience with the standardized protocol for evaluating pubic-related parameters. The new ratings was collected using REDCap [1]. The radiologists were trained and calibrated on all radiographic parameters by PH, an orthopedic surgeon and author of the Aspetar protocol [2]. Rater 2 (TT) rated all radiographs twice with an 8-week interval. Hip- and pubic-related parameters are illustrated in Figures 3a-3f and 4a-4e, respectively. Pubic-related parameters, ischial spine sign, posterior wall sign, and crossover sign were rated 21 weeks before the alpha angle, lateral center-edge angle, acetabular index angle, and hip joint space width due to technical issues accessing mediCAD. Furthermore, Rater 1 identified a technical error when measuring the lateral center-edge angle in mediCAD - one reference line was not calibrated correctly to the radiograph orientation. As a results, Rater 2 had to re-measure the lateral center-edge angle in 57 participants. To assess the radiographic integrity, each radiologist screened for pelvic tilt by measured the distance from the sacrococcygeal joint to the upper rim of the pubic bones/joint, excluding radiographs if the distance < 25 or > 55 mm. Radiographs were also excluded if the gonad shields covered the symphysis joint or inferior rami of the pubic bone, or if the radiologists judged that the positioning or quality issues would influence parameter accuracy.

2. Descriptive radiographic hip-related findings

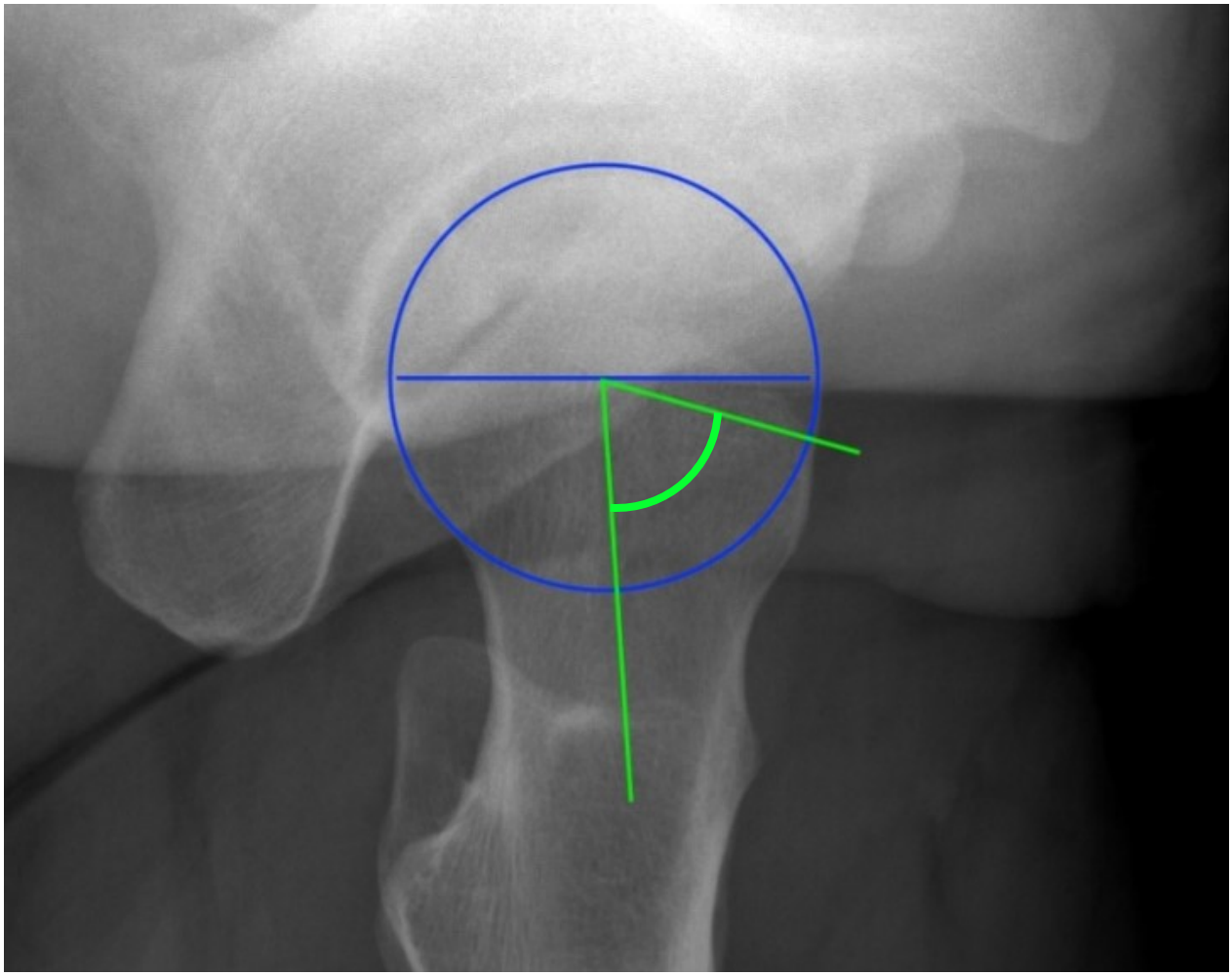
Participants were classified with CAM (alpha angle >60°[3,4]), pincer (LCEA ≥ 40°[4] OR LCEA ≥ 35° and a acetabular index angle < 0°[4]), borderline hip dysplasia (LCEA 20-25°) and/or hip dysplasia (a LCEA < 20° or Acetabular index angle > 13°[5]).

Alpha-Angle.

Definition: The angle between 1) a line from the center of the femoral neck to the center of the femoral head, and 2) a line from the center of the femoral head to the point where the femoral head-neck junction extends beyond the margin of the circle [3].

View: Cross-table lateral hip.

Defines: *Cam morphology* as alpha angle ≥ 60° [3].



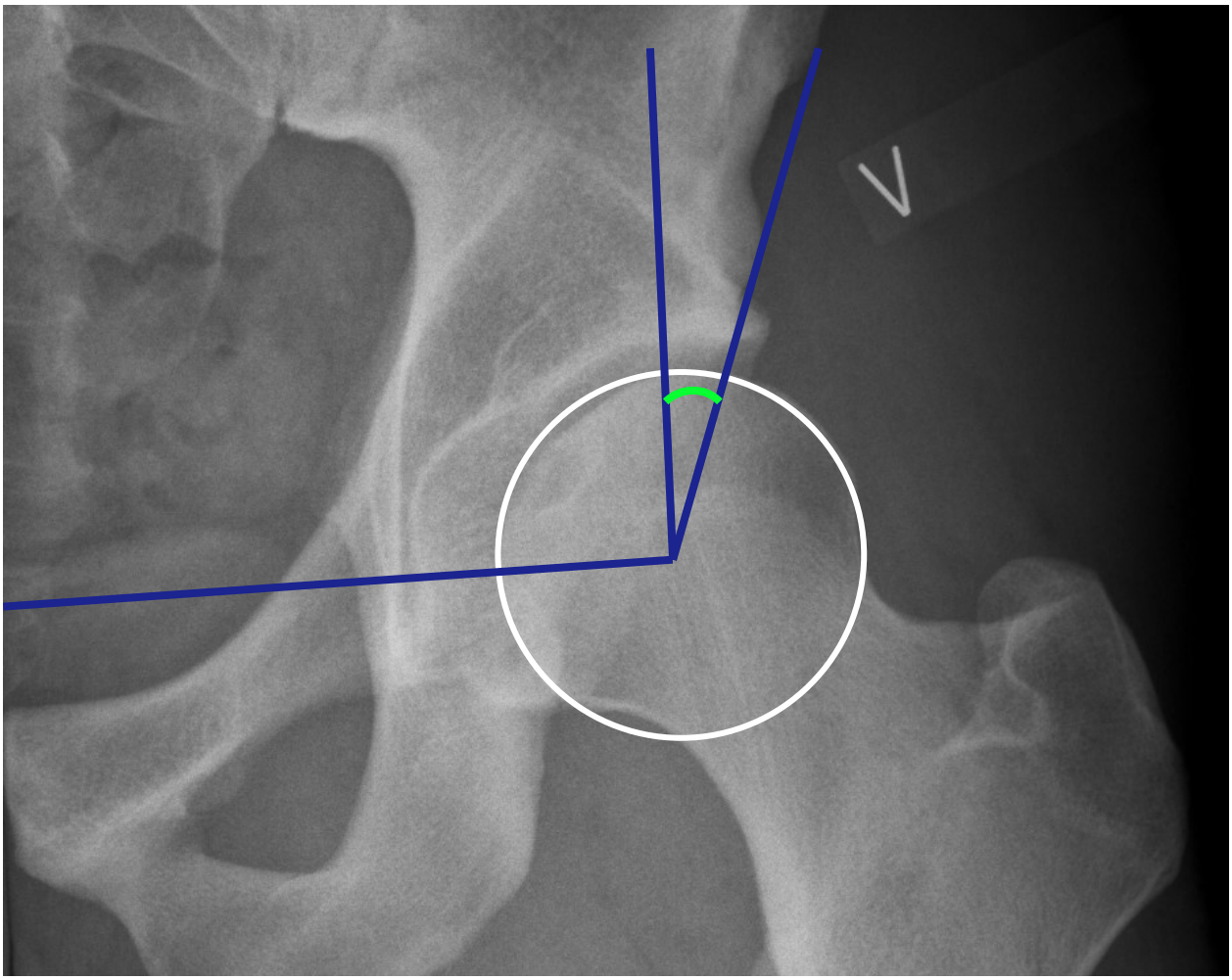
Lateral Center Edge Angle.

Definition: The angle between 1) a vertical line through the femoral head center and 2) a line between the femoral head center and the lateral sourcil of the acetabulum, as defined by Wiberg [3].

View: Anteroposterior.

Defines: *Pincer morphology* as 1) a lateral center edge angle ≥ 40° OR 2) a lateral Center Edge angle ≥ 35° AND Acetabular index < 0° [3].

Hip dysplasia as 1) lateral center edge angle ≤ 25



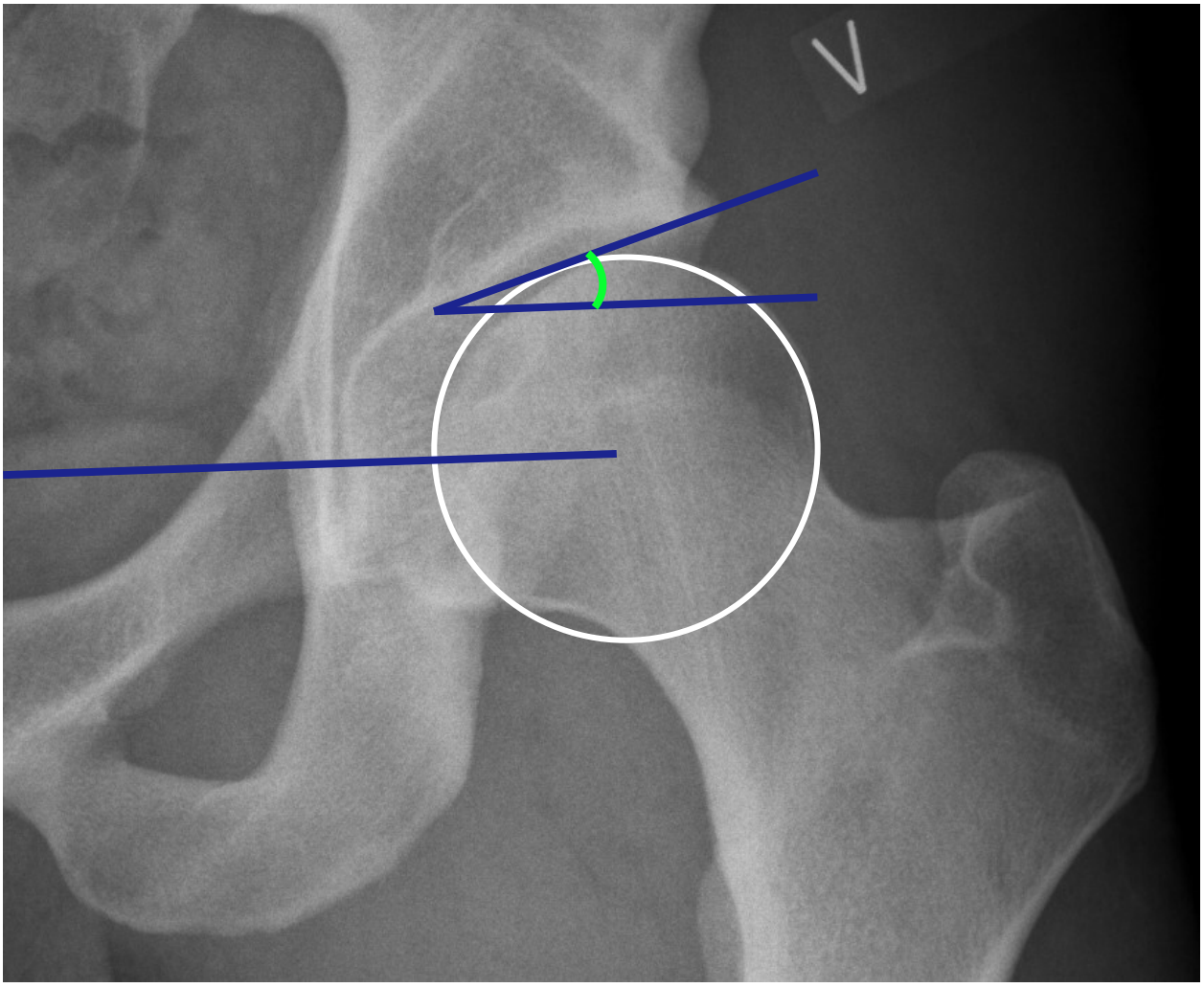
Acetabular Index Angle.

Definition: The angle between a horizontal line and a line through the most medial point of the sclerotic zone of the acetabulum and the sourcil [3].

View: Anteroposterior.

Defines: *Pincer morphology* as 2) a lateral Center Edge angle ≥ 35° AND Acetabular index < 0° [3].

Hip dysplasia as 2) acetabular index > 13° [3].

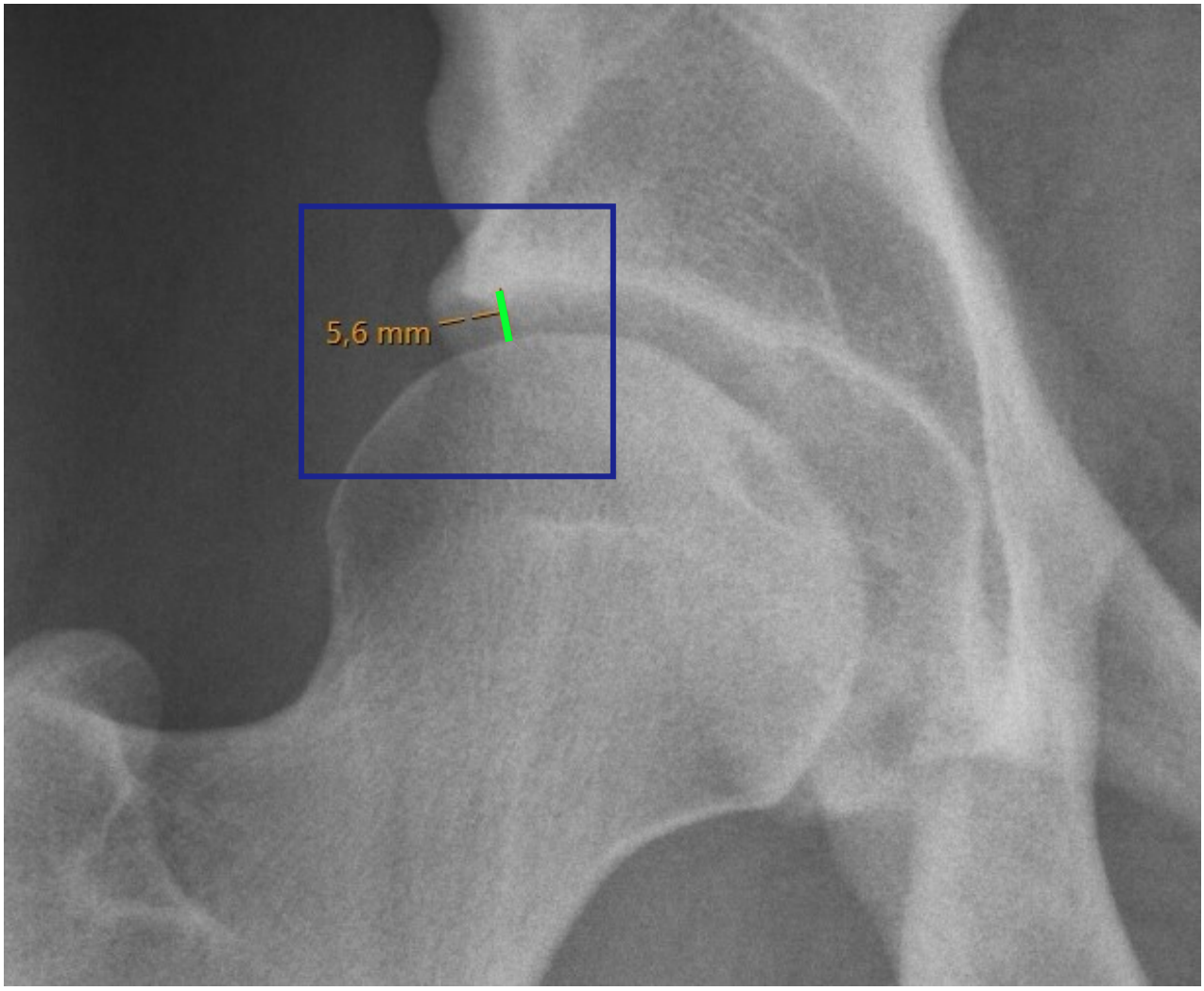


Hip Joint Space Width.

Definition: The distance between the femoral head and the lateral sourcil at the acetabulum [3].

View: Anteroposterior.

Defines: *Joint space narrowing* as hip joint space width < 3mm.

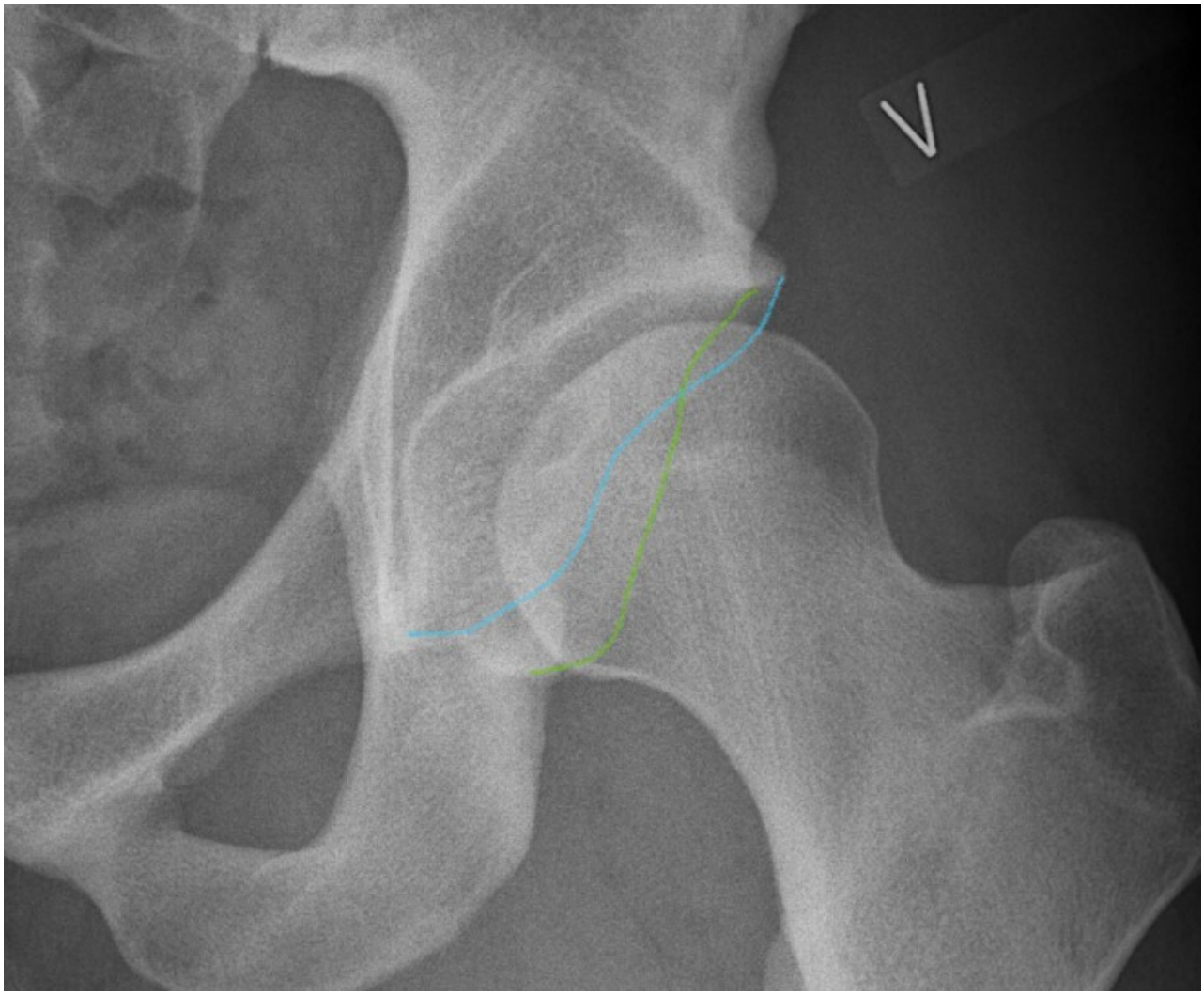


Cross-over sign.

Definitions: *Cross-over sign:* The anterior wall contour intersects and becomes lateral to the posterior wall contour. [3]

View: Anteroposterior.

Defines: *Pincer morphology* as a positive Crossover sign AND posterior wall sign AND Ischial spine sign [3].

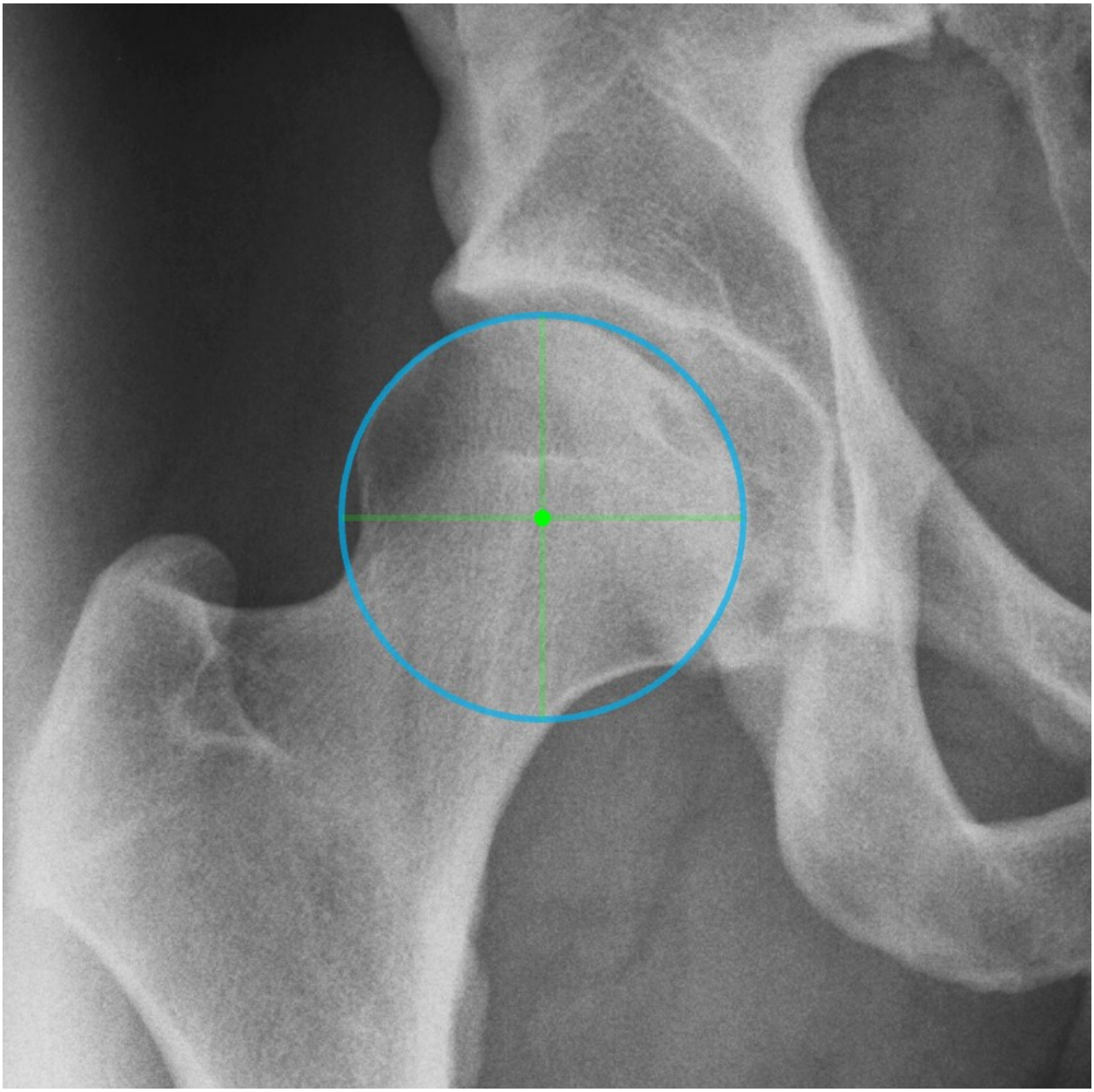


Posterior Wall Sign.

Definition: The posterior acetabular wall projection is medial to the femoral head center projection[3].

View: Anteroposterior

Defines: *Pincer morphology* as a positive Crossover sign AND posterior wall sign AND Ischial spine sign [3].

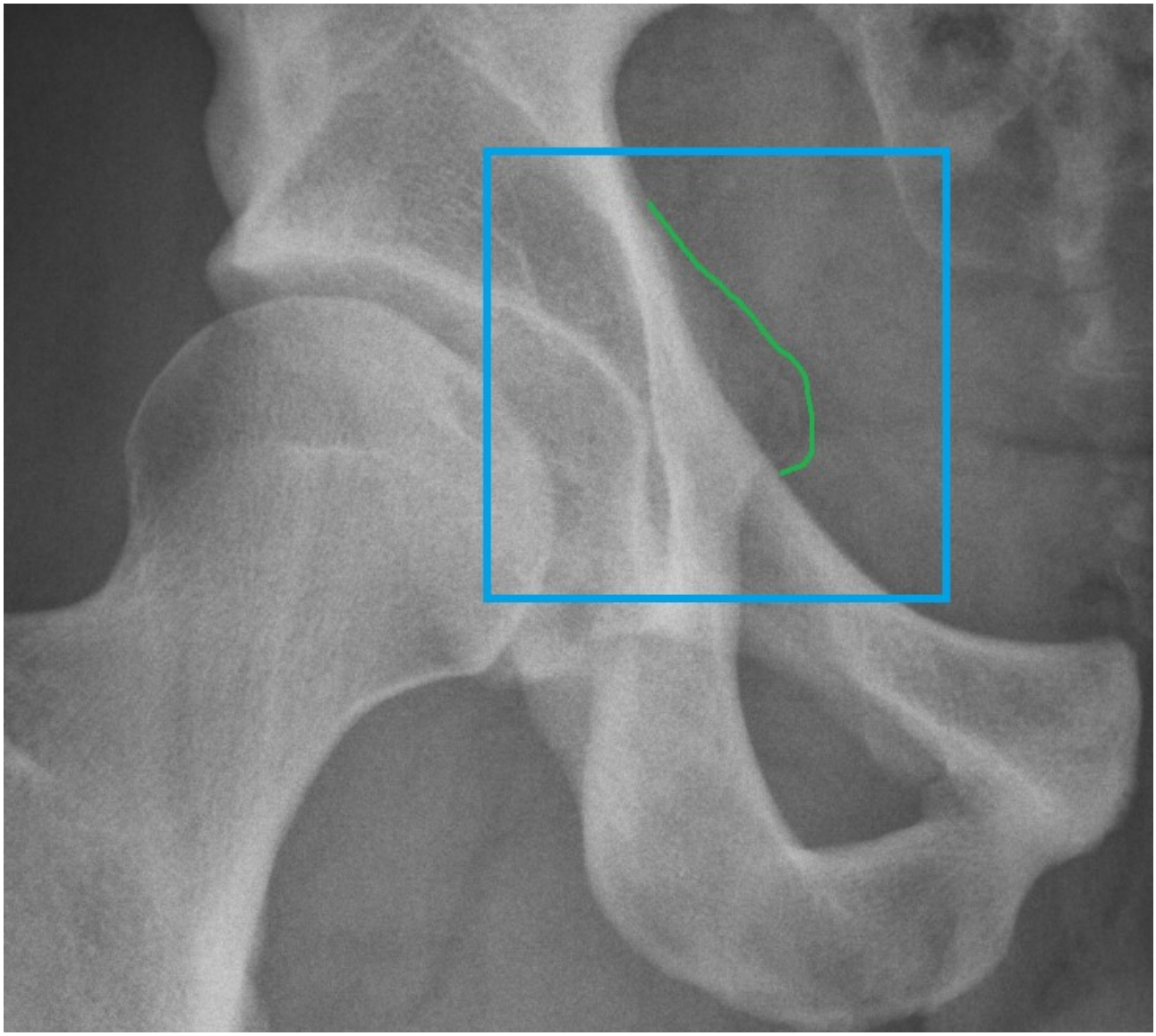


Ischial Spine sign.

Definition: The ischial spine is visible medially to the pelvic rim[3]. (just lateral to the green line on the image)

View: Anteroposterior.

Defines: *Pincer morphology* as a positive Crossover sign AND posterior wall sign AND Ischial spine sign [3].



3. The Copenhagen 5-Second Squeeze Test



Reprinted from Physical Therapy Sport: *Fig. 1. The 5SST Setup in Nielsen MF, Thorborg K, Krommes K, et al. Hip adduction strength and provoked groin pain: A comparison of long-lever squeeze testing using the ForceFrame and the Copenhagen 5-Second-Squeeze test. Physical Therapy in Sport. 2022;55:28-36. doi:10.1016/j.ptsp.2022.02.002, license: CC BY 4.0.*

4. Clinical examination and pain provocation tests

Table S1 Pain provocation tests used for the clinical examination

Pain provocation tests	Description of a positive test:
Adductor longus palpation	Pain on palpation of the adductor longus muscle origin at the pubic bone
Gracilis palpation	Pain on palpation of the origin of the gracilis muscle at the pubic bone
Squeeze with 0° hip flexion†	Pain at the adductor insertion at the pubic bone on bilateral hip adduction in 0° hip flexion against manual resistance at the ankles
Passive adductors stretch	Pain on passive stretching of the adductor muscles
Psoas palpation (supra-inguinal)	Pain on palpation of the psoas muscle through the abdomen right above the inguinal ligament
Iliopsoas palpation (infra-inguinal)	Pain on palpation of the iliopsoas muscle just below the inguinal ligament, medial to the sartorius muscle, and lateral to the femoral artery
Passive hip extension in the modified Thomas test	Pain on passive stretching of the hip flexors in the modified Thomas test position
Resisted hip flexion in 90° hip and knee flexion	Pain on manually resisted single-leg hip flexion in 90° hip and knee flexion with the patient supine
Resisted hip flexion in the modified Thomas test	Pain on manually resisted single-leg hip flexion in the modified Thomas test position
Snapping hip test	Pain and snapping hip on active hip flexion to 90°, followed by active combined extension and abduction of the hip.
Rectus abdominis palpation ‡	Pain on palpation of the rectus abdominis muscle at the pubic bone
Conjoint tendon palpation	Pain on palpation of the conjoint tendon at the pubic tubercle
Resisted sit-up ‡	Pain in the groin when performing a sit-up against manual resistance
External inguinal ring palpation	Pain on palpation of the external inguinal ring
Valsalva & inguinal palpation	Pain on valsalva manoeuvre during palpation of the inguinal canal with invagination
Inguinal canal palpation	Pain on palpation of the inguinal canal with invagination
Symphysis palpation ‡	Pain on palpation of the symphysis joint
Posterior impingement test	Pain in the groin on passive movement of a single leg in an extension, abduction, and external rotation
FADIR	Pain in the groin on a combined passive hip flexion adduction internal rotation
FABER	Pain in the groin on a combined passive hip flexion abduction external rotation
Apprehension test	Pain in the groin on passive movement of a single leg in an external rotation, while the hip is extended over the end of an examination table. The contralateral hip is hold by the subject in 90° flexion.
Log roll test	Pain in the groin on passive movement of a single leg from end-range external rotation to end-range internal rotation with the hip neutral

The provoked pain should correspond to the patient's known and recognizable groin pain. † The test was performed once per athlete, but assessed pain in sides; ‡ The test was performed once per athlete

5. Clinical entities of groin pain

Table S2 The 2015 Doha agreement on terminology for clinical entities of groin pain. Reproduced from Weir et al.[6]

Entity	Definition
Adductor-related groin pain	Adductor tenderness† (a positive Adductor longus palpation or Gracilis palpation) AND pain on resisted adduction testing (a positive Squeeze test with 0° hip flexion)
Iliopsoas-related groin pain	Iliopsoas tenderness† (a positive Psoas (suprainguinal) palpation or Iliopsoas (infrainguinal) palpation)
Inguinal-related groin pain	Pain in the inguinal canal region AND tenderness* of the inguinal canal (a positive Conjoint tendon palpation or External inguinal ring palpation). No palpable inguinal hernia present.
Pubic-related groin pain	Tenderness† of the pubic symphysis and immediately adjacent bone (a positive Symphysis palpation)
Hip-related groin pain	Clinical suspicion of hip-joint being primary cause of pain based on history and/or examination

† Tenderness is defined as "discomfort or pain when the area is palpated, and the athlete recognizes this to be their specific injury pain".[6]

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STUDY III

Hip adduction strength and provoked groin pain: A comparison of long-lever squeeze testing using the ForceFrame and the Copenhagen 5-Second-Squeeze test

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Hip adduction strength and provoked groin pain: A comparison of long-lever squeeze testing using the ForceFrame and the Copenhagen 5-Second-Squeeze test

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ABSTRACT

Objectives: To compare long-lever squeeze testing using the ForceFrame and the Copenhagen 5-Second-Squeeze test (5SST) for assessment of hip adduction strength and provoked groin pain in elite male soccer players.
Design: Cross-sectional study.
Setting: Pre-season testing at facilities of a Danish professional 1st tier soccer club and academy.
Participants: Elite male soccer players (n = 83, mean age; 16 ± 2.7 years) from U13, U14, U15, U17, U19 and senior teams cleared for full training and match participation.
Main outcome measures: Maximum isometric hip adduction strength (Nm/kg) and provoked groin pain (NRS 0–10).
Results: Hip adduction strength was 16% lower in the ForceFrame. A Bland-Altman plot showed a systematic bias (−0.47 Nm/kg, 95% CI [-0.57; −0.38]) and lack of agreement (95% limits of agreement: -1.31; 0.39 Nm/kg). In the ForceFrame, provoked groin pain was less intense (median NRS 0 [IQR: 0–1] vs. 5SST: 1 [IQR: 0–3], $p < 0.001$) and reported by fewer players (NRS >0) (27% [n = 22] vs. 5SST: 61.4% [n = 51], $p < 0.001$).
Conclusions: The ForceFrame and the 5SST lack agreement and are not interchangeable methods. This may have implications when selecting a method for screening and detecting early groin problems in male soccer players.
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1. Introduction

Hip adduction strength has been identified as an important factor for risk profiling of groin problems (Bourne et al., 2019; Delahunt, Fitzpatrick, & Blake, 2017; Esteve et al., 2021; Moreno-Pérez et al., 2019). Hip adduction strength can be assessed with several devices (e.g. a handheld or stationary dynamometer or a sphygmomanometer), muscle contractions (e.g. isometric, eccentric, concentric, or isokinetic) and test setups (e.g. uni- or bilateral, long- or short-lever, seated, side-lying or supine, with/without hip abduction and flexion) (Bourne et al., 2019; Delahunt et al., 2017; Esteve et al., 2021; Gerodimos et al., 2015; Light & Thorborg, 2016; Thorborg, Petersen, Magnusson, & Hölmich, 2009). Of these methods, the traditional supine long-lever squeeze test with a handheld dynamometer (HHD), 0° hip and knee flexion and testers forearm with HHD as resistance between ankles, is often preferred as it is easy, accessible, have excellent reliability, and produce high hip adduction strength values which are clearly associated to risk of groin problems (Esteve et al., 2021; Light & Thorborg, 2016; Wörner, Thorborg, & Eek, 2019). The long-lever squeeze test is also a preferred clinical tests for detecting adductor-related groin problems (Drew et al., 2016; Serner et al., 2016). A recent variation of the long-lever squeeze test, the Copenhagen Five-Second-Squeeze test (5SST), involves rating intensity of groin pain provoked during testing on a 0–10 numerical rating scale (NRS) (Thorborg, Branci, Nielsen, Langelund, & Hölmich, 2017). The 5SST

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score (0–10) correlates negatively with groin-related sports function (Thorborg et al., 2017). Accordingly, long-lever squeeze testing with a HHD and evaluation of provoked groin pain serves as a quick, easy and accessible method for assessment of hip adduction strength, sports function, detection of groin problems and overall risk profiling in male soccer players (Esteve et al., 2021; Light et al., 2019; Thorborg et al., 2017; Wollin, Pizzari, Spagnolo, Welvaert, & Thorborg, 2018).

The ForceFrame is a novel strength assessment system consisting of a sturdy adjustable rig with four load cells allowing for concurrent measurements of both legs. The ForceFrame is designed for easy and rapid testing of large teams and offers multiple options for assessments of strength (VALD Performance, Albion, Australia). The ForceFrame is widely used for assessment of unilateral hip adduction strength in short- and long-lever setups, although testing is usually performed as bilateral squeeze tests (Bourne et al., 2019; DeLang et al., 2020; Desmyttere, Gaudet, & Begon, 2019; Jones, Clair, et al., 2021;Jones, Mullen, et al., 2021; O'Brien, Bourne, Heerey, Timmins, & Pizzari, 2019; Oliveras, Bizzini, Brunner, & Maffiuletti, 2020; Ryan, Kempton, Pacecca, & Coutts, 2019). Hip adduction strength assessed using the ForceFrame is associated with new groin problems in senior soccer players (Bourne et al., 2019). However, the association only exists when hip adduction strength is part of a principal component variable combining long- and short-lever hip ad- and abductor strength (Bourne et al., 2019), making it difficult to translate the results into everyday clinical practice. Long-lever hip adduction strength assessed using the ForceFrame correlates with assessment using a HHD (O'Brien et al., 2019). However, these correlations were between two different test setups; a bilateral long-lever isometric squeeze test (the ForceFrame), and a unilateral isometric hip adduction test (testing leg straight and the non-testing leg in 45° hip and knee flexion) (O'Brien et al., 2019). Thus, it is unclear whether bilateral long-lever hip adduction strength from the ForceFrame can be used interchangeably with the 5SST with HHD as an isolated measure for risk for groin problems (Esteve et al., 2021). It is also unknown whether long-lever squeeze testing using the ForceFrame provokes groin pain similarly to the 5SST, and thus could be used to detect adductor-related groin pain and monitor groin-related disability and function.

Long-lever squeeze testing using the ForceFrame and 5SST have slight differences. The hip abduction angle seems larger in the 5SST than in the ForceFrame due to the different ways of exerting resistance onto the ankles (DeLang et al., 2020; Light & Thorborg, 2016; O'Brien et al., 2019). Since hip abduction angle can affect the output when assessing hip adduction strength (Delp & Maloney, 1993; Welsh, Howitt, & Howarth, 2020), the consequences of the discrepancy between the 5SST and the ForceFrame warrants further investigation.

The purpose of this study was to compare long-lever squeeze testing using the ForceFrame and the 5SST for measures of hip adductor squeeze strength and provoked groin pain.

2. Materials and methods

We conducted a cross-sectional study with data from an ongoing cohort from which two studies have been published (Ishøi et al., 2019, 2021). Data was collected during two pre-seasons (February 2020 and January 2021), at the facilities of a Danish professional 1st tier soccer club and academy. The study was conducted in accordance with the Declaration of Helsinki and the Danish Ethics Committee of the Capital Region (ID: 19026064). Informed consent was obtained from players and club staff including coaches, health professionals, and the technical director prior to study initiation.

2.1. Participants

By convenience sampling, we included 83 elite male soccer players from the academy and senior team of one professional soccer club competing in the highest ranked Danish soccer leagues according to their age groups (Table 1). Inclusion criteria were male elite soccer player competing at the U13, U14, U15, U17, U19 or Senior level, available for pre-season adductor strength assessment and cleared for full participation in all pre-season training activities including match play. All players were familiar with the strength assessments, as these are part of the standard pre-season testing protocol at the academy and club.

2.2. Procedure

Data were collected as part of the regular pre-season test session which included assessment of isometric hamstring and quadriceps strength (reported elsewhere; Ishøi et al., 2021), isometric bilateral hip adduction and abduction strength and pain during assessment. The ForceFrame was used to assess both hip adduction and abduction strength. The 5SST was used as an additional assessment for this study. The primary measures of hip adduction strength and provoked groin pain were peak torque-to-body mass ratio (Force [Newton] * lever arm length [meter]/body mass [kilogram]) and intensity on 0–10 NRS, respectively. Secondary measures of strength were peak force (N), peak torque (force [N] * lever arm length [m]), peak force-to-body mass ratio (force [N]/body mass [Kg]) and peak force-to-body weight ratio (force [N]/body weight [N]). We also counted players with and without provoked groin pain (NRS>0) (Weir et al., 2015), and players with and without potential groin problems (NRS>2) (Thorborg et al., 2017).

Before the test session, all players performed warm-up initiated by the academy/club physiotherapist (e.g. stationary biking for 5–15 min). Players presented for the session in small groups of 5–8 players. First players were measured (lever-arm length) and weighted. Subsequently, by convenience, players were alternatingly allocated to either the ForceFrame or the 5SST. The ForceFrame and 5SST was either the first or last assessment during the test session and thus separated by hamstring and quadriceps strength assessment. Due to the pragmatic setup and time-constraints a pre-randomized assessment sequence was not feasible, as this could result in excessive cueing at either method.

2.2.1. Long-lever squeeze testing using the ForceFrame

The ForceFrame test was administered by the first author (a physiotherapist with 3 years of experience with performing assessments with the ForceFrame). Long-lever squeeze testing using the ForceFrame was performed with players supine on an exercise mat with 0° hip flexion, knees fully extended, and both medial malleoli touching the two inner load cells of the ForceFrame resulting in players having approximately 0–5° of hip abduction angle (Fig. 2). The distance between the center of the load cells was roughly 0.17 m. Both load cells recorded raw pressure force (Newton) at 100 Hz simultaneously. The lever arm was the distance from the anterior superior iliac spine to the center of the medial malleoli. The ForceFrame has excellent reliability for hip adduction strength assessed with a short-lever squeeze test (ICC 0.85–96) (Desmyttere et al., 2019; Ryan et al., 2019). Reliability and minimal detectable change (MDC) have not yet been reported for long-lever squeeze testing using the ForceFrame.

2.2.2. The Copenhagen Five-Second-Squeeze test

The 5SST was administered by two physiotherapists, one in February 2020, another in January 2021. Both were trained by the senior author to ensure adequate technique and had 6 months of

Table 1
Descriptive data of included players.

Team	Age, years			Height, cm			Mass, kg			BMI			Dominant leg	Previous groin injury*
	Mean (SD)	Median [IQR]	Range	Mean (SD)	Median [IQR]	Range	Mean (SD)	Median [IQR]	Range	Mean (SD)	Median [IQR]	Range	left/right	yes/no
All (n = 83)	16.0 (2.7)	16 [14 −18]	11 −24	174.7 (10.0)	175.0 [168.5 −182.0]	150 −195	66.5 (13.0)	68.0 [57.3 −75.5]	35 −93	21.6 (2.5)	21.9 [19.7 −23.3]	15.4 −31.1	18/65	19/64
U13 (n = 7)	12.0 (0.8)	12 [11 −13]	11 −13	160.1 (10.4)	156.9 [151.2 −170.5]	151 −178	45.2 (9.8)	42.0 [37.0 −56.0]	35 −61	17.2 (1.5)	17.0 [16.2 −19.1]	15.4 −19.4	1/6	3/4
U14 (n = 12)	13.0 (0.4)	13 [13-13]	12 −14	163.5 (5.9)	163.2 [160.2 −165.2]	156 −179	52.7 (8.1)	51.0 [46.2 −59.4]	42 −67	19.6 (2.1)	19.2 [18.1 −20.2]	17.4 −24.0	2/10	4/8
U15 (n = 12)	14.3 (0.6)	14 [14 −15]	13 −15	172.9 (5.9)	173.2 [170.4 −175.6]	162 −185	59.7 (5.2)	58.1 [56.3 −62.7]	54 −70	19.9 (1.2)	19.7 [19.0 −21.0]	18.4 −21.9	5/7	3/9
U17 (n = 15)	15.6 (0.7)	16 [15 −16]	14 −17	179.8 (7.2)	180.0 [173.5 −188.0]	168 −191	71.4 (7.3)	72.0 [66.0 −75.5]	56 −84	22.0 (1.2)	22.1 [21.1 −22.8]	19.7 −24.5	3/12	2/13
U19 (n = 18)	17,2 (0.8)	17 [17 −18]	15 −18	179.9 (7.0)	179.8 [175.6 −185.5]	169- 193	74.7 (7.4)	74.0 [70.0 −79.5]	65 −93	23.9 (1.2)	23.1 [22.2 −23.7]	21.1 −25.7	3/15	4/14
Senior (n = 19)	19,5 (1.8)	19 [19 −20]	17 −24	179,3 (7.4)	178.5 [172.0 −185.0]	168 −195	75.9 (8.3)	76.0 [69.0 −82.0]	63 −91	23.6 (2.2)	23.5 [22.2 −24.5]	20.6 −31.1	4/15	3/16

cm = centimeter, kg = kilogram, BMI = body mass index, *Previous groin injury within the last 6 months, SD = standard deviation, IQR = interquartile range.



Fig. 1. The 5SST setup.
The HHD and arm of the assessor work as a "passive" and "moveable" resistance which the player actively squeezes both legs into as hard as possible. The assessor does not actively push, hold, or fixate the arm against any of the legs.



Fig. 2. The ForceFrame long-lever squeeze test setup.
The ForceFrame consists of a sturdy rig with two inner load cells and two outer load cells. The two inner load cells are fixated to the rig, so they work as an immoveable resistance with a fixed width.

experience with performing the 5SST before data collection. The 5SST was performed as the traditional long-lever squeeze test with players supine on an examination bed with 0° hip flexion, knees fully extended and the assessor's forearm and a HHD (Hoggan MicroFET2, Scientific L.L.C., Salt Lake City, USA) as resistance between the ankles of the player (Fig. 1). The HHD recorded raw pressure force (Newton) at 100 Hz. The assessors only used the HHD with their dominant hand. The length of the forearm plus HHD was roughly 0.35 m for both testers resulting in players having approximately 10–15° of bilateral hip abduction angle (Fig. 1). The lever arm was the distance from the anterior superior iliac spine to 5 cm proximal of the edge of the medial malleoli. The 5SST (long-lever squeeze testing) with HHD has excellent inter- and intra-tester reliability for hip adduction strength (ICC 0.95 and 0.90–0.97, respectively) and excellent intra-tester reliability for provoked groin pain intensity (CCC 0.90) (Light & Thorborg, 2016; Thorborg et al., 2017; Wörner et al., 2019). The MDC in hip adduction strength is 13.6–13.7% for a single trial and 8.7–11.8% for the best of three trials (Light & Thorborg, 2016).

2.2.3. Data collection

In both the ForceFrame and 5SST, players first performed a single trial at 50% of self-perceived maximum effort to warm-up and re-familiarize with assessment, followed by rest for approximately 60 s and verbal feedback on form if necessary. Subsequently, players needed to perform two valid trials at 100% of perceived maximum effort separated by 60 s. The rest period corresponded with previous studies assessing isometric hip adduction strength (Bourne et al., 2019; Jones, Mullen, et al., 2021; Light & Thorborg, 2016; O'Brien et al., 2019). Players were instructed to isometrically and continuously squeeze both legs as hard as possible for 5 s, into either the assessor's arm and HHD (the 5SST) or the inner load cells (ForceFrame). Each trial was initiated and encouraged using the standardized command "3-2-1-Go-Push-Push-Push-Push-And-Stop". All trials were visually monitored. If excessive hip or knee extension/flexion was displayed or effort was not held for 5 s trials was discarded, and an extra 100% trial was performed. No player performed more than 3 100% trials.

From the 5SST, peak force (N) from each of the two valid 100% trials were extracted and the trial with the highest peak force were used for analyses. For the ForceFrame, peak force (N) from both load cells from the two valid 100% trials were extracted and for analyses, we used the trial with highest average peak force from both load cells. During peer-review we performed a sensitivity analyses using the single highest peak force from either of the two inner ForceFrame load cells. This showed similar results and were therefore not included in the manuscript.

After each 100% trial, players rated intensity of provoked groin pain on a 0–10 NRS using the standardized question "On a scale from 0 to 10, with 0 being 'no pain' and 10 being 'worst imaginable pain', how much pain did you feel in the groin area during the test?". For both the ForceFrame and the 5SST, the trial with single highest peak provoked groin pain intensity (NRS 0–10) was used for analyses.

2.3. Analyses

Descriptive data are reported using means (standard deviations), medians (interquartile range) and range for continuous variables and numbers (percentages) for ordinal and nominal variables. We used scatterplots and Pearson's correlation coefficients to investigate the linear association between strength measures (Nm/Kg, Nm, N, N/Kg, N/N) obtained from the ForceFrame and the 5SST. Whilst, for pain measures Kendalls Tau was used. Correlations was interpreted according to Schober, Boer, & Schwarte, 2018. Between-method differences in strength (Nm/Kg, Nm, N, N/Kg, N/N) approximated normality distribution when evaluated using histograms (Giavarina, 2015). Accordingly, agreement between the ForceFrame and 5SST for strength (Nm/kg, Nm, N, N/kg) were investigated using Bland-Altman plots with 95% limits of agreement (LOA) (Martin Bland & Altman, 1986). Bland-Altman plots were created using absolute and percentage differences between methods in strength variables (Nm/kg, Nm, N, N/kg, N/N) (Giavarina, 2015). Agreement was considered good if the upper and lower 95% LOA ranged from ± 15% difference between methods, as this corresponds to a change in hip adduction strength that is considered clinically meaningful (Wollin et al., 2018). Between-method differences with 95% confidence intervals were estimated using paired t-tests for strength (Nm/kg, Nm, N, N/kg), whilst provoked groin pain intensity (0–10 NRS) was compared using a Wilcoxon signed rank test. Proportion of players reporting groin pain (NRS >0) and potential groin problems (NRS>2) (Thorborg et al., 2017) were compared with a Fischer's exact test of proportions. *P*-values were considered statistically significant at an alpha level of 0.05. Statistical analyses were performed in SPSS (v. 23, IBM Corporation, New York, USA) and Stata (Stata IC v. 16, Stata Corporation, USA).

3. Results

3.1. Participants

We assessed 92 players, of which 9 were excluded due to technical errors, such as missing data. In total, 83 players were included from the U13 (n = 7), U14 (n = 12), U15 (n = 12), U17 (n = 15), U19 (n = 18) and senior (n = 19) team. Descriptive data are presented in Table 1. Five players only performed one 100% trial in the 5SST, due to error by one assessor, but were kept in the analyses (sensitivity analyses showed no difference in outcome; Appendix a). Six players were tested twice but kept in the analyses as separate datasets, they were U-15 players in February 2020 and U-17 players in January 2021.

3.2. Hip adduction strength

The scatterplot (Fig. 3) indicated a linear association and strong correlation (Pearson's $r = 0.73$) for hip adduction strength (Nm/kg) assessed using the ForceFrame and the 5SST, respectively. Hip adduction strength (Nm/Kg) was significantly lower when assessed using the ForceFrame compared to the 5SST (between-method difference of 16%; $p < 0.0001$; Table 2). The Bland-Altman plots did not indicate good agreement and 57% (47/83) of players were more than 15% stronger in the 5SST compared to the ForceFrame (Fig. 4, statistics in appendix a). Similar results (appendix a) were observed when analyzing torque (Nm), force (N), force-to-body mass ratio (N/kg) and peak force-to-body weight ratio (N/N).

3.3. Provoked groin pain

Intensity of provoked groin pain showed a moderate positive correlation between methods (Kendalls Tau = 0.40, $p < 0.0001$). Provoked groin pain intensity was significantly lower in the ForceFrame compared to the 5SST (Table 3). Frequency of each pain intensity level is presented in Fig. 5. In total, 61% (32/51) of players who reported NRS >0 in the 5SST did not report pain when using the ForceFrame, and 35% (18/51) reported a NRS >2 in the 5SST but an NRS <2 in the ForceFrame.

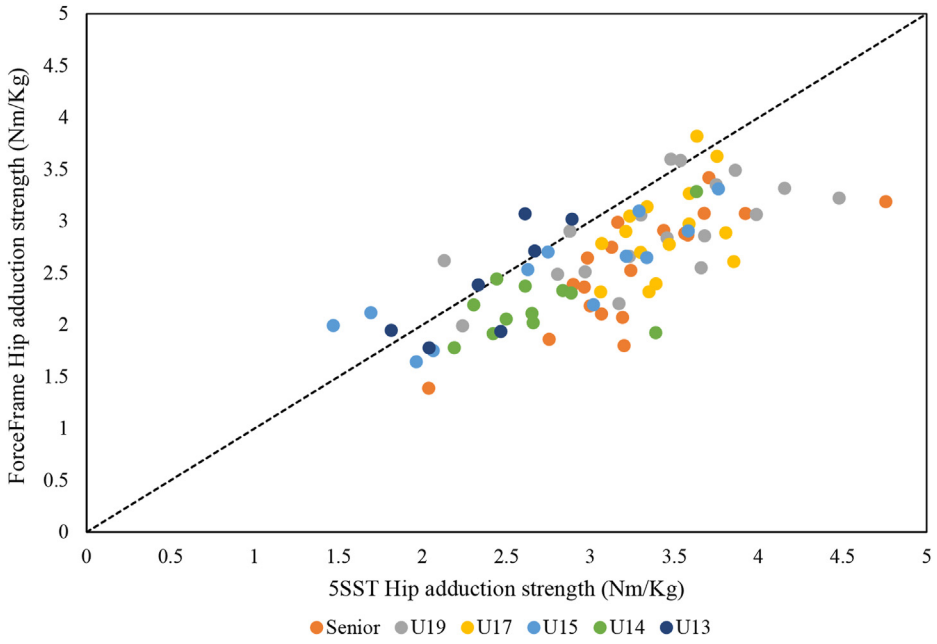


Fig. 3. Scatterplot and line of equality for hip adduction strength (Nm/Kg).

Table 2
Hip adduction strength (Nm/Kg) assessed with the ForceFrame and the 5SST.

Team	ForceFrame			5SST			ForceFrame vs 5SST		
	Mean (SD)	Median (IQR)	Range	Mean (SD)	Median (IQR)	Range	Mean difference(95% CI)	p-value	Cohens *d*
All (n = 83)	2.62 (0.53)	2.65 [2.19–3.05]	1.39–3.82	3.09 (0.63)	3.19 [2.66–3.58]	1.47–4.75	-0.47 (-0.57; -0.38)	<0.0000	-2.182
U13 (n = 7)	2.41 (0.54)	2.38 [1.93–3.02]	1.78–3.07	2.40 (0.37)	2.47 [2.04–2.67]	1.81–2.89	-0.00 (-0.30; 0.30)	0.9820	0.019
U14 (n = 12)	2.23 (0.39)	2.15 [1.97–2.35]	1.78–3.28	2.71 (0.43)	2.63 [2.43–2.86]	2.19–3.63	-0.48 (-0.71; -0.25)	0.0008	-2.771
U15 (n = 12)	2.46 (0.53)	2.59 [2.05–2.80]	1.64–3.31	2.73 (0.77)	2.88 [2.01–3.31]	1.47–3.76	-0.27 (-0.54; 0.00)	0.0501	-1.327
U17 (n = 15)	2.90 (0,44)	2.89 [2.61–3.14]	2.32–3.82	3.44 (0.25)	3.39 [3.23–3.63]	3.06–3.85	-0.54 (-0.76; -0.32)	0.0001	-2.776
U19 (n = 18)	2.91 (0.47)	2.88 [2.55–3.32]	1.99–3.60	3.38 (0.62)	3.47 [2.97–3.75]	2.13–4.48	-0.47 (-0.70; -0.24)	0.0005	-2.078
Senior (n = 19)	2.55 (0.54)	2.60 [2.10–3.00]	1.40–3.40	3.28 (0.55)	3.19 [2.98–3.58]	2.04–4.76	-0.72 (-0.89; -0.55)	<0.0000	-4.151

Nm/Kg = Newton*meter/kilogram, 5SST = Five-Second Squeeze Test, SD = Standard deviation, IQR = Interquartile range, CI = Confidence interval.

4. Discussion

We compared a long-lever squeeze test using the ForceFrame with the 5SST for measures of hip adduction strength and provoked groin pain. Our main finding is that the ForceFrame is not interchangeable with the 5SST due to the lack of agreement for measures of hip adduction strength and provoked groin pain. This is highlighted by the ForceFrame producing 16% lower strength measures, provoking less intense groin pain and provoking groin pain in fewer players.

In the present study, hip adduction strength correlated strongly between the 5SST and the ForceFrame. This is similar to what O'Brien et al. reported when correlating hip adduction strength from the ForceFrame to unilateral measured hip adduction strength (O'Brien et al., 2019). Despite the observed strong correlation, the Bland-Altman plots showed a systematic bias and very wide 95% limits of agreement with only 39% (32/83) of players within the prespecified acceptable limits of agreement (±15% between-method difference). An effect size of 15% is considered to represent clinical meaningful change in long-lever squeeze strength (Wollin et al., 2018), which if negative could be a potential indicator of an upcoming groin problem (Crow et al., 2010). Consequently, the 5SST and the ForceFrame cannot be considered interchangeable methods and it remains unknown whether long-lever hip adduction strength assessed using a ForceFrame can be used as a single variable to monitor risk of groin problems in male senior soccer (Esteve et al., 2021).

The observed lack of agreement and absolute differences in hip adduction strength can likely be explained by differences in the ForceFrame and 5SST setups. This encompass hip abduction angle (approx. 0° in the ForceFrame; approx. 10–15° in the 5SST) and placement of resistance (medial malleoli in the ForceFrame; approx. 5 cm proximal to the edge of the medial malleoli in the 5SST). To account for placement of resistance, we used torque-to-body mass ratio (Nm/Kg) as the primary strength measure. Accordingly, the distance between the ankles and the hip abduction angle are most likely the explanations of the discrepancy in strength. This is in line with a recent biomechanical study of unilateral hip adduction strength at different hip abduction angles, which showed that higher hip adduction torque were produced at 10° and 20° hip abduction compared to neutral (Welsh et al., 2020). Together with our results, this suggest that increasing the hip abduction angle in the frontal plane allows for greater force generation, as also suggested by biomechanical models (Arnold, Ward, Lieber, & Delp, 2010; Delp & Maloney, 1993).

We observed a positive and moderate correlation between the ForceFrame and the 5SST for provoked groin pain intensity. This indicates that long-lever squeeze testing using the ForceFrame provokes groin pain similarly to the 5SST. However, we also observed that provoked groin pain intensity and proportion of

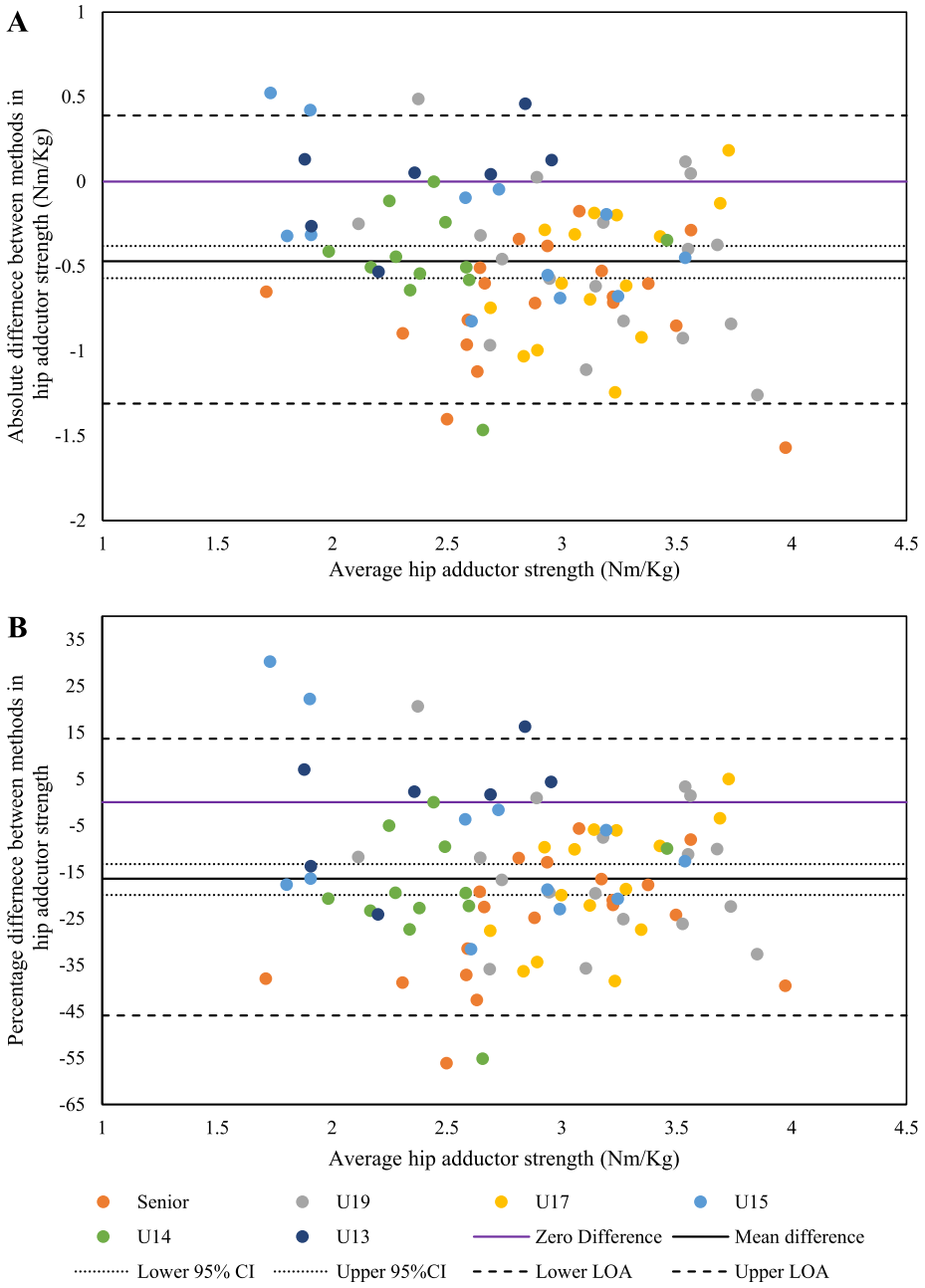


Fig. 4. Bland-Altman plots of (A) absolute torque-to-body mass ratio (Nm/Kg) and (B) percentage (%) difference between methods for hip adduction strength (Nm/Kg).

Table 3
Provoked groin pain (NRS 0–10) assessed using the ForceFrame and the 5SST.

Team	ForceFrame			5SST			ForceFrame vs 5SST†	Players with NRS >0, n (%)		Players with NRS >2, n (%)	
	Mean (SD)	Median [IQR]	Range	Mean (SD)	Median [IQR]	Range	p-value	ForceFrame	5SST	ForceFrame	5SST
All (n = 83)	0.8 (1.6)	0 [0–1]	0–7	1.7 (1.8)	1.0 [0–3]	0–7	<0.000	22 (27%)	51 (61%)*	14 (17%)	29 (35%)**
U13 (n = 7)	0.0 (0.0)	0 [0-0]	0–0	1.0 (1.4)	0.0 [0–3]	0–3	0.250	0 (0%)	3 (42%)	0 (0%)	2 (29%)
U14 (n = 12)	0.3 (0.9)	0 [0-0]	0–3	0.4 (1.2)	0.0 [0-0]	0–4	0.750	1 (8%)	2 (17%)	1 (8%)	1 (8%)
U15 (n = 12)	0.7 (1.3)	0 [0–1]	0–4	1.5 (1.3)	1.5 [0–3]	0–3	0.047	3 (25%)	8 (67%)	1 (8%)	4 (8%)
U17 (n = 15)	0.5 (1.8)	0 [0-0]	0–7	1.6 (1.5)	1.0 [0–3]	0–4	0.021	1 (7%)	11 (73%)	1 (7%)	5 (33%)
U19 (n = 18)	0.8 (1.6)	0 [0–1]	0–5	2.3 (2.5)	1.5 [0–4]	0–7	0.027	5 (28%)	12 (67%)	3 (17%)	7 (39%)
Senior (n = 19)	1.9 (1.8)	2 [0–3]	0–5	2.4 (1.5)	3.0 [2–4]	0–4	0.220	12 (63%)	15 (79%)	8 (42%)	10 (53%)

NRS = Numerical rating scale, 5SST = Five-Second Squeeze Test, †Comparison of group level pain intensity using a Wilcoxon signed rank test, SD = Standard deviation, IQR = Interquartile range, *Fischer's exact test p = 0.005, **Fischer's exact test p < 0.001.

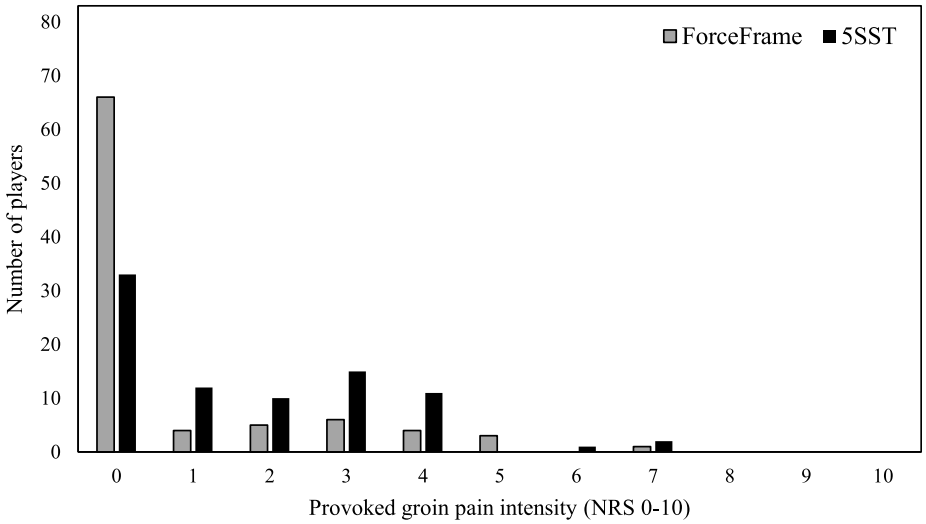


Fig. 5. Frequency of each provoked groin pain intensity level among all players (n=83).

players reporting pain were significantly higher in the 5SST. Suggesting that the 5SST is more provocative and stressful for the groin area than long-lever squeeze testing using the ForceFrame. A possible explanation for these observations is that the 5SST and testing with increased hip abduction causes more mechanical stress to the groin than using the ForceFrame. Mechanical stress has previously been suggested as the potential mechanism of groin pain during squeeze testing athletes with longstanding groin pain (Verrall, Slavotinek, Barnes, & Fon, 2005). Long-lever squeeze testing is known to provoke pain when nociceptors in the adductor myotendinous structures are sensitized by either acute tissue injury (Serner et al., 2016) or experimentally induced pain (Drew et al., 2016). Further, mechanical stress increases when torque and force production increases (Buchanan, 1995). Consequently, a combination of high mechanical stress and/or potentially sensitized nociceptors seems as the apparent mechanism behind the differences in provoked groin pain intensity.

We included 83 injury-free players cleared for full pre-season soccer participation. Yet, 61% reported provoked groin pain (NRS >0) in the 5SST, suggesting that many players could have been experiencing non-time loss groin problems without having reported so (DeLang, Garrison, & Thorborg, 2021). However, soccer and strength training most likely induce strain and peripheral sensitization of groin structures (Dupré, Tryba, & Potthast, 2021; Dupré et al., 2018; Polglass, Burrows, & Willett, 2019), without causing an apparent injury or problem (DeLang et al., 2021; Dooley et al., 2021), but causing provoked groin pain when the groin region is exposed to high and focused mechanical stress, such as the 5SST. This explains why low intensity groin pain (NRS = 0–2) is common during the 5SST without indicating loss of sport function (Thorborg et al., 2017), and why groin problems without loss of sports function are highly prevalent during the pre-season (Esteve et al., 2020; Harøy et al., 2019). Contrary, provoked groin pain NRS >2 may indicate a need for clinical attention based on significant association to decreased groin-related sports function (Thorborg et al., 2017). We observed 14 and 29 players reporting a provoked groin pain NRS >2 using the ForceFrame and 5SST, respectively. Importantly, 18 players reported NRS >2 in the 5SST but NRS <2 when assessed using the ForceFrame, suggesting that 62% (n = 18/29) of players with potential clinical groin problems are not detected by long-lever squeeze testing using the ForceFrame. This could be a highly important finding for clinicians, as it indicates that the 5SST with HHD is more sensitive for detecting potential clinical groin problems in need of clinical attention than long-lever squeeze testing using the ForceFrame.

4.1. Limitations

This study has some limitations. Pre-testing activities (i.e. warm-up), hamstring and quadriceps assessment and performing all assessments on the same day could have influenced strength and pain scores e.g. due to fatigue or being cold, however, by using a paired design and within player comparisons, the effect of pre-testing activities can be assumed to influence both methods equally. Additionally, performing all assessments on a single day eliminates day-to-day variability in both strength and pain. Rather than being randomized, players were allocated alternatingly to the ForceFrame and 5SST, respectively. Unfortunately, randomization as was not feasible due to time-constraints and the pragmatic setup provided by the club and academy. This increases the risk of a bias, however, as all players were allocated alternatingly this should reduce any bias due to muscle fatigue in the method being used last. Providing 60 s of rest between maximum trials could be insufficient for full recovery between trials, however this is corresponding with previous studies having shown excellent reliability (Light & Thorborg, 2016; Wörner et al., 2019). We lack a direct measure of hip abduction angle during data collection. Thus, we measured the width of the resistance between the ankles in the two methods, as increasing the distance between the feet in the frontal plane will increase the hip abduction angle. This distance was approximately 17 and 35 cm for the ForceFrame and 5SST, respectively. Consequently, players had a larger hip abduction angle when assessed using the 5SST compared to ForceFrame. We ensured that all assessors were blinded to the results of the opposite method during data collection, had adequate training, and used a standardized instruction to avoid potential bias from deviations from the testing protocol. Several players reported pain during assessment and could be dealing with non-time loss groin problems, causing low strength scores and high pain scores. Although, a post-hoc analyses suggested otherwise with no to weak correlation between provoked pain intensity and strength (ForceFrame $r_s = -0.025$; 5SST $r_s = 0.186$). The generalizability of the specific strength and pain scores is limited by not accounting for maturational status and only including male soccer players from a single

professional 1st tier club and academy. Thus, the scores reflect the players and training at this single club/academy, rather than soccer players in general. However, with regards to the primary aim, the sample does not limit the generalizability of the primary findings as these findings most likely can be attributed to the test setup differences. Furthermore, we accounted for differences in leg-length and body mass by using torque-to-body mass ratio as primary measure of strength. This approach is accordance with previous studies (DeLang et al., 2020; Esteve et al., 2018, 2020; O'Brien et al., 2019), and facilitates generalizability of the results, despite assuming a perfect correlation between torque and body mass which in this study is of $r = 0.767$ and $r = 0.823$ for the ForceFrame and 5SST, respectively.

4.2. Clinical implications

Assessment of hip adduction strength and provoked pain is commonly applied in soccer settings to manage groin injury risk (Light, Smith, Delahunt, & Thorborg, 2018). We observed that long-lever squeeze testing using the ForceFrame and the 5SST can assess hip adduction strength and can provoke groin pain. However, the ForceFrame and the 5SST are not interchangeable. Thus, measures from the two methods should not be directly compared or pooled in a clinical setting. Importantly, the 5SST allowed for higher strength values than the ForceFrame and was more sensitive for detecting potentially meaningful groin pain. Suggesting that subclinical groin problems may be picked up more easily by using the 5SST compared to the ForceFrame which could facilitate early management strategies. Nevertheless, clinicians need to be aware that implementing a regular (weekly or biweekly) use of a long-lever squeeze testing could be met by a lack of enthusiasm from players if the chosen method is associated with discomfort and being painful. Reporting of provoked pain from testing are also at risk of being underreported if players believe that reporting pain leads to medical screening and being prevented participation in practice and games for something which they might not consider a real injury or problem (DeLang et al., 2021). Based on the current findings provoked pain and discomfort could be a smaller barrier when using the ForceFrame. Consequently, the ForceFrame could be a valuable and less provocative alternative to the 5SST and might be easier to implement as a device for regular monitoring of hip adduction strength. Nevertheless, our results indicate that hip adduction strength measures from long-lever squeeze testing using the ForceFrame should not be substituted with measures from the 5SST to estimate risk of groin problems (Esteve et al., 2021). Whether this is more than speculation and the differences in pain provocative nature and hip adduction strength of the two test setups impacts the ability to detect very early groin problems still needs further investigation.

5. Conclusion

Long-lever squeeze testing using the ForceFrame is not interchangeable with the 5SST for measures of hip adduction strength and provoked groin pain in male elite soccer players. This is indicated by the wide limits of agreement in Bland-Altman plots for hip adduction strength, players producing 16% less torque and reporting lower intensities of provoked groin pain, when assessed using the ForceFrame compared to the 5SST. These findings are novel and clinically relevant as they could have implications for how a soccer club and academy choose to monitor and detect early groin problems.

Ethical approval

Study approval was obtained from the Danish Ethics Committee of the Capital Region (ID: 19026064).

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Ethical statement

The study was conducted in accordance with the Declaration of Helsinki and study approval was obtained from the Danish Ethics Committee of the Capital Region (ID: 19026064). Informed consent was obtained from players and club staff including coaches, responsible health professionals, and the technical director prior to study initiation.

Declaration of competing interest

None declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2022.02.002.

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SUPPLEMENTARY FILE

Hip adduction strength and provoked groin pain: A comparison of long-lever squeeze testing using the ForceFrame and the Copenhagen 5-Second-Squeeze test

Table 1 Sensitivity analyses excluding players without two valid measurements from both the 5SST and the ForceFrame. Data are group level hip adduction strength (Nm/kg, N, N/kg, Nm), pain intensity and differences between the ForceFrame and the 5SST

	ForceFrame			5SST			Differences between methods		
N = 78	**Mean (SD)**	**Median (IQR)**	**Range**	**Mean (SD)**	**Median (IQR)**	**Range**	**Mean difference (95% CI)**	**p-value**	**Cohens *d***
Torque-to-body mass ratio (Nm/kg)	2.64 (0.54)	2.66 (2.19-3.05)	1.39-3.82	3.13 (0.61)	3.2 (2.75-3.58)	1.47-4.76	-0.49 (-0.59; -0.39)	< 0.0000	-2.275
Torque (Nm)	178.7 (54.6)	191.2 (132.3-215.5)	71.2-288.3	213.1 (66.0)	224.3 (174.8-268.7)	73.6-353.9	-34.5 (-41.6; -27.2)	< 0.0000	-2.140
Force (N)	191.9 (53.2)	199 (153-234)	89-294	241.7 (68.1)	256.7 (201.5-294.0)	94.3-388.3	-49.80 (-57.9; -41.7)	< 0.0000	-2.772
Force-to-body mass ratio (N/kg)	2.86 (0.55)	2.85 (2,41-3.30)	1.44-3.87	3.58 (0.65)	3.59 (3.26-4.0)	1.67-5.47	-0.72 (-0.83; -0.61)	< 0.0000	-3.016
Pain, NRS (0-10)	0.87 (1.62)	0.0 (0.0-1.0)	0-7	1.75 (1.79)	1.0 (0.0-3.0)	0-7	-	-	-

*Wilcoxon Signed-rank test

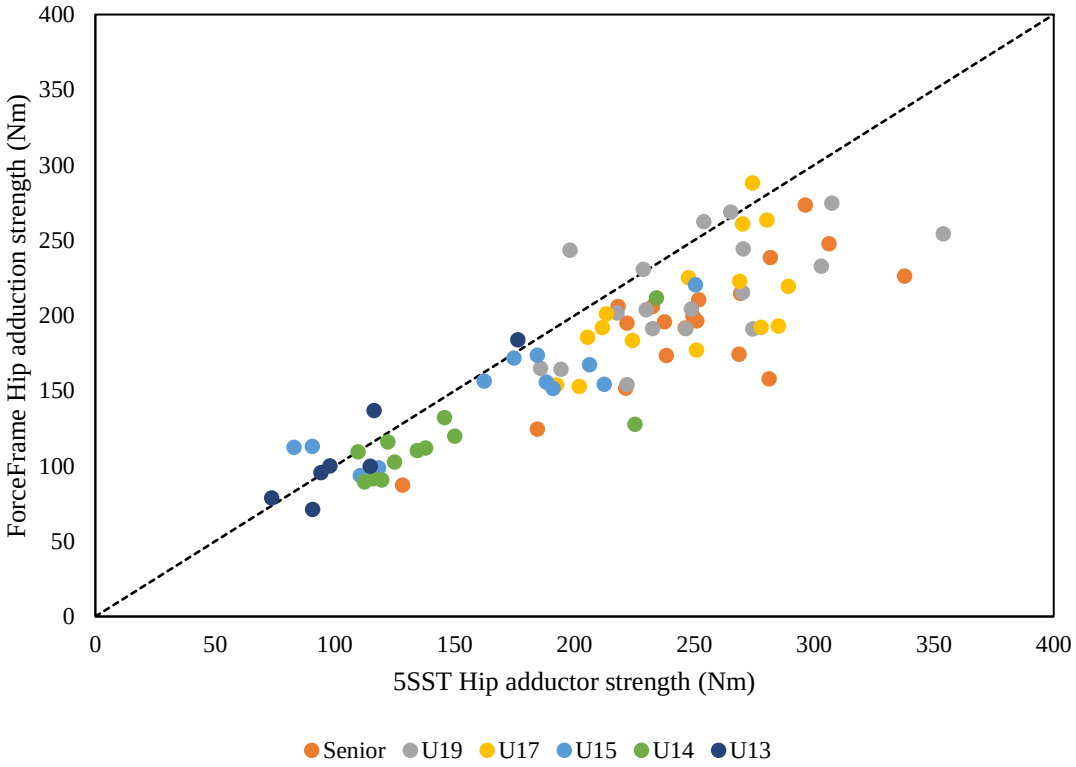


FIGURE 1a Scatterplot and line of equality for hip adduction strength measured as peak torque (Nm)

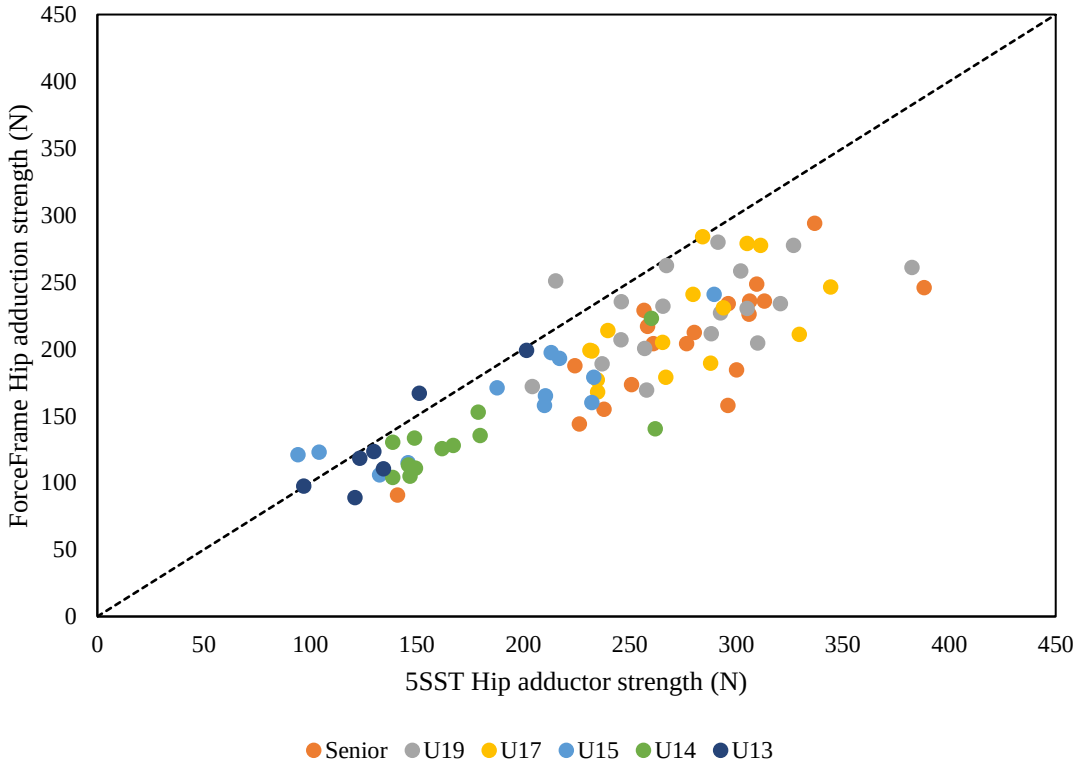


FIGURE 1b Scatterplot and line of equality for hip adduction strength measured as peak force (N)

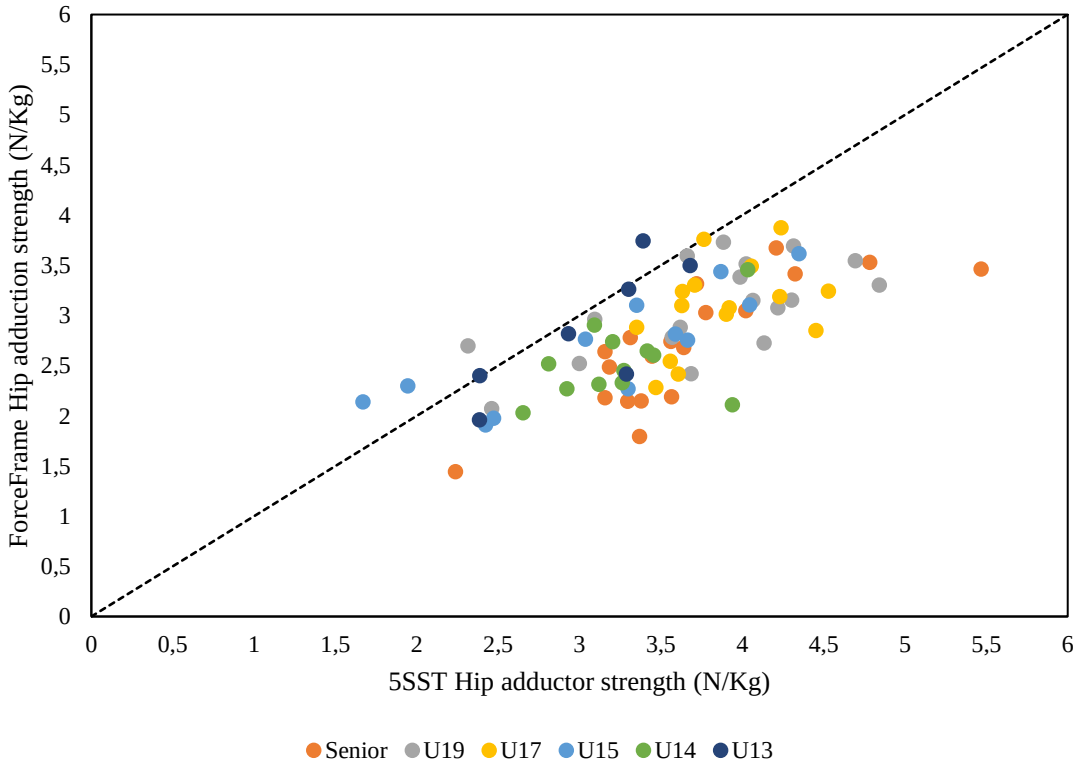


FIGURE 1c Scatterplot and line of equality for hip adduction strength measured as force-to-body mass ratio (N/Kg)

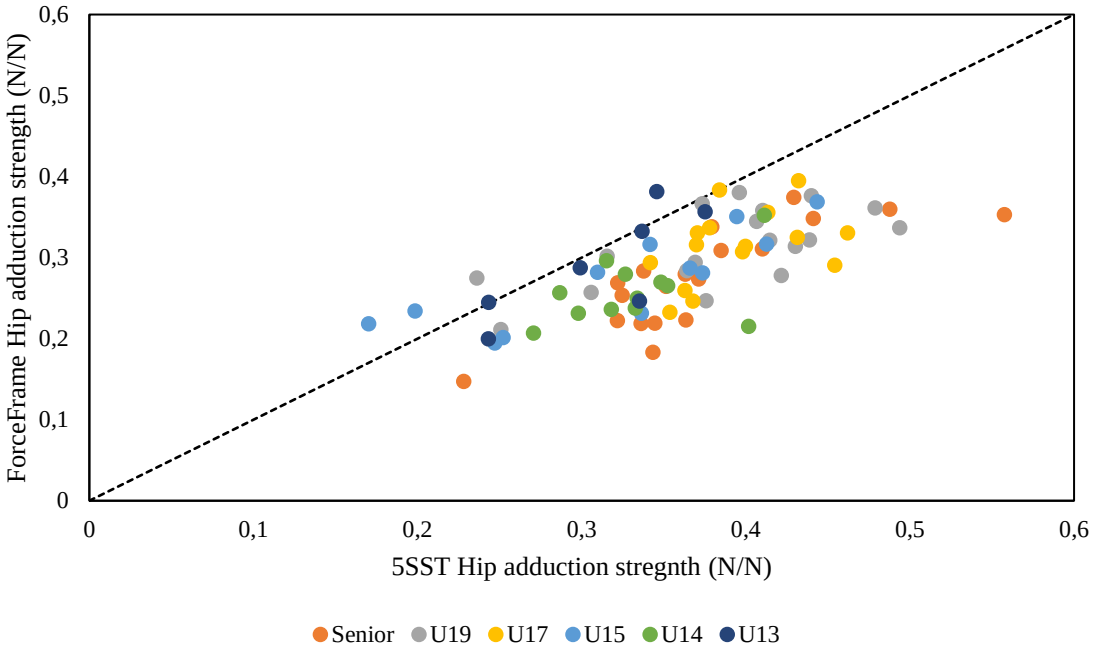


FIGURE 1d Scatterplot and line of equality for hip adduction strength measured as force-to-body weight ratio (N/N)

TABLE 2 Correlation coefficients for the relationships between the ForceFrame and the 5SST for strength and groin pain intensity

Measurement	**Pearson's r**	**P-value**
Torque-to-body mass ratio (Nm/Kg)	0.731	< 0.000
Torque (Nm)	0.877	< 0.000
Force (N)	0.857	< 0.000
Force-to-body mass ratio (N/Kg)	0.701	< 0.000
Force-to-body weight ratio (N/N)	0.701	< 0.000
Groin pain intensity (0-10)	0.401*	< 0.000

* Kendall's tau

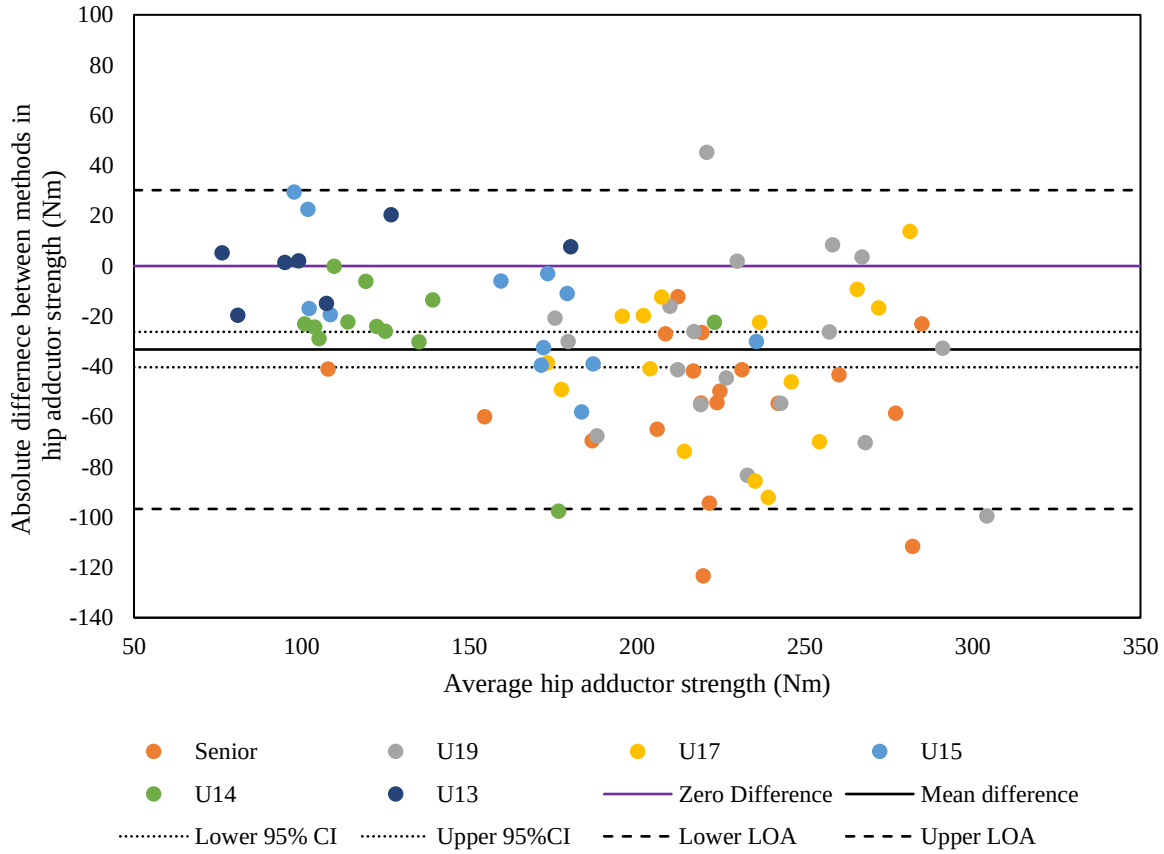


FIGURE 2a Bland-Altman plots for squeeze strength using difference in peak torque (Nm)

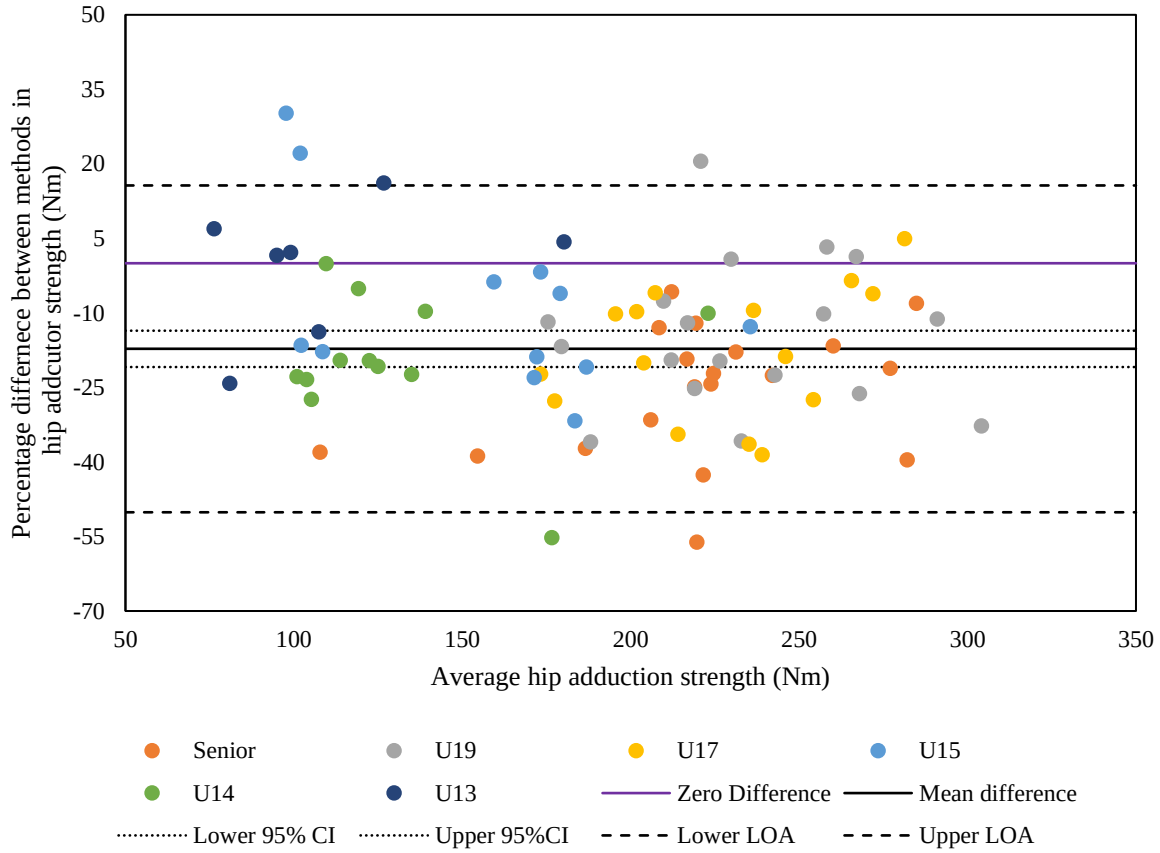


FIGURE 2b Bland-Altman plots for squeeze strength using percentage difference in peak torque (Nm)

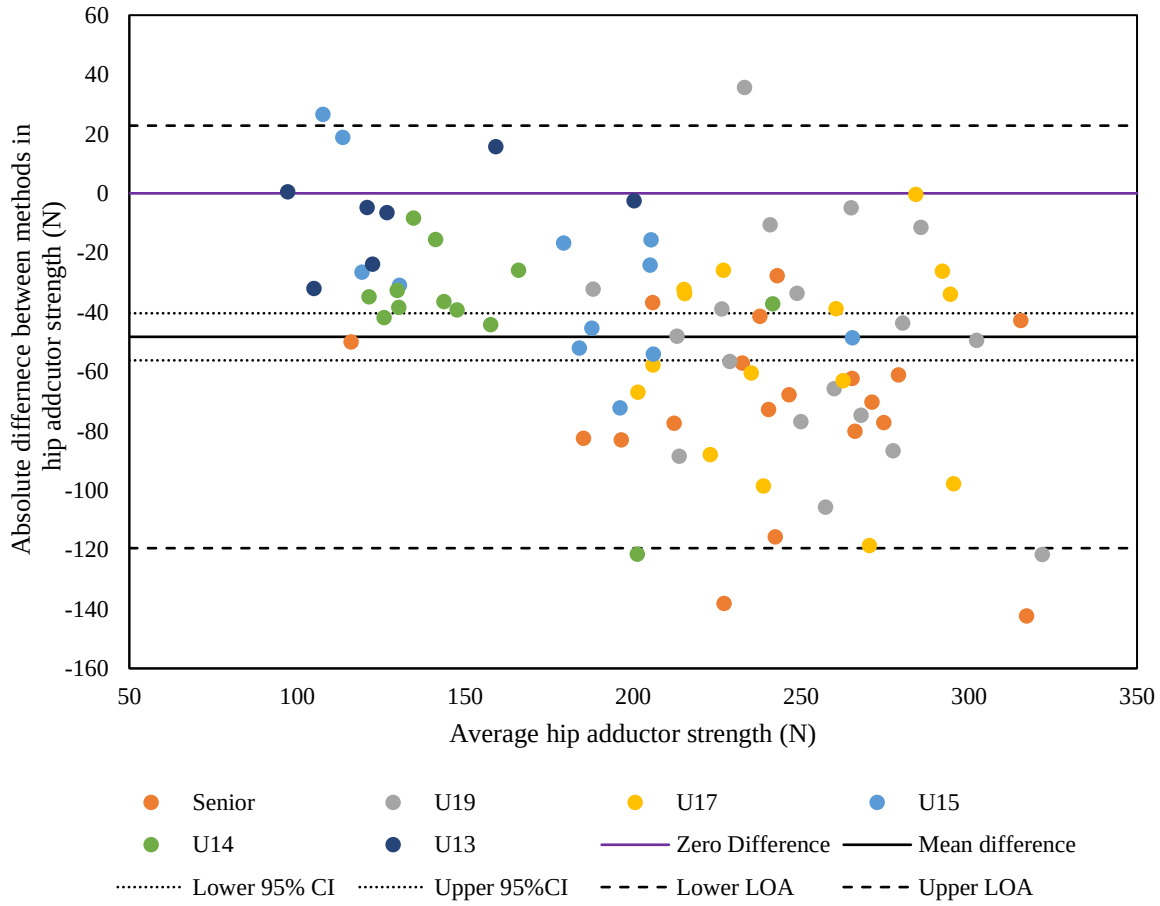


FIGURE 2c Bland-Altman plots for squeeze strength using difference in peak force (N)

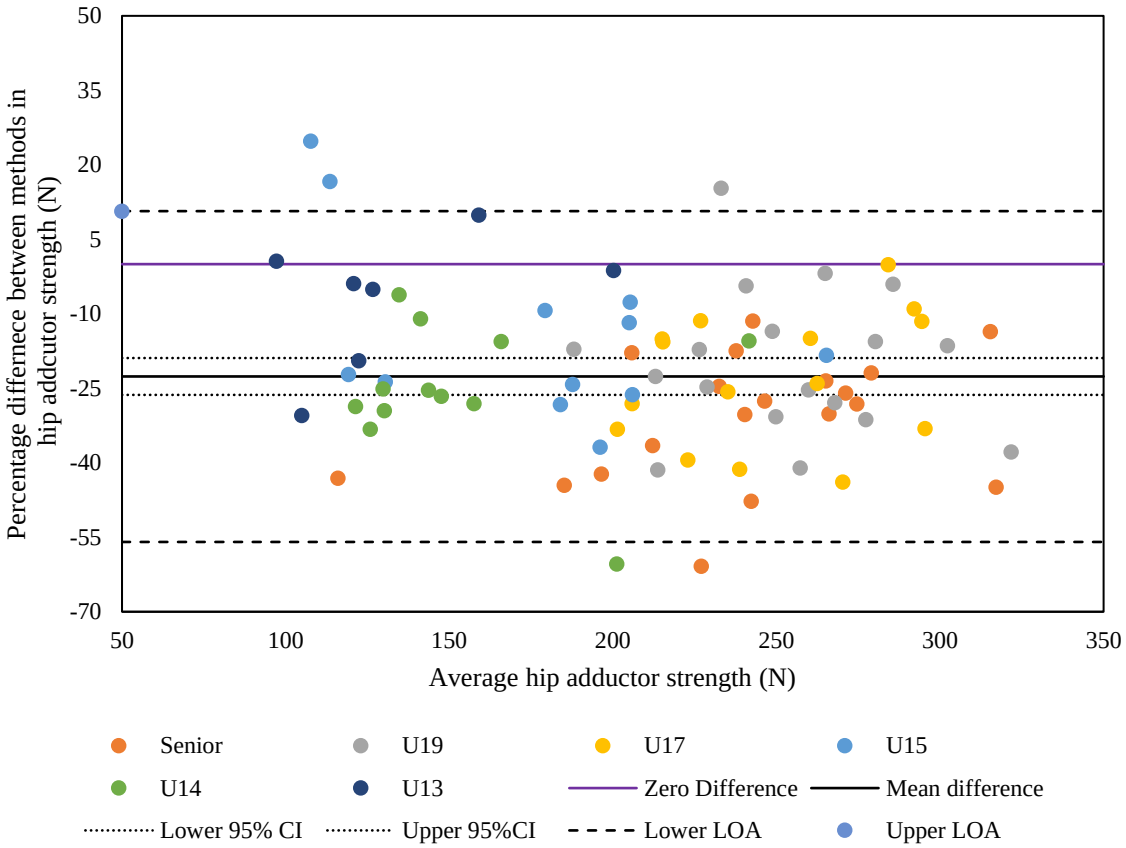


FIGURE 2d Bland-Altman plots for squeeze strength using percentage difference in peak force (N)

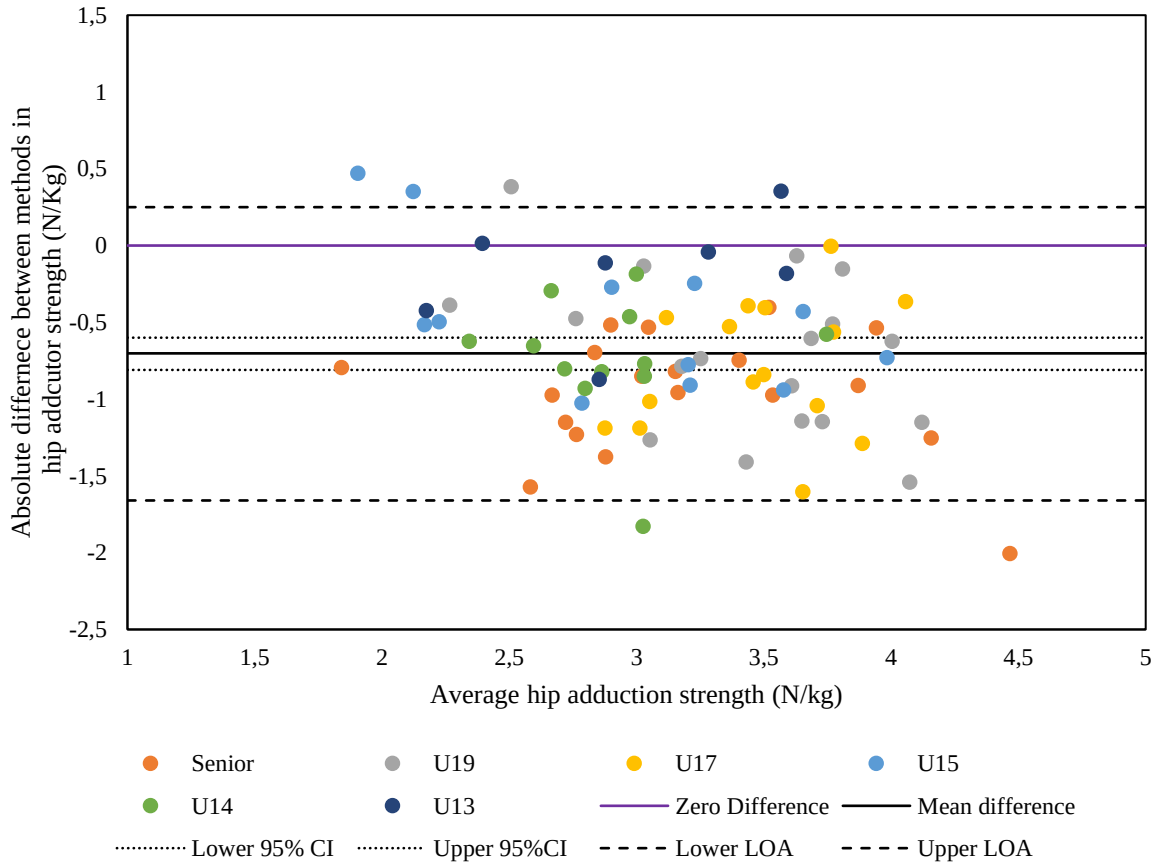


FIGURE 2e Bland-Altman plots for squeeze strength using difference in force-to-body mass ratio (N/Kg)

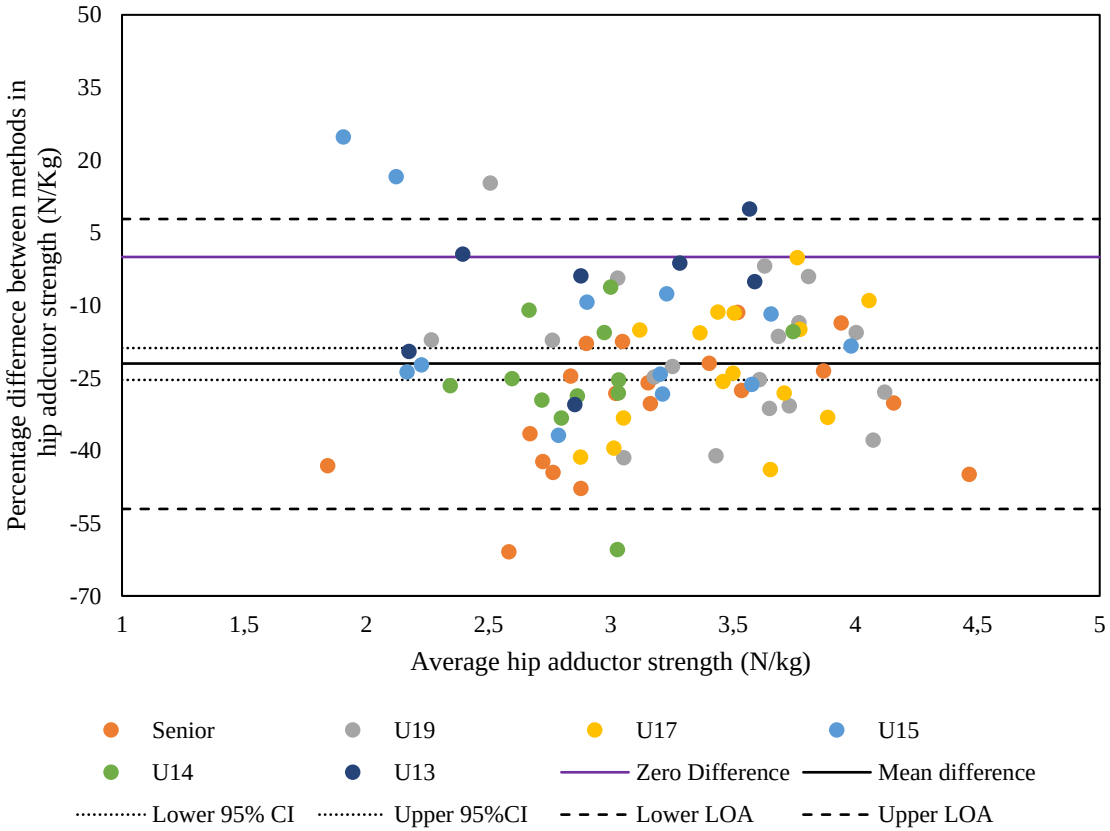


FIGURE 2f Bland-Altman plots for squeeze strength using percentage difference in force-to-body-mass ratio (N/Kg)

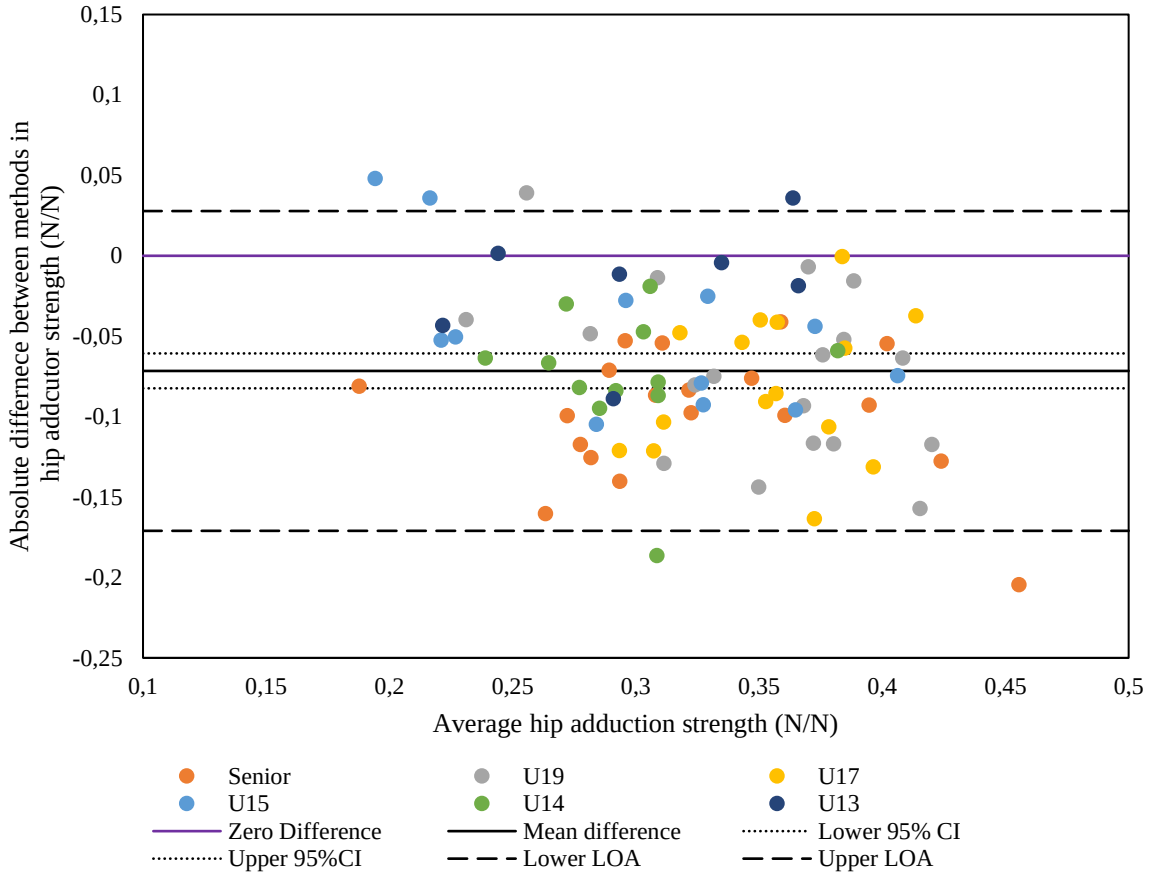


FIGURE 2g Bland-Altman plots for squeeze strength using absolute difference in force-to-body-weight ratio (N/N)

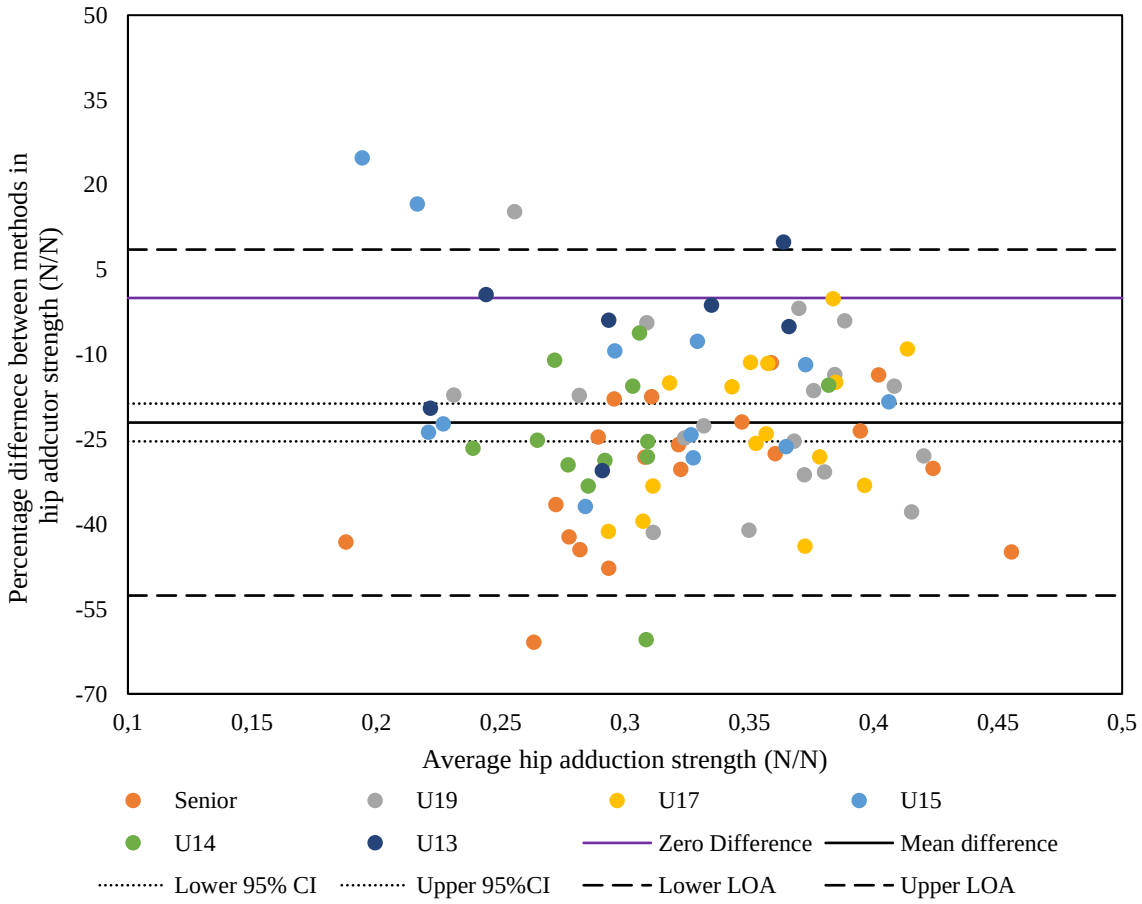


FIGURE 2h Bland-Altman plots for squeeze strength using percentage difference in force-to-body-weight ratio (N/N)

TABLE 3 Statistics used for Bland-Altman plots

Strength measurement	Mean difference	Standard error	Standard deviation	95% CI for mean difference	95% Limits of agreement
Torque-to-body mass ratio (Nm/Kg)	-0.47	0.048	0.437	-0.57; -0.38	-1.31; 0.39
Converted to percentages	-16.5%			-19.9%, -13.3%	-45.8%, 13.7%
Torque (Nm)	-33.22	3.55	32.37	-40.3; -26.2	-96.7; 30.2
Converted to percentages	-17.2%			-20.9%, -13.6%	-50.1%, 15.7%
Force (N)	-48.32	3.99	36.31	-56.25; -40.39	-119.5; 22.8
Converted to percentages	-22.6%			-26.3%; -18.9%	-55.9%; 10.7%
Force-to-body mass ratio (N/Kg)	-0.702	0.053	0.487	-0.81; -0.60	-1.66; 0.25
Converted to percentages	-22.0%			-25.4%; -18.8%	-52.0%; 7.8%
Force-to-body weight ratio (N/N)	-0.0716	0.0055	0.0497	-0.0824; -0.0607	-0.171; 0.0278
Converted to percentages	-22,0%			-25.4%; -18.7%	-52.6%; 8.5%

Table 4a Hip adduction strength measured as Force (N) assessed with the ForceFrame and the 5SST

	ForceFrame			5SST			ForceFrame vs 5SST	
Team	**Mean (SD)**	**Median [IQR]**	**Range**	**Mean (SD)**	**Median [IQR]**	**Range**	**Mean difference (95% CI)**	**p-value**
All (n=83)	189.4 (53.4)	197.5 [144.0-232.0]	89-294	237.7 (69.5)	246.0 [179.7-292.7]	94.3-388.3	-48.3 (-56.25; -40.39)	< 0.0000
U13 (n = 7)	129.3 (39.6)	118.5 [97.5-167]	89-199	136.9 (32.8)	129.9 [121-151.2]	96.9-201.5	-7.57 (-22-24, 7.09)	0.253
U14 (n=12)	133.6 (31.8)	129.3 [112.3-138.0]	104-223	173.2 (43.3)	155.7 [146,5-179.3]	138.8-262.0	-39.6 (-57.4, -21.9)	0.0005
U15 (n=12)	160.8 (39.8)	162.5 [122.0-186.0]	106-241	189.2 (58.3)	210.2 [139.2-224.7]	94.3-289.6	-28.4 (-47.0, -9.8)	0.0064
U17 (n=15)	220.0 (38,3)	211 [189.5-246.5]	168-284	276.1 (36.8)	279.8 [234.9-305.2]	231.3-344.4	-56.1 (-74.5, -37.7)	0.0000
U19 (n=18)	228.0 (33.5)	231.3 [204.5-258.5]	169.5-280	278.7 (43.5)	277.8 [246.0-305.2]	204.2-382.6	-50.7 (-70.1, -31.3)	0.0000
Senior (n=19)	204.2 (26.3)	212.5 [173.5-236.0]	91-294	277.2 (51.8)	280.3 [250.9-306.3]	141-388	-72.9 (-87.9, -57.9)	0.0000

Table 4b Hip adduction strength measured as Torque (Nm) assessed with the ForceFrame and the 5SST

	ForceFrame			5SST			ForceFrame vs 5SST	
Team	**Mean (SD)**	**Median [IQR]**	**Range**	**Mean (SD)**	**Median [IQR]**	**Range**	**Mean difference (95% CI)**	**p-value**
All (n=83)	176.3 (54.7)	184.1 [127.9-214.8]	71.2-288.3	209.5 (66.9)	221.8 [150.0-265.2]	73.6-353.9	-33.22 (-40.29; -26.15)	< 0.0000
U13 (n = 7)	109.6 (38.9)	100.0 [78.9-136.9]	71.2-184.1	109.2 (33.0)	97.9 [90.8-116.4]	73.6-176.3	0.42 (-12.2, 13,0)	0.937
U14 (n=12)	117.9 (32.7)	111.2 [97.2-123.9]	89.4-211.9	144.4 (41.9)	129.6 [117,8-147.9]	109.7-234.2	-26.5 (-41.8, -11.1)	0.0030
U15 (n=12)	147.5 (36.8)	155.2 [112.8-169.6]	93.8-220.5	164.4 (52.6)	179.6 [114.4-198.7]	83.0-250.5	-16.9 (-33.1, -0.64)	0.0429
U17 (n=15)	207.5 (39,4)	193.1 [183.5-225.3]	152.9-288.3	246.3 (34.5)	250.9 [211.6-277.9]	192.5-289.2	-38.8 (-55.8, -21.8)	0.0002
U19 (n=18)	216.4 (37.0)	209.9 [191.4-244.3]	154.3-274.7	250.2 (43.0)	247.7 [221.9-270.4]	185.8-353.9	-33.8 (-51.5, -16.0)	0.0009
Senior (n=19)	193.3 (43.0)	196.6 [17.5-214.8]	87.4-273.4	248.6 (46.0)	249.5 [222,0-281,3]	128.3-337.8	-55.,3 (-69.2, 41.4)	0.0000

Table 4c Hip adduction strength measured as Force-to-body mass ratio (N/Kg) assessed with the ForceFrame and the 5SST

	ForceFrame			5SST			ForceFrame vs 5SST	
Team	**Mean (SD)**	**Median [IQR]**	**Range**	**Mean (SD)**	**Median [IQR]**	**Range**	**Mean difference (95% CI)**	**p-value**
All (n=83)	2.84 (0.55)	2.82 [2.42-3.30]	1.44-3.88	3.54 (0.67)	3.57 [3.18-4.02]	1.67-5.47	-0.70 (-0.81; -0.60)	< 0.0000
U13 (n = 7)	2.87 (0.65)	2.82 [2.40-3.50]	1.96-3.74	3.05 (0.50)	3.29 [2.39-3.39]	2.39-3.68	-0.18 (-0.53, 0.17)	0.261
U14 (n=12)	2.53 (0.39)	2.49 [2.30-2.70]	2.03-3.46	3.27 (0.41)	3.23 [3,01-3.44]	2.65-4.03	-0.73 (-0.99, -0.47)	0.0001
U15 (n=12)	2.68 (0.57)	2.76 [2.21-3.11]	1.91-3.62	3.14 (0.85)	3.32 [2.45-3.77]	1.67-4.35	-0.46 (-0.76, -0.15)	0.0070
U17 (n=15)	3.09 (0,45)	3.10 [2.85-3.30]	2.28-3.88	3.87 (0.36)	3.77 [3.61-4.23]	3.35-4.53	-0.78 (-1.03, -0.54)	0.0000
U19 (n=18)	3.07 (0.47)	3.12 [2.73-3.52]	2.07-3.73	3.77 (0.69)	3.94 [3.57-4.22]	2.32-4.84	-0.70 (-0.96, -0.44)	0.0000
Senior (n=19)	2.70 (0.62)	2.68 [2.18-3.32]	1.4-3.7	3.66 (0.69)	3.56 [3.30-4.02]	2.24-5.47	-.96 (-1.15, -.77)	0.0000

Table 4d Hip adduction strength measured as Force-to-body weight ratio (N/N) assessed with the ForceFrame and the 5SST

	ForceFrame			5SST			ForceFrame vs 5SST	
Team	**Mean (SD)**	**Median [IQR]**	**Range**	**Mean (SD)**	**Median [IQR]**	**Range**	**Mean difference (95% CI)**	**p-value**
All (n=83)	0.289 (0.056)	0.287 [0.246-0.337]	0.147-0.395	0.361 (0.069)	0.364 [0.325-0.410]	0.170-0.558	-0.072 (-0.082, -0.061)	< 0.000
U13 (n = 7)	0.293 (0.066)	0.287 [0.245-0.357]	0.200-0.381	0.311 (0.051)	0.335 [0.243-0.346]	0.243-0375	-0.018 (-0.054, 0.018)	0.261
U14 (n=12)	0.258 (0.039)	0.253 [0.233-0.277]	0.207-0.353	0.333 (0.042)	0.330 [0.302-0.351]	0.270-0.411	-0.075 (-0.101, -0.048)	< 0.000
U15 (n=12)	0.274 (0.058)	0.282 [0.222-0.317]	0.195-0.369	0.321 (0.087)	0.339 [0.248-0.389]	0.170-0.443	-0.047 (-0.078, -0.016)	0.007
U17 (n=15)	0.315 (0.0459)	0.316 [0.291-0.337]	0.233-0.395	0.395 (0.0368)	0.384 [0.368-0.431]	0.342-0.462	-0.080 (-0.105, -0.055)	< 0.000
U19 (n=18)	0.313 (0.048)	0.318 [0.277-0.359]	0.211-0.381	0.384 (0.070)	0.401 [0.352-0.432]	0.236-0.494	-0.072 (-0.098, -0.045)	< 0.000
Senior (n=19)	0.275 (0.063)	0.274 [0.223-0.338]	0.147-0.375	0.374 (0.071)	0.363 [0.336-0.410]	0.228-0.558	-0.098 (-0.118, -0.078)	< 0.000

STUDY IV

Pain sensitivity, psychological factors, and muscle function in male athletes with long-standing groin pain and matched controls

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SECTION IV: SPORTS MEDICINE & ORTHOPAEDICS

TITLE

Pain sensitivity, psychological factors, and muscle function in male athletes with longstanding adductor-related groin pain and matched controls

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ABSTRACT

Longstanding groin pain has traditionally been viewed as a local musculoskeletal injury. Reduced maximal strength, multiple painful sites without clear injuries, and decreased quality of life suggest that neural-, and psychological-related factors may also characterize the condition. The aim was to explore differences in pain sensitivity, psychological factors, and muscle function between male athletes with longstanding adductor-related groin pain (ARGP) and matched asymptomatic athletes. We included 20 male athletes with ARGP for >12 weeks, and 20 sex, age and sports-matched asymptomatic controls. Pain sensitivity was assessed with pressure pain thresholds (PPT) at the adductor longus muscle and origin, iliopsoas tendon, pubic bone, gluteus maximus, pubic symphysis and the elbow. Additionally, pain detection thresholds (PDT), pain tolerance thresholds, temporal summation of pain, and conditioned pain modulation were assessed at the lower leg with computer-controlled cuff-pressure algometry. Psychological factors (catastrophizing, fear of movement, pain self-efficacy, depression, anxiety, stress, loneliness, sleep quality) were evaluated with 13 brief questions. Muscle function was assessed with hip adduction squeeze and abduction-press tests and a handheld dynamometer to measure maximal strength (Nm/kg) and explosive strength (rate of torque development [RTD, Nm/s/kg] in 0-100ms and 0-200ms intervals). Between group effect sizes in favor of asymptomatic athletes are reported as Cohen's d and rank-biserial correlation r. Large to moderate effect sizes were seen in squeeze RTD-100 (d = 0.55), squeeze RTD-200 (d = 0.84), abduction-press RTD-100: d = 0.91, abduction-press RTD-200 d = 0.68), abduction-press maximal strength (d = 0.62), pain sensitivity (PPT all sites: d = 0.73 to 1.21, PDT: d = 0.71), and psychological factors (catastrophizing: r = 0.58), fear of movement: r = 0.61), pain self-efficacy: r = 0.63). For the remaining variables, effects were small to negligible. Male athletes with longstanding ARGP display widespread mechanical hyperalgesia, elevated pain catastrophizing, fear of movement and depressive symptoms, reduced pain self-efficacy and reduced explosive hip strength compared to matched controls.

1 INTRODUCTION

Adductor-related groin pain (ARGP) is the most common clinical entity of groin pain in male football players with longstanding groin pain[1,2] and it causes significant reduced participation in football,[2–4] substantial deficits in physical- and sports-related function,[5,6] and reduced quality of life.[4,6–8] Athletes with longstanding ARGP often report an unilateral pain that is aggravated by physical activity and have lasted for up to 12 months.[2,9,10] Pain is typically centered around the adductor longus origin,[2,10,11] but may also radiate throughout the groin region to the medial thigh, anterior hip, and lower abdomen.[2,10,11] Up to one-third of athletes with ARGP report bilateral groin pain,[2,8,10,11] which is associated to larger painful area,[2] multiple concomitant groin pain entities[10] (e.g., iliopsoas-, inguinal-, pubic-, or hip joint-related groin pain), higher pain intensity,[10] worse disability,[10] higher time-loss from sport,[12,13] and worse treatment outcome.[11] The number of clinical entities also correlate with pain intensity and disability.[4] Which altogether suggest that the spatial extent of groin pain is related with severity of pain and disability.

Management of ARGP aims to alleviate pain and restore physical function by targeting groin pain entities and physical deficits with progressive strength, balance, and coordination exercises.[11,14,15] While most athletes return to sport, between 14% to 50% of athletes with longstanding ARGP fail to return to pre-injury sport and performance,[11,15–17] and even in those returning to sport significant groin-related disability and physical deficits are common even after RTS.[18–21] This suggest that full return to sport with normalized disability, and function, may be influenced by other factors than clinical entities and physical deficits[20] which are not yet considered by the current management of ARG.[11,14,15]

In 2017 a International Olympic Committee (IOC) consensus statement advocated for incorporating a biopsychosocial model of pain in the of pain in athletes.[22] They suggested that assessment and management should including a broad spectrum of neurophysiological, psychological and biomechanical factors that may contribute to pain in athletes.[23–25]

Pain sensitivity could be an important neurophysiological factor as it reflect the function of peripheral and central nociceptive pain mechanisms.[22,24,25] Pain sensitivity is assessed with quantitative sensory testing (QST) and variables such as pressure pain thresholds (PPT), temporal summation of pain (TSP) and conditioned pain modulation (CPM).[26] QST has been widely used to phenotype patients with musculoskeletal pain,[27,28] and to predict treatment outcomes.[29–31] However, only one study has examined QST in athletes with groin pain,[32] identifying hyperalgesia (reduced PPT) at the adductor longus tendon as a key factor explaining pain across clinical entities

in male Australian football players.[32] In patients with hip-joint related groin pain (HRGP), higher pain intensity before and after hip arthroscopy was associated with TSP assessed on the hand.[33] These novel findings suggest that understanding pain sensitivity in athletes with longstanding AGRP could pave a way to improve management strategies. pain.

Psychological factors constitute a core element in athlete's subjective pain experience.[24,25] Athletes with longstanding ARGP have significant reductions in disability measures such as HAGOS[34] and iHOT-33[35] which contain single items/questions on fear avoidance behavior, sleep disturbances, negative mood, and frustration.[34,35] However, only one study of athletes with longstanding pubic- and/or adductor-related groin pain has measured a distinct psychological factor and observed elevated levels of pain catastrophizing that resolved over 3 and 12 months with non-surgical treatment.[19] Similarly, in patients with HRGP undergoing hip arthroscopy higher levels of pain catastrophizing,[36–40] fear of movement/kinesiophobia,[37–41] low self-efficacy,[39,40] depression,[39,40,42] anxiety,[39,40,42] and poor mental health,[43,44] are associated with worse pain,[36,39] disability,[39,42,44] function[44] and treatment outcomes.[36–38,40,43,44] There is therefore a need for further mapping of psychological factors in athletes with longstanding ARGP.

Longstanding pain influences central neuromuscular mechanism regulating motor output and muscle function.[45,46] Athletes with ARGP move differently than asymptomatic athletes[47] and have deficits in maximal hip muscle strength.[5,6,20,48] However, as maximal hip muscle strength only explain a small proportion of self-reported function,[20] it may be relevant to explore aspects of muscle function. Explosive strength, expressed as rate of torque development (RTD), is a centrally driven strength component that is highly important for sports performance[49] and may be even more sensitive to pain and nociceptive stimulus than isometric strength.[50] RTD could be important for self-reported function and disability as well as return to sport and performance in athletes with longstanding ARGP,[49] however, it has not yet been measured in these athletes.

The aim for this study was therefore to explore new modifiable and non-modifiable factors in male athletes with longstanding adductor-related groin pain. More specifically, our objective was to compare measures of pain sensitivity, psychological factors, and muscle function between symptomatic athletes and matched controls.

2 METHODS

This explorative cross-sectional case-control study was approved by the Danish Capital Region ethics committee (H-20055130) and conducted in accordance with the Declaration of Helsinki. Reporting follows the STROBE guidelines.[51] The study protocol is available upon reasonable request. Data collection occurred from November 2021 to April 2024 at the Sports Orthopedic Research Center – Copenhagen at Copenhagen University Hospital Amager-Hvidovre in Hvidovre, Denmark. All athletes provided informed consent. Reimbursement after participation were a treatment consultation for symptomatic athletes and 300 DKK for asymptomatic athletes.

2.1 Participants

Male athletes (18-35 years, fluent in Danish), from the Capital Region and Zealand, Denmark were recruited via social media, online ads, and football clubs. Symptomatic and asymptomatic athletes were group-matched by sex (male), age (± 1-2 years) and sport to control for sex, age, and sports as potential confounders.

Symptomatic athletes had adductor-related groin pain ≥ 3 months, and an average weekly sports activity of ≥3 hours. Exclusion criteria included hip-joint related groin pain (a positive FADIR test and a positive diagnostic hip injection), hip dysplasia (lateral center edge angle < 20°), borderline hip dysplasia (lateral center edge angle = 20-25°), pre-existing hip osteoarthritis (lateral joint space width < 3 mm), Perthes' disease, slipped upper femoral epiphysis, avascular necrosis, acetabular fracture, hip dislocation, femoral neck fracture, stress fracture, referred pain from facet or sacroiliac joints, previous hip surgery, serious pathology, competing diseases or a reduced sports-activity level for reasons other than groin pain.

Asymptomatic athletes met the same criteria, but had no hip and groin pain, or musculoskeletal pain or injuries in the past 3 months, and no groin pain during a Copenhagen five-second squeeze test.

2.2 Study procedures

Athletes underwent a telephone screening, in-person screening, standardized clinical and radiographic examinations, and an experimental session. The experimental session assessed mechanical pain sensitivity, psychosocial factors, muscle function, pain intensity, pain location, Copenhagen Hip and Groin Outcome Score (HAGOS), and demographic data in a predetermined order (procedures are detailed in the supplementary File).

One male physiotherapist (MFN) with five years of experience, conducted telephone and in-person screening, clinical examinations of asymptomatic athletes, and experimental session. A male orthopedic surgeon (PH), with 33 years of experience and specialized in groin pain, performed the clinical examinations of symptomatic athletes, including clinical interpretation of radiographic examination.

For the experimental session, athletes received standardized, scripted instructions about each procedure to ensure comprehensive information and to minimize fear of the procedures. Athletes were instructed to avoid pain medication for eight hours before any study assessments. Due to practical constraints, assessor blinding during the experimental session was not possible.

2.3 Clinical and radiological examination

The examination included history taking, palpation, manual resistance testing, passive stretching, the Flexion-Adduction-Internal Rotation (FADIR) test, the Flexion-Abduction-External Rotation (FABER) test and an evaluation of anteroposterior pelvic view and a cross-table lateral hip view radiograph. Clinical tests were positive if they provoked known and recognizable groin pain. The radiographs were evaluated for exclusion criteria, and commonly used hip-related parameters.[52] Based on the findings, symptomatic athletes were classified according to the Doha agreement.[8,53] A musculoskeletal radiologists independently evaluated all radiographs for hip- and pubic-related parameters[54] for descriptive purposes.

2.4 Pain Sensitivity

Pain sensitivity was assessed using the quantitative sensory testing measures: pressure pain thresholds (PPT) measured with a handheld pressure algometer with a 1 cm^2 tip (Somedic, Sweden);[32,55] pain detection thresholds (PDT),[55] pain tolerance thresholds (PTT),[55] temporal summation of pain (TSP)[55] and conditioned pain modulation (CPM)[56] assessed with a computer-controlled cuff-pressure algometer (Nocitech and Aalborg University, Denmark).[55,56] The cuff algometer consisted of two tourniquet cuffs (placed 5 cm below the tibial tuberosity), an electronic visual analog scale (VAS, 0-10 cm, “no pain” to “worst pain imaginable”), and a cuff-pressure termination button.[55,56] To standardize pain sensitivity assessments, each leg was designated as either the index or secondary side. For symptomatic athletes, the index side was the most painful, while the secondary side was the least painful or pain-free. For asymptomatic athletes, side designation was randomized with no consideration of dominant side.

2.4.1 Pressure pain thresholds

PPT were assessed bilaterally, starting with the secondary side. PPTs were measured by applying pressure perpendicular to the skin at 30 kPa/s across 12 sites.[55] Two PPT measurements, separated by approximately 1 minute, were conducted per site and averaged for analysis.[55] The PPT was the pressure (kPa) at which athletes signaled a transition from pressure to pain using a hand-held button.[55] The PPT sites were the adductor longus muscle belly (ADL), adductor longus muscle origin (ADL Origin), iliopsoas just inferior to the inguinal ligament (Iliopsoas), pubic bone (Pubic Bone), pubic symphysis joint (Pubic Symphysis, not measured bilaterally), gluteus maximus muscle (Glut Max), and contralateral lateral elbow epicondyle (Elbow, not measured bilaterally). A maximum of 1000 kPa was set as a safety limit. PPTs assessed with handheld algometry have almost perfect test-retest reliability (ICC: 0.87 to 0.89).[55]

2.4.2 Pain detection and tolerance thresholds

PDT and PTT were assessed once per side, starting with the index side. PDT and PTT were measured using a ramp increase in cuff-pressure from 0-100 kPa at 1 kPa/s.[55] Athletes continuously rated the cuff-induced pain intensity on the electronic VAS (0-10 cm) and pressed the termination button when pain became intolerable or VAS = 10.[55] PDT was the pressure (kPa) when the VAS >1 cm,[55] while PTT was the pressure when the cuff-stimulation was terminated.[55] Assessment of PDT and PTT at the leg using a cuff algometer have substantial to almost perfect test-retest reliability (ICC: 0.74-0.87).[55]

2.4.3 Temporal summation of pain

TSP was assessed by applying 10 repeated cuff-pressure stimulations to the lower leg on the index side.[55] Each stimulation consisted of rapid inflation (100kPa/s) of the cuff to a painful pressure (corresponding to index side PTT) for 1-second followed by a deflation of the cuff to a non-painful pressure (5 kPa) for 2-seconds.[55] Using the VAS, athletes continuously rated cuff-induced pain intensity of each painful pressure stimuli.[55] Mean VAS scores were calculated for intervals 1-4 (VAS-1), intervals 5-7 (VAS-2) and intervals 8-10 (VAS-3).[55] TSP was the ratio between VAS-3 and VAS-1. Assessment of TSP using a cuff algometer have moderate reliability (ICC: 0.6).[55]

2.4.4 Conditioned pain modulation

CPM was assessed using an additional assessment of PDT and PTT (see above) on the index side, and on the secondary side a simultaneous conditioning stimulus was applied at 75% of the secondary side PTT pressure.[56] The conditioning stimulation was maintained until the index side PDT and PTT assessments were completed.[56] The CPM-effect was evaluated as the absolute difference in index side PDT and PTT from before to during the conditioning stimulus.[56] Assessment of CPM using this approach has moderate to almost perfect relative test-retest reliability (ICC range: 0.53-0.75).[56]

2.5 Psychological factors

Psychological factors were assessed using 13 brief screening questions[57–59] (Table 3) on pain beliefs (catastrophizing [2-items], fear of movement [2-items], pain self-efficacy [2-items]) and mental health (depression [2-items], anxiety [1-item], stress [1-item], loneliness [1-item], and sleep [2-items]).[57–59] Responses were rated from 0 (not affected) to 10 (highly affected),[58,59] except for sleep amount (weekly average hours) and pain self-efficacy (scored 0–6, with 0 being the lowest).[57] Pain self-efficacy item scores were aggregated, with a total of ≥8 indicating a desirable level.[57] The brief screening questions have acceptable concurrent validity compared to full-length questionnaires,[58,59] but their reliability has yet to be established.

2.6 Muscle Function

Muscle function was assessed as maximal strength and rate of torque development (RTD) using a handheld dynamometer (MicroFET2, Hoggan, Scientific L.L.C., Salt Lake City, USA) during hip adduction squeeze and hip abduction-press tests.[49,60] The dynamometer recorded force (N) at 100 Hz with torque (Nm) calculated based on the distance (m) from the anterior superior iliac spine to the dynamometer's center of pressure.[49] Maximal strength was normalized to body mass (kg) as isometric peak torque (Nm/kg).[49] RTD was normalized change in torque (Nm/s/kg) over 0-100 milliseconds (RTD_{100}) and 0-200 ms (RTD_{200}) intervals.[49] Test-evoked groin pain intensity was recorded on a 0-10 numeric rating scale (NRS, "no pain" to "worst pain imaginable").[60,61] Athletes performed a 50% and a 100% effort warm-up trial, followed by three 100% max effort trials where they squeezed/pressed as fast and hard as possible.[49] The highest values across valid trials were used in the analyses.[49] This method shows substantial to almost perfect intra-tester reliability (Torque ICC = 0.93, RTD_{100} ICC = 0.63, RTD_{200} ICC = 0.86).[49]

2.7 Descriptive Data

Descriptive data included age, pain duration, injury mechanism, previous treatment, sport type and participation level, pain medication use, educational level, body mass, and height. Symptomatic athletes rated current, worst, least and usual groin pain over the past week using a verbal pain NRS.[62] They also reported distribution of usual groin pain during sports using reliable and validated digital pain drawings on high-resolution 2D body charts in Navigate Pain (Aglance Solutions, Aalborg Denmark).[2] Hip- and groin-related disability was assessed using the revised Copenhagen hip and groin outcome score (HAGOS).[34,63]

2.8 Sample size

This explorative study aimed to detect large to very large effect sizes (Cohen's d > 0.8), as such effects likely indicate meaningful signals for future research. Based on previous studies,[27,28,64] a large effect size (Cohen's *d* > 0.9) in PPTs could be detected with 80% power and 5% significance level using 20 symptomatic and 20 asymptomatic athletes.

2.9 Statistics

Descriptive data are presented as mean and standard deviation, median and interquartile range, or numbers and percentages as appropriate.

All pain sensitivity variables were compared between groups, according to index and secondary side measurements, using two-sided unpaired t-tests and effect sizes were estimated as Cohens *d.* To control for bilateral pain influencing secondary side comparisons, the symptomatic athletes were sub-grouped based on uni- or bilateral groin pain. To account for the repeated measures subject variability in PPT measures, we also conducted a repeated measures analysis of variance (ANOVA) for PPT values including Group (Symptomatic athletes, Asymptomatic Athletes) as between subject factor, Site (Adductor Longus Muscle, Adductor Longus Origin, Iliopsoas, Pubic Bone, Pubic Symphysis, Gluteus Maximus, Elbow) as within-subject factor and their interaction. As the ANOVA model violated the sphericity assumption both Greenhouse–Geisser and Huynh–Feldt corrections were applied, and all p-values from post-hoc comparisons were Benjamini-Hocberg adjusted.

Psychological variables did not approximate normality and were compared between groups using Wilcoxon rank-sum tests, with effect sizes as rank-biserial correlation *r*.

Muscle function variables approximated normality and were compared between groups using two-tailed unpaired t-tests and effect sizes were estimated as Cohens d.

All effect sizes were interpreted as small (0.2), moderate (0.5) and large (0.8).[65] We report Both unadjusted p-values and adjusted p-values, using the Benjamini-Hocberg procedure.[66] Statistical analyses were performed in R version 4.3.0, RStudio 2022.12.0+353.

3 RESULTS

3.1 Participants

Participant flow and characteristics are presented in Figure 1 and Table 1, respectively. Pain distributions are visualized in Figure 2. Additional clinical and radiographic findings are available in appendix Table A1 and A2.

FIGURE 1 HERE

TABLE 1 HERE

FIGURE 2 HERE

3.2 Pain Sensitivity

3.2.1 Pressure pain thresholds

PPTs for the index and secondary side are presented in Figures 3-4 and Appendix Tables A3, A5 and A6. Symptomatic athletes showed moderate to large reductions in PPTs at every site on the index side compared to asymptomatic athletes (Cohen's d = 0.73 to 1.21).

FIGURE 3 HERE

On the secondary side, athletes with bilateral groin pain also showed large reductions in PPTs at all other sites than the adductor longus origin (Cohen's d > 1.17). Athletes with unilateral groin pain showed a large reduction in PPTs only at the Gluteus Maximus muscle (d = 0.85) on the secondary side. The two-way ANOVA analyses showed statistically significant main effects of group ($F(1, 38) = 13.15$, $p = 0.00084$) and site ($F(6, 228) = 78.66$, $p < 0.0001$), with no group x site interaction ($F(6, 228) = 1.87$, $p = 0.087$) (see appendix and supplementary files for details).

FIGURE 4 HERE

3.2.2 Pain Detection Thresholds, Pain Tolerance Thresholds, Temporal Summation of Pain and Conditioned Pain Modulation

All PDT, PTT, TSP and CPM measures are presented in Table 2. On the index side, symptomatic athletes had large reductions in PDT, and higher pain intensities at PTT and cPTT compared to asymptomatic athletes.

On the secondary side, athletes with unilateral groin pain also showed large reductions in PDT, whereas both athletes with uni- and bilateral groin pain reported higher pain intensity at PTT compared to asymptomatic athletes. No between-group differences were observed for TSP or CPM variables.

TABLE 2 HERE

3.3 Psychological factors

Psychological factors are presented in Table 3. Symptomatic athletes reported reduced pain self-efficacy and higher levels of pain catastrophizing, fear of movement and depressive symptoms compared to asymptomatic athletes. No between-group differences were observed for the remaining items.

TABLE 3 HERE

3.4 Muscle function

Maximal and explosive strength are presented in Figure 5 and Appendix Table A4. Symptomatic athletes showed large reductions in hip adduction squeeze RTD_{200} (d = 0.84) and hip abduction RTD_{100} (d = 0.92), as well as moderate reductions in hip adduction RTD_{100} (d = 0.55).

Symptomatic athletes reported severe (NRS median: 7.0 [IQR: 4.0 to 8.0]) and mild (NRS median 2.5 [IQR: 0.8 to 5.0]) groin pain from hip adduction and abduction testing, respectively. Asymptomatic athletes reported no provoked pain.

FIGURE 5 HERE

4 DISCUSSION

This study compared comprehensive pain sensitivity measures, multiple psychological factors as well as maximal and explosive hip strength between male athletes with longstanding adductor-related groin pain and matched controls. Symptomatic athletes displayed widespread lower pressure-pain thresholds, elevated levels of pain catastrophizing, fear of movement and depressive symptoms, lower levels of pain self-efficacy, and reduced explosive hip adduction and abduction strength compared to matched controls.

4.1 Pain Sensitivity

Using QST we found large reductions in PPTs at the most symptomatic groin and moderate reductions at contralateral groin and remote sites, indicating widespread mechanical hyperalgesia in the symptomatic athletes. However, TSP and CPM did not differ between groups, suggesting that modulatory pain mechanisms are not significantly different from matched controls. Collectively, these results indicate that athletes with longstanding adductor-related groin pain exhibit altered nociceptive function, but no clear dysfunction of higher-order pain modulation. In comparison, Drew et al. found that Australian football players with groin pain exhibit mechanical hyperalgesia at the adductor-longus tendon, irrespective of type of groin pain entity, but no remote hyperalgesia at the tibialis anterior was presented in their study.[32] Several factors may account for these discrepancies with our findings. First, pain severity is recognised as a potent driver of altered nociceptive function.[67,68] Drew et al. did not describe pain duration, intensity or disability, whereas our symptomatic athletes had a median pain duration of 52 weeks, an pain intensity of 6.7, and notably low HAGOS scores (Table 1). Second, It has been suggested that groin pain develops due to compensating strategies in muscle surrounding the pelvis and could be viewed as a pelvic overload syndrome, that is not specifically overloading one structure in isolation, but several structures in combination.[21,69] This concept may explain the observed regional hyperalgesia, remote hyperalgesia at the lower leg, and why longstanding ARGP is often accompanied by additional groin pain entities[1,10] (symptomatic athletes had 3 entities on average in our present study). By overloading several structures concomitantly the extent of tissues producing nociceptive stimuli increases, which thereby may maintain and facilitate a vicious cycle of peripheral sensitization within the tissues and central sensitization at the T12–L5 spinal segments.[67,68] However, this explanation does not account for the increased pain sensitivity at the elbow seen in our study, which suggests sensitization of higher spinal segments independent of the hip and groin region.

Widespread hyperalgesia and sensitization of central pain mechanisms have also been observed in other and potentially more debilitating longstanding musculoskeletal pain conditions such as patellofemoral pain, low back pain, fibromyalgia, whiplash, knee osteoarthritis and chronic widespread pain.[67,68] However, the findings are not common in athletes with longstanding pain, as highlighted by two recent meta-analyses finding that athletes with lower-limb tendinopathies are characterized by local hyperalgesia at their primary site of pain, and not regional or widespread hyperalgesia.[70,71] Nevertheless, two studies involving pain in the hip and groin region have used the Central Sensitization Inventory (CSI) questionnaire in patients with HRGP.[36,72] They found that higher CSI scores, indicating sensitization of central pain mechanisms, are associated with higher pain intensity, worse mental health and lower pain self-efficacy before and after hip arthroscopy.[36,72]

Very few studies have explored higher-order pain modulation in athletes with longstanding groin pain. One study detected facilitated TSP with von Frey filaments applied at a finger in 23 of 51 (41 %) patients with HRGP.[33] The divergent TSP results compared to the findings of our study may be explained by Von Frey filaments preferentially activating cutaneous nociceptors, whereas cuff-algometry targets deep-tissue nociceptors. Another explanation could again be pain severity: the HRGP patients with facilitated TSP had a mean pain duration of 31 months which is substantially longer than the current sample. It is also not unreasonable that the rich mechanoreceptor and nociceptor innervation of the hip joint[73] is a more potent driver of nociceptive input than the adductor-complex. Continuous hip-joint loading during everyday activities could therefore sensitize central pain pathways more extensively in HRGP than in ARGP. Still, the current results of our study are here in line with a recent meta-analysis that also found no results of impaired CPM in athletes with lower-limb tendinopathies.[74]

4.2 Psychological Factors

Athletes with longstanding ARGP showed statistically significant increases in pain catastrophising, fear of movement, and depressive symptoms, together with lower pain self-efficacy compared with the matched controls. Although the differences reached small-to-moderate effect sizes, the scores seem lower than in patients with different longstanding pain conditions such as widespread pain, pain in multiple spinal areas, pain in spine and extremities, low back pain, and pain in extremities.[59,75,76] Interpretation of the brief screening questions is complicated by the fact that diagnostic cut-points for the brief screening questions were derived from populations with diverse

chronic pain conditions. The original validation studies derived the following thresholds: an average pain-catastrophising score ≥ 7 (or single-item score ≥ 7); fear-of-movement average ≥ 7 (or single-item ≥ 5); depressive-symptom score ≥ 7 or ≥ 6 on both questions; and pain self-efficacy total < 8 indicating low pain self-efficacy. When these thresholds are applied to the present data, psychological conditions can be ruled out for most symptomatic athletes, suggesting that while common psychological factors and traits may exist, they do not reach the level seen in patients with longstanding pain and psychological conditions.[59,75,76] Nevertheless, recent qualitative studies highlight that psychological factors are very important for athletes, as pain is intertwined with their lives, identities and daily actions.[77–79] Support for this in athletes with groin pain comes from Schöberl et al.,[19] who administered the full Pain Catastrophizing Scale (PCS; range 0-52) to 44 athletes with longstanding pubic-related groin pain and found a mean PCS of 22, with scores up to 42[19]. The mean PCS in these athletes exceeded reference values for healthy individuals (PCS ≈ 15) and for patients with lower-limb pain (PCS ≈ 13),[80] although it was below 30, the threshold for clinically relevant catastrophizing in patients with longstanding pain.[59]

4.3 Muscle function

The symptomatic athletes demonstrated 40% and 15% deficits in adduction and abduction RTD_{200}, respectively. This is well above the reported $MDC\%_{group}$ of 7.5% in healthy athletes.[49] Comparable reductions in hip-flexor and hip-extensor explosive strength have been reported in patients with hip-joint related groin pain before and after surgery.[81,82] For hip adduction squeeze RTD_{100}, the between-group difference was moderate but not statistically significant, likely due to high variation (Fig. 5) and limited sample size. Reliability concerns may also have attenuated this result, as RTD_{200} for hip adduction and abduction shows good intra-tester reliability, while RTD_{100} for both tests shows poor reliability.[49]

For maximal isometric strength, the small and moderate between-group differences were not statistically significant. This is in line with a previous study using handheld dynamometry,[83] while studies using sphygmomanometers reported bilateral adduction deficits.[5,6] However, the sphygmomanometer method has been questioned as this method suffers from ceiling effect and poor validity compared to dynamometers.[84,85]

The difference between explosive and maximal strength suggests that rapid force production is more sensitive to longstanding groin pain than peak torque, which is in line with findings from upper limb/shoulder pain.[86,87] This could be explained by neural inhibition activated by the acute

provocation of intense groin pain during testing.[86,88] In rest athletes with longstanding groin pain rarely experience pain[89,90] while during the explosive testing the rapid and forceful hip adduction muscle contractions generates a high amount of biomechanical stress that would initiate an intense barrage of nociceptive stimuli from the groin tissues to the spinal cord[46,68] especially with a presence of mechanical hyperalgesia in the groin.[4,32,90] In contrast, contractions at a slower speed would reduce the peak biomechanical stress and thereby reduce the likelihood of initiating nociception.[68] Slower contraction may also improve the activation of painful muscles and compensatory synergist muscles[86] that together would allow to generate near normal maximal strength within 5 seconds despite reduction of explosive strength.[86,91,92] Finally, it has been argued that cortical inhibition, from fear avoidance, could be a more important and potent determinant of explosive strength than neural inhibition in longstanding musculoskeletal pain.[86,87] Supporting this, reduced explosive strength and increased fear of movement in slaughterhouse workers with chronic upper limb pain[87] In line with this, we also found increased levels of fear of movement and pain catastrophizing in addition to the reductions in explosive hip muscle strength in the athletes with longstanding groin pain.[90] These results indicate that athletes with groin pain can maintain near-normal maximal force despite marked impairments in neuromuscular power, adding to the hypothesis that longstanding groin pain to a high degree influences central neurophysiological mechanisms.

4.4 Strengths and limitations

This exploratory case-control study was designed to detect large and potentially clinically relevant signals that can guide and inform future research. However, the cross-sectional nature limits causal inference, while the participants limit generalisability beyond male athletes with persistent adductor-related groin pain.

A main limitation is the lack of assessor blinding. The handheld algometer, used for PPTs, are assessor-dependent and therefore susceptible to expectation bias. Contrary, the computer-controlled cuff algometer, handheld dynamometer, pain drawings and paper questionnaires are to a large degree assessor-independent. Although logistical constraints prevented assessor blinding, the use of a single assessor likely enhanced consistency and reliability of procedures and measurements.

Psychological factors were screened with 13 brief questions to provide a pragmatic overview and minimise respondent burden. These items were derived from primary-care instruments but have not been validated in athletic populations.[58,59]

Symptomatic and asymptomatic athletes were matched by age and sport to reduce potential confounding by these factors.[93] Nevertheless, 35% (n = 7) of asymptomatic athletes reported previous groin pain, which may have attenuated group differences, while 65% (n = 13) of symptomatic athletes were receiving or had previously received treatment, potentially moderating impairments.

Groin pain was classified according to the Doha consensus[53] with detailed procedures and results (Appendix Table A1). Although we classified a mean of 3 entities, all symptomatic athletes met the criteria for adductor-related groin pain, and their pain drawings mirrored earlier cohorts[2]. Although several symptomatic athletes were classified with hip-joint related radiographic findings such as cam morphology it is unlikely that they should have been classified with HRGP. In the diagnostic work-up we used a positive FADIR-test followed by a positive diagnostic intra-articular injection to classify HRGP, however, none of the symptomatic athletes exhibited a positive FADIR test.

The sample size (n = 20 per group) is relatively small, and there are multiple statistical comparisons, which increase the risk of both false negative and false-positive findings (Type 1 and 2 error). We therefore present both unadjusted and Benjamini-Hocberg adjusted p-values.[66] However, we focused interpretation on effect sizes due to the exploratory nature of the study and to not write off findings with potential relevance for future and larger studies.

4.5 Perspective

ARGP have been explained by tissue pathologies developed due to cumulative mechanical overload of the groin structures. However, a single pathological source does not seem to exist in these athletes, as tissue pathologies vary significantly between studies, and multiple different tissue abnormalities on imaging are common in both athletes with and without longstanding groin pain.[93–96] Rather, the current results of widespread hyperalgesia, affected psychological factors and impaired explosive strength indicates that athletes with longstanding ARGP may have altered function of both peripheral and central pain mechanisms superimposed on local tissue stress.[24,25] This also supports our earlier work discussing that facilitated pain mechanisms may explain why some athletes with longstanding and severe groin pain are sensitive to clinical pain provocation testing during the clinical examination and are classified with multiple groin pain entities.[10]

The current evidence-based treatment of longstanding ARGP has not yet included a clear focus on altered nociceptive function, psychological factors or explosive strength.[11,15–17] Future treatment

could potentially benefit from addressing these factors by including person-centred assessment and intervention strategies that integrate pain-education, graded activity, and psychological support in addition to targeted strength training.[25,97,98] Such treatments will not only be in line with frameworks described in consensus work by the IOC,[24,25] but also support a shift towards a biopsychosocial approach to athletes longstanding groin pain.

5 CONCLUSION

Male athletes with longstanding adductor-related groin pain display widespread mechanical hyperalgesia, elevated pain catastrophizing, fear of movement and depressive symptoms, reduced pain self-efficacy, and impaired explosive hip strength compared to matched asymptomatic athletes.

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AUTHOR CONTRIBUTIONS

The first author is the lead and corresponding author. Contributions to the paper are described using the CRediT taxonomy by Brand, A., Allen, L., Altman, M., Hlava, M., & Scott, J. (2015).: Conceptualization: MFN, LI, PH, and KT; Methodology: MFN, LI MBC, CJ, SB, TGN, PH and KT; Formal Analysis: MFN; Investigation: MFN, PH and KT; Resources: MBC, SB, TGN, PH, and KT; Data Curation: MFN, SB; Writing – Original Draft: MFN and KT; Writing – Review and Editing manuscript: MFN, LI, MBC, CJ, SB, TGN, PH and KT; Visualization: MFN, SB; Supervision: PH, LI, and KT; Project Administration: MFN, PH, and KT; Funding Acquisition: MFN, PH, LI, and KT.

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CONFLICT OF INTEREST STATEMENT

All other authors declare they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICAL AND DATA APPROVAL STATEMENT

The study protocol was approved by the local ethics committee of the Capital Region in Denmark (H-20055130).

PARTICIPANT CONSENT

Participants provided written informed consent before undergoing any study related activities. The study was approved by the Danish Capital Region ethics committee (H-20055130).

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work the author used ChatGPT o1 by OpenAI in order to trim the wordcount without loss of meaning as well as improve the grammar and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

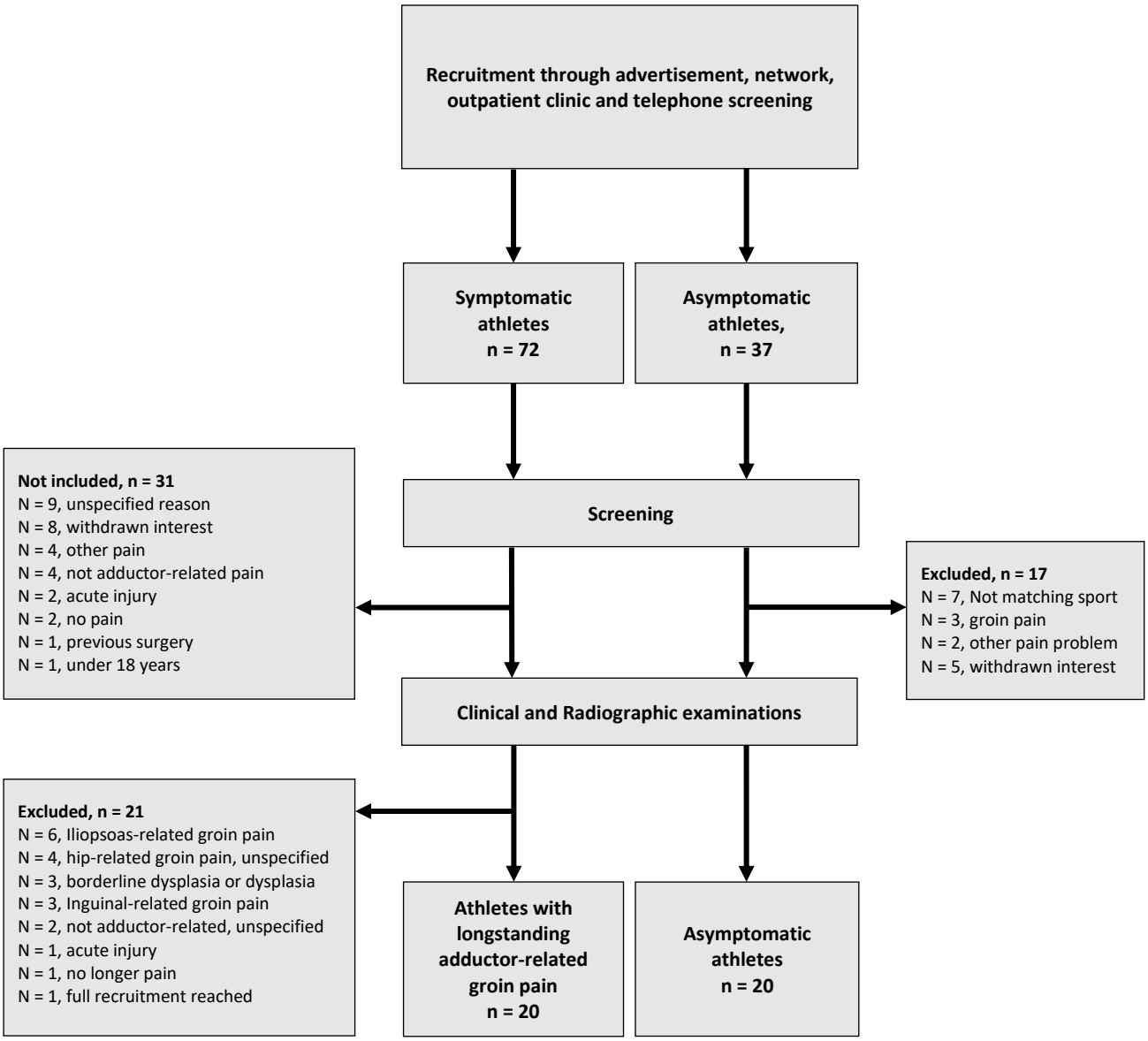


Figure 1 Participant flow

Table 1 Participant characteristics

Characteristics	Symptomatic athletes	Asymptomatic athletes
N	20	20
Age, years, mean (SD)	26.6 (5.6)	25.7 (4.3)
Height, cm, mean (SD)	180.9 (7.8)	183.5 (5.0)
Weight, kg, mean (SD)	77 (10)	81 (8)
BMI, mean (SD)	23.30 (1.88)	24.16 (2.83)
Sport, hours per week, mean (SD)	6.50 (3.11)	6.87 (3.29)
Sport type		
Football, n (%)	18 (90%)	18 (90%)
Volleyball, n (%)	1 (5%)	1 (5%)
Climbing, n (%)	1 (5%)	1 (5%)
Sport level		
Elite, n (%)	3 (16%)	2 (10%)
Competition, n (%)	10 (53%)	8 (40%)
Leisure activity, n (%)	6 (32%)	10 (50%)
Education level		
Elementary or less, n (%)	3 (15%)	0 (0%)
High School, n (%)	5 (25%)	11 61%)
Vocational education, n (%)	4 (20%)	0 (0%)
Short higher education, n (%)	1 (5%)	2 (11%)
Medium higher education, n (%)	4 (20%)	3 (17%)
Long higher education or more, n (%)	3 (15%)	2 (11%)
Dominant leg		
Left, n (%)	2 (10%)	4 (20%)
Right, n (%)	18 (90%)	16 (80%)
Painful side		
Left, n (%)	4 (20%)	-
Right, n (%)	9 (45%)	-
Bilateral, n (%)	7 (35%)	-
Most painful side		
Left, n (%)	1 (14%)	-
Right, n (%)	6 (86%)	-
Injury mechanism		
Acute after specific situation, n (%)	7 (35%)	4 (57%)
Gradual after specific situation, n (%)	6 (30%)	2 (29%)
Gradual and unspecific, n (%)	7 (35%)	1 (14%)
Previously treated for current groin pain, n (%)	13 (65%)	
Physiotherapy, unspecified, n (%)	7 (35%)	
Chiropractor, n (%)	1 (5%)	-
Massage, n (%)	3 (20%)	-
Exercises, n (%)	3 (20%)	-
Body SDS, n (%)	1 (5%)	-
Pain medication use, n (%)	3 (15%)	
Average days per week, median (IQR)	3 [2, 4]	
Types of pain medication		
Paracetamol, n (%)	3 (15%)	
Ibuprofen, n (%)	2 (10%)	
Pain duration, weeks, median (IQR)	51 (26, 175)	
Pain intensity in preceding week		
Worst pain, median (IQR)	6.50 (4.8, 7.0)	-
Least pain, median (IQR)	0.50 (0.0, 1.3)	-
Average pain, median (IQR)	3.00 (2.0, 4.0)	-
Current pain intensity, median (IQR)	2.50 (0.0, 3.3)	-
Pain intensity composite score, median (IQR)	2.00 (1.0, 2.5)	-

Table 1 Participant characteristics

Characteristics	Symptomatic athletes	Asymptomatic athletes
N	20	20
HAGOS		
Pain, median (IQR)	71.9 (61.7, 87.5)	100 (100, 100)
Symptoms, median (IQR)	52.1 (40.6, 67.7)	95.8 (87.5, 96.9)
ADL, median (IQR)	68.8 (60.9, 89.1)	100 (100, 100)
Sport/Rec., median (IQR)	41.7 (31.3, 54.2)	100 (100, 100)
PA, median (IQR)	37.5 (9.4, 43.8)	100 (100, 100)
QOL, median (IQR)	43.8 (29.7, 56.3)	100 (100, 100)
Clinical Entities of groin pain		
Adductor-related, n (%)	20 (100%)	-
Pubic-related, n (%)	4 (20%)	-
Inguinal-related, n (%)	7 (37%)	-
Iliopsoas-related, n (%)	14 (70%)	-
Total number of clinical entities, mean (SD)	3 (2)	-
Pubic-related radiographic findings		
Bone lucency, n (%)	13 65%)	-
Proliferation, n (%)	12 (60%)	-
Fragmentation, n (%)	0 (0%)	-
Sclerosis, n (%)	2 (10%)	-
Pubic joint space width, n (%)	3 (1)	-
Narrow Pubic joint space width, n (%)	9 (45%)	
Hip-related radiographic morphologies		
Cam morphology, n (%)	5 (25%)	-
Pincer morphology, n (%)	1 (5%)	-
Borderline Dysplasia, n (%)	6 (30%)	-
Dysplasia, n (%)	0 (0%)	-

Cam morphology = alpha angle ≥ 60° on a cross-table lateral radiograph, Pincer morphology = LCEA ≥ 40° OR LCEA ≥ 35° and an acetabular index angle < 0°, borderline hip dysplasia = LCEA 20-25°, hip dysplasia = LCEA < 20° OR Acetabular index angle > 13°

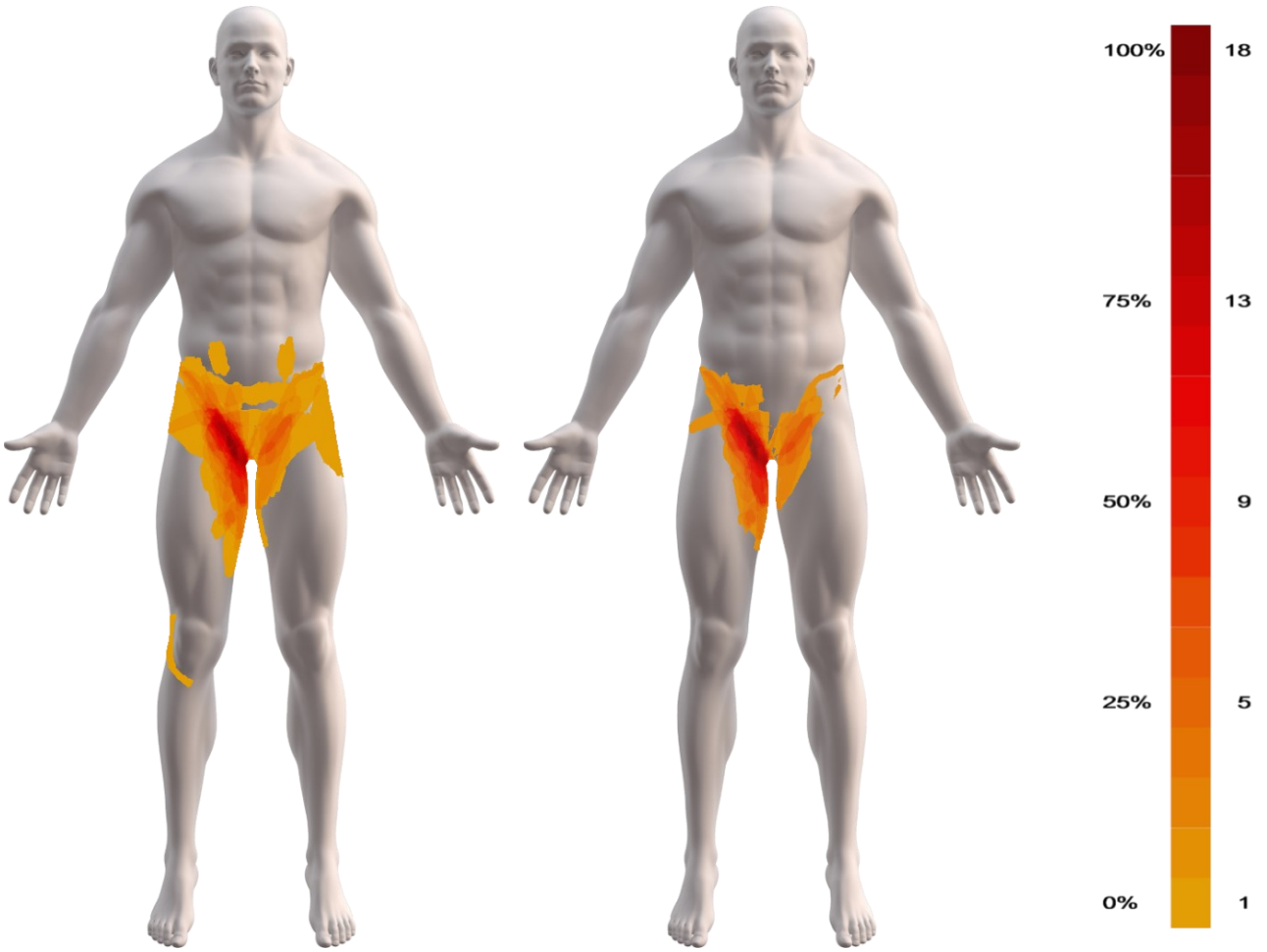


Figure 2 Overlay drawings of usual groin pain during sport activity. *Left drawing illustrates all areas drawn by minimum one symptomatic athlete. Right drawing illustrates areas drawn by minimum two symptomatic athletes. Drawings were "normalized/flipped" according to most painful side, so right side of the body chart is the most painful side, and left side is the least painful side.*

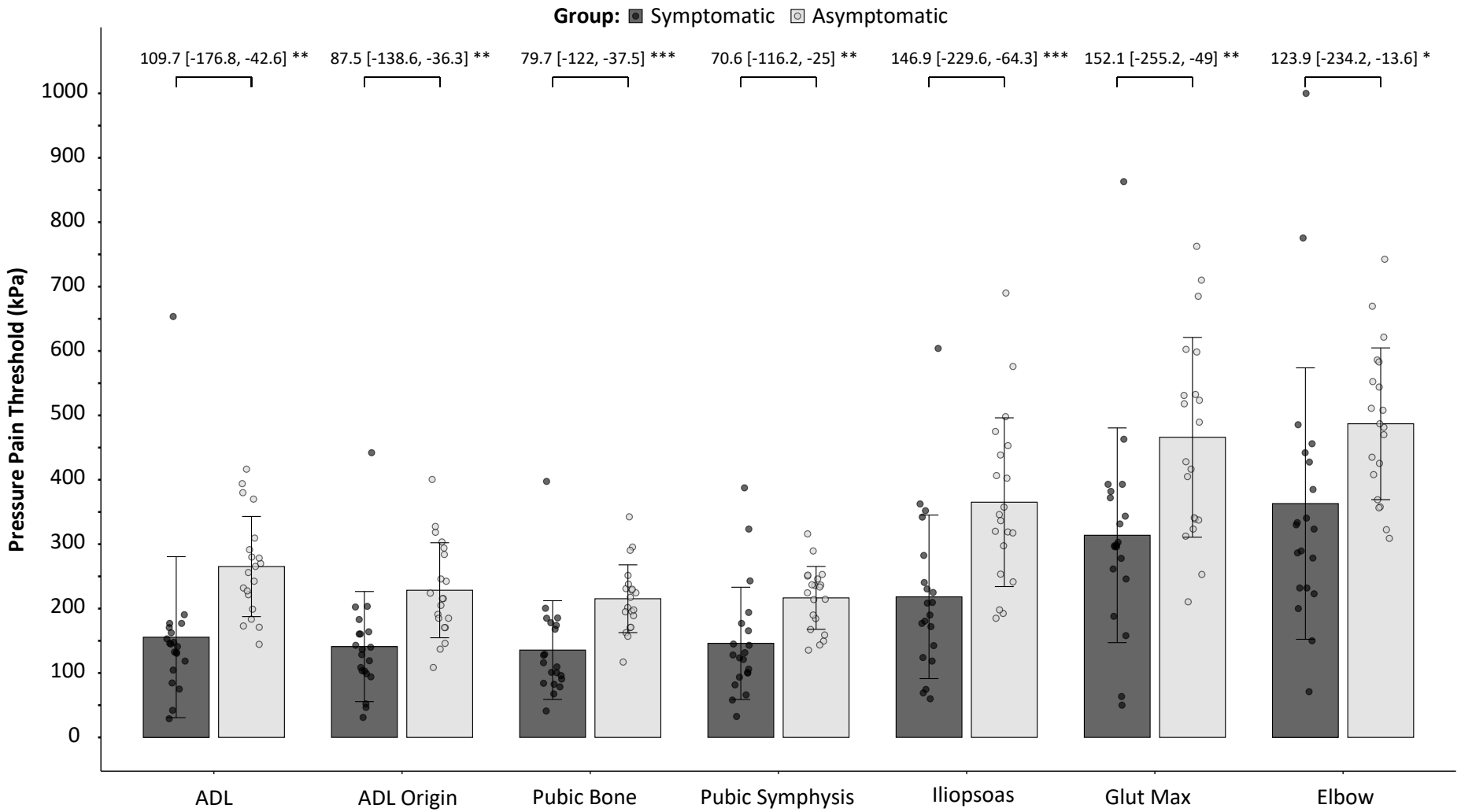


Figure 3 Pressure pain thresholds on the index side *Bars are means. Error bars are standard deviations. Dots are individual data points. * p < 0.05, ** p < 0.01, *** p < 0.001*

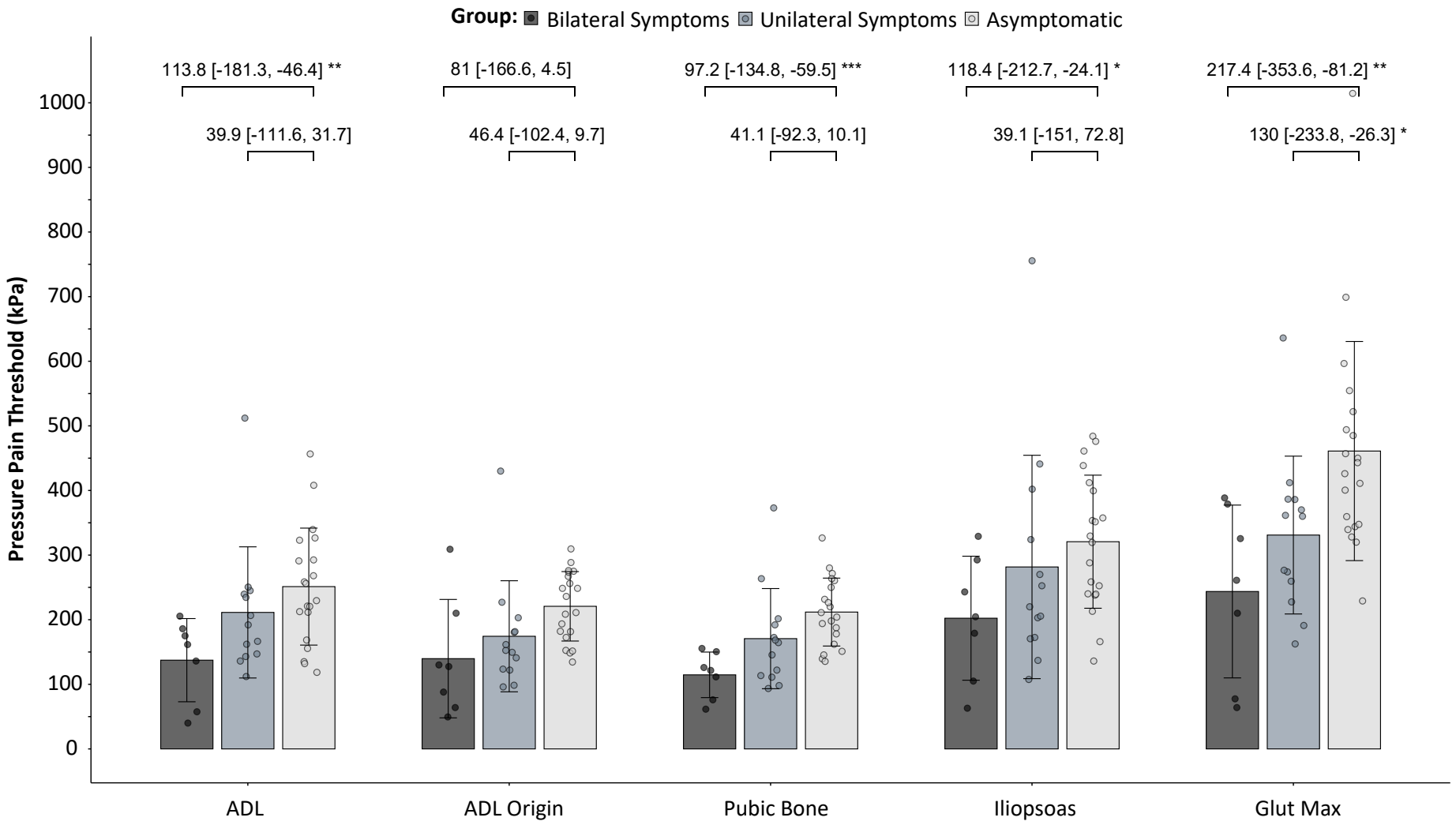


Figure 4 Pressure pain thresholds on the secondary side *Bars are means. Error bars are standard deviations. Dots are individual data points. * p < 0.05, ** p < 0.01, *** p < 0.001*

Table 2 Pain detection threshold, pain tolerance threshold, temporal summation of pain and conditioned pain modulation

	Symptomatic		Asymptomatic		Symptomatic vs Asymptomatic					
Index side	**Mean**	**(SD)**	**Mean**	**(SD)**	**Diff**	**(95% CI)**	***ES***	**(95% CI)**	**P-value**	**Adj. P-value**
PDT	19.46	(7.58)	26	(10.55)	-6.54	(-12.45 to -0.64)	0.71	(0.07 to 1.35)	0.03	0.09
PTT	88.86	(14.57)	88.75	(14.73)	0.11	(-9.27 to 9.5)	0.01	(-0.63 to 0.61)	0.98	0.98
PTT pain	9.73	(0.48)	8.93	(1.29)	0.8	(0.17 to 1.43)	0.82	(0.16 to 1.48)	0.02	0.06
cPDT	29.48	(14.38)	37.84	(19.2)	-8.36	(-19.25 to 2.53)	0.49	(-0.14 to 1.12)	0.13	0.29
cPTT	89.08	(23)	91.97	(12.13)	-2.89	(-14.78 to 9.01)	0.16	(-0.47 to 0.78)	0.62	0.76
cPTT pain	9.34	(0.82)	8.1	(1.99)	1.24	(0.24 to 2.23)	0.81	(0.14 to 1.46)	0.02	0.06
TSP	1.53	(0.66)	1.62	(0.71)	-0.09	(-0.53 to 0.35)	0.13	(-0.49 to 0.75)	0.68	0.76
CPM - ΔPDT	10.03	(12.24)	11.84	(13.75)	-1.81	(-10.15 to 6.52)	0.14	(-0.48 to 0.76)	0.66	0.76
CPM - ΔPTT	0.23	(20.37)	3.22	(5.31)	-3.0	(-12.77 to 6.77)	0.20	(-0.42 to 0.82)	0.53	0.76
CPM - ΔPTT pain	-4.12	(6.42)	-10.31	(13.77)	6.19	(-0.78 to 13.16)	0.58	(-0.07 to 1.21)	0.08	0.20
Secondary side										
Unilateral pain, n = 13										
PDT	20.15	(6.87)	28.8	(10.22)	-8.65	(-14.72 to -2.58)	0.99	(0.27 to 1.7)	0.01	0.04
PTT	89.5	(13.03)	89.86	(14.29)	-0.36	(-10.25 to 9.52)	0.03	(-0.66 to 0.72)	0.94	0.98
PTT pain	9.82	(0.32)	8.81	(1.34)	1.01	(0.36 to 1.65)	1.03	(0.32 to 1.72)	< 0.00	0.04
Bilateral pain, n = 7										
PDT	22.53	(10.01)	28.8	(10.22)	-6.27	(-16.03 to 3.49)	0.62	(-0.29 to 1.5)	0.18	0.37
PTT	83.09	(13.9)	89.86	(14.29)	-6.78	(-20.35 to 6.79)	0.48	(-0.41 to 1.35)	0.29	0.53
PTT pain	9.81	(0.32)	8.81	(1.34)	1.00	(0.34 to 1.67)	1.03	(0.31 to 1.73)	< 0.00	0.04

PDT = Pain Detection Threshold, PTT = Pain Tolerance Threshold, PTT pain = Pain intensity at PTT, TSP = Temporal summation of pain, cPDT = conditioned pain detection threshold, cPTT = conditioned pain tolerance threshold, cPTT Pain = Pain intensity at cPTT, CPM = Conditioned pain modulation, ΔPDT = Absolute change in PDT, ΔPTT = absolute change in PTT, ΔPTT pain = Absolute change in PTT Pain, ES = effect size estimated as Cohen's *d,* Ajd. P-value = Benjamini-Hocberg adjusted p-values.

Table 3 Psychological factors

Psychological factors	Symptomatic Athletes	Asymptomatic Athletes			
	Median (IQR)	Median (IQR)	*ES*	p-value	Adj. p-value
Pain Catastrophizing					
Context: How often do you have had the following thoughts about your pain during the past 4 weeks?					
Q1: "When I feel the pain, it is terrible, and I feel that it's never going to get better." Response: 0 "Never do that" to 10 = "Always do that"	4.0 (1.0 to 6.0)	0.0 (0.0 to 0.0)	0.58	< 0.00	< 0.00
Q2: "When I feel pain, I feel that I can't stand it anymore" Response: 0 "Never do that" to 10 = "Always do that"	1.0 (0.0 to 3.3)	0.0 (0.0 to 0.0)	0.56	< 0.00	< 0.00
Fear of Movement					
Context: To what extent do you disagree or agree with the statements?					
Q1: "Physical activity might damage me" Response: 0 = "Completely disagree" to 10 = "Completely agree"	3.5 (2.0 to 7.3)	0.5 (0.0 to 2.0)	0.41	0.01	0.02
Q2: "I should not do physical activities which (might) make my pain worse" Response: 0 = "Completely disagree" to 10 = "Completely agree"	5.5 (6.2 to 7.0)	0.5 (0.0 to 2.3)	0.46	< 0.00	0.01
Pain Self-Efficacy					
Context: Please rate how confident you are that you can do the following things at present, despite the pain.					
Q1: "I can do some form of work, despite the pain (''work'' includes housework and paid and unpaid work)" Response: 0 = not at all confident to 6 = completely confident.	6.0 (5.8 to 6.0)	6.0 (6.0 to 6.0)	0.37	0.02	0.03
Q2: "I can live a normal lifestyle, despite the pain." Response: 0 = not at all confident to 6 = completely confident.	5.0 (4.8 to 6.0)	6.0 (6.0 to 6.0)	0.64	< 0.00	< 0.00
Total Score	11.0 (10.0 to 12)	12.0 (12.0 to 12)	0.63	< 0.00	< 0.00
Depression					
Q1: "During the past month, have you often felt sad, depressed or had a sense of hopelessness?" Response : 0 = "Never" to 10 = "All the time"	2.5 (1.0 to 4.5)	1.0 (0.8 to 2.3)	0.32	0.04	0.06
Q2: "During the past month, have you felt bothered by little interest or pleasure in to do something?" Response : 0 = "Never" to 10 = "All the time"	2.5 (0.8 to 3.3)	1.0 (0.0 to 1.3)	0.37	0.02	0.03
Anxiety					
Q: "Do you feel anxious?" Response: 0 = "Not at all anxious" to 10 = "Quite anxious"	1.0 (0.0 to 3.0)	1.0 (0.0 to 2.3)	0.01	0.98	0.98
Stress					
Q: "Do you feel stressed?" Response: 0 = "Not at all stressed" to 10 = "Very stressed"	2.0 (0.0 to 2.3)	3.0 (2.0 to 4.0)	0.27	0.10	0.12
Loneliness					
Q: "Are you lonely?" Response: 0 "Not at all lonely" to 10 = "Quite lonely"	0.5 (0.0 to 2.0)	0.5 (0.0 to 1.0)	0.09	0.59	0.62
Sleep					
Q1: How would you rate the average quality of your sleep over the past week? Response: 0 = "Best quality" to 10 = "Worst quality"	5.0 (2.0 to 6.3)	3.0 (2.0 to 5.3)	0.10	0.55	0.62
Q2: How many hours did you sleep on average per night over the past week? Response: hours	7.0 (6.2 to 7.1)	7.0 (6.9 to 8.0)	0.24	0.14	0.17

ES = effect size estimated as rank-biserial correlation r

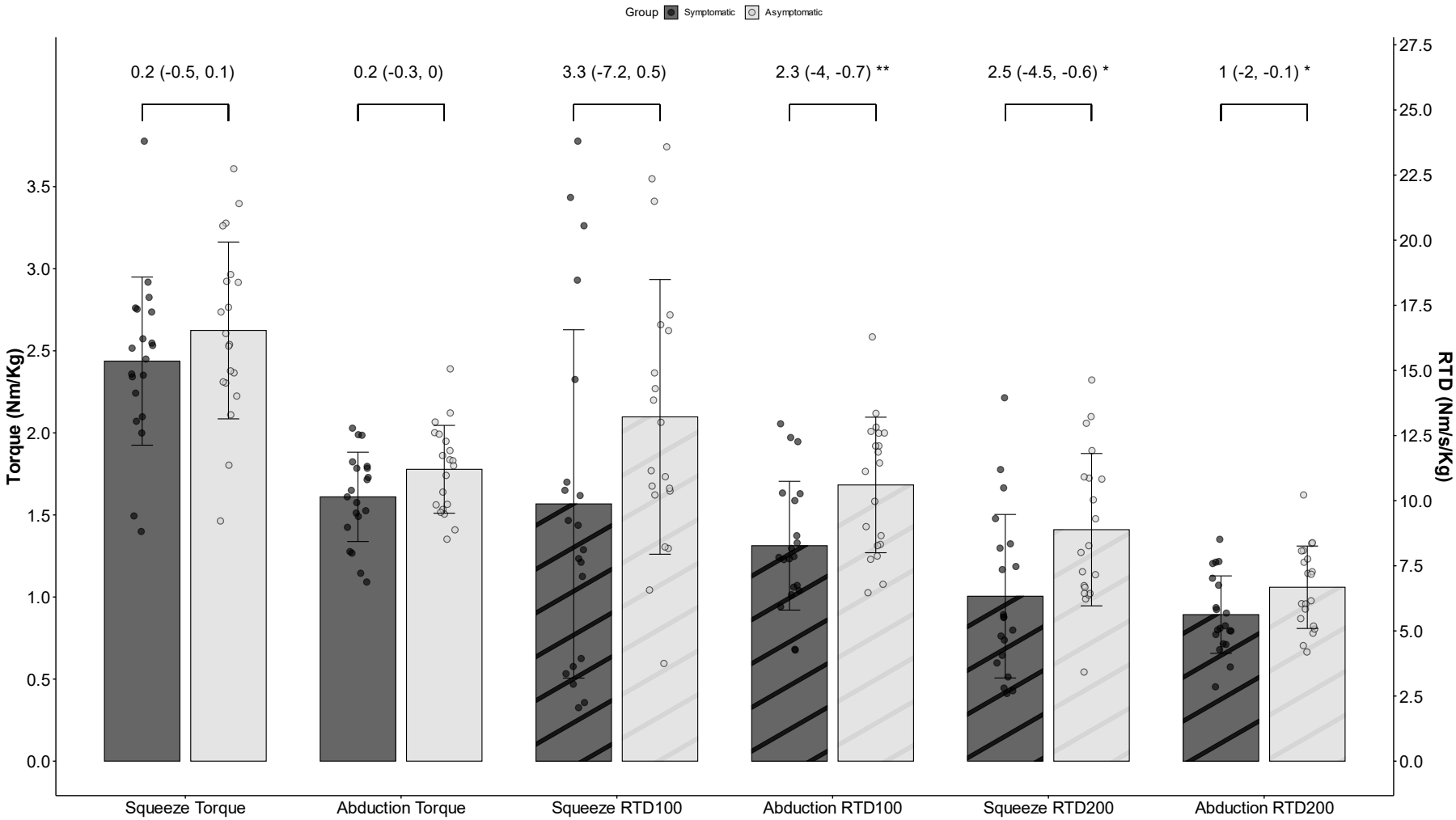


Figure 5 Muscle function. *Bars are means. Error bars are standard deviations. Dots are individual data points. Full color bars are maximal isometric strength. Pattern bars are explosive strength. * p < 0.05, ** p < 0.01, *** p < 0.0*

APPENDIX FILE

Pain sensitivity, psychological factors, and muscle function in male athletes with longstanding adductor-related groin pain and matched asymptomatic athletes

Nielsen MF, Ishøi L, Clausen MB, Juhl C, Boudreau S, Graven-Nielsen T, Hölmich P, Thorborg K.

Table A1 Descriptive data from clinical examination of included symptomatic athletes.

Clinical examination	Individual	Right	Left
Palpation			
Adductor longus insertion point at the pubic bone, n (%)	20 (100%)	16 (80%)	8 (40%)
Upper insertion of Adductor Magnus, n (%)	6 (30%)	5 (25%)	3 (15%)
Pubic bone just medial and inferior to the pubic tubercle, n (%)	3 (15%)	2 (10%)	1 (5%)
Rectus abdominus insertion/Pyramidalis-anterior pubic ligament adductor longus complex, n (%)	2 (11%)	1 (5%)	1 (5%)
Attachment of the Conjoined tendon, n (%)	8 (40%)	6 (30%)	3 (15%)
The superficial inguinal ring, n (%)	6 (46%)	4 (20%)	2 (10%)
Psoas muscle belly superior to inguinal ligament, n (%)	12 (60%)	9 (45%)	7 (35%)
Iliopsoas muscle tendon inferior to inguinal ligament and the insertion of iliopsoas at the lesser trochanter of the femur, n (%)	11 (55%)	8 (40%)	5 (25%)
Pubic symphysis and adjacent pubic bone, n (%)	2 (10%)		
Resistance, stretch and passive movement tests			
Bilateral adduction squeeze with straight legs, n (%)	20 (100%)	16 (80%)	8 (40%)
Passive stretching of the adductor muscles, n (%)	8 (40%)	6 (30%)	3 (15%)
Resisted straight and oblique sit-ups, n (%)	5 (25%)	4 (20%)	2 (10%)
Resisted hip flexion in supine, n (%)	5 (25%)	3 (15%)	3 (15%)
The modified Thomas test, n (%)	6 (30%)	4 (20%)	2 (10%)
Flexion-Adduction-Internal-Rotation (FADIR), n (%)	0 (0%)	0 (0%)	0 (0%)
Flexion-Abduction-External-Rotation (FABER), n (%)	4 (20%)	2 (10%)	2 (10%)
Diagnostic ultrasound guided intra-articular anesthetic injection	-	-	-
Post-injection palpation of distale iliopsoas , n (%)	-	-	-
Post-injection FADIR-Test, n (%)	-	-	-
Clinical Entities of groin pain			
Adductor-related, n (%)	20 (100%)	16 (80%)	7 (35%)
Pubic-related, n (%)	4 (20%)	3 (15%)	2 (10%)
Inguinal-related, n (%)	7 (37%)	5 (26%)	3 (16%)
Iliopsoas-related, n (%)	14 (70%)	11 (55%)	7 (35%)
Cumulative scores			
Total number of positive pain provocation tests, mean (SD)	6 (2)	7 (4)	
Total number of clinical entities, mean (SD)	3 (2)	3 (2)	

Table A2 Descriptive data from radiographic examination of included symptomatic athletes.

Radiographic Examinations	Individual	Right	Left
Hip-related radiographic parameters			
Alpha angle, mean (SD)	53 (11)	52 (9)	56 (13)
Lateral Center Edge Angle, mean (SD)	29.6 (4.6)	29.5 (5.5)	29.7 (4.2)
Acetabular Index Angle, mean (SD)	5.5 (3.8)	6.4 (3.8)	4.7 (4.2)
Hip Joint Space Width, mean (SD)	4.46 (0.66)	4.45 (0.69)	4.48 (0.73)
Cross Over Sign, n (%)	65% (13)	55% (11)	50% (10)
Ischial Spine Sign, n (%)	70% (14)	50% (10)	60% (12)
Posterior Wall Sign, n (%)	35% (7)	30% (6)	25% (5)
Hip-related radiographic morphologies			
Cam morphology, n (%)	5 (25%)	2 (10%)	4 (20%)
Pincer morphology, n (%)	1 (5%)	0 (0%)	1 (5%)
Borderline Dysplasia, n (%)	6 (30%)	5 (25%)	3 (15%)
Dysplasia, n (%)	0 (0%)	0 (0%)	0 (0%)
Pubic-related radiographic parameters			
Bone lucency, n (%)	13 (65%)	11 (55%)	12 (60%)
Erosion Like Configuration (ELC), n (%)	13 (65%)	11 (55%)	12 (60%)
ELC Central/Superior, n (%)	10 (50%)	9 (45%)	8 (40%)
ELC Inferior, n (%)	11 (55%)	7 (35%)	10 (50%)
Cysts, n (%)	0 (0%)	0 (0%)	0 (0%)
Proliferation, n (%)	12 (60%)	10 (50%)	10 (50%)
Superior proliferation, n (%)	5 (20%)	4 (20%)	4 (20%)
Central proliferation, n (%)	5 (20%)	4 (20%)	4 (20%)
Inferior proliferation, n (%)	11 (55%)	8 (40%)	8 (40%)
Fragmentation, n (%)	0 (0%)	0 (0%)	0 (0%)
Central/Superior fragmentation, n (%)	0 (0%)	0 (0%)	0 (0%)
Inferior fragmentation, n (%)	0 (0%)	0 (0%)	0 (0%)
Sclerosis, n (%)	2 (10%)	2 (10%)	2 (10%)
Pubic joint space width, mean (SD)	3.3 (1.2)	-	-
Narrow Pubic joint space width, n (%)	9 (45%)	-	-
Total number of pubic-related findings, mean (SD)	4.5 (3.3)	5.2 (4.0)	

TABLE A3 Pressure pain thresholds

Index side	Symptomatic		Asymptomatic		Symptomatic vs Asymptomatic					
	Mean	(SD)	Mean	(SD)	Diff	(95% CI)	SMD	(95% CI)	P-value	Adj. P-value
ADL	155.6	(125.0)	265.3	(77.7)	-109.7	(-176.8 to -42.6)	1.05	(0.38 to 1.70)	< 0.00	0.01
ADL Origin	141.0	(85.5)	228.5	(73.8)	-87.5	(-138.6 to -36.3)	1.10	(0.40 to 1.80)	< 0.00	0.01
Iliopsoas	218.3	(127.0)	365.2	(131.0)	-147.0	(-229.5 to -64.4)	1.14	(0.46 to 1.80)	< 0.00	0.01
Pubic Bone	135.6	(76.6)	215.3	(52.6)	-79.7	(-122.0 to -37.5)	1.21	(0.50 to 1.88)	< 0.00	0.00
Pubic Symphysis	146.0	(87.1)	216.6	(48.8)	-70.6	(-116.2 to -25.0)	1.00	(0.30 to 1.65)	< 0.00	0.01
Glut Max	313.9	(166.7)	466.0	(155.1)	-152.1	(-255.2 to -49.0)	0.94	(0.28 to 1.59)	< 0.00	0.01
Elbow	363.1	(210.8)	487.0	(117.8)	-123.9	(-234.2 to -13.6)	0.73	(0.08 to 1.36)	0.03	0.04
Secondary side										
Unilateral pain, n = 13										
ADL	211.3	(101.5)	251.2	(90.5)	-39.9	(-111.5 to 31.7)	0.42	(0.3 to 1.1)	0.26	0.28
ADL Origin	174.3	(85.9)	220.7	(53.7)	-46.4	(-102.4 to 9.7)	0.68	(0.0 to 1.4)	0.10	0.12
Iliopsoas	281.6	(172.8)	320.7	(103.0)	-39.1	(-151.0 to 72.8)	0.29	(0.4 to 1.0)	0.47	0.47
Pubic bone	170.7	(77.5)	211.8	(52.6)	-41.1	(-92.4 to 10.1)	0.65	(0.1 to 1.4)	0.11	0.12
Glut Max	331.0	(122.1)	461.0	(169.6)	-130.0	(-233.8 to -26.3)	0.85	(0.1 to 1.6)	0.02	0.02
Bilateral pain, n = 7										
ADL	137.4	(64.4)	251.2	(90.5)	-113.8	(-181.3 to -46.4)	1.34	(0.4 to 2.3)	0.00	0.01
ADL Origin	139.7	(91.6)	220.7	(53.7)	-81.0	(-166.5 to 4.5)	1.25	(0.3 to 2.2)	0.06	0.08
Iliopsoas	202.3	(96.0)	320.7	(103.0)	-118.4	(-212.7 to -24.1)	1.17	(0.2 to 2.1)	0.02	0.03
Pubic Bone	114.6	(35.3)	211.8	(52.6)	-97.2	(-134.8 to -59.5)	1.98	(1.0 to 3.0)	0.00	0.00
Glut Max	243.6	(133.7)	461.0	(169.6)	-217.4	(-353.6 to -81.2)	1.34	(0.4 to 2.3)	0.00	0.01

ADL = adductor longus muscle belly, ADL Origin = adductor longus muscle origin, Iliopsoas = iliopsoas tendon below inguinal ligament, Pubic Bone = Pubic bone adjacent to the pubic symphysis, Pubic Symphysis = Pubic symphysis joint, Glut Max = Gluteus Maximus, Elbow = lateral elbow epicondyle

Table A4 Muscle function

	Symptomatic Athletes		Asymptomatic Athletes		Symptomatic vs Asymptomatic Athletes					
Adduction Squeeze Test	**Mean**	**(SD)**	**Mean**	**(SD)**	**Mean Diff**	**(95% CI)**	**SMD**	**(95% CI)**	**P-value**	**Adj. P-value**
Peak torque, Nm/kg	2.44	(0.51)	2.62	(0.54)	-0.19	(-0.52 to 0.15)	0.36	(-0.27 to 0.98)	0.27	0.27
RTD_{100}, Nm/s/kg	9.88	(6.69)	13.22	(5.27)	-3.34	(-7.2 to 0.52)	0.55	(-0.08 to 1.18)	0.09	0.11
RTD_{200}, Nm/s/kg	6.33	(3.14)	8.89	(2.92)	-2.55	(-4.5 to -0.61)	0.84	(0.19 to 1.49)	0.01	0.03
Abduction Press Test										
Peak torque, Nm/kg	1.61	(0.27)	1.78	(0.27)	-0.17	(-0.34 to 0.00)	0.62	(-0.02 to 1.25)	0.06	0.08
RTD_{100}, Nm/s/kg	8.27	(2.47)	10.6	(2.6)	-2.33	(-3.96 to -0.71)	0.92	(0.26 to 1.57)	0.01	0.03
RTD_{200}, Nm/s/kg	5.63	(1.49)	6.68	(1.58)	-1.05	(-2.03 to -0.07)	0.68	(0.04 to 1.32)	0.04	0.07

Table A5 Between-Group Mean Differences in PPTs on the index side

PPT Site	Mean Diff. (95% CI)		p-value
Adductor Longus Muscle	-109.70	(-176.34 to -43.06)	0.002
Adductor Longus Origin	-87.48	(-138.59 to -36.36)	0.001
Iliopsoas	-146.95	(-229.54 to -64.36)	0.001
Pubic Bone	-79.73	(-121.81 to -37.64)	0.000
Gluteus Maximus	-152.10	(-255.17 to -49.03)	0.005
Pubic Symphysis	-70.60	(-115.81 to -25.39)	0.003
Elbow	-123.93	(-233.22 to -14.63)	0.027

p-values are adjusted p-values and Greenhouse–Geisser or Huynh–Feldt corrections

Table A6 Within-group comparisons between sites for Symptomatic Athletes (n=20)

Comparison: First minus second site	Mean Diff.	(95% CI)	p-value	Lowest PPT
Adductor longus Muscle - Adductor longus Origin	14.58	(-28.05 to 57.20)	0.337	
Adductor longus Muscle - Iliopsoas	-62.65	(-115.19 to -10.11)	0.001	Adductor longus Muscle
Adductor longus Muscle - Pubic Bone	20.00	(-27.14 to 67.14)	0.230	
Adductor longus Muscle - Gluteus Maximus	-158.27	(-227.63 to -88.92)	0.000	Adductor longus Muscle
Adductor longus Muscle - Pubic Symphysis	9.58	(-44.41 to 63.56)	0.627	
Adductor longus Muscle - Elbow	-207.48	(-311.87 to -103.08)	0.000	Adductor longus Muscle
Adductor longus Origin - Iliopsoas	-77.22	(-134.30 to -20.15)	0.000	Adductor longus Origin
Adductor longus Origin - Pubic Bone	5.42	(-32.76 to 43.61)	0.679	
Adductor longus Origin - Gluteus Maximus	-172.85	(-247.60 to -98.10)	0.000	Adductor longus Origin
Adductor longus Origin - Pubic Symphysis	-5.00	(-50.47 to 40.47)	0.722	
Adductor longus Origin - Elbow	-222.05	(-327.15 to -116.95)	0.000	Adductor longus Origin
Iliopsoas - Pubic Bone	82.65	(17.88 to 147.42)	0.000	Pubic Bone
Iliopsoas - Gluteus Maximus	-95.63	(-161.56 to -29.69)	0.000	Iliopsoas
Iliopsoas - Pubic Symphysis	72.22	(-0.15 to 144.60)	0.004	Pubic Symphysis
Iliopsoas - Elbow	-144.83	(-259.21 to -30.44)	0.000	Iliopsoas
Pubic Bone - Gluteus Maximus	-178.27	(-263.56 to -92.99)	0.000	Pubic Bone
Pubic Bone - Pubic Symphysis	-10.43	(-45.32 to 24.47)	0.393	
Pubic Bone - Elbow	-227.48	(-331.29 to -123.66)	0.000	Pubic Bone
Gluteus Maximus - Pubic Symphysis	167.85	(79.83 to 255.87)	0.000	Pubic Symphysis
Gluteus Maximus - Elbow	-49.20	(-162.73 to 64.33)	0.230	
Pubic Symphysis - Elbow	-217.05	(-314.96 to -119.14)	0.000	Pubic Symphysis

p-values are adjusted p-values and Greenhouse–Geisser or Huynh–Feldt corrections

Table A7 Within-group comparisons between sites for Asymptomatic Athletes (n=20)

Comparison: First minus second site	Mean Diff.	(95% CI)	p-value	Lowest PPT
Adductor longus muscle - Adductor longus Origin	36.80	(-5.82 to 79.42)	0.010	Adductor longus Origin
Adductor longus muscle - iliopsoas	-99.90	(-152.44 to -47.36)	0.000	Adductor longus muscle
Adductor longus muscle - pubic bone	49.98	(2.84 to 97.11)	0.002	Pubic Bone
Adductor longus muscle - gluteus maximus	-200.68	(-270.03 to -131.32)	0.000	Adductor longus muscle
Adductor longus muscle - pubic symphysis	48.67	(-5.31 to 102.66)	0.007	Pubic Symphysis
Adductor longus muscle - elbow	-221.70	(-326.09 to -117.31)	0.000	Adductor longus muscle
Adductor longus Origin - Iliopsoas	-136.70	(-193.78 to -79.62)	0.000	Adductor longus Origin
Adductor longus Origin - Pubic Bone	13.17	(-25.01 to 51.36)	0.313	
Adductor longus Origin - Gluteus Maximus	-237.48	(-312.22 to -162.73)	0.000	Adductor longus Origin
Adductor longus Origin - Pubic Symphysis	11.87	(-33.59 to 57.34)	0.443	
Adductor longus Origin - Elbow	-258.50	(-363.60 to -153.40)	0.000	Adductor longus Origin
Iliopsoas - Pubic Bone	149.87	(85.10 to 214.65)	0.000	Pubic Bone
Iliopsoas - Gluteus Maximus	-100.78	(-166.71 to -34.84)	0.000	Iliopsoas
Iliopsoas - Pubic Symphysis	148.57	(76.20 to 220.95)	0.000	Pubic Symphysis
Iliopsoas - Elbow	-121.80	(-236.19 to -7.41)	0.002	Iliopsoas
Pubic Bone - Gluteus Maximus	-250.65	(-335.93 to -165.37)	0.000	Pubic Bone
Pubic Bone - Pubic Symphysis	-1.30	(-36.19 to 33.59)	0.904	
Pubic Bone - Elbow	-271.68	(-375.49 to -167.86)	0.000	Pubic Bone
Gluteus Maximus - Pubic Symphysis	249.35	(161.33 to 337.37)	0.000	Pubic Symphysis
Gluteus Maximus - Elbow	-21.03	(-134.56 to 92.51)	0.578	
Pubic Symphysis - Elbow	-270.38	(-368.29 to -172.46)	0.000	Pubic Symphysis

p-values are adjusted p-values and Greenhouse–Geisser or Huynh–Feldt corrections

SUPPLEMENTARY FILE

Pain sensitivity, psychological factors, and muscle function in male athletes with longstanding adductor-related groin pain and matched asymptomatic athletes

Nielsen MF, Ishøi L, Clausen MB, Juhl C, Boudreau S, Graven-Nielsen T, Hölmich P, Thorborg K.

Content:

- Predetermined order of procedures in the experimental session
- Description of the clinical examination and classification of groin pain.
- Clinical examination procedure
- Description of radiographic examination
- Muscle function assessment procedure
- Pain Sensitivity
- Pressure pain thresholds
- Description of digital pain drawings using Navigate pain.
- Navigate Pain instruction
- Navigate Pain 2D body charts illustration

Predetermined order of procedures in the experimental session

Table S1
Predetermined order of procedures in the experimental session

#	Procedure / outcome
1	Patient demographics assessed with a self-developed baseline questionnaire
2	Self-reported hip and groin disability assessed with Copenhagen Hip and Groin Outcome Score (HAGOS)
3	Psychosocial factors assessed with 13 screening questions
4	Current pain intensity in rest and pain intensity in the preceding week assessed with a numerical pain rating scale (NRPS)
5	Pain drawings made with Navigate Pain, illustrating usual pain during sport
6	Pressure Pain Thresholds (PPTs) measured with manual pressure algometry on both the test side (most painful groin) and the contralateral side. Measurement sites: 1) Midpoint of adductor longus muscle belly – secondary side 2) Adductor longus insertion into the pubic bone – secondary side 3) Iliopsoas tendon just distally to the inguinal ligament. – secondary side 4) The pubic bone just adjacent to the symphysis joint – secondary side 5) Midpoint of adductor longus muscle belly – index side 6) Adductor longus insertion into the pubic bone – index side 7) Iliopsoas tendon just distally to the inguinal ligament. – index side 8) The pubic bone just adjacent to the symphysis joint – index side 9) Anterior part of the symphysis joint 10) The Gluteus maximus muscle – secondary side 11) The Gluteus maximus muscle – index side 12) Lateral elbow epicondyle contralateral to the test side
7	Pain detection threshold (PDT) and pain tolerance threshold (PTT) measured on the index side at the lower leg using a computer-controlled cuff pressure algometer
8	Temporal summation of Pain (TSP) measured on the index side at the lower leg using a computer-controlled cuff pressure algometer
9	Pain detection threshold (PDT) and pain tolerance threshold (PTT) measured on the secondary side at the lower leg using a computer-controlled cuff pressure algometer
10	Conditioned pain modulation (CPM) measured on the index side at the lower leg using a computer-controlled cuff pressure algometer
11	Evoked pain intensity (NRPS), bilateral hip adduction peak rate of torque and peak force assessed with the long-lever squeeze test and a handheld dynamometer.
12	Pain drawings made with Navigate Pain, illustrating evoked pain during the Copenhagen 5 second squeeze test
13	Evoked pain intensity (NRPS), bilateral hip abduction peak rate of torque and peak force assessed with the long-lever hip abduction press test and a handheld dynamometer.

Description of the clinical examination and classification of groin pain.

Prior to the full clinical examination, patients was screened for potential other severe causes of hip and groin pain. If such causes were identified, the patient was excluded and referred appropriately. All eligible Symptomatic athletes went through the same standardized clinical examination to determine eligibility for participation in experimental testing [1–3]. The examination of Symptomatic athletes was performed by an orthopaedic surgeon (PH) in the outpatient clinical at Hvidovre hospital.

Based on the clinical examination the subject was categorized with the clinical entities [2]:

- **Adductor-related groin pain**: Adductor tenderness on palpation AND pain on resisted adduction testing.
- **Iliopsoas-related groin pain**: Iliopsoas tenderness on palpation, above or below the inguinal ligament.
- **Inguinal-related groin pain**: Pain location in the inguinal canal region AND tenderness of the inguinal canal.
- **Pubic-related groin pain**: Local tenderness of the pubic symphysis and the immediately adjacent bone.
- **Hip-related groin pain**: A positive FADIR test AND a positive diagnostic ultrasound guided intra-articular anesthetic hip injection.

The clinical examination was based on the procedure described by Hölmich et al [1], which altogether includes palpation of muscle, tendon and bone structures, pain on manual resistance muscle testing, pain on muscle stretching. Additionally, two special orthopedic tests (FABER and FADIR) were performed, and an diagnostic ultrasound guided anaesthetic hip injection was performed if a FADIR test was positive[3]. An intra-articular anesthetic injection has been suggested as a useful examination procedure to distinguish between intra- and extra-articular sources of hip and groin pain[3]. In this study, the intra-articular injection was performed with 8-10 mL 1% lidocaine and did not include corticosteroid. The injection was performed in accordance with the following procedure:

Prior to and 5-15 minutes after administration of the ultrasound guided intra-articular anesthetic hip injection the orthopedic surgeon palpates the distal iliopsoas muscle below the inguinal ligament and medially to the sartorius muscle and performs the FADIR test. During the post-injection assessment, the patient was instructed to indicate the effect of the injection on hip and groin pain using a five-point Likert scale (certain of pain relief; uncertain of pain relief; no change in pain; uncertain of pain worsening; certain of pain worsening) for both iliopsoas palpation and the FADIR test. Inspired by previous studies, a positive response to the injection was defined as “certain of pain relief” whereas we consider “uncertain of pain relief” to “certain of pain worsening” as a negative response [4]. To blind the patient, only a positive response during the FADIR test was considered a positive intra-articular injection. To limit the risk of false negative findings, a second assessment of iliopsoas palpation and FADIR test was performed if no pain relief during the FADIR test was obtained 5 minutes post-injection. In such symptomatic athletes, patients were instructed to remain in the outpatient clinic for a duration of 15-30 minutes before a second assessment of iliopsoas palpation and FADIR test was performed. Subsequently, the pain response (positive or negative) during only the FADIR test was used by the physiotherapist or orthopedic surgeon to evaluate and classify Symptomatic athletes with hip-joint related groin pain.

Clinical examination procedure

1. History taking.
2. Screening tests for ruling out symptoms due to other pathology/problems than hip and groin related
3. Palpation sites for tenderness and known pain:
    1. The adductor longus insertion point at the pubic bone
    2. The upper insertion of Adductor Magnus
    3. The pubic bone just medial and inferior to the pubic tubercle
    4. Rectus abdominus insertion/or the Pyramidalis-anterior pubic ligament adductor longus complex (PLAC)
    5. Attachment of the Conjoined tendon
    6. The superficial inguinal ring
    7. Pubic symphysis and adjacent pubic bone
    8. The psoas muscle belly superior to inguinal ligament
    9. The iliopsoas muscle belly/tendon inferior to inguinal ligament and the insertion of iliopsoas at the lesser trochanter of the femur
4. Muscle resistance and passive range of motion testing for known pain.
    1. Adduction of legs against resistance
    2. Passive stretching of the adductor muscles
    3. Resisted straight and oblique sit-ups
    4. Resisted hip flexion in supine
    5. The modified Thomas test
5. Special tests:
    - Flexion adduction internal rotation (FADIR) test
    - Flexion abduction external rotation (FABER) test
6. If FADIR Test is positive → Diagnostic ultrasound guided intra-articular anesthetic injection
    - Palpation of iliopsoas as above (3.8 and 3.9) + FADIR test
    - Diagnostic injection
    - Walk- around for 10-15 minutes
    - Repeated Palpation of iliopsoas as above (3.8 and 3.9) + FADIR test

Description of radiographic examination

The radiographic examination consisted of one image with an anterior-posterior pelvic view and one to two images with cross-table lateral view to measure cam and pincer morphology, and to exclude other potential causes of chronic hip and groin pain such as hip dysplasia, stress fracture, osteoarthritis etc. [5]. This assessment protocol corresponds to the standardized procedure for all patients with chronic hip and/or groin pain seen in the department of orthopedics at Hvidovre Hospital. Findings from the radiological assessment was collected using a standardized case-report form.

The anterior-posterior pelvic view was obtained with the subject standing with equal weight distribution on the legs, hip width distance between the feet and legs internally rotated 15 degrees, so the toes were nearly touching each other. The buttocks of the patient was in contact with the "film". The pelvis should be centred and positioned symmetrically. The distance from the upper rim of the pubic bone/symphysis joint to the coccyx-sacral joint was between 3-5 cm to obtain near normal inclination of the pelvis. The symphysis joint or the inferior rami of the pubic bone was not covered by the gonad shield.

The cross-table lateral view was obtained with the patient supine and the assessed leg internally rotated 15°. The contralateral hip was flexed and thus lifted out of the x-ray field to avoid interference. The x-ray beam was horizontal and angled 45° from the contralateral side with a distance of 1.2 meters from the transmitter to the film.

Participants were classified with cam (alpha angle >60°[6,7]), pincer (LCEA ≥ 40°[7] OR LCEA ≥ 35° and a acetabular index angle < 0°[7]), borderline hip dysplasia (LCEA 20-25°) and/or hip dysplasia (a LCEA < 20° or Acetabular index angle > 13°[8]).

From the cross-table lateral view and the anterior-posterior pelvic view the following hip joint-related radiographic findings as described in Lisbon agreement[6,9,10] were evaluated:

- **Alpha Angle** was defined as the angle between 1) a line from the center of the femoral neck to the center of the femoral head, and 2) a line from the center of the femoral head to the point where the femoral head-neck junction extends beyond the margin of the circle [7].
- **Lateral Center Edge Angle** was defined as The angle between 1) a vertical line through the femoral head center and 2) a line between the femoral head center and the lateral sourcil of the acetabulum, as defined by Wiberg.
- **acetabular index angle** was defined as the angle between a horizontal line and a line through the most medial point of the sclerotic zone of the acetabulum and the sourcil [6].
- **hip joint space width** was defined as The distance between the femoral head and the lateral sourcil at the acetabulum [6].
- **cross-over sign** was defined as the anterior wall contour intersects and becomes lateral to the posterior wall contour. [6]
- **posterior wall sign** was defined as the posterior acetabular wall projection is medial to the femoral head center projection[6].
- **Ischial spine sign** was defined as the ischial spine is visible medially to the pelvic rim[6].

From the anterior-posterior pelvic view, the following pubic-related radiographic findings as described by Serner et al[11] were evaluated:

- **Bone lucency** "A clear area of decreased attenuation compared to the surrounding bone, which corresponds to an erosion-like configuration and/or cyst."

- **Erosion-Like Configuration (ELC):** “Irregularities of the cortical bone surface, potentially accompanied by loss of the adjacent trabecular bone.”
- **Superior/Central ELC**: ELC at the superior two thirds of the joint surface
- **Inferior ELC**: ELC at the lower third of the joint surface - “If the entire lower half was considered to have an erosion-like configuration, both of the above were scored as positive"
- **Cysts** “Areas of bone lucency with a sclerotic rim inside the trabecular bone compartment, without accompanying cortical bone surface irregularity.”
- **Proliferation**: “Clear osteophyte outgrowths at the joint margins or within the articular space.”
- **Superior proliferation**: "This can be considered “bone spurs” or classified as “pubic beaking” when bilateral. Well rounded (smooth) bumps at the superior aspect, even if asymmetrical in size, were not considered proliferation. For superior proliferation, the “sharpness” of the superior bone corner angle was used for assistance with angles higher than 90 deg. (obtuse angle) considered “rounded” and scored negative/absent, whereas angles lower than 90 deg. (acute angle) were considered “sharp” and scored as positive/present."
- **Central proliferation**: “Proliferation at the central portion of the articular space.”
- **Inferior proliferation**: "Similar considerations as superior proliferation."
- **Fragmentation** “Clear loose fragment(s) within the symphyseal joint space, or at the inferior medial margin of the pubic bone.”
- **Central fragmentation**: “Clear loose fragment(s) within the symphyseal joint space"
- **Inferior fragmentation**: “Clear loose fragment(s) at the inferior medial margin of the pubic bone.”
- **Sclerosis** “A clear area of increased attenuation of the subchondral bone compared to the surrounding bone, corresponding to an area of increased bone density.”
- **Pubic Symphysis Joint Space Width** “Symphyseal joint space measured in millimeters at the narrowest point of the joint surfaces.”
- **Narrow Joint Space Width**. “if measured to less than 3mm”

Muscle function assessment procedure

Muscle function was assessed as maximal isometric and explosive strength during hip adduction squeeze and hip abduction-press tests. Athletes lay supine on an examination bed with legs straight, toes upwards, and hands gripping the bed. In the hip adduction squeeze test, the dynamometer was placed 5 cm proximal to the medial malleoli between the ankles, with the hips abducted ~15°.[12] In the abduction press test, the dynamometer was fixated 5 cm proximal to the lateral malleoli using a rigid belt, ensuring matched hip abduction angle. For each test, athletes performed one warm-up trial at 50% and one at 100% of perceived max effort, followed by at three valid trials at 100% effort. They were instructed to squeeze or press as fast and hard as possible against the resistance and hold it for 5 seconds.

Pain Sensitivity

For assessment of pain sensitivity, athletes lay supine on an examination bed, with support under the knees, and the headrest in a comfortable position.

Pressure pain thresholds

For symptomatic athletes, PPTs were assessed on the least painful side before the most painful side. For asymptomatic athletes, the side order was randomized. PPTs were assessed bilaterally at the palpatory middle part of the adductor longus muscle belly (ADDUCTOR LONGUS MUSCLE), the adductor longus muscle origin at the anterior surface of the superior pubic rami (Adductor longus Origin), the iliopsoas

tendon at the point just distally of the inguinal ligament and medial to the rectus femoris and sartorius and lateral to the femoral nerve (Iliopsoas), the pubic bone lateral to the symphysis joint (Pubic Bone), the gluteus maximums at the midpoint between the sacrum and trochanter major (Gluteus Maximus). PPTs were assessed unilaterally at the anterior part of the symphysis joint (Pubic Symphysis) and at the lateral elbow epicondyle (Elbow) contralateral to the most painful side (symptomatic athletes), or second side (asymptomatic athletes).

Description of digital pain drawings using Navigate pain.

The symptomatic athletes reported the quality, intensity, and distribution of usual groin pain during sports activities and evoked groin pain during the hip adduction squeeze test by drawing on high-resolution digital 2D body charts in the web-based application Navigate Pain (Aglance Solutions, Aalborg Denmark). The app was accessed through Google Chrome on an Apple iPad (6. Generation) (Apple Inc., USA) and the drawings were made with an Apple Pencil (Apple Inc., USA). The body charts included front, back and side views, and the app allowed for zooming to improve accuracy. Athletes were instructed to first draw on the front view, and afterwards draw on the other views, using a standardized and scripted instruction. Accordingly, athletes were allowed to draw pain outside of the groin, if they felt it was relevant for their pain experience. Pain was drawn using 11 different quality descriptors (Pain, Dull/Aching, Burning, Throbbing, Stabbing, Tingling, Electric, Numbness, Cold, Itchy, Other), and the 3 intensity levels mild (NRS 0-4), moderate (NRS 5-7) or intense (NRS 8-10). Each descriptor and intensity were drawn with a unique colour and athletes were allowed to create an overlap between descriptors and intensities by drawing with more than one colour on the same area. Pain drawing overlays were used to visualize the pain distribution of all symptomatic athletes in a single figure, with a colour scheme to show the relative frequency of each drawn pixel.

Navigate Pain instruction

Outcome assessor:

"We would like to know more about where you experience your pain and how this feels. This will be done using this iPad using this pen to produce two digital pain drawings. Before we get started, I will go through the process for you."

"The two drawings should illustrate your usual groin pain during physical activity or sports and your pain during a test, which we perform later in this session."

"You have to start by drawing on the front of the digital body schema. If it is relevant to you and your pain experience, you should also draw on the right, left or back of the digital body schema. "

"Please use the pen to first select pain or a discomfort quality descriptor and then the intensity of that descriptor. Using the pen draw as accurately as possible and to the best of your ability on the digital body schema. When you draw ensure to color in the areas of pain and discomfort completely. Avoid using circle outlines or cross-marks to draw your pain."

"Now, I would like you to draw the first drawing of your current groin pain, here and now, when you are at rest."

Patient:

Asks any questions, comments, and makes the first drawing

Outcome assessor:

"Thank you, now we move on to the next tests of your pain mechanisms before the last drawing which is after a muscle function test."

[Performs other data collection.]

Outcome assessor:

“Now we are going to test how hard you can squeeze your legs together.”

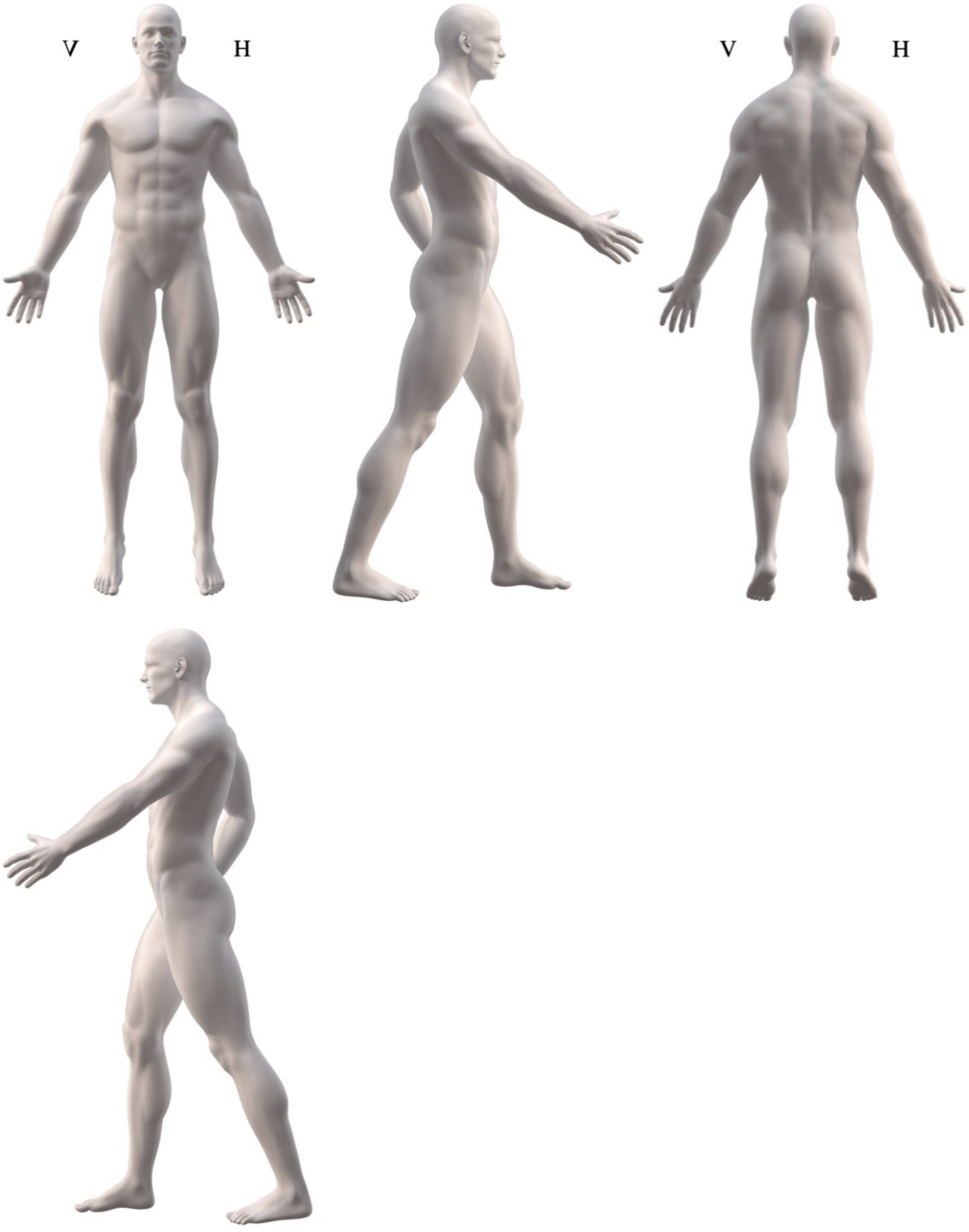
[Test instruction of the Copenhagen 5-Second-Squeeze test]

"After the test, I would like you to draw the final pain drawing, which should illustrate the pain experience you had during the test."

[Performs the Copenhagen 5-Second-Squeeze test]

“Now, I would like you to draw where you experienced groin pain during the squeeze test. Remember to draw as accurately as possible and to the best of your ability on the digital body schema. When you draw ensure to color in the areas of pain and discomfort completely. Avoid using circle outlines or cross-marks to draw your pain.”

Navigate Pain 2D body charts illustration



Description of the Copenhagen Hip And Groin Outcome Score (HAGOS)

HAGOS is a patient reported outcome measure (PROM) designed to measure hip- and groin-related disability in a young and active populations and recommended for studies on athletes with groin pain[13–15]. HAGOS consists of 37 items on the subscales pain, symptoms, physical function in daily living (ADDUCTOR LONGUS MUSCLE), function in sport and recreation (Sport), participation in physical activities (PA), and quality of life (QoL). Each item is answered on a five-point Likert scale with a corresponding score of 0-4. Each subscale is summarized in a score ranging from 0 (extreme symptoms) to 100 (no symptoms).[15]. HAGOS has adequate content,[21] and construct validity,[21] good test-retest reliability (intraclass correlation coefficients across subscales range from 0.82 to 0.92), is responsive (changes in subscales correlate with Global Perceived Effect),[21] and can discriminate between players with and without hip and groin pain.[24–26] HAGOS was recently revised from 37 to 30 items based on evaluation of the structural validity.[27] We report revised HAGOS scores.