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The association between patella alignment and morphology and knee osteoarthritis

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Abstract

Objective This study aims to quantitatively assess the relationship between the patella alignment and morphology and knee osteoarthritis (KOA), as well as the kinematics and kinetics of the knee, using gait analysis.

Methods Eighty age-matched patients with KOA and control subjects were evaluated. Incident radiographic osteoarthritis (iROA) was identified using a Kellgren-Lawrence (KL) grade of ≥ 2. The modified Insall-Salvati ratio (Mod-ISR), patellar tilt angle (PTA), and patella index (PI) were utilized to evaluate the sagittal and transverse alignment of the patella and its morphology, respectively. Regression analyses were conducted to explore associations between patellar measurements and KOA, iROA, kinematics, and kinetics.

Results Significant differences were observed between the control and KOA groups in terms of KL grade, patella alta, abduction angle, and reaction force to the ground ($P < 0.05$, respectively). Following adjustment for covariates, a significant positive association was found between patella alta and KOA (OR = 0.307, 95%CI: 0.103 to 0.918, $P = 0.035$). Additionally, a significant negative association was observed between PTA and abduction angle (B = -0.376, 95%CI: -0.751 to -0.002; $P = 0.049$). The PI exhibited a statistically significant association with log-transformed vertical ground reaction force (B = 0.002, 95%CI: 0.001 to 0.003, $P = 0.002$). Furthermore, adjustment for covariates did not reveal any significant correlations with other indicators ($P > 0.05$, respectively).

Conclusion This study provides further evidence that proper alignment and morphology of the patella might be associated with maintaining normal biomechanical function. In addition, intervention measures targeting relevant patellar parameters, such as Mod-ISR, PTA, and PI, may positively impact KOA treatment outcomes.

Keywords Patella, Alignment, Morphology, Knee, Kinematics, Kinetics

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Introduction

Osteoarthritis (OA) is the most prevalent chronic joint disease, significantly impacting multiple joints throughout the human body [1]. It was reported that OA was the leading cause of global disability, imposing substantial personal, social, and economic burdens [2]. Notably, knee osteoarthritis (KOA) comprises 83% of the total OA burden [3]. An epidemiological study reported a global prevalence of 22.9% for KOA among individuals aged 40 and older, with an estimated 40% increase projected by 2025, thus constituting a significant public health concern [4, 5]. Therefore, the search for effective prevention and treatment modalities for KOA remains paramount in clinical practice.

The knee is one of the most complex joints, bearing the highest functional demands and experiencing the greatest stress among all joints in the human body [6, 7]. The knee joint, composed of the femur, tibia, fibula, and patella, is surrounded by soft tissues such as ligaments, tendons, and muscles. It bears the entire weight of the body during all physical activities and is stabilized by the tensile forces exerted by tendons and ligaments. Essentially, the harmonious interaction between bones and soft tissues facilitates joint function.

While the detailed etiology and pathophysiology of KOA remain unclear, biochemical and biomechanical factors are recognized as key mechanisms in its onset and progression [8, 9]. Biomechanically, abnormal stress distribution in the knee joint and lower-extremity malalignment are associated with KOA development [10]. Many studies [11–13] have confirmed the significant role of the patella in knee joint biomechanics. For example, abnormal patellar maltracking could alter stress distribution, leading to joint pain and pathological changes, thereby contributing to KOA [12]. It is widely believed that the alignment and morphology of the patella are closely linked to the kinematics and kinetic of the knee joint. However, this association lacks reliable and explicit data to support it [14].

Recent advancements have rendered gait analysis a non-invasive, convenient, reproducible, and standardized method for evaluating knee function [15]. Therefore, by utilizing of 3D gait analysis, we aim to provide quantitative evidence and further validate the associations between the alignment and morphology of the patella and various factors, including knee kinematics, knee kinetics, symptomatic KOA, and iROA.

Materials and methods

Study population

All patients diagnosed with KOA who underwent a weight-bearing full-leg anteroposterior and skyline view X-ray image, Magnetic Resonance Imaging (MRI), and knee gait test from January 2021 to December 2022 were included in this study. This study received approval from the Ethics Committee of our center, and written informed consent was obtained from all participants at our institution before their inclusion. Inclusion criteria comprised clinical diagnosis according to the European League Against Rheumatism guidelines [16] and complete information record. Exclusion criteria were defined as follows: participants with contraindications for MRI scans, a history of knee surgery or lower limb injuries, presence of tumors or tuberculosis, lower limb deformities, or diseases impacting gait patterns. Healthy subjects were defined as individuals who had no knee pain in the past year and had not been diagnosed with symptomatic KOA. And the healthy individuals were matched in a 1-to-1 ratio as the control group, ensuring similar ages and body mass index (BMI) to the population with KOA. The study comprised two groups of participants.

MRI technique

All participants were positioned with the knee in mild flexion of approximately 15 degrees and stabilized using a cotton cushion during scanning. Knee MRI images were obtained using 3T superconducting magnets (Siemens Magnetom Verio, Erlangen, Germany) and standard 8-channel knee coils with patients positioned supine. In our study, T2-weighted three-dimensional dual-echo steady-state_we_iso sagittal images were acquired with a section thickness of 0.5 mm and an in-plane resolution of 256×256 pixels. The modified Insall-Salvati ratio (ModISR), a reliable index for evaluating the sagittal alignment of the patella [17], was defined as the ratio of the distance from the lower edge of the patellar joint surface to the patellar tendon insertion point to the length of the patellar joint surface (Fig. 1A). Detailed parameters are provided in the Supplementary Material.

Radiology assessment

All knee radiography (AXIOM Aristos VX, Siemens, Germany) was conducted from two distinct perspectives: a weight-bearing full-leg anteroposterior view and a skyline view. The severity of patellofemoral OA was assessed using the Kellgren-Lawrence (KL) radiographic grading system following the criteria established by Kellgren and Lawrence [18]. Incident radiographic osteoarthritis (iROA) was defined as KL grade ≥ 2 [19] to clarify. In the skyline view, transverse alignment and bony morphology were measured using established methods from prior studies [20, 21]. The patellar tilt angle (PTA) [20], a measure describing the transverse alignment of the patella, was defined as the angle between the equatorial line of the patella and the line connecting the anterior limits of the femoral condyles (Fig. 1B). The patella index (PI) [21], an evaluation measure of patellar morphology and a guide for understanding and diagnosing

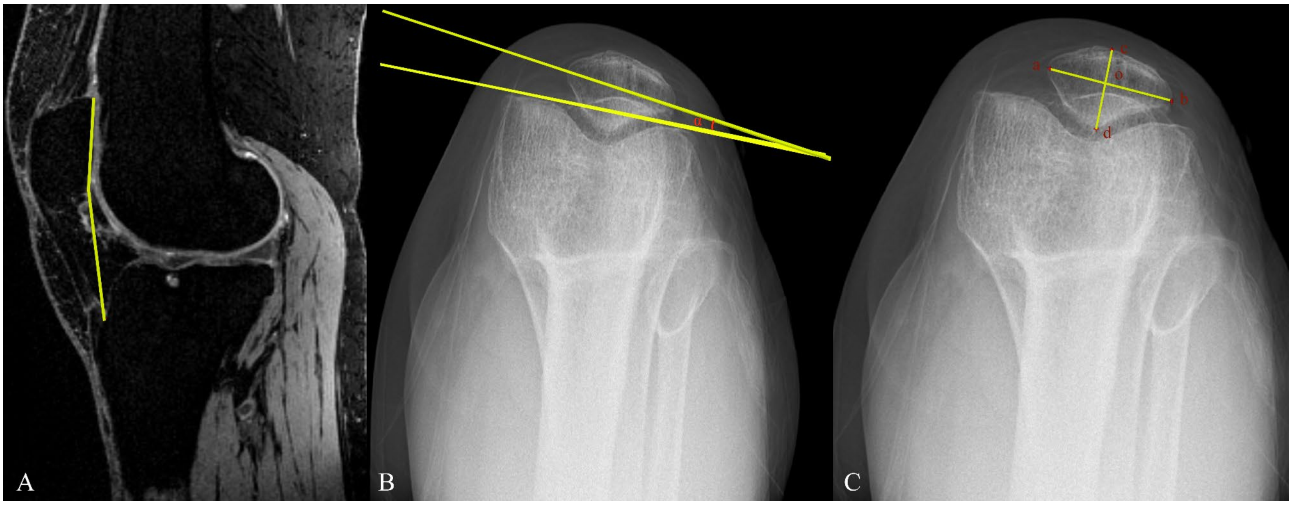

Fig. 1 The alignment and morphology of the patella of measured radiograph. (**A**) Modified Insall Salvati ratio. It is the ratio of ratio of the distance between the distal pole of the patellar articular surface and the tibial tuberosity to the articular surface length of the patella. (**B**) Patellar tilt angle. It was defined as the angle subtended by the equatorial line of the patella and the line connecting the anterior limits of the femoral condyles. (**C**) Patella index. It was drawn by the two perpendicular lines ("ab"and "cd"), "ab" through the maximum width and "cd" through the maximum height of the patella, with their intersection point labelled "o." Patella index was calculated as the ratio of (ab) to (bo-ao)

patella instability, was calculated as follows (Fig. 1C): two perpendicular lines were drawn through the maximum width and height of the patella, intersecting at point "o." Points where "o" intersected the medial or lateral cortex were labeled "a" or "b." PI was calculated as the ratio of (ao+bo) to (bo-ao).

Evaluation of three-dimension gait

The instrument was calibrated before each test. The gait test procedure, as detailed in our previous study [22], was followed, providing a comprehensive explanation. The gait tests were conducted in the gait laboratory. Participants were instructed to walk along an 8-meter walkway at a self-selected speed without a cane, completing five to seven steady trials. Data for analysis consisted of the average of five steps per trial, excluding the initial and final two steps. Motion data from retro-reflective markers were captured using the VICON motion capture and analysis system (VICON, Oxford, UK), equipped with 16 cameras operating at a sampling rate of 100 Hz. Reflective markers were attached to the participants' lower limbs at the anterior superior iliac spine, posterior superior iliac spines, calcaneus, and additional bony markers in accordance with a pre-existing model [23]. These markers were used as anatomical references to define anatomical reference frame and centers of rotations of the joints. Five rigid plates were secured to the head, lower leg, thigh, and pelvis using an elastic bandage (Fabrifoam, USA) to monitor the movement of these segments during the study. The Calibrated Anatomical System (CAST) technique was employed to analyze the motion paths and anatomical relevance of the rigid segments during the walking test.

Consistent with previous studies [23, 24], gait kinematic and kinetic data were imported and processed in Visual 3D software (Version 6.01.16, C-motion, USA) utilizing a custom script. Both kinematic and analog data were filtered using a Butterworth 4th-order digital filter with cut-off frequencies set at 6 Hz for kinematics and 25 Hz for analog data. Biomechanical outcomes were extracted and time-normalized to 101 data points (0-100%) throughout the stance phase, defined as heel strike to toe-off [25]. Negative values indicate a specific direction. Knee angles in the sagittal, frontal, and transverse planes were recorded. The external knee moment and vertical ground reaction force (vGRF) were normalized to each participant's body mass.

Statistical analysis

Shapiro-Wilk tests were used to assess the normality of continuous variables. Normally distributed data were presented as mean±standard deviation, and non-normally distributed data were summarized using median and interquartile range. Categorical data were expressed as counts and percentages. Continuous variables were assessed using t-tests and Mann-Whitney U tests, as appropriate. Categorical variables were compared using the chi-squared test or Fisher exact test. The vGRF was log-transformed due to skewness. Odds ratios (OR) were calculated for both univariate and multivariate logistic regression analyses, with continuous variables discretized based on their median values. Statistical analysis was conducted using SPSS software (version 16.0; IBM, Armonk, NY), with significance set at $P=0.05$. Confidence intervals were reported at the 95% confidence level (CI).

Results

Demographic and clinical characteristics

Table 1 presents demographic and clinical characteristics of the participants. A total of 80 subjects participated in the study, consisting of 32.5% males and 77.5% females. There were 46 left knees and 34 right knees, with a median age of 55.7 years (range: 40 to 70 years). The mean BMI was 23.04 kg/m², ranging from 16.16 to 29.43 kg/m². There were no significant differences in demographic factors (age, sex, BMI, and affected side) between healthy participants and patients with KOA ($P>0.05$, respectively). Regarding KL grade, the whole participants were distributed as follows: 10 in grade 0, 32 in grade I, 27 in grade II, and 11 in grade III. Subjects with KOA exhibited significantly higher KL grade compared to healthy participants ($P<0.001$). All participants underwent screening for patella alta, resulting in 15 subjects and 7 control subjects diagnosed with the condition ($P=0.045$). No significant differences were observed in the transverse alignment and morphology of the patella between the groups ($P>0.05$, respectively). Additionally, the values for PTA and PI for the entire population were recorded as 2.0 (3.0) and 7.3 (5.2), respectively.

Kinematic and kinetic Outcomes

Detailed kinematic and kinetic outcomes obtained from three-dimensional gait analysis are presented in Table 1. Concerning knee joint kinematics, although the control group exhibited higher flexion, extension, and internal rotation angles compared to the patient group, these differences were not statistically significant ($P=0.148$, $P=0.107$, $P=0.138$, respectively). Similarly, there were no significant differences between the two groups in terms of adduction and external rotation angles ($P>0.05$, respectively). However, when compared to individuals with KOA, those in the control group exhibited a significantly higher abduction angle ($P=0.019$, Fig. 2A). In terms of knee joint kinetics, no significant differences were found between the two groups in knee flexion moment, extension moment, adduction moment, internal rotation moment, and external rotation moment ($P=0.159$, $P=0.494$, $P=0.490$, $P=0.245$, $P=0.336$, respectively). Conversely, the vGRF in control group was significantly higher when compared with individuals in patient group ($P=0.006$, Fig. 2B).

Regression analysis

Table 2 illustrates the associations of patella alta, PTA, and PI with KOA. In unadjusted analyses, patella alta was significantly associated with an increased risk of KOA

Table 1 Demographic and clinical characteristics

	Total (*n*=80)	KOA (*n*=40)	Control (*n*=40)	*P* value
Age (years)	55.70 ± 8.27	55.5 ± 8.9	55.9 ± 7.7	0.830
BMI (kg/m^2)	23.04 ± 2.82	23.3 ± 2.7	22.8 ± 2.9	0.435
Male, n (%)	26 (32.5)	10 (25.0)	16 (40.0)	0.152
Left, n (%)	46 (57.5)	23 (57.5)	23 (57.5)	1.000
KOA#, n				< 0.001*
Gr 0 / 1 / 2 / 3 or 4	10 / 32 / 27 /11 / 0	0 /10 / 19 / 11 / 0	10 / 22 / 8 / 0 / 0	
Assessment of patella				
Patella alta, n (%)	22 (27.5)	15 (37.5)	7 (17.5)	0.045*
Patellar tilt angle (degrees)	2.0 (3.0)	2.9 (3.4)	2.0 (2.7)	0.371
Patella index	7.3 (5.2)	7.3 (5.7)	7.2 (4.6)	0.751
Kinematic and kinetic evaluation				
Flexion angle (degrees)	67.67 ± 5.02	66.85 ± 4.93	68.48 ± 5.0	0.148
Extension angle (degrees)	2.68 ± 3.97	1.97 ± 3.99	3.40 ± 3.87	0.107
Adduction angle (degrees)	-3.48 ± 4.02	-4.19 ± 4.02	-2.76 ± 3.94	0.114
Abduction angle (degrees)	8.22 ± 5.29	6.85 ± 4.62	9.60 ± 5.62	0.019*
Internal rotation angle (degrees)	2.51 ± 5.94	1.52 ± 6.69	3.50 ± 4.96	0.138
External rotation angle (degrees)	2.63 ± 5.92	-13.08 ± 6.23	-12.52 ± 5.17	0.663
Flexion moment (N·m/kg)	0.56 ± 0.21	0.53 ± 0.21	0.60 ± 0.21	0.159
Extension moment (N·m/kg)	-0.34 ± 0.09	-0.35 ± 0.09	-0.33 ± 0.09	0.494
Adduction moment (N·m/kg)	0.42 ± 0.13	0.43 ± 0.13	0.41 ± 0.13	0.490
Internal rotation moment (N·m/kg)	0.15 ± 0.05	0.16 ± 0.05	0.15 ± 0.05	0.245
External rotation moment (N·m/kg)	-0.11 ± 0.03	-0.11 ± 0.03	-0.10 ± 0.03	0.336
vGRF (body weight)	1.15 (0.13)	1.11 (0.17)	1.17 (0.09)	0.006*

KOA, knee osteoarthritis; BMI, body mass index; KL grade, Kellgren-Lawrence grade; MRI, magnetic resonance imaging; vGRF, vertical ground reaction force. #Values were evaluated using the Kellgren-Lawrence scale of the patellofemoral joint. *Indicates *P* value < 0.05

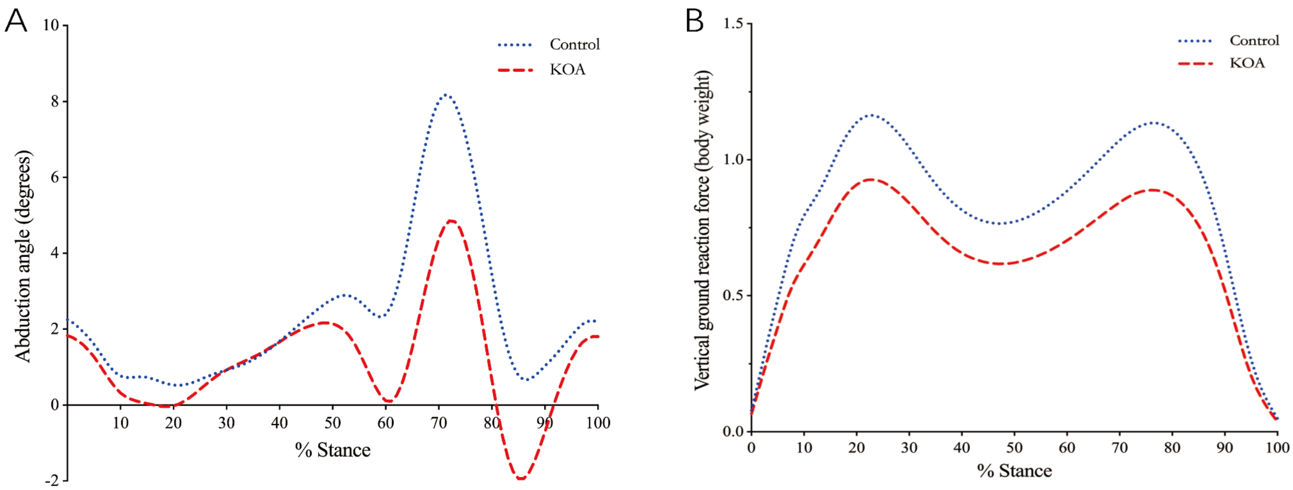

Fig. 2 The abduction angle and vertical ground reaction force during walking in KOA and control subjects. (A) The abduction angle. (B) Vertical ground reaction force. KOA, knee osteoarthritis.

Table 2 Logistic regression analysis between KOA with patella alta, patellar tilt angle, and patella index

	OR (95% CI)	*P* value	OR (95% CI)*	*P* value*
Patella alta	0.354 (0.125–0.997)	**0.049**	0.307 (0.103–0.918)	**0.035**
Patellar tilt angle	1.099 (0.945–1.278)	0.219	1.144 (0.947–1.381)	0.163
Patella index	0.986 (0.962–1.010)	0.251	0.986 (0.965–1.008)	0.221

KOA, knee osteoarthritis; OR, odd ratio; CI, Confidence interval. *Adjustment for age, body mass index, and gender. Boldface indicates *P* value < 0.05

Table 3 Logistic regression analysis between iROA with patella alta, patellar tilt angle, and patella index

	OR (95% CI)	*P* value	OR (95% CI)*	*P* value*
Patella alta	0.524 (0.194–1.420)	0.204	0.454 (0.157–1.313)	0.145
Patellar tilt angle	0.991 (0.865–1.154)	0.999	0.965 (0.828–1.125)	0.647
Patella index	1.004 (0.993–1.014)	0.466	1.003 (0.992–1.015)	0.556

iROA, incident radiographic osteoarthritis; OR, odd ratio; CI, Confidence interval. *Adjustment for age, body mass index, and gender. Boldface indicates *P* value < 0.05

Table 4 Linear regression analysis between the abduction angle with patella alta, patellar tilt angle, and patella index

	B (95% CI)	*P*	B (95% CI)*	*P**
Patella alta	-1.957 (-4.577 to 0.662)	0.141	-1.628 (-4.201 to 0.946)	0.212
Patellar tilt angle	-0.305 (-0.688 to 0.079)	0.118	-0.376 (-0.751 to -0.002)	**0.049**
Patella index	0.004 (-0.016 to 0.024)	0.703	0.001 (-0.019 to 0.021)	0.913

CI, Confidence interval. *Adjustment for age, body mass index, and gender. Boldface indicates *P* value < 0.05

(OR = 0.354, 95% CI: 0.125 to 0.997, P = 0.049). This association remained consistent after adjusting for age, BMI, and gender (OR = 0.307, 95% CI: 0.103 to 0.918, P = 0.035). Patella alta emerged as a significant predictor of KOA. Unexpectedly, neither PTA nor PI showed significant associations with KOA (P > 0.05 for both). These relationships remained unchanged even after adjusting for other variables (P > 0.05, respectively). Furthermore, regression analysis showed no significant relationship between iROA and patella alta, PTA, or PI in this study (P > 0.05 for all, Table 3). These relationships remained unchanged even after adjustment of variables (P > 0.05, respectively, Table 3).

Concerning kinematics, in adjusted analyses, no significant relationships were found between abduction angle and patella alta or PI (P > 0.05 for both). However, after adjusting for age, BMI, and gender, PTA exhibited a significant negative association with abduction angle (B = -0.376, 95% CI: -0.751 to -0.002; P = 0.049, Table 4).

Regarding kinetics, in univariable analysis, only PI exhibited a statistically significant association with log-vGRF (B = 0.002, 95%CI: 0.001 to 0.003, P = 0.002, Table 5). This association remained unchanged even after adjusting for other variables (B = 0.001, 95%CI: 0.001 to 0.003, P = 0.001).

Discussion

As mentioned above, the patella plays an important role in the knee joint, abnormalities in its position and morphology may be an underlying cause of KOA [26].

Table 5 Linear regression analysis between the log-transformed vGRF with patella alta, patellar tilt angle, and patella index

	B (95% CI)	*P*	B (95% CI)	*P**
Patella alta	-0.030 (-0.170 to 0.109)	0.666	-0.038 (-0.174 to 0.097)	0.577
Patellar tilt angle	-0.002 (-0.022 to 0.019)	0.855	0.000 (-0.020 to 0.020)	0.972
Patella index	0.002 (0.001 to 0.003)	**0.002**	0.001 (0.001 to 0.003)	**0.001**

vGRF, vertical ground reaction force; CI, Confidence interval. *Adjustment for age, body mass index, and gender. Boldface indicates P value < 0.05

However, understanding the precise impact of patellar alignment and morphology on the pathogenesis of KOA requires rigorous investigation. It is widely acknowledged that relying solely on imaging evaluation may not provide a comprehensive understanding of KOA development [27]. Therefore, we utilized three-dimensional gait analysis as a valuable assessment tool to quantify knee movement, in order to investigate the relationship between patella (in both alignment and morphology) and knee kinematics or kinetics. In this study, both healthy individuals and KOA patients participated as experimental subjects. Some notable findings emerged from the regression analysis. Specifically, a high patella was identified as a risk factor for KOA, even after adjusting for other factors. Moreover, a negative correlation was observed between PTA and the knee abduction angle. Additionally, PI showed a positive correlation with log-vGRF.

The alignment of the patella primarily involves its sagittal and transverse positions, with the sagittal alignment often categorized as high or low [28]. Patella alta, indicative of a high position, has been assessed in sagittal MRI sequences through various methods, with the Insall-Salvati ratio (ISR) being the most common [29]. Of note, this measurement can be influenced by patellar morphology [30]. The Mod-ISR is independent of weight bearing or knee flexion degree and more reproducible than the ISR [31]. Therefore, Mod-ISR was utilized to assess the sagittal patella position in the study.

Patella alta is a kind of abnormal patellar position which can result in patellar maltracking, leading to knee cartilage damage and osteoarthritis [13, 32]. Pfitzner et al. [31] observed that people with patella alta had less osseous stability than people with normal patellar position. Patella alta is often situated against a shallower femoral sulcus, increasing the risk of patellar dislocations and accelerated cartilage loss [33]. Additionally, the elevated patellar position usually reduces the contact area in the knee joint, leading to higher joint stresses, dysfunction, and pain, which may predispose individuals to KOA [34]. Also worthy of note is, a relatively longer patellar tendon would reduce the mechanical advantage afforded by the patella, this would increase knee compression and the risk of excessive cartilage loss [33]. While according to the formula for measuring patella alta, a longer patellar tendon corresponds to patella alta. Intriguingly, there was also evidence that patella alta was associated with fat pad edema, suggesting that high patella may contribute to osteoarthritis through inflammatory responses [35]. Overall, patella alta consistently emerges as a risk factor for knee osteoarthritis, with individuals having a high patella being 2.2 times more likely to develop knee osteoarthritis than those with a normal patella, consistent with previous studies [36, 37]. Hence, clinicians should consider patella alta when evaluating clinical complaints and selecting treatment options, with combined surgical interventions possibly warranted.

We also assessed the PTA to examine the alignment of the patellar cross-section, which reflects the inclination of the patella and indicates the tightness or looseness of its lateral stabilizing mechanism. Evidence suggested that patellar tilt was consistently linked to full-thickness cartilage damage and knee pain, with individuals having a higher PTA, indicating more lateral tilt and being more likely to exhibit features of KOA [38, 39]. One reason may be that patellar tilt could reduce the contact area of the joint and increase contact stress on the joint surface, potentially leading to biomechanical abnormalities and knee pain [40]. Lankhorst NE et al. systematically summarized that patellofemoral pain is associated with a larger PTA [41]. The knee joint abduction angle reflects the range of abduction and adduction activities. Specifically, a general reduction in its magnitude is characteristic of individuals with KOA [42]. Our research findings revealed a significant negative correlation between the PTA and the abduction angle after adjusting for relevant parameters. Based on the findings presented, it is hypothesized that an abnormal elevation in PTA could potentially impact KOA by diminishing the strength of knee joint abduction or resulting in biomechanical abnormalities. There was also evidence that a retraining method involving a wide step could increase the knee joint abduction angle in obese population, thus reducing joint load [43]. Considering the findings of this study, it may be beneficial in clinical treatment to attempt reducing the PTA by adjusting the abduction angle, thereby mitigating stress load and slowing down the progression of KOA.

PI is a radiographic measure used to evaluate patellar morphology, calculated based on the dimensions of the medial and lateral facets of the patella. Reductions in the size of the medial facet are frequently associated with joint instability, a significant risk factor for KOA [21, 44]. The patella transferred muscle force from the quadriceps muscles to the tibia through the quadriceps tendon and patellar tendon. Moreover, the vastus lateralis and vastus medialis attach to the lateral and medial borders of the patella, respectively [45]. Reductions in the size of the medial facet result in increased surface contact stress, which contributes to the development of KOA. Of note, gait serves as a crucial indicator of clinical symptoms and disease progression in KOA patients. The vGRF is a biomechanical parameter that assesses the force exerted from the ground to the foot during the stance phase, reflecting the load on the knee joint during movement [46]. In individuals at risk of OA, inadequate loading of the knee joint is linked to negative outcomes in knee joint health, with vGRF levels in KOA patients lower than those in the general population [47]. Research indicated that abnormally reduced medial patellar facet size could result in aberrant physiological loading in the knee joint, contributing to cartilage degradation and knee pain [48], ultimately leading to decreased vGRF on the affected side. The study findings revealed a significant positive correlation between PI and log-GRF. Even after adjusting for other factors, this relationship remained largely consistent, suggesting that individuals with higher PI values tend to demonstrate increased negative work at the knee. Therefore, interventions, such as exercise training and non-steroidal anti-inflammatory drugs, may be employed to modify stress distribution around the patella, enhance GRF and optimize patellar morphology [49, 50].

KOA has traditionally been associated with iROA. However, recent investigations suggested that iROA may not consistently correlate with KOA severity. In other words, individuals could experience knee pain despite lacking radiographic evidence, and vice versa [51]. Our regression analysis revealed patella alta and PTA as protective factors for iROA, while PI emerged as a risk factor, although statistical significance was not attained. Notably, the influence of these factors on iROA is diametrically opposed to their effect on KOA. Hence, it is evident that imaging should not serve as a standalone diagnostic tool for KOA alone; instead, it should complement other diagnostic criteria such as symptoms and physical signs. Future research may entail nested case-control studies to explore the temporal relationship and magnitude of specific factors with the changing risk profile of iROA. These emerging data could provide valuable insights for designing subsequent studies in this domain.

The findings of this study highlighted the significance of assessing patellar alignment and morphology in understanding human gait kinematics and kinetics. The identification of factors such as patella alta, PTA, and PI in KOA progression may aid in early prediction and intervention strategies. Nonetheless, several limitations warrant acknowledgment. Firstly, MRI images were acquired with patients in a supine position rather than weight-bearing, potentially limiting the ability to capture dynamic changes in patellar position. Consequently, our findings may conservatively estimate measures influenced by weight-bearing, such as PTA. Secondly, this study is retrospective and non-randomized, with a limited sample and a specific population cohort, underscoring the need for larger studies to draw more precise conclusions. Thirdly, gender, BMI, repetitive activities and physical labor are common risk factors for KOA. However, we did not investigate the participants' daily activities, which could potentially impact the conclusions. Nonetheless, the gender and BMI profiles are well-balanced and comparable between both groups. So, our conclusions possess a certain degree of reliability. Furthermore, we did not conduct a longer follow-up to use joint replacement time as an indicator of study outcomes. Additionally, the study's cross-sectional design restricted our ability to establish a direct relationship between patellar parameters and KOA. Hence, further longitudinal research is warranted to assess the predictive value of patellar alignment and morphology measurements from standard MRI scans in KOA development.

Conclusion

The study results suggest that there is an association between patella alta and KOA, and an abnormally increased PTA may contribute to KOA development. Furthermore, individuals with higher PI demonstrate increased negative work at the knee. Therefore, proper alignment and morphology of the patella are crucial for preserving normal function of knee. Specifically, interventions targeting the adjustment of relevant patellar parameters, such as manual therapy, yoga, tai chi, and surgery, could potentially have a positive impact on KOA treatment. Additionally, further longitudinal studied with larger sample size are essential to better evaluate the predictive value of patellar alignment in KOA development and enhance the credibility of the results.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-024-05001-6.

Supplementary Material 1

Acknowledgements

Not applicable.

Author contributions

WYY and WZM wrote the manuscript. LJH, ZM, PFW and LZY collected and analyzed the data. WZM contributed to the illustration. CLY, LZY, and ZHS critically revised and interpreted the manuscript. ZHS contributed to the supervision of the manuscript. All the authors proofread and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the Ethics Committee of the Shuguang Hospital Affiliated to Shanghai University of Traditional Chinese Medicine.

Consent for publication
Not applicable.

Competing interests
The authors declare that the research was conducted in the absence of any financial or personal relationships that could be construed as a potential conflict of interest.

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References

1. Leyland KM, Gates LS, Sanchez-Santos MT, Nevitt MC, Felson D, Jones G, Jordan JM, Judge A, Prieto-Alhambra D, Yoshimura N, et al. Knee osteoarthritis and time-to all-cause mortality in six community-based cohorts: an international meta-analysis of individual participant-level data. Aging Clin Exp Res. 2021;33(3):529–45.
2. Yahaya I, Wright T, Babatunde OO, Corp N, Helliwell T, Dikomitis L, Mallen CD. Prevalence of osteoarthritis in lower middle- and low-income countries: a systematic review and meta-analysis. Rheumatol Int. 2021;41(7):1221–31.
3. Vos T, Flaxman AD, Naghavi M, Lozano R, Michaud C, Ezzati M, Shibuya K, Salomon JA, Abdalla S, Aboyans V, et al. Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the global burden of Disease Study 2010. Lancet. 2012;380(9859):2163–96.
4. Cui A, Li H, Wang D, Zhong J, Chen Y, Lu H. Global, regional prevalence, incidence and risk factors of knee osteoarthritis in population-based studies. EClinicalMedicine 2020, 29–30:100587.
5. Freijo V, Navarro C, Molina B, Villalba J. Low correlation between Gait and Quality of Life in Advanced knee osteoarthritis. J Funct Morphol Kinesiol 2023, 8(2).
6. Yan M, Liang T, Zhao H, Bi Y, Wang T, Yu T, Zhang Y. Model properties and clinical application in the Finite element analysis of knee Joint: a review. Orthop Surg. 2024;16(2):289–302.
7. Logerstedt DS, Ebert JR, MacLeod TD, Heiderscheit BC, Gabbett TJ, Eckenrode BJ. Effects of and response to mechanical loading on the knee. Sports Med. 2022;52(2):201–35.
8. Vina ER, Kwoh CK. Epidemiology of osteoarthritis: literature update. Curr Opin Rheumatol. 2018;30(2):160–7.
9. van Tunen JA, Dell'Isola A, Juhl C, Dekker J, Steultjens M, Lund H. Biomechanical factors associated with the development of tibiofemoral knee osteoarthritis: protocol for a systematic review and meta-analysis. BMJ Open. 2016;6(6):e011066.
10. Georgiev T, Angelov AK. Modifiable risk factors in knee osteoarthritis: treatment implications. Rheumatol Int. 2019;39(7):1145–57.
11. Sit RWS, Chan KKW, Zou D, Chan DCC, Yip BHK, Zhang DD, Chan YH, Chung VCH, Reeves KD, Wong SYS. Clinic-based patellar mobilization therapy for knee osteoarthritis: a Randomized Clinical Trial. Ann Fam Med. 2018;16(6):521–9.
12. Connolly KD, Ronsky JL, Westover LM, Küpper JC, Frayne R. Differences in patellofemoral contact mechanics associated with patellofemoral pain syndrome. J Biomech. 2009;42(16):2802–7.
13. Ward SR, Terk MR, Powers CM. Patella alta: association with patellofemoral alignment and changes in contact area during weight-bearing. J Bone Joint Surg Am. 2007;89(8):1749–55.
14. White DK, Master H. Patient-reported measures of physical function in knee osteoarthritis. Rheum Dis Clin North Am. 2016;42(2):239–52.
15. Tanpure S, Phadnis A, Nagda T, Rathod C, Kothurkar R, Chavan A. Gait variability and biomechanical distinctions in knee osteoarthritis: insights from a 3D analysis in an adult elderly cohort. J Orthop. 2024;49:172–9.
16. Zhang W, Doherty M, Peat G, Bierma-Zeinstra MA, Arden NK, Bresnihan B, Herrero-Beaumont G, Kirschner S, Leeb BF, Lohmander LS, et al. EULAR evidence-based recommendations for the diagnosis of knee osteoarthritis. Ann Rheum Dis. 2010;69(3):483–9.
17. Grelsamer RP. S Meadows 1992 The modified Insall-Salvati ratio for assessment of patellar height. Clin Orthop Relat Res 282 170–6.
18. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis. 1957;16(4):494–502.
19. Kohn MD, Sassoon AA, Fernando ND. Classifications in brief: Kellgren-Lawrence classification of Osteoarthritis. Clin Orthop Relat Res. 2016;474(8):1886–93.
20. Sasaki T, Yagi T. Subluxation of the patella: investigation by computerized tomography. Int Orthop. 1986;10(2):115–20.
21. Cross MJ, Waldrop J. The patella index as a guide to the understanding and diagnosis of patellofemoral instability. Clin Orthop Relat Res 1975(110):174–6.
22. Zhang M, Pang J, Lu J, Kang M, Chen B, Jones RK, Zhan H, Liu A. The Immediate Effect of Backward Walking on External Knee Adduction Moment in Healthy Individuals. *J Healthc Eng* 2022, 2022:4232990.
23. Jones RK, Zhang M, Laxton P, Findlow AH, Liu A. The biomechanical effects of a new design of lateral wedge insole on the knee and ankle during walking. Hum Mov Sci. 2013;32(4):596–604.
24. Riazati S, McGuirk TE, Perry ES, Sihanath WB, Patten C. Absolute reliability of Gait parameters Acquired with Markerless Motion capture in living domains. Front Hum Neurosci. 2022;16:867474.
25. Büttner C, Lisee C, Buck A, Bjornsen E, Thoma L, Spang J, Blackburn T, Pietrosimone B. Early Gait Biomechanics Linked to Daily steps following anterior Cruciate Ligament Reconstruction. J Athl Train 2024.
26. Zikria B, Rinaldi J, Guermazi A, Haj-Mirzaian A, Pishgar F, Roemer FW, Hakky M, Sereni C, Demehri S. Lateral patellar tilt and its longitudinal association with patellofemoral osteoarthritis-related structural damage: analysis of the osteoarthritis initiative data. Knee. 2020;27(6):1971–9.
27. Roemer FW, Jarraya M, Hayashi D, Crema MD, Haugen IK, Hunter DJ, Guermazi A. A perspective on the evolution of semi-quantitative MRI assessment of osteoarthritis: past, present and future. Osteoarthritis Cartilage 2024.
28. Stefanik JJ, Guermazi A, Zhu Y, Zumwalt AC, Gross KD, Clancy M, Lynch JA, Segal NA, Lewis CE, Roemer FW, et al. Quadriceps weakness, patella alta, and structural features of patellofemoral osteoarthritis. Arthritis Care Res (Hoboken). 2011;63(10):1391–7.
29. Insall J, Salvati E. Patella position in the normal knee joint. Radiology. 1971;101(1):101–4.
30. Biedert RM, Tscholl PM. Patella Alta: a Comprehensive Review of current knowledge. Am J Orthop (Belle Mead NJ). 2017;46(6):290–300.
31. Pfitzner T, Perka C, Matziolis G. [Patella height after total knee replacement: influence of the radiological setting]. Orthopade. 2009;38(7):616–21.
32. Jibri Z, Jamieson P, Rakhra KS, Sampaio ML, Dervin G. Patellar maltracking: an update on the diagnosis and treatment strategies. Insights Imaging. 2019;10(1):65.
33. Kalichman L, Zhang Y, Niu J, Goggins J, Gale D, Felson DT, Hunter D. The association between patellar alignment and patellofemoral joint osteoarthritis features–an MRI study. Rheumatology (Oxford). 2007;46(8):1303–8.
34. Ward SR, Powers CM. The influence of patella alta on patellofemoral joint stress during normal and fast walking. Clin Biomech (Bristol Avon). 2004;19(10):1040–7.
35. Widjajahakim R, Roux M, Jarraya M, Roemer FW, Neogi T, Lynch JA, Lewis CE, Torner JC, Felson DT, Guermazi A, et al. Relationship of Trochlear morphology and Patellofemoral Joint Alignment to Superolateral Hoffa Fat Pad Edema on MR images in individuals with or at risk for Osteoarthritis of the knee: the MOST study. Radiology. 2017;284(3):806–14.
36. Stefanik JJ, Zhu Y, Zumwalt AC, Gross KD, Clancy M, Lynch JA, Frey Law LA, Lewis CE, Roemer FW, Powers CM, et al. Association between patella alta and the prevalence and worsening of structural features of patellofemoral joint osteoarthritis: the multicenter osteoarthritis study. Arthritis Care Res (Hoboken). 2010;62(9):1258–65.

37. Haj-Mirzaian A, Guermazi A, Pishgar F, Pourvaziri A, Roemer FW, Sereni C, Hakky M, Zikria B, Stefanik JJ, Demehri S. Association of patella alta with worsening of patellofemoral osteoarthritis-related structural damage: data from the Osteoarthritis Initiative. Osteoarthritis Cartilage. 2019;27(2):278–85.
38. Macri EM, Felson DT, Zhang Y, Guermazi A, Roemer FW, Crossley KM, Khan KM, Stefanik JJ. Patellofemoral morphology and alignment: reference values and dose-response patterns for the relation to MRI features of patellofemoral osteoarthritis. Osteoarthritis Cartilage. 2017;25(10):1690–7.
39. van Middelkoop M, Macri EM, Eijkenboom JF, van der Heijden RA, Crossley KM, Bierma-Zeinstra SMA, de Kanter JL, Oei EH, Collins NJ. Are Patellofemoral Joint alignment and shape Associated with Structural magnetic resonance imaging abnormalities and symptoms among people with Patellofemoral Pain? Am J Sports Med. 2018;46(13):3217–26.
40. Stephen JM, Kader D, Lumpaopong P, Deehan DJ, Amis AA. Sectioning the medial patellofemoral ligament alters patellofemoral joint kinematics and contact mechanics. J Orthop Res. 2013;31(9):1423–9.
41. Lankhorst NE, Bierma-Zeinstra SM, van Middelkoop M. Factors associated with patellofemoral pain syndrome: a systematic review. Br J Sports Med. 2013;47(4):193–206.
42. Nagano Y, Naito K, Saho Y, Torii S, Ogata T, Nakazawa K, Akai M, Fukubayashi T. Association between in vivo knee kinematics during gait and the severity of knee osteoarthritis. Knee. 2012;19(5):628–32.
43. Yocum D, Weinhandl JT, Fairbrother JT, Zhang S. Wide step width reduces knee abduction moment of obese adults during stair negotiation. J Biomech. 2018;75:138–46.
44. Hashimoto Y, Nishino K, Tomohiro T, Tsumoto S, Nakamura H. The remaining parameters of patellar instability could be affected for osteoarthritic change after medial patellofemoral ligament reconstruction with or without anteromedialization of the tibial tubercle osteotomy for patellar instability: a retrospective cohort study. BMC Musculoskelet Disord. 2023;24(1):56.
45. Wheatley MGA, Rainbow MJ, Clouthier AL. Patellofemoral mechanics: a review of Pathomechanics and Research Approaches. Curr Rev Musculoskelet Med. 2020;13(3):326–37.
46. Hunt MA, Birmingham TB, Giffin JR, Jenkyn TR. Associations among knee adduction moment, frontal plane ground reaction force, and lever arm during walking in patients with knee osteoarthritis. J Biomech. 2006;39(12):2213–20.
47. Costello KE, Felson DT, Neogi T, Segal NA, Lewis CE, Gross KD, Nevitt MC, Lewis CL, Kumar D. Ground reaction force patterns in knees with and without radiographic osteoarthritis and pain: descriptive analyses of a large cohort (the Multicenter Osteoarthritis Study). Osteoarthritis Cartilage. 2021;29(8):1138–46.
48. Ruggeri M, Gill HS, Leardini A, Zaffagnini S, MacLeod A, Ortolani M, Faccia F, Grassi A, Fabbro GD, Durante S, et al. Superimposition of ground reaction force on tibial-plateau supporting diagnostics and post-operative evaluations in high-tibial osteotomy. A novel methodology. Gait Posture. 2022;94:144–52.
49. Zeng CY, Zhang ZR, Tang ZM, Hua FZ. Benefits and mechanisms of Exercise training for knee osteoarthritis. Front Physiol. 2021;12:794062.
50. Boyer KA, Angst MS, Asay J, Giori NJ, Andriacchi TP. Sensitivity of gait parameters to the effects of anti-inflammatory and opioid treatments in knee osteoarthritis patients. J Orthop Res. 2012;30(7):1118–24.
51. Bedson J, Croft PR. The discordance between clinical and radiographic knee osteoarthritis: a systematic search and summary of the literature. BMC Musculoskelet Disord. 2008;9:116.

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