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ORIGINAL ARTICLE

Role of Meniscal Pathology in the Development of Spontaneous Insufficiency Fractures of the Knee (SIFK): A Radiological Perspective

Seetharaman Cannane,[1,*] Gayathri Priyadharshinee B,[2] Jeevithan Shanmugam,[3] Raghul Sugumar[4] and Rajiv Sathianarayanan Menon[4]

[1]*Associate Professor in Radiology, KMCH Institute of Health Sciences and Research, Coimbatore–14*
[2]*Consultant Radiologist, Spotters.ai, Bangalore, India*
[3]*Professor in Community Medicine, KMCH Institute of Health Sciences and Research, Coimbatore-14*
[4]*DNB Resident, Radiodiagnosis, KMCH Hospitals Ltd, Coimbatore -14*

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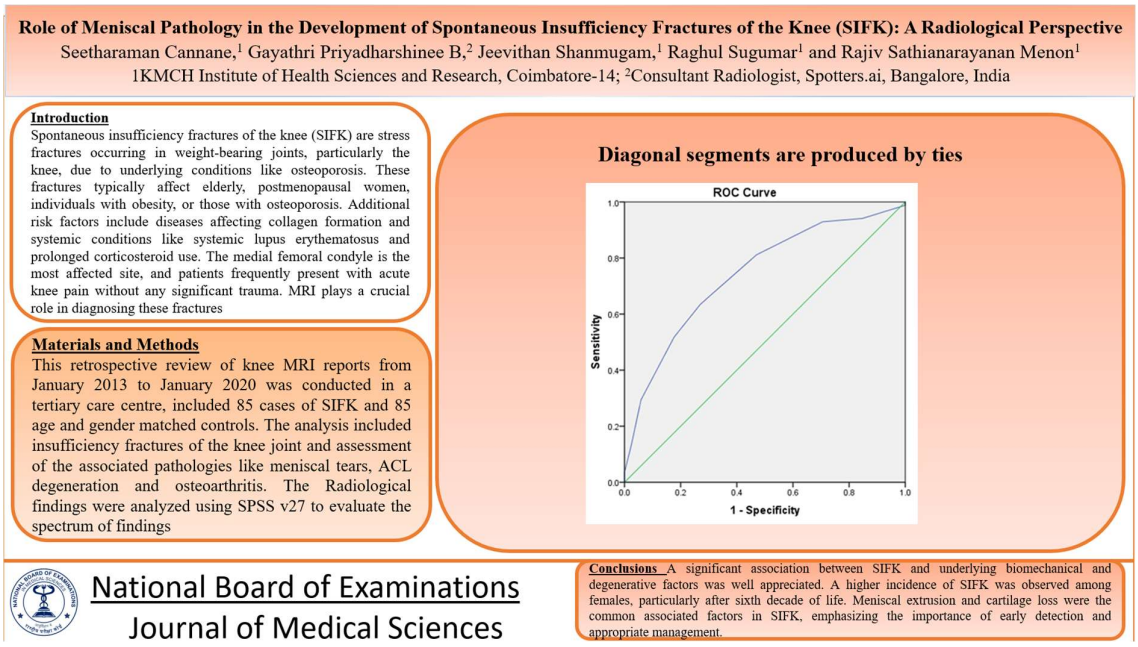
Abstract

Introduction: Spontaneous insufficiency fractures of the knee (SIFK) are stress fractures occurring in weight-bearing joints, particularly the knee, due to underlying conditions like osteoporosis. These fractures typically affect elderly, postmenopausal women, individuals with obesity, or those with osteoporosis. Additional risk factors include diseases affecting collagen formation and systemic conditions like systemic lupus erythematosus and prolonged corticosteroid use. The medial femoral condyle is the most affected site, and patients frequently present with acute knee pain without any significant trauma. MRI plays a crucial role in diagnosing these fractures. **Materials and Methods:** This retrospective review of knee MRI reports from January 2013 to January 2020 was conducted in a tertiary care centre, included 85 cases of SIFK and 85 age and gender matched controls. The analysis included insufficiency fractures of the knee joint and assessment of the associated pathologies like meniscal tears, ACL degeneration and osteoarthritis. The Radiological findings were analyzed using SPSS v27 to evaluate the spectrum of findings**.** **Results:** Majority of the study population (59.4%) were females, with the medial femoral condyle being the most frequently affected site. Partial-thickness cartilage loss was the most common finding in both femoral and tibial cartilages, and posterior meniscal tears was observed in 78.8% of cases. ACL degeneration was present in 54.1% of cases, while osteoarthritis was present in 78.8%. The study also introduced a novel scoring system to evaluate the severity and association of insufficiency fractures with meniscal pathology and other related factors. **Conclusion:** A significant association between SIFK and underlying biomechanical and degenerative factors was well appreciated. A higher incidence of SIFK was observed among females, particularly after sixth decade of life. Meniscal extrusion and cartilage loss were the common associated factors in SIFK, emphasizing the importance of early detection and appropriate management of associated degenerative changes of the knee joint so as to prevent the progression into insufficiency fractures.

Keywords: Spontaneous insufficiency fractures, knee, meniscal pathology, osteoarthritis, MRI

*Corresponding Author: Seetharaman Cannane
Email: drcseetharaman@gmail.com

Graphical Abstract



Introduction

Insufficiency fractures, a type of stress fracture which is caused by normal or physiological stress applied to bones that are weakened by underlying conditions, such as osteoporosis or osteomalacia. These fractures generally impact the weight-bearing synovial joints - the hips, knees, and ankles, as well as the vertebrae and also the sacrum. Elderly, postmenopausal women, individuals with obesity and those with osteoporosis are the most commonly affected. Additional risk factors include diseases affecting collagen formation, such as Marfan syndrome and fibrous dysplasia, as well as systemic conditions like systemic lupus erythematosus, Paget's disease, and prolonged corticosteroid use. Insufficiency fractures may also occur in transplant recipients (renal and liver) and as a consequence of chemotherapy or radiation therapy [1].

Among weight-bearing joints, the knee is particularly prone to insufficiency fractures, with the medial femoral condyle being the most frequently affected site. Patients commonly present with an acute onset of severe knee pain without any preceding history of significant trauma [2]. Magnetic Resonance Imaging (MRI) plays a critical role in diagnosing these fractures. The hallmark finding in acute stages is a linear subchondral T1 hypo intensity accompanied by surrounding bone marrow edema on MRI. Without timely diagnosis and management, these fractures may progress to complications such as secondary osteonecrosis, subchondral collapse, or rapidly progressive osteoarthritis, potentially requiring surgical intervention or joint replacement [3-5].

Notably, insufficiency fractures of the knee (spontaneous insufficiency fractures of the knee, or SIFK) have been associated with meniscal pathology, particularly posterior root tears, which compromise the biomechanical stability of the joint [6-9]. Other contributing factors include osteoporosis9 and previous meniscectomy, which further alter the

biomechanical load distribution across the joint [10]. This interplay between insufficiency fractures and associated intra-articular pathologies underlines the importance of a comprehensive evaluation of the knee joint in affected patients.

This study was planned to understand the epidemiology and clinical findings of insufficiency fractures of the knee joint with a specific focus on the associations with meniscal pathology, particularly posterior root tears, as well as anterior cruciate ligament (ACL) tears, osteoarthritis, and articular cartilage degeneration using MRI findings so as to get insights that may aid in improving the early diagnosis and management strategies.

Materials and Methods:

This retrospective cross sectional study was conducted after obtaining approval from the Institutional Human Ethics Committee (IHEC) and adhered to ICMR ethical principles for research involving human participants.

MRI Knee reports from the hospital Radiology Information System (RIS) between January 2013 and January 2020 was retrieved using the keyword search for "insufficiency fracture". A total of 93 cases were obtained initially. Cases with suboptimal image quality, lack of subchondral low T1 signal intensity, or absence of bone marrow edema on inversion recovery sequences were excluded. A total of 8 cases were excluded based on these criteria, leaving 85 cases for inclusion in the study. Age- and gender-matched controls (n = 85) with no evidence of insufficiency fractures were selected to provide a comparative baseline. Matching was performed to minimize potential confounders and ensure comparability between groups.

The clinical data and imaging findings were systematically recorded using a standardized study proforma. Demographic information, including age, gender, laterality, and clinical history, was extracted from patient records. All imaging evaluations were performed by a musculoskeletal radiologist with 12 years of experience in MR imaging. The analysis included precise localization of insufficiency fractures within the medial femoral condyle (MFC), lateral femoral condyle (LFC), medial tibial plateau (MTP), and lateral tibial plateau (LTP). The fractures were further categorized based on their position in the sagittal plane (anterior, central, or posterior) and coronal plane (inner, mid, or outer). The size of the hypointense T1 line was measured in millimetres on both sagittal and coronal images.

Radiological findings were also assessed for joint effusion, meniscal tears (notably posterior root or radial tears), medial meniscal body extrusion (>3 mm or <3 mm), anterior cruciate ligament (ACL) degeneration or tears, articular cartilage loss, Baker's cysts, and osteoarthritic changes. Meniscal extrusion was quantified on coronal T1 images as the distance of extrusion from the medial tibial plateau. Articular cartilage loss was classified into categories: no loss, partial-thickness loss, full-thickness loss, or chondral fissures. Osteophytes were graded subjectively as none, small, moderate, or large.

All MRIs were performed using a 1.5 T MRI system (Philips Ingenia 1.5T) following a standard knee imaging protocol. The sequences included proton density (PD) with a TR/TE of 2100/30 ms, T1-weighted (TR/TE of 645/10 ms), and T2-weighted (TR/TE of 2500/100 ms). Subchondral fractures were identified by

linear hypointense signals on T1-weighted images with surrounding hyperintensity on inversion recovery sequences, indicative of marrow edema.

Data were analysed using SPSS v27 (IBM Corp.). Descriptive statistics were summarized as means with standard deviations and as frequencies and percentages for categorical variables. Group comparisons were conducted using the independent t-test for normally distributed continuous variables. Categorical variables were analysed using the Chi-square test. A p-value < 0.05 was considered statistically significant.

A new scoring system was developed with femoral articular cartilage loss (no cartilage loss =0, partial thickness loss = 1, full thickness loss = 2), Tibial articular cartilage loss(no cartilage loss =0, partial thickness loss = 1, full thickness loss = 2), Presence of radial tear(no tear = 0, presence = 2), Osteoarthritis (present =2, absent =0) and level of meniscal extrusion(less than 2 mm was given a score of 0, 2-4 mm as 1 and more than 4 mm as 2). ROC curve was drawn for the same and yonden cut off was calculated (Figure 1).

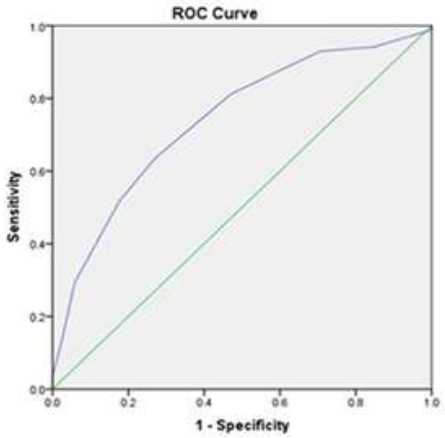


Figure 1. Diagonal segments are produced by ties.

Results

Out of the study population, 59.4% were females, and 54.1% had left-sided knee involvement. Partial-thickness cartilage loss was the most common finding in both femoral (63.5%) and tibial cartilage (67.6%), while full-thickness loss affected 33.5% and 26.5%, respectively. Posterior meniscal tears were prevalent in 78.8%, and radial tears were seen in 25.9%. (Table 1).

Table 1. Distribution of Study Population According to Socio Demographic Parameters

Parameter	Sub classification	FREQUENCY	PERCENTAGE
GENDER	MALE	69	40.6
	FEMALE	101	59.4

SIDE	LEFT	92	54.1
	RIGHT	78	45.9
CARTILAGE LOSS FEM ARTICUALR CARTILAGE LOSS	NO CL	5	2.9
	PARTIAL THICKNESS CL	108	63.5
	FULL THICKNESS CL	57	33.5
CARTILAGE LOSS TIB ARTICUALR CARTILAGE LOSS	NO CL	10	5.9
	PARTIAL THICKNESS CL	115	67.6
	FULL THICKNESS CL	45	26.5
POSTERIOR TEAR	NO	36	21.2
	YES	134	78.8
RADIAL TEAR	NO	126	74.1
	YES	44	25.9

ACL degeneration was observed in 54.1%, predominantly mild (43.5%). ACL and PCL tears were uncommon, with complete tears seen in only 1.8% for both ligaments. Osteoarthritis was present in 78.8% of cases, Baker's cysts in 30%, and joint effusion in 97.6%, mostly mild (72.4%). Osteophytes were identified in 95.9%, with 51.8% mild and 38.2% moderate (Table 2).

Table 2. Distribution of Study Population According to Clinical Findings

Parameter	Sub classification	FREQUENCY	PERCENTAGE
ACL DEGENERATION	NO	78	45.9
	MILD/MINIMAL	74	43.5
	MODERATE	8	4.7

	SEVERE	10	5.9
ACL TEAR	NO	155	91.2
	PARTIAL TEAR	12	7.1
	COMPLETE TEAR	3	1.8
PCL DEGENERATION	NO	156	91.8
	PARTIAL TEAR	11	6.5
	COMPLETE TEAR	3	1.8
OA FEATURES	NO	36	21.2
	YES	134	78.8
BAKERS	YES	51	30.0
	NO	119	70.0
JOINT EFFUSION	NO	4	2.4
	MILD/MINIMAL	123	72.4
	MODERATE	40	23.5
	SEVERE	3	1.8
H/O TRAUMA	NO	95	55.9
	YES	10	5.9
	NA (CONTROLS)	65	38.2
OSTEOPHYTES	NO	7	4.1
	MILD	88	51.8
	MODERATE	65	38.2
	SEVERE	10	5.9

There is no significant association between cases and controls with respect to Gender, side of the insufficient fracture, tibial articular cartilage loss, radial tear, posterior loss, ACL degeneration, Bakers, joint effusion and osteophytes using chi square test. There was a significant association between cases and controls in femoral articular cartilage loss, radial tear and OA Features. Full thickness Femoral cartilage loss was more prevalent in cases (63.2%) compared to controls (36.8%), establishing it as a strong predictor of insufficiency fractures. 41.17% of the cases had radial tear compared to 10.58% of controls. 95.29% of the cases had OA compared to 62.36% of controls.

The mean age of cases and controls was identical (60.87 ± 10.45 years), with no statistically significant difference ($p = 1.000$). Meniscal extrusion was significantly greater in cases (2.99 ± 1.76) compared to controls (2.15 ± 1.42), with a mean difference of 0.842 ($t = 3.422$, $p = 0.001$), indicating a strong association between meniscal extrusion and insufficiency fractures.

Receiver operator characteristics was drawn for the newly developed scoring system against fracture status (cases Vs controls). The area under the curve was 0.741 and P value was <0.001. The composite scoring system for predicting insufficiency fractures of the knee demonstrates moderate sensitivity (63.5%) and specificity (72.9%), for a score of 5, indicating its ability to accurately identify both cases and non-cases. Among those with a score of 5 or less, 54 had insufficiency fractures, while 23 did not, reflecting a positive predictive value (PPV) of 70.1%. Conversely, for scores above 5, 62 individuals were correctly identified as not having fractures, while 31 were misclassified, yielding a negative predictive value (NPV) of 66.7%. These findings suggest that the composite score is a reasonably reliable tool for assessing the likelihood of insufficiency fractures based on the parameters evaluated. It can be used as a screening tool (Table 3).

Table 3. Diagnostic accuracy of composite score index

	Insufficiency fracture of knee	
Composite Score	Present	Absent
Less than or equal to 5	54	23
More than 5	31	62
Sensitivity – 63.5%		
Specificity – 72.9%		
PPV – 70.1%		
NPV – 66.7%		

Discussion

This study highlights several important findings about spontaneous insufficiency fractures of the knee (SIFK) and their associated pathologies.

The current study demonstrated a higher incidence of SIFK in females, with a female-to-male ratio of 1.8:1. This is consistent with previous literature reporting a female predominance, with some studies citing ratios as high as 4.8:1 [7,20-24].

However, a few studies have shown an almost equal incidence between males and females [20]. The observed female predominance in this study aligns with findings that insufficiency fractures are more common in postmenopausal women due to reduced bone mineral density and hormonal changes that affect bone strength [20,21,23,25-27].

Age distribution in the study showed that SIFK was most common in the seventh decade of life, corresponding to the 60–69 age group. This pattern is consistent with existing literature, which also reports a peak incidence in older adults. Age-related decreases in bone quality and cartilage resilience likely contribute to this distribution [20,23,25-27].

The mid-third of the knee joint, both in the coronal and sagittal planes, was the most frequently affected location in SIFK cases in this study. This finding can be attributed to the central weight-bearing surface of the joint bearing the majority of the transmitted mechanical load, rendering it more susceptible to insufficiency fractures.

A significant association was noted between SIFK and meniscal pathology, particularly radial tears and meniscal extrusion. Meniscal extrusion was strongly associated with SIFK. This aligns with findings in the literature that describe meniscal root tears and radial tears as contributing factors to altered biomechanics and degenerative joint disease, leading to increased susceptibility to insufficiency fractures [22,24,26]. Previous studies have also shown that meniscal extrusion >3 mm correlates strongly with degenerative joint disease, radial tears, and complex meniscal tears [28,29].

Cartilage loss was another significant finding associated with SIFK in this study. Loss of articular cartilage disrupts the even distribution of mechanical forces across the joint, leading to increased stress on subchondral bone and a higher risk of insufficiency fractures. Biomechanical forces alter the meniscal and articular cartilage loss which contribute to the development of an insufficiency fracture.

Our study result also observed a strong evidence for the interplay between altered biomechanical forces and the development of insufficiency fractures in the knee joint. Our study also highlights the importance of evaluating associated joint pathologies such as meniscal tears, meniscal extrusion, and cartilage loss in patients with SIFK for a better understanding of their aetiology and further progression.

A novel scoring system was developed to aid in evaluating and quantify the severity and association of insufficiency fractures with meniscal pathology, articular cartilage loss, and other related factors. While this scoring system has been designed based on observed patterns and radiological findings among our study population, it currently lacks external validation or evidence from the current existing literature. Nevertheless, the scoring framework could serve as a foundational tool for future studies, facilitating a more structured and standardized evaluation in insufficiency fractures and their associated findings.

Conclusion

A significant association between spontaneous insufficiency fractures of the knee (SIFK) and underlying biomechanical and degenerative factors such as meniscal pathology, cartilage loss, and osteophytes

was observed. A higher incidence of SIFK was observed among females, particularly in their seventh decade of life, with the mid-third of the knee joint being the most frequently affected region. Meniscal extrusion, radial tears, and posterior root tears were strongly associated with SIFK, emphasizing their role in altering joint biomechanics and increasing stress on subchondral bone. Cartilage loss and osteophyte formation further contributed to the uneven distribution of load across the joint, predisposing it to these fractures.

Our study findings necessitate the importance of early detection and management of associated degenerative changes in the knee joint so as to prevent the progression of insufficiency fractures.

Statements and Declarations

Conflicts of interest

The authors declare that they do not have conflict of interest.

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