Both Intraoperative Medial and Lateral Soft Tissue Balances Influence Intraoperative Rotational Knee Kinematics in Bi-Cruciate Stabilized Total Knee Arthroplasty: A Retrospective Investigation.

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Research Article

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Abstract

Background

Tibial internal rotation following total knee arthroplasty (TKA) is important in achieving favorable postoperative clinical outcomes. Studies have reported the effect of intraoperative soft tissue balance on tibial internal rotation in conventional TKA, however, its effect on bi-cruciate stabilized (BCS) TKA has not reported enough. Furthermore, although studies have shown that both medial and lateral soft tissue balances are important for a good tibial internal rotation, no studies have evaluated the effects of soft tissue balance at medial or lateral compartments separately on tibial internal rotation in BCS TKA. The purpose of this study was to clarify the relationship between medial or lateral component gaps and rotational knee kinematics in BCS TKA.

Methods

One hundred fifty-eight knees that underwent BCS TKA were included in this study. They were divided into two groups according to the medial or lateral joint laxities, which was defined as the value of component gap minus the selected thickness of the tibial component at 30°, 60°, and 90° flexion, respectively: Group M-stable (medial joint laxity, ≤2 mm) or Group M-loose (medial joint laxity, ≥3 mm) and Group L-stable (lateral joint laxity, ≤3 mm) or Group L-loose (lateral joint laxity, ≥4 mm). The intraoperative rotational knee kinematics was compared between Group M-stable and Group M-loose or between Group L-stable and Group L-loose at each angle, respectively.

Results

The rotational angular difference between 30° flexion and maximum flexion was significantly larger in Group M-stable at 30° flexion than that in Group M-loose at 30° flexion. The rotational angular difference between 60° flexion and maximum flexion was significantly larger in Group L-loose at 60° flexion than that in Group L-stable at 60° flexion. The rotational angular difference between 60° flexion and maximum flexion was significantly larger in Group L-loose at 90° flexion than that in Group L-stable at 90° flexion.

Conclusion

Surgeons should pay attention to the importance of medial joint stability at midflexion and lateral joint laxities at midflexion and 90° flexion on a good tibial internal rotation from midflexion to deep flexion in BCS TKA.

Introduction

Total knee arthroplasty (TKA) is a reliable procedure for relieving pain or restoring function for progressed knee joint destruction. Many factors affect postoperative pain or function following TKA [1, 2]. As for knee kinematics, the knees following TKA do not always show a medial pivot pattern but a lateral or less pivot pattern [3], although normal or osteoarthritic knees present a medial pivot pattern [4, 5]. The medial pivot pattern following TKA is important in achieving good postoperative patient-reported outcome measures (PROMs) [6]. Furthermore, some studies have reported that the amount of intraoperative tibial internal rotation, which was determined between 60° and 120° flexion or between 60° and 135° flexion, was positively correlated with postoperative knee flexion angle in cruciate-retaining (CR) or posterior-stabilized (PS) TKA, respectively [7, 8]; therefore, for surgeons, understanding how to acquire a favorable tibial internal rotation, especially from midflexion to deep flexion following TKA is important.

Recently, a bi-cruciate stabilized (BCS) knee system, Journey II BCS (Smith & Nephew, Memphis, TN, USA), was created to approximate normal knee kinematics [9] and was described as a guided motion TKA. The BCS knee system generates a tibial internal rotation during knee flexion by the guidance of the surface geometry and two cam-post mechanisms that substitute for the anterior and posterior cruciate ligaments. Inui et al [10]. have reported that the amount of intraoperative tibial internal rotation between 30° and maximum flexion and between 60° and maximum flexion was correlated with improvement of postoperative PROMs following BCS TKA. Although studies have reported the relationship between the tibial rotational angle and intraoperative soft tissue balance in CR or PS TKA [7, 8], only one study has evaluated the effect of soft tissue balance on tibial internal rotation in BCS TKA [11]. Furthermore, although studies have shown that both medial and lateral soft tissue balances are important for good tibial internal rotation [7, 8], no study has evaluated the effects of soft tissue balance at medial or lateral compartments separately on tibial internal rotation in BCS TKA.

The authors hypothesized that both medial and lateral soft tissue balances influence rotational knee kinematics in BCS TKA. The purpose of this study was to retrospectively investigate the relationship between medial or lateral component gaps and rotational knee kinematics in BCS TKA.

Materials And Methods

The institutional review board of the authors' institution approved this study, and all patients who participated provided written informed consent.

From February 2016 to October 2019, 226 knees underwent TKA using Journey II BCS at the authors' institution. In this study, the inclusion criteria were the following: (1) knees with varus deformity, (2) the use of the image-free navigation system (Precision N; Stryker Orthopedics, Mahwah, NJ, USA), and (3) availability of complete data (patient characteristics, preoperative variables, and intraoperative measurements). One hundred fifty-eight knees met the inclusion criteria and thus were included in this study. Their characteristics and preoperative variables were shown in Table 1. All the procedures were performed using the same surgical technique by five knee surgeons. A senior surgeon (HI) participated in all procedures as either the chief surgeon or first assistant.

Table 1
Patient characteristics and preoperative variables

Age (years)	**72.7 ± 8.6**
Gender (female/male)	21/137
BMI (kg/m^2)	26.7 ± 4.1
Preoperative range of motion Maximum extension (degrees) Maximum flexion (degrees)	−9.5 ± 7.2 118.3 ± 15.4
Preoperative HKA angle (degrees)	169.4 ± 5.7
Data are expressed as mean ± standard deviation	
BMI; body mass index, HKA; hip−knee−ankle	

Surgical procedure

All patients underwent TKA using a paramedian approach, and the patella was not everted. The medial soft tissues were minimally released for bone resection. The balancing techniques focused on medial compartment stability [12, 13]. The distal femur and proximal tibia were osteotomized through the navigation system. Femoral alignment was aimed at a placement of 90° to the mechanical axis in the frontal plane and 4° of flexion in the sagittal plane. For the tibia, alignment was aimed at 90° to the mechanical axis in the frontal plane and 3° of posterior slope in the sagittal plane. The extension and flexion gaps were measured using a ligament tensioner, and the amount of posterior femur resection was adjusted to make the extension and flexion gaps of the medial compartment equal to acquire medial joint stability. Femoral rotation was determined as being parallel to the surgical epicondylar axis, allowing residual lateral ligamentous laxity [12, 13]. Tibial rotational alignment was determined using the range of motion technique in which the knee was put through a full range of flexion and extension, allowing the tibial trial to orient itself to the best position relative to the femoral component and reducing component rotational mismatch [14].

Intraoperative gap measurement

After these procedures, the extension and flexion gaps between the osteotomized surfaces were measured twice by the chief surgeon using the same ligament tensioner with a distraction force of 80 N for each compartment, and the averages were used. The mean (± standard deviation [SD]) joint gaps at extension and flexion were 22.1 ± 1.7 mm and 22.5 ± 1.9 mm, respectively, in the medial compartment and 24.2 ± 2.2 mm and 23.8 ± 2.4 mm, respectively, in the lateral compartment.

After evaluating the soft tissue balance between the osteotomized surfaces, the tensor device was put on the osteotomized surface of the tibia by placing the femoral trial component and reducing the patellofemoral joint. The tensor device consisted of three parts: upper compartment-specific plates, a lower platform plate, and an extra-articular main body [12]. The upper plates had identical shapes to that of the medial and lateral compartments of the polyethylene trial surface of the Journey II BCS system. This device was designed to allow surgeons to measure every millimeter of the joint component gaps of medial and lateral compartments. Using this tensor device, the component gaps of medial and lateral compartments were assessed at maximum extension and 30°, 60°, and 90° flexion with a joint distraction force of 80 N for each compartment. The medial or lateral joint laxities, which were defined as the value of component gap minus the selected thickness of the tibial component, were evaluated.

Intraoperative tibial rotational angle evaluation

The tibial rotational angles after implantation at maximum extension and 30°, 60°, 90°, and maximum flexion were obtained for each patient using the navigation kinematic data during the motion cycles from maximum extension to maximum flexion. Among these rotational kinematic data, the following two parameters were evaluated because previous studies have considered that the amount of tibial internal rotation from midflexion to deep flexion influenced postoperative clinical outcomes [7, 8, 10]: (1) the rotational angular difference between 30° flexion and maximum flexion (RAD 30) and (2) the rotational angular difference between 60° flexion and maximum flexion (RAD 60). The tibial internal rotation relative to the femur was defined as a positive value.

Statistical analyses

A previous study has shown that intraoperative joint laxities in BCS TKA were nearly constant at 2.8 ± 1.6 mm in the medial compartment and 3.3 ± 2.3 mm in the lateral compartment [15]; therefore, the patients enrolled in this study were divided into two groups based on their intraoperative joint laxities in the medial and lateral compartments at maximum extension and 30°, 60°, and 90° flexion, respectively. The groups according to the medial compartment were as follows: Group M-stable (medial joint laxity of ≤ 2 mm) and Group M-loose (medial joint laxity of ≥ 3 mm). The groups according to the lateral compartment were as follows: Group L-stable (lateral joint laxity of ≤ 3 mm) and Group L-loose (lateral joint laxity of ≥ 4 mm). Among the 158 knees in this study, the numbers at maximum extension and 30°, 60°, 90° flexion between Group M-stable and Group M-loose and between Group L-stable and Group L-loose were shown in Tables 2 and 3.

Table 2
The numbers at each angle between Group M-stable and Group M-loose

	Group M-stable	Group M-loose
Maximum extension	156 knees	2 knees
30° flexion	93 knees	65 knees
60° flexion	88 knees	70 knees
90° flexion	73 knees	85 knees

Table 3
The numbers at each angle between Group L-stable and Group L-loose

	Group L-stable	Group L-loose
Maximum extension	131 knees	27 knees
30° flexion	51 knees	107 knees
60° flexion	68 knees	90 knees
90° flexion	62 knees	96 knees

Statistical analyses were performed using the statistical software EZR (version 1.31; Saitama Medical Center, Jichi Medical University, Saitama, Japan) [16]. The unpaired Student's two-tailed *t*-test was used to compare RAD 30 and RAD 60 between the two groups in the medial or lateral compartments, respectively. The estimated sample size was 132 ($1 - \beta = 0.80$, $\alpha = 0.05$) according to the statistical power analysis using G*Power (version 3.1.9.4, Heinrich Heine University, Düsseldorf, Germany) [17] Post hoc power analyses were adequate (> 0.80) except for the comparisons of medial or lateral joint laxity at maximum extension; therefore, the authors investigated the comparisons between RAD 30 or RAD 60 and medial or lateral joint laxities at 30°, 60°, and 90° flexion, respectively. The level of significance was set at $p < 0.05$. The data were shown as the mean ± SD.

Results

The mean medial and lateral joint laxities at each angle were shown in Table 4. The medial joint laxity was significantly smaller than the lateral joint laxity at each angle ($p < 0.05$ at each angle).

Table 4
Intraoperative medial or lateral joint laxity at each angle

	medial	**lateral**	**p value**
Maximum extension	−0.5 ± 1.4 mm	1.4 ± 2.2 mm	< 0.05
30° flexion	2.2 ± 1.6 mm	4.8 ± 2.7 mm	< 0.05
60° flexion	2.4 ± 1.7 mm	4.3 ± 2.7 mm	< 0.05
90° flexion	2.9 ± 1.6 mm	4.4 ± 2.6 mm	< 0.05
Data are expressed as mean ± standard deviation			

Figure 1 showed the analysis between the medial joint laxity at each angle and RAD 30 or RAD 60. RAD 30 was significantly larger in Group M-stable at 30° flexion than that in Group M-loose at 30° flexion. No statistical correlation was observed between RAD 60 and the medial joint laxity at each angle.

Figure 2 showed the analysis between the lateral joint laxity at each angle and RAD 30 or RAD 60. RAD 60 was significantly larger in Group L-loose at 60° flexion than that in Group L-stable at 60° flexion and was significantly larger in Group L-loose at 90° flexion than that in Group L-stable at 90° flexion. No statistical correlation was observed between RAD 30 and the lateral joint laxity at each angle.

Discussion

The most important finding in this study was that both medial and lateral soft tissue balances influenced the intraoperative rotational knee kinematics in BCS TKA. The medial joint laxity of 2 mm or less at 30° flexion and the lateral joint laxity of 4 mm or more at 60° and 90° flexion were important to achieve better tibial internal rotation.

Medial joint stability was previously reported to be important for achieving good rotational knee kinematics following conventional TKA. Wada et al. [18] have investigated the influence of medial collateral ligament (MCL) release on rotational knee kinematics in frozen cadaveric knee undergoing PS TKA. They argued that extensive MCL release reduced the amount of tibial internal rotation during knee flexion. Similarly, substantial medial release including semimembranosus tendon also reported to reduce tibial internal rotation during flexion in CR TKA [19]. Nakamura et al. [20] have evaluated the relationship between the postoperative flexion gap measured using axial radiography and *in vivo* knee kinematics using fluoroscopy in cruciate-substituting TKA and concluded that medial joint laxity caused abnormal knee kinematics. As for the relationship between intraoperative component gap and intraoperative tibial rotational angle, the amount of tibial internal rotation was negatively correlated with the medial component gap at 60° flexion in PS TKA [7]. This study showed that RAD 30 was significantly larger in Group M-stable at 30° flexion than that in Group M-loose at 30° flexion in BCS TKA. Increasing joint laxity at midflexion was reported to negatively influence postoperative PROMs [21], and from the results of this study, medial joint stability at midflexion was also important for achieving good tibial internal rotation in BCS TKA.

Regarding lateral soft tissue balance, lateral joint laxities in a normal knee have reported to be greater than medial joint laxities in both extension and flexion [22, 23]. Furthermore, lateral joint laxity has reported to positively correlate with postoperative flexion angle [24] or PROMs [25] following conventional TKA. As for the relationship between intraoperative component gap and intraoperative tibial rotational angle, the amount of tibial internal rotation was positively correlated with the lateral component gap at 60°, 90°, and 120° flexion in CR TKA [19]. This study showed that RAD 60 was significantly larger in Group L-loose at 60° flexion than that in Group L-stable at 60° flexion, and was significantly larger in Group L-loose at 90° flexion than that in Group L-stable at 90° flexion in BCS TKA. As well as conventional TKA, lateral joint laxity was thought to be important for achieving good tibial internal rotation in BCS TKA. However, some reports have shown that lateral joint laxity has somewhat negative effects on PROMs [26]; therefore, further investigation to clarify the most appropriate amount of lateral joint laxity to achieve better clinical results in BCS TKA is required.

This study has several limitations. First, this was a retrospective study. Second, the sample size was relatively small, although post hoc power analyses were adequate except for the comparisons of medial or lateral joint laxities at maximum extension. Therefore, the authors cannot argue the clinically meaningful significance for the comparison of medial or lateral joint laxities at maximum extension from this study. Further investigations with large cohort are needed in the future. Third, the authors only investigated varus deformities; therefore, the results of this study cannot be generalized and applied to valgus deformities. Fourth, the alignments of the femoral and tibial components were not evaluated. Fifth, the authors did not evaluate the influence of the differences between Group M-stable and Group M-loose and between Group L-stable and Group L-loose on postoperative clinical outcomes.

Conclusions

The relationship between intraoperative joint laxity and intraoperative tibial rotational angle in BCS TKA was investigated in this study. The medial joint laxity of 2 mm or less at 30° flexion and the lateral joint laxities of 4 mm or more at 60° and 90° flexion were important in achieving better tibial internal rotation. Surgeons should pay attention to the importance of medial joint stability at midflexion and lateral joint laxities at midflexion and 90° flexion to achieve good tibial internal rotation in BCS TKA.

List Of Abbreviations

TKA, Total knee arthroplasty; PROM, Patient-reported outcome measure; CR, Cruciate-retaining; PS, Posterior-stabilized; BCS, Bi-cruciate stabilized; RAD, Rotational angular difference; MCL, Medial collateral ligament.

Declarations

Ethics approval and consent to participate

This study was approved by the institutional review board of Tokyo University Hospital. All the patients in this study provided with written, informed consent prior to participation. All the methods were performed in accordance with relevant guidelines and regulations.

Consent for publication

All authors agree to the publication of this article.

Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due to privacy concern of participants but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors have read and approved the manuscript. KT: The first author, surgeon of this series. HI: The corresponding author, main surgeon of this series. RY, KK, and SS: The surgeons of this series. KK and TK: The analysts of kinematics. ST and ST were involved in study design and data interpretation.

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References

1. Liebs TR, Kloos SA, Herzberg W, Rüther W, Hassenpflug J. The significance of an asymmetric extension gap on routine radiographs after total knee replacement: A new sign and its clinical significance. Bone Joint J. 2013;95-B:472–7.
2. Seil R, Pape D. Causes of failure and etiology of painful primary total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2011;19:1418–32.
3. Dennis DA, Komistek RD, Mahfouz MR, Haas BD, Stiehl JB. Multicenter determination of in vivo kinematics after total knee arthroplasty. Clin Orthop Relat Res. 2003;416:37–57.

4. Freeman MAR, Pinskerova V. The movement of the normal tibio-femoral joint. J Biomech. 2005;38:197–208.
5. Hamai S, Moro-oka T, Miura H, et al. Knee kinematics in medial osteoarthritis during in vivo weight-bearing activities. J Orthop Res. 2009;27:1555–61.
6. Nishio Y, Onodera T, Kasahara Y, Takahashi D, Iwasaki N, Majima T. Intraoperative medial pivot affects deep knee flexion angle and patient-reported outcomes after total knee arthroplasty. J Arthroplasty. 2014;29:702–6.
7. Kamenaga T, Takayama K, Ishida K, et al. Medial knee stability at flexion increases tibial internal rotation and knee flexion angle after posterior-stabilized total knee arthroplasty. Clin Biomech. 2019;68:16–22.
8. Matsuzaki T, Matsumoto T, Kubo S, et al. Tibial internal rotation is affected by lateral laxity in cruciate-retaining total knee arthroplasty: an intraoperative kinematic study using a navigation system and offset-type tensor. Knee Surg Sports Traumatol Arthrosc. 2014;22:615–20.
9. Kono K, Inui H, Tomita T, et al. Bicruciate-stabilised total knee arthroplasty provides good functional stability during high-flexion weight-bearing activities. Knee Surg Sports Traumatol Arthrosc. 2019;27:2096–103.
10. Inui H, Taketomi S, Yamagami R, et al. Comparison of intraoperative kinematics and their influence on the clinical outcomes between posterior stabilized total knee arthroplasty and bi-cruciate stabilized total knee arthroplasty. Knee. 2020;27:1263–70.
11. Inui H, Taketomi S, Yamagami R, Shirakawa N, Kawaguchi K, Tanaka S. The Relationship between Soft-Tissue Balance and Intraoperative Kinematics of Guided Motion Total Knee Arthroplasty. J Knee Surg. 2019;32:91–6.
12. Inui H, Taketomi S, Yamagami R, Kawaguchi K, Nakazato K, Tanaka S. The relationship between anteroposterior stability and medial-lateral stability of the bi-cruciate stabilized total knee arthroplasty. Knee. 2018;25:1247–53.
13. Tsubosaka M, Muratsu H, Takayama K, Miya H, Kuroda R, Matsumoto T. Comparison of intraoperative soft tissue balance between cruciate-retaining and posterior-stabilized total knee arthroplasty performed by a newly developed medial preserving gap technique. J Arthroplasty. 2018;33:729–34.
14. Eckhoff DG, Metzger RG, Vandewalle MV. Malrotation associated with implant alignment technique in total knee arthroplasty. Clin Orthop Relat Res. 1995;321:28–31.
15. Kaneko T, Kono N, Mochizuki Y, Hada M, Toyoda S, Musha Y. Bi-cruciate substituting total knee arthroplasty improved medio-lateral instability in mid-flexion range. J Orthop. 2017;14:201–6.
16. Kanda Y. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. Bone Marrow Transplant. 2013;48:452–8.
17. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 2007;39:175–91.

18. Wada K, Hamada D, Tamaki S, Higashino K, Fukui Y, Sairyo K. Influence of Medial Collateral Ligament Release for Internal Rotation of Tibia in Posterior-Stabilized Total Knee Arthroplasty: A Cadaveric Study. J Arthroplasty. 2017;32:270–3.
19. Matsumoto T, Takayama K, Muratsu H, Matsushita T, Kuroda R, Kurosaka M. Semimembranosus Release Reduces Tibial Internal Rotation and Flexion Angle in Cruciate-Retaining Total Knee Arthroplasty. J Arthroplasty. 2015;30:1537–41.
20. Nakamura S, Ito H, Yoshitomi H, Kuriyama S, Komistek RD, Matsuda S. Analysis of the flexion gap on in vivo knee kinematics using fluoroscopy. J Arthroplasty. 2015;30:1237–42.
21. Hasegawa M, Naito Y, Yamaguchi T, Wakabayashi H, Sudo A. Factors contributing to patient satisfaction and expectations following computer-assisted total knee arthroplasty. J Knee Surg. 2018;31:448–52.
22. Okazaki K, Miura H, Matsuda S, et al. Asymmetry of mediolateral laxity of the normal knee. J Orthop Sci. 2006;11:264–6.
23. Tokuhara Y, Kadoya Y, Nakagawa S, Kobayashi A, Takaoka K. The flexion gap in normal knees. An MRI study. J Bone Joint Surg Br. 2004;86:1133–6.
24. Nakano N, Matsumoto T, Muratsu H, Takayama K, Kuroda R, Kurosaka M. Postoperative knee flexion angle is affected by lateral laxity in cruciate-retaining total knee arthroplasty. J Arthroplasty. 2016;31:401–5.
25. Tsukiyama H, Kuriyama S, Kobayashi M, et al. Medial rather than lateral knee instability correlates with inferior patient satisfaction and knee function after total knee arthroplasty. Knee. 2017;24:1478–84.
26. Romero J, Stähelin T, Binkert C, Pfirrmann C, Hodler J, Kessler O. The clinical consequences of flexion gap asymmetry in total knee arthroplasty. J Arthroplasty. 2007;22:235–40.

Figures

Fig. 1

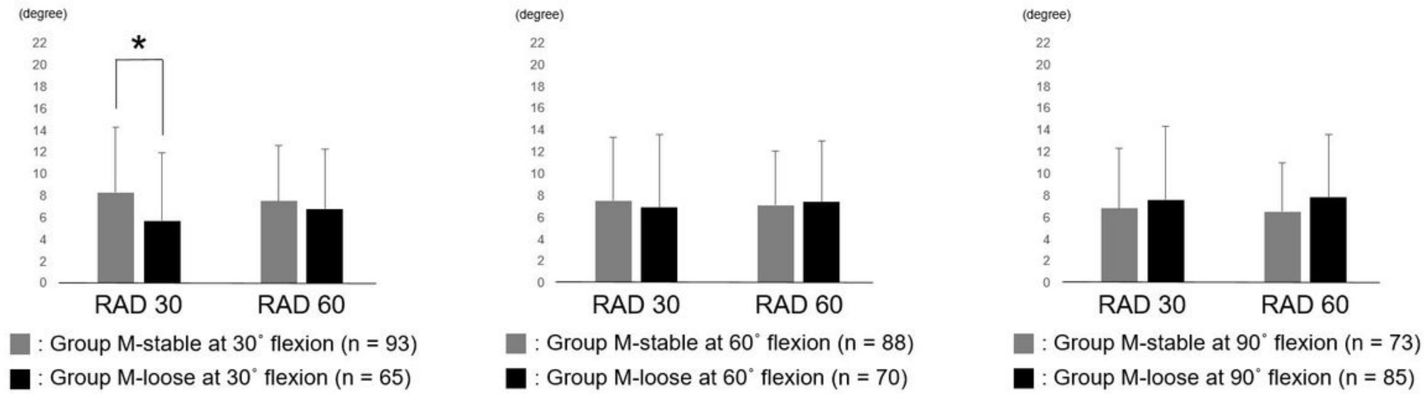

Figure 1

The analysis between the medial joint laxity and RAD 30 or RAD 60. RAD 30 was significantly larger in Group M-stable at 30° flexion than that in Group M-loose at 30° flexion (*p < 0.05) RAD 30, the rotational angular difference between 30° flexion and maximum flexion; RAD 60, the rotational angular difference between 60° flexion and maximum flexion

Fig. 2

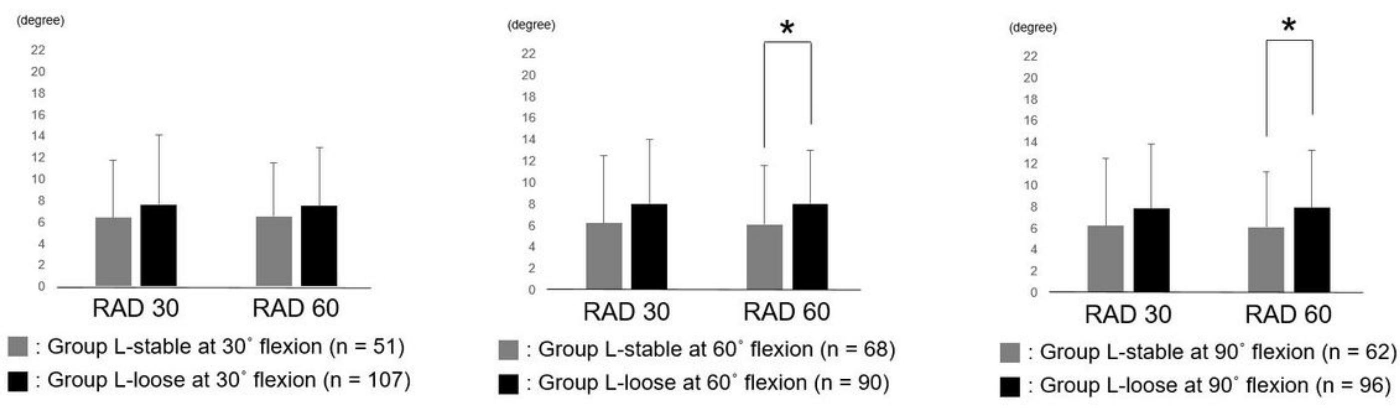

Figure 2

The analysis between the lateral joint laxity and RAD 30 or RAD 60. RAD 60 was significantly larger in Group L-loose at 60° flexion than that in Group L-stable at 60° flexion (*p < 0.05). RAD 60 was significantly larger in Group L-loose at 90° flexion than that in Group L-stable at 90° flexion (*p < 0.05)

RAD 30, the rotational angular difference between 30° flexion and maximum flexion; RAD 60, the rotational angular difference between 60° flexion and maximum flexion