



Intraoperative physiological lateral laxity in extension and flexion for varus knees did not affect short-term clinical outcomes and patient satisfaction

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Abstract

Purpose Medial release during total knee arthroplasty (TKA) is used to correct ligament imbalance in knees with varus deformity. However, questions remain on whether residual ligament imbalance would be related to inferior clinical results. The purposes of the present study were to measure the intraoperative joint gap and to evaluate the effect of intraoperative soft tissue condition on the new Knee Society Score (KSS 2011) at 2-year follow-up, without the maneuver of additional medial release to correct the asymmetrical gap balance.

Methods Varus–valgus gap angle and joint gap were measured using a tensor device without medial release for 100 knees with preoperative varus deformity. The knees were categorized according to the varus–valgus gap angle and the laxity. The preoperative and postoperative clinical outcomes using KSS 2011 were compared between the groups.

Results The average varus–valgus angles had a residual imbalance of 2.8° varus and 1.3° varus in extension and flexion, respectively. In comparison, according to varus–valgus joint gap angle and knee laxity in extension and flexion, no significant differences were found in postoperative range of motion and subscale of KSS 2011 among the groups.

Conclusion Intraoperative asymmetrical joint gap and physiological laxity do not affect early clinical results after TKA.

Level of evidence III.

Keywords Total knee replacement · Total knee arthroplasty · Genu varum · Collateral ligaments · Joint laxity

Abbreviations

TKA	Total knee arthroplasty
KSS	Knee Society Score
MCL	Medial collateral ligament
SD	Standard deviation
HKA	Hip–knee–ankle
FMA	Femoral mechanical angle

TMA	Tibial mechanical angle
WOMAC	Western Ontario and McMaster Universities Arthritis Index

Introduction

Achieving proper soft tissue balance is one of the important factors for successful total knee arthroplasty (TKA) [18]. Generally, an additional procedure is used to correct imbalance of the medial and lateral joint gap in knee extension and flexion, which is believed to improve clinical outcomes and durability. Release of the medial structure has been performed frequently when the medial joint gap is tighter than the lateral joint gap in the knees with varus deformity. For mild varus knees, release of the deep medial collateral ligament (MCL) and posteromedial capsule is usually sufficient [4, 12, 33]. In the severe varus knee with increased lateral laxity, the superficial MCL is often released to acquire equal medial–lateral gap [11]. Various methods of medial release

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have been reported, in which functional ligament balancing including the release of the anterior and posterior oblique portions of MCL is necessary in up to 80% of patients with severe varus deformity in the mechanical alignment technique [3, 6, 35].

However, medial release has risks for causing medial instability. In previous cadaveric studies, extensive MCL release reduced tibial internal rotation during knee flexion [15]. In a fluoroscopic analysis, laxity of the MCL induced abnormal anterior motion of the femur in deep knee flexion [21]. On the contrary, lateral laxity does not seem to worsen clinical results, and a certain amount of lateral laxity may be necessary to have medial pivot motion as well as good range of motion to represent ligament balance in normal knees [14, 24, 28], although asymmetric lateral flexion instability can cause significant problems to the patient such as limited flexion and anterior knee pain [25]. Some studies evaluated soft tissue condition in osteoarthritic knees, and reported that soft tissue on the medial side did not have contracture, but lateral laxity increased in the varus knees [26, 31]. It seems unnecessary to extensively release ligaments on the not-contracted medial side to match the loose lateral side for varus knees. Concerning the coronal alignment, functional knee phenotypes in the female and male population are investigated, in which functional knee phenotypes enable a simple, but detailed assessment of a patient's individual anatomy and thereby could be a helpful tool to individualize the approach to TKA [8]. Further, in a biomechanical study, no condylar lift-off was detected in a neutrally aligned TKA, even if the lateral laxity was excessive [13]. Therefore, lateral laxity can be left without medial release if the varus–valgus imbalance existed, aiming for the neutral alignment.

In the present study, clinical outcomes were evaluated without additional medial release for consecutive TKA with preoperative varus deformity, even if lateral laxity was observed during surgery. The purposes of the present study were to measure the varus–valgus gap angle and laxity in extension and flexion using a tensor device during consecutive TKA, and to evaluate whether good clinical outcomes using the new Knee Society Score (KSS 2011) were achieved at 2-year follow-up, without the maneuver of additional medial release to correct the asymmetrical gap balance. The first hypothesis was that the ligament balance during TKA is kept in varus extension and flexion without extensive medial release. The second hypothesis was that residual asymmetrical joint gap does not affect clinical outcomes including range of motion and subscale of KSS 2011 after TKA for the knee with preoperative varus deformity.

Methods

This study was conducted to evaluate our hypotheses using consecutive primary TKAs performed with a single implant design, in which prospectively collected data were retrospectively analyzed. All surgeries and gap measurements using a tensor device were executed, and clinical outcomes were evaluated at 2-year follow-up for 100 knees. Inclusion criteria were primary TKA for medial osteoarthritis of the knee using a ceramic tri-condylar posterior-stabilized implant (Bi-Surface 5: Kyocera, Kyoto, Japan) [20, 22, 23]. 17 patients presenting any valgus deformity were excluded from this analysis. Informed consent was obtained from all patients. The study design was approved by the institutional ethics review boards, and all procedures performed were in accordance with the ethical standards of the institutional research committee. A total of 15 male and 85 female knees with an average age of 75.7 years [standard deviation (SD) = 6.9 years] were included for surgery. The average preoperative hip–knee–ankle (HKA) angle, based on the angles between a mechanical axis of the femur and the tibia, was 11.5° varus (SD = 5.2°, range 0.6° to 24.5° varus). Ten knees had HKA smaller than 5°. The average preoperative femoral mechanical angle (FMA, the medial angle between the femoral mechanical axis and a tangent to the distal femoral condyles) and tibial mechanical angle (TMA, the medial angle between the tibial mechanical axis and a tangent to the proximal tibial joint surface) were 88.7° varus (SD = 2.5°) and 83.3° varus (SD = 2.7°), respectively. The delta values of HKA, FMA, and TMA between preoperative and postoperative alignment were calculated. The postoperative decrease of the varus deformity was denoted as positive. The average height and weight were 151.7 cm (SD = 6.9 cm) and 61.4 kg (SD = 11.0 kg), respectively, and the mean body mass index was 26.6 (SD = 3.9). Regarding statistical power, a post hoc power analysis was conducted because the data were retrospectively analyzed, in which the present study had 80% power to detect a parameter estimate of 0.3.

TKA was performed with mechanical alignment method in a uniform manner, and the goal of the coronal alignment was neutral alignment with the femoral and tibial components perpendicular to the respective mechanical axis. The medial parapatellar approach was used. The posterior cruciate ligament (PCL) was sacrificed, and the bone was cut using the following measured resection technique. The distal femur was cut perpendicular to its mechanical axis. Concerning the rotational alignment, the angle between the surgical epicondylar axis and the posterior condylar axis was measured preoperatively using a computed tomography. The cutting jig was set in accordance

with the measured angle relative to the posterior condylar axis. The size of the femoral component was determined based on the antero-posterior length of the femur, which was independent of the flexion gap. Smaller size was chosen in between sizes. The tibia was cut perpendicular to the mechanical axis in the coronal plane. Approximately 10 mm of bone was resected from the most proximal part of the lateral tibial plateau. In the sagittal plane, the posterior slope was set to 5° relative to the tibial shaft. Rotational alignment of the tibial component was adjusted to the antero-posterior axis of the tibia (the Akagi line) [1]. Osteophytes on the medial side of the femur and tibia were removed. The patella was resurfaced for all knees.

Regarding ligament balancing in extension, the deep layer of the MCL was released within 1 cm from the joint line for bone resection and osteophyte removal. No further extensive medial release was performed to acquire equal medio-lateral joint gap balance, even if lateral laxity was observed. The superficial layer of the MCL, semimembranosus, and posterior oblique ligament were not released. In flexion, gap imbalance was left uncorrected without additional ligament release or bony resection. After setting the femoral component trial, a tensor device was used to measure the joint gap at the center of the knee joint and the varus–valgus angle of the joint gap. The joint gap and the varus–valgus angle were measured applying a distraction force of 178 N with the knee in extension and 90° of flexion (Fig. 1). All components were fixed with Simplex bone cement (Stryker, Kalamazoo, MI, USA). The incision was closed with the knee in 100° of flexion.

The same postoperative rehabilitation programs were applied for all patients. Knee flexion exercises were continued in routine rehabilitation programs with physical therapists for one month. Following rehabilitation, patients were free to carry out deep flexion activities and were able to perform most activities without any restrictions, including deep knee flexion. Physical examination and knee scoring were conducted preoperatively and for 2 years postoperatively using the KSS 2011. Range of motion was passively measured with a long-arm goniometer in the supine position. In a previous study, intra-class correlation coefficient using a long-arm goniometer was 0.996 and 0.993 in inter-rater and intra-rater reliability, respectively, and the minimum significant difference was 10° [7]. Preoperative and postoperative examinations were performed by physical therapists that were independent from the surgeons performing the surgery.

To evaluate the effects of ligament imbalance, the knees were divided according to the intraoperative varus–valgus angle of the joint gap in knee extension and 90° of flexion independently. The balanced group consisted of knees with the varus–valgus angle of the joint gap being less than 3° . The varus imbalance group consisted of knees with the medio-lateral angle of the joint gap having 3° – 6° of varus imbalance. The severe varus imbalance group consisted of knees with the varus–valgus angle of the joint gap being 6° and more. The valgus imbalance group consisted of knees with the medio-lateral angle of the joint gap having 3° and more of valgus imbalance, respectively.

To evaluate the effects of the joint laxity on clinical outcomes, the knees were divided according to the estimated

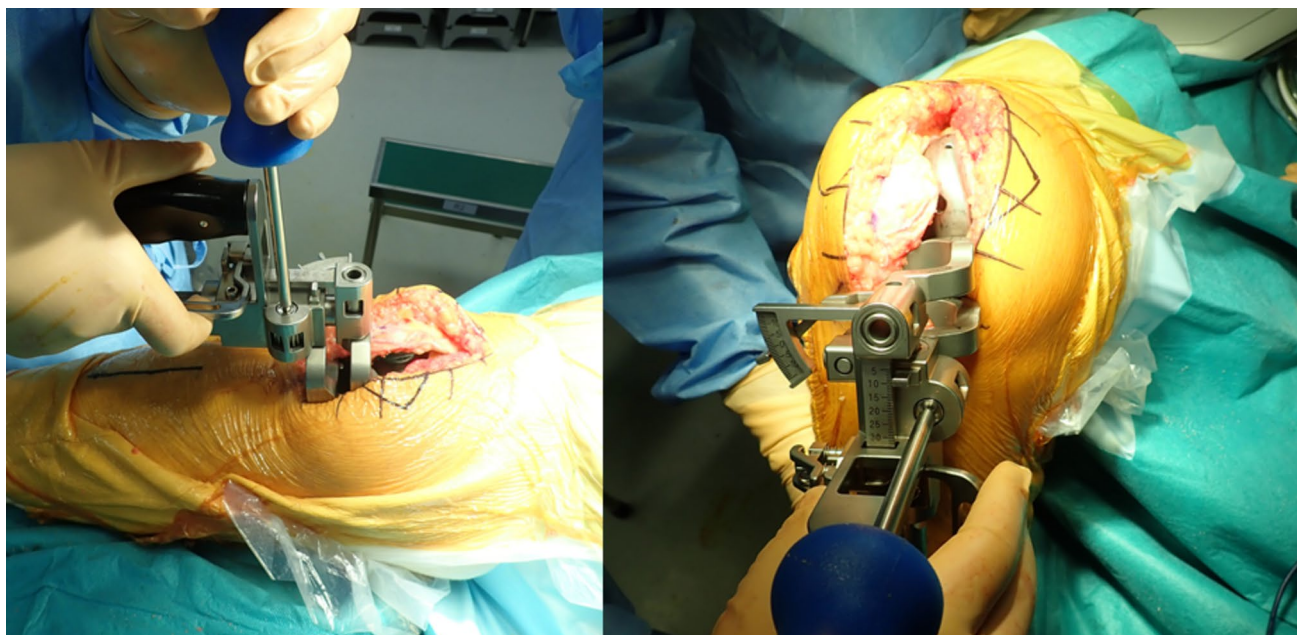


Fig. 1 Measurement of the joint gap and the varus–valgus angle in extension (left) and 90° of flexion (right)

laxity after implantation, which was calculated by subtracting the polyethylene thickness from the joint gap in extension and flexion. Grouping was performed with 2 mm gap increments, because previous clinical and biomechanical studies show that 2 mm increase in the joint gap has significant effect on clinical outcomes and knee kinematics and kinetics [9, 34]. In extension, the tight group consisted of knees with a laxity of -2 mm and less. The moderate and loose group consisted of knees with the laxity of -2 mm to 0 mm and more than 0 mm, respectively. In flexion, the tight group consisted of knees with the laxity of 0 mm and less. The moderate, loose, and over-loose group consisted of knees with the laxity of 0 mm to 2 mm, 2 mm to 4 mm, and more than 4 mm, respectively. To evaluate the accuracy of the measurement of the varus–valgus angle and the joint gap, measurement was conducted 5 times in extension and at 90° of flexion for six knees. The standard errors of the measurement of the varus–valgus angle were 0.1° and 0.2° in extension and flexion, respectively. Those of the joint gap were 0.2 mm and 0.1 mm.

All analyses were performed using JMP Pro software version 12.2.0 (SAS Institute Inc., Cary, NC). Clinical outcomes including preoperative and postoperative KSS 2011, range of motion, and alignment were compared between groups using either an ANOVA test or Wilcoxon signed rank test, whichever appropriate. Pearson correlation coefficients were calculated to determine the correlations. Post hoc analyses were conducted using the Tukey–Kramer method.

Results

KSS 2011 scores except patient expectation were significantly improved postoperatively (Table 1). The average preoperative extension angle was significantly improved postoperatively, and preoperative flexion angle was maintained at 2 years after TKA. Regarding limb, femoral and

tibial alignment, neutral alignment was achieved postoperatively. Preoperative alignment had no significant correlation with postoperative alignment in HKA ($p=0.166$), FMA ($p=0.540$), and TMA ($p=0.501$) (Fig. 2).

The average residual varus–valgus imbalance was 2.8° (SD = 2.8°) varus in extension and 1.3° (SD = 4.0°) varus in flexion. The average varus–valgus angles were kept varus in extension and flexion, respectively (Fig. 3). The average extension gap was smaller than the flexion gap. The average extension and flexion gaps were 9.4 mm (SD = 2.5 mm) and 12.7 mm (SD = 2.8 mm), respectively. The average thickness of polyethylene insert was 10.0 mm (SD = 1.4 mm). The distribution of the laxity in flexion was more variable than in extension (Figs. 4, 5). Analyzing correlation with the alignment and the gap angle and joint laxity, the delta HKA angle had significant correlation with the joint gap angle, and the preoperative TMA and delta TMA had significant correlation with the laxity in extension (Table 2). Larger correction angle of limb alignment showed more varus joint gap in extension, and larger varus deformity and correction angle of the tibia showed more laxity in extension.

In comparison, according to the varus–valgus joint gap angle in extension, no valgus imbalance group was found, and no significant differences in patient demographics, preoperative and postoperative clinical outcomes were observed among the groups except BMI and preoperative HKA angle (Table 3). In comparison, according to the varus–valgus joint gap angle in flexion, there were no significant differences in patient demographics, preoperative and postoperative clinical outcomes among the groups (Table 4).

In comparison, according to the knee laxity in extension, there were no significant differences in clinical outcomes among the groups (Table 5). In comparison, according to the knee laxity in flexion, preoperative patient expectation had significant difference between moderate and loose groups and between moderate and over loose groups. However, no

Table 1 Overall clinical outcomes and alignment

	Preoperation	Postoperation	<i>p</i> value
KSS 2011			
Symptoms	8.6 (SD=5.7)	21.2 (SD=4.2)	<0.001
Patient satisfaction	15.0 (SD=5.3)	27.0 (SD=7.6)	<0.001
Patient expectation	13.5 (SD=2.0)	10.2 (SD=2.8)	<0.001
Functional activities	40.7 (SD=18.5)	64.8 (SD=19.8)	<0.001
Range of motion			
Extension (degrees)	-9.2 (SD=7.5)	-2.3 (SD=4.2)	<0.001
Flexion (degrees)	119.9 (SD=13.0)	119.5 (SD=14.9)	0.400
HKA angle (degrees)	11.5 (SD=5.2) varus	1.4 (SD=2.7) varus	<0.001
FMA (degrees)	88.7 (SD=2.5)	90.5 (SD=2.0)	<0.001
TMA (degrees)	83.3 (SD=2.7)	89.9 (SD=1.8)	<0.001

HKA hip–knee–ankle, FMA femoral mechanical angle, TMA tibial mechanical angle

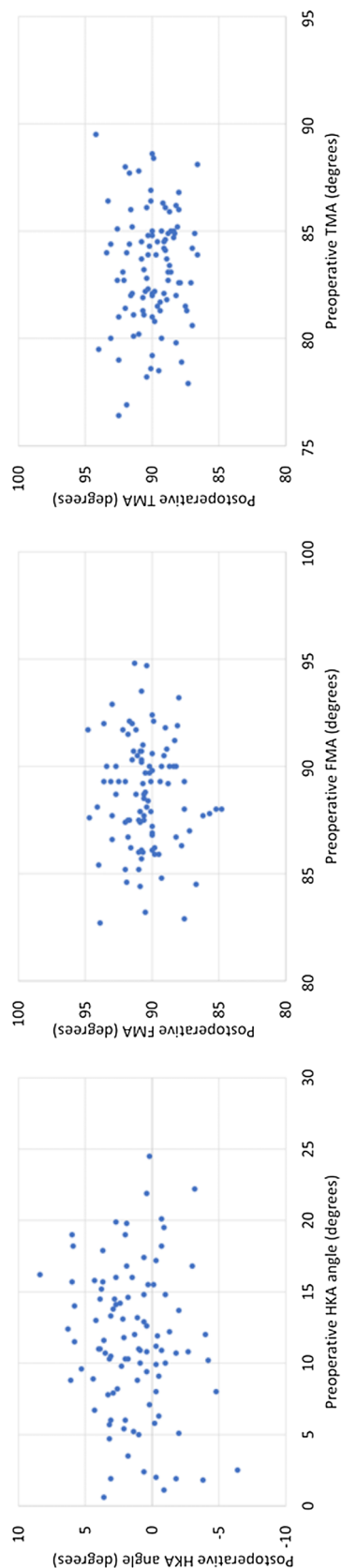


Fig. 2 Scatter plot of preoperative and postoperative hip–knee–ankle (HKA) angle, femoral mechanical angle (FMA), and tibial mechanical angle (TMA)

significant differences were observed in postoperative clinical outcomes (Table 6).

Discussion

The most important findings of the present study were that asymmetrical varus–valgus balance at full extension and 90° of flexion had no effect on postoperative range of motion and the subscales of the KSS 2011 and that relatively large varus imbalance did not worsen clinical symptoms at 2 years after TKA.

In the present study, the same surgical technique was applied for consecutive knees with preoperative varus deformity, and the measurement of the varus–valgus gap angle and joint gap was performed in a uniform manner. Medial release was limited to the deep layer of the MCL even if the varus–valgus imbalance was observed with the aim of neutral coronal alignment. The average varus–valgus imbalance was 2.8° varus in extension and 1.3° varus in flexion. In terms of functional knee phenotype, mechanical alignment target was obtained postoperatively in most of the patients, whereas the preoperative alignment was variable [8].

So far, it is still under discussion whether varus–valgus imbalance affects clinical outcomes. A previous study measuring the joint gap with a tensor device revealed achieving equalized rectangular gaps at extension and flexion did not influence 2-year postoperative clinical outcomes [14]. In several reports, however, asymmetrical gap balance affected negatively the University of California, Los Angeles activity level at 4 months, the postoperative knee flexion at 1 year, and Western Ontario and McMaster Universities Arthritis Index (WOMAC) score at 34 months, although these studies did not separately evaluate the knees with varus and valgus imbalance [10, 16, 32]. In the present study, the effect on clinical outcomes was analyzed at 2 years using KSS 2011 for consecutive knees with preoperative varus deformity. In extension, the groups with the residual varus and severe varus imbalance during TKA showed no significant differences in clinical outcomes including range of motion and KSS 2011 in comparison with the balanced group. However, the effect of valgus imbalance was unclear, because no knee showed postoperative valgus imbalance. In flexion, the groups with residual valgus, varus, and severe varus imbalance also showed no significant differences in comparison with the balanced group, although valgus imbalance was correlated with poor postoperative outcomes in several studies [24, 32]. The findings of the present study suggest that the asymmetrical gap seems to have no relation with early postoperative knee function and patient satisfaction. However, further research should be conducted to evaluate long term durability for the knees with asymmetrical

Fig. 3 Distribution of varus–valgus angle in extension and flexion

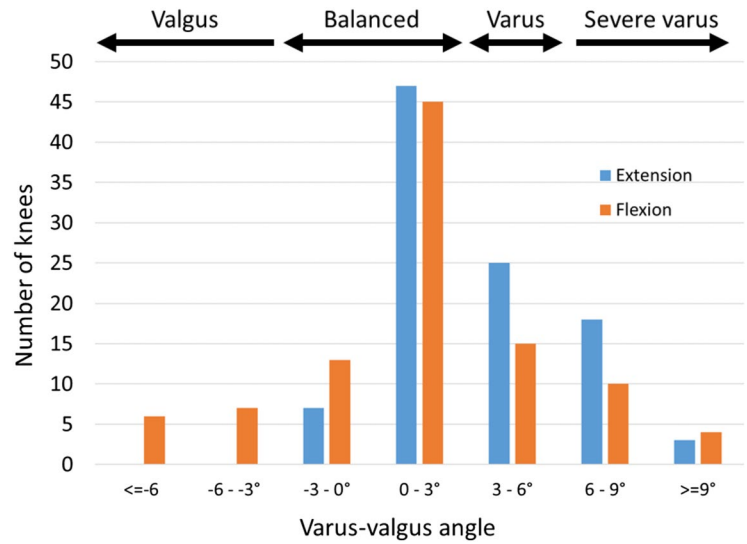


Fig. 4 Distribution of laxity in extension

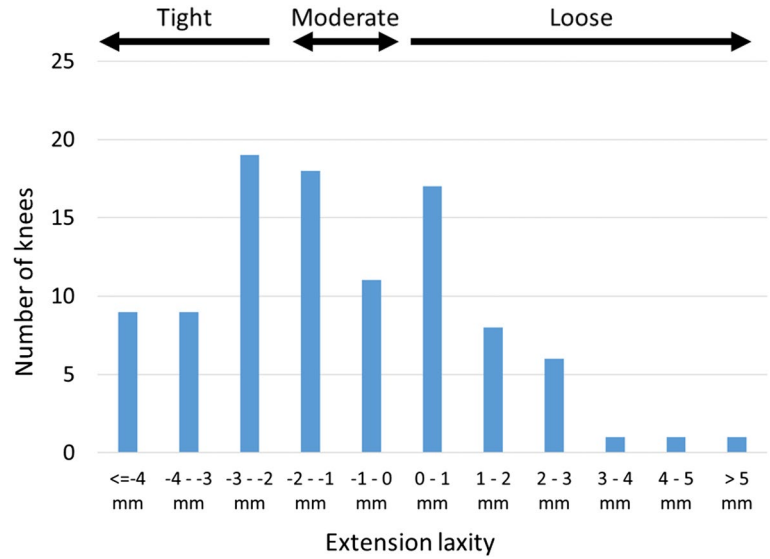
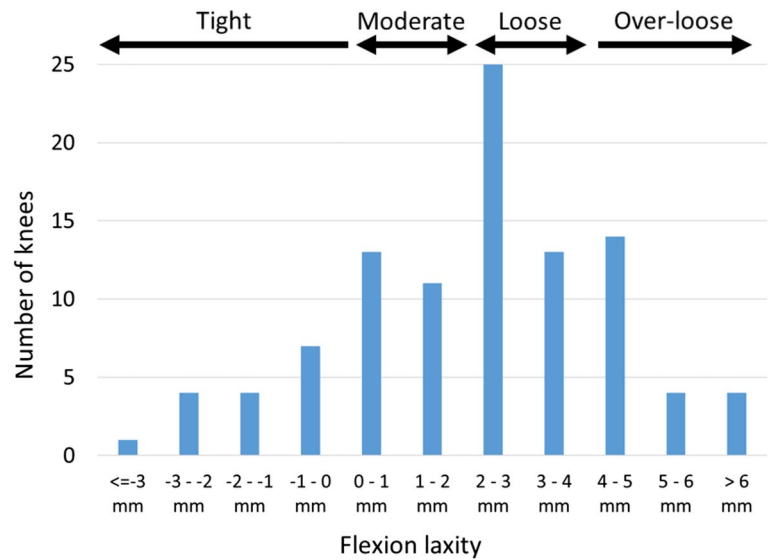


Fig. 5 Distribution of laxity in flexion



varus–valgus balance, because 2-year follow-up is too short to comment on wear and aseptic loosening.

Several reasons can be suggested why residual lateral laxity had no effect on postoperative outcomes. First, larger lateral laxity has been reported in normal knees [28, 30]. One study showed that the mean angle was 4.9° in varus stress and 2.4° in valgus stress in extension and that the mean angle was 4.8° in varus stress and 1.7° in valgus stress in

flexion. Therefore, larger lateral laxity, which is seen in normal knees, did not cause patient discomfort. Second, several clinical studies after TKA support our findings. Favorable outcomes were reported for the patients with lateral laxity after TKA, in which lateral laxity was positively correlated with postoperative knee flexion angle [24]. On the contrary, medial laxity had negative effects on postoperative pain and functions [3]. In the kinematic analysis after TKA, medial

Table 2 Correlation with alignment and gap angle and laxity

	Gap angle in extension		Gap angle in flexion		Laxity in extension		Laxity in flexion	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Preoperative HKA angle	0.185	0.066	0.070	0.489	0.165	0.100	0.027	0.793
Postoperative HKA angle	−0.170	0.092	−0.172	0.087	0.019	0.849	−0.034	0.734
Delta HKA angle	0.257	0.010	0.151	0.135	0.147	0.146	0.042	0.679
Preoperative FMA	0.058	0.563	−0.023	0.822	0.075	0.561	0.188	0.061
Postoperative FMA	−0.028	0.781	0.003	0.975	0.189	0.060	0.105	0.297
Delta FMA	−0.065	0.518	0.021	0.839	0.058	0.567	−0.087	0.391
Preoperative TMA	−0.052	0.607	−0.145	0.149	−0.280	0.005	−0.109	0.280
Postoperative TMA	0.126	0.211	0.141	0.162	0.009	0.932	−0.086	0.197
Delta TMA	0.109	0.281	0.193	0.055	0.232	0.020	0.043	0.667

HKA hip–knee–ankle, FMA femoral mechanical angle, TMA tibial mechanical angle

Table 3 Comparison according to varus–valgus gap angle in extension

	Balanced	Varus	Severe varus	<i>p</i> value	Significance
Patient demographics					
Number	54	21	25		
Sex (female)	43 (80%)	19 (90%)	23 (92%)	0.262	n.s.
Age (years)	75.5 (SD=6.8)	76.4 (SD=6.9)	75.7 (SD=7.5)	0.893	n.s.
BMI	26.5 (SD=3.4)	25.4 (SD=3.5)	28.3 (SD=4.9)	0.035	V vs SV
Preoperative HKA (degrees)	11.0 (SD=5.1) varus	10.5 (SD=5.0) varus	14.0 (SD=4.9) varus	0.040	n.s.
Postoperative HKA (degrees)	1.5 (SD=2.5) varus	2.0 (SD=2.5) varus	0.4 (SD=3.2) varus	0.103	n.s.
Preoperative range of motion					
Extension (degrees)	−8.4 (SD=7.1)	−9.6 (SD=8.4)	−10.7 (SD=7.6)	0.481	n.s.
Flexion (degrees)	121.2 (SD=13.2)	118.0 (SD=14.3)	118.6 (SD=10.6)	0.527	n.s.
Preoperative KSS 2011					
Symptoms	8.1 (SD=5.8)	8.7 (SD=5.7)	9.7 (SD=5.7)	0.558	n.s.
Patient satisfaction	15.4 (SD=5.9)	14.2 (SD=5.3)	14.0 (SD=3.9)	0.649	n.s.
Patient expectation	13.3 (SD=2.4)	14.0 (SD=1.1)	13.2 (SD=1.8)	0.306	n.s.
Functional activities	43.2 (SD=18.3)	35.6 (SD=19.4)	40.2 (SD=17.7)	0.230	n.s.
Postoperative range of motion					
Extension (degrees)	−2.3 (SD=4.0)	−2.2 (SD=3.6)	−2.6 (SD=5.6)	0.956	n.s.
Flexion (degrees)	120.8 (SD=16.0)	118.6 (SD=11.5)	116.9 (SD=11.5)	0.563	n.s.
Postoperative KSS 2011					
Symptoms	21.1 (SD=4.1)	20.5 (SD=4.7)	22.0 (SD=4.0)	0.480	n.s.
Patient satisfaction	27.4 (SD=7.3)	25.8 (SD=8.2)	27.2 (SD=7.8)	0.690	n.s.
Patient expectation	10.4 (SD=2.9)	9.6 (SD=2.8)	10.4 (SD=2.5)	0.499	n.s.
Functional activities	65.3 (SD=19.7)	64.4 (SD=18.1)	63.7 (SD=22.8)	0.948	n.s.

n.s. not significant, V varus, SV severe varus

Table 4 Comparison according to varus–valgus gap angle in flexion

	Valgus	Balanced	Varus	Severe varus	<i>p</i> value	Significance
Patient demographics						
Number	13	58	15	14		
Sex (female)	9 (69%)	49 (84%)	14 (93%)	13 (93%)	0.275	n.s.
Age (years)	74.7 (SD=8.1)	75.9 (SD=6.8)	75.9 (SD=6.2)	74.7 (SD=8.1)	0.953	n.s.
BMI	27.1 (SD=3.3)	26.7 (SD=4.2)	25.5 (SD=3.0)	26.9 (SD=4.1)	0.709	n.s.
Preoperative HKA (degrees)	9.7 (SD=5.3) varus	11.8 (SD=5.1) varus	10.4 (SD=4.5) varus	12.9 (SD=5.7) varus	0.325	n.s.
Postoperative HKA (degrees)	2.0 (SD=3.9) varus	1.7 (SD=2.1) varus	1.0 (SD=3.2) varus	0.3 (SD=3.0) varus	0.266	n.s.
Preoperative range of motion						
Extension (degrees)	− 13.5 (SD=8.0)	− 8.6 (SD=6.9)	− 8.7 (SD=6.9)	− 8.2 (SD=9.5)	0.187	n.s.
Flexion (degrees)	116.9 (SD=10.9)	120.2 (SD=13.9)	121.3 (SD=13.0)	119.6 (SD=11.7)	0.831	n.s.
Preoperative KSS 2011						
Symptoms	6.8 (SD=4.3)	8.2 (SD=6.0)	11.2 (SD=5.5)	9.1 (SD=5.8)	0.183	n.s.
Patient satisfaction	15.7 (SD=5.7)	15.1 (SD=5.8)	14.5 (SD=4.7)	14.3 (SD=4.1)	0.895	n.s.
Patient expectation	13.6 (SD=1.9)	13.2 (SD=2.3)	14.4 (SD=0.7)	13.4 (SD=1.6)	0.227	n.s.
Functional activities	39.2 (SD=14.6)	39.2 (SD=19.4)	47.9 (SD=16.9)	40.9 (SD=19.6)	0.442	n.s.
Postoperative range of motion						
Extension (degrees)	− 2.3 (SD=2.6)	− 2.5 (SD=4.2)	− 1.0 (SD=2.8)	− 3.2 (SD=6.4)	0.546	n.s.
Flexion (degrees)	116.9 (SD=19.4)	122.2 (SD=13.3)	114.3 (SD=17.0)	116.1 (SD=12.7)	0.188	n.s.
Postoperative KSS 2011						
Symptoms	22.2 (SD=3.0)	21.5 (SD=4.1)	19.7 (SD=5.2)	20.4 (SD=4.7)	0.313	n.s.
Patient satisfaction	26.3 (SD=7.9)	27.8 (SD=7.4)	26.0 (SD=7.7)	25.4 (SD=8.5)	0.679	n.s.
Patient expectation	9.5 (SD=2.3)	10.6 (SD=2.7)	10.5 (SD=3.9)	9.0 (SD=2.0)	0.179	n.s.
Functional activities	63.0 (SD=19.0)	65.4 (SD=19.2)	67.7 (SD=19.9)	60.6 (SD=24.1)	0.781	n.s.

n.s. not significant

laxity induced abnormal knee kinematics, whereas lateral laxity had little effects on knee kinematics [21]. Finally, in a computer simulation study, no lift-off motion was observed with excessive lateral laxity alone in a neutrally aligned TKA [13]. In the present study, neutral alignment was almost achieved postoperatively with 1.4° varus of HKA angle on average, whereas the residual varus–valgus imbalance was 2.8° varus in extension and 1.3° varus in flexion. Therefore, varus–valgus imbalance and lateral laxity during surgery may be acceptable for the varus knees if the postoperative neutral alignment is achieved.

The joint gap during TKA has been known as one of important factors to influence postoperative range of motion. The intraoperative extension gap is correlated with the postoperative extension angle, in which tight component gap in extension causes postoperative flexion contracture [2, 27]. The intraoperative flexion gap is positively correlated with postoperative flexion angle [24, 29]. In the present study, the joint gap in extension and flexion was measured using a tensor device, and the comparison was made according to the laxity of the joint gap. Both joint gaps in extension and flexion were not correlated with the postoperative range of motion and KSS 2011. These results might be due to the limited range of joint gap during surgery within

physiological lateral laxity or due to the limited number of each group.

Medial release is one of the essential steps toward the achievement of ligament balancing during TKA in patients with varus deformity. Several studies conduct extensive medial release up to complete detachment of MCL until the medial gap opens enough to balance the lateral gap. In these studies, the joint gap opening for knees with extensive medial release is similar, and knee kinematics and clinical outcomes are not altered in comparison with knees with minimal medial release [5, 17]. In the present study, 25 and 14 knees showed more than 6° of varus imbalance in extension and flexion, respectively. However, similar clinical outcomes were observed for knees with residual severe varus gap angle, although further studies are needed to evaluate the effect of residual ligament imbalance on long-term clinical outcomes and implant durability.

This study had several limitations. First, the number of patients in each group was relatively small, which can be underpowered to detect differences between groups, although the post hoc power analysis suggested adequate power. Moreover, only KSS scores were evaluated in the present study. Another patient reported outcome measure may be more responsive to these differences in knee

Table 5 Comparison according to laxity in extension

	Tight	Moderate	Loose	<i>p</i> value	Significance
Patient demographics					
Number	37	29	34		
Sex (female)	30 (81%)	26 (90%)	29 (85%)	0.618	n.s.
Age (years)	74.3 (SD=7.2)	77.1 (SD=7.6)	76.1 (SD=5.9)	0.244	n.s.
BMI	26.6 (SD=3.4)	26.3 (SD=4.3)	26.9 (SD=4.2)	0.836	n.s.
Preoperative HKA (degrees)	11.0 (SD=5.9) varus	10.6 (SD=4.3) varus	12.8 (SD=4.8) varus	0.202	n.s.
Postoperative HKA (degrees)	1.3 (SD=2.8) varus	1.4 (SD=2.2) varus	1.5 (SD=3.0) varus	0.956	n.s.
Preoperative range of motion					
Extension (degrees)	-8.8 (SD=6.8)	-9.7 (SD=7.9)	-9.3 (SD=8.2)	0.897	n.s.
Flexion (degrees)	121.2 (SD=12.0)	120.9 (SD=15.6)	117.5 (SD=11.5)	0.431	n.s.
Preoperative KSS 2011					
Symptoms	8.5 (SD=5.3)	8.1 (SD=5.5)	9.0 (SD=6.5)	0.829	n.s.
Patient satisfaction	14.6 (SD=4.2)	15.9 (SD=5.3)	14.7 (SD=6.5)	0.590	n.s.
Patient expectation	13.7 (SD=1.8)	12.7 (SD=2.6)	13.8 (SD=1.5)	0.065	n.s.
Functional activities	42.5 (SD=16.9)	39.0 (SD=18.3)	41.1 (SD=20.6)	0.624	n.s.
Postoperative range of motion					
Extension (degrees)	-2.3 (SD=3.7)	-2.6 (SD=4.6)	-2.2 (SD=4.7)	0.928	n.s.
Flexion (degrees)	118.9 (SD=19.1)	119.0 (SD=12.8)	120.4 (SD=11.2)	0.894	n.s.
Postoperative KSS 2011					
Symptoms	21.5 (SD=3.8)	19.9 (SD=5.1)	21.8 (SD=3.8)	0.170	n.s.
Patient satisfaction	26.2 (SD=7.0)	27.7 (SD=8.5)	27.3 (SD=7.6)	0.704	n.s.
Patient expectation	10.5 (SD=2.9)	10.7 (SD=2.8)	9.5 (SD=2.6)	0.156	n.s.
Functional activities	66.1 (SD=17.9)	61.2 (SD=20.7)	66.3 (SD=21.3)	0.526	n.s.

n.s. not significant

balancing. Second, this study used a single posterior-stabilized implant design, and the results of this study might be specific to this specific TKA implant. Third, the measurements were made intraoperatively with a tensor with the trial components in place, and this might not reflect the final situation, since uneven cement mantle thickness and differences in intraoperative component positioning during cementation may affect the final gap. In addition, the gap angle and the joint gap were measured at full extension and 90° of flexion, but not in between. The condition at mid-flexion may affect clinical outcomes. Fourth, the number of the patients with extensive knee deformity of more than 20° was small. The results of the present study cannot be applied for the knees with severe varus deformity. Moreover, most of the knees included in the current study were of female patients, because consecutive TKA patients were recruited without any adjustment for sex. In previous clinical studies in Asian countries, female predominance among patients undergoing TKA is well documented [19, 20, 22]. Finally, the follow-up period was relatively short, and the effects of ligament imbalance during surgery were evaluated with clinical

outcomes at 2 years after TKA. It was assumed that the ligament imbalance might cause functional disabilities and poor patient satisfaction in the short-term follow-up. Thus, the effects on clinical outcomes were analyzed for 2 years. However, ligament imbalance could have long-term effects on postoperative knee function, range of motion, patient satisfaction, and durability. Further studies are needed to evaluate the effect of residual ligament imbalance on the longevity of the implants.

Conclusions

Intraoperative asymmetrical joint gap and physiological laxity at full extension and 90° of flexion do not affect postoperative early clinical results after TKA, although mid-flexion stability is not evaluated, and the present study can be underpowered to detect differences due to the small number of each group. Medial release seems unnecessary for knees with preoperative varus deformity, and residual asymmetrical joint gap may be permitted during TKA.

Table 6 Comparison according to laxity in flexion

	Tight	Moderate	Loose	Over-loose	<i>p</i> value	Significance
Patient demographics						
Number	16	24	38	22		
Sex (female)	13 (81%)	21 (88%)	31 (82%)	20 (91%)	0.728	n.s
Age (years)	73.7 (SD=8.3)	77.2 (SD=7.1)	75.0 (SD=6.6)	77.0 (SD=6.1)	0.321	n.s
BMI	26.4 (SD=3.2)	26.9 (SD=3.7)	26.5 (SD=4.1)	26.7 (SD=4.6)	0.968	n.s
Preoperative HKA (degrees)	10.3 (SD=5.9) varus	12.4 (SD=5.7) varus	11.5 (SD=4.5) varus	11.4 (SD=5.2) varus	0.663	n.s
Postoperative HKA (degrees)	1.5 (SD=2.4) varus	0.9 (SD=2.7) varus	2.1 (SD=2.6) varus	0.7 (SD=2.9) varus	0.174	n.s
Preoperative range of motion						
Extension (degrees)	-7.5 (SD=7.3)	-11.3 (SD=5.9)	-9.2 (SD=8.6)	-8.2 (SD=7.3)	0.400	n.s
Flexion (degrees)	124.4 (SD=10.8)	118.3 (SD=15.9)	119.2 (SD=13.0)	119.3 (SD=10.8)	0.499	n.s
Preoperative KSS 2011						
Symptoms	9.9 (SD=5.7)	6.9 (SD=4.3)	8.4 (SD=6.2)	9.7 (SD=6.2)	0.304	n.s
Patient satisfaction	16.6 (SD=3.0)	13.9 (SD=5.5)	15.3 (SD=5.2)	14.5 (SD=6.6)	0.424	n.s
Patient expectation	13.3 (SD=1.9)	12.3 (SD=3.0)	13.9 (SD=1.1)	14.0 (SD=1.6)	0.006	M vs L, M vs OL
Functional activities	49.8 (SD=19.6)	37.9 (SD=16.6)	41.7 (SD=17.2)	35.5 (SD=20.4)	0.096	n.s
Postoperative range of motion						
Extension (degrees)	-1.6 (SD=3.0)	-3.1 (SD=5.7)	-2.2 (SD=4.0)	-2.3 (SD=3.7)	0.734	n.s
Flexion (degrees)	117.2 (SD=15.5)	116.5 (SD=17.0)	122.1 (SD=12.4)	119.8 (SD=16.0)	0.469	n.s
Postoperative KSS 2011						
Symptoms	19.8 (SD=5.1)	20.6 (SD=4.1)	21.7 (SD=4.1)	21.9 (SD=4.0)	0.353	n.s
Patient satisfaction	24.9 (SD=7.1)	26.3 (SD=7.4)	27.7 (SD=7.6)	27.9 (SD=8.3)	0.558	n.s
Patient expectation	10.7 (SD=2.5)	9.8 (SD=2.5)	10.1 (SD=3.1)	10.6 (SD=2.7)	0.676	n.s
Functional activities	63.0 (SD=20.3)	62.9 (SD=21.6)	64.2 (SD=21.5)	68.9 (SD=14.7)	0.730	n.s

n.s. not significant, *M* moderate, *L* loose, *OL* over loose

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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