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The association between patella alignment and knee pain and function: an MRI study in persons with symptomatic knee osteoarthritis[1,2]

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Summary

Objective: The aim of the study was to examine the association between patellofemoral (PF) alignment (using standard magnetic resonance imaging (MRI) images of extended knees) and knee pain and function.

Design: Subjects were recruited to participate in a natural history study of symptomatic knee osteoarthritis, called the Boston Osteoarthritis of the Knee Study (BOKS). The association of predictive variable (patellar alignment in sagittal and transverse planes) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain and function were examined using a linear regression model while adjusting for age, sex, body mass index (BMI), Center for Epidemiologic Studies Depression Scale (CES-D) score and Kellgren and Lawrence score.

Results: Increasing trochlear angle (TA) was associated with both WOMAC ($P = 0.06$) pain and WOMAC function subscale ($P = 0.04$). Increasing lateral patellar title angle (LPTA) and decreasing bisect offset (increasing lateral subluxation) appeared to be associated with increasing WOMAC pain. However, no such an association was observed for other predictors.

Conclusions: The findings of the present study suggest that increasing TA is associated with increased functional impairment. Other measures of PF malalignment were not significantly associated with either knee pain or functional impairment.

Key words: Knee, Osteoarthritis, Patellofemoral joint, Patellar alignment, Pain.

Abbreviations: OA osteoarthritis, PF patellofemoral (joint), BOKS Boston Osteoarthritis of the Knee Study, PLR patellar length ratio, SA sulcus angle, LTI lateral trochlear inclination, TA trochlear angle, LPTA lateral patellar tilt angle, BO bisect offset, K–L Kellgren and Lawrence (grading scheme).

Introduction

Osteoarthritis (OA) is the most widespread cause of pain and disability in populations after retirement age. Increases in life expectancy and aging of the populations are expected to make OA the fourth leading cause of disability in the general population by the year 2020[1].

OA frequently affects the tibiofemoral and patellofemoral (PF) joints. Despite extensive investigation[2], the relationship between structural changes in knee OA and symptoms has not been strongly associated. This may be in part because of the predominant focus upon the tibiofemoral joint. Several studies have found that the symptoms in knee OA are frequently related to alterations in the PF joint[3–5].

During knee flexion, the dorsal part of the patella (that covered by the thickest cartilage in the human body) is in contact with the underlying femoral trochlea, a cartilage covered groove in a distal femur. Patellae that are located centrally in the trochlear groove, and not malaligned are thought to be less likely to develop OA[6–8]. Translational or rotational deviation of the patella relative to any axis is termed as patellar malalignment, and this may cause an aberrant dispersion of the forces transmitted through this joint and has been proposed as a major component of patellar pain in adults[9,10].

Theoretical knowledge and anecdotal observation suggest that if the patella is tilted, lateral side down, painful stresses can develop on its lateral aspect[11]. Pain from patellar malalignment appears to be related to multiple factors with variable clinical expression, and imperfect understanding of these factors may explain the all-too-frequent failure to achieve adequate pain relief with the use of realignment procedures[9].

Plain radiographic studies of patellar malalignment predominate in the literature[12–16]. Typically X-ray evaluation of the knee comprises three images: (1) in anterio-posterior plane, (2) in lateral plane and (3) the skyline view. The lateral and skyline views have been widely used in the evaluation of the PF joint. Included among the various proposed methods are lateral plane – evaluation of relationship between patellar height and patellar ligament length (TL)[17,18]; in a skyline view – evaluation of trochlear sulcus angle (SA) and depth[19], evaluation of lateral PF angle[16,20], lateral patellar tilt angle (LPTA)[21], bisect offset (BO) of patella[22] and evaluation of congruence angle[21].

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In the last decade, we are witnessing the growing use of magnetic resonance imaging (MRI) technology for evaluation of knee OA. This non-invasive method helps to improve our understanding of the exact shape of patellar and femoral cartilages. However, very few studies have evaluated PF alignment using MRI[23–25]. Muellner *et al.*[23] performed the measurements that were analogous to those that were accepted in X-ray evaluation. In this study, the MRI images were obtained with knees flexed 20° and 45°. The knee flexion allows evaluating the PF relations when patella is located in opposition to femoral trochlear sulcus. However, in common clinical practice MRI of the knees is usually obtained in supine position with fully extended knees. Therefore, the assessment of patellar alignment on frequently used clinical MRI can provide an additional tool for evaluation of patients with knee pain and disability.

The aim of our study was to examine the association between PF alignment (using standard MRI images of extended knees) and knee pain and function.

Methods

SAMPLE

Subjects were recruited to participate in a natural history study of symptomatic knee OA, called the Boston Osteoarthritis of the Knee Study (BOKS). Subjects in this study are a subset of subjects whose recruitment has been described in detail elsewhere[26]. Briefly, subjects were recruited from two prospective studies of the quality of life of veterans (one of men and one of women), from clinics at the Veterans Administration Boston Health Care System and from advertisements in local newspapers. Potential participants were asked two questions: 'Do you have pain, aching or stiffness in one or both knees on most days?' and 'Has a doctor ever told you that you have knee arthritis?' For subjects who answered positively to both questions, we conducted a follow-up interview in which we asked about other types of arthritis that could cause knee symptoms. If no other forms of arthritis were identified, then the individual was eligible for recruitment. To determine whether subjects had radiographic OA, they underwent a series of knee radiographs (see below under radiographic assessment). If the subject had a definite osteophyte on any view in the symptomatic knee, they were eligible for the study. By having frequent knee symptoms and radiographic OA, all subjects met American College of Rheumatology (ACR) criteria for symptomatic knee OA[27]. For the natural history study, we enrolled subjects who were interested in participating and who could walk with or without a cane. The study included a baseline examination and follow-ups at 15 and 30 months. The analysis conducted in this study uses MRI data from the baseline visit. The study was approved by the Boston University Medical Center and the Veterans Administration Boston Health Care System IRBs. Each subject's written consent was obtained according to the Declaration of Helsinki.

MRI EVALUATIONS

All studies were performed with a Signa 1.5 T MRI system (General Electric Corp., Milwaukee, WI) using a phased-array knee coil. A standard anchoring device for the ankle and knee was used to ensure uniformity of positioning between patients and for follow-up. This device provided consistent knee extension. The imaging protocol included sagittal spin-echo proton density- and T2-weighted images (repetition time [TR] 2200 ms; time to echo [TE] 20/80 ms) with a slice thickness of 3 mm, a 1-mm interslice gap, one excitation, a field of view (FOV) of 11−12 cm, and a matrix of 256 × 192 pixels; and coronal and axial spin-echo fat-suppressed proton density- and T2-weighted images (TR 2200 ms; TE 20/80 ms) with a slice thickness of 3 mm, a 1-mm interslice gap, one excitation, and with the same FOV and matrix.

PATELLAR ALIGNMENT EVALUATION

In the present study, we retrospectively evaluated MRIs that were previously acquired for BOKS. The 213 MRIs used in this analysis were those that were available in a digital archive thus allowing us to measure PF alignment as subsequently described. The patellar alignment evaluation in this study was performed using eFilm Workstation (Version 2.0.0) software. We measured patellar alignment in two planes: sagittal and transverse (axial). In the sagittal plane, we measured patellar length ratio (PLR) according to the modified Insall and Salvati method[18]. For these we found the slice with clearly recognizable patellar margins and where the patella bone volume appeared to be maximal. To measure patellar and TL according to the modified Insall and Salvati method we drew two lines and measured (Fig. 1): inner patellar length (PL) − from upper to lower point of inner (articulating) surface of the patella excluding osteophytes and TL − from lower inner point of patella to the highest point of tibial tuberosity. PLR was calculated according to the equation: PLR = PL/TL.

In the transverse plane, we measured two groups of indices: (1) indices that describe the trochlear depth and inclination: SA, lateral trochlear inclination (LTI) and trochlear angle (TA) (Fig. 2); and (2) indices that describe patellar position: LPTA and BO (Fig. 3).

For the measurements of trochlear indices we found the axial slice that refers to 1/3rd of the femoral trochlear curve. For this end, we draw on the sagittal view vertical line as a continuation of posterior border of the shaft of femur; after that we draw perpendicular line at the upper level of

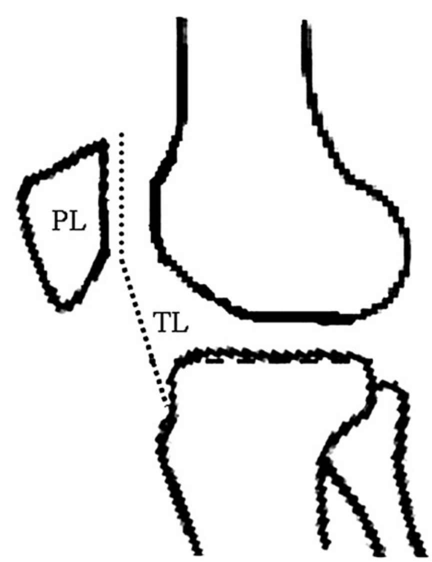

Fig. 1. Schema of measured patellar alignment indices in sagittal plane.

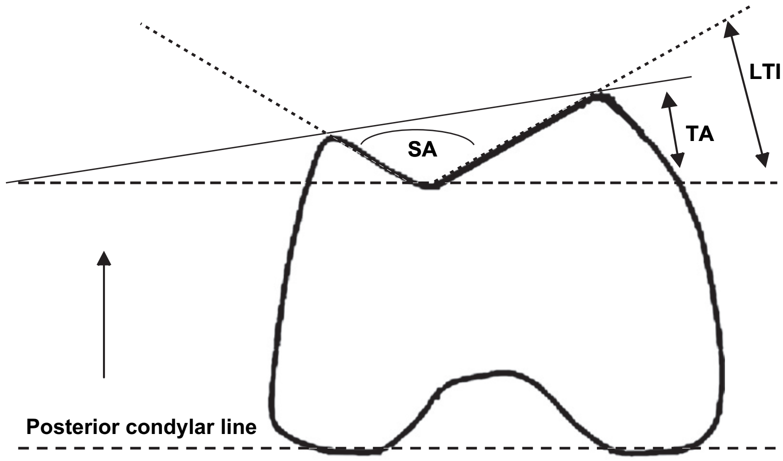

Fig. 2. Schema of measured patellar alignment indices in transverse (axial) plane.

posterior part of femoral condyle; from the crossing point we draw the line down at 30° toward anterior part of trochlea. At the point of intersection between this line and trochlea we, using the 3D cursor, found the relevant axial slice [Fig. 2]. SA is an angle between two lines: from the lowest point of the trochlear sulcus, one on a lateral bony margin and second on a medial bony margin. LTI is an angle between posterior condylar line and line from the deepest point of sulcus through the lateral bony margin of the trochlea. TA is an angle between posterior condylar line and line between two highest points of trochlea. If lateral condyle was higher than medial, the TA was considered as positive.

For the measurements of patellar alignment we found the axial slice that refers to middle of patella by using the 3D cursor on the sagittal image. LPTA is an angle between posterior condylar line and line drawn through the lateral interior bony margin of patella. For BO measurements, we drew the posterior condylar line and perpendicular line up through the lowest point of the sulcus and through the patella. The distance between lateral border of patella and this vertical line (*a*) and between medial border of patella and this vertical line (*b*) was measured. BO was calculated according to the formula: BO $= (a \times 100)/(a + b)$ (Fig. 3).

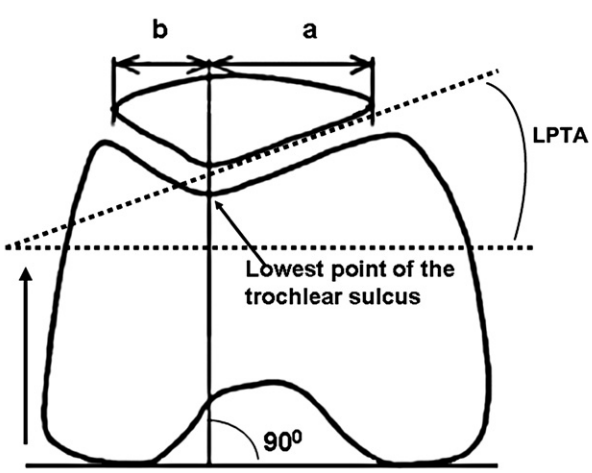

Fig. 3. Schema of BO measurement and LPTA.

RELIABILITY OF MRI READINGS

First, we (LK and DH) read a batch of MRIs and decided on the protocol of evaluation of patellar alignment. Using this protocol, 10 MRIs were read and then re-read by two investigators separately to estimate the intra- and inter-rater reliability of the readings of each of the patellar alignment features. All discrepancies were reviewed for systematic errors. This exercise continued until the reliability was high (Intraclass correlation coefficient (ICC) > 0.8). Once high intra- and inter-rater reliability were established, one investigator (LK) read the remainder of the MRIs, still blinded to patient identifiers and patient symptom status. To evaluate for reader-drift, we re-assessed intra-rater reliability by inserting one original reliability scan for every 10 new scans. Before reading of each batch of MRIs LK re-read five MRIs, which have been previously read, to "calibrate" his readings to a standard. The intra-observer reliability for reading for different patellar alignment indices varied between 0.86 and 0.96.

PAIN AND PHYSICAL FUNCTION EVALUATION

All participants in the present study were evaluated using the Western Ontario and McMaster Universities Osteoarthritis Index (hereafter called WOMAC), a survey based on self-report, that has been extensively validated and is both recommended by the Osteoarthritis Research Society and widely used in OA clinical trials. The WOMAC has three components: pain, stiffness and physical function. All the scales have high test–retest reliability, and validation studies have shown high correlations with other indices probing the same dimensions[28]. For evaluation of knee pain we used the WOMAC visual analog scale pain subscale which consists of five questions, each of which asks about pain during a particular activity. To evaluate knee-related function we used the WOMAC function scale.

Table I
Characteristics of the studied sample

Characteristics	*n*	Mean	Range
Age	213	66.7	47–93
Sex (women)	213	40.8%	
BMI	213	31.4	21.5–55.9
K–L ≥ 2	212	75.0%	0–4
CES-D	196	7.0	0–24

Table II
Outcomes and predictors of the study

Characteristics	*n*	Mean	Range
WOMAC pain	213	7.07	0–18
WOMAC function	213	23.28	0–54
PLR	207	1.60	1.09–2.24
SA	205	120	98–155
LTI	186	27	7–45
TA	186	0	−10–12
LPTA	204	17	−25–35
BO	202	61.93	38.46–100.00

CES-D MEASUREMENT

The Center for Epidemiologic Studies Depression Scale (CES-D) scale is a subjective report of depressive symptoms. The scale has been shown to have valid and reliable psychometric properties[29,30].

BODY MASS INDEX (BMI)

BMI was computed as the ratio of weight (in kg) divided by height (in m^2).

RADIOGRAPHIC OA CATEGORIES

All subjects underwent weight-bearing posteroanterior (PA) radiography of the knee, using the protocol of Buckland-Wright *et al.*[31] We evaluated knee OA of tibiofemoral joints using Kellgren and Lawrence grading scheme[32].

STATISTICAL ANALYSIS

Using the mean ($\overline{X}$) and standard deviation (SD) from each predictive variable, we divided the subjects into five groups, i.e., the lowest group ($< \overline{X} - \text{SD}$); lower group ($\geq \overline{X} - \text{SD}$ and $< \overline{X} - 0.5\text{SD}$), reference group ($\geq \overline{X} - 0.5\text{SD}$ and $< \overline{X} + 0.5\text{SD}$); higher group ($\geq \overline{X} + 0.5\text{SD}$ and $< \overline{X} + \text{SD}$), and the highest group ($\geq \overline{X} + \text{SD}$). We examined the association of each predictive variable and WOMAC pain using a linear regression model while adjusting for age, sex, BMI, CES-D score and Kellgren and Lawrence score. The multivariable adjusted means of WOMAC pain (least square means) were estimated for each category of predictive variable from multivariable regression model. To test for trend we replaced category variables created above with the actual value of that particular predictor. We used the same approach to assess the association between each predictor and WOMAC physical function.

Results

Of the 324 patients entering BOKS, 311 obtained an MRI of their more symptomatic knee at baseline. Eighty-five percent of entering subjects completed a full comprehensive follow-up at a later time-point. Table I demonstrates the characteristics of the 213 study participants selected at random from the larger study sample. Study sample composed of 126 males (average age 68.0) and 87 females (average age 64.7). On average, the subjects were obese with a mean BMI of 31.2 for males and 31.6 for females and had radiographic knee OA (K–L score ≥ 2 in 65.9% of males and 87.4% of females). 64.3% of evaluated knees had PF OA, and 58.1% had mixed PF and tibiofemoral OA. Mean CES-D in the studied population was 7.0.

Table II shows the mean values and range of all measured indices of patellar alignment and of outcome values (indices of knee pain and dysfunction).

The relation between patella alignment measures and pain and function is presented in Tables III and IV. Increasing TA was associated with both WOMAC ($P = 0.06$) pain and WOMAC function subscale ($P = 0.04$). Increasing LPTA and decreasing BO (increasing lateral subluxation) appeared to be associated with increasing WOMAC pain. However, no such an association was observed for other predictors.

Discussion

The present study evaluates the association between patellar alignment evaluated using MRI and knee pain in cross-sectional study of association between patellar alignment and indices of knee pain and dysfunction. We have demonstrated that increasing TA is associated with increasing functional impairment as measured on the WOMAC function subscale. Other measures of PF malalignment were not significantly associated with either knee pain or functional impairment.

These findings are consistent with the predominant site of disease and source of symptoms coming from the lateral PF joint. Previous studies in PF pain syndrome have highlighted that the likely source of symptoms comes from impingement of structures in the lateral aspect of the joint. The findings in our study are commensurate with these and could possibly be used for the development of interventions in knee pain and dysfunction in persons with knee OA.

There were numerous limitations of the present study that need to be recognized. First, the MRI images were performed in a supine position of the patients and not in a weight bearing. This limitation is likely to have reduced our opportunity to measure dynamic changes in patella position with weight bearing and thus underscore that our findings are likely to be conservative for measures that potentially could change with weight bearing such as BO and the LPTA. Another limitation of our study was that MRI was obtained in fully extended knee. This position, as we mentioned before, is common in clinical practice, but in extended knee the patella is not positioned against trochlear sulcus and it makes the measurement of their

Table III
Association between patella alignment (five groups) and adjusted means of WOMAC pain

	WOMAC pain l-s mean PLR	WOMAC pain l-s mean SA	WOMAC pain l-s mean LTI	WOMAC pain l-s mean TA	WOMAC pain l-s mean LPTA	WOMAC pain l-s mean BO
Highest group	7.45	7.96	7.29	7.79	7.73	5.98
Higher group	6.77	8.34	6.81	7.60	7.39	6.74
Reference group	6.73	6.85	7.01	6.88	6.99	7.03
Lower group	7.41	6.79	6.95	6.38	7.80	7.79
Lowest group	7.46	6.94	7.45	7.10	5.09	7.28
P for trend	0.51	0.19	0.90	0.06	0.07	0.16

Table IV
Association between patellar alignment (five groups) and adjusted means of WOMAC function

	WOMAC function l-s mean PLR	WOMAC function l-s mean SA	WOMAC function l-s mean LTI	WOMAC function l-s mean TA	WOMAC function l-s mean LPTA	WOMAC function l-s mean BO
Highest group	21.33	25.68	26.23	25.35	25.47	21.85
Higher group	24.58	24.56	21.89	24.27	24.43	21.35
Reference group	22.38	22.29	22.22	22.76	22.44	22.89
Lower group	24.63	24.00	23.94	21.43	23.93	25.18
Lowest group	24.47	24.19	23.92	22.57	22.78	25.11
P for trend	0.09	0.56	0.48	**0.04**	0.50	0.39

Adjusted for age, sex, BMI, CES-D score and Kellgren and Lawrence score.

congruence less precise. Nevertheless, the trait that was the best predictor of knee pain and dysfunction in our study was TA, which is not influenced by knee position. Another limitation was that this study was performed in a group of persons with symptomatic knee OA with symptoms that were not necessarily emanating from the PF joint. Whilst this is likely to provide a more generalizable understanding of the relation of the PF articulation to knee pain a less conservative assessment may come from assessing this in persons with disease primarily affected the PF joint. Finally, as we examined a number of exposures and outcomes multiple testing may be a concern.

A full understanding of the risk factors for pain and other symptoms in knee OA requires consideration of a range of biopsychosocial factors[33]. The symptoms of knee OA are often described as mechanical, that is, they occur with physical activity. The alignment of the patella may be an important source of symptoms due to aberrant distribution of forces with activity. In our recent study, we have demonstrated a strong relation between the measures of patellar alignment on MRI and radiographic manifestations of PF OA (both osteophytes' and joint space narrowing)[34]. Based upon the results of this study it does appear what non-weight bearing, full extension assessment of patella alignment does increase our understanding of the reasons for knee pain. Further consideration of the importance of PF alignment needs to occur, preferably in more functional positions than supine and non-weight bearing.

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