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CLINICAL RESEARCH

Intraoperative Joint Gaps Affect Postoperative Range of Motion in TKAs With Posterior-stabilized Prostheses

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Abstract

Background Joint gaps and mediolateral (ML) soft tissue balance have long been known to affect clinical scores and patient function after TKA, but the relationship between gaps and soft tissue balance remain poorly defined. If specific relationships exist between soft tissue tension and patient function, then objective targets could be established to assist surgeons in achieving more consistent postoperative knee function.

Questions/purposes By performing instrumented gap measurements during TKA, we sought to quantify the relationships between intraoperative soft tissue tension and clinical scores and patient function.

Methods We prospectively followed 57 patients with 63 primary TKAs with posterior-stabilized prostheses. Joint gaps and ML soft tissue balance were measured intraoperatively from 0° to 135° with the patella reduced after independent bone cuts and soft tissue releases. We determined the relationships between these intraoperative measurements and postoperative ROM and Knee Society scores at minimum 2-year followup.

Results Larger joint gaps at 120° and 135° flexion predicted larger postoperative knee flexion ($r = 0.296$ and $r = 0.393$, respectively), whereas larger gaps at 10° flexion predicted greater postoperative knee extension ($r = 0.285$). Knees with rectangular joint gaps did not show better ROM or Knee Society scores compared with knees with trapezoidal joint gaps. In the range of normal surgical variation, neither joint gaps nor gap asymmetry affected the incidence of postoperative instability.

Conclusions Avoiding small joint gaps in extension and in deep flexion should allow patients who undergo TKAs to obtain maximum ROM.

Level of Evidence Level II, prognostic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

A TKA is one of the most effective methods to relieve pain and improve function in patients with arthritic knees [4, 5, 25, 29, 36]. Obtaining functional ROM after TKA is one of

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Each author certifies that Tsuchiura Kyodo General Hospital and the University of Florida approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
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the most important goals for normal daily activities [1, 10, 22]. Preoperative ROM is reportedly the most important factor influencing postoperative ROM [9, 13, 26], but many other factors, including implant design [6, 23], mediolateral (ML) soft tissue balance [32], flexion-extension gap balance [11, 18], joint-line height [20], femoral posterior condylar offset [3, 8], and PCL tension [24, 39], also influence postoperative ROM.

Intraoperative joint gaps and ML soft tissue balance are potentially modifiable surgical variables affecting clinical outcomes after TKA [14, 30, 32]. Various devices to measure joint gaps and ML soft tissue balance have been reported, including lamina spreaders [7], tensors [19, 27, 38], and electronic instruments [33, 41]. Intraoperative joint gaps usually are measured with the patella everted or laterally shifted, which tightens lateral structures and reduces the effect of the extensor mechanism in deep flexion. This may preclude accurate evaluation of joint gaps and ML soft tissue balance [18, 19, 41]. In addition, intraoperative joint gaps generally are measured in extension and 90° flexion, which provides limited information in mid- and deep flexion. Measuring joint gaps with the patella reduced and in smaller flexion intervals will provide detailed characterization of intraoperative coronal joint laxity. Using a tensor to measure joint gaps over the ROM with the patella in place, Matsumoto et al. [18] showed a correlation between joint gap changes from 90° to 135° flexion and postoperative knee flexion. Despite these efforts, the causal relationships between joint gaps and tissue balance, and clinical function like ROM, remain unclear.

We therefore addressed four questions related to soft tissue procedures during TKA: (1) How do intraoperative joint gaps affect clinical results, especially ROM? (2) How does intraoperative ML soft tissue balance affect clinical results, especially ROM? (3) How do intraoperative joint gaps and ML soft tissue balance affect postoperative knee instability? (4) How does preoperative femorotibial angle (FTA) affect intraoperative gaps and ML balance?

Patients and Methods

We prospectively followed all 66 patients who underwent 72 primary TKAs with implantation of posterior-stabilized (PS) prostheses between January 2006 and August 2008. All patients requiring TKAs received PS prostheses during this period. All patients gave informed consent for this institutional review board-approved study. Joint gaps and ML soft tissue balance were recorded during each case. Two patients (two knees) with previous high tibial osteotomies were excluded; seven patients (seven knees) also were excluded from the study because unsatisfactory initial balance required additional soft tissue releases, and there was not enough time to conduct a second comprehensive measurement of joint gaps. These nine exclusions left 57 patients (63 knees). A sample of 52 knees was computed to produce 80% power (1-β) for correlating intraoperative joint gaps and postoperative ROM using an effect size of 0.33, or an r^2 value explaining 10% of the data variance.

Subject age at the time of surgery averaged 72 years (range, 51–84 years). The study cohort included six men (10 knees) and 44 women (53 knees) with a preoperative diagnosis of osteoarthritis in 54 knees and rheumatoid arthritis in nine. Of the 63 knees, 22 (35%) had at least an AP instability ($\geq$ 5 mm) or ML instability ($\geq$ 5°) as defined by the Knee Society scoring system [12]. Preoperative measurements were obtained within 1 month before surgery by one observer (TW) (Table 1). FTA was measured using standing knee AP radiographs showing at least 15 cm of bone above and below the joint line. The minimum followup was 2 years (mean, 2.3 years; range, 2–3 years).

One surgeon (TW) performed all TKAs using generally accepted techniques for minimally invasive surgery and the same prosthesis (NexGen® LPS Flex Mobile; Zimmer, Warsaw, IN, USA) without a navigation system. An air tourniquet was pressurized to 330 mm Hg during surgery. The mini-midvastus approach, with an independent bone-cutting technique, was used for all knees [35]. The distal femur was cut perpendicular to its mechanical axis, removing the amount of bone corresponding to the prosthetic femoral component thickness. The proximal tibia was cut perpendicular to its coronal mechanical axis and with a 7°-sagittal posterior tibial slope, removing bone on the intact side that corresponded to the prosthetic tibial component thickness. The posterior femoral condyles were cut with 3° external rotation from the posterior condylar line. Whiteside's line was used as a femoral rotation reference in valgus knees [37]. The patella was not resurfaced in these knees.

Traditional gap balancing techniques, including osteophyte removal and soft tissue releases, were used to obtain rectangular joint gaps independent of the instrumented tensor. The PCL was sacrificed in all knees. The deep layer of the medial collateral ligament (MCL) was released in all knees with varus deformities. After osteophyte removal, the superficial layer of the MCL, posterior capsule, semimembranosus, and pes anserinus were released sequentially until adequate ML soft tissue balance was achieved. No soft tissue release of lateral structures was required to obtain acceptable ML soft tissue balance for two valgus knees with less than 170° FTA.

Joint gaps and ML soft tissue balance were measured after performing soft tissue releases. Femoral cuts were performed, and the femoral trial was put in place. A tensor (Offset Repo-Tensor®; Zimmer, Tokyo, Japan), developed by Kobe University [19], was placed between the tibial cut surface and the femoral trial. The tensor consisted of three parts: (1) an upper seesaw plate; (2) a lower platform plate; and (3) an extraarticular main body (Fig. 1A). The lower platform plate was fixed on the center of the tibial cut surface and held in place with small pins protruding from the bottom side of the plate. The seesaw plate had a post that fit into the intercondylar space and articulated with the cam of the femoral trial. This post-cam mechanism controlled the tibiofemoral translation in the coronal and sagittal planes over the entire knee flexion arc. Although the tibiofemoral articulation is flat, the kinematics between the tensor and the femoral trial are close to that between the tibial tray and the femoral implant. The main body connected the other two parts. The tensor was small enough to be used for minimally invasive procedures, and the offset arm allowed surgeons to use the device with the patella reduced. The tensor provided numerical measures of the joint gap at the center of the knee and the ML tilting angle from full extension to deep flexion. The patella was reduced to the original position and several sutures were used to maintain correct patellofemoral position throughout the ROM (Fig. 1B). A joint distraction force of 40 lb (18 kg) was applied by the tensor at each knee angle, and the central joint gaps and ML tilting angles were directly measured at 0°, 10°, 30°, 60°, 90°, 120°, and 135° flexion (Fig. 1C). Preliminary studies with this tensor indicated the joint gap, at full extension with 40 lb of joint distraction force, corresponded most closely to the appropriate tibial insert thickness [19]. One observer (TW) measured all cases with direct supervision over the surgical assistant who supported the thigh to maintain appropriate sagittal alignment and reduce the influence of thigh mass on knee forces. The accuracy of this measurement has been estimated to be ± 0.3 mm in the joint gap [19]. The original protocol assessed joint gaps at 0°, 30°, 60°, 90°, and 120° flexion, and this was augmented after the first 21 knees to include 10° (51 knees) and 135° (48 knees) flexion to better assess the terminal ranges of motion.

We defined the clinical gap as the measured joint gap minus the tibial construct thickness (tibial baseplate plus polyethylene insert implanted in each patient), which

Table 1. Preoperative and postoperative clinical values*

Variables	Preoperative	Followup	p value (paired t-test)	p, r values (correlation)
Extension (°)	−7 ± 9	−1 ± 3	< 0.001	< 0.001, r = 0.433
Flexion (°)	124 ± 21	126 ± 18	0.455	< 0.001, r = 0.604
Knee Society knee score	38 ± 13	93 ± 6	< 0.001	0.537
Knee Society function score	42 ± 17	65 ± 22	< 0.001	< 0.001, r = 0.638
Instability (+/−)	22/41	28/35	0.516 (chi square)	
Femorotibial angle (°)	185 ± 8 (162–203)	175 ± 2 (170–179)	< 0.001	0.695

* Data are shown as the mean ± SD (range); r = Pearson's correlation coefficient.

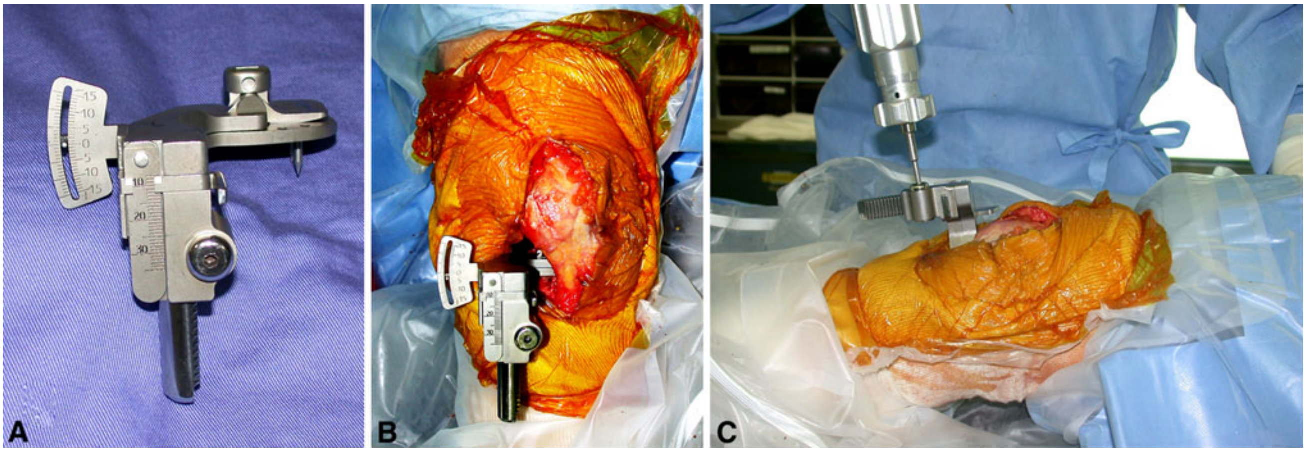

Fig. 1A–C (**A**) The tensor used in this study consisted of an upper seesaw plate, a lower platform plate, and an extraarticular main body. The central joint gap and the ML soft tissue balance (tilting angle) could be measured though the entire ROM. (**B**) The tensor had an offset arm allowing measurement with the patella reduced during minimally invasive TKA (flexed left knee, the right side shows the proximal part of the leg). (**C**) A joint distraction force of 40 lb (18 kg) was applied to the tensor during gap measurements.

represents the postimplantation laxity at each angle. When the measured gap was smaller than the thickness of the implanted tibial construct, the clinical gap had a negative value. ML soft tissue balance was assessed by calculating the mean joint gap-tilting angle over all flexion angles for each patient.

Postoperatively, continuous epidural anesthesia was continued for 2 days. The day after surgery, quadriceps setting and active straight-leg raising were encouraged. Full weightbearing on the surgically treated knee was allowed. On the second day after surgery, the drainage tube and the epidural catheter were removed. ROM exercise was started, and gait exercise bearing full weight was encouraged. Continuous passive motion machines were used for all patients. The goal of rehabilitation was a stable gait with a single cane, although this was ascertained for each patient depending on the preoperative gait ability.

Patients were followed postoperatively at 1 month, 3 months, 6 months, 1 year, and every year thereafter. Physical examinations including Knee Society knee score and function score [12] were performed, and radiographs of the surgically treated knee were obtained before surgery and at each followup.

Based on the mean joint gap tilting angle, the 63 knees were classified into three groups: (1) knees with mean joint gap tilting less than −1.0° (lateral tight group, 17 knees); (2) knees with mean joint gap tilting between −1.0° and 1.0° (well-balanced group, 17 knees); and (3) knees with mean joint gap tilting greater than 1.0° (medial tight group, 29 knees); the clinical results were compared among these three groups. Joint instability at the final followup also was considered. The intraoperative measurements of knees with postoperative instability and those without instability were compared. Finally, we examined the relation between the preoperative FTA and intraoperative measurements. Correlations between clinical gaps and last followup values of ROM, Knee Society knee and function scores were evaluated using Pearson's test. ANOVA with post hoc Tukey's test was used for the last followup value comparisons among the three joint gap-tilting groups. An unpaired t-test was used for clinical gap comparisons between knees with and without postoperative instability. A chi-square test was used to compare postoperative instability among the three tilting groups. ANOVA was used to compare preoperative FTA among the three tilting groups. SPSS statistical software (IBM, Armonk, NY, USA) was used for these analyses.

Results

Clinical gaps at 120° and 135° correlated with postoperative knee flexion ($r = 0.296$, $p = 0.018$; $r = 0.393$, $p = 0.006$, respectively) (Fig. 2), and clinical gaps at 10° correlated with postoperative knee extension ($r = 0.285$, $p = 0.043$) (Table 2). Clinical gaps, however, did not correlate with Knee Society knee or function score (Table 2). Average clinical gaps were smallest at 0° knee flexion, increased over 2 mm at 10°, gradually increased an additional 2 mm up to 90°, and then progressively decreased at 120° and 135° (Fig. 3). Maximum clinical gaps of 5.1 mm were observed at 90° knee flexion.

We found no differences among the three tilting groups in terms of postoperative knee extension angle, flexion angle, Knee Society knee or function score (Table 3). The mean joint gap-tilting angle of all knees averaged 0.6° (range, −9.3° to 9.0°).

Clinical gaps did not affect postoperative stability. No clinical gaps differed between knees with postoperative instability and knees without instability (Table 4). Average tilting angles did not affect ($p = 0.369$) postoperative stability (Table 3). Of 28 knees (44%) with at least AP or ML instability at last followup, 22 had AP instability (≥ 5 mm), two had ML instability (≥ 5°), and four had AP and ML instability. These were mostly anterior laxities detected during manual examination of the patients' knees with relaxed muscles, not clinical instabilities reported by patients. None of these knees had AP or ML instability

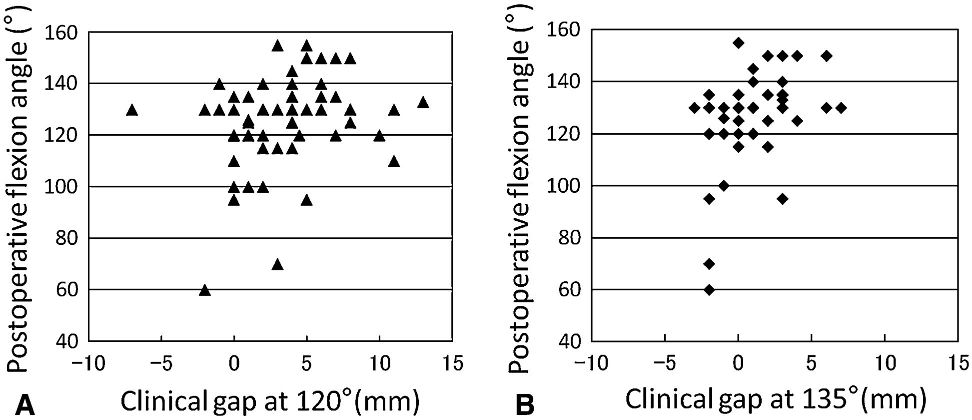

Fig. 2A–B (**A**) A clinical gap at 120° had positive correlations with postoperative knee flexion angles ($r = 0.296$, $p = 0.018$, $n = 63$). (**B**) A clinical gap at 135° had positive correlations with postoperative knee flexion angles ($r = 0.393$, $p = 0.006$, $n = 48$).

Table 2. Correlation between clinical gaps and clinical values

Knee flexion	p, r values (correlation)				
	Postoperative extension	Postoperative flexion	Postoperative KS	Postoperative FS	Preoperative FTA
0° (n = 63)	p = 0.434	p = 0.930	p = 0.684	p = 0.472	p = 0.462
10° (n = 51)	p = 0.043 r = 0.285	p = 0.477	p = 0.111	p = 0.934	p = 0.043 r = 0.285
30° (n = 63)	p = 0.175	p = 0.697	p = 0.178	p = 0.952	p = 0.102
60° (n = 63)	p = 0.579	p = 0.833	p = 0.127	p = 0.353	p = 0.063
90° (n = 63)	p = 0.377	p = 0.336	p = 0.107	p = 0.525	p = 0.068
120° (n = 63)	p = 0.360	p = 0.018 r = 0.296	p = 0.297	p = 0.972	p = 0.989
135° (n = 48)	p = 0.371	p = 0.006 r = 0.393	p = 0.227	p = 0.596	p = 0.427

r = correlation coefficient; KS = Knee Society knee score; FS = Knee Society function score; FTA = femorotibial angle.

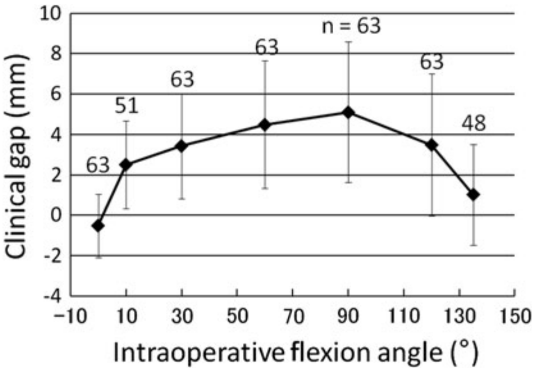

Fig. 3 The average clinical gap, defined as the measured joint gap minus the combined thickness of the tibial component and polyethylene insert, increases with knee flexion until 90° and then decreases with further flexion. There were statistical differences between the clinical gaps at all flexion angles: between 0° and 10°, 30°, 60°, 120° ($p < 0.001$); between 10° and 60° ($p = 0.004$); 90° ($p < 0.001$); between 30° and 90° ($p = 0.017$); 135° ($p < 0.001$); between 60° and 135° ($p < 0.001$); between 90° and 120° ($p = 0.023$); 135° ($p < 0.001$); and between 120° and 135° ($p < 0.001$).

greater than 10 mm nor did any knee have functional instability or require revision surgery.

The preoperative FTA positively correlated with ($r = 0.285$, $p = 0.043$) the clinical gap at 10° flexion (Table 2). However, the preoperative FTA did not differ among the three joint gap-tilting groups (Table 3).

Discussion

It remains debatable how surgeons should tension soft tissues for knee arthroplasties. Tissues are manipulated most easily during surgery, so it is important to establish objectively the relationships between intraoperative tissue tension and postoperative clinical and functional outcomes. We, therefore, addressed four questions related to soft tissue procedures during TKA: (1) How do intraoperative joint gaps affect clinical results, especially ROM? (2) How does intraoperative ML soft tissue balance affect clinical

Table 3. Relationship between joint gap tilt and clinical results or preoperative FTA*

Variables	Lateral tight (n = 17)	Well-balanced (n = 17)	Medial tight (n = 29)	p value
Tilting angle (°)	−4.0 ± 2.7 (−9.3 to −1.1)	0.0 ± 0.7 (−1.0 to 1.0)	3.6 ± 2.1 (1.3 to 9.0)	< 0.001 (ANOVA)
Extension (°)	−1 ± 2	−2 ± 3	−1 ± 2	0.575 (ANOVA)
Flexion (°)	125 ± 13	124 ± 21	124 ± 20	0.987 (ANOVA)
Knee Society knee score	95 ± 5	91 ± 5	93 ± 7	0.126 (ANOVA)
Knee Society function score	66 ± 13	71 ± 22	62 ± 26	0.343 (ANOVA)
Instability (+/−)	7/10	10/7	11/18	0.369 (chi square)
Preoperative FTA (°)	188 ± 6 (179–203)	183 ± 8 (162–195)	185 ± 9 (165–203)	0.254 (ANOVA)

* Data are shown as the mean ± SD (range); FTA = femorotibial angle.

results, especially ROM? (3) How do intraoperative joint gaps and ML soft tissue balance affect postoperative knee instability? (4) How does preoperative FTA affect intraoperative gaps and ML balance?

Several study limitations need to be acknowledged. First, our patient cohort was sufficient to address the primary study question but lacked statistical power to address the secondary questions. Larger subject cohorts are required to provide definitive findings for our Questions 2 through 4. Second, many factors affect knee arthroplasty outcomes, so one must take a narrow view to focus solely on the relationships between intraoperative laxity measurements and clinical results. Acknowledging this limitation, we believe a single-surgeon series is appropriate to assess these relationships. Third, our subject cohort consisted primarily of women with osteoarthritis. Our findings may not generalize to men or patients with rheumatoid arthritis.

Table 4. Clinical gaps of knees with and without postoperative instability*

Clinical gap	With postoperative instability (mm)	Without postoperative instability (mm)	p value (unpaired t-test)
0° (n = 63)	−0.7 ± 1.3	−0.4 ± 1.8	0.493
10° (n = 51)	2.8 ± 1.9	2.3 ± 2.4	0.404
30° (n = 63)	3.9 ± 2.4	3.0 ± 2.7	0.176
60° (n = 63)	4.8 ± 3.2	4.2 ± 3.2	0.453
90° (n = 63)	5.7 ± 3.8	4.6 ± 3.2	0.230
120° (n = 63)	4.0 ± 3.2	3.1 ± 3.7	0.302
135° (n = 48)	1.3 ± 2.7	0.7 ± 2.3	0.452

* Data are shown as the mean ± SD.

Consistent with our expectation, clinical gaps at 120° and 135° had positive correlations with postoperative flexion angle, whereas clinical gaps at 10° showed a positive correlation with postoperative extension angle. Adequate joint spaces should contribute positively to the outcome of TKA [15, 16] (Table 5). Matsumoto et al. [18] used the same tensor with and without patella eversion and reported gap differences (135°–90°) with the patella reduced showed a positive correlation with postoperative knee flexion (Table 5). Asano et al. [2] observed that soft tissue tension in extension during surgery positively correlated with postoperative extension deficits (Table 5). In our study, clinical gaps in deep knee flexion showed positive correlations with postoperative knee flexion, whereas the clinical gap at 10° showed a positive correlation with postoperative knee extension. These results highlight the importance of adequate joint gaps greater than 90° for greater postoperative flexion and gaps at 10° knee flexion for full postoperative knee extension. Clinical gaps were greater in midflexion, but none of our observations suggest these knees had midflexion functional instability. Average clinical gaps in midflexion did not exceed the average gap at 90°, which was 5 mm (Fig. 3). Gaps greater than 5 mm appear to offer no additional benefit for knee ROM (Fig. 2).

We did not find well-balanced knees had better ROM or Knee Society scores. Knees with average tilting angles

Table 5. Comparison of effect of joint gap or laxity on clinical results from past and current studies

Study	Findings	Number of knees	Followup (years)
Kuster et al. [15]	Varus and valgus laxity between 4° and 8° on either side in 20° flexion improved patient satisfaction, ROM without deleterious short- to mid-term effects	44	4.5 (range, 2–7)
Matsuda et al. [17]	Coronal laxity, especially balanced laxity, is important for achieving improved ROM in mobile-bearing TKAs	80	1
Matsumoto et al. [18]	Joint gap change value (135°–90°) by reducing patellofemoral joint showed positive correlation with postoperative knee flexion angle	25	2
Asano et al. [2]	The extension deficit became larger with an increase of soft tissue tension	64	1
Current study	Clinical gaps at 120° and 135° had positive correlations with postoperative flexion angle, whereas clinical gaps at 10° showed a positive correlation with postoperative extension angle; well-balanced knees did not show better clinical results	63	2.3 (range, 2–3)

greater than 1° had comparable results to those with neutrally balanced knees. Several studies [14, 30, 32] report that ML soft tissue balance is an important factor for a successful TKA and that inadequate ML soft tissue balance is believed to result in poor outcomes. Some studies [17, 28] have suggested that intraoperative and postoperative ML soft tissue balances averaged 0° to 2° at extension and at 90° knee flexion. We found gap tilt averaged 0.6°, consistent with previous reports. Perfect balance is difficult to achieve [7], and it has been questioned whether rectangular gaps are the ideal goal because the normal joint gap is trapezoidal [31]. Our data did not show superior clinical outcomes in the most well-balanced knees. Our data suggested that as much as 4° gap tilt is consistent with good short-term results using a PS prosthesis.

Clinical gaps or tilting angles did not affect postoperative instability. Too much joint laxity is associated with persistent pain and poor long-term outcomes resulting from instability [12, 21, 34]. We suspected greater postoperative instability would result from greater joint gaps and/or imbalanced ML soft tissues. In our series, 44% of knees had a carefully detected small amount of AP or ML laxity. Neither of these intraoperative variables, however, considerably affected postoperative stability for the ranges we observed. Yamakado et al. [40] reported the mean AP and ML laxities of knees with cruciate-retaining prostheses as 9.7 mm and 10.6°, respectively. Mitts et al. [21] found 37% of knees with AP laxity greater than 5 mm and 78% of knees with ML laxity greater than 5° in their knee arthroplasties with cruciate-retaining prostheses. It appears a range of joint laxities is consistent with good short-term outcomes, and future work is required to determine the magnitude of laxity that tips the balance toward instability and poor clinical outcomes.

Preoperative FTA did not affect the average tilting angle after adequate soft tissue balancing. Some studies have reported an increase of varus deformity negatively affected the postoperative ROM [13, 26]. Our results did not exhibit a strong correlation between preoperative FTA and postoperative ROM. The preoperative FTA, however, showed a positive correlation with the clinical gap at 10°. Knees with severe varus deformity required a more medial soft tissue release to equalize tension with the elongated lateral structures, resulting in a larger gap near extension. The preoperative FTA did not differ among the three joint gap-tilting groups, indicating more aggressive soft tissue releases were performed in more severely deformed knees to achieve ML soft tissue balance.

Understanding the characteristics of intraoperative joint gaps in TKA using PS prostheses with the patella reduced makes it possible to predict postoperative ROM and provides surgeons objective guidance for soft tissue balancing during surgery. Intraoperative joint gaps at deep knee flexion affect postoperative knee flexion, whereas joint gaps near extension affect knee extension. We could not determine specific target ranges for ML soft tissue balance in TKAs with PS prostheses. Further investigation will be done to determine adequate ML soft tissue balance during surgery to achieve better postoperative knee function.

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