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The prevalence of, and risk factors for distal femoral cortical irregularity in the adolescent population

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ABSTRACT

Introduction: There is uncertainty around the pathogenesis and prevalence of distal femoral cortical irregularities (DFCI). We aimed to assess the prevalence of DFCI in a cohort of adolescents that underwent MRI and identify and assess associated risk factors.

Methods: A historical cohort study of adolescents (age 10 - <20 years) undergoing MRI scans was conducted. Data was collected for a period of five years using the Picture Archive and Communication System database at a large tertiary hospital. Data collected included sex, age, mechanism of injury and other pathology present in the original MRI report. Binary logistic regression was used to investigate potential risk factors for DFCI.

Results: 897 scans (mean age, 15.3 (SD 2.59) years; 499 (55.6 %) male) were analysed. Prevalence of DFCI among adolescents who had a MRI scan was 9.1 % (95 % CI: 7.3 %–11.2 %). Patients that had experienced DFCI were younger than those that had not (mean age 14.5 vs 15.3 years, P = 0.002). The mechanism of injury differed between patient groups (P = 0.015); Patients with DFCI were more likely to have had a patella instability/dislocation (22.8 % vs 16.1 %), and less likely to have had a pivotal knee injury (12.7 % vs 29.0 %). When compared to patients aged 10–13 years, older children had reduced odds of a DFCI: 13–16 years had an adjusted odds ratio (aOR) of 0.79 (95 % CI: 0.45 to 1.39); 16–20 years (aOR = 0.36; 95 % CI: 0.18 to 0.71). Males had reduced odds of a DFCI (aOR = 0.38; 95 % CI: 0.22 to 0.66).

Conclusions: Female sex and younger age were risk factors for development of DFCI. There was no statistically significant association between mechanism of injury and developing a DFCI. Further research is required to establish its prevalence in those who are asymptomatic and why younger adolescent females are more likely to experience DFCI.

1. Introduction

The knee is the joint most injured in adolescence, and it is estimated that the global incidence ranges from 10 to 25 %.[1] It is estimated that 2.5 million adolescent athletes present with sports-related injuries to emergency departments in the United States alone annually.[2] Common types of injury include strains, contusions and lacerations.[2] Assessment should commence with clinical examination to detect obvious deformities or trauma. Radiological investigation such as plain radiography or magnetic resonance imaging (MRI) may be required to detect non-visible abnormalities and to further establish extent of injury.[3] Examples include assessment of patellar dislocation or ligament rupture, and detection of minimally displaced fractures.[3]

A distal femoral cortical irregularity (DFCI) is seen as a lesion in the cortex of the bone, and in adolescents it is most commonly found in the posterior region of the distal medial femur.[4–6] It was first described by Kimmelstiel and Rapp in 1951.[7] It is thought to be a benign lesion, sometimes referred to as a "bufkin lesion" or "cortical desmoid". This lesion is thought to cause no symptoms and is diagnosed on plain radiographs or MRI.[4] Variable characteristics of DFCI have been described in the literature, including hypointense on T1-weighted, and

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List of abbreviations:

DFCI	distal femoral cortical irregularities
aOR	adjusted odds ratio
MHG	medial head of gastrocnemius
REC	Research Ethics Committee
HRA	Health Research Authority
HRCW	Health and Care Research Wales
PACS	Picture Archive and Communication System
CI	confidence interval

hyperintense on T2-weighted MRI. Additionally, a dark rim may be present at or near the sites of the medial head of gastrocnemius (MHG) attachment. Marrow oedema, adjacent soft-tissue oedema, and periostitis have also been observed in cases of DFCI associated with acute trauma.[5,8]

Several case reports have described DFCIs in very sporty and therefore physically active adolescents, but the pathogenesis is still not fully understood.[9–11] It is thought the lesion occurs due to repetitive mechanical stress at the attachment site of skeletal muscle to the distal femur. The most common site for the DFCI to occur is the posteromedial distal femur, to which the MHG and the aponeurosis of the adductor magnus attach.[4] An alternative theory is that the DFCI is the result of an avulsion injury. However, histological and radiological evidence have shown that the cortical irregularity is identical whether or not it occurs at a tendinous attachment.[4–6]

Despite studies indicating that DFCI is a chronic repetitive traction injury, acute knee trauma has also been associated with DFCI.[4] A pivotal injury is defined as trauma to the knee and surrounding structures following a rotational movement, often when jumping, landing, or attempting to turn during an activity. Stern et al. demonstrated a higher prevalence of DFCI in adolescent alpine skiers who repetitively put stress through their knees. They did not investigate pivotal injuries as a risk factor for DFCI, which is a common musculoskeletal injury, within this age group.[4]

Due to the uncertainty around the pathogenesis of DFCI, this study aimed to assess its prevalence in a cohort of adolescents that underwent MRI. Adolescence was defined as age 10 - <20 in keeping with the definition by the World Health Organisation (WHO).[12] Furthermore, epidemiological and pathologic parameters were compared between adolescents who suffered pivotal knee injuries with or without DFCI.

2. Methods

2.1. Ethical approval

This study received ethical approval from Health Research Authority (HRA). IRAS project ID 289205, Protocol number 20.0244, REC reference 21/WA/0041.

2.2. Data collection

A historical cohort study of adolescents (age 10- <20 years) undergoing MRI scans was conducted. Cohort participants were identified by performing a search of the Picture Archive and Communication System (PACS) database at St. George's Hospital Trust. Participants were defined as an adolescent on the date of the MRI and were included if they presented within a five-year period between January 1, 2014 and December 31, 2019.

The adolescents included had a knee MRI scan performed for indications such as pain, trauma to the knee, or feeling of instability. All patients had been reviewed by a Trauma and Orthopaedic consultant or registrar in the clinic and had subsequently requested a scan and followed the patient up. Study participants were excluded if they had any previous surgery, other than a diagnostic arthroscopy, on the knee that had the MRI scan. Patients were also excluded if the indication for MRI included malignancy, vascular abnormality, inflammatory arthritis, or infection. Polytrauma patients were also excluded.

A pivotal knee was identified by establishing the mechanism of the injury documented in clinic letters or the emergency department discharge letter. We also aimed to identify high level athletes, defined as someone who played regional or national sport competitively. Various definitions have been used, but this was considered the most appropriate for the adolescent population studied.

All subjects were scanned at our institution with either a 3-T MRI scanner (Philips Ingenia; Philips, Amsterdam, Netherlands) or a 1.5-T MRI scanner (GE Signa HDx; General Electric, Boston, United states). Our standard unenhanced MRI protocol for examination of the knee includes sagittal (Fig. 1), axial (Fig. 2), and coronal proton density-weighted fat-saturated sequences (Table 1). The MRI scans were reported by two consultant musculoskeletal (MSK) radiologists specifically to determine the presence of DFCI. Proton density fat saturated sequences were read in the sagittal and axial planes to determine whether a DFCI was present. A DFCI was defined as a lobulated lesion which measured greater than 2 mm on the sagittal sequence.[4] The size of the DFCI was recorded along with its anatomical position in relation to the attachment of tendons.

Demographic data collected included sex and age. Clinical information included mechanism of injury, and incidental pathology present within the knee joint at the time of the scan. This information was extracted from the original MRI report.

2.3. Statistical analyses

2.3.1. Bivariate Analyses

Bivariate Analyses: The groups based on DFCI status (yes versus no) were compared in their demographic and clinical characteristics. As distributional assumptions could be made in the continuous variable of

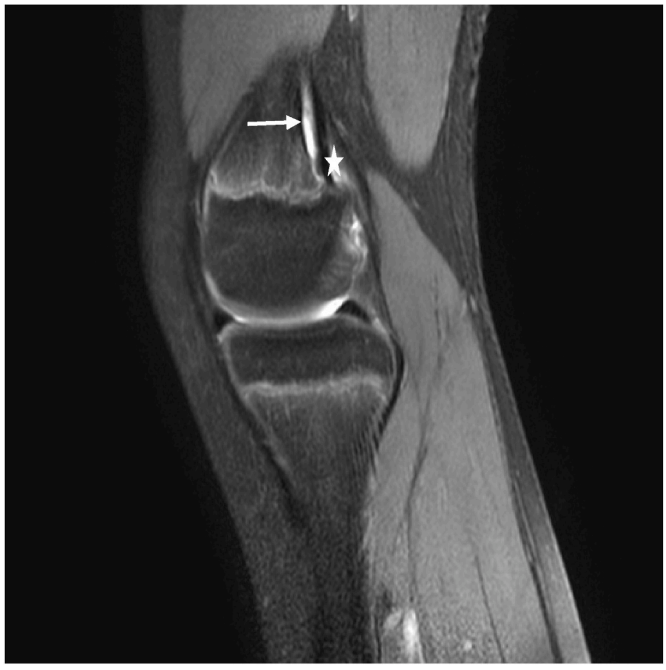

Fig. 1. Sagittal fat-saturated proton density–weighted MRI scan in a 12-year-old female with distal femoral cortical irregularity (DFCI) (white arrow) at the level of the tendon attachment of the medial head of the gastrocnemius muscle (MHG) (*). The patient presented with chronic intermittent knee pain and clicking.

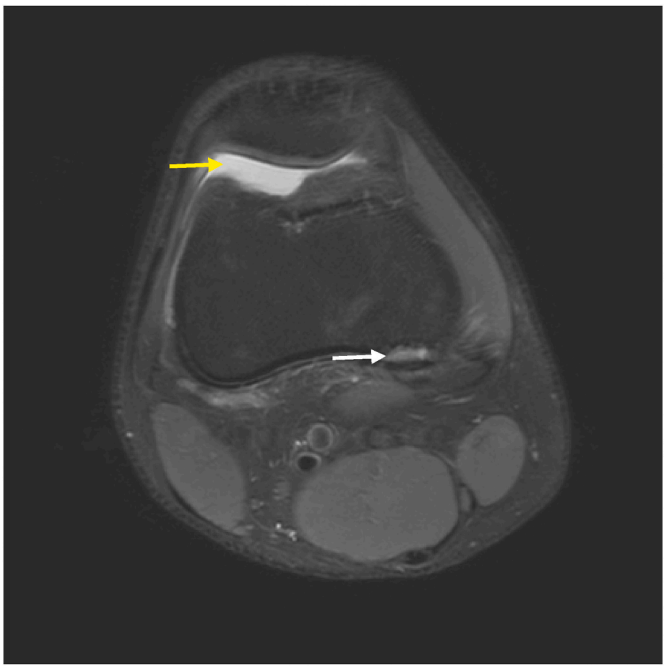

Fig. 2. Axial fat-saturated proton density–weighted MRI scan in a 19-year-old female with distal femoral cortical irregularity (DFCI) displaying a lobulated pattern (white arrow). The patient sustained an injury while playing football and presented with knee locking and pain. Joint effusion was observed (yellow arrow).

Table 1
MRI protocol.

Philips Ingenia (3T)						
Sequence	TR (msec)	TE (msec)	FOV	Matrix	NEX	Slice Thickness (mm)/Slice Gap
Sag PD FS	4304	30	16	356 × 268	1	3/0.3
Sag PD	3240	30	16	400 × 269	1	3/0.3
Sag IR	4346	30	16	236 × 161	1	3/0.3
Cor PD FS	3052	30	16	292 × 303	1	3.5/0.5
Ax PD FS	3229	30	16	272 × 269	1	4/0.4
GE Signa HDx (1.5T)						
Sequence	TR (msec)	TE (msec)	FOV	Matrix	NEX	Slice Thickness (mm)/Slice Gap
Sag PD FS	2774	9	19	352 × 256	2	3.5/0.3
Sag PD	1993	9	19	352 × 256	2	3.5/0.3
Sag IR	3500	8.5	19	224 × 192	2	3.5/0.3
Cor PD FS	2893	12.4	18	352 × 224	2	3.5/0.3
Ax PD FS	2600	12	18	384 × 224	2	4.5/0.5

Key.
Sag: Sagittal.
Cor: Coronal.
Ax: Axial.
TR: repetition time.
TE: echo time.
NEX: Number of excitation.
FOV: Field of view.

age, groups based on the presence of a DFCI (yes *vs* no) were compared using the independent samples *t*-test (test statistic denoted by *t*). The groups based on DFCI status (yes *vs* no) were compared in categorical variables using the Chi-Squared test (test statistic denoted by χ^2). When invalid, Fisher's Exact test was used (test statistic denoted by FI). Degrees of freedom were denoted by df. The critical level of statistical significance was set to 0.05 (5 %). The critical level of significance was adjusted using Bonferroni's correction factor to account for multiple hypothesis testing.

2.3.2. Multivariable Analyses

Multivariable Analyses: For each of the demographic and clinical characteristics, logistic regression was undertaken to obtain the unadjusted (OR) and adjusted odds ratios (aOR) along with their associated 95 % confidence interval (CI), for the occurrence of DFCI. The *P*-value for the test of significance of the overall effect of each factor was obtained. If an OR was not estimable, either overall for a variable or a category, then the variable was not entered into the regression model. The variable age was not linear in the estimated logit. Therefore, categorised age was entered into the regression model. Age was categorised as follows: 10 to less than 13 years, 13 to less than 16 years, 16 to less than 20 years. The rationale for categorising age as described was based on obtaining categories with sufficient numbers of participants in each, rather than any clinical reason. All statistical analyses were performed using SPSS Version 28. (SPSS Inc, Armonk, New York, USA).[13]

3. Results

Between January 1, 2014 and December 31, 2019, a total of 897 scans were identified for inclusion, whilst a total of 116 scans were excluded according to the pre-specified exclusion criteria (Fig. 3).

A DFCI was mentioned in the radiological report for six (7.3 %) adolescents for whom a DFCI was identified upon review of the scan, whilst eight (1.0 %) who were reported as having a DFCI in the radiological report were not identified as having a DFCI upon review of the scan.

3.1. Demographic and clinical characteristics

3.1.1. Bivariate Analyses

The demographic and clinical characteristics of those patients with and without a DFCI are shown in Table 2.

The group that experienced a DFCI were statistically significantly

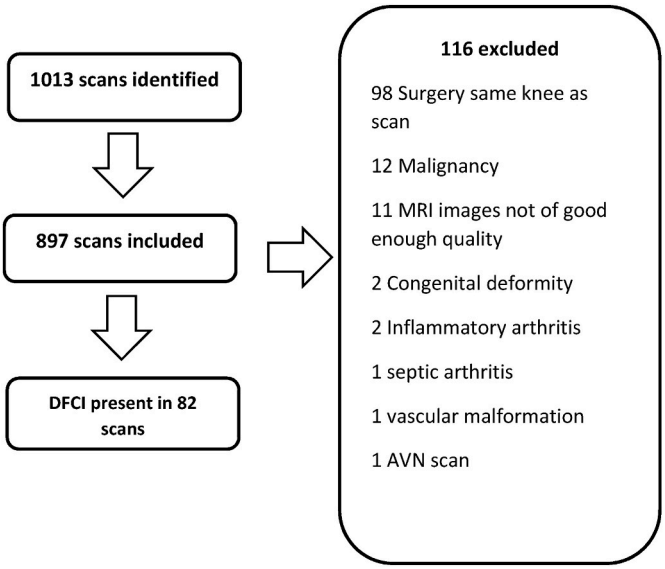

Fig. 3. Flowchart depicting eligibility criteria of study participants.

Table 2
Comparison of demographics and clinical characteristics between patients with and without DFCI.

		DFCI Present			
		No (n = 815)	Yes (n = 82)	Total (897)	Test Statistics
Age (years)	Mean (SD)	15.4 (2.59)	14.5 (2.44)	15.3 (2.59)	$t = 3.15$, df = 895, $P = 0.002$,
	Median (LQ: UQ)	15.4 (13.5 : 17.4)	14.3 (12.6 : 15.8)	15.3 (13.4 : 17.4)	diff = 0.94,
	Min: Max	10.0 : 20	10.0 : 19.9	10 : 20	95 % CI (0.35,1.52)
Age (categorised)	≥10, <13 years	158 (19.4)	27 (32.9)	185 (20.6)	$\chi^2 = 13.97$, df = 2,
	≥13, <16 years	312 (38.3)	36 (43.9)	348 (38.8)	$P < 0.001$
	≥16, ≤ 19 years	345 (42.3)	19 (23.2)	364 (40.6)	
Sex	Female	342 (42.0)	56 (68.3)	398 (44.4)	$\chi^2 = 20.95$, df = 1,
	Male	473 (58.0)	26 (31.7)	499 (55.6)	$P < 0.001$
Knee Examined	Left	420 (51.5)	44 (53.7)	464 (51.7)	$\chi^2 = 0.14$, df = 1,
	Right	395 (48.5)	38 (46.3)	433 (48.3)	$P = 0.729$
High Performing Athlete (Total n = 111)	No	43 (39.8)	1 (33.3)	44 (39.6)	
	Yes	65 (60.2)	2 (66.7)	67 (60.4)	
Sport Played (n = 326)	Athletics	29 (9.6)	4 (16.7)	33 (10.1)	
	Badminton	5 (1.7)	0	5 (1.5)	
	Ballet	3 (1.0)	0	3 (0.9)	
	Basketball	19 (6.3)	2 (8.3)	21 (6.4)	
	Cricket	2 (0.7)	0	2 (0.6)	
	Cycling	5 (1.7)	0	5 (1.5)	
	Dance	11 (3.6)	1 (4.2)	12 (3.7)	
	Football	122 (40.4)	8 (33.3)	130 (39.9)	
	Go Karting	2 (0.7)	0	2 (0.6)	
	Gymnastics	11 (3.6)	3 (12.5)	14 (4.3)	
	Horse-riding	1 (0.3)	0	1 (0.3)	
	Ice-skating	2 (0.7)	0	2 (0.6)	
	Martial arts	9 (3.0)	0	9 (2.8)	
	Netball	9 (3.0)	1 (4.2)	10 (3.1)	
	Rugby	44 (14.6)	3 (12.5)	47 (14.4)	
	Skateboarding	4 (1.3)	0	4 (1.2)	
	Skiing	11 (3.6)	1 (4.2)	12 (3.7)	
	Snowboarding	3 (1.0)	0	3 (0.9)	
	Swimming	1 (0.3)	0	1 (0.3)	
	Tennis	1 (0.3)	1 (4.2)	2 (0.6)	
	Trampolining	5 (1.7)	0	5 (1.5)	
	Volleyball	3 (1.0)	0	3 (0.9)	
Mechanism of Injury (Total n = 841)	Patella instability/ dislocation	123 (16.1)	18 (22.8)	141 (16.8)	$\chi^2 = 10.49$, df = 3, $P = 0.015$
	Pivotal knee injury	221 (29.0)	10 (12.7)	231 (27.5)	
	Trauma	141 (18.5)	15 (19.0)	156 (18.5)	
	Atraumatic knee pain	277 (36.4)	36 (45.6)	313 (37.2 %)	
Bone Oedema	No	468 (57.4)	54 (65.9)	522 (58.2)	$\chi^2 = 2.18$, df = 1,
	Yes	347 (42.6)	28 (34.1)	375 (41.8)	$P = 0.159$
Joint Effusion (Total n = 896)	No	495 (60.8)	59 (72.0)	554 (61.8)	$\chi^2 = 3.92$, df = 1,
	Yes	319 (39.2)	23 (28.0)	342 (38.2)	$P = 0.056$
ACL Tear	No	668 (82.0)	77 (93.9)	745 (83.1)	$\chi^2 = 7.55$, df = 1,
	Yes	89 (10.9)	3 (3.7)	92 (10.3)	$P < 0.023$
	Partial	58 (7.1)	2 (2.4)	60 (6.7)	
MCL Tear	No	731 (89.7)	78 (95.1)	809 (90.2)	FI = 1.89, $P = 0.331$
	Yes	6 (0.7)	0	6 (0.7)	
	Partial	78 (9.6)	4 (4.9)	82 (9.1)	
PCL Tear	No	804 (98.7)	82 (100.0)	886 (98.8)	FI = 1.13, $P = 0.647$
	Yes	1 (0.1)	0	1 (0.1)	
	Partial	10 (1.2)	0	10 (1.1)	
LCL Tear	No	794 (97.4)	81 (98.8)	875 (97.5)	FI = 1.00, $P = 0.739$
	Yes	1 (0.1)	0	1 (0.1)	
	Partial	20 (2.5)	1 (1.2)	21 (2.3)	
Medial Meniscus Injury (Total n = 896)	No	746 (91.6)	76 (92.7)	822 (91.7)	$\chi^2 = 0.11$, df = 1,
	Yes	68 (8.4)	6 (7.3)	74 (8.3)	$P = 0.837$
Lateral Meniscus Injury (Total n = 896)	No	736 (90.4)	78 (95.1)	814 (90.8)	$\chi^2 = 1.98$, df = 1,
	Yes	78 (9.6)	4 (4.9)	82 (9.2)	$P = 0.169$
Patellofemoral Injury (Total n = 896)	No	684 (83.9)	69 (85.2)	753 (84.0)	$\chi^2 = 0.087$, df = 1,
	Yes	131 (16.1)	12 (14.8)	143 (16.0)	$P = 0.874$

younger than the group that had not experienced a DFCI (14.5 (SD 2.44) vs 15.4 (SD 2.59) years; $P = 0.002$). Patients with a DFCI were more likely to be female (68.3 % (n = 56) vs 42.0 % (342); $P < 0.001$), and less likely to have experienced an ACL tear (3.7 % (n = 3) vs 10.9 % (n = 89); $P = 0.023$). There was a statistically significant difference between groups in the mechanism of injury ($P = 0.015$); those that experienced a DFCI were more likely to have a patella instability/dislocation (22.8 % (n = 18) vs 16.1 % (n = 141)), whilst less likely to have had a pivotal knee injury (12.7 % (n = 10) vs 29.0 % (n = 221)).

For other variables, there was no statistically significant difference observed between the DFCI groups: knee observed ($P = 0.729$), bone oedema ($P = 0.159$), joint effusion ($P = 0.056$), MCL tear ($P = 0.331$), PCL tear ($P = 0.647$), LCL ($P = 0.739$), medical meniscus injury ($P = 0.837$), lateral meniscus injury ($P = 0.169$), patellofemoral injury (0.874). The DFCI groups were not compared statistically in the variables of high-performance athlete (yes vs no), or sport played because there was a high percentage of missing observations overall. Following adjustment for multiple hypothesis testing in Table 2 using Bonferroni's correction factor (14 tests; adjusted critical level of significance = 0.0036), the only statistically significant differences between the DFCI groups that remained were age (continuous and categorised) plus sex.

4.3.1.2. Multivariable analysis. For each demographic and clinical characteristic, the unadjusted (OR) and adjusted odds ratios (aOR) plus their associated 95 % confidence intervals (CI) for the occurrence of DFCI are presented in Table 3. The *P*-values shown are for the test of significance of the overall effect of each factor. When an unadjusted OR was not estimable, either overall for a variable or a category, the

Table 3
The unadjusted and adjusted odds ratios (ORs) plus 95 % confidence intervals (CI) for the occurrence of DFCI.

		Unadjusted OR (95 % CI)	*P*-value	Adjusted OR (95 % CI)	*P*-value
Age (categorised)	>10, <13 years	(1)	$P = 0.001$, df = 2	(1)	$P = 0.011$, df = 2
	≥13, <16 years	0.68 (0.40, 1.15)		0.79 (0.45, 1.39)	
	≥16, <20 years	0.32 (0.17, 0.60)		0.36 (0.18, 0.71)	
Sex	Female	(1)	$P <$ 0.001, df = 1	(1)	$P <$ 0.001, df = 1
	Male	0.34 (0.21, 0.55)		0.38 (0.22, 0.66)	
Knee Examined	Left	(1)	$P = 0.714$, df = 1	(1)	$P = 0.770$, df = 1
	Right	0.92 (0.58, 1.45)		0.93 (0.57, 1.51)	
Mechanism of Injury (Total n = 841)	Patella instability/ dislocation	(1)	$P = 0.021$, df = 3	(1)	$P = 0.183$, df = 3
	Pivotal knee injury	0.31 (0.14, 0.69)		0.39 (0.16, 0.94)	
	Trauma	0.73 (0.35, 1.50)		0.82 (0.37, 1.80)	
	Atraumatic knee pain	0.89 (0.49, 1.63)		0.82 (0.41, 1.63)	
Bone Oedema	No	(1)	$P = 0.142$, df = 1	(1)	$P = 0.745$, df = 1
	Yes	0.70 (0.43, 1.13)		1.1 (0.62, 1.95)	
Joint Effusion (Total n = 896)	No	(1)	$P = 0.050$, df = 1	(1)	$P = 0.973$, df = 1
	Yes	0.61 (0.37, 1.00)		0.99 (0.55, 1.80)	
ACL Tear	No	(1)	$P = 0.035$, df = 2	(1)	$P = 0.664$, df = 2
	Yes	0.29 (0.09, 0.95)		0.80 (0.21, 3.00)	
	Partial	0.30 (0.07, 1.25)		0.51 (0.11, 2.30)	
MCL Tear	No	(1)	$P = 0.379$, df = 2		
	Yes	Not Estimable			
	Partial	0.48 (0.17, 1.35)			
PCL Tear	No	(1)			
	Yes	Not Estimable			
	Partial	Not Estimable			
LCL Tear	No	(1)	$P = 0.787$, df = 2		
	Yes	Not Estimable			
	Partial	0.49 (0.07, 3.70)			
Medial Meniscus Injury (Total n = 896)	No	(1)	$P = 0745$, df = 1	(1)	$P = 0.412$, df = 1
	Yes	0.87 (0.36, 2.06)		1.54 (0.55, 4.30)	
Lateral Meniscus Injury (Total n = 896)	No	(1)	$P = 0.168$, df = 1	(1)	$P = 0.261$, df = 1
	Yes	0.48 (0.17, 1.36)		0.43 (0.1, 1.89)	
Patellofemoral Injury (Total n = 896)	No	(1)	$P = 0.768$, df = 1	(1)	$P = 0.426$, df = 1
	Yes	0.91 (0.48, 1.72)		0.72 (0.32, 1.63)	

variable was not entered in the regression to derive adjusted OR.

When adjusted for potential confounding, the only factors that had a statistically significant effect overall upon the occurrence of a DFCI was categorised age ($P = 0.014$), and sex ($P < 0.001$). When compared to patients aged between 10 and 13 years, older children had reduced odds of a DFCI with children aged between 13 and 16 years (aOR = 0.79; 95 % CI: 0.45 to 1.39), and children aged between 16 and 20 years (aOR 0.36; 95 % CI: 0.18 to 0.71). Males had reduced odds of a DFCI compared to females (aOR = 0.38; 95 % CI: 0.22 to 0.66).

4. Discussion

Previous studies aimed at establishing DFCI prevalence included sample sizes of 197 and 210 scans.[4,6] This historical cohort study is, to our knowledge, the largest study of adolescents looking for the presence of DFCI on MRI scan. We identified 82 MRIs (9.1 %) that showed evidence of a DFCI. We further characterised this to identify potential risk factors for developing a DFCI. This study identified that age was a risk factor; the odds of a DFCI decreased with increasing age. We also identified that males were less likely to have a DFCI than females.

Muramatsu et al. reviewed 197 plain radiographs in adolescents and reported that DFCI was more prevalent in younger patients.[6] This was similar to our findings where the odds of a DFCI decreased with increasing age. However, compared to the study by Muramatsu and colleagues, we used MRI images to identify DFCI, which has been shown to be more specific and sensitive compared to plain radiographs.[14] In contrast, Muramatsu also identified a higher prevalence in males whereas our study reported a higher prevalence in females. Matini[15] observed a higher prevalence of knee injuries, including pivotal injuries in females, which could be attributed to their significantly increased q angle compared to males.[15] Univariate analysis showed females had a higher prevalence of DFCI, and prevalence of DFCI was higher in those with patellofemoral instability including patella dislocation. However, adjusting for confounders showed this did not reach significance. Therefore, we cannot conclude that mechanism of injury, including pivotal knee injuries and patellofemoral instability, are a statistically significant risk factor for DFCI. However, we hypothesize that femoral malrotation drives traction changes which can lead to increased stress of the MHG at its insertion on the femur, resulting in the formation of a DFCI. Further research must be carried out to investigate this hypothesis.

Ritschl et al. postulated that DFCIs occur due to repetitive stress at tendon attachments at the distal femur, due to extensive mechanical load.[16] The development of a DFCI is an insidious process seen in active adolescents, with chronic traction applied at the insertion of the MHG. We hypothesize these heal over time, possibly due to bone healing. Further research should aim to establish whether patients with DFCI diagnosed during adolescence persist into adulthood.

Stern et al. found DFCI was more common in youth competitive alpine skiers than in the control group, which included adolescents who underwent a MRI of their knee for trauma, chronic pain or instability.[4] Our results suggest the occurrence of DFCI is not limited to this sport but could be associated with recurrent traction on the tendinous insertion due to being very active. We identified DFCI in adolescents who practised athletics, basketball, football, and rugby, suggesting this is not a phenomenon exclusive to competitive alpine skiers.

DFCI are often incidental findings on imaging with most patients being asymptomatic. However, some patients may have localised pain or swelling associated with the DFCI. Knowledge of younger age and female sex as risk factors for DFCI may aid its diagnosis. A review for DFCI should be undertaken on all adolescent knee MRI scans. This will allow for faster identification of the abnormality. It is thought that DFCI is largely asymptomatic and therefore unlikely to change management. However, if no other pathology is identified then subsequent initiation of appropriate physiotherapeutic and analgesic treatment should be initiated due to the possible pathogenesis being a tractional injury. In

addition, radiologists should be able to differentiate between DFCI and similar pathologies (e.g., cysts, fibrous cortical defects), since these may differ in treatment and prognosis. Distal femoral cortical irregularities are often unreported. In our cohort, 8 (1.0 %) adolescents were mistakenly reported to have DFCI when they did not, while only 6 (7.3 %) of those with DFCI were mentioned in reports. Radiologists should have greater awareness of the occurrence and appearance of this phenomenon to be able to identify it.

One of the strengths of our study is the large sample size compared to previously published work. The next largest study in published literature was performed by Stern et al.,[4] followed by Muramatsu et al.,[6] who reviewed 210 MRI scans and 197 plain radiographs, respectively.

A limitation of this study is that a DFCI is largely asymptomatic, and an adolescent requires a reason such as pain or injury, as well as a clinical review usually from an orthopaedic surgeon before they have a MRI of their knee. Therefore, the prevalence of DFCI we have shown does not include those asymptomatic patients who never have a MRI, and therefore we may underestimate its prevalence. There is a risk of selection bias with this cohort of patients, and future studies should establish the prevalence of DFCI in asymptomatic individuals. Furthermore, it is difficult to differentiate between an acute or chronic DFCI, or whether a new tractional injury has occurred at the same site resulting in DFCI. This makes identifying DFCI even more challenging, even for the most experienced of radiologist and may have led to bias in our data collection.

A further limitation of our study was that data were collected retrospectively. We were unable to determine the association between high performing athletes or sports played and the prevalence of DFCI. Clinic letters and MRI scans were reviewed retrospectively, and while we were able to identify information on most parameters from clinic letters or MRI requests, the level of sport played was often not included. Furthermore, the duration of symptoms experienced by the patients leading to the MRI, and the time from the clinic appointment to the scan was not recorded. These limitations do raise the possibility of bias which might affect the conclusions we have made.

5. Conclusion

Distal femoral cortical irregularity is a lesion identified in adolescents. The prevalence of DFCI was found to be 9.1 %, with female sex and young age shown to be risk factors for the development of this lesion. There was no statistically significant association between mechanism of injury and developing a DFCI. However, patients with DFCI were more likely to have patellar instability/dislocation, whilst less likely to have had a pivotal knee injury. This study provides insight into the pathogenesis of DFCI, which is benign and largely asymptomatic. Thus, further work exploring the prevalence of this lesion in asymptomatic individuals should be carried out. Further research should also be performed to assess the association of DFCI with femoral rotation profile, particularly in adolescent females and those who experience patellofemoral instability.

CRediT authorship contribution statement

Andrew Gaukroger: Conceptualization, Methodology, Data Collection, Writing – original draft, preparation. **Abrar Gani:** Conceptualization, Methodology, Data Collection, Writing – original draft, preparation. **Philip Martin Sedgwick:** Formal analysis, Writing – critically revising work. **Diego Agustín Abelleyra Lastoria:** Writing – original draft, preparation. **Antoine Corentin Georges Kerouedan:** Writing – original draft, preparation. **Vivian Ejindu:** Conceptualization, Methodology, Data Collection. **Anshul Rastogi:** Conceptualization, Methodology, Data Collection, Writing – critically revising work. **Caroline Blanca Hing:** Conceptualization, Methodology, Writing – critically revising work, Supervision.

Informed consent

Not applicable.

Institutional ethical committee approval

Not applicable.

Ethical statement

This study was reviewed by the Research Ethics Committee (REC) and received ethical approval from Health Research Authority (HRA) and Health and Care Research Wales (HRCW). IRAS project ID 289205, Protocol number 20.0244, REC reference 21/WA/0041.

Patient content

The prevalence and risk factors of distal femoral cortical irregularity in the adolescent population – Guardian/Patient's consent: not applicable.

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Declaration of competing interest

None.

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