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Association of markers of patellofemoral maltracking to cartilage damage and bone marrow lesions on MRI: Data from the 2016 Olympic Games of Rio De Janeiro

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ABSTRACT

Background: Patellofemoral joint (PFJ) disease is a common ailment in elite athletes. Our aim is to report the frequency of superolateral Hoffa's fat pad (SHFP) edema, and PFJ cartilage damage and bone marrow lesions (BML), among Olympian athletes, and to study the association between measurements of trochlear morphology and vertical patellar position and a) PFJ cartilage damage or BML, and b) SHFP edema.
Methods: All knee MRI, performed in the Olympic Village and polyclinics, of participating athletes in the 2016 Olympic Games of Rio de Janeiro were included. MRI were scored for PFJ cartilage damage and BML, and SHFP edema. Trochlear morphology measurements included sulcus angle, trochlear angle, lateral trochlear inclination, and medial trochlear inclination. Insall-Salvati ratio was also assessed.
Results: One hundred twenty-one knee MRIs were included (62 female, 51.2 %). The highest frequencies of PFJ cartilage damage, combination of PFJ cartilage damage and BML, and SHFP edema were found among Beach Volleyball and Volleyball athletes. SHFP edema was more common among female compared to male Olympian athletes. We found no statistically significant associations between different measurements of trochlear morphology/vertical patellar position, and 1. SHFP edema, and 2. PFJ cartilage damage/BML.
Conclusion: SHFP edema and the combination of PFJ cartilage damage and BML are highly frequent among Olympic athletes especially those competing in Beach volleyball and Volleyball. SHFP edema is more common among female athletes. Further studies are needed to determine whether PFJ cartilage damage has a stronger association to sports disciplines rather than trochlear morphology.

1. Introduction

Patellofemoral joint (PFJ) structural damage is common among young individuals and athletes [1], and is reported in association with increased physical demand such as squatting, kneeling, and heavy weightlifting [2]. Several measurements of PFJ maltracking, including vertical patellar position, have been associated with increased risk of PFJ cartilage damage, both cross-sectionally and longitudinally [3,4]. Superolateral Hoffa's fat pad (SHFP) edema, considered to be a structural manifestation of maltracking, has received increased attention over the past two decades and has been shown to be associated with more laterally displaced patella, more anterior trochlear facet, and

Abbreviations: BML, bone marrow lesion; IOC, International Olympic Committee; LTI, lateral trochlear inclination; MTI, medial trochlear inclination; OA, osteoarthritis; PFJ, patellofemoral joint; TA, trochlear angle; SA, sulcus angle; SHFP, superolateral Hoffa's fat pad.

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patella alta [3,5]. SHFP edema was also associated with PFJ cartilage damage [4]. In a cross-sectional study involving 16 collegiate volleyball athletes, SHFP edema was found in 50 % of the athletes and was associated with markers of PFJ maltracking [6].

MRI played an important role for the evaluation of sports injuries and knee pain among athletes participating to the 2016 Olympic Games of Rio de Janeiro [7]. Descriptive epidemiology of cartilage and ligamentous injuries among these athletes has been reported previously [8,9]. In particular, a study showed a high prevalence of PFJ cartilage damage in this population, especially in certain disciplines such as weightlifting, volleyball and beach volleyball [9]. However, associations of measurements of MRI markers of PFJ maltracking to local cartilage damage and BML have not been studied in elite athletes.

The aim of this study is 1. to examine the frequency of PFJ cartilage damage and bone marrow lesions (BML), as well as SHFP edema stratified by sex and sports discipline, and 2. to examine the cross-sectional association between trochlear morphology and vertical patellar position to PFJ cartilage damage and BML, as well as SHFP edema among athletes who participated in the 2016 Olympic Games of Rio de Janeiro.

2. Material and methods

We included all knee MRI performed on participating athletes during the 2016 Olympic Games. MRIs were all acquired in the International Olympic Committee (IOC) official clinic within the Olympic village, and during the time Olympic village was open. MRI referral was made either because of acute knee injury or knee pain without inciting event.

2.1. Data collection

MRI were acquired using a 3.0-T Discovery MR750w (GE Healthcare), and 1.5-T Optima 450 MRw (GE Healthcare). Fat-suppressed proton density-weighted images were obtained in the axial, sagittal, and coronal planes, and T2-weighted images were acquired in the sagittal plane. T1-weighted images were mostly acquired in the sagittal plane. Imaging data were collected from the Centricity Radiological Information System and Picture Archiving and Communication System, provided by GE Healthcare. Anonymized demographic data was also collected and stratified according to gender, age, and type of sport.

2.2. Confidentiality and ethical approval

Our study was approved by the IOC, with approval to use anonymized imaging and demographic data for publication. In addition, this study was approved by the medical research ethics division committee of the Southeastern Norway Regional Health Authority (#S-07196C). Finally, Institutional Review Board (IRB) approval was obtained from Boston University (#H-36593). The accreditation numbers were used to query the IOC athlete database for age, gender, disciplines and nationality of the athletes who had a knee MRI. All data was de-identified and remained confidential. Because the information in this epidemiological study was anonymized and de-identified, the need for informed consent was waived. The collection, storage and analysis of data was made in strict compliance with data protection and confidentiality.

2.3. MRI interpretation and measurements

Images were interpreted by two musculoskeletal radiologists: AJK (7 years of subspecialized musculoskeletal experience), and MJ (9 years of musculoskeletal imaging and MRI-based semiquantitative assessment of knee osteoarthritis (OA)). Both readers were blinded to initial reports. All MRIs were evaluated by AJK and MJ for cartilage damage and bone marrow lesions (BML) in the PFJ compartment. In case of disagreement, findings were adjudicated by a third MSK radiologist (AG) with 20 year-experience of musculoskeletal imaging and semiquantitative assessment of knee OA. Cartilage scoring was based on the modified Outerbridge grading system. Grade 1: Areas of hyperintensity with normal surface contour; Grade 2: Less than 50 % thickness cartilage loss; Grade 3: Greater than 50 % of cartilage thickness; Grade 4: Full thickness cartilage loss. Area extent was not considered in the grading. Cartilage damage was considered present of grade 1 and higher. Subchondral bone marrow lesions were scored as 0: Absent or 1: Present (Fig. 1).

Trochlear morphology, vertical position of the patella, and SHFP edema were assessed by MJ. For trochlear morphology, the axial MRI image on which the medial and lateral posterior femoral condyles were the most posterior was used. The posterior condylar line was drawn by connecting the medial and lateral posterior femoral condyles [3]. Using this same image, sulcus angle was defined as the angle between the medial and lateral trochlear facets. The lateral trochlear inclination angle was defined as the angle between the line along the lateral facet and the posterior condylar line. The medial trochlear inclination angle was defined as the angle between the line along the medial facet and the posterior condylar line [3]. Finally, the trochlear angle was defined as the angle between a line extending along the most anterior points of medial and lateral trochlear facets and the posterior condylar line [3] (Fig. 2).

The vertical position of the patella was assessed using sagittal MRI in which the anterior tibial tuberosity was most prominent [10]. The Insall-Salvati ratio (ISR) is the ratio between the length of the patellar tendon and length of the patella measured on the reference sagittal image (Fig. 3). Trochlear morphology and vertical position of the patella were performed using an open-source medical viewer (Horos version 3.3.6, Pixmeo, https://horosproject.org).

2.4. Statistical analysis

We first calculated descriptive statistics for all variables used in the study. These statistics were the mean, standard deviation, and range for continuous variables and frequency counts for categorical variables. We also determined the frequency of SHFP edema stratified by gender and discipline. To determine the relationship of measures of trochlear morphology and ISR, to SHFP edema, and PFJ cartilage damage or BML, we used separate logistic regression models for each measure of alignment and morphology (exposure variable), adjusting for age and gender. Measurements were grouped into quartiles with the lowest quartile considered the reference.

In a separate model, each exposure variable was entered as a continuous variable to assess its linear relationship to SHFP edema (P value for linear trend). All analyses were performed (L.L.) by using software (SAS 9.4; SAS Institute, Cary, NC).

3. Results

One hundred twenty-one knee MRIs from 114 athletes were included (62 female, 51.2 %) with a mean age of 27.2 years. Descriptive data of trochlear morphology, SHFP edema and vertical patellar position are shown in Table 1.

Table 2 shows the frequency of PFJ cartilage damage, combined PFJ cartilage damage and BML, and SHFP edema stratified by sport discipline and sex. All three features were most frequent among Beach Volleyball & Volleyball competing athletes (78.9 % for PFJ cartilage damage, 36.8 % for combined PFJ cartilage damage and BML, and 68 % for SHFP edema). Weightlifters showed the second highest frequency of PFJ cartilage damage (70 %), however SHFP edema in weightlifting (50 %) was slightly lower than hockey (62.5 %), Athletics (59.3 %), and wrestling (54.5 %). Combined PFJ cartilage damage and BML had the second highest frequency among Handball athletes (23.1 %), followed by weightlifting (20 %). SHFP edema was more common among female than male athletes (64.5 versus 39 %, $p = 0.05$), however the difference between male and female athletes was not statistically significant for PFJ cartilage damage, and combined PFJ cartilage damage and BML.

The associations between trochlear morphology measurements and

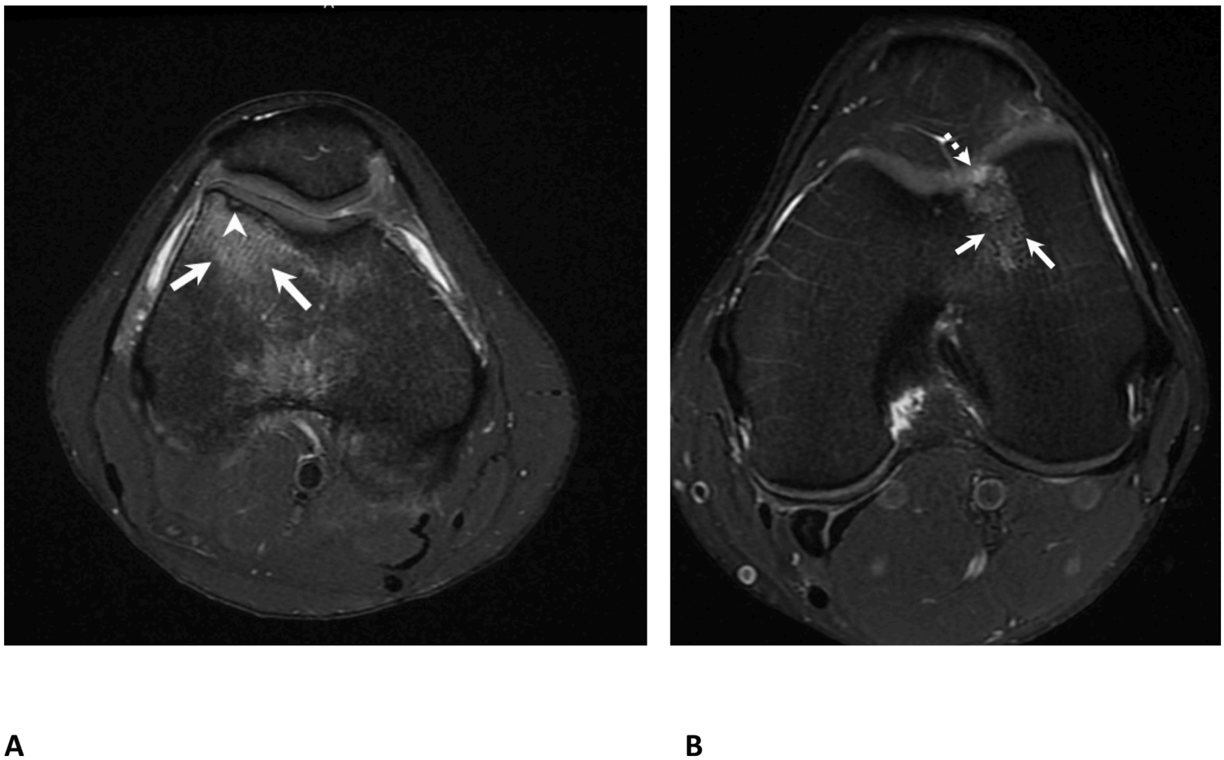

Fig. 1. A. Axial proton density-weighted fat-suppressed (PDFS) MRI in a 22-year-old female Hockey player with extensive bone marrow lesions of the lateral trochlea (arrows), and subchondral insufficiency fracture (arrowhead). Small joint effusion is also noted. **B.** In a different athlete, a 33-year-old male Beach Volleyball player, axial PDFS MRI of the right knee shows full-thickness cartilage loss of the lateral trochlea (dashed arrow) with underlying marked bone marrow lesion (arrows).

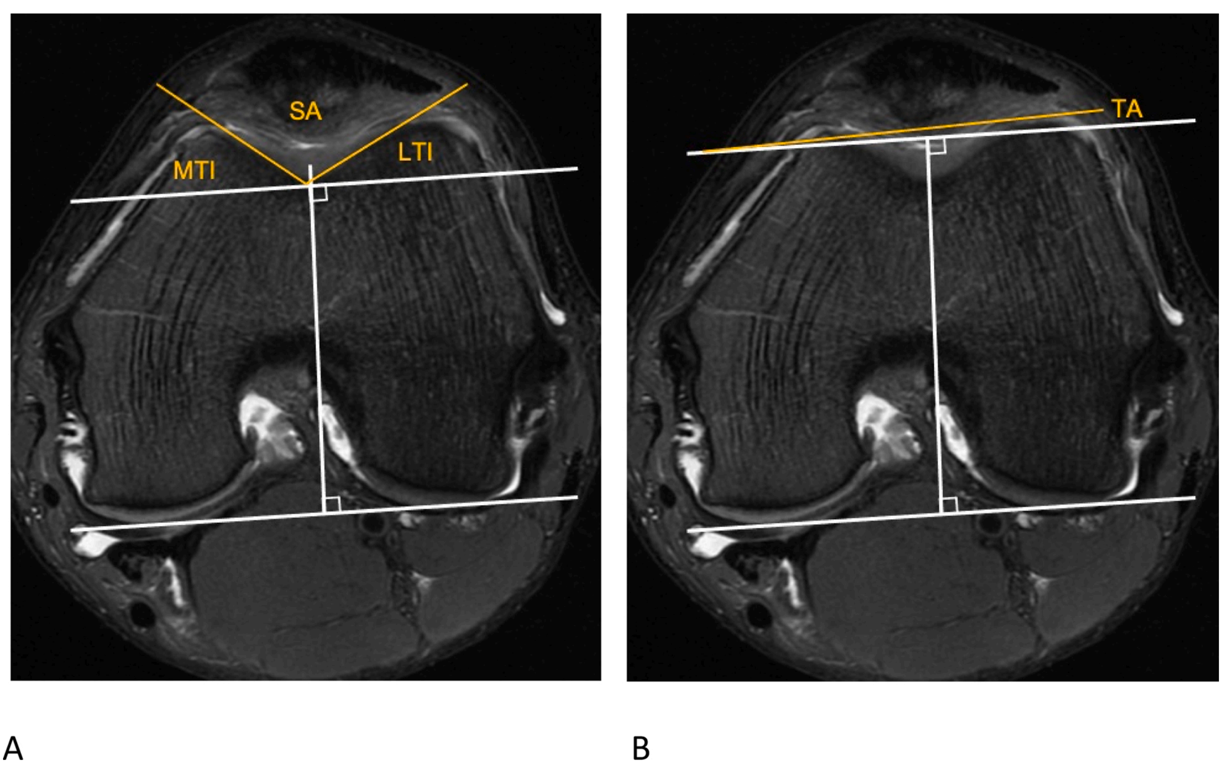

Fig. 2. Axial proton density-weighted fat-suppressed MRI show assessment of trochlear morphology. A. Posterior condylar line and sulcus angle (SA) are drawn first. Lateral trochlear inclination (LTI) and medial trochlear inclination (MTI) angles are determined from SA and the posterior condylar line. B. Trochlear angle (TA) is drawn with vertex on medial side.

Fig. 3. Sagittal proton density-weighted fat-suppressed MRI shows assessment of Insall-Salvati ratio (ISR): patellar tendon (PT) / patellar length (PL).

Table 1
Descriptive statistics of sample population.

Characteristic	Data
Number of female athlete knees (%)	62 (51.2)
Mean Age (range)	27.2 (17–38)
Number of knees with SHFP edema (%)	63 (52.1)
Mean Sulcus Angle (range)	123.6 (98–149)
Mean Lateral trochlear inclination (range)	26.17 (11–43)
Mean Medial trochlear inclination (range)	30.28 (16–51)
Mean Trochlear Angle (range)	2.70 (0–11)
Mean Insall-Salvati Ratio (range)	1.30 (0.9–2.1)

1. PFJ cartilage damage/BML, and 2. SHFP edema are presented in Table 3. Compared with measurements in the lowest sulcus angle quartile (taken as reference), those with measurements in the highest quartile had 1.77 times the odds of PFJ cartilage damage/BML (Confidence Interval (CI): 0.63–5.0), and 1.42 the odds of SHFP edema (CI: 0.48−4.22). Compared with those with measurements in the lowest lateral trochlear inclination quartile, those with measurement in the highest quartile had 0.74 times the odds of SHFP edema (CI: 0.24–2.3), and 0.84 times the odds of PFJ cartilage damage/BML (CI:0.28−2.45). Compared with those with measurements in the lowest medial trochlear inclination quartile, those with measurement in the highest quartile had 0.55 times the odds of SHFP edema (CI: 0.19−1.57), and 0.36 times the odds of PFJ cartilage damage/BML (CI:0.13−1.03). Compared with those with measurements in the lowest trochlear angle quartile, those with measurements in the highest quartile had 2.42 times the odds of SHFP edema (CI: 0.93−6.32), and 1.14 times the odds of PFJ cartilage damage/BML (CI: 0.45−2.84).

Table 4 shows the association between ISR and 1. PFJ cartilage damage/BML, and 2. SHFP edema. Compared with those with measurements in the lowest ISR quartile, those with measurements in the highest quartile had 2.18 times the odds of SHFP edema (CI: 0.76−6.26), and 2.77 times the odds of PFJ cartilage damage/BML (CI: 0.96−7.99).

Table 2
Frequency of patellofemoral joint (PFJ) cartilage damage, combination of PFJ cartilage damage and bone marrow lesions (BML), and superolateral Hoffa's fat pad (SHFP) edema by sport and by gender (p values refer to sex difference).

Sport	Number of knees with MRI	Number of knees with PFJ cartilage damage (%)	Number of knees with PFJ cartilage damage and BML (%)	Number of knees with SHFP Edema (%)
Athletics	27	10 (37.0 %)	3 (11.1 %)	16 (59.3 %)
Beach volleyball & Volleyball	19	15 (78.9 %)	7 (36.8 %)	13 (68.4 %)
Handball	13	5 (38.5 %)	3 (23.1 %)	6 (46.2 %)
Hockey	8	1 (12.5 %)	1 (12.5 %)	5 (62.5 %)
Judo	8	2 (25.0 %)	0 (0%)	2 (25.0 %)
Weightlifting	10	7 (70.0 %)	2 (20 %)	5 (50.0 %)
Wrestling	11	3 (27.3 %)	1 (9%)	6 (54.5 %)
Aquatics - Water polo, Rowing, Shooting, Tennis [#]	4	0 (0.0 %)	0 (0%)	1 (25.0 %)
Other sports [*]	21	11 (52.4 %)	2 (9.5 %)	9 (42.9 %)
Total	121	52 (42.6 %)	19 (15.7)	63 (52.1 %)
Male	59	27 (45.8 %)	8 (13.6 %)	23 (39.0 %)
Female	62	27 (43.5 %) P = 0.8	11 (17.7 %) P= 0.53	40 (64.5 %) **P = 0.05**

[#] Sports with 1 athlete each without cartilage damage.
[*] Sports with 4 athletes or less, and with cartilage damage.

4. Discussion

In this study, we found that the frequency of PFJ cartilage damage was comparable among male and female athletes, however SHFP edema was found to be more prevalent among female athletes. This observation is in line with a prior study in a non-athlete population [3]. In addition, the frequency of SHFP edema by discipline showed striking similarities with the frequency of PFJ cartilage damage/BML, with both features being most common among Beach Volleyball and Volleyball athletes. This observation is also in line with prior studies suggesting SHFP edema as a local biomarker of PFJ cartilage damage/BML [3].

The particularly high frequency of PFJ cartilage damage among athletes participating in Beach Volleyball and Volleyball, as well as weightlifting was previously reported in the same cohort [9]. In weightlifting, it has been suggested that cartilage damage risk increases with exposure to high loading forces while performing squats [11]. Regarding Beach Volleyball and Volleyball, we found higher frequency of PFJ cartilage damage/BML in comparison with a recent study including adolescents and adults volleyball players, which showed frequency of cartilage damage not exceeding 38 % [12]. The latter study showed an increased frequency of cartilage damage among adult participants raising concern for increased risk of PFJ OA [12]. In volleyball, the knee joint is the second most common site of injury following the ankle joint [13]. The repetition of forceful and rapid movements of the whole body with different patterns including jumping and landing explains the relatively high frequency of gradual onset injuries [14]. This emphasizes the importance of preventive measures to mitigate the risk of PFJ cartilage damage.

Despite finding higher odds of SHFP edema and PFJ cartilage damage among those with highest quartile of ISR, our results were not statistically significant, which is possibly related to the small sample size and the highly selected cohort that was based on availability of MRI examinations only and MRIs were performed for a multitude of reasons. Prior studies have suggested an association between vertical patellar position, and SHFP edema and PFJ cartilage damage/BML [3,15]. In fact, patella alta has previously been associated to structural features of OA in the PFJ and to an increased risk of OA progression in the same compartment [15].

Our study has several limitations. First, we did not have data on knee

Table 3
Association of trochlear morphology measurements according to quartile, with superolateral Hoffa's fat pad edema (SHFP) edema, and patellofemoral joint (PFJ) cartilage damage or bone marrow lesions (BML). REF stands for the quartile used as reference.

Measurement	Quartile 1	Quartile 2	Quartile 3	Quartile 4	Trend
Sulcus Angle					
Number of knees	32	27	31	30	
Range	98−117	118−123	124−129	130−149	
Number of knees with SHFP edema	20	8	15	20	0.5160
Odds ratio	1.0 (REF)	0.29 (0.09−0.92)	0.69 (0.24−1.98)	1.42 (0.48−4.22)	
Number of knees with PFJ cartilage damage or BML	13	13	14	16	0.3772
Odds ratio	1.0 (REF)	1.28 (0.53−4.68)	1.15 (0.41−3.23)	1.77 (0.63−5.00)	
Lateral Trochlear Inclination					
Number of knees	28	38	27	27	
Range	11−22	23−26	27−29	30−43	
Number of knees with SHFP edema	18	16	13	16	0.8888
Odds ratio	1.0 (REF)	0.39 (0.14−1.11)	0.46 (0.15−1.41)	0.74 (0.24−2.30)	
Number of knees with PFJ cartilage damage or BML	14	15	15	12	0.9639
Odds ratio	1.0 (REF)	0.7 (0.26−1.94)	1.18 (0.40−3.47)	0.84 (0.28−2.45)	
Medial Trochlear Inclination					
Number of knees	35	28	29	28	
Range	16−26	27−30	31−34	35−51	
Number of knees with SHFP edema	23	13	12	15	0.2438
Odds ratio	1.0 (REF)	0.47 (0.16−1.33)	0.37 (0.13−1.07)	0.55 (0.19−1.57)	
Number of knees with PFJ cartilage damage or BML	21	8	17	10	0.2380
Odds ratio	1.0 (REF)	0.26 (0.09−0.75)	1.05 (0.37−2.94)	0.36 (0.13−1.03)	
Trochlear Angle					
Number of knees	46	22	18	34	
Range	0−1	2	3	4−11	
Number of knees with SHFP edema	21	8	11	23	0.0279
Odds ratio	1.0 (REF)	0.78 (0.26−2.28)	1.90 (0.60−5.99)	2.42 (0.93−6.32)	
Number of knees with PFJ cartilage damage or BML	22	8	10	16	0.8449
Odds ratio	1.0 (REF)	0.62 (0.21−1.79)	1.22 (0.40−3.73)	1.14 (0.45−2.84)	

Table 4
Association of Insall-Salvati ratio according to quartile, with superolateral Hoffa's fat pad edema (SHFP) edema, and patellofemoral joint (PFJ) cartilage damage or bone marrow lesions (BML). REF stands for the quartile used as reference.

Measurement	Quartile 1	Quartile 2	Quartile 3	Quartile 4	Trend
Insall-Salvati Ratio					
Number of knees	31	29	30	31	
Range	0.90−1.14	1.15−1.28	1.29−1.38	1.39−2.10	
Number of knees with SHFP edema	13	15	15	20	0.0989
Odds ratio	1.0 (REF)	1.49 (0.52−4.27)	1.38 (0.49−3.92)	2.18 (0.76−6.26)	
Number of knees with PFJ cartilage damage or BML	11	14	14	18	0.0978
Odds ratio	1.0 (REF)	1.66 (0.58−4.78)	1.66 (0.58−4.74)	2.77 (0.96−7.99)	

pain to correlate to PFJ cartilage damage/BML or SHFP edema. However, this study was retrospective and such data was not available. In addition, because of the relatively small sample of this cohort, findings lacked statistical significance.

In summary, SHFP edema is more frequent among female versus male Olympian competing athletes. PFJ cartilage damage, the combination of PFJ cartilage damage and SHFP edema were all most frequent among Volleyball and Beach Volleyball players. The absence of statistically significant associations between measurements of trochlear morphology/vertical patellar position, and PFJ cartilage damage, and SHFP edema may be related to the small size of the sample. Further studies are needed to better evaluation the contribution of PFJ maltracking in the development of cartilage damage among elite athletes.

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Confidentiality and ethical approval

Our study was approved by the International Olympic Committee (IOC), with approval to use anonymized imaging and demographic data for publication. In addition, this study was approved by the medical research ethics division committee of the Southeastern Norway Regional Health Authority (#S-07196C). Finally, IRB approval was obtained from Boston University (#H-36593). The accreditation numbers were used to query the IOC athlete database for age, gender, and nationality of the athletes who had a knee MRI. All data was de-identified and remained confidential. Because the information in this epidemiological study was anonymized and de-identified, the need for informed consent was waived. The collection, storage and analysis of data was made in strict compliance with data protection and confidentiality.

Data availability statement

Not applicable.

CRediT authorship contribution statement

Mohamed Jarraya: Conceptualization, Methodology, Data curation, Writing - original draft. **Frank W. Roemer:** Data curation, Formal analysis, Writing - review & editing. **Lars Engebretsen:** Writing - review & editing, Visualization, Investigation. **Andrew J. Kompel:** Data curation, Writing - review & editing, Supervision. **Kirstin M. Small:** Data curation, Validation, Writing - review & editing. **Stacy E. Smith:** Data curation, Writing - review & editing. **Ali Guermazi:** Supervision, Writing - review & editing.

Declaration of Competing Interest

Ali Guermazi is shareholder of Boston Imaging Core Lab (BICL), LLC, and a consultant to MerckSerono, AstraZeneca, Pfizer, Novartis, Regeneron and TissueGene. Frank Roemer is a shareholder of BICL, LLC and a consultant to Calibr - California Institute of Biomedical Research. Lars Engebretsen is a consultant to Arthrex and Smith and Nephew. Andrew J. Kompel, Kirstin Small, Stacy E. Smith, and Mohamed Jarraya have nothing to disclose.

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