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Original Article

Anatomy Section

Comparison of Patellofemoral Morphometric Parameters in Individuals with Patellofemoral Pain Syndrome versus Healthy Controls: A Cross-sectional Study

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ABSTRACT

Introduction: Patellofemoral Pain Syndrome (PFPS) is one of the most common causes of anterior knee pain, yet its radiographic diagnostic indicators remain poorly defined.

Aim: To evaluate morphometric parameters, including Q angle, sulcus angle, patellar tilt angle, and Insall-Salvati ratio, in individuals with PFPS compared to healthy controls.

Materials and Methods: A cross-sectional study with 110 clinically confirmed PFPS patients and 110 age- and sex-matched controls was conducted at the Department of Anatomy, Saveetha Medical College and the Department of Radiology, HOSMAT Hospitals Bangalore Rural, Karnataka, India, between 01.02.2025 and 31.10.2025. Standardised lateral, and skyline (Merchant/ Tangential) view radiographs were analysed using INSTARISPACS® software to obtain morphometric parameters such as the Q angle (clinical parameter during patient assessment), sulcus angle, patellar tilt angle, and Insall–Salvati ratio. Group differences were assessed using the independent t-test. Correlation analysis and binary logistic regression were performed to identify predictors of PFPS.

Results: A total of 220 participants (110 PFPS cases and 110 controls) were included. The mean age of cases was 38.9±8.2 years, while controls had a mean age of 37.9±9.1 years. In the PFPS group, 48 (43.64%) were male and 62 (56.36%) were female, whereas the control group included 57 (51.82%) males and 53 (48.18%) females. The mean Q angle in the PFPS group was significantly higher than the control values (21.55±2.76° vs. 15.8±2.5°, p-value <0.001). The Insall–Salvati index was slightly but significantly higher in PFPS patients than in controls (1.05±0.30 vs 1.00±0.12; p-value=0.021). Spearman's correlation analysis demonstrated a moderate negative correlation between Q angle and sulcus angle (r=-0.292, p-value <0.001) and a moderate positive correlation between Q angle and patellar tilt angle (r=0.466, p-value <0.001).

Conclusion: Radiographic measurements, particularly Q angle and patellar tilt angle, are reliable indicators of PFPS. Patellofemoral structural alignment has a greater impact on PFPS than anthropometric characteristics such as body composition. Further longitudinal studies are recommended to validate these markers for early detection and intervention.

Keywords: Insall-salvati ratio, Knee alignment, Patellar tilt angle, Patellofemoral pain syndrome, Q angle, Radiographic morphometry, Sulcus angle

INTRODUCTION

The PFPS, also known as anterior knee pain or "runner's knee", is among the primary sources of knee pain in teenagers and young adults. It is especially prevalent among individuals who regularly engage in activities that increase patellofemoral joint loading, such as running, stair climbing, squatting, and other high-impact sports [1,2]. The PFPS accounts for approximately 23% of adults and 29% of adolescents in the general population, and affects almost 36% of professional cyclists [3]. In a study by Manoharan A et al., 29% (N=281) of the respondents reported positive for anterior knee pain. Of these, 30% (N=152) were females and 28% (N=129) were males [4].

Despite its high prevalence, PFPS remains challenging to diagnose, as its aetiology is multifactorial, encompassing structural variations, abnormal lower-limb biomechanics, neuromuscular imbalance, and overuse [5,6]. Radiographic assessment plays a crucial role in evaluating patellofemoral alignment. Parameters such as the Quadriceps (Q) angle, sulcus angle, patellar tilt angle, and patellar height indices (Insall–Salvati Ratio) provide quantitative insights into joint morphology and stability. An increased Q angle can augment the quadriceps' lateral pull on the patella, predisposing individuals to patellar maltracking [7,8]. Similarly, variations in the sulcus angle reflect trochlear groove morphology, which may influence patellar stability and tracking patterns [9,10]. Patellar tilt and patellar height also affect joint congruence and have been associated with altered patellofemoral kinematics and anterior knee pain in imaging-based studies [11,12]. However, previous research demonstrates substantial variability in radiographic techniques, anatomical landmarks, and measurement protocols, limiting cross-study comparability and diagnostic consistency [13,14].

To address the gaps in population-specific morphometric data, the present study aimed to evaluate key patellofemoral radiographic parameters including Q angle, sulcus angle, patellar tilt angle, and Insall–Salvati Ratio using standardised digital radiographs and DICOM-based measurements in PFPS subjects and age- and sex-matched controls. Associations between these radiographic parameters and anthropometric variables such as height, weight, and Body Mass Index (BMI) were also examined.

MATERIALS AND METHODS

The present cross-sectional study was conducted at Saveetha Medical College and Hospital, Chennai, and HOSMAT Hospitals, Bangalore, between 01st February 2025 and 31st October 2025. These centres were selected to ensure the availability of high-quality radiographic imaging facilities and experienced musculoskeletal imaging personnel. Ethical approval for the study was obtained from the Institutional Ethics Committee of Saveetha Medical College and Hospital (Approval No: SMCH-IEC/009/01/2025).

Sample size: Participants were recruited using convenience sampling, based on the number of eligible individuals attending the orthopaedics and physiotherapy outpatient departments during the study period. A total of 220 participants were included in the study, consisting of 110 patients with clinically diagnosed PFPS and 110 healthy controls matched for age and sex.

PFPS group: A total of 110 participants with clinically diagnosed PFPS were consecutively recruited from orthopaedic and physiotherapy outpatient departments.

Inclusion criteria: Participants aged 18-50 years were eligible if they reported anterior or retro-patellar knee pain aggravated by activities that load the patellofemoral joint, including stair climbing, prolonged sitting, squatting, running, and kneeling, with symptom duration of at least one month. These clinical features are widely recognised as diagnostic criteria for PFPS [15,16].

Exclusion criteria: Participants with a history of patellar dislocation or subluxation, ligamentous injury of the knee, previous knee surgery, radiographic evidence of osteoarthritis, inflammatory joint disease, congenital lower-limb deformities, or pregnancy were excluded. Radiographs with suboptimal positioning or inadequate image quality were excluded.

Healthy control group: The control group consisted of 110 asymptomatic individuals, age- and sex-matched to the PFPS group, recruited using the same consecutive sampling approach.

Inclusion criteria: Participants aged 18-50 years with no current or previous history of anterior knee pain or knee-related symptoms were eligible for inclusion. Controls were matched to PFPS participants within a ±2-year age range to reduce potential confounding related to age-dependent biomechanical variation.

Exclusion criteria: Control participants were excluded if they had any history of knee pain, patellar instability, ligamentous injury, knee surgery, inflammatory joint disease, congenital lower-limb deformities, or radiographic evidence of osteoarthritis. Pregnant individuals and those with radiographs of inadequate diagnostic quality were also excluded to maintain sample homogeneity and measurement validity.

Morphometric measurements of patellar alignment: The radiographic parameters were measured from standardised knee radiographic projections.

Q Angle Measurement

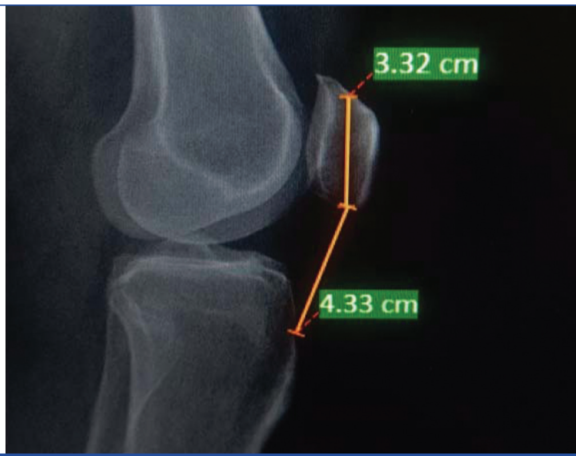
The Q angle was measured as a clinical parameter during patient assessment and not from radiographic images. With the patient positioned supine and the lower limb in full extension, anatomical landmarks including the Anterior Superior Iliac Spine (ASIS), the centre of the patella, and the tibial tuberosity were identified by palpation. An imaginary line was drawn from the ASIS to the centre of the patella, and a second line was drawn from the centre of the patella to the tibial tuberosity. The angle formed at the patellar centre by the intersection of these two lines was measured with a standard goniometer [17,18] and recorded as the Q angle.

Radiographic Imaging Procedure

Standardised radiographic imaging of the affected knees was performed using digital X-ray systems. Two projections (Lateral and Skyline view) were used for each participant.

Insall-salvati Ratio Measurement

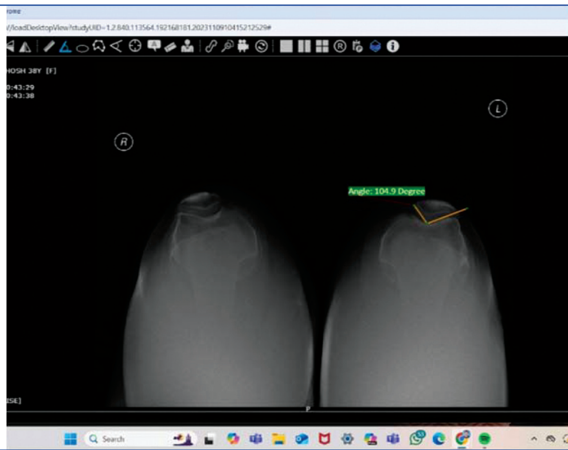
The Insall–Salvati ratio was calculated on true lateral radiographs as the ratio of patellar tendon length to patellar length. Patellar length was measured as the maximum pole-to-pole distance between the superior and inferior poles of the patella. The patellar tendon length was measured from the inferior pole of the patella to its insertion at the tibial tuberosity, along the longitudinal axis of the tendon [19,20]. All measurements were performed using calibrated digital tools to ensure accuracy [Table/Fig-1].



[Table/Fig-1]: Insall-Salvati ratio measured on the lateral knee radiograph as the ratio of patellar tendon length to the greatest diagonal length of the patella.

Sulcus Angle Measurement

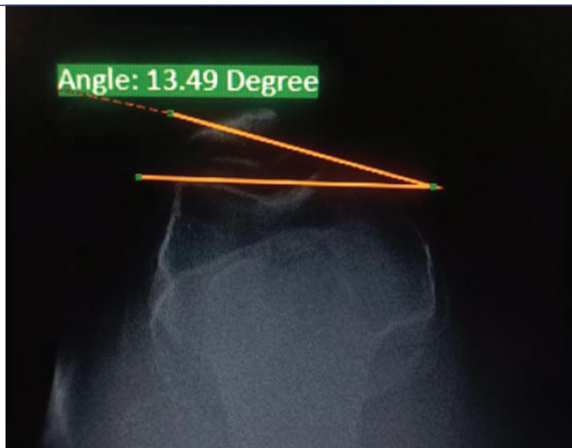
The sulcus angle was measured by identifying the highest points of the medial and lateral femoral condyles and drawing lines from these points to the deepest point of the trochlear groove [9]. The angle formed at this apex was recorded as the sulcus angle [Table/Fig-2].



[Table/Fig-2]: Sulcus angle measured on the Merchant's tangential radiographic view by joining the highest points of the medial and lateral femoral condyles with the deepest point of the trochlear groove.

Patellar Tilt Angle Measurement

The patellar tilt angle was determined by drawing a line across the maximal transverse width of the patella and a second line along the posterior femoral condylar line [21], and the angle between them was recorded as the patellar tilt angle [Table/Fig-3].



[Table/Fig-3]: Patellar tilt angle measured on the Merchant's view as the angle between the line across the maximal transverse diameter of the patella and the posterior femoral condylar line.

Digital image analysis: Radiographs were evaluated using the INSTARISPACS® DICOM software (Version 5.0.0), which provides calibrated digital tools for accurate angular and linear measurements.

All morphometric parameters were independently measured by two blinded observers to minimise measurement bias.

STATISTICAL ANALYSIS

All data were analysed using IBM Statistical Package for the Social Sciences (SPSS) Statistics Version 26.0. The data are presented as means and standard deviations for continuous variables, and as frequencies and percentages for categorical variables. Data normality was tested with the Shapiro-Wilk test. Comparisons between groups were made using independent-samples t-tests. Spearman's correlation coefficient was used to evaluate associations between anthropometric variables and radiographic parameters. Results with a p-value <0.05 were considered to be statistically significant in this analysis.

RESULTS

The PFPS group consisted of clinically diagnosed unilateral cases, and only the symptomatic knee was included for radiographic analysis. In the control group, one knee per participant was selected for comparison. Reliability analysis was performed on 20% of randomly selected radiographs. The intra-rater reliability demonstrated excellent agreement (ICC=0.91), while inter-rater reliability showed good to excellent agreement (ICC=0.87), as assessed using the Intraclass Correlation Coefficient (ICC) based on a two-way random-effects model with absolute agreement.

Among the 110 PFPS cases, the highest frequency of PFPS cases was observed in the 41-50 years age group, particularly among females (30.00%), followed by females in the 31-40 years group (22.73%) [Table/Fig-4].

Group	Gender	Age group (Years) 19-30 n (%)	Age group (Years) 31-40 n (%)	Age group (Years) 41-50 n (%)	Total n (%)
Cases (n=110)	Male	10 (9.09)	18 (16.36)	20 (18.18)	48 (43.64)
	Female	4 (3.64)	25 (22.73)	33 (30.00)	62 (56.36)
Controls (n=110)	Male	11 (10.00)	21 (19.09)	25 (22.73)	57 (51.82)
	Female	9 (8.18)	21 (19.09)	23 (20.91)	53 (48.18)

[Table/Fig-4]: Gender and age distribution among cases and controls (n=220).

The mean height of persons with PFPS (164±9.01 cm) was much lower than that of controls (169±6.31 cm) [Table/Fig-5].

Parameter	Group	Mean±SD	95% CI (Lower-Upper)	t-test (p-value)
Height (cm)	Case	164±9.01	162-166	< 0.001 ***
	Control	169±6.31	168-171	
Weight (kg)	Case	66.2±11.9	64-68.5	< 0.001 ***
	Control	71±9.94	69.1-72.9	
BMI (kg/m²)	Case	24.8±5.12	23.8-25.8	0.758
	Control	24.9±3.86	24.1-25.6	

[Table/Fig-5]: Descriptive statistics for anthropometric parameters (n=220).
Notes: *p<0.05, **p<0.01, ***p<0.001; NS = Not Significant

The mean Q angle in the PFPS group was significantly higher than the control values (21.55±2.76° vs. 15.8±2.5°, p-value <0.001), indicating increased lateral vector forces acting on the patella in PFPS subjects. The Insall–Salvati index was slightly but significantly higher in PFPS patients than in controls (1.05±0.30 vs. 1.00±0.12; p-value=0.021), indicating a tendency toward patellar height alteration in the case group [Table/Fig-6].

Spearman's correlation analysis demonstrated a moderate negative correlation between Q angle and sulcus angle (r=-0.292, p-value <0.001) and a moderate positive correlation between Q angle and patellar tilt angle (r=0.466, p-value <0.001). Height showed a weak but statistically significant negative correlation with Q Angle (r=-0.224, p-value <0.001) and patellar tilt angle (r=-0.190, p<0.01) [Table/Fig-7].

Parameter	Group	Mean±SD	95% CI (Lower-Upper)	t-test (p-value)
Q angle (°)	Cases	21.55±2.76	21.03 - 22.07	<0.001*
	Controls	15.8±2.5	15.33 - 16.27	
Sulcus angle (°)	Cases	132.02±8.53	130.41 - 133.63	<0.001*
	Controls	138.5±6.0	137.39 -139.61	
Patellar tilt angle (°)	Cases	21.13±7.82	19.65 - 22.60	<0.001*
	Controls	10.2±3.1	9.62 - 10.78	
Insall–Salvati index	Cases	1.05±0.30	0.99 - 1.11	0.021*
	Controls	1.00±0.12	0.98 - 1.02	

[Table/Fig-6]: Descriptive statistics for radiographic parameters in PFPS vs controls.
Notes: *p<0.05, **p<0.01, ***p<0.001; NS = Not Significant

Parameters	Q Angle	Sulcus angle	Patellar tilt angle	Insall-Salvati ratio	BMI	Height (cm)	Weight (kg)
Q angle	-						
Sulcus angle	-0.292***	-					
Patellar tilt angle	0.466***	-0.117	-				
Insall-Salvati ratio	0.09	-0.148*	-0.006	-			
BMI	-0.017	-0.091	-0.046	-0.031	-		
Height (cm)	-0.224***	0.281***	-0.19**	-0.074	-0.443***	-	
Weight (kg)	-0.165*	0.073	-0.171*	-0.082	0.837***	0.11	-

[Table/Fig-7]: Correlation matrix (r) of radiographic and anthropometric parameters.
Notes: *p<0.05, **p<0.01, ***p<0.001; NS = Not Significant

Binary Logistic Regression Analysis

Binary logistic regression analysis was performed to determine the independent predictors of PFPS. PFPS status (0=Control, 1=PFPS) was entered as the dependent variable. The independent variables included Q angle, sulcus angle, patellar tilt angle, Insall-Salvati Ratio, BMI, height and weight. Among the radiographic parameters, Q Angle and Patellar Tilt Angle emerged as a strong independent predictor of PFPS (p-value <0.001), with increasing Q angle associated with higher odds of PFPS. BMI, height, and weight were not found to be statistically significant predictors of PFPS [Table/Fig-8].

Predictor	Regression Coefficient (B)	Standard Error (SE)	p-value	Odds Ratio (OR)	95% CI for OR
Q angle	0.063	0.005	<0.001***	1.065	1.055-1.075
Sulcus angle	-0.006	0.003	0.011*	0.994	0.989-0.998
Patellar tilt angle	0.026	0.003	<0.001***	1.026	1.020-1.032
Insall-Salvati ratio	0.165	0.081	0.042*	1.179	1.007-1.380
BMI	0.047	0.044	0.280 (NS)	1.048	0.964-1.140
Height	0.008	0.013	0.541 (NS)	1.008	0.983-1.034
Weight	0.018	0.021	0.391 (NS)	1.018	0.977-1.061

[Table/Fig-8]: Binary logistic regression model predicting PFPS Classification.
Notes: *p<0.05, **p<0.01, ***p<0.001; NS: Not significant

DISCUSSION

The demographic distribution of the study population showed a slightly higher proportion of females among PFPS cases (56.36%) compared with males (43.64%). This finding was consistent with a previous study by Boling M et al., which reported an incidence rate of 22/1000 person-years for PFPS. Females were 2.23 times (95% CI: 1.19, 4.20) more likely to develop PFPS compared with males [1]. A study by del Mar Carrión Martín M et al., evaluated the knees of 52 consecutive patients with idiopathic patellofemoral pain using Computed Tomography (CT). In patients with idiopathic patellofemoral pain, greater Q angle and internal condylar facet width in symptomatic knees compared with asymptomatic knees were observed [22].

Similarly, Herrington L and Nester C, conducted a radiographic and clinical comparison study and reported increased Q angle and altered patellar alignment in individuals with PFPS compared to asymptomatic controls, reinforcing the contribution of malalignment to patellofemoral pain [18]. These findings are consistent with the present study, where alignment-related parameters showed significant differences between groups.

Excessive lateral patellar tilt has been widely recognised as an indicator of abnormal patellofemoral tracking. Kalichman L et al., reported that alterations in patellar alignment, including increased tilt, are strongly associated with knee pain and functional limitations [11].

Overall, the findings of the present study indicate that PFPS is more strongly associated with patellofemoral alignment abnormalities than with general anthropometric characteristics.

Limitation(s)

The cross-sectional design limits the ability to establish a causal relationship between the observed associations. Additionally, the measurements were obtained from static radiographic images, which may not accurately reflect dynamic patellofemoral tracking during functional activities. Therefore, future longitudinal studies incorporating dynamic imaging modalities such as Magnetic Resonance Imaging (MRI) and multicentre cohorts are recommended to better clarify the causal relationship between patellofemoral alignment abnormalities and the progression of PFPS.

CONCLUSION(S)

In this study, the Q angle and patellar tilt angle showed the most pronounced differences between individuals with PFPS and healthy controls, underscoring their importance as indicators of patellar maltracking. Furthermore, the observed association between radiographic parameters and functional outcomes highlights the clinical relevance of these alignment measures. Therefore, comprehensive radiographic evaluation, combined with functional assessment, may play a crucial role in the early identification and clinical management of PFPS, facilitating more targeted and effective rehabilitation.

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