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Original Article

Tibial plateau non-uniform settlement, malalignment, coronal subluxation, and tibia rotation in medial compartment osteoarthritis: a geometrically radiographic study

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Abstract: Background: We aimed to correlate deformities including non-uniform tibial plateau settlement, malalignment, coronal subluxation, and tibia rotation in knee osteoarthritis (KOA). We investigated the relationship of disease severity and deformity aggravation, and secondary changes after primary deformity aggravation. Methods: Patients with primary medial compartment KOA that were admitted to our hospital from January to December 2016 were retrospectively analyzed. Plain radiography and computed tomography were performed in all patients. Kellgren and Lawrence grade (KL grade), settlement value, hip-knee-ankle angle (HKA angle), subluxation, tibia rotation, and joint space width were obtained by radiography. All participants were diagnosed and classified according to KL grades. Logistic regression analyses were used to assess the association between geometrical factors and KL grade. Partial correlation coefficients were calculated to determine the relationships between geometrical factors. Results: Sixty-six patients (12 men and 54 women) and 104 knees (men, 17 knees; women, 87 knees) were included in this study. Mean patient age was 62.26±8.62 (range, 40-84) years. Twenty-five, 58, and 21 knees were KL grade 2, KL grade 3, and KL grade 4, respectively. Settlement value, HKA angle, and subluxation value were 6.65±4.60 (range, -2.79-20.09) mm, 173.17±4.81 (range, 158-184) degrees, and 11.95±6.57% (range, -7.9-28.92%), respectively. The average tibia rotation was 1.08±4.41 (range, -13.5-13.2) degrees. The average medial and lateral joint space width was 3.54±1.47 (range, 0-7.03) mm and 5.79±1.35 (range, 3.37-10.16) mm, respectively. On logistic regression analysis, the settlement value was independently associated with KL grade (OR=1.534, 95% CI=1.228-1.917, P=0.000). HKA angle and subluxation were correlated with settlement value and each other (all $P < 0.05$). In addition, HKA angle and subluxation were correlated with tibia rotation. Medial joint space width was correlated with settlement value, HKA angle, and tibia rotation ($P < 0.05$). Lateral joint space width was correlated with settlement value and HKA angle ($P < 0.05$). Conclusions: Settlement value was independently associated with KL grade in patients with KOA. The settlement value might be the primary geometrical change in KOA.

Keywords: Knee osteoarthritis, tibia malalignment, settlement value, hip-knee-ankle angle

Introduction

The pathogenesis of knee osteoarthritis (KOA) remains unclear. In recent studies, the role of biomechanics in osteoarthritis (OA) development and progression, especially of the lower limb, has been shown to be integral in current disease knowledge [1]. For various reasons, the stress concentration in the medial compartment and cartilage degeneration lead to the onset of KOA. The stress concentration in the medial compartment is closely associated with knee joint geometrical changes [2]. These geometrical changes mainly include malalignment [3], coronal subluxation [4], tibia rotation [5], and tibia articular surface changes [6, 7]. The typical example is varus deformity. Many studies have shown that lower extremity varus malalignment could over stress the medial compartment, leading to cartilage wear [8, 9]. However, knee joint deformities in patients with KOA are systemic and complex. In addition to varus malalignment, coronal subluxation, tibia rotation, and settlement of the tibial plateau

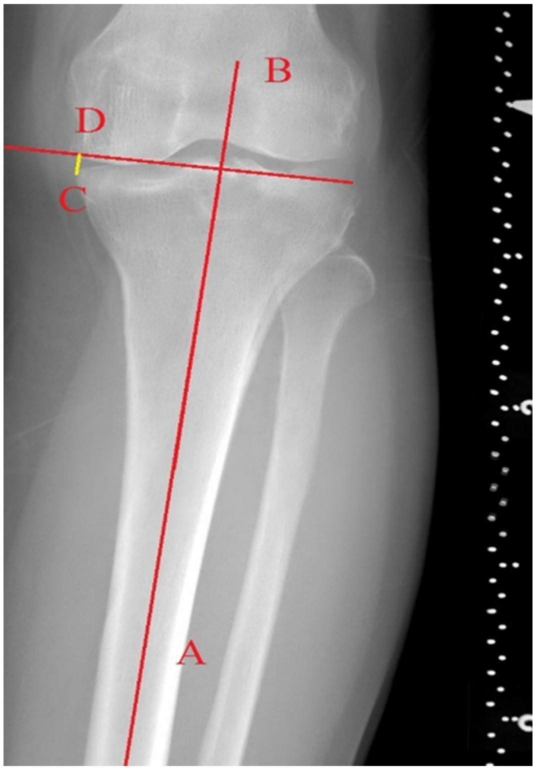

Figure 1. Line AB is the mechanical axes of the tibia. Line CD (Yellow) is defined as settlement value of the medial tibial platform.

[10] have also been shown to be correlated with KOA. Studies have demonstrated the presence of significant tibial external rotation in patients with varus malalignment. Furthermore, the degree of external rotation is correlated to the degree of varus malalignment [5]. Another study showed that the varus deformities are also correlated with coronal subluxation [11]. In addition, in recent studies, geometrical changes of the tibial articular surface have been considered as another important risk factor for KOA. This deformity was called "non-uniform-settlement of plateau" in our previous study [10], and "coronal tibial slope" by Driban [7]. Similarly, it has been defined as a decreased tibial plateau angle by Higano [6]. Despite different measurement methods, this deformity is a phenomenon causing the medial plateau to be significantly lower than the lateral plateau in medial compartment KOA. It has been shown that non-uniform-settlement of plateau is correlated with varus malalignment [10]. The above results show that deformities in KOA do not exist in isolation, but are closely related to one another. However, the current studies often deal with only one or two deformity correlations, such as varus and subluxation, and varus and tibia rotation. There are no systematic studies on the correlations between different knee joint deformities. Additionally, by studying only two deformity types, the confounding factors are difficult to detect. This study aimed to correlate different deformities including non-uniform settlement of tibial plateau, malalignment, coronal subluxation, and tibia rotation in KOA. We also investigated the relationship between disease severity and deformity aggravation, and secondary changes after primary deformity aggravation.

Materials and methods

Study population

Patients with primary medial compartment KOA, admitted to our hospital from January to December 2016, were retrospectively analyzed in this study. Patients were diagnosed according to American College of Rheumatology criteria [12]. Exclusion criteria were as follows: rheumatoid arthritis, posttraumatic arthritis, lower extremity congenital deformities, joint infection, history of ligament or meniscus injury, and significant lateral compartment abnormality. The patient's extremities were evaluated independently. The study was approved by the Ethical Committee of the Third Hospital of Hebei Medical University and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from the patients prior to their participation in this study.

Radiographic examinations and evaluations

Radiographic examinations included plain radiography and computed tomography (CT). Radiography included the knee joint anterior-posterior and lateral views and splicing of the total length of the lower extremity. The knee joint anterior-posterior view and splicing of total length of lower extremities were obtained with the patient in a weight-bearing position with the knees fully extended. The lateral view was obtained with the patient in a non-weight-bearing position, with the knees in semi-flexion (45 degrees). CT was performed with the patient in a supine position, with the knees fully extended, and from the distal femur to the proximal tibia, including the whole knee joint with a scan

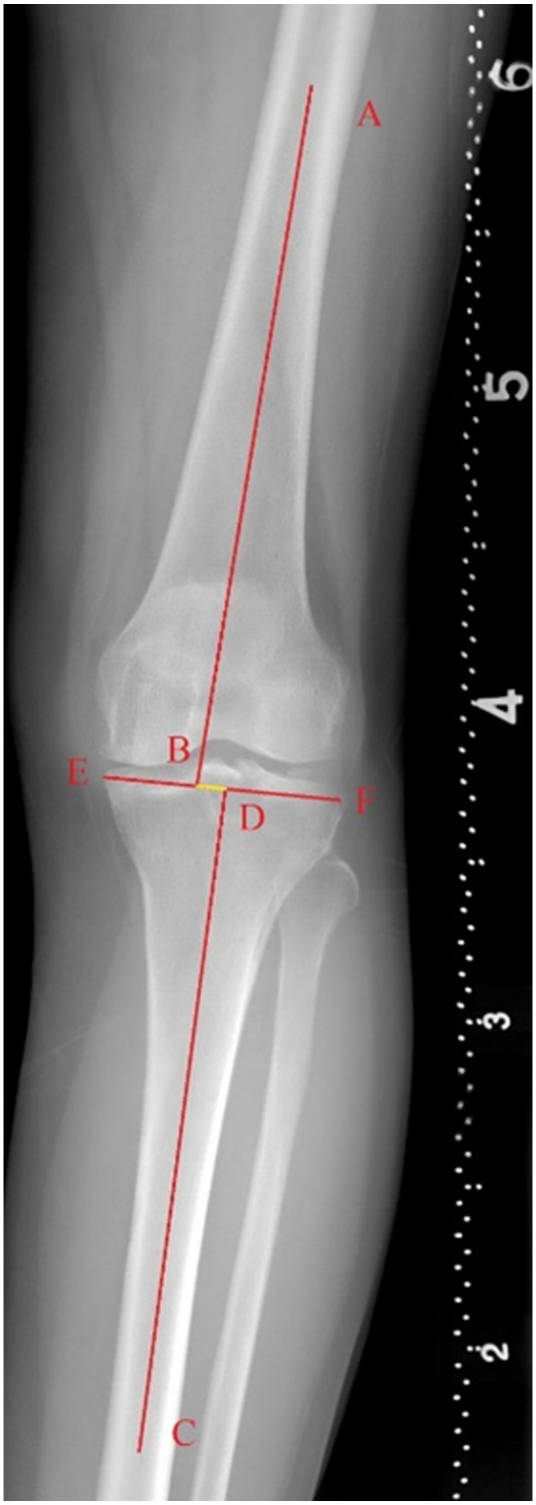

Figure 2. Line AB is the mechanical axes of femur and line CD is the mechanical axes of tibia. Line EF is the width of the tibia plateau. Subluxation distance was determined as the length of line BD (Yellow). To adjust for different knee sizes, this value was converted to a percentage that was calculated as BD/EF × 100. If the point B was medial to point D, it was assigned a positive value.

thickness of 1-mm. Images were collected by a picture archiving and communication systems (PACS) (Science & Technology General Company of Hebei Medical University, Shijiazhuang, China).

Kellgren and Lawrence (KL) grade [13] was used to evaluate the OA severity on AP radiographs. The degree of non-uniform-settlement was determined by the settlement value (**Figure 1**) [10]. Alignment was determined by hip-knee-ankle angle (HKA angle) [10]. Coronal subluxation was determined by subluxation value and assessed using the method described by Akamatsu [11] (**Figure 2**). Rotational deformity was determined by clinical epicondylar axis (CEA) and the medial third of the patella tendon as previously described (**Figure 3**). Medial and lateral joint space widths were determined by a method previously described by Tourville [14]. Settlement value, HKA angle, and subluxation value were measured on a spliced image of the total length lower extremities with local amplification. Rotational deformity was measured on CT axial view. Measurements were obtained by computerized goniometers and length meters of the Synapase System (Fujifilm Medical Systems, Stamford, U.S.A.) and RadiAnt DICOM Viewer (Medixant, Warsaw, Poland).

To test intra-and inter-observer reproducibility, two orthopedic surgeons performed all radiographic measurements in 20 randomly selected patients. The measurements were repeated after 1 week. The intra-class correlation coefficient (ICC) was used for assessment of intra-and inter-observer reliabilities. The results showed good reliability (all ICC > 0.7 for each measurement).

Statistical analyses

Statistical analyses were performed using SPSS version 19.0 statistical software for Windows (IBM, Armonk, New York). Continuous variables are expressed as the mean ± SD and categorical variables were expressed as frequencies. Ordinal logistic regression analyses were used to assess the association between geometrical factors and KL grade. Partial correlation coefficients were calculated to determine the relationship between geometrical factors. Except for two variables, all other variables were considered control variables after calculation of the partial correlation coefficient. A *P*

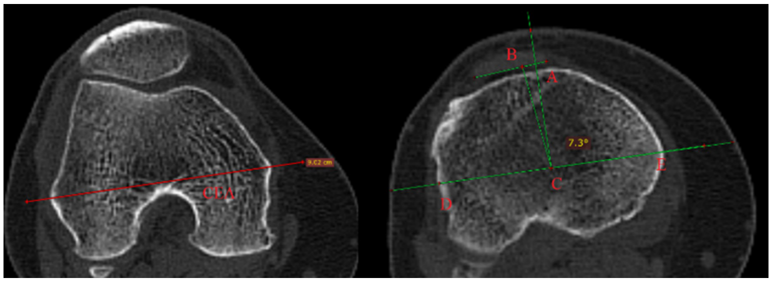

Figure 3. Line AC is the femoral reference line based on projection of the clinical epicondylar axis (CEA) onto the tibia (Line DE). Line BC is the tibial reference line which connects the midpoint of Line DE and medial 1/3 of the patella tendon. Angle ACB was measured as the femorotibial rotational position. When Line AC was located on the medial side relative to Line BC, the angle was expressed as a positive value.

value < 0.05 was considered to be statistically significant.

Results

A total of 66 patients with 104 knees were involved in this study, including 12 men (17 knees) and 54 women (87 knees). The mean age was 62.26±8.62 (range, 40-84) years. All participants were diagnosed and classified according to KL grades. Twenty-five, 58 and 21 knees were KL grade 2, KL grade 3, and KL grade 4, respectively. The average settlement value was 6.65±4.60 (range, -2.79-20.09) mm. The average HKA angle was 173.17±4.81 (range, 158-184) degrees. The average subluxation value was 11.95±6.57% (range, -7.9-28.92%). The average tibia rotation was 1.08±4.41 (range, -13.5-13.2) degrees. The average medial and lateral joint space width was 3.54±1.47 (range, 0-7.03) mm and 5.79± 1.35 (range, 3.37-10.16) mm, respectively. Knee geometrical measurement results in patients with different KL grades are shown in **Table 1**.

On logistic regression analysis, settlement value was the sole geometrical factor independently associated with KL grade. The other independent factor associated with KL grade was medial joint space width. Other geometrical factors, such as HKA angle, subluxation value, and tibia rotation, were not independently associated with KL grade. Logistic regression analysis results are shown in **Table 2**.

HKA angle and subluxation value were correlated with settlement value and with each other. Additionally, HKA angle and subluxation value were correlated with tibia rotation. The partial correlation coefficients between geometrical factors are shown in **Table 3**. Medial joint space width was correlated with settlement value, HKA angle, and tibia rotation. Lateral joint space width was correlated with settlement value and HKA angle. The partial correlation coefficients between geometrical measurements and joint space width are shown in **Table 4**.

Discussion

Geometrical deformities in patients with KOA are the following: varus alignment (change of HKA 167 angle), medial plateau settlement, coronal plane subluxation, and tibia external rotation. In patients with severe disease, these deformities tend to be more obvious. In patients with higher KL grades, varus deformity and settlement value are more obvious [10]. Khamaisy [4] concluded that knee joint subluxation is related to OA occurring mainly in the early stages. In addition, Matsui [5] proved that tibia rotation is correlated with varus alignment.

In our study, ordinal logistic regression analysis showed that only settlement value and medial joint space width are independently associated with KL grade. This suggested that, when the disease is aggravated, medial plateau settlement might be a primary deformity. Other geometrical deformities, such as varus malalignment, coronal subluxation, and tibia rotation, might be secondary changes following medial plateau settlement.

Settlement value was correlated with HKA angle and subluxation value in this study. A previous study demonstrated that medial plateau settlement is associated with varus deformity [10]. Due to medial plateau lowering, the femoral condyle loses its medial support, leading to varus deformity. Coronal tibiofemoral subluxation is a factor contributing to impaired load transmission and knee OA. This is related to poor Western Ontario and McMaster Universities (WOMAC) pain scores [15], tibial spine impingement on the femoral condyle

Table 1. Knee radiographic geometry parameters in osteoarthritis patients

K-L Grade	Gender (male/female)	Age	Settlement value	HKA angle	Subluxation vale	Tibia rotation	Medial joint space width	Later joint space width
2	4/21	61.24±11.72	4.24±3.39	176.52±3.56	13.87%±4.38%	3.89±3.49	5.06±0.75	5.65±1.51
3	10/48	62.53±7.50	6.00±3.81	173.71±3.30	11.21%±6.49%	-0.03±4.52	3.27±1.09	5.76±1.20
4	3/18	62.71±7.51	11.31±4.74	167.71±5.19	11.69%±8.54%	0.79±3.68	2.46±1.66	6.03±1.57

K-L grade, Kellgren and Lawrence grade; HKA angle, hip-knee-ankle angle.

Table 2. Results of ordinal logistic regression for Kellgren and Lawrence grades versus radiographic geometry parameters and joint space width

	OR	95% CI	P
Settlement value	1.534	1.228-1.917	< 0.001
HKA angle	1.006	0.820-1.234	0.955
Subluxation value	0.034	0.000-396.233	0.480
Tibia rotation	0.901	0.783-1.037	0.145
Medial joint space width	0.253	0.140-0.456	< 0.001
Lateral joint space width	1.079	0.737-1.580	0.694

HKA angle, hip-knee-ankle angle; CI, confidence interval for odds ratio.

Table 3. Partial correlation coefficient between different radiographic geometry parameters

	Settlement value	HKA angle	Subluxation value	Tibia rotation
Settlement value	1.000*	-0.718*	0.450*	-0.159
HKA angle	-0.718*	1.000*	0.331*	-0.300*
Subluxation value	0.450*	0.331*	1.000*	0.368*
Tibia rotation	-0.159	-0.300*	0.368*	1.000*

K-L grade, Kellgren and Lawrence grade; HKA angle, hip-knee-ankle angle. *P < 0.05.

Table 4. Partial correlation coefficient between geometry parameters and joint space width

	Settlement value	HKA angle	Subluxation value	Tibia rotation
Medial joint space width	0.498*	0.480*	-0.036	0.246*
Lateral joint space width	-0.277*	-0.386*	0.004	-0.131

HKA angle, hip-knee-ankle angle. *P < 0.05.

[16], and is a possible reason for unexplained pain following unicondylar knee arthroplasty [17]. However, the mechanisms of coronal subluxation in patients with medial knee OA remain unclear [11, 13-19]. In this study, the subluxation value was also positively associated with settlement value, suggesting that medial plateau settlement may be a cause of subluxation. This might be because after medial plateau settlement, the tibia articular surface slopes toward the medial side, and the femoral condyle slides to the medial side. Additionally, after non-uniform-settlement of the tibial plateau, the matching of the tibiofemoral joint worsens, making tibiofemoral subluxation easier. HKA angle was correlated with subluxation value in this study. We speculated that this could be related to the settlement position and range. When the settlement was mainly located on the medial side and had a larger range, tibiofemoral subluxation tended to occur more easily. In contrast, if the settlement was located relatively central and had a smaller range, the matching of the tibiofemoral joint remained ideal, and the knee joint tended to be varus.

Subluxation and HKA angle were correlated with tibia external rotation. Patients with a high subluxation value and varus deformity tended to have obvious tibia external rotation. Matsui [5] showed that malalignment is associated with tibia external rotation, but no study has correlated subluxation and tibia rotation. Our study demonstrated the relationship between subluxation and tibia rotation. Similar to subluxation, tibia rotation might be a consequence of worsening of tibiofemoral joint matching. Subluxation or malalignment may also contribute to this, because the medial soft tissue becomes less rigid and the lateral soft tissue stretches leading to tibia external rotation.

The degeneration of articular cartilage and the meniscus is the most important pathological change in KOA, and this may be commonly associated with knee joint geometrical changes [2]. As in previous studies [20, 21], varus malalignment was correlated with medial joint space narrowing. When lower extremity varus malalignment occurred, the stress was concentrated on the medial compartment, leading to cartilage degeneration [2]. Following cartilage thinning, we observed joint space narrowing on radiography. In our previous study, settlement value was negatively correlated with joint space width [10]. However, despite a change in measurement methods, settlement value had a positive partial correlation with medial joint space width in this study. This demonstrated that after eliminating the interaction with other geometrical deformities (e.g., varus malalignment), the direct result of medial plateau settlement was an increase in joint space width. After lowering the medial plateau and fixing the position of the femoral condyle, the joint space width tended to increase. However, medial plateau settlement was accompanied by varus malalignment and subluxation, and the latter deformities could result in medial joint space narrowing. Thus, joint space narrowing occurred along with the disease progression. Additionally, tibia external rotation was weakly negatively correlated with medial joint space narrowing, and the settlement value was weakly positively correlated with lateral joint space narrowing. The reasons and clinical significance of this remain unclear.

Similar to our study, Higano [6] introduced the concept of the tibial plateau angle, which is the inner angle formed by the tibial anatomical axis and the tibia joint surface. A smaller tibial plateau angle indicates lowering of the medial plateau. Driban [7] had introduced the concept of tibia coronal slope angle, which is the angle between the tibia long axis and the line connecting the medial and lateral aspects of the tibial plateau. A larger tibia coronal slope angle indicates that the lateral edge of the tibial plateau is more proximal than the medial edge. Despite different measurement methods, these studies are in agreement. In the Higano [6] study, the tibial plateau angle decreased more in patients with early-OA than in patients with non-OA, and decreased more in patients with advanced-OA than in non-OA and early-OA patients. They also demonstrated that the tibial plateau angle was independently associated with advanced-OA. They suggested that the smaller tibial plateau angle played a role in the onset of knee OA. In Driban [7] study, the tibia coronal slope angle was also larger in accelerated KOA than in common KOA or non-KOA. They suggested that coronal tibia slope was an important risk factor for incident-accelerated KOA. In summary, we suggest that KOA onset could be a consequence of non-uniform-settlement. After medial plateau settlement, secondary varus malalignment and subluxation occurs and these deformities lead to stress concentration on the medial compartment. Then, with cartilage and meniscus degeneration, pain and disability presented in patients.

We believe our results will be useful to help elucidate KOA pathogenesis. Furthermore, as a classical surgical procedure for KOA, high tibial osteotomy (HTO) aims to correct lower extremity varus malalignment. However, considering non-uniform-settlement, the objective of HTO should be to correct medial plateau settlement. In addition, it is important to pay attention to the settlement value to evaluate the disease severity in patients with KOA.

There are several limitations of this study. First, it lacks a control group. Therefore, we cannot identify if non-uniform-settlement is a distinctive geometrical change of KOA. Second, identifying the existence of settlement and its role in the pathogenesis process of medial compartment OA is challenging without a prospective study design. In addition, only some deformities were measured in standing, and the change of position may have influenced the measurements. Additionally, the assessment method of subluxation in this study was associated with the mechanical axis of femur and tibia; thus, the correlation between HKA angle and subluxation might be affected by systematic errors.

Conclusions

This study clarified the correlations between geometrical factors in patients with medial compartment KOA. In conclusion, settlement value was independently associated with KL grade in patients with KOA. HKA angle and subluxation value were correlated with settlement value and with each other. Additionally, tibia rotation was correlated with HKA angle and subluxation value. Settlement value might be the primary geometrical change in KOA. We believe this may provide useful information to help elucidate the pathogenesis of KOA and to determine appropriate osteotomy position in total knee arthroplasty and HTO.

Acknowledgements

The study was approved by the Ethical Committee of the Third Hospital of Hebei Medical University and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from the patients prior to their participation in this study.

Disclosure of conflict of interest

None.

Abbreviations

KOA, knee osteoarthritis; OA, osteoarthritis; CT, computed tomography; PACS, picture archiving and communication systems; KL grade, Kellgren and Lawrence grade; HKA angle, hip-knee-ankle angle; CEA, clinical epicondylar axis; ICC, intra-class correlation coefficient; WOMAC pain scores, Western Ontario and McMaster Universities pain scores; HTO, high tibial osteotomy.

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