Predictive value of the indicators of lateral and medial knee morphology for total knee arthroplasty in patients with varus knee osteoarthritis

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Abstract

Purpose

This study aimed to establish a predictive model to aid in patient selection and decision-making efforts regarding total knee arthroplasty (TKA).

Methods

Using data collected from our retrospective TKA database, 132 patients with varus knee osteoarthritis (153 knees) were included in the study. We focused on patients with a diagnosis of Kellgren–Lawrence (K-L) grade II in the initial stage of knee osteoarthritis (OA) and K-L grade IV with TKA at the endpoint. The interval between baseline and endpoint was defined as the remaining life of the knee joint. The following lateral and medial knee indicators were assessed using standard anteroposterior (AP) and lateral radiography: fibula height (FH), lateral plateau widening (LPW), medial proximal tibial angle (MPTA), and joint line convergence angle (JLCA) at baseline (FH_0, LPW_0, $MPTA_0$, and $JLCA_0$, respectively); FH, LPW, MPTA, and JLCA in the TKA period (FH_T, LPW_T, $MPTA_T$, and $JLCA_T$, respectively); changes in FH, LPW, MPTA, and JLCA between baseline and TKA periods (cFH, cLPW, cMPTA, and cJLCA, respectively); and rates of change in FH, LPW, MPTA, and JLCA between baseline and TKA periods (ΔFH, ΔLPW, ΔMPTA, and ΔJLCA, respectively). Multivariate linear regression analysis was performed for comparisons of indicators with the remaining life of the knee joint.

Results

Rates of change in FH and LPW between baseline and TKA periods were negatively correlated with the remaining life of the knee joint (ΔFH, $\beta = -335.901$, $t = -2.182$, $P = 0.035$; ΔLPW, $\beta = -488.516$, $t = -2.588$, $P = 0.013$). There were positive correlations of ΔMPTA and ΔJLCA with risk of requiring TKA, respectively ($r = -0.523$ and -0.480, respectively, all $P < 0.001$), but these correlations were not statistically significant in the predictive model of the remaining life of the knee joint. Other indicators were not significantly correlated with the remaining life of the knee joint (all $P > 0.05$).

Conclusions

Rates of change in FH and LPW robustly predict the risk of requiring TKA.

Level of Evidence: Retrospective Study Level III

Introduction

Knee osteoarthritis (OA) is the most common cause of aging-related disability, and no pharmaceutical interventions are available to halt or reverse its progression. Total knee arthroplasty (TKA) is the major surgical treatment for end-stage osteoarthritis [1, 2]. The demand for primary TKA surgeries performed annually in the USA is expected to increase nearly sevenfold: from 450,000 in 2005 to 3.48 million by

2030 [3]. The high costs and burden to society and healthcare systems require means of delaying or preventing the requirement for TKA.

Some patients with knee OA do not progress to a condition that requires surgical joint replacement. Early identification of individuals at risk of needing TKA is essential for effective prevention strategy implementation. Weight loss, knee injury prevention, and personalized exercise regimens are important and useful for preventing OA and the subsequent need for TKA [4–8]. Joint preservation is the goal of all preoperative treatments for knee OA. Despite full explanations from their surgeons, however, many patients with mild arthritis do not understand the severity of their arthritis or the end of life status of their knee joints; this may be the main reason for poor compliance in patients and the corresponding high incidence of TKA. Providing patients with a prediction of the maximum joint preservation time to focus their attention on OA is expected to improve patient compliance. Multiple studies have examined factors influencing TKA utilization, including willingness to consider joint replacement, socioeconomic status, general health status, arthritis severity, educational level, age, and sex [9–11]. However, the objective prediction of knee arthroplasty timing in a particular individual is complex.

Imaging markers have been used as indirect surrogate measures of disease status and progression with variable success. A previous study used magnetic resonance imaging to identify knees at risk of requiring joint replacement in the following year [12]. However, because of its high costs, magnetic resonance imaging is not widely used for this purpose; such a model for predicting arthritis outcome after 1 year may lead to missed opportunities for joint preservation. Arthritis severity indexes, such as medial and lateral knee joint space narrowing and Kellgren–Lawrence (K-L) grade, may be used to predict the risk of needing joint replacement [13]. In addition, changes in proximal tibiofibular joint morphology have been shown to predict the risk of TKA [14].

Recently, we found that knee OA is related to both proximal tibiofibular joint morphology and the distance from the fibular head to the tibial plateau; meanwhile, misalignment of lateral knee joints may also be associated with knee degeneration (Fig. 1). Measurement of these two indirect indicators of OA by X-ray examination is both feasible and economical. We suspect that lateral morphological changes may indicate lateral knee joint degeneration. For varus knee OA, usually, determination of the degree of medial compartment degeneration is useful in decision-making efforts concerning whether the selection of conservative or surgical treatment in the early stages of knee OA. In clinical TKA operation, we find that the lateral knee joint cartilage of some patients whose medial knee joint cartilage is badly worn may be intact or very mildly worn. Which surgical approach, such as TKA, unicondylar knee arthroplasty and high tibial osteotomy, is more suitable for these patients should be considered. Therefore, when knee OA is aggravated, concurrent evaluation of medial and lateral knee joint degeneration will enable more comprehensive assessment and it may be useful for selecting a more reasonable surgical approach in some patients; meanwhile, it may provide us a new method to predict the aggravation of knee OA.

The purpose of our preliminary study included the following: (i) explore whether the two lateral morphological indicators and other related indicators could effectively predict the risk of requiring TKA;

(ii) build a predictive model regarding the remaining life of the knee joint using several effective indicators.

Methods

Study population

The inclusion criteria were as follows: mild symptomatic varus knee OA diagnosed as K-L grade II in at least one knee at baseline, and TKA record accompanied by diagnosis of K-L grade IV at the end of review (i.e., endpoint); knee symptoms including severe pain, severely limited activity, and poor quality of life, determined by review of medical records or telephone interviews; and standard anteroposterior (AP) and lateral radiography obtained at baseline and the endpoint. The exclusion criteria were as follows: previous knee trauma or surgery; congenital deformity or skeletal dysplasia of the knee. The interval between baseline and endpoint was defined as the remaining life of the knee joint. The study population consisted of 132 patients treated between January 2014 and July 2021 [153 knees; 33 men, 99 women; mean age at onset of knee OA, 63.38 (range 51–76) years; mean body mass index, 26.19 (range 19.96–32.23) kg/m^2; mean remaining life of the knee joint, 73.28 (range 24–190) months].

In total, 7635 knees were excluded because of incomplete radiological data, valgus deformity, poor image quality, skeletal dysplasia, rheumatoid arthritis, or history of lower limb trauma or surgery. This study was approved by the Research Ethics Committee of the Affiliated Hospital of Qingdao University (approval No. QYFYWZLL 26088). Written informed consent for data analysis was retrospectively obtained from all patients.

Radiological measurements

Standard AP and lateral radiographs of the knee were obtained in all patients at baseline and during TKA periods. The measurements were made independently by one radiologist with 3 years of experience in postprocessing procedures and by a second radiologist with 2 years of experience in orthopedic radiology; all measurements were performed using a Picture Archiving and Communication System. Each patient’s position was adjusted such that the toes were pointing straight forward with the feet separated sufficiently for balance.

All measurements were made on standard AP radiographs. Fibula height (FH) was measured as the shortest distance from the tibial plateau to the base of the fibular styloid process on plain radiographs. Lateral plateau widening (LPW) was determined by measuring the distance between the lateral line along the lateral margin of the distal femoral condyle and the line along the lateralmost aspect of the proximal tibia; both lines were perpendicular to the medial tibial articular surface (Fig. 2). The medial proximal tibial angle (MPTA) was measured as the angle between the tibial plateau and the mechanical axis of the tibia. The joint line convergence angle (JLCA) was measured as the angle between the line connecting the distal femur and proximal tibial articular surfaces on AP radiographs. Intraarticular varus deformity caused by narrowing of the medial joint space often manifests as a positive JLCA value (Fig. 3). TKA was confirmed by radiography.

Consistent magnification of the two images is the most important factor to ensure measurement accuracy. We measured the width of the horizontal position of the upper edge, which had the highest density on X-rays and was named the fibula width; we judged the consistency of the magnification by comparison of data that were obtained both times (Fig. 4).

The radiographic severity of knee OA was assessed with the K-L grading system: grade 0, definite absence of X-ray changes in osteoarthrosis; grade I, suspected narrowing of joint clearance and possible osteophytes; grade II, obvious osteophytes and slight narrowing of the joint space; grade III, moderate osteophytes, narrowing of joint space, mild sclerosis of subchondral bone, and small range of motion; and grade IV, formation of a large number of osteophytes, which can spread to the chondroid surface, with a narrower joint gap, extremely obvious hardening changes, joint hypertrophy, and obvious deformity [15, 16].

Indicators

(1) FH, LPW, MPTA, and JLCA at baseline (FH_0, LPW_0, $MPTA_0$, and $JLCA_0$, respectively); (2) FH, LPW, MPTA, and JLCA in the TKA period (FH_T, LPW_T, $MPTA_T$, and $JLCA_T$, respectively); (3) changes in FH, LPW, MPTA, and JLCA between baseline and TKA periods (cFH, cLPW, cMPTA, and cJLCA, respectively); and (4) rates of change in FH, LPW, MPTA, and JLCA between baseline and TKA periods (ΔFH, ΔLPW, ΔMPTA, and ΔJLCA, respectively).

The equations used to calculate indicators (3) and (4) were as follows:

$cFH = FH_0 - FH_T$

$cLPW = LPW_T - LPW_0$

$cJLCA = JLCA_T - JLCA_0$

$cMPTA = MPTA_0 - MPTA_T$

$\Delta FH = (FH_0 - FH_T)$/remaining life of knee joint

$\Delta LPW = (LPW_T - LPW_0)$/remaining life of knee joint

$\Delta MPTA = (MPTA_0 - MPTA_T)$/remaining life of knee joint

$\Delta JLCA = (JLCA_T - JLCA_0)$/remaining life of knee joint

Statistical analysis

All statistical evaluations were performed using PASW Statistics 25.0 (SPSS, Chicago, IL, USA). The Kolmogorov–Smirnov normality test was conducted before statistical analyses to determine whether the use of a parametric test was appropriate. Continuous variables conforming to normal distribution were expressed as means and standard deviations. Categorical variables were expressed as frequencies (%). Paired *t*-tests were used to compare the two measurements of fibular width, which can reflect consistent magnification of the images. Pearson correlation analysis and Kendall tau-b correlation analysis were performed to determine whether each indicator was associated with the remaining life of the knee joint. The absolute correlation coefficient (r) was used to define very strong (r = 0.80–1.00), strong (r = 0.60–0.79), moderate (r = 0.40–0.59), weak (r = 0.20–0.39), and no (r < 0.20) correlations. If there were pairwise correlations between several indicators and the remaining life of the knee joint, multivariate linear regression analysis was performed for further validation. Intra- and interclass correlation coefficients with 95% confidence intervals were used to assess intra- and interrater variabilities. An interclass correlation coefficient > 0.75 was considered to indicate excellent agreement. In all analyses, $P < 0.05$ was considered to indicate statistical significance.

Results

Basic information

In total, 153 knees in 132 patients were included in this study. The mean remaining life of the knee joint was 73.28 (range 24–190) months. Good to excellent intra- and interobserver variabilities were achieved for all measurements with intra- and interrater interclass correlation coefficients of 0.901–0.957 and 0.876–0.933, respectively.

Comparison of fibular width measurements at baseline and during TKA periods

The difference in measurement of fibula width at baseline and during TKA periods reflects the consistent magnification of images taken at the two time points. Paired *t*-test analysis showed no significant difference in fibula width between the two periods ($t = -0.359$, $P = 0.723$) (Table 1).

Table 1. Difference in fibula width at baseline and TKA periods

			95% CI of the difference			
	$\bar{X}$	S	Lower	Upper	t value	P value
Fibula width difference: baseline period - TKA period	-0.07	1.04	-0.48	0.34	-0.359	0.723

Table 1.`X, mean value, S, standard deviation, CI, confidence interval

Correlations between indicators and remaining life of the knee joint

Pearson and Kendall tau-b correlation analyses showed that ΔFH, ΔLPW, ΔMPTA, and ΔJLCA were significantly correlated with the remaining life of the knee joint (all $P < 0.05$). In contrast, age at onset, sex, body mass index, FH_0, LPW_0, $MPTA_0$, $JLCA_0$, FH_T, LPW_T, $MPTA_T$, $JLCA_T$, cFH, cLPW, cMPTA, and cJLCA were not significantly correlated with the remaining life of the knee joint (all $P > 0.05$) (Tables 2–4).

Table 2. Correlations between basic information and remaining life of knee joints

		Onset age	Gender	BMI
remaining life of knee joints	r	-0.056	0.054	-0.148
	P	0.701	0.650	0.306

Table 2. BMI, Body mass index

Table 3

Correlations between medial knee indicators and remaining life of knee joints

		$MPTA_0$	$JLCA_0$	$MPTA_T$	$JLCA_T$	cMPTA	cJLCA	ΔMPTA	ΔJLCA
remaining life of knee joints	r	-0.012	-0.268	0.091	0.021	-0.096	0.148	-0.523	-0.480
	P	0.934	0.060	0.528	0.886	0.508	0.306	< 0.001	< 0.001

Table 3. BMI, Body mass index

Table 4

Correlations between lateral knee indicators and remaining life of knee joints

		FH_0	LPW_0	FH_T	LPW_T	cFH	cLPW	ΔFH	ΔLPW
remaining life of knee joints	r	0.042	-0.019	0.111	-0.165	-0.181	-0.249	-0.654	-0.684
	P	0.773	0.895	0.443	0.253	0.209	0.081	< 0.001	< 0.001

Table 4. BMI, Body mass index

Model for prediction of the remaining life of the knee joint

We used ΔFH, ΔLPW, ΔMPTA, and ΔJLCA to develop a model for prediction of the remaining life of the knee joint. Multivariate linear regression analysis showed that ΔFH and ΔLPW were significantly negatively correlated with the remaining life of the knee joint (all $P < 0.05$) (Table 5).

Prediction model: remaining life of the knee joint = 164.851 − 335.901 × ΔFH − 488.516 × ΔLPW

Table 5. Multivariate linear regression analysis of remaining life of knee joints

	Unstandardized coefficient	**Standardized coefficient B**	**t-value**	**P-value**	**B 95%CI**	
Intercept	164.851		3.910	< 0.001	79.776	249.926
Onset age	-0.546	-0.153	-1.395	0.170	-1.336	0.244
Gender	-4.267	-0.069	-0.660	0.513	-17.321	8.786
BMI	-0.900	-0.087	-0.807	0.424	-3.150	1.351
ΔFH	-335.901	-0.398	-2.182	0.035	-646.629	-25.173
ΔLPW	-488.516	-0.413	-2.588	0.013	-869.415	-107.617
ΔMPTA	69.133	0.139	0.735	0.466	-120.593	258.859
ΔJLCA	-100.271	-0.146	-0.969	0.338	-309.029	108.486

Table 5. B, regression coefficient, CI, confidence interval

Discussion

To our knowledge, this is the first study with a large sample size to develop a model for the prediction of risk of requiring TKA based on dynamic changes in two indirect radiological indicators: FH and misalignment of the lateral knee joint. In this study, we found that larger ΔFH and ΔLPW were associated with shorter remaining life of the knee joint and greater risk of requiring TKA. ΔMPTA and ΔJLCA were positively correlated with risk of TKA (r = −0.523, − 0.480, all $P < 0.001$), but these correlations were not statistically significant in the predictive model of the remaining life of the knee joint. The changes in FH and LPW indicate lateral knee joint degeneration, while changes in MPTA and JLCA indicate varus deformity and narrowing of the medial knee compartments.

Previous studies have shown that willingness to consider joint replacement, socioeconomic status, general health status, arthritis severity, educational level, age, and sex are important factors determining the utilization rate of TKA[9–11]. Willingness to consider joint replacement appears to be the most dominant factor associated with utilization of TKA; low socioeconomic status, poor general health status, low educational level, and female sex are associated with low TKA utilization rates. Lower limb disability and high TKA utilization rate are associated with substantial social and economic burdens. Therefore, delaying OA progression and reducing the need for TKA are important but challenging issues. Defining the maximum remaining life of the knee joint (i.e., the risk of TKA and residual life of the knee joint) will help to improve patient awareness and compliance, preventing the need for TKA via early medical intervention, which will help to reduce the social costs of severe knee OA.

Here, we proposed the use of two indicators of lateral knee degeneration for prediction of disease progression and remaining life of the knee joint; our model was confirmed to be effective and reliable. X-rays were used to calculate the rate of change in vertical distance between the lateral tibial plateau and the fibular head, as well as the rate of change in lateral dislocation of the tibial plateau. This procedure is economical, convenient, and time-saving; it effectively quantifies lateral knee compartment degeneration in varus knee OA.

Zhang reported that fibular cortical support is an important reason for uneven pressure distribution between the lateral and medial knee compartments, which leads to a much higher incidence of varus knee OA than valgus knee OA [17]. A reduced medial proximal tibial angle is commonly found in varus knee OA, suggesting that the medial tibial plateau is compressed and lower than the lateral tibial plateau. Although the lateral tibial plateau is supported by the fibula, it can also exhibit slow settling during the progression of OA. Therefore, a rapid decrease in FH is positively correlated with OA progression. Long-term intraarticular pressure causes knee joint degeneration [18]. We refer to the wear of the medial knee compartment as destruction caused by great pressure; and degeneration of the lateral knee compartment is caused by the accumulation of long-term pressure. Degeneration of the knee joint is accelerated when the load-bearing capacity of the knee is insufficient to withstand the applied pressure. In the early stages of varus knee OA, pressure in the medial knee compartment is unbalanced with tibial plateau load-bearing capacity but does not involve the lateral tibial plateau; in the advanced stage of varus knee OA, imbalance in the lateral knee compartment is also present. Because the remaining life of the knee joint is related to the rates of change in the two lateral degeneration indicators, but not the rates of change in the medial indicators, the risk of requiring TKA is related to the relationship between lateral intraarticular pressure and load-bearing capacity.

We presume that the changes in lateral knee morphological characteristics observed in this study contribute to knee OA progression by aggravating the knee joint instability. Theoretically, the function of the posterolateral ligament complex (i.e., maintaining the normal force line of the knee and the normal tibial rotation angle) declines during upward shift, because it relaxes. First, the pressure in the medial knee compartment increases when knee varus deformity occurs [19, 20], which eventually leads to knee degeneration (e.g., hyperosteogeny and osteosclerosis). Simultaneously, an abnormally increased tibial rotation angle is associated with increased pressure in the lateral knee compartment [19, 20]. Therefore, in addition to reflecting bone degeneration, the fibula shifts upward relative to the tibial plateau; this manifests as a decrease in FH, which could also indicate accelerated functional degeneration of muscles and ligaments. The relative outward displacement of the tibial plateau, observed as an increase in LPW, represents increased lateral structural stress; this reflects the lack of medial and lateral constraint strength, which affects the state of the fibula head [21, 22]. An increase in LPW may be the direct cause of increased stress in lateral structures when varus knee OA occurs.

To our knowledge, there is no clear consensus regarding indications or appropriateness criteria for TKA [10]. Generally, when OA only occurs in the medial compartment, unicondylar knee arthroplasty or high tibial osteotomy can be considered [23–26]. When both medial and lateral compartments are involved, TKA is chosen. Therefore, the degeneration of lateral knee structures appears to be more closely related to the use of TKA for varus knee OA. Accelerated deterioration of the disease is often accompanied by significant symptomatic or functional deterioration, which could increase a patient's willingness to seek medical treatment or undergo TKA [11]. Therefore, the rates of change in FH and LPW can help surgeons to distinguish between mild and advanced knee OA; this helps to reduce the incidences of missed diagnosis and misdiagnosis. Patients with high risk of requiring TKA can be differentiated from patients with mild knee OA alone; early medical intervention (e.g., weight loss, personalized exercise, and knee-preserving surgery) may enable postponement or prevention of TKA, thus reducing the burdens on healthcare and medical insurance systems.

The data presented here are clinically advanced in the following four respects. First, X-ray examination is economical and convenient, greatly improving the rates of patient examination and re-examination; this facilitates knee OA evaluation based on dynamic changes. Second, all patients enrolled in this study had TKA indications, such as K-L grade IV, severe pain, severe limitation of activity, and poor quality of life. However, they had been treated with TKA, thus avoiding some bias (e.g., low rate of TKA utilization because of low socioeconomic status, poor general health status, and/or low educational level). Third, risk of requiring TKA can be shown intuitively by this mathematical model which helps us to identify patients with rapidly aggravated knee OA and intuitive and pellucid result is helpful to improve patients' compliance by improving their understanding of knee OA and TKA. Early medical intervention will be carried out strictly for these patients to delay the progress of OA. Fourth, for varus knee OA (considering medial knee joint degeneration alone), unicondylar knee arthroplasty, high tibial osteotomy, and TKA could all be chosen; however, these lack clear appropriateness criteria. The use of indicators of lateral knee joint degeneration could facilitate more rational use of TKA.

This study had several limitations. First, patients without records of TKA after the longest follow-up period in this study were excluded; this ensured that the study focused only on TKA risk, rather than the threshold for determining whether TKA surgery will be performed in the future. Therefore, additional systematic studies are required. Second, retrospective research can explore correlations in data and build a correlation model based on random sampling. However, to make the predictive model more convincing, additional prospective studies are needed to verify its sensitivity and reliability by comparing differences between theoretical and actual values. Third, although the total amount of data was large, a small amount of data met our study criteria, reflecting incomplete follow-up because of patient concerns regarding X-rays or a lack of appropriate understanding concerning the seriousness of knee OA.

Conclusions

The rates of change in FH and LPW reliably predict the risk of requiring TKA. According to ΔFH and ΔLPW findings obtained by radiography of the knee joint, patients with high risk of TKA can be differentiated from patients with mild knee OA. Early medical intervention may enable postponement or prevention of TKA, thus reducing the burdens on healthcare and medical insurance systems.

Declarations

Authorship declaration

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.

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Conflicts of interest

The authors declare that they have no conflict of interest.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Chunpu Li, Guangzhen Liu. The first draft of the manuscript was written by Wenru Ma and the necessary corrections and additions to the manuscript was made by Shengnan Sun. Youliang Shen gave theoretical guidance. Tengbo Yu and Yi Zhang were responsible for the overall direction and review. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Ethics approval and consent to participate

Approval was obtained from the research ethics committee of the Affiliated Hospital of QingDao University. (Ethics number: QYFYWZLL 26499) All methods were carried out in accordance with relevant guidelines and regulations. Verbal informed consent was obtained from all individual participants included in the study and this was approved by the ethics committee.

Availability of data and materials

The datasets used during the current study available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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Figures

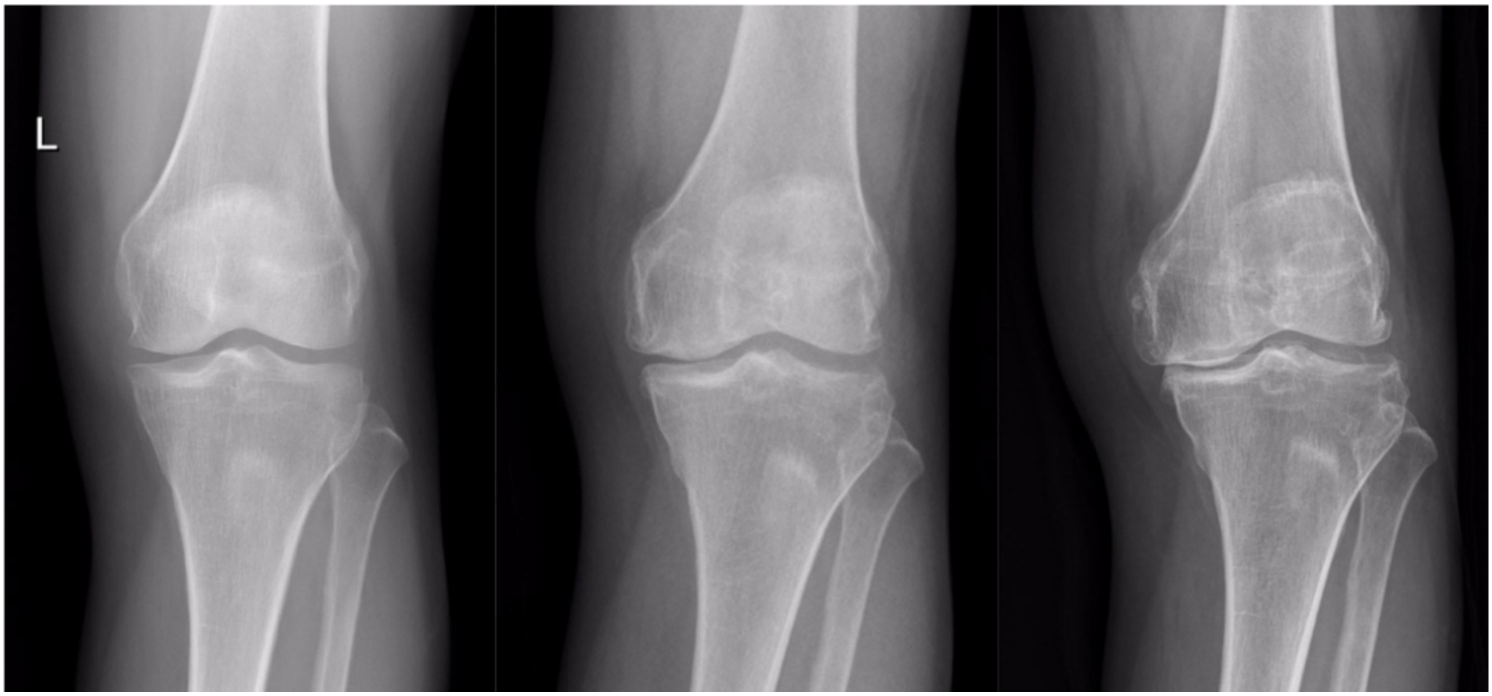

Figure 1

Imaging manifestations of different progression periods in patient with varus knee OA.

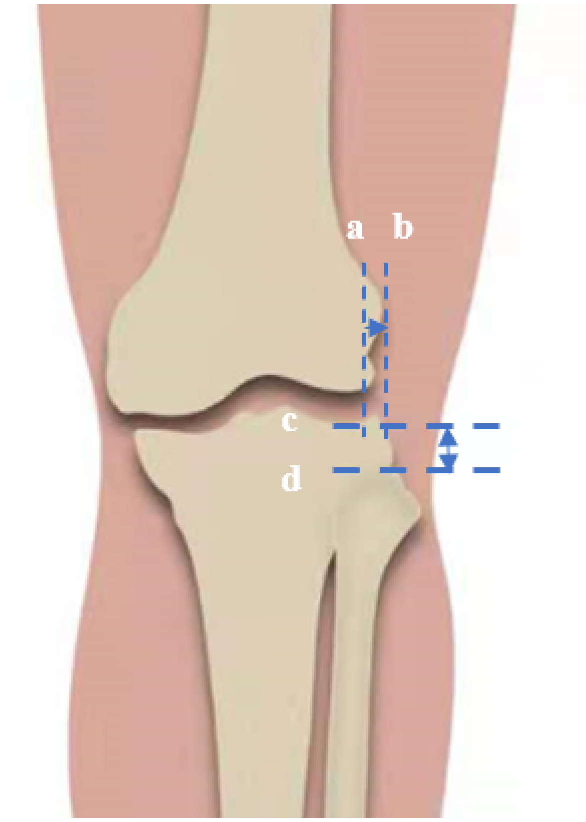

Figure 2

The two-way arrow indicates FH, the one-way arrow indicates LPW.

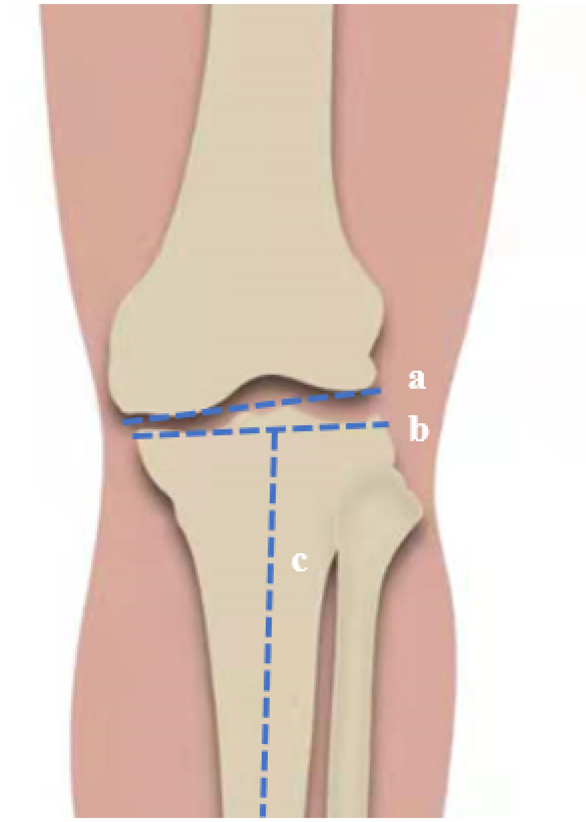

Figure 3

MPTA was measured as the medial angle between line b and line c, JLCA was measured as the angle between line a and line b.

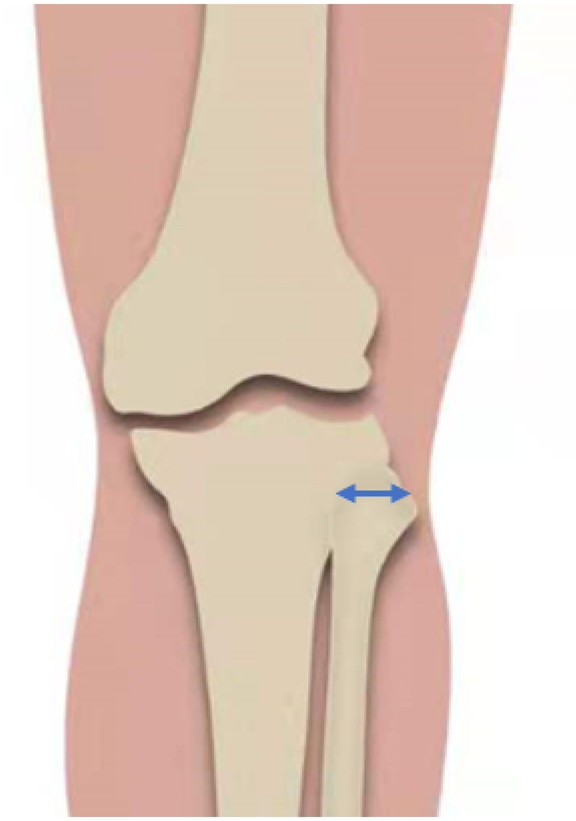

Figure 4

Fibula width, measured as the width of horizontal position of the upper edge where was with highest density on X-rays. (two-way arrow)