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Analysis of Risk Factors on Patellofemoral Osteoarthritis: Distribution Characteristics and Radiographic Parameters of Patellofemoral Joint

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Keywords: knee | osteoarthritis | patellofemoral joint | radiology | regression analysis

ABSTRACT

Objective: The risk factors for the degeneration of the patellofemoral joint (PFJ) have not been adequately and thoroughly studied. This study aimed to analyze the population distribution characteristics of patients with patellofemoral osteoarthritis (PFOA) and assess the correlation between PFOA and radiological parameters, including patella morphology, PFJ congruity, and patellar alignment. Moreover, the risk factors across various demographic groups were further analyzed.

Methods: A retrospective analysis was conducted to examine the population distribution characteristics of PFOA patients from September 2020 to September 2023. Radiological parameters of the PFJ were measured from the anteroposterior and lateral views of knee joint as well as axial view of patella using X-ray imaging and the PACS imaging system at the First Affiliated Hospital of Kunming Medical University. These parameters included patella morphology (patella type, width, thickness, and Wiberg index), PFJ congruity (patella height, Wiberg angle, sulcus angle, and lateral patella angle), and patellofemoral alignment (patella tilt angle, displacement, and lateral patellofemoral angle). PFOA severity was classified according to the Iwano PFJ radiological classification, and its correlation with the aforementioned parameters was examined. Additionally, risk factors for PFOA across different populations were further evaluated.

Results: The study included 1080 patients according to the inclusion and exclusion criteria. Age, female gender, overweight or obesity, and manual workers were significantly associated with PFOA. Moreover, type III patella (OR = 3.03, $p < 0.05$), greater patella width (OR = 1.12, $p = 0.01$), sulcus angle (OR = 1.04, $p < 0.01$), patella tilt angle (OR = 1.13, $p < 0.01$), and patella displacement (OR = 1.22, $p < 0.01$) as well as smaller patella thickness (OR = 0.87, $p < 0.01$), Insall–Salvati index (OR = 0.24, $p = 0.04$), and lateral patellofemoral angle (OR = 0.93, $p = 0.02$) were identified as risk factors for PFOA. Furthermore, greater patella thickness (OR = 1.17, $p < 0.05$) and smaller patella displacement (OR = 0.79, $p < 0.01$) correlated with higher Kujala patellofemoral scores. Discrepancies in risk factors across different populations were also observed.

Conclusions: Older age, female gender, obesity, manual workers, and specific aberrations in patellofemoral parameters are predictive factors for PFOA. Additionally, greater patella thickness and smaller patella displacement were associated with increased severity of clinical symptoms. Thus, more attention should be paid to the discrepancies that exist in different populations.

Jianlin Zhao and Jinsong Liu contributed equally to this work.

1 | Introduction

Knee osteoarthritis (KOA), the most common degenerative disease among middle-aged and elderly individuals, is characterized by joint swelling, pain, and activity limitation [1, 2]. KOA is generally divided into tibiofemoral joint osteoarthritis and patellofemoral joint osteoarthritis (PFOA) based on the location of a lesion. However, most of the studies focused on the tibiofemoral joint rather than on the patellofemoral joint (PFJ). Studies indicate that approximately 60% of KOA patients with clinical symptoms exhibit PFJ disorders [3]. PFOA is a leading cause of anterior knee pain [4]. Yet, PFOA-related risk factors remain insufficient. Previous clinical studies [5, 6] have explored the correlation between patellofemoral radiological parameters and PFOA, including patella type, height, sulcus angle, and lateral patella angle. They identified type III patella and sulcus angle to be associated with radiological PFOA and observed a U-shaped correlation between patella height and the severity of lateral PFOA [5, 6]. However, there are still some limitations, such as scant parameters, small sample sizes, and the absence of systematic evaluations.

Therefore, a single-center large-sample study was designed to investigate: (1) the association between population distribution characteristics (gender, age, body mass index [BMI], occupation) and radiographic PFOA; (2) the correlation between patellofemoral radiological parameters (patella morphology: type, width, thickness, Wiberg index; PFJ congruity: height, Wiberg angle, sulcus angle, lateral patella angle; patellofemoral alignment: tilt angle, displacement, lateral patellofemoral angle) and PFOA (radiological and clinical evaluation); and (3) the risk factors of PFOA among various populations.

2 | Materials and Methods

2.1 | Inclusion and Exclusion of Study Samples

This retrospective analysis enrolled 1149 patients with anterior knee pain or discomfort from the First Affiliated Hospital of Kunming Medical University between September 2020 and September 2023. This study was approved by the ethics committee of the First Affiliated Hospital of Kunming Medical University (Approval No. L2023190). The general information, including age, gender, BMI, and occupation, was collected from all patients. Inclusion criteria were as follows: (1) patients aged 18–80 years; (2) patients with pain in anterior knee joints; (3) patients without knee ligament laxity; (4) patients without knee meniscus injury-related pain; and (5) patients who underwent clinical physical examination and X-ray imaging, involving anteroposterior and lateral views of knee joint as well as axial view of patella. Exclusion criteria were as follows: (1) patients with a history of knee joint trauma (e.g., fractures, dislocations, ligament injuries); (2) patients with a history of knee surgery (e.g., fracture fixation, ligament reconstruction, total knee arthroplasty); (3) patients with structural changes caused by the neoplasm and infection of knee joint; (4) patients with rheumatoid arthritis; (5) patients with patella dislocation upon clinical examination; (6) patients with severe varus or valgus deformities of the knee joint [7, 8]; and (7) patients with pain in the medial and lateral compartments of the knee joint.

Finally, one patient who was diagnosed with knee rheumatoid arthritis, six patients who had experienced knee joint traumas, and three patients with a history of knee surgery were excluded from this study. In addition, 16 patients who suffered from patella dislocations, 12 patients with severe varus or valgus deformities of the knee joint, and 31 patients without any bone anatomy markers identified on X- rays due to severe osteophytes were also excluded from this study. Therefore, a total of 1080 patients were included in the final analysis.

2.2 | Radiological Evaluation of PFOA

According to the Iwano PFJ radiological classification proposed by Merchant et al. [9], the assessment of PFJ space narrowing was categorized into five stages: stage 0 denoted a completely normal PFJ, while stages I–IV represented progressive degeneration (Figure 1). Stage I denoted mild narrowing of the joint space, where the narrowest part of the articular surface measured ≥ 3 mm. Stage II indicated moderate narrowing, with the narrowest part of the articular surface measuring < 3 mm but without bony contact. Stage III suggested severe narrowing, with partial bony contact occurring below one-quarter of the joint space. Finally, stage IV indicated extremely severe narrowing, where the bony joint surfaces were entirely in contact with each other.

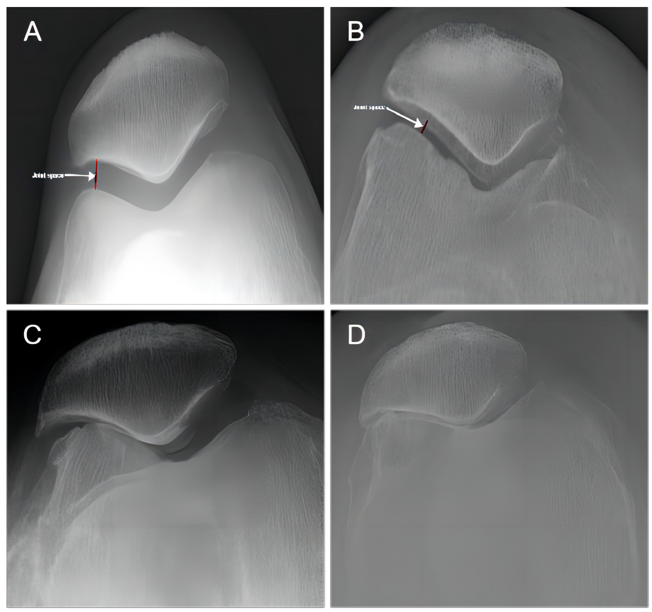

FIGURE 1 | Iwano patellofemoral joint radiological classification. (A) Stage I: Mild narrowing of the joint space, where the narrowest part of the articular surface is ≥ 3 mm. (B) Stage II: Moderate narrowing of the joint space, with the narrowest part of the articular surface < 3 mm, but without bony contact. (C) Stage III: Severe narrowing of the joint space, with partial bony contact encompassing less than one-quarter of the joint space. (D) Stage IV: Extremely severe narrowing of the joint space, with complete contact between the bony joint surfaces.

2.3 | Measurement of Radiological Parameters of PFJ

The radiological assessment of the PFJ was conducted from the anteroposterior and lateral views of the knee joint, as well as the axial view of the patella using X-ray imaging and the PACS imaging system (Neusoft Hospital Information System, HIS 5.0, CN) at the First Affiliated Hospital of Kunming Medical University. Two orthopedic surgeons with extensive experience in reading musculoskeletal images measured the data independently using the same criteria and repeated them 4 weeks later., Then, the intra-observer correlation coefficient between each indicator was calculated. These measurements included various parameters: patella morphology (such as type patella [10], patella width, patella thickness, and Wiberg index [11]), PFJ congruity (such as patella height [12], Wiberg angle, sulcus angle, and lateral patella angle), and patellofemoral alignment (such as patella tilt angle [13], patella displacement [14], and lateral patellofemoral angle). The measurement methods were as follows: (1) Wiberg and Baumgartl classification of the patella: Type I patella: the patella ridge is positioned approximately in the center, with equal-sized medial and lateral facets; Type II patella: the patella ridge is slightly shifted toward the medial border, and the medial facet is smaller than the lateral; Type III patella: the patella ridge is medially displaced, resulting in a steep forward and medial slope of the medial facet; Type IV patella: the patella ridge is further medially displaced, and the medial facet is slightly convex. (2) Patella width: defined as the distance between the innermost (b) and outermost edges (a) of the patella. (3) Patella thickness: the distance between the leading edge (e) and the trailing edge (d) of the patella. (4) Wiberg index: the ratio of the patella lateral articular surface's horizontal distance (a–c) to the patella width (a, b). (5) Lateral patella angle: the angle between the width of the patella and the lateral articular surface of the patella. (6) Patella height (Insall–Salvati [IS] index): the ratio of the patella tendon length (g, h) to the distance (f, g) between the upper and lower poles of the patella on lateral view X-ray. (7) Wiberg angle: the angle formed by the medial and lateral articular surfaces of the patella. (8) Sulcus angle: the angle formed by the medial and lateral articular surfaces of the trochlea. (9)Patella tilt angle: the angle between the line connecting the highest point of the internal and external condyles of the femur and the width of the patella. (10) Lateral patellofemoral angle: the angle formed by the line between the highest point of the internal and external condyle of the femur and the tangent line of the lateral articular surface of the patella. (11) Patella displacement: measured as the distance between two vertical lines: one drawn through the highest point of the internal and external condyle of the femur and the other connecting the internal margin of the patella with the highest point of the internal and external condyle of the femur (Figure 2).

2.4 | Clinical Evaluation of PFOA

The Kujala patellofemoral score (KPS) [15], including 13 items such as pain intensity during stair climbing, discomfort with prolonged knee flexion, and limitations in knee flexion, served as the assessment tool for evaluating the extent of PFJ degeneration among patients with PFOA. A previous study [16] has established that the individual item scores of the Kujala scale are summed up to yield a total score ranging from 0 to 100, indicating a good outcome. Subsequently, the overall scores of all patients were categorized into four groups: excellent (> 95), good (95–82), medium (81–62), and poor (< 62).

2.5 | Statistical Analysis

All statistical analyses were conducted using SPSS 27.0 (IBM, Armonk, NY, USA). To determine the measurement reliability of radiographic parameters of PFJ, a consistency test was conducted, and the ICC value > 0.75 indicated good reliability. Logistic regression was used to find the risk factors of patellofemoral osteoarthritis and predict its probability of occurrence under certain conditions. Prior to the analysis, multicollinearity between population distribution characteristics and radiological parameters was assessed. Subsequently, multiple ordered logistic regression was used to analyze the data. The model met the assumptions of proportional odds. The data pertaining to population demographics and the Iwano PFJ radiological classification were then incorporated into the regression model to explore their relationship with PFOA. Moreover, the scores of clinical evaluations were categorized into four groups and used as the dependent variable to examine correlations with the parameters. Finally, continuous values of the measured radiographic parameters of the PFJ were integrated into the model to analyze their correlation with PFJ degeneration. Statistical significance was set at $p < 0.05$.

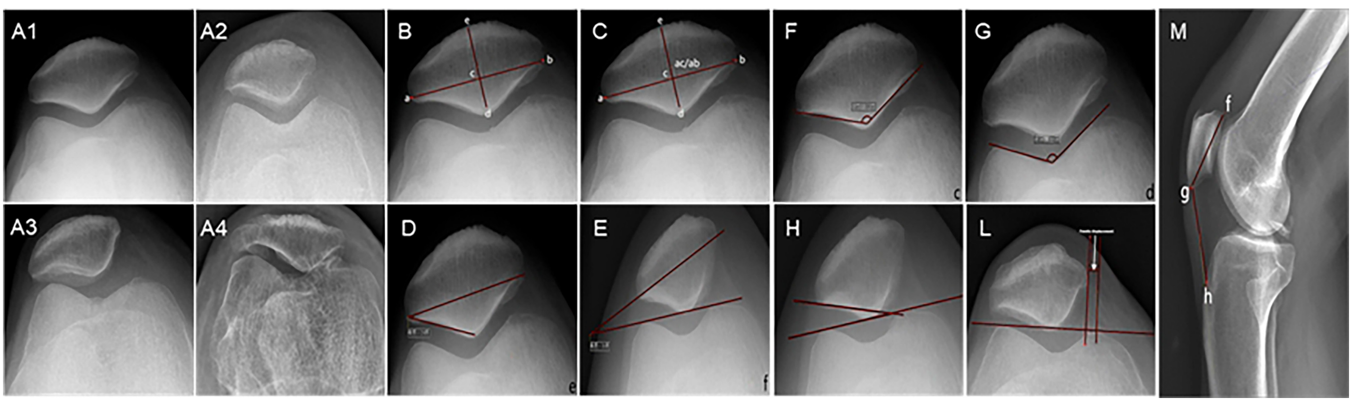

FIGURE 2 | (A1–A4) Wiberg and Baumgartl classification of the patella. (B) Patella width; Patella thickness; (C) Wiberg index; (D) Lateral patella angle; (E) Patella tilt angle; (F) Wiberg angle; (G) Sulcus angle; (H) Lateral patellofemoral angle; (L) Patella displacement; (M) Insall–Salvati index.

3 | Results

3.1 | Population Distribution Characteristics of PFOA Patients

Among the 1080 participants in this study, 254 (23.5%) were male and 826 (76.5%) were female. Regarding age distribution, 94 participants (8.7%) were aged 20–30 years, 104 participants (9.6%) were aged 31–40 years, 118 participants (10.9%) were aged 41–50 years, 293 participants (27.1%) were aged 51–60 years, 336 participants (31.2%) were aged 61–70 years, and 135 participants (12.5%) were aged 71–80 years. Besides, the distribution of participants' BMI was as follows: 18 (1.7%) were underweight (BMI < 18.5), 450 (41.7%) fell within the normal weight range (BMI 18.5–23.9), 432 (40%) were overweight (BMI 24–27.9), and 180 (16.7%) were obese (BMI ≥ 28). In addition, 589 (54.5%) patients were manual workers, while the remaining 491 (45.5%) were not engaged in physical labor. Detailed information is depicted in Figure 3.

3.2 | Correlation Between Population Distribution Characteristics and Radiographic PFOA

Compared to patients aged 71–80 years old, those aged 31–40 years (OR = 0.04, $p < 0.01$) and 41–50 years (OR = 0.18, $p < 0.01$) had a lower prevalence of radiographic PFOA. However, there was no significant difference in patients from other age groups. Meanwhile, a lower prevalence of radiographic PFOA was observed in the male group (OR = 0.47, $p = 0.03$) compared to the female group. Furthermore, underweight, normal weight, and overweight patients had a lower prevalence of radiographic PFOA compared to obese patients (OR = 0.07, $p = 0.03$; OR = 0.36, $p = 0.01$; OR = 0.41, $p = 0.02$; respectively). Moreover, manual workers (OR = 3.26, $p < 0.01$) had a higher prevalence of radiographic PFOA than non-manual workers. Detailed information is provided in Table 1.

3.3 | Reliability Assessment for Measures of Radiographic Parameters of PFJ

For the measurement of radiographic parameters of PFJ, the inter-observer and intra-observer correlation coefficient between each indicator results ranged from 0.85 to 0.94 and 0.92 to 0.99, respectively. Detailed information is depicted in Table 2.

3.4 | Correlation Between Radiographic Parameters and Radiographic PFOA

Type IV patella was excluded from the data analysis of patella type in this study due to its small sample size. Compared to type III patella, type I (OR = 0.32, $p < 0.01$) and type II (OR = 0.33, $p < 0.01$) demonstrated a lower prevalence of radiographic PFOA. Conversely, greater patella width, sulcus angle, patella tilt angle, and patella displacement (OR = 1.12, $p = 0.01$; OR = 1.04, $p < 0.01$; OR = 1.13, $p < 0.01$; OR = 1.22, $p < 0.01$) were associated with a higher prevalence of radiographic PFOA. In addition, smaller patella thickness, IS index, and lateral patellofemoral angle (OR = 0.87, $p = 0.01$; OR = 0.24, $p = 0.04$; OR = 0.93, $p = 0.02$) were related to a higher prevalence of radiographic PFOA. However,

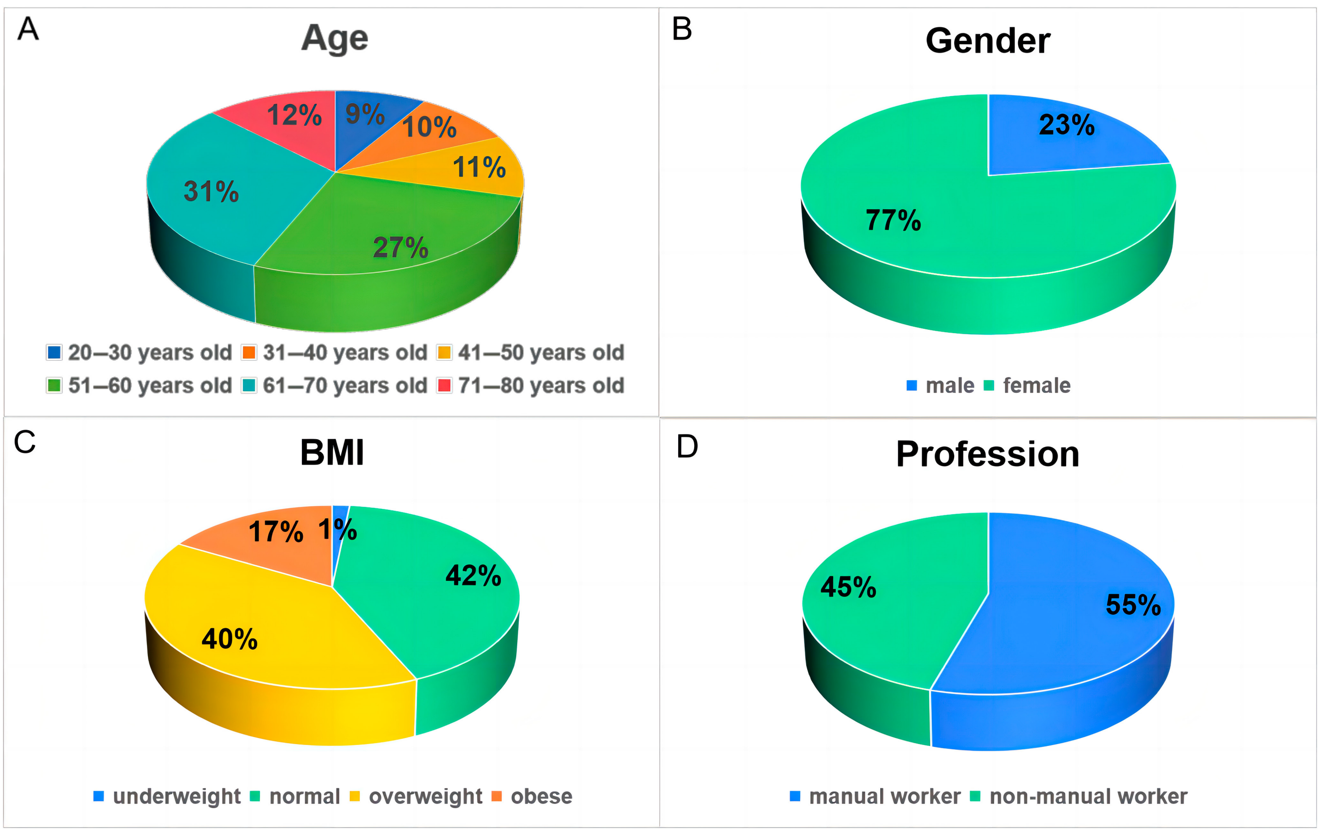

FIGURE 3 | Population distribution characteristics of PFOA patients. (A) Proportion of age distribution; (B) proportion of gender distribution; (C) proportion of BMI distribution; and (D) proportion of profession distribution.

TABLE 1 | Statistical results of correlation between population distribution and PFOA ($n = 1080$ knees).

Variable		(Mean ± SD)	*p* value	OR (95% CI)
Age (years)	20–30	23.1 ± 3.6	0.97	< 0.01 (0.001–2.56)
	31–40	37.0 ± 2.4	< 0.01**	0.04 (0.01–0.16)
	41–50	44.8 ± 3.1	< 0.01**	0.18 (0.08–0.56)
	51–60	56.5 ± 2.8	0.42	0.71 (0.32–1.61)
	61–70	65.5 ± 2.9	0.33	0.66 (0.29–1.51)
	71–80	76.5 ± 2.4	—	1.0
Gender	Male	—	0.03&	0.47 (0.24–0.92)
	Female	—	—	1.0
BMI	Underweight	17.7 ± 0.4	0.03#	0.07 (0.01–0.75)
	Normal	21.5 ± 1.7	0.01#	0.36 (0.16–0.80)
	Overweight	25.8 ± 1.1	0.02#	0.41 (0.20–0.87)
	Obese	30.9 ± 2.9	—	1.0
Profession	Manual worker	—	< 0.01▲▲	3.26 (1.79–5.93)
	Nonmanual worker	—	—	1.0

Note: 71–80 years old group as control: ***p* < 0.01; female group as control: &*p* < 0.05; obese group as control: #*p* < 0.05; non-manual worker group as control: ▲▲*p* < 0.01.

TABLE 2 | Reliability assessment for measures of radiographic parameters of PFJ.

Variable		Interrater (ICC)	Intrarater (ICC)
Patella morphology	Type I	0.94	0.99
	Type II	0.88	0.95
	Type III	0.89	0.92
	Type IV	0.92	0.96
	PW (mm)	0.93	0.97
	PT (mm)	0.90	0.94
	WI	0.92	0.96
Patellofemoral joint compatibility	ISI	0.91	0.96
	WA (°)	0.86	0.94
	SA (°)	0.87	0.95
	LPA (°)	0.83	0.94
Patellofemoral alignment	PTA (°)	0.91	0.98
	LPFA (°)	0.85	0.94
	PD (mm)	0.86	0.96

Abbreviations: ISI = Insall–Salvati index; LPA = lateral patella angle; LPFA = lateral patellofemoral angle; PD = patella displacement; PT = patella thickness; PTA = patella tilt angle; PW = patella width; SA = sulcus angle; WA = Wiberg angle; WI = Wiberg index.

there was no statistical difference in other parameters such as Wiberg index, Wiberg angle, and lateral patella angle (Table 3).

3.5 | Correlation Between Radiographic Parameters and Clinical Function

The KPS was used to assess the PFJ function in this study. Greater patella thickness (OR = 1.17, $p = 0.048$) and smaller patella displacement (OR = 0.79, $p < 0.01$) were correlated with higher KPSs. However, no significant difference was observed in the remaining parameters, including patella height, Wiberg angle, sulcus angle, and lateral patella angle (Table 4).

3.6 | Correlation Between Population Distribution and Radiological Parameters of PFJ

This study identified significant differences in the radiological parameters of the PFJ across different populations.

TABLE 3 | Statistical results of correlation between radiological parameters of patellofemoral joint and PFOA.

Variable		Mean ± SD	*p* value	OR (95% CI)
Patella morphology	Type I	—	< 0.01**	0.32 (0.13–0.75)
	Type II	—	< 0.01**	0.33 (0.15–0.72)
	Type III	—	—	1.0
	Type IV	—	—	—
	PW (mm)	46.68 ± 3.99	0.01	1.12 (1.03–1.21)
	PT (mm)	26.29 ± 3.09	0.01	0.87 (0.78–0.97)
	WI	0.57 ± 0.04	0.06	12.56 (1.02–14.67)
Patellofemoral joint compatibility	ISI	1.06 ± 0.15	0.04	0.24 (0.06–0.98)
	WA (°)	126.44 ± 7.29	0.23	1.03 (0.98–1.08)
	SA (°)	129.1 ± 7.77	< 0.01	1.04 (1.01–1.07)
	LPA (°)	24.59 ± 3.88	0.20	1.05 (0.97–1.14)
Patellofemoral alignment	PTA (°)	10.14 ± 4.99	< 0.01	1.13 (1.04–1.23)
	LPFA (°)	13.33 ± 6.30	0.02	0.93 (0.89–0.98)
	PD (mm)	3.26 ± 4.37	< 0.01	1.22 (1.15–1.30)

Note: Type III group as control: ***p* < 0.01.
Abbreviations: ISI = Insall–Salvati index; LPA = lateral patella angle; LPFA = lateral patellofemoral angle; PD = patella displacement; PT = patella thickness; PTA = patella tilt angle; PW = patella width; SA = sulcus angle; WA = Wiberg angle; WI = Wiberg index.

TABLE 4 | Statistical results of radiographic parameters of patellofemoral joint and clinical evaluation of patellofemoral joint.

Variable		Mean ± SD	*p* value	OR (95% CI)
Patella morphology	Type I	—	0.46	2.45 (0.88–6.86)
	Type II	—	0.71	2.24 (0.86–5.86)
	Type III	—	—	1.0
	Type IV	—	—	—
	PW (mm)	46.68 ± 3.99	0.49	1.04 (0.92–1.18)
	PT (mm)	26.29 ± 3.09	0.048	1.17 (0.99–1.37)
	WI	0.57 ± 0.04	0.82	0.29 (0.86–8.23)
Patellofemoral joint compatibility	ISI	1.06 ± 0.15	0.28	3.04 (0.41–22.71)
	WA (°)	126.44 ± 7.29	0.73	0.99 (0.91–1.07)
	SA (°)	129.1 ± 7.77	0.55	1.01 (0.97–1.06)
	LPA (°)	24.59 ± 3.88	0.46	0.96 (0.85–1.08)
Patellofemoral alignment	PTA (°)	10.14 ± 4.99	0.26	1.08 (0.94–1.24)
	LPFA (°)	13.33 ± 6.30	0.76	0.98 (0.87–1.11)
	PD (mm)	3.26 ± 4.37	< 0.01	0.79 (0.72–0.87)

Abbreviations: ISI = Insall–Salvati index; LPA = lateral patella angle; LPFA = lateral patellofemoral angle; PD = patella displacement; PT = patella thickness; PTA = patella tilt angle; PW = patella width; SA = sulcus angle; WA = Wiberg angle; WI = Wiberg index.

Subsequently, we conducted further analysis to explore the association between these radiological parameters and distinct populations. Patella thickness was the primary radiological parameter associated with PFOA across various age groups (31–40 years old: OR = 0.52, $p = 0.01$; 51–60 years old: OR = 0.72, $p = 0.03$), BMI groups (overweight: OR = 0.79, $p = 0.02$; obese: OR = 0.75, $p = 0.04$), and genders (males: OR = 0.68, $p < 0.01$; females: OR = 0.77, $p < 0.01$). Conversely, patella displacement was the main radiological parameter associated with PFOA across diverse age groups (51–60 years: OR = 1.23, $p < 0.01$; 61–70 years old: OR = 1.55, $p < 0.01$), BMI groups (normal weight: OR = 1.28, $p < 0.01$; overweight: OR = 1.33, $p < 0.01$), genders (males: OR = 1.41, $p < 0.01$; females: OR = 1.24, $p < 0.01$), and occupational groups (manual workers: OR = 1.24, $p < 0.01$). In addition, some radiological parameters exhibited associations with PFOA in specific age groups, BMI groups, genders, and occupational groups. For instance, the IS index was associated with PFOA in patients aged 41–50 years old (OR = 0.86, $p = 0.01$), 61–70 years old (OR = 0.02, $p = 0.01$), and 71–80 years old (OR = 0.44, $p = 0.02$). The lateral patellofemoral angle was associated with PFOA in patients aged 41–50 years old (OR = 0.78, $p = 0.04$), with normal weight (OR = 0.88, $p = 0.04$), and with manual workers (OR = 0.89, $p < 0.01$). Furthermore, the patella tilt angle was a predictor of PFOA in patients aged 41–50 years old (OR = 1.12, $p = 0.04$) and 51–60 years old (OR = 1.26, $p = 0.04$). Finally, patella width (OR = 1.21, $p = 0.04$) and sulcus angle (OR = 1.12, $p = 0.03$) were identified as unique predictors of PFOA in patients aged 51–60 years old and males. Detailed information is provided in Table 5.

4 | Discussion

A systematic correlation analysis between population distribution characteristics, patellofemoral radiological parameters, and PFOA was conducted to determine the risk factors of PFOA. Additionally, we explored the risk factors related to the severity of clinical symptoms in PFOA patients based on radiological parameters of the PFJ. Our findings were as follows: (1) Older age, female gender, overweight or obesity, and engagement in manual workers were identified as risk factors for PFOA. (2) Specific patella morphologies, including type III patella, greater patella width, and smaller patella thickness, were associated with a higher severity of radiological PFOA. (3) Poor congruity of the PFJ, characterized by greater sulcus angle and smaller IS index, correlated with a higher severity of radiological PFOA. (4) Poor alignment of the PFJ, indicated by greater patella tilt angle, larger patella displacement, and smaller lateral patellofemoral angle, was related to the severity of radiological PFOA. (5) Certain radiological parameters, specifically greater patella thickness and smaller patella displacement, were predictors for higher clinical function scores of the PFJ. Furthermore, our analysis of susceptible populations for radiological PFOA revealed that patella thickness and patella displacement were high-risk radiological parameters for PFOA. However, several discrepancies in the risk factors were observed across different populations.

4.1 | Population Distribution Characteristics of Patients With Radiological PFOA

The analysis of population distribution characteristics of PFOA in this study revealed that the degeneration of the PFJ exacerbates with advancing age, with the majority of PFOA patients concentrated in the age range of 51–70 years. It may be attributed to the natural aging process of the PFJ [17], potentially exacerbated by osteoporosis [18]. However, no studies have been conducted to confirm this hypothesis due to the lack of effective methods to accurately assess local bone mass in the knee joint. Moreover, consistent with previous findings, our study demonstrated a higher incidence of PFOA in females than in males, particularly prevalent in females over 50 years old [19]. This phenomenon is closely related to osteoporosis caused by decreased estrogen levels in postmenopausal females [18, 20]. Additionally, differences exist in relevant parameters between males and females, possibly contributing to this gender-based disparity. Studies have indicated that males tend to have greater patella thickness, typically around 5 mm larger than females across all ethnicities, while females have narrower femoral condyles or tibia platforms than males [21, 38–40]. In addition, the excessive load experienced by overweight or obese individuals accelerates the progression of PFOA and induces abnormal change in patellofemoral mechanics [22, 24–26]. Similarly, manual workers tend to have a higher susceptibility to PFOA due to the overload and overwear of the PFJ during prolonged labor [27]. Therefore, the elderly, females, overweight or obese individuals, and manual workers were identified as high-risk populations for PFOA progression.

4.2 | Characteristics of PFJ Parameters in Radiological PFOA and Clinical Symptoms of PFOA

Previous studies have underscored the impact of abnormalities in three key anatomical parameters of the PFJ—patella morphology, PFJ congruity, and patellofemoral alignment—on the development of pathological changes in the PFJ [23, 28]. Consistent with these findings, our study also revealed associations between these parameters and the progression of radiological PFOA. Regarding patella morphology, our findings indicated that greater patella width, smaller patella thickness, and type III patella were linked to the advancement of radiological PFOA. Existing research suggests that increased patella thickness and width may result in improper patellar contact within the femoral trochlea, leading to varying degrees of anterior knee pain [29, 30]. Similarly, the prominence of the medial articular surface and the lateral displacement of the patella crest in type III patella may induce excessive contact and pressure in the lateral compartment of the PFJ, particularly during knee flexion, ultimately resulting in lateral PFOA [31]. Moreover, our study revealed that a smaller IS index and a larger sulcus angle—two indicators reflecting PFJ congruity—indicated more severe radiological PFOA. Previous research has reported a U-shaped association between patella height (Caton-Deschamps index) [32] and the severity of lateral PFOA, suggesting that excessive or insufficient patella height may exacerbate lateral PFOA [31]. Similarly, studies have implicated excessively large or small sulcus angles in increasing susceptibility to PFOA [33, 34], possibly due to resulting patellar instability or trochlear dysplasia [35]. Furthermore, we explored the correlation between patellofemoral alignment parameters and radiological PFOA and found that a greater patella tilt angle, increased patella displacement, and a smaller lateral patellofemoral angle were related to more severe PFOA, possibly resulting from the biomechanical alterations that occur as the patella shifts position. Specifically, the lateral compartments of the PFJ experience a diminished contact area, which in turn leads to an increase in contact stress [36, 37]. Van Haver et al. [38] found that poor patellofemoral alignment changed the balance of the original patellofemoral pressure distribution, leading to the degeneration of lateral compartment of the PFJ due to the excessive pressure. Therefore, abnormal changes in anatomical parameters of the PFJ—such as type III patella, greater patella width, increased patella tilt angle

TABLE 5 | Statistical results of correlation between radiological parameters of patellofemoral joint and different populations.

Variable		*p* value	OR (95% CI)	Variable		*p* value	OR (95% CI)
40 years	PW (mm)	0.49	1.14 (0.78–1.68)	BMI (overweight)	PW (mm)	0.05	1.15 (1.00–1.33)
	PT (mm)	0.01	0.52 (0.31–0.88)		PT (mm)	0.02	0.79 (0.66–0.96)
	WI	0.96	2.36 (0.01–5.68)		WI	0.08	0.94 (0.68–3.22)
	ISI	0.28	0.06 (0.01–1.92)		ISI	0.52	0.39 (0.02–4.57)
	WA (°)	0.33	0.93 (0.80–1.08)		WA (°)	0.70	0.99 (0.92–1.06)
	SA (°)	0.29	0.93 (0.83–1.06)		SA (°)	0.40	1.02 (0.97–1.07)
	LPA (°)	0.10	0.74 (0.52–1.06)		LPA (°)	0.15	0.91 (0.79–1.04)
	PTA (°)	0.25	1.23 (0.87–1.75)		PTA (°)	0.97	1.00 (0.88–1.14)
	PD (mm)	0.95	1.01 (0.79–1.29)		PD (mm)	< 0.01	1.28 (1.15–1.43)
	LPFA (°)	0.31	1.14 (0.89–1.46)		LPFA (°)	0.69	1.02 (0.92–1.13)
41–50 years	PW (mm)	0.21	1.27 (0.88–1.83)	BMI (obese)	PW (mm)	0.12	1.19 (0.95–1.49)
	PT (mm)	0.92	1.03 (0.61–1.73)		PT (mm)	0.04	0.75 (0.56–1.00)
	WI	0.11	1.25 (0.01–2.68)		WI	0.49	2.83 (0.91–3.12)
	ISI	0.01	0.86 (0.13–2.78)		ISI	0.18	0.07 (0.02–3.19)
	WA (°)	0.53	0.95 (0.81–1.11)		WA (°)	0.55	0.98 (0.90–1.05)
	SA (°)	0.65	0.97 (0.85–1.10)		SA (°)	0.52	1.02 (0.96–1.09)
	LPA (°)	0.65	0.94 (0.71–1.24)		LPA (°)	0.88	0.99 (0.84–1.17)
	PTA (°)	0.04	1.12 (0.99–1.24)		PTA (°)	0.26	1.10 (0.93–1.29)
	PD (mm)	0.05	1.37 (1.00–1.88)		PD (mm)	0.07	1.15 (0.99–1.33)
	LPFA (°)	0.04	0.78 (0.61–0.99)		LPFA (°)	0.45	1.05 (0.92–1.21)
51–60 years	PW (mm)	0.04	1.21 (1.00–1.47)	Male	PW (mm)	0.62	1.05 (0.86–1.29)
	PT (mm)	0.03	0.72 (0.54–0.97)		PT (mm)	< 0.01	0.68 (0.51–0.90)
	WI	0.59	0.14 (0.01–2.18)		WI	0.65	0.11 (0.05–1.68)
	ISI	0.40	0.22 (0.04–2.43)		ISI	0.45	0.24 (0.02–1.73)
	WA (°)	0.41	0.94 (0.82–1.08)		WA (°)	0.94	1.01 (0.89–1.13)
	SA (°)	0.42	1.03 (0.96–1.10)		SA (°)	0.03	1.02 (0.84–1.17)
	LPA (°)	0.03	1.28 (1.03–1.60)		LPA (°)	0.29	0.85 (0.63–1.15)
	PTA (°)	0.04	1.26 (1.08–1.38)		PTA (°)	0.93	0.99 (0.84–1.18)
	PD (mm)	< 0.01	1.23 (1.08–1.41)		PD (mm)	0.17	1.15 (0.94–1.41)
	LPFA (°)	0.08	0.81 (0.65–1.02)		LPFA (°)	0.21	0.88 (0.72–1.08)
61–70 years	PW (mm)	0.32	1.13 (0.89–1.42)	Female	PW (mm)	0.01	1.12 (1.03–1.23)
	PT (mm)	0.52	0.90 (0.67–1.23)		PT (mm)	< 0.01	0.77 (0.68–0.87)
	WI	0.40	2.53 (0.68–4.41)		WI	0.64	0.28 (0.07–2.50)
	ISI	0.01	0.02 (0.01–0.36)		ISI	0.87	0.88 (0.20–3.94)
	WA (°)	0.35	0.94 (0.82–1.07)		WA (°)	0.29	1.02 (0.99–1.05)
	SA (°)	0.35	0.96 (0.88–1.05)		SA (°)	0.43	1.01 (0.98–1.04)
	LPA (°)	0.19	0.89 (0.75–1.06)		LPA (°)	0.54	0.98 (0.92–1.04)
	PTA (°)	0.61	1.06 (0.85–1.31)		PTA (°)	0.06	1.07 (1.00–1.15)

(Continues)

TABLE 5 | (Continued)

Variable		*p* value	OR (95% CI)	Variable		*p* value	OR (95% CI)
	PD (mm)	< 0.01	1.55 (1.29–1.86)		PD (mm)	< 0.01	1.41 (1.31–1.52)
	LPFA (°)	0.90	0.99 (0.79–1.23)		LPFA (°)	0.24	1.04 (0.98–1.10)
71–80 years	PW (mm)	0.97	1.01 (0.67–1.51)	Manual worker	PW (mm)	0.63	0.97 (0.85–1.10)
	PT (mm)	0.06	0.64 (0.40–1.03)		PT (mm)	0.92	1.01 (0.84–1.21)
	WI	0.19	2.89 (0. 92–3.27)		WI	0.21	0.49 (0.07–2.67)
	ISI	0.02	0.44 (0.02–2.57)		ISI	0.16	0.15 (0.01–2.07)
	WA (°)	0.80	1.03 (0.83–1.27)		WA (°)	0.43	1.02 (0.97–1.08)
	SA (°)	0.10	1.13 (0.98–1.30)		SA (°)	0.25	1.03 (0.98–1.08)
	LPA (°)	0.29	0.85 (0.64–1.14)		LPA (°)	0.48	0.97 (0.90–1.05)
	PTA (°)	0.97	0.99 (0.69–1.44)		PTA (°)	0.10	0.92 (0.82–1.02)
	PD (mm)	0.16	0.82 (0.63–1.08)		PD (mm)	< 0.01	1.24 (1.11–1.38)
	LPFA (°)	0.47	0.09 (0.67–1.21)		LPFA (°)	< 0.01	0.89 (0.82–0.96)
BMI (normal)	PW (mm)	0.37	0.91 (0.74–1.12)	Nonmanual worker	PW (mm)	0.42	1.07 (0.91–1.27)
	PT (mm)	0.52	1.10 (0.83–1.45)		PT (mm)	0.26	0.89 (0.72–1.09)
	WI	0.57	2.29 (0. 62–3.14)		WI	0.87	0.25 (0.11–2.67)
	ISI	0.62	0.42 (0.06–3.71)		ISI	0.99	1.02 (0.06–3.41)
	WA (°)	0.96	1.00 (0.95–1.06)		WA (°)	0.55	1.03 (0.92–1.16)
	SA (°)	0.28	0.96 (0.90–1.03)		SA (°)	0.31	0.97 (0.92–1.03)
	LPA (°)	0.62	1.03 (0.90–1.19)		LPA (°)	0.43	1.07 (0.90–1.28)
	PTA (°)	0.09	0.88 (0.76–1.02)		PTA (°)	0.35	0.90 (0.71–1.13)
	PD (mm)	< 0.01	1.33 (1.12–1.58)		PD (mm)	< 0.01	1.24 (1.11–1.38)
	LPFA (°)	0.04	0.88 (0.78–1.00)		LPFA (°)	0.32	0.90 (0.74–1.10)

Abbreviations: ISI = Insall–Salvati index; LPA = lateral patella angle; LPFA = lateral patellofemoral angle; PD = patella displacement; PT = patella thickness; PTA = patella tilt angle; PW = patella width; SA = sulcus angle; WA = Wiberg angle; WI = Wiberg index.

and displacement, smaller patella thickness, and reduced lateral patellofemoral angle—are identified as high-risk factors for the progression of PFOA.

It is noteworthy that the severity of radiological changes in the PFJ does not always correlate perfectly with the clinical symptoms of patients. Therefore, we further investigated the correlation between radiological PFJ parameters and KPS, commonly used to evaluate the function of PFJ, especially the subjective experience of patients [15]. Our findings revealed a positive correlation between patella thickness and KPS, whereas a negative correlation was observed between patella displacement and KPSs. Previous research has indicated that ideal patella thickness may facilitate proper patellar contact within the femoral trochlea, potentially mitigating or preventing anterior knee pain [29, 41]. Moreover, the ideal patella thickness, as identified in this study, corresponds to type I or II patella morphology. Similarly, larger patella displacement can elevate contact stress, leading to varying degrees of anterior knee pain [26, 29, 42]. Thus, patella thickness and patella displacement may be the most significant predictors for the clinical symptoms of PFOA patients.

4.3 | Discrepancies of PFJ Parameters of Radiological PFOA in Different Populations

Based on our previous findings, the significant susceptibility of PFOA existed across different populations. Thus, we further analyze the association between anatomical parameters of the PFJ in these populations and the Iwano classification. Surprisingly, we observed that patella thickness (in the 31–40 years old, 51–60 years old, overweight, male, and female groups) and the lateral patellofemoral angle (in the 41–50 years old, normal weight, manual worker groups) were negatively related to the Iwano classification. Conversely, patella displacement (in the 51–60 years old, 61–70 years old, overweight, normal weight, female, manual worker groups), patella width (in the 51–60 years old, female group), and sulcus angle (in the male group) were positively correlated with the Iwano classification. In essence, these results suggest the roles of patella thickness and patella displacement in the progression of PFOA were consistent across various populations, On the other hand, patella width and sulcus angle, as the more specific parameters, have been demonstrated to vary between females and males. It is speculated that the differences reflect distinct anatomical parameters of PFJ between the sexes. Furthermore, the identification of these parameters, predominantly in overweight patients and manual workers, suggests a concentration of pressure on the PFJ within these populations. Taken together, our findings suggest that patella thickness, width, sulcus angle, patella displacement, and lateral patellofemoral angle may serve as predictors for the progression of PFOA within the corresponding populations mentioned above.

4.4 | Strengths and Limitations

In conclusion, this study provided insights into both the population distribution characteristics of PFOA patients and relevant risk factors for PFOA in terms of radiological and clinical symptoms. However, certain limitations should be acknowledged. Firstly, as a single-center retrospective cohort study, the sample size was relatively limited. We should conduct multicenter prospective studies with larger sample sizes to enhance the robustness of the findings in the future. Additionally, discrepancies in patient positioning during radiography could introduce bias in the measurement of radiological parameters of the PFJ. Standardizing patient posture during radiography in future studies would help mitigate this potential source of bias [43, 44]. Moreover, some cases included in this study involved PFOA patients with concurrent tibiofemoral joint degeneration, which could compromise the accuracy of PFOA assessment, despite efforts to include only patients with anterior knee pain and exclude those with severe varus and valgus deformities or pain in the medial and lateral compartments. Addressing these limitations in future research endeavors would further enhance the understanding of PFOA and its associated risk factors.

5 | Conclusion

In summary, this paper systematically examined the population distribution characteristics of PFOA patients in a single-center setting, revealing a trend for older individuals, females, overweight or obese individuals, and manual workers to develop PFOA. Furthermore, the study explored the association between anatomical parameters of the PFJ and radiological PFOA, and found that type III patella, greater patella width, sulcus angle, patella tilt angle, and patella displacement, as well as smaller patella thickness, IS index, and lateral patellofemoral angle were closely associated with more severe radiological PFOA. Moreover, we analyzed the correlation between radiological PFJ parameters and KPS, proving patella thickness to be a positive predictor and patella displacement to be a negative predictor for the clinical symptoms of PFOA patients. Importantly, the study further analyzed the relationship between various anatomical parameters of the PFJ and the severity of radiological PFOA across different populations, confirming the significance of patella thickness, patella displacement, and lateral patellofemoral angle in predicting the progression of PFOA.

Author Contributions

Jianlin Zhao participated in the design of this study, performed statistical analysis, and drafted the manuscript. Jing Han, Xiaoyu Wan, Wenqian Xu, and Zengrui Zhang collected the clinical data and conducted the study. Yingxing Xu and Jinsong Liu directed the study conception, design, and manuscript drafting. All authors approved the final manuscript.

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Ethics Statement

This study was approved by Ethics Committee of the First Affiliated Hospital of Kunming Medical University (Approval No. L2023190).

Conflicts of Interest

The authors declare no conflicts of interest.

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