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Original Article

Kinematics of the anterior interval in individuals with knee osteoarthritis

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Abstract. [Purpose] Abnormal anterior interval kinematics may be associated with knee pain and loss of knee motion. We investigated the anterior interval kinematics during passive knee extension in individuals with knee osteoarthritis (OA). [Participants and Methods] The anterior interval space was evaluated in 13 healthy knees (healthy group) and 11 knees with OA (knee OA group) at 30° and 15° knee flexion using ultrasonography. We measured the angle between the anterior tibia and patellar tendon, known as the patellar tendon–tibial angle (PTTA). [Results] The PTTA significantly increased as the angle of knee flexion decreased in the healthy group. In the knee OA group, the PTTA did not change significantly at 30° and 15° knee flexion. The knee OA group had a considerably higher PTTA at 30° knee flexion and a smaller amount of change in PTTA during knee angle changes than the healthy group. However, after adjusting for age and body mass index (BMI), no significant differences were observed between groups. [Conclusions] Differences in the anterior interval kinematics during knee motion between groups may be due to aging and high BMI. Further research is required to address most of the factors influencing these abnormalities.

Key words: Anterior interval, Knee osteoarthritis, Ultrasonography

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INTRODUCTION

Knee osteoarthritis (OA) is a prevalent joint condition responsible for pain and limitations in functional ability. Knee OA develops in 22.9% of people aged >40 years. The global prevalence of knee OA remained high from 2000 to 2020[1)]. It is a severe problem for individuals with knee OA and the global healthcare system.

Risk factors for knee OA include obesity, aging, sex, and quadriceps muscle weakness[2, 3)]. Recent studies have reported the potential involvement of the infrapatellar fat pad (IPFP) in the progression of knee OA[4, 5)]. IPFP is situated in the knee anterior space[6)]. The IPFP adjusts its position depending on the changes in the anterior knee space and acts as a deformable space filler[7)]. Therefore, to understand IPFP movement, the kinematics of the space in which the IPFP exists must be clarified.

The IPFP exists in the anterior interval[8)]. The anterior interval is the area composed of the patellar tendon anteriorly and the anterior border of the tibia and the transverse meniscal ligament posteriorly[8)]. The behavior of IPFP is associated with changes in the anterior interval space. During knee flexion, the anterior interval space decreases, and the IPFP moves backward (emptying the space), whereas it increases with knee extension, and the IPFP moves forward (filling the space)[9)]. The opening and closing of the anterior interval could be impacted by the kinematics of the patellofemoral and tibiofemoral joints[10)]. Degenerative changes of patellofemoral and tibiofemoral joints and limited range of motion commonly manifest in individuals with knee OA. Therefore, the kinematics of patellofemoral and tibiofemoral joints in individuals with knee

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OA may differ from healthy knees. These deviations may also affect the kinematics of the anterior interval, and individuals with knee OA may have a reduced ability to change the anterior interval during knee motion. However, the kinematics of the anterior interval has not been clarified during knee movement in individuals with knee OA.

This study aimed to determine the kinematics of the anterior interval during knee movement in individuals with knee OA. Our hypothesis is that individuals with knee OA would experience a small than average changes in the anterior interval space occurring in response to knee motion.

PARTICIPANTS AND METHODS

This study enrolled 11 individuals with knee OA (2 males and 9 females, mean age 70.8 ± 9.1 years, mean height 154.1 ± 6.2 cm, mean weight 63.0 ± 16.9 kg, mean body mass index [BMI] 26.4 ± 6.0 kg/m^2) classified as the knee OA group. They were recruited from the patients at Soseigawadori Orthopedic Clinic and diagnosed with knee OA based on clinical knee symptoms and radiography (Kellegren–Laurence grades 1–4)[11]. In the knee OA group, the more painful side was the limb to measure in the case of bilateral knee OA. As a result, 11 knees were selected to represent the OA knee group. Individuals with knee OA were evaluated physically, with their flexion and extension ranges of motion measured by a goniometer. Measurements were performed 3 times at 1° increments. Thirteen knees from 7 healthy individuals (3 males and 4 females, mean age 34.6 ± 4.5 years, mean height 167.3 ± 4.3 cm, mean weight 55.4 ± 8.0 kg, mean BMI 19.7 ± 1.9 kg/m^2) were categorized as healthy group for comparison. Healthy individuals were recruited from the staff of the Soseigawadori Orthopedic Clinic. The criteria for exclusion consisted of individuals who faced knee pain, have prior history of knee surgery or injury, and show restricted knee mobility.

The research received approval from the ethics committee of the Health Sciences University of Hokkaido (#21R162156) and it adhered to the principles of the Declaration of Helsinki. Verbal and written informed consent was obtained from all participants before the initiation of the study.

Kinematics of the anterior interval were evaluated using ultrasonography. Measurement of patellar tendon–tibial angle (PTTA) has been commonly used for kinematic evaluation of the anterior interval[10, 12, 13], and in recent years, measuring the PTTA using ultrasonography has been reported as a reliable method[12, 13]. Ultrasonography was performed using a FC1-X (Fujifilm Corp., Tokyo, Japan) along with the L15-6 linear probe. One researcher (H.K.) evaluated the ultrasonic data. Because abnormal kinematics in the anterior interval result in a loss of terminal knee extension[8], previous research has evaluated the PTTA from 30° of knee flexion to full knee extension[12]. However, because in individuals with knee OA, it is difficult to obtain measurements at 0° of knee flexion due to knee flexion contracture, for both groups, the knee flexion angles used for measurement were 30° and 15° of flexion. The participants were instructed to lie supine on the bed. The angle of knee joint was adjusted to the desired position with the popliteal fossa set up on a pillow. A goniometer was used to evaluate the flexion angle of the knee joint. Participants were instructed to remain at rest because contractions of quadriceps muscles might affect measurements of the knee's anterior soft tissue dynamics[14]. The IPFP, anterior tibia, and patellar tendon were scanned with the probe positioned along the patellar tendon's natural trajectory (Fig. 1). Three separate, high-quality ultrasound images were taken each set of measurements. The probe was held firmly against the patellar tendon and the proximal tibia by manual pressure.

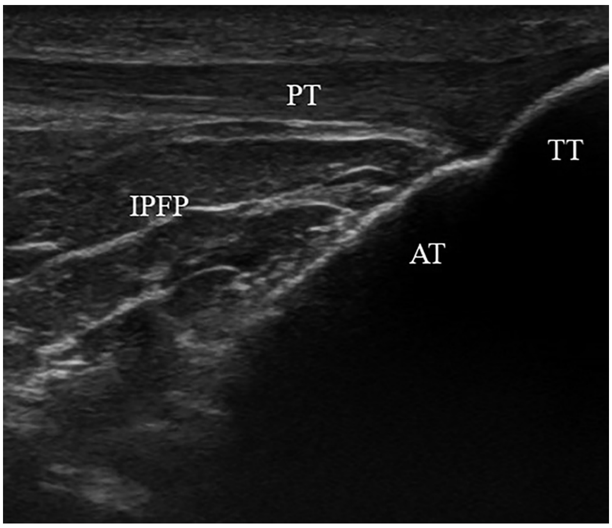

Fig. 1. Ultrasound image of the anterior interval.
AT: anterior border of the proximal tibia; IPFP: infrapatellar fat pad; PT: patellar tendon; TT: tibial tuberosity.

Data obtained from the ultrasonographic images were uploaded to a computer and analyzed using the ImageJ software (https://imagej.nih.gov/ij/). The outcome was the PTTA[10, 13)], which is the angle made by the anterior border of the tibia and inferior border of patellar tendon (Fig. 2). On ultrasonography, the patellar tendon showed a typical fibrillar pattern[15)], which was used as an indicator to identify the anatomical boundary between the IPFP and inferior border of patellar tendon. The anterior interval space is reflected in the PTTA, with a larger angle indicating greater space and a smaller angle indicating lesser space. The PTTA at each knee flexion angle and its amount of change were examined. Amount of change in PTTA was calculated by subtracting the PTTA at 30° knee flexion from the PTTA at 15° knee flexion. The PTTA analysis by Image-J was conducted by the same examiner (H.K.) who took the ultrasonography measurements, resulting in unblinded analysis data.

R version 2.8.1 (R Foundation, Vienna, Austria) was used for statistical analyses. Intergroup differences in the number of male and females were compared using the χ^2 test. Participants' age, height, weight and BMI in each group were compared using unpaired t-test or Mann–Whitney U-test based on the normality of the data. In intragroup comparisons, the effect of change in knee angle on PTTA was examined. The paired t-test was used for statistical analysis. Between groups, the PTTA at each knee flexion angle and the amount of change in PTTA were compared using an unpaired t-test. The mean value of the three experimental results was used for the analysis. Each t-test was conducted after the normality of the data was confirmed by the Shapiro–Wilk test. For items showing significant results in the unpaired t-test for PTTA at each knee flexion angle and the amount of change in PTTA, an analysis of covariance (ANCOVA) was conducted with age and BMI as covariates. This was done to reduce the potential impact of age and BMI on the between-group comparisons. Height and weight values were excluded as covariates because they are reflected in BMI. For each statistical studies, the alpha level was fixed at 0.05. To confirm the reliability of the PTTA measurement, we calculated the intraclass correlation coefficient (ICC) for types (1, 3), as well as the standard error of measurement (SEM) and 95% confidence interval (CI). The ICC is used to assess the relative reliability of the measurement, with values ranging from <0.50 for poor reliability, 0.50−0.75 for moderate reliability, 0.75−0.90 for good reliability, and >0.90 for excellent reliability[16)]. ICC was calculated from PTTA values measured three times in all participants of both groups at each knee joint angle. SEM, indicative of the absolute reliability of the measurement, was calculated using the formula: SEM=standard deviation (SD) × $\sqrt{1 - \text{ICC}}$[17)]. Furthermore, the 95% CI for SEM was calculated as follows: 95% CI for SEM=mean value of the three experimental results in each group ± 1.96 × SEM[17)].

RESULTS

Table 1 shows the basic characteristics in both groups. The knee OA group was significantly shorter in stature, had a higher BMI, and was older than the healthy group. Results of the χ^2 test showed no significant difference in the number of male or females between the groups.

Table 2 shows the ICC values for types (1, 3), SEM and its 95% CI. At 30° knee flexion, the ICC (1, 3) for the PTTA was 0.97 (95% CI: 0.94–0.99), and at 15° knee flexion, it was 0.95 (95% CI: 0.90–0.98). In the healthy group, the 95% CIs for SEM of the PTTA were 31.3–35.1° at 30° knee flexion and 36.6–41.3° at 15° knee flexion. In the knee OA group, the 95% CIs for SEM of the PTTA were 36.1–40.0° at 30° knee flexion and 38.0–42.7° at 15° knee flexion.

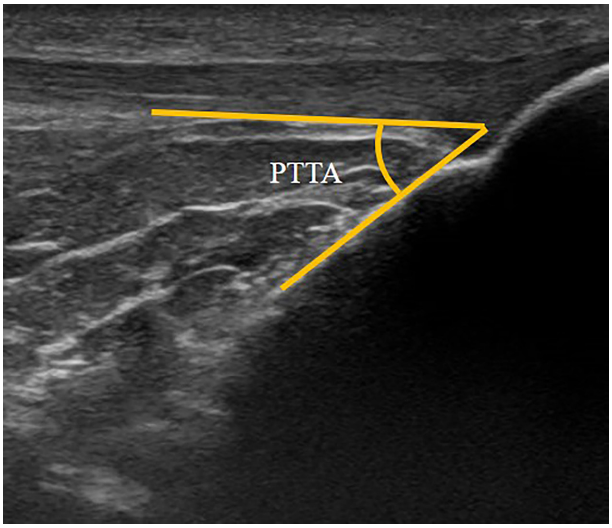

Fig. 2. Patella tendon–tibial angle (PTTA) measurement.
The PTTA was measured as the angle between the anterior border of the proximal tibial epiphysis and the patellar tendon.

The PTTAs for the both groups are presented in Table 3. The healthy group had PTTAs of 33.2 ± 5.8° and 39.0 ± 6.1° at 30° and 15° knee flexion, respectively. The PTTA rose significantly in the healthy group from 30° to 15° knee flexion. At 30° and 15° of knee flexion, the PTTAs were 38.1 ± 4.6° and 40.3 ± 3.8°, respectively, in the knee OA group. In this group, the PTTA did not change significantly when the knee angle varied. For intergroup comparisons, PTTA at 30° knee flexion was significantly higher in the knee OA group. There was no substantial difference in the PTTA at 15° knee flexion between the groups. From 30° to 15° knee flexion, the amount of change in PTTA was significantly less in the knee OA group compared to the healthy group. However, the ANCOVA results revealed no significant difference in PTTA at 30° knee flexion or the amount of change in PTTA between the groups.

Table 1. Basic data for both groups

		Knee OA group	Healthy group
Male		2	3
Female		9	4
Age (years)		70.8 ± 9.1	34.6 ± 4.5**
Height (cm)		154.1 ± 6.2	167.3 ± 4.3**
Weight (kg)		63.0 ± 16.9	55.4 ± 8.0
BMI (kg/m^2)		26.4 ± 6.0	19.7 ± 1.9 *
Kellgren–Lawrence grade	grade 1	0	-
	grade 2	1	-
	grade 3	7	-
	grade 4	3	-
Range of motion	Knee flexion (°)	126.0 ± 15.3	-
	Knee extension (°)	−9.0 ± 4.2	-

The age, BMI, and knee range of motion values are presented as means ± standard deviations.
Negative values for knee extension range of motion indicate the presence of flexion contracture.
*Unpaired t-test p<0.05, **Unpaired t-test p<0.01.
†Mann–Whitney U test p<0.05, ††Mann–Whitney U test p<0.01.
OA: osteoarthritis; BMI: body mass index.

Table 2. Intraclass correlation coefficient, standard error of measurement and its 95% coefficient interval at the patellar tendon-tibial angle for each knee angle

		Knee flexed at 30°	Knee flexed at 15°
ICC (95% CI)		0.97 (0.94–0.99)	0.95 (0.90–0.98)
SEM		0.97	1.20
SEM for 95% CI in PTTA	Healthy group	31.3–35.1	36.6–41.3
	Knee OA group	36.1–40.0	38.0–42.7

CI: confidence interval; ICC: intraclass correlation coefficient, PTTA: patella tendon–tibial angle; OA: osteoarthritis.

Table 3. Patellar tendon-tibial angle for each knee angle and its amount of change in both groups

	Healthy group (n=13)			Knee OA group (n=11)		
	Knee flexed at 30°	Knee flexed at 15°	Amount of change	Knee flexed at 30°	Knee flexed at 15°	Amount of change
PTTA (°)	33.2 ± 5.8	39.0 ± 6.1**	5.8 ± 4.2	38.1 ± 4.6†	40.3 ± 3.8	2.3 ± 3.4†

Values are presented as means ± standard deviations.
The effect of different knee flexion angles on PTTA was examined using paired t-tests in intragroup. PTTA at each knee flexion angle and the amount of change in PTTA was compared between groups using an unpaired t-test. Comparisons were made by ANCOVA adjusted for age and BMI for items that were considerably different by the unpaired t-test.
*paired t-tests p<0.05, **paired t-tests p<0.01.
†unpaired t-test p<0.05, ††unpaired t-test p<0.01.
§ANCOVA p<0.05, §§ANCOVA p<0.01.
PTTA: patella tendon–tibial angle; OA: osteoarthritis, ANCOVA; analysis of covariance.

DISCUSSION

To the best of our knowledge, only a few studies have investigated the kinematics of the anterior interval in individuals with knee OA. Consistent with our hypothesis, the knee OA group showed less change in the PTTA with changes in knee joint angle. Given that there was no discernible difference in the number of males and females between the groups, it suggests that gender had little impact on the study's findings. However, based on the ANCOVA results, it was concluded that the abnormal kinematics of anterior interval demonstrated by individuals with knee OA were influenced not only by the knee OA condition, but also by age and BMI.

In this study, young healthy adults were used as control group. The kinematics of the anterior interval in individuals with knee OA have rarely been examined and must first be characterized in comparison with the normal knee. Some elderly individuals are asymptomatic; however, they develop deformities of the knee joint as can be observed in radiographic images[18]. Ethical considerations make it difficult to X-ray knee joints in asymptomatic individuals. Therefore, using age-matched asymptomatic older adults as the healthy knee group for comparison with knee OA group is not optimal, as it is unclear whether they have knee joint deformities on radiography. Hence, young healthy adults were recruited as a control group in this study to compare knee OA with knees in optimal condition. Due to ethical constraints, radiographs were not obtained in the healthy group, and the presence of knee joint deformity was not definitively confirmed. The healthy group in this study had an average age of 34.6 ± 4.5 years, with a reported low prevalence of knee OA in the 30s at 2.5%[1]. Furthermore, the healthy group did not have obesity or a history of knee injury, which are well-known risk factors for developing knee OA[2]. Furthermore, no one in this group reported experiencing knee pain during daily activities. Therefore, it seems reasonable to assume that the healthy group's knee joints have not developed any deformities and are in good condition.

In this study, the ICC (1, 3) was used as an index to evaluate the intra-rater reliability of measurements. The results showed an ICC (1, 3) greater than 0.9 at each knee angle, indicating excellent intra-rater reliability in the ultrasonographic measurement of the PTTA. The 95% CI for SEM is interpreted as the boundary within which the true value is expected to exist 95% of the time[17]. In the healthy group, PTTA increased significantly by 5.8° from 30° to 15° of knee flexion. The lack of overlap in the 95% CI of the SEM between 30° and 15° knee flexion in healthy group indicates the ability to detect changes beyond the margin of error. Therefore, the PTTA measurement in this study was deemed sufficiently reliable.

This study results showed that the kinematics of the PTTA during knee angle change differed between the knee OA and healthy groups. In the healthy group, the PTTA significantly increased from 30° to 15° knee flexion. This result is consistent with those of the previous studies and suggests that the space of the anterior interval widens with knee extension[9, 10]. The PTTA did not change significantly in the knee OA group as the knee angle varied. Furthermore, the amount of change in PTTA was smaller than that in the healthy group during knee motion. This may reflect that the area of the anterior interval expansion is inhibited at knee extension in the knee OA group. However, there was no significant difference in change of PTTA during knee motion between groups in the ANCOVA results, after controlling for the effects of age and BMI. This finding suggests that old age and high BMI can influence the change in PTTA during knee motion in the knee OA group. A previous study indicated that the mechanics of the anterior interval could be influenced by the kinematics of both the patellofemoral and tibiofemoral joints[10]. Age-related changes in connective tissue, resulting in increased its stiffness[19]. This increase in connective tissue stiffness, especially if it occurs around the anterior knee, may induce kinematic abnormalities of the patellofemoral joint. Furthermore, it has been reported that obesity can exacerbate joint degeneration due to increased joint load, adipose tissue inflammation, and impaired lipid metabolism[20]. The degenerative changes in the knee joint associated with such a high BMI may cause abnormal kinematics in both the patellofemoral and tibiofemoral joints, influencing the kinematics of the anterior interval. Hence, it can be inferred that older age and higher BMI may contribute to abnormal mechanics in the anterior interval, resulting from altered knee joint kinematics.

According to the results of the unpaired t-test, the knee OA group had a significantly higher PTTA at 30° knee flexion than the healthy group. However, after using ANCOVA to adjust for age and BMI, no significant difference was found in this comparison. This suggests that the elevation of PTTA at 30° knee flexion was influenced by age and BMI. Chuckpaiwong et al. found that IPFP volume correlated with age in individuals with knee OA[21]. In addition, Burda et al. noted that BMI related to the IPFP volume[22]. Thus, aging and high BMI may have increased IPFP size in the knee OA group in this study. The anterior interval could be expanded to accommodate this augmented IPFP, which could then be stored within the anterior knee space. As a result, PTTA at 30° knee flexion would have been higher in the knee OA group in a comparison that did not adjust for age and BMI. Optimal mobility of the patella and surrounding connective tissues may be critical for increasing space of anterior knee. However, the presence of knee flexion contracture in the knee OA group may have limited patellar and surrounding connective tissues mobility as the knee joint approached full extension, preventing anterior interval widening. Therefore, this is thought to be the reason for the lack of significant differences in PTTA at 15° of knee flexion by unpaired t-tests.

Based on our findings, we can conclude that kinematic abnormalities in the anterior interval may occur in the knee OA group because of old age and high BMI, in addition to the presence of knee OA. Abnormal kinematics of the PTTA may influence pain and range of motion of the knee joint. Steadman et al. described the findings of arthroscopic surgical release in individuals with the anterior interval scarring[8]. The IPFP is immobile during knee motion when the anterior interval has closed because of a scar. Following the surgical removal of the scar, symptoms (knee pain and restricted knee extension) in most patients were alleviated[8]. The anterior interval structures must be opened and closed during knee movement so that the IPFP moves normally and impingement can be avoided[10]. Therefore, the kinematic abnormalities of the anterior interval observed in the knee OA group may inhibit IPFP movement and contribute to pain in the anterior knee and limited range of motion. Further research is needed to elucidate the multifaceted factors contributing to the kinematic aberrations in the anterior interval among individuals with knee OA.

This study has several limitations. First, the healthy and knee OA groups were not matched for age or BMI. Although an ANCOVA was used to adjust for the effects of age and BMI, the optimal study design was to match the age and BMI of the control and knee OA groups. However, it is ethically difficult to identify knee deformities radiographically in healthy older adults. Thus, comparing the knee OA group solely with an age- and BMI-matched control group does not fully elucidate the impact of knee OA on anterior interval kinematics. Therefore, future studies should compare three groups: a knee OA group, a group of healthy older adults matched for age and BMI with the knee OA group, and a group of healthy younger adults. This approach will help clarify the kinematics of the anterior interval in individuals with knee OA, while accounting for the effects of age and BMI. Second, no comparison was made to the severity of knee OA. Because pathological changes on IPFP are associated with the severity of knee OA[23], the kinematics of the anterior interval may differ depending on its severity. Therefore, the best study design was to standardize the Kellegren–Laurence grades within the knee OA group and investigate the kinematics of the anterior interval in individuals with knee OA, while controlling for the impact of knee OA grade. Unfortunately, the sample size in the knee OA group was insufficient to compare OA grades. Consequently, future research should focus on increasing the sample size, ensuring that Kellegren–Laurence grades are unified and accounting for the effect of knee OA severity. Third, this study was not blinded, which could have introduced bias and influenced the results. Last, the study results cannot be adapted to weight-bearing conditions. Dragoo et al. reported that the change in the PTTA with knee motion was reduced in weight-bearing conditions than in non-weight-bearing conditions[10]. In the future, whether differences in measurement conditions affect the kinematics of anterior interval in individuals with knee OA must be elucidated.

Finally, individuals with knee OA showed differences in the kinematic characteristics of the anterior interval compared to healthy young adults. However, these disparities are due to more than just knee OA; they also include aging and high BMI. Future research is needed to identify most issues that cause kinematic abnormalities in the anterior interval.

Conference presentation

Part of this research was presented at the 11th Annual Meeting of the Japanese Society of Musculoskeletal Physical Therapy.

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Conflict of interest

None of the authors have any conflict of interest to declare.

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