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Every second retired elite female football player has MRI evidence of knee osteoarthritis before age 50 years: a cross-sectional study of clinical and MRI outcomes

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Abstract

Purpose To assess knee health in retired female football players, using magnetic resonance imaging (MRI) and self-report. The focus of analysis were degenerative changes of the tibiofemoral joint, and their relationship to osteoarthritis symptoms and previous knee injury.

Methods Forty-nine retired elite, female football players (98 knees) aged 37 years on average participated. Tibiofemoral cartilage and meniscus status of both knees were evaluated using MRI and graded according to modified Outerbridge and Stoller classifications, respectively. Symptoms were assessed through a standardised questionnaire (Knee Osteoarthritis Outcome Score: KOOS). Knee injury history was recorded via a semi-structured interview. To investigate how injury variables relate to outcomes, binary logistic regression models were used and reported with odds ratios (OR).

Results Fifty-one per cent of players ($n = 25$) fulfilled the MRI criterion for knee osteoarthritis, 69.4% ($n = 34$) had substantial meniscal loss and 59.6% ($n = 28$) reported substantial clinical symptoms. Chondral- and meniscal loss were associated with significantly lower scores on three of five KOOS subscales ($p < .05$). Both chondral and meniscal loss were significantly predicted by previous traumatic knee injury (OR = 4.6, OR = 2.6), the injury affecting the non-striking leg (OR = 8.6, OR = 10.6) and type of injury; participants with combined ACL/meniscus injuries had the highest risk for substantial chondral and meniscal loss (OR = 14.8, OR = 9.5). Chondral loss was significantly predicted by isolated meniscus injury treated with partial meniscectomy (OR = 5.4), but not by isolated reconstructed ACL injury. Clinical symptoms were only significantly predicted by previous traumatic knee injury (OR = 5.1).

Conclusions Serious degenerative changes were found in a high number of retired female football players' knees 10 years after their career. Meniscal integrity is key for knee osteoarthritis outcomes in young adults, and thus, its preservation should be a priority.

Keywords Football (soccer) · Osteoarthritis · Knee injury · Long-term outcomes · Meniscus · Female athlete

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Introduction

Osteoarthritis of the hip and knee (KOA) is presently the 11th leading cause of disability worldwide, and its prevalence is expected to rise substantially over the coming years, as the population is growing older and becoming more over-weight [11, 43]. While OA prevalence increases rapidly with age, the disease may be particularly burdensome for young adults, who still have high demands and expectations regarding their level of physical activity and work capacity [1, 33].

The main risk factors for early onset KOA are previous knee injuries and certain sporting activities [33]. Elite athletes in sports with heavy knee joint loading and high knee injury incidence were found to have an increased risk of KOA [14, 17–19, 39]. In a recent review, a three times higher KOA-risk was reported in male football players when compared to matched controls from the general population [14]. This finding was supported by results from a large cohort study ($n = 5292$) that found UK-based male ex-footballers to have a 2–3 times increased likelihood of current knee pain, radiographic KOA and total knee replacement [17]. Football players with a history of ACL injury were observed to develop radiographic KOA 12–14 years after injury in 41% of male [41] and 51% of female athletes [25]. Similarly, previous isolated meniscectomy was associated with a 43% prevalence of radiographic KOA 16 years after surgery [16]. Thus, around half of all individuals incurring an ACL or meniscal injury in their teens or tweens can expect to present with radiographic KOA between the ages 30 and 50 years.

While knee injuries may have serious long-term consequences, several authors have suggested that uninjured football players also have an increased risk of developing KOA compared to the general population [23]. In a study by Fernandes et al. [17], after adjusting for injury and other risk factors, male ex-footballers were still at an over twofold increased risk for KOA. The authors hypothesised that this is due to lasting damage from repetitive micro-trauma to the knee inherent to football play. Three recent reviews on KOA prevalence in professional football reported rates in former, male players ranging from 14 to 80% [22, 24, 30]. The wide range in prevalence rates is in large part due to varying OA definitions and diagnosis modalities as well as age differences in the study population. In a study with 152 retired female football players aged on average 33 years, a 14% rate of clinician-diagnosed KOA was observed [31]. Thus, early onset of KOA is a major concern for former elite football players.

To date only two studies have been conducted focusing on female retired players [25, 31]. However, both studies had limited ability to assess KOA prevalence. Lohmander et al. [25] only included players with previous ACL injuries, and Prien et al. [31] assessed KOA via self-report only. This is an important gap in the literature, as the prevalence of KOA in the general population and related burden of disease in young adults (15–49 years) is higher among women than men [1, 11]. Further, women are more prone to ACL injury, which is an important risk factor for KOA [32, 38]. Therefore, the primary aim of this study was to assess knee health in retired female football players with and without previous injury, using MRI as well as self-report modalities. A specific focus was placed on abnormalities of the tibiofemoral cartilage and meniscus, and their relationship to KOA symptoms. A secondary aim was to assess injury-related risk factors for KOA, since these may be modifiable and thus, preventable. Finally, knee-related QOL and other self-reported KOA outcomes in this group were compared to the general population and to male football players. It was hypothesized that the knees of young retired female football players would present with a high prevalence of degenerative changes on MRI, particularly previously injured knees. Further, it was expected that the severity of associated KOA symptoms would be similar to or worse than reported in young retired male football players and the general population.

Materials and methods

This was a quantitative, cross-sectional study combining patient-reported symptoms with MR imaging to investigate knee health in a cohort of young retired female football players. Included were all German former elite female football players, who had retired for at least 2 years and were aged between 30 and 50 years. Football players were defined as former elite, if they had participated in the first German league and/or played for the national team between 2000 and 2013. This time frame was chosen because it captured the professional phase of women's football which provided a more homogenous population in relation to training volume and intensity. Players with a severe non-football-related knee injury or a symptomatic generalised musculoskeletal disease were excluded from the study.

MRI outcomes

Tibiofemoral cartilage and meniscus status of both knees were evaluated using a standardised MRI protocol. Images were acquired on a 1.5T Siemens Aera MRI (Siemens AG, Germany). A knee transmit/receive 15-channels coil was used to perform the imaging of the left and the right knee sequentially. Sequences used were coronal stir, 3D T2 TrueFISP with water excitation (suppression of fat signal) in sagittal orientation, and T2 mapping in transverse and

Table 1 Sequence parameters of the MRI protocol

Sequence	STIR	3D T2 trueFISP	T2 map	T2 map
Orientation	Coronal	Sagittal	Transverse	Coronal
FOV, mm	170	160	160	160
In-plane resolution, mm^2	0.5 × 0.5	0.6 × 0.6 Reconstructed 0.3 × 0.3	0.6 × 0.6	0.6 × 0.6
Slice thickness/gap, mm	3/0.3	0.6/0	3/0.6	3/0.3
No of slices	30	176	11	30
TR/TE, ms	4300/43	10.79/4.78	1000/13.8, 27.6, 41.4, 55.2, 69.0	2280/13.8, 27.6, 41.4, 55.2, 69.0
Fat suppression	IR with TI = 160 ms	Water excitation	None	None
Acceleration	None	Grappa factor 3	None	None
Averages	2	1	1	1
Bandwidth, Hz/px	191	190	227	227
Acquisition time, min	3.58	6.12	2.20	5.14

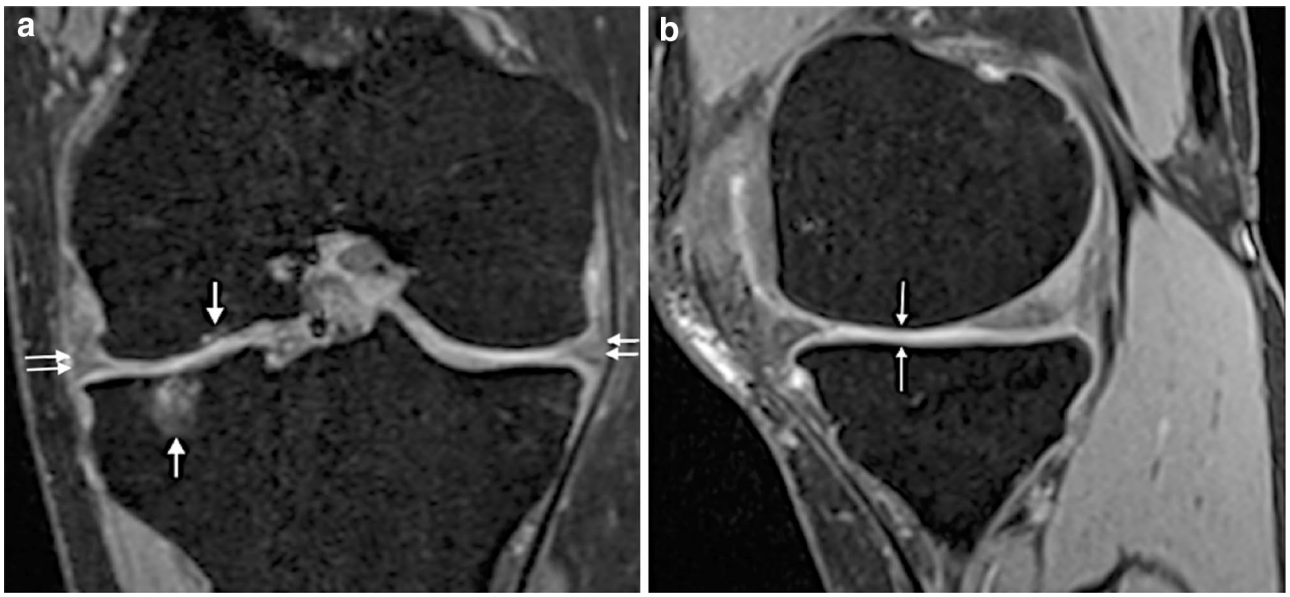

Fig. 1 Coronal (**a**) and sagittal (**b**) reconstructions of 3D T2 TrueFISP sequence. Right knee of a 33-year-old player 6 years after isolated meniscus injury. **a** Bilateral meniscal extrusion of ≥ 2 mm (double arrows), resulting in a meniscus score of 4 on both sides. Chondral grade 5 lesion of the lateral femur condyle and grade 4 of the tibial plateau (thick arrows), resulting in a lateral tibiofemoral cartilage score of 41. **b** Chondral grade 3 lesion of the medial femur condyle and grade 2 of the tibial plateau, resulting in a medial tibiofemoral cartilage score of 13

coronal orientations (Table 1). Evaluation of the MRIs was performed by an experienced musculoskeletal radiologist (initials) and a senior orthopaedic fellowship trained knee surgeon (initials). Both readers were blinded to the participants' injury history and other personal details. In case of disagreement consensus was achieved through discussion.

Cartilage status of the medial and lateral femur condyles (MFC, LFC) and tibial plateaus (MTP, LTP) was scored according to the modified Outerbridge classification [10, 26], grades 1–4; additional subchondral bone oedema or cyst formation was scored with a grade 5 (Fig. 1a). Based on these grades, tibiofemoral cartilage scores for the medial (MTF) and lateral (LTF) compartment were calculated as follows: $MTF = MFC^2 + MTP^2$ and $LTF = LFC^2 + LTP^2$. Thus, compartment scores emphasise severe damage in one location over mild damage in several locations (Fig. 1a, b). Knees were classified as presenting with substantial chondral loss if they had a MTF or LTF score ≥ 16 (range 0–50; Fig. 1a, b, 2a, b). Evaluation of medial and lateral meniscal status (MM, LM) was based on the Stoller classification

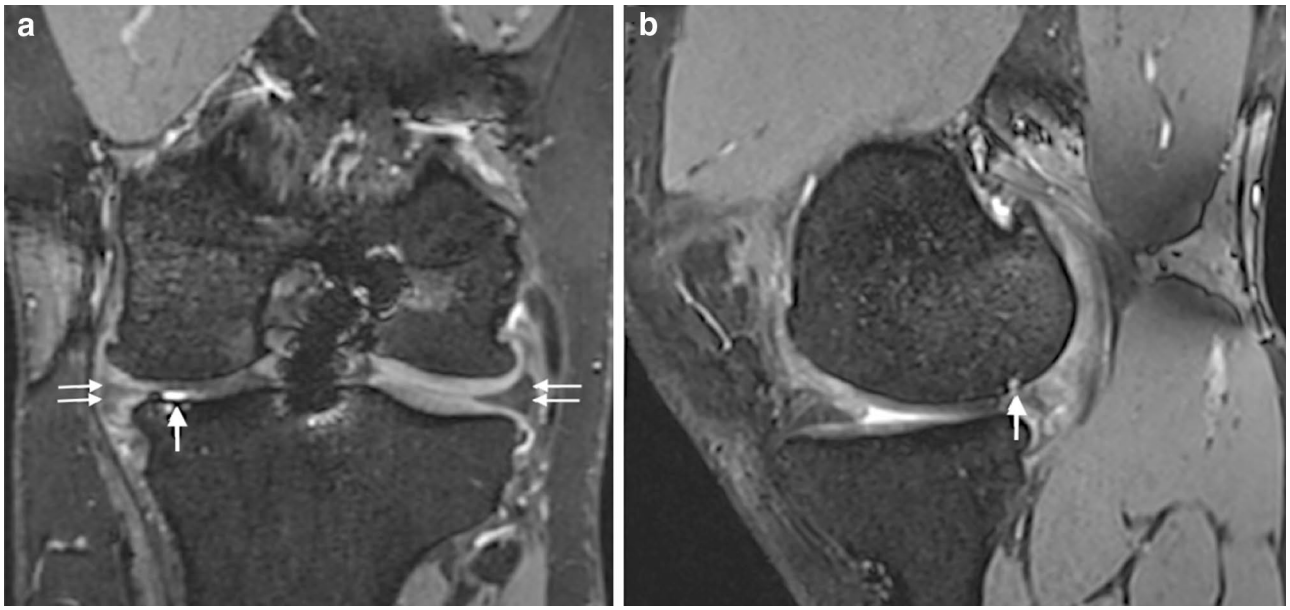

Fig. 2 Coronal (**a**) and sagittal (**b**) reconstructions of 3D T2 True-FISP sequence. Left knee of a 30-year-old player 9 years after ACL revision surgery with combined partial medial meniscectomy. **a** Bilateral meniscal extrusion of ≥ 2 mm (double arrows) resulting in a meniscus score of 4 on both sides. **a**, **b** Chondral grade 4 lesion to the medial femur condyle and tibial plateau (thick arrows), resulting in a medial tibiofemoral cartilage score of 32. **b** Probable chronic posteromedial subluxation of the medial femur condyle

[37], grades 1–4, with some modifications: 1—horizontal/intrasubstantial tear; 2—incomplete radial or oblique tear; 3—complex tear; 4—avulsed root or meniscal extrusion > 2 mm. To calculate meniscal extrusion, a line was drawn to join the tibial and femoral cortex medially and laterally at the level of the meniscus corpus; meniscal extrusion was measured in millimetres. Knees were classified as presenting with substantial meniscal loss if they had a MM or LM score ≥ 3 (Figs. 1a, 2a).

KOA symptoms and previous knee injuries

Information on personal and football-related characteristics was collected through an online survey. Details on previous knee injuries with associated time-loss of ≥ 28 days were recorded via a semi-structured interview. Injuries were defined as overuse injuries, if there was no specific, clearly identifiable injury event. Self-reported KOA symptoms were assessed using the Knee Osteoarthritis Outcome Score (KOOS) [20, 34]; in case of bilateral knee injury, participants were asked to report on the 'worse' knee. The KOOS is a widely used KOA-specific questionnaire comprising of five subscales scored from 0 to 100 with higher scores indicating less disability. Participants were considered to have substantial KOA-related symptoms if they scored equal to or below criterion in the KOOS QOL subscale (87.5) and at least two of the four remaining subscales [pain 86.1; symptoms 85.7; activities of daily living (ADL) 86.8; sports/recreation (sports/rec) 85.0] [25].

The present study was approved by the ethical commission Münster, Germany (2016-449-f-S).

Statistical analysis

All data were processed with SPSS (V.234, IBM) and Excel (Microsoft Office 2016). Descriptive statistics used were means with standard deviation (SD), frequencies with percentage and point prevalence with 95% confidence intervals (CI, Wilson Score Method). To investigate how injury variables relate to KOA outcomes binary logistic regression models were used. Injury details were assessed in isolation, while controlling for age and body mass index (BMI). The relationship between MRI outcomes and KOA symptoms was assessed via independent samples *t* tests. Reference values were extracted from the two studies with the best matching sample demographics and inclusion criteria to compare knee health of female players with male players (Greek men aged 35–55, $n = 100$) [28] and the general population (Swedish women aged 35–54 years, $n = 82$) [27]. Analysis was run using one sample *t* tests. Significance was accepted at $p < 0.05$.

Table 2 Characteristics of German retired female football players

Personal and football characteristics		Knee health and injury characteristics	
Response rate, *n* (%)	49 (20.0)	Any knee injury[a], *n* (%)	40 (81.6)
Age, mean (SD, range)	37.2 (4.9, 30–47)	ACL injury, *n* (%)	18 (36.7)
BMI, mean (SD, range)	22.4 (2.7, 19–31)	Meniscus injury, *n* (%)	25 (51.0)
Career years, mean (SD, range)	9.9 (5.3, 1–20)	Knee surgery, *n* (%)	36 (73.5)
Retirement years, mean (SD, range)	9.6 (4.0, 2–20)	Sub. chondral loss, *n* (%)	25 (51.0)
Trainings/week, mean (SD, range)	5.0 (1.3, 3–8)	Sub. meniscal loss, *n* (%)	34 (69.4)
Matches/year, mean (SD, range)	25.4 (12.4, 6–55)	KOA symptoms, *n* (%)	28 (59.6)

BMI body mass index, *SD* standard deviation, *ACL* anterior cruciate ligament, *Sub.* substantial, *KOA* knee osteoarthritis

[a]Time loss ≥ 28 days

Table 3 Relationship of MRI outcomes and self-reported KOA symptoms

KOA symptoms	All players	No loss	Chondral loss		Meniscal loss	
	Mean (SD)	Mean (SD)	Mean (SD)	*p*	Mean (SD)	*p*
Pain	79.7 (15.8)	86.4 (11.4)	76.9 (16.3)	NS	76.5 (16.9)	NS
Symptoms	70.1 (19.0)	79.2 (17.9)	65.9 (18.9)	NS	66.0 (18.9)	0.048[a]
ADL	89.6 (11.1)	92.4 (5.8)	90.1 (11.6)	NS	87.5 (12.4)	NS
Sports/rec	70.9 (25.6)	81.4 (11.9)	65.4 (28.4)	0.023[a]	65.3 (28.4)	0.013[a]
QOL	68.5 (24.2)	81.3 (17.7)	59.5 (24.1)	0.011[a]	63.1 (25.2)	0.033[a]

KOA knee osteoarthritis, *SD* standard deviation, *ADL* activities of daily living, *sports/rec* sports and recreation, *QOL* quality of life

[a]Significant difference compared to 'no degeneration' group

Results

Of the 245 German former elite football players who could be contacted, 57 registered for the study. Six volunteers were not available during the study period or stopped responding, and two had to be excluded due to a severe non-sport related knee injury ($n = 1$) or symptomatic generalized musculoskeletal disease ($n = 1$). Finally, 49 players (response rate: 20.0%) took part in the bilateral MRI examination ($n = 98$ knees). Details on sample characteristics can be found in Table 2.

Previous knee injuries

In total, 77 traumatic and 18 overuse injuries in 60 (61.9%) knees of 39 (81.3%) players (21 bilateral) were reported. Injuries affected an almost equal number of right ($n = 31$) and left ($n = 29$) knees or striking ($n = 28$) and non-striking ($n = 30$) legs. Isolated ACL injuries were reported in 13 (13.3%) knees, isolated meniscus injuries in 16 (16.3%) knees, and 17 (17.3%) knees had combined or subsequent ACL/meniscus injuries. All knees with previous ACL injury underwent ACL reconstruction. All but two meniscus injuries were treated with partial meniscectomy, one was repaired with sutures and one was treated conservatively. On average, index knee injuries were incurred 15.5 years ago (SD = 6.1), and every fourth ($n = 12$, 24.5%) player had her first knee injury before age 20.

MRI outcomes

Chondral loss of grade 3 or higher was found in a quarter of knees on the LFC ($n = 24$, 24.5%) and in a quarter of knees on the MFC ($n = 25$, 25.5%), in almost a third of knees on the LTP ($n = 31$, 31.6%) and in 18.4% ($n = 18$) of knees on the MTP. Thirty (30.6%) knees of 25 (51.0%) players (5 bilateral) fulfilled the criterion for substantial tibiofemoral chondral loss. The medial side was affected in 12.2% ($n = 12$) of knees, the lateral side in 21.4% ($n = 21$) of knees, and both sides were affected in three knees (3.1%). Substantial meniscal loss of grade 3 or higher was observed in a third of lateral and medial menisci; thus, both sides were affected equally (each $n = 32$, 32.7%). Meniscus extrusion of more than 2 mm was measured in 24 (24.5%) medial and 25 (25.5%) lateral menisci. In total, 52 (53.1%) knees of 34 (69.4%) players (18 bilateral) fulfilled the criterion for substantial meniscal loss.

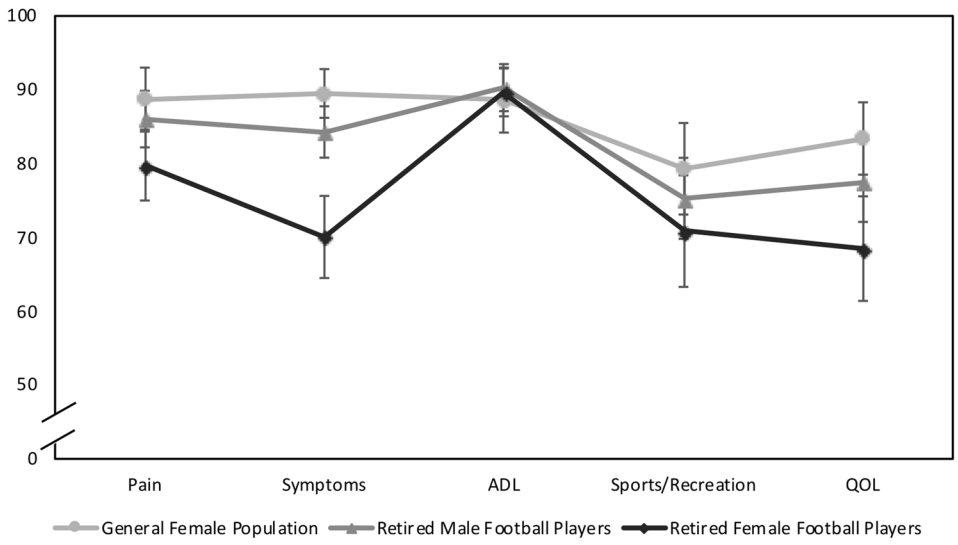

Fig. 3 Mean KOOS values and 95% CIs in the general female population [27] and retired male [28] and female football players. *ADL* activities of daily living, *QOL* quality of life

KOA symptoms

Mean KOOS scores for retired female football players can be found in Table 3. Over half of the players ($n = 28$, 59.6%) fulfilled the criteria for substantial KOA symptoms. Compared to reference values collected in the general female population [27] and retired male football players [28], retired female football players scored significantly lower (worse) on the pain, symptoms and QOL subscales ($p < 0.05$, Fig. 3). Significant group differences on the sports/rec subscale were only found between the study sample ($M = 70.9$, SD = 25.6) and the general female population ($M = 79.3$, SD = 27.7, $p = 0.028$). No significant differences were observed on the ADL subscale.

MRI outcomes and KOA symptoms

Data for MRI outcomes and KOA symptoms was available for 47 players. Of those, 11 (23.4%) players fulfilled neither the MRI nor the KOOS criteria for KOA. Eleven (23.4%) players had substantial KOA symptoms only, 8 (17.0%) had substantial chondral loss only and 17 (36.2%) presented with both. When comparing KOOS values in players with and without substantial chondral or meniscal loss, significant differences were found on the symptom, sports/rec and QOL subscales ($p < 0.05$, Table 3). Participants with substantial chondral or meniscal loss had lower (worse) scores than those without. The largest differences were observed on the QOL subscale.

Regression analysis

Binomial logistic regression models were calculated to ascertain the effects of injury details on the likelihood that participants have substantial KOA symptoms, chondral or meniscal loss (Table 4). Chondral and meniscal loss were significantly associated with previous traumatic knee injury (OR = 4.6, $p = 0.002$; OR = 2.6, $p = 0.023$), the injury affecting the non-striking leg (OR = 8.6, $p = 0.001$; OR = 10.6, $p < 0.001$) and the type of injury; participants with combined ACL/meniscus injuries had the highest likelihood to present with significant chondral (OR = 14.8, $p < 0.001$) and meniscal loss (OR = 9.5, $p = 0.001$). Further, isolated meniscus injury was a significant predictor for substantial chondral loss (OR = 5.4, $p = 0.026$), while isolated ACL injury was not. Younger age at index ACL/meniscus injury was significantly associated with an increasing likelihood of substantial meniscal loss (OR = 0.78, $p = 0.022$). KOA symptoms were only significantly associated with previous traumatic knee injury (OR = 5.1, $p = 0.023$).

Discussion

The most important finding of this study was the high prevalence of serious degenerative changes in the knees of retired female football players. Half of the players fulfilled the MRI criterion for KOA, over two-thirds had substantial meniscal loss and over half reported substantial KOA-related symptoms in a cohort as young as 37 years on average. The prevalence of symptomatic KOA, defined as presenting with both substantial chondral loss and associated symptoms, was 36% in the present cohort. In an online survey of the same population with a bigger sample size ($n = 152$) [31], only 13.8% of players reported physician-diagnosed KOA. However, participants of the precursor study were on average 5 years younger, and KOA assessment did not include imaging-modalities or a standardized symptom questionnaire. Thus, while there is likely a sampling bias in the current study, the

Table 4 Binary logistic regression models predicting KOA outcomes based on injury details

	Chondral loss			Meniscal loss			KOA symptoms		
	PP (95% CI)[a]	OR (95% CI)[b]	*p*	PP (95% CI)[a]	OR (95% CI)[b]	*p*	PP (95% CI)[a]	OR (95% CI)[b]	*p*
Traumatic injury									
No	14.9 (7.4–27.7)	1		40.4 (27.6–54.7)	1		30.8 (12.7–57.6)	1	
Yes	44.0 (31.2–57.7)	4.61 (1.72–12.36)	0.002[c]	64.0 (50.1–75.9)	2.64 (1.14–6.10)	0.023[c]	69.7 (52.7–90.4)	5.14 (1.25–21.07)	0.023[c]
Injured leg									
No injury	10.8 (4.3–24.7)	1		29.7 (17.5–45.8)	1				
Non-striking	53.3 (36.1–69.8)	8.63 (2.42–30.73)	0.001[c]	80.0 (62.7–90.5)	10.59 (3.18–35.28)	< 0.001[c]	n/a	n/a	n/a
Striking	32.1 (17.9–50.7)	3.68 (0.98–13.78)	NS	53.6 (35.8–70.5)	2.66 (0.89–7.86)	NS	n/a	n/a	n/a
Type of injury									
No injury	10.8 (4.3–24.7)	1		29.7 (17.5–45.8)	1		33.3 (12.1–64.6)	1	
ACL only	30.8 (12.7–57.6)	3.74 (0.77–18.22)	NS	61.5 (35.5–82.3)	3.55 (0.93–13.55)	NS	60.0 (23.1–88.2)	2.67 (0.26–27.00)	NS
M. only	37.5 (18.5–61.4)	5.41 (1.22–23.94)	0.026[c]	62.5 (38.6–81.5)	3.42 (0.96–12.23)	NS	69.2 (42.4–87.3)	4.10 (0.65–26.06)	NS
ACL and M.	64.7 (41.3–82.7)	14.83 (3.51–62.69)	< 0.001[c]	76.5 (52.7–90.4)	9.47 (2.38–37.62)	0.001[c]	75.0 (46.8–91.1)	6.06 (0.87–42.03)	NS
Other injury	33.3 (15.2–58.3)	4.25 (0.94–19.12)	NS	66.7 (41.7–84.8)	5.28 (1.40–19.96)	0.014[c]	50.0 (21.5–78.5)	2.04 (0.28–14.77)	NS
Age M./ACL injury	n/a	0.86 (0.71–1.04)	NS	n/a	0.78 (0.63–0.97)	0.022[c]	n/a	0.96 (0.77–1.19)	NS

KOA knee osteoarthritis, *PP* point prevalence, *OR* odds ratio, *CI* confidence interval, *ACL* anterior cruciate ligament, *M.* meniscus

[a]Per 100 knees/players

[b]Adjusted for age and BMI

[c]Significant difference compared to reference category

higher prevalence rate may also be an effect of the differences in sample age and recording method. The latter is in line with the literature on KOA; while reported prevalence rates are highly variable, typically lower rates are reported in studies using self-report than in studies using imaging modalities [29]. Pooled prevalence estimates reported in a recent review on retired male football players (self-report 14.6%, imaging-based 53.7%) [30] were comparable to those found in retired female football players in the present study (imaging-based 51.0%) and the precursor study (self-report 13.8%) [31].

Compared to the general population and to male football players, female football players in the current study reported significantly more disability due to knee problems. Particularly they reported more pain, more severe symptoms and lower knee-related QOL. Similar results have been described by two case–control studies comparing male ex-footballers to the general population. Arliani et al. [3] also reported significantly lower scores on the three KOOS subscales pain, symptoms and QOL in a cohort of Brazilian ex-footballers, and Fernandes et al. [17] found a near twofold increased risk for current knee pain among ex-footballers from the UK. However, another study comparing KOOS values between Greek male ex-footballers and a matched control group of military personnel did not find significant differences [28]. In fact, military personnel reported more pain, despite having less advanced KOA and fewer knee surgeries. The authors hypothesized that this is due to a higher pain tolerance or altered pain perception among former elite athletes [28]. Likewise, the most pronounced differences in the present study were found on the symptoms and QOL subscales of the KOOS, which may indicate that pain should indeed not be used in isolation as a measure for severity of injury or disease in an elite athlete population. The fact that no differences were found on the ADL subscale is not surprising, as it has been described previously that this subscale has better content validity for older populations [9].

Studies integrating both KOA imaging and symptom criteria in football are scarce. This is partly explained by the fact that severity of cartilage damage and severity of symptoms generally correlate poorly [13]. When comparing KOA symptoms between players with substantial chondral loss and those without any loss, two of five subscales showed significant differences, while a third subscale approached significance (symptoms $p = 0.056$). Interestingly, when comparing players with substantial meniscal loss to those without any loss, similar results were found. This suggests that meniscus status and cartilage status play an at least equally relevant role for patient-reported KOA outcomes in this age group, especially given that meniscal loss was more prevalent than chondral loss. It has been suggested previously that degenerative meniscus lesions are frequently associated with early-stage radiographic KOA and may represent the first signal feature [15]. These findings are in line with the recent shift towards a more holistic view of KOA, which regards it as a total joint failure that may affect any knee joint structure rather than a disease manifesting in cartilage degeneration alone [5, 12].

The importance of the meniscus also transpires in the regression analysis. While any traumatic knee injury increased the risk for both structural and clinical outcomes with odds ratios of 2.6–5.1, type of injury seems to play a significant role. When compared to uninjured participants, players with a previous combined ACL/meniscus injury were 15 times more likely to present with substantial chondral loss, and 10 times more likely to have substantial meniscal loss. Isolated meniscus injury also significantly increased the risk for substantial chondral loss, while isolated ACL injury did not. The authors hypothesized that time to follow-up may have confounded the results; however, participants with isolated ACL injuries had in fact incurred index injuries longer ago (mean = 14 years) than participants with isolated meniscus injuries (mean = 12 years). This corroborates results of a review by Claes et al. [7], who found the prevalence of radiographic KOA to be low 10 years after isolated ACL reconstruction (16%) compared to the prevalence in patients who had associated meniscal resection (50%). The findings of the present study may be reflective of the young age of the cohort, and the fact that the vast majority of participants with meniscus injury were treated with partial meniscectomy. While knee instability due to isolated ACL injury may affect cartilage and meniscal health only later in life, meniscus injury and associated loss of function may accelerate cartilage loss significantly and lead to earlier onset of imaging-based KOA [8]. Thus, preserving meniscal function seems to be key for preventing/delaying KOA in young adults. This is in line with literature advocating meniscal repair over removal to improve long-term outcomes [35, 36, 42].

Further, some authors have proposed that meniscus injuries or resections on the lateral side have worse long-term outcomes than on the medial side [4, 6]. This may be a rationale for the study data showing substantial cartilage degeneration to affect the lateral compartment almost two times more often than the medial compartment. However, another study [2] found only medial and not lateral meniscectomy to be associated with the onset of KOA. In a recent review by van Meer et al. [40] the evidence for the association of lateral meniscectomy and tibiofemoral OA was described as conflicting. As the higher prevalence of substantial cartilage degeneration on the lateral side may be explained by a variety of other factors related to football exposure, previous injury or morphological characteristics, more evidence is needed to shed light on this issue.

Finally, regression analysis demonstrated leg dominance to be an important factor for long-term outcomes. While

knee injuries were distributed equally among both legs, only non-striking legs were significantly more likely to present with substantial chondral and meniscal loss, while striking injured legs showed no significant risk increase. These results extend previous findings by Kranjc et al. [21], who reported retired male football players to suffer more injuries and experience more KOA-related symptoms on their non-striking leg. These differences in long-term outcomes may be explained by higher biomechanical loads acting on the non-striking leg, such as rotational strain during kicking, eccentric landing forces and impact during tackles [21]. Therefore, adequate rehabilitation programmes and sufficient recovery time may be particularly important for injured weight-bearing legs, and leg dominance should be taken into account for return to sport protocols.

This study has several limitations. First, KOA prevalence rates likely overestimate true values in this population as the low response rate (20%) may have led to sampling bias. However, reported prevalence rates were in line with results from studies with retired male football players. Further, when comparing KOOS scores between football players and the general population, the control group was not matched to the study population. Therefore, the reported differences may be partly attributable to differences between the German and Swedish population. Further, injury data were recorded retrospectively; therefore, a recall bias is possible and pre-injury data on cartilage and meniscus status are lacking. However, injury data collection was carried out using detailed semi-structured interviews to aid accurate recall. Finally, this study focused on tibiofemoral cartilage status only‘; therefore, future studies focusing on patellofemoral cartilage status, and its relation to symptoms, injuries and football exposure are warranted.

Conclusion

Serious degenerative changes were found in a high number of former elite female football players knees as soon as 10 years after their professional career with a significant impact on their QOL. The main clinical implications of our findings are (a) preserving meniscal function is key to improve long-term knee health, i.e. repair over removal; (b) allowing sufficient recovery time is especially important for injuries affecting the weight bearing leg and (c) active female football players need to be further encouraged to include effective knee injury prevention programs in their training regime.

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Compliance with ethical standards

Conflict of interest Annika Prien, Sana Boudabou, Astrid Junge, Evert Verhagen, Bénédicte M. A. Delattre and Philippe M. Tscholl declare that they have no conflict of interest.

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References

1. Ackerman IN, Kemp JL, Crossley KM, Culvenor AG, Hinman RS (2017) Hip and knee osteoarthritis affects younger people, too. J Orthop Sports Phys Ther 47:67–79
2. Ahn JH, Kim JG, Wang JH, Jung CH, Lim HC (2012) Long-term results of anterior cruciate ligament reconstruction using bone-patellar tendon-bone: an analysis of the factors affecting the development of osteoarthritis. Arthroscopy 28:1114–1123
3. Arliani GG, Astur DC, Yamada RKF, Yamada AF, Miyashita GK, Mandelbaum B et al (2014) Early osteoarthritis and reduced quality of life after retirement in former professional soccer players. Clinics 69:589–594
4. Beaufils P, Becker R, Kopf S, Matthieu O, Pujol N (2017) The knee meniscus: management of traumatic tears and degenerative lesions. EFORT Open Rev 2:195–203
5. Brandt KD, Radin EL, Dieppe PA, van de Putte L (2006) Yet more evidence that osteoarthritis is not a cartilage disease. Ann Rheum Dis 65:1261–1264
6. Chatain F, Adeleine P, Chambat P, Neyret P (2003) A comparative study of medial versus lateral arthroscopic partial meniscectomy on stable knees: 10-year minimum follow-up. Arthroscopy 19:842–849
7. Claes S, Hermie L, Verdonk R, Bellemans J, Verdonk P (2013) Is osteoarthritis an inevitable consequence of anterior cruciate ligament reconstruction? A meta-analysis. Knee Surg Sports Traumatol Arthrosc 21:1967–1976
8. Cohen M, Amaro JT, Ejnisman B, Carvalho RT, Nakano KK, Peccin MS et al (2007) Anterior cruciate ligament reconstruction after 10–15 years: association between meniscectomy and osteoarthrosis. Arthroscopy 23:629–634
9. Collins NJ, Prinsen CAC, Christensen R, Bartels EM, Terwee CB, Roos EM (2016) Knee Injury and Osteoarthritis Outcome Score (KOOS): systematic review and meta-analysis of measurement properties. Osteoarthr Cartil 24:1317–1329
10. Crema MD, Roemer FW, Marra MD, Burstein D, Gold GE, Eckstein F et al (2011) Articular cartilage in the knee: current MR imaging techniques and applications in clinical practice and research. Radiographics 31:37–61
11. Cross M, Smith E, Hoy D, Nolte S, Ackerman I, Fransen M et al (2014) The global burden of hip and knee osteoarthritis: estimates from the Global Burden of Disease 2010 study. Ann Rheum Dis 73:1323–1330
12. Dieppe PA (2011) Developments in osteoarthritis. Rheumatology 50:245–247
13. Dieppe PA, Lohmander LS (2005) Pathogenesis and management of pain in osteoarthritis. Lancet 365:965–973

14. Driban JB, Hootman JM, Sitler MR, Harris KP, Cattano NM (2017) Is participation in certain sports associated with knee osteoarthritis? a systematic review. J Athl Train 52:497–506
15. Englund M (2004) Meniscal tear—a feature of osteoarthritis. Acta Orthop Scand 75:1–45
16. Englund M, Roos EM, Lohmander LS (2003) Impact of type of meniscal tear on radiographic and symptomatic knee osteoarthritis: a 16-year followup of meniscectomy with matched controls. Arthritis Rheum 48:2178–2187
17. Fernandes GS, Parekh SM, Moses J, Fuller C, Scammell B, Batt ME et al (2018) Prevalence of knee pain, radiographic osteoarthritis and arthroplasty in retired professional footballers compared with men in the general population: a cross-sectional study. Br J Sports Med 52:678–683
18. Gouttebarge V, Inklaar H, Backx F, Kerkhoffs G (2015) Prevalence of osteoarthritis in former elite athletes: a systematic overview of the recent literature. Rheumatol Int 35:405–418
19. Iosifidis MI, Tsarouhas A, Fylaktou A (2015) Lower limb clinical and radiographic osteoarthritis in former elite male athletes. Knee Surg Sports Traumatol Arthrosc 23:2528–2535
20. Kessler S, Lang S, Puhl W, Stöve J (2003) Der knee injury and osteoarthritis outcome score—ein funktionsfragebogen zur outcome-messung in der knieendoprothetik. Z Orthop 141:277–282
21. Krajnc Z, Vogrin M, Recnik G, Crnjac A, Drobnic M, Antolic V (2010) Increased risk of knee injuries and osteoarthritis in the non-dominant leg of former professional football players. Wien Klin Wochenschr 122(Suppl 2):40–43
22. Kuijt MT, Inklaar H, Gouttebarge V, Frings-Dresen MH (2012) Knee and ankle osteoarthritis in former elite soccer players: a systematic review of the recent literature. J Sci Med Sport 15:480–487
23. Larsen E, Jensen PK, Jensen PR (1999) Long-term outcome of knee and ankle injuries in elite football. Scand J Med Sci Sports 9:285–289
24. Lohkamp M, Kromer TO, Schmitt H (2017) Osteoarthritis and joint replacements of the lower limb and spine in ex-professional soccer players: a systematic review. Scand J Med Sci Sports 27:1038–1049
25. Lohmander LS, Ostenberg A, Englund M, Roos H (2004) High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players 12 years after anterior cruciate ligament injury. Arthritis Rheum 50:3145–3152
26. Outerbridge RE (1961) The etiology of chondromalacia patellae. J Bone Joint Surg Br 43B:752–757
27. Paradowski PT, Bergman S, Sundén-Lundius A, Lohmander LS, Roos EM (2006) Knee complaints vary with age and gender in the adult population. Population-based reference data for the Knee injury and Osteoarthritis Outcome Score (KOOS). BMC Musculoskelet Disord 7:38
28. Paxinos O, Karavasili A, Delimpasis G, Stathi A (2016) Prevalence of knee osteoarthritis in 100 athletically active veteran soccer players compared with a matched group of 100 military personnel. Am J Sports Med 44:1447–1454
29. Pereira D, Peleteiro B, Araújo J, Branco J, Santos RA, Ramos E (2011) The effect of osteoarthritis definition on prevalence and incidence estimates: a systematic review. Osteoarthr Cartil 19:1270–1285
30. Petrillo S, Papalia R, Maffulli N, Volpi P, Denaro V (2018) Osteoarthritis of the hip and knee in former male professional soccer players. Br Med Bull 125:121–130
31. Prien A, Prinz B, Dvořák J, Junge A (2017) Health problems in former elite female football players: prevalence and risk factors. Scand J Med Sci Sports 27:1404–1410
32. Prodromos CC, Han Y, Rogowski J, Joyce B, Shi K (2007) A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury-reduction regimen. Arthroscopy 23:1320–1325
33. Roos EM (2005) Joint injury causes knee osteoarthritis in young adults. Curr Opin Rheumatol 17:195–200
34. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD (1998) Knee Injury and Osteoarthritis Outcome Score (KOOS)—development of a self-administered outcome measure. J Orthop Sports Phys Ther 28:88–96
35. Seil R, Becker R (2016) Time for a paradigm change in meniscal repair: save the meniscus! Knee Surg Sports Traumatol Arthrosc 24:1421–1423
36. Stein T, Mehling AP, Welsch F, von Eisenhart-Rothe R, Jäger A (2010) Long-term outcome after arthroscopic meniscal repair versus arthroscopic partial meniscectomy for traumatic meniscal tears. Am J Sports Med 38:1542–1548
37. Stoller DW, Martin C, Crues J 3rd, Kaplan L, Mink JH (1987) Meniscal tears: pathologic correlation with MR imaging. Radiology 163:731–735
38. Sutton KM, Bullock JM (2013) Anterior cruciate ligament rupture: differences between males and females. J Am Acad Orthop Surg 21:41–50
39. Tveit M, Rosengren BE, Nilsson J-Å, Karlsson MK (2012) Former male elite athletes have a higher prevalence of osteoarthritis and arthroplasty in the hip and knee than expected. Am J Sports Med 40:527–533
40. van Meer BL, Meuffels DE, van Eijsden WA, Verhaar JA, Bierma-Zeinstra SM, Reijman M (2015) Which determinants predict tibiofemoral and patellofemoral osteoarthritis after anterior cruciate ligament injury? A systematic review. Br J Sports Med 49:975–983
41. von Porat A (2004) High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. Ann Rheum Dis 63:269–273
42. Weber J, Koch M, Angele P, Zellner J (2018) The role of meniscal repair for prevention of early onset of osteoarthritis. J Exp Orthop 5:10
43. Woolf AD, Pfleger B (2003) Burden of major musculoskeletal conditions. Bull World Health Organ 81:646–656