Research Square

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Optimal distraction force for evaluating joint laxity following total knee arthroplasty

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Abstract

Background

Appropriate intraoperative soft-tissue balance is essential for achieving successful outcomes following total knee arthroplasty (TKA). However, the optimal distraction force for evaluating joint laxity remains unclear. This study aimed to compare joint laxities measured using specific distraction forces with those obtained under manual varus–valgus stress and assess the interobserver variability.

Methods

A total of 55 bi-cruciate-stabilized TKAs were performed using a robotic system. Medial and lateral joint laxities were evaluated using a force-controlled tensioner device under a distraction force of 60 and 80 N at 10°, 30°, 60°, and 90° of flexion and under manual varus–valgus stress using the robotic system. To determine interobserver differences, measurements were conducted by two surgeons

Results

In the medial compartment, joint laxity under manual stress was comparable to that measured using a distraction force of 80 N at 10° and 30° of flexion and a distraction force of 60 N at 60° and 90° of flexion. In the lateral compartment, joint laxity under manual stress was similar to that measured using a distraction force of 80 N across at 10° and 90° of flexion. Interobserver variability was greater in the lateral compartment than in the medial compartment, especially at higher flexion angles.

Conclusions

Manual stress evaluation corresponded to different distraction forces depending on the compartment and flexion angle. The lateral compartment showed greater measurement variability, suggesting the need for careful assessment and standardization of intraoperative joint laxity evaluation during robot-assisted TKA.

Introduction

Achieving good clinical outcomes following total knee arthroplasty (TKA) requires appropriate soft-tissue balancing, as well as accurate osteotomy and implantation [1–3]. Several previous studies have reported that coronal stability during knee extension, mid-flexion, and 90° flexion can affect postoperative clinical outcomes and range of motion (ROM) [4–7]. Therefore, surgeons need to ensure appropriate soft-tissue balance during surgery. Measuring the joint gap using tensioner devices has been a widely used technique for evaluating intraoperative soft-tissue balance [8]. Another technique for

evaluating intraoperative soft-tissue balance involves the use of computer-based tools, such as robotic systems and navigation techniques [9, 10].

Numerous studies have investigated the relationship between intraoperative joint laxity, measured by applying a distraction force using tensioner devices, and postoperative clinical outcomes. Accordingly, these studies have proposed several intraoperative joint laxity values that could be targeted to achieve favorable clinical outcomes [11, 12]. Although soft-tissue balance can be quantitatively evaluated using the tensioner device, similar quantification is difficult to achieve given that computerized assessments of soft-tissue balance require manual stress application [13]. Assessment of soft-tissue balance using a robot that requires manual stress application can produce highly variable results based on the force applied by the surgeon and the degree of knee flexion [14–16]. Therefore, clarifying the association between joint laxity measured using a specific distraction force and that measured under varus-valgus stress, as well as the reproducibility of measurements obtained under manual stress application may greatly improve our understanding of the optimal soft-tissue balance required for successful treatment outcomes following robot-assisted TKA.

The current study aimed to compare joint laxities assessed under varus–valgus stress with those measured using distraction forces of 60 and 80 N across a range of flexion angles, as well as evaluate the presence of interobserver variability.

Methods

This study was approved by the institutional review board. All patients provided written informed consent prior to participation.

From May 2024 to August 2025, 61 primary bi-cruciate-stabilized (BCS) (Journey II BCS, Smith and Nephew, Memphis, TN, United States) TKAs were performed by a single senior surgeon using a robotic system (CORI, Smith and Nephew, Memphis, TN, United States). Among them, 55 BCS TKAs were performed in 51 patients (10 males and 41 females; average age, 73.4 ± 7.8 years, range 54 to 85 years) who were included for the analysis. Moreover, 53 and 2 knees were diagnosed with osteoarthritis and osteonecrosis, respectively. The average preoperative hip–knee–ankle (HKA) angle was 172.0 ± 7.7° (range 151°–190°).

Surgical procedures

All patients underwent a paramedian approach with no eversion of the patella. The surgeon performed aggressive removal of osteophytes and minimal release of medial soft tissues for bone resection.

Femoral alignment was performed at a placement of 90° to the mechanical axis in the frontal plane and 4° of flexion in the sagittal plane using the robotics system. Tibial alignment was performed at a placement of 90° to the mechanical axis in the frontal plane and 4° of posterior slope in the sagittal plane.

The extension and flexion gaps were measured using a force-controlled compartment-specific ligament tensioner with a distraction force of 80 N each for the medial and lateral compartments (i.e., a total of 160 N) [17]. For posterior femur resection, the amount of tissue resected was adjusted to ensure that the extension and flexion gaps of the medial compartment remained equal to secure medial stability. Femoral rotation was parallel to the surgical epicondylar axis, allowing for residual lateral ligamentous laxity [18, 19]. Tibial rotational alignment was determined using the range of motion anatomical technique, thereby reducing the rotational mismatch of the components [20].

Medial and lateral joint laxities evaluated using the tensioner device

Component gaps were measured by the chief surgeon using a femoral trial implant and force-controlled, compartment-specific ligament tensioner [21, 22], with distraction forces of 60 and 80 N for the medial and lateral compartments, at a knee flexion of 10°, 30°, 60°, and 90° (Fig. 1). The flexion angle was measured using the robotic system. The patellofemoral joint was reduced while the joint gap was decreased. Medial and lateral joint laxities evaluated using the tensioner device (JLT) were defined as the difference between the component gap value and the selected thickness of the tibial component.

Medial and lateral joint laxities evaluated using the robotic system

After prosthesis implantation, the medial and lateral laxities were evaluated by applying the maximum manual varus–valgus stress using the robotic system. First, the surgeon performed gentle, manual, and mild passive knee flexion without angular acceleration, while moving the leg from full extension to deep flexion. Next, using the maximum manual varus–valgus stress, the surgeon steadily moved the knee from full extension to flexion. Stress application and measurement cycles were repeated until the display registered no further changes in the recorded mediolateral joint laxity. The joint laxities of each compartment evaluated using the robotic system (JLR) were automatically shown on the display during the surgery (Fig. 2). To evaluate the inter-measurer variability, measurements were performed by two surgeons, first by the senior surgeon (HI) and then by the first assistant surgeons consisting of three knee surgeons with moderate experience. They averted their gazes from the robotic system's monitor during the senior surgeon's evaluation to keep the measurements obtained by the senior surgeon unknown to them.

Statistical analysis

Data were analyzed using the Bell Curve 2016 (SSRI Co., Ltd., Tokyo, Japan) software package for Microsoft Windows. Tests for normality and distribution were performed using the Kolmogorov–Smirnov test. Student's paired t-test was used to compare the quantitative variables and differences between the three groups. A one-way repeated-measures analysis of variance (ANOVA) was performed to compare the JLR, JLT60N, and JLT80N. *Post hoc* pairwise comparisons were conducted using the Bonferroni

correction. Power analysis using G*Power 3 (Heinrich Heine Universitat Dusseldorf, FRG) determined that a sample size of 42 patients was needed to compare the joint laxities among the three groups, which was consistent with that reported in one previous study [16]. All significance tests were two-tailed, with a P value of < 0.05 indicating statistical significance for all tests.

Results

Figure 3 shows the JLT60N, JLT80N, and JLR of the medial compartment at 10°, 30°, 60°, and 90° knee flexion. At 10° flexion, JLR ($P < 0.001$) and JLT80N ($P < 0.001$) were significantly larger than JLT60N. At 30° knee flexion, JLR ($P < 0.001$) and JLT80N ($P < 0.001$) were significantly larger than JLT60N. No significant differences were observed between JLR and JLT80N at 10° and 30° knee flexion. At 60° knee flexion, JLT80N was significantly larger than JLR ($P < 0.001$) and JLT60N ($P < 0.001$), whereas JLR was significantly larger than JLT60N ($P = 0.047$). At 90° knee flexion, JLT80N was significantly larger than JLR ($P < 0.001$) and JLT60N ($P < 0.001$), whereas no significant difference was noted between JLR and JLT60N.

Figure 4 shows the JLT60N, JLT80N, and JLR of the lateral compartment at 10°, 30°, 60°, and 90° knee flexion. At 10° knee flexion, JLR ($P < 0.001$) and JLT80N ($P < 0.001$) were significantly larger than JLT60N, whereas no significant difference was noted between JLR and JLT80N. At 30° knee flexion, JLR was significantly larger than JL60N ($P < 0.001$) and JLT80N ($P = 0.014$), whereas JLT80N was significantly larger than JLT60N ($P < 0.001$). At 60° knee flexion, JLR was significantly larger than JLT80N ($P < 0.001$) and JLT60N ($P < 0.001$), whereas JLT80N was significantly larger than JLT60N ($P < 0.001$). At 90° knee flexion, JLR ($P < 0.001$) and JLT80N ($P < 0.001$) were significantly larger than JLT60N, whereas no significant difference was noted between JLR and JLT80N.

Table 1 shows the JLRs evaluated by the senior surgeon and first assistants. Notably, no significant differences in all JLR parameters were observed between the two groups. Figure 5 presents the absolute inter-observer error values at each flexion angle. The absolute error values in the lateral compartment were significantly greater than those in the medial compartment at flexion angles of 30° ($P = 0.010$), 60° ($P = 0.022$), and 90° ($P < 0.001$). In the lateral compartment, the absolute error values at a flexion angle of 90° were significantly larger than those at 10° ($P = 0.007$) and 30° ($P = 0.002$), whereas no significant differences in absolute error values were observed among each flexion angle in the medial compartment.

Table 1
JLR evaluated by the senior surgeon and first assistants

Medial	Flexion angle	Senior surgeon	First assistants	P value
	10°	**1.5 ± 0.5mm**	**1.5 ± 0.6mm**	**0.792**
compartment	30°	1.7 ± 0.7mm	1.8 ± 0.8mm	0.284
	60°	1.1 ± 0.7mm	1.2 ± 0.7mm	0.267
	90°	1.3 ± 0.6mm	1.3 ± 0.8mm	0.601
Lateral	10°	4.0 ± 1.3mm	4.1 ± 1.4mm	0.791
compartment	30°	4.5 ± 1.3mm	4.8 ± 1.4mm	0.272
	60°	4.1 ± 1.3mm	4.0 ± 1.7mm	0.825
	90°	4.8 ± 1.3mm	4.4 ± 1.8mm	0.127
JLR: joint laxity evaluated using the robotic system				

Discussion

The most important findings obtained in the current study were that JLR parameters were similar to JLKB80N at 10° and 30° and that those of JLR were similar to JLKB60N at 60° and 90° in the medial compartment. Additionally inter-observer differences for the lateral compartment were larger than those for the medial compartment.

Knee joint stability in the coronal plane has been identified as a key factor for achieving successful treatment outcomes after TKA [23, 24]. Therefore, surgeons need to ensure appropriate soft-tissue balance during surgery through quantitative evaluation achieved using the tensioner device. However, the optimal distraction force to be used intraoperatively remains unclear. Asano et al. had applied 60–180 N to the medial and lateral components during knee extension and flexion to investigate soft-tissue properties during posterior stabilized-type implants [25]. Accordingly, they reported stiffness values of 8.9 and 8.5 N/mm with a distraction force of 60 N during knee extension and stiffness values of 26.6 and 21.4 N/mm with a distraction force of 180 N during flexion. Moreover, they revealed that stiffness increased with distraction force. In contrast, Heesterbeek et al. showed that when forces higher than 60 N in each compartment (total of 120 N) are used for gap distraction, the ligamentous sleeve of the knee might experience over-tension [26]. Thus, the appropriate distraction force needed for gap measurements has remained controversial. One recent report showed that joint laxities evaluated under manual varus–valgus stress during robot-assisted surgery at extension were comparable to those measured under an 80 N/80 N distraction force using a tensioner device, whereas joint laxity values at other flexion angles were not equivalent [27]. The current study showed that joint laxities in the medial compartment measured under manual stress at 10° and 30° were comparable to those measured under 80 N using a tensioner device, whereas those measured under manual stress at 60° and 90° were

comparable to those measured under an 60 N using a tensioner device. These results could be attributed to the different behaviors of the capsular structures and collateral ligaments of the medial compartment at various knee flexion angles [28]. Surgeons should be aware that joint laxity evaluated using manual stress might be weak enough to underestimate the joint laxity evaluated using a tensioner device during flexion.

Regarding the reproducibility with respect to study results between surgeons, we found no significant interobserver difference in either the medial or lateral compartments when evaluated using the mean values. Somiya et al. reported that surgeon experience was a potent factor in the prediction of final soft-tissue balance [16]. When performing robot-assisted surgery, an experienced surgeon produces larger gaps using manual stress in both compartments when compared to an inexperienced surgeon. One of the reasons might be the extensive experience of the three first assistants in performing TKA, including robot-assisted TKA procedures. Also, Somiya et al. applied distraction forces to the medial and lateral compartments using manual stress via the Z-shaped retractor [16].

However, when evaluated using the absolute error values, the errors in the lateral compartment were greater than those in the medial compartment at flexion angles of 30°, 60°, and 90° and increased with greater degrees of flexion. A maximum inter-observer error of 4.0 mm was observed at 90° flexion in the lateral compartment. Although the lateral compartment possesses physiological laxity [19, 29], suggesting that a strict soft-tissue balance assessment may not be as necessary as that in the medial compartment, surgical concepts, such as kinematic alignment and functional alignment, which help optimize medial–lateral balance, are becoming more widespread [30, 31]. Studies have reported that during BCS TKA, joint laxity in the lateral compartment at 90° flexion was associated with patient satisfaction [32]. Therefore, ensuring the reliability of lateral compartment evaluation has become increasingly important, warranting future investigations to improve its reproducibility.

Limitation

Some limitations of the current study need to be discussed. First, varus–valgus stress was provided manually and was not quantified. Second, few patients were evaluated. Third, we failed to clarify the association between joint laxities evaluated using different methods and clinical outcomes. Fourth, the current analysis was performed using a single type of prosthesis (BCS type). Thus, the current results cannot be applied to other prostheses (i.e., posterior-stabilized, cruciate-retaining, or medial pivot type).

Conclusions

Joint laxity in the medial compartment evaluated under manual varus–valgus stress was comparable to that measured using a distraction force of 80 N during extension and 60 N during flexion. In the lateral compartment, joint laxity evaluated under manual varus–valgus stress was similar to that measured using a distraction force of 80 N during extension and flexion. Interobserver variability was greater in the lateral compartment, especially at higher flexion angles. These findings indicate that the optimal

distraction force for reproducing manual stress conditions differs according to the compartment and flexion angle, highlighting the need for standardized evaluation methods during robot-assisted TKA.

Declarations

Ethics approval and consent to participate

The present study was approved by the institutional review board of Saitama Medical Center, Saitama Medical University and signed informed consent for participation was obtained from all study patients.

Consent for publication

All authors agree to the publication of this article.

Availability of data and material

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

Competing interest

Our institute has received donations for research from Smith & Nephew Japan KK. They played no role in the design of this study; in the collection, analysis, or interpretation of the data; or in the writing of this manuscript. The authors declare that they have no personal competing interest.

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Authors' contributions

All authors have read and approved the manuscript.

The first and corresponding author HI was responsible for the surgical procedure and article writing. HN, RT, MU and KS were responsible for data collection. TY were responsible for the experimental design and RM was responsible for statistical analysis.

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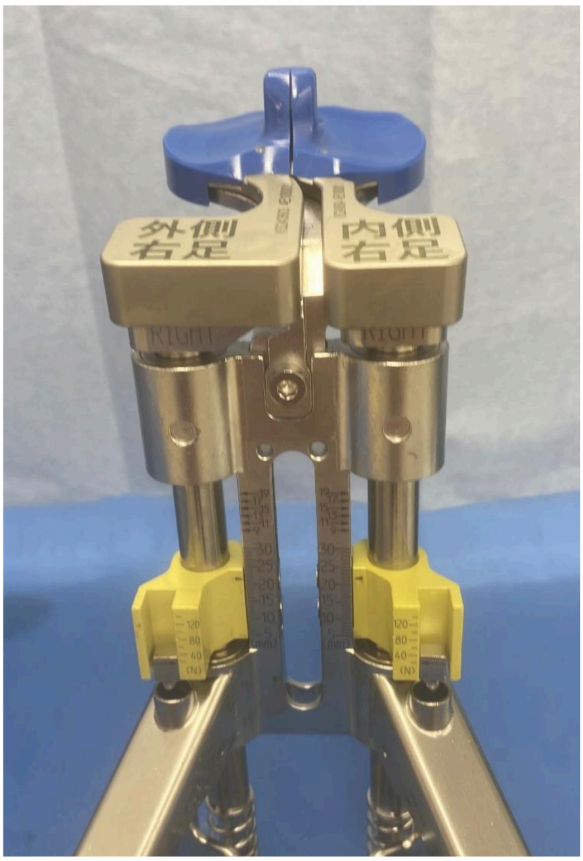
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Figures

(A)

(B)



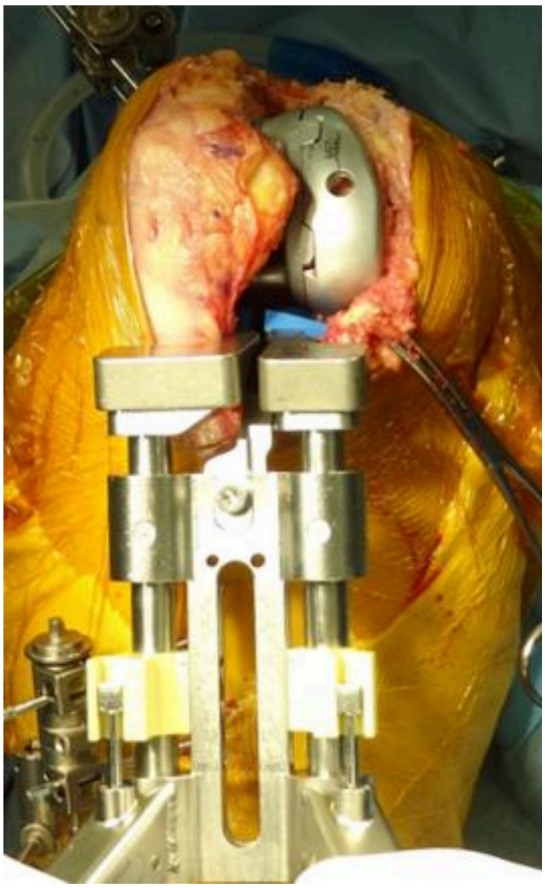


Figure 1

Force-controlled compartment-specific ligament tensioner.

The upper plates had identical shapes of medial and lateral compartments of the polyethylene trial surface of the Journey II BCS system.

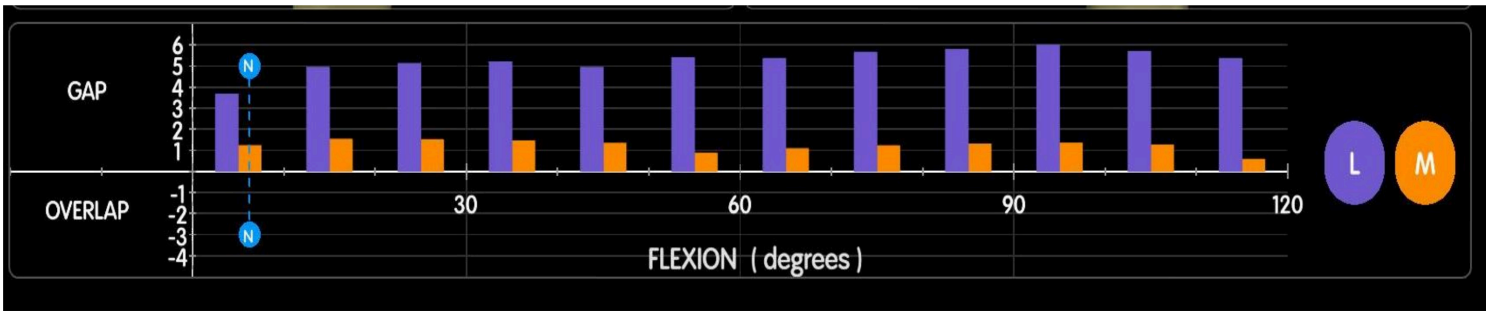


Figure 2

Measurements of varus and valgus coronal laxities at knee extension on the varus and valgus stress radiographs.

The angle between the line in contact with the medial (A) and lateral (B) lowest points of the femoral prosthesis and the line in contact with the lower surface of the tibial insert on varus, valgus, and neutral radiographs was measured.

MOA: medial opening angle; LOA: lateral opening angle

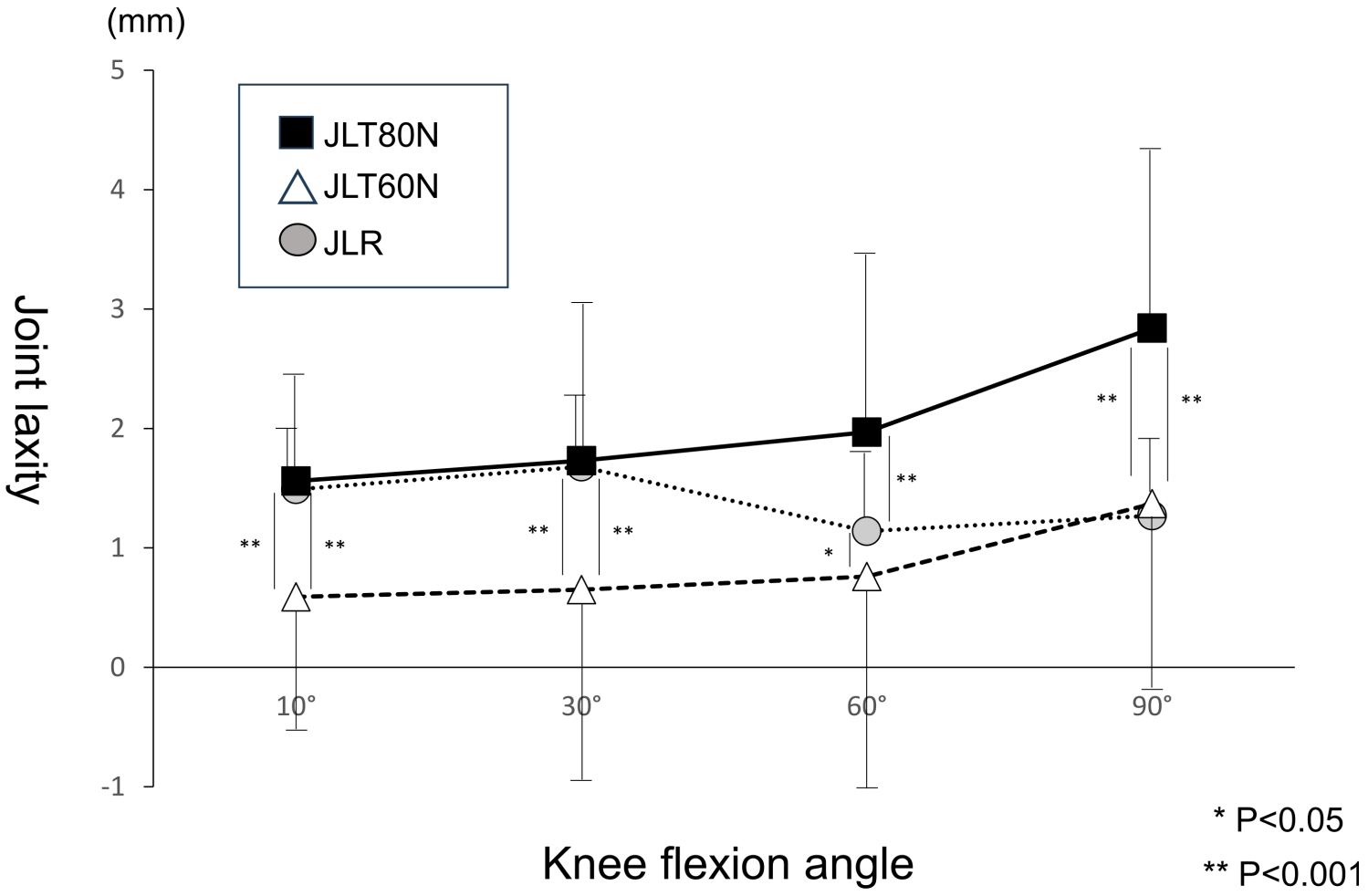


Figure 3

The comparison of the JLT60N, JLT80N and JLR of the medial compartment.

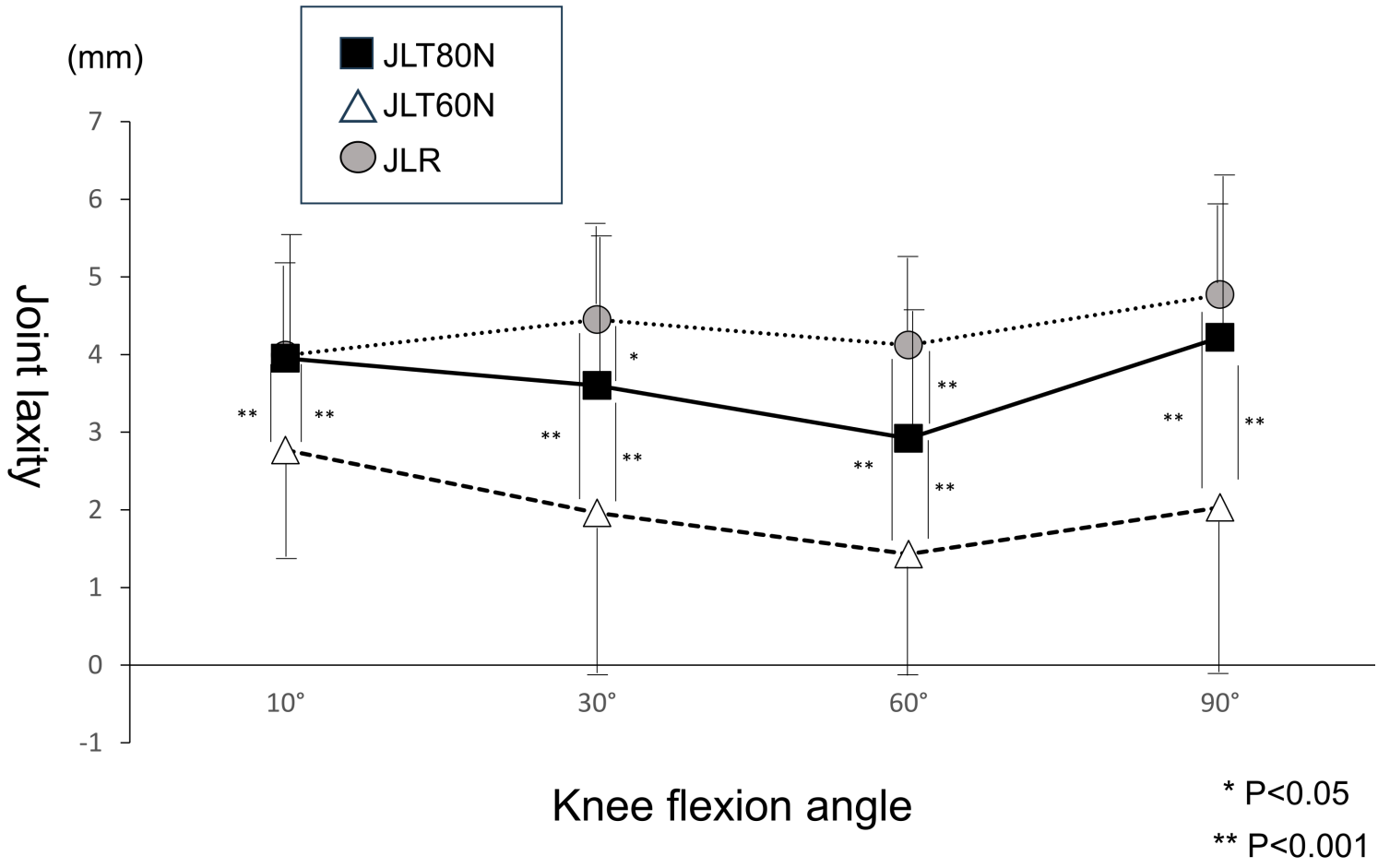


Figure 4

The comparison of the JLT60N, JLT80N and JLR of the lateral compartment.

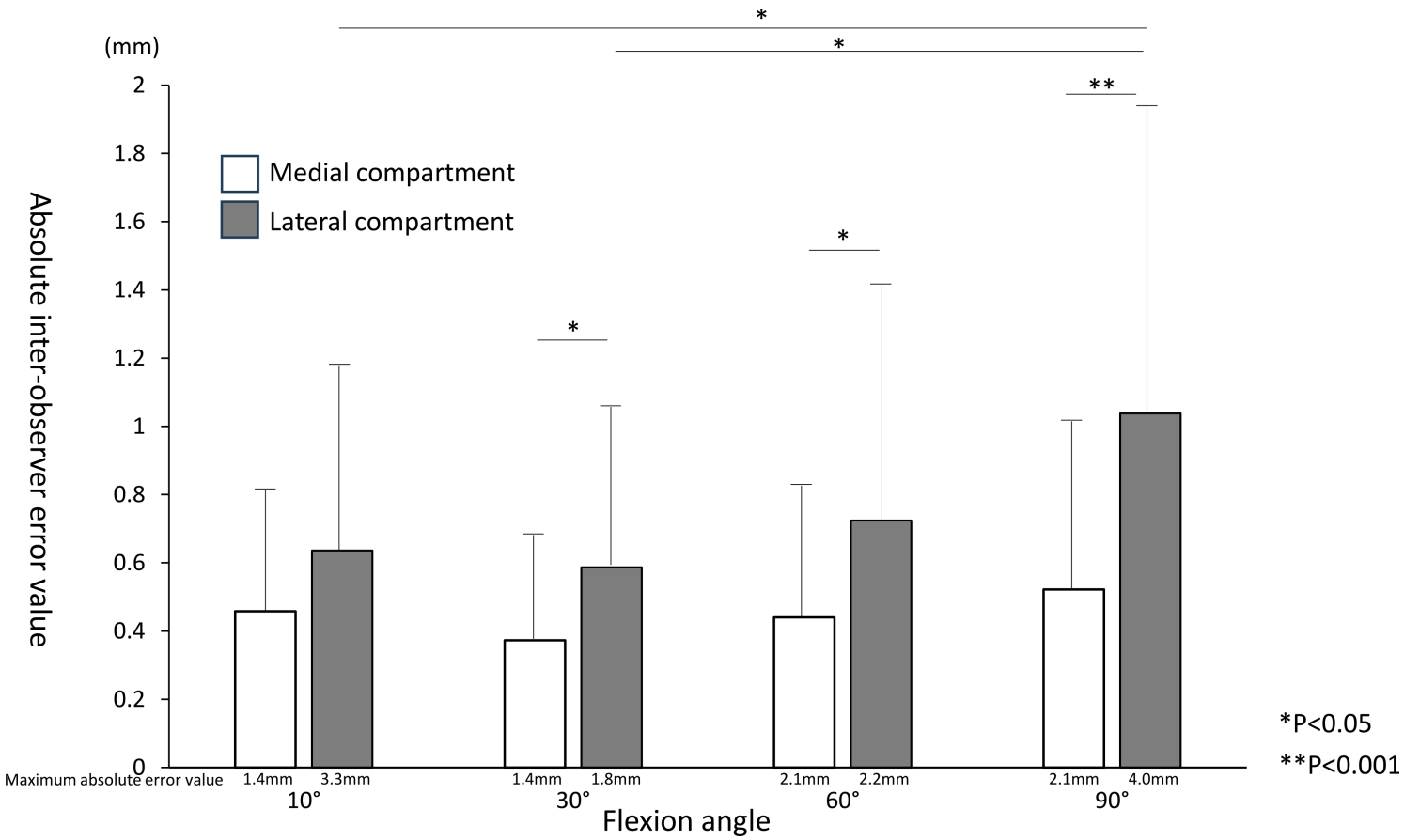


Figure 5

The absolute inter-observer error values at each flexion angle.