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Kinematically Aligned Total Knee Arthroplasty for Valgus Osteoarthritis of More than 10°—*Is It Still a "Challenging Surgery"*?

Yoshinori Soda[1,2*], Toshiya Kano[2], Mitsuhiro Nakamura[3]

[1]Midorii Orthopaedics, Joint Reconstruction & Arthroscopy Center, Hiroshima, Japan
[2]Department of Orthopaedic Surgery, Hiroshima City Hiroshima Citizens Hospital, Hiroshima, Japan
[3]Department of Orthopaedic Surgery, Hiroshima Prefectural Hospital, Hiroshima, Japan
Email: *ysoda35@ybb.ne.jp, t.kano0317@gmail.com, mitsuhiro@m3.dion.ne.jp

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Abstract

Mechanically aligned total knee arthroplasty (TKA) for valgus knee is considered a "challenging surgery." Recently, the kinematic alignment (KA) method has gained attention. This study aimed to present objective clinical data, such as intraoperative balance assessment and radiographic evaluation of postoperative lower extremity alignment after TKA using the KA method for valgus deformity. Twenty-one TKA knees (mean age, 74 years; 2 males, 19 females) with KA for severe valgus deformity (hip-knee-ankle-angle ≥ 10°) performed at our department in the past 3 years were included in this study. Intraoperative gap and balance measurements and postoperative radiographic evaluation were performed. A total arc of range of motion was achieved up to 98% of preoperative values at 3 weeks postoperatively. Intraoperative gap and balance were stable throughout the entire range of motion. In addition, there were no statistically significant differences in either balance or gap values at each flexion angle. KA TKA is a "simple surgery" rather than a "challenging surgery" because additional soft tissue procedures are not required, operative time is short, intraoperative and postoperative balance is very stable, and a good alignment is achieved. This procedure may relieve surgeons of the stress of TKA for valgus deformities.

Keywords

Total Knee Arthroplasty, Kinematic Alignment, Valgus Deformity, Calipered Technique

1. Background

There is no doubt that total knee arthroplasty (TKA) is one of the most established treatments for osteoarthritis of the knee. Approximately 10% of these patients have valgus deformities; however, the pathophysiology is diverse and complex, including hypoplasia of the lateral femoral condyle and lateral soft tissue contractures. [1] [2] Furthermore, in TKA surgery, the progressive addition of soft tissue dissection to achieve good alignment and balance complicates the surgical procedure, and the selection of a constrained-type implant must be considered, if necessary. Due to the complexity of the pathophysiology and the surgical technique for correction, TKA for valgus deformity has been described as a "*challenging* surgery" as per most studies; [1]-[6] however, they were almost all based on the mechanical alignment (MA) method.

Kinematically aligned TKA [7] proposed by Howell *et al.*, is based on the concept of more resurfacing and soft tissue respect, without placing restrictions on the preoperative deformity and postoperative correction and without ligament release. In other words, soft tissue procedures are unnecessary or minimal, following the underlying principles of kinematic alignment (KA), thus reducing the complexity of the surgical procedure.

This study aimed to present an overview of our TKA surgical technique using the KA method for valgus deformity, to present objective clinical data such as intraoperative balance assessment and radiographic evaluation of postoperative lower extremity alignment, and to discuss the validity and limitations of the KA method.

2. Methods

2.1. Study Participants

A total of 676 TKAs (92 males 120 knees and 443 females 556 knees, mean age 75 years, range 50 to 94) were performed using the KA method at our institution during a 3-year period from May 2019 to April 2022, and 56 knees (8 males 9 knees and 44 females 47 knees, mean age 75 years, range 50 to 90), accounting for 8% of the total, had valgus deformity with a hip-knee-ankle-angle (HKA) of 1˚ or more on preoperative standing frontal long leg radiographs. Of these, 21 knees (2 males 2 knees and 18 females 19 knees, mean age 74 years, range 62 to 87) with a high degree of valgus deformity (HKA of 10˚ or more) were included in this study. In addition, the so-called *wind-swept deformity* was observed in 8 knees. Follow up period averaged 27.8 months (range, 12 to 45).

As shown in **Table 1**, a cruciate retaining (CR) type implant was used, except for one case in which a semi-constrained type implant was used on the side of flaccid paralysis due to polio. Statistical analysis was performed with paired Student's t-test using StatView software (version 5.0; SAS Institute, Cary, NC, USA). Statistical significance was considered at $p < 0.01$. This study was approved by the Ethics Committee of our institution, and informed consent was obtained in the form of opt-out on the website.

2.2. Investigation Items

1) Surgical time, 2) Range of motion, 3) Additional soft tissue treatment, 4)

Table 1. Implant models.

Type	Model	Maker	Number
CR-type	Persona CR	(Zimmer Biomet®, Warsaw, IN, USA)	1
	Vanguard ID	(Zimmer Biomet®, Warsaw, IN, USA)	1
	Sphere CR	(Medacta®, Castel San Pietro, Switzerland)	1
	Triathlon CR	(Stryker®, Mahwah, NJ, USA)	8
	TriMax CR	(Ortho Development®, Draper, UT, USA)	9
Semi-constrained type	Triathlon TS	(Stryker®, Mahwah, NJ, USA)	1

CR: Cruciate retaining.

Intraoperative gap and balance measurement data, and 5) Postoperative radiographic evaluation.

1) Surgical time

The time required for the surgeon to make a skin incision and close the wound.

2) Range of motion

Active extension and flexion were measured using a goniometer preoperatively and at 3 weeks postoperatively.

3) Additional soft tissue treatment

Selective dissection and incision of the lateral soft tissues were performed in patients with residual flexion contractures or uncorrectable varus/valgus balance.

4) Intraoperative gap and balance measurements

Using a seesaw-type sensor, 30 lbs of distraction force were applied to measure the gap and balance. The gap and balance under the femoral trial component were measured at 0˚, 30˚, 60˚, 90˚, and 120˚ of knee flexion as a component gap (CG) and component balance (CB), respectively. In addition, the gap and balance between the femur and tibia cutting surfaces were measured as the bone gap (BG) and bone balance (BB), respectively, at 0˚ and 90˚ knee flexion. Finally, paired Student's t-tests were used to compare the values of the CG, CB, BG, and BB.

5) Postoperative radiographic evaluation

Coronal Alignment Evaluation

Standing long leg radiographs were used to evaluate the medial proximal tibial angle (MPTA; the angle of inclination of the tibial axis with respect to the medial articular surface of the tibia), joint line orientation angle (JLOA; the angle of inclination of the articular surface of the tibia with respect to the floor, with a negative value denoting an inclination outward and downward), HKA (the angle between a line joining the center of the femoral head and the distal femoral sulcus and the tibial axis, with a negative value denoting varus alignment), and mechanical lateral distal femoral angle (mLDFA; the angle between the femoral mechanical axis and the distal femoral articular surface) were measured (**Figure 1**). Moreover, Coronal Plane Alignment of the Knee (CPAK) Classification, [8] proposed by MacDessi *et al.* (2020), was also used in the study.

Evaluation of Flexion Stability

The lift-off angle (the angle between the tibial implant surface and the distal femoral articular surface; the lateral joint opening was positive) was measured to evaluate flexion instability using the Axial Radiography (*Kanekasu's view*) [9] (**Figure 2**).

2.3. Outline of Our Surgical Technique

Surgery was performed by a senior surgeon (YS), who was familiar with TKA. The procedure was performed according to previous reports. [10] [11] A conventional medial parapatellar approach was used, the osteophyte was resected with minimal soft tissue release, and alignment was confirmed using the manual in-line traction technique [12] reported by Brown *et al.* The anterolateral approach was not used.

First, the distal femur was cut; however, since the medial condyle was usually not worn, the lateral condyle wear was compensated (2 - 4 mm), and the distal femur was resected for the thickness of the component. Next, the posterior femoral condyle was cut in the same manner, and resection was performed parallel to the posterior condylar axis to the thickness of the component. Thus, the femoral osteotomy was completed.

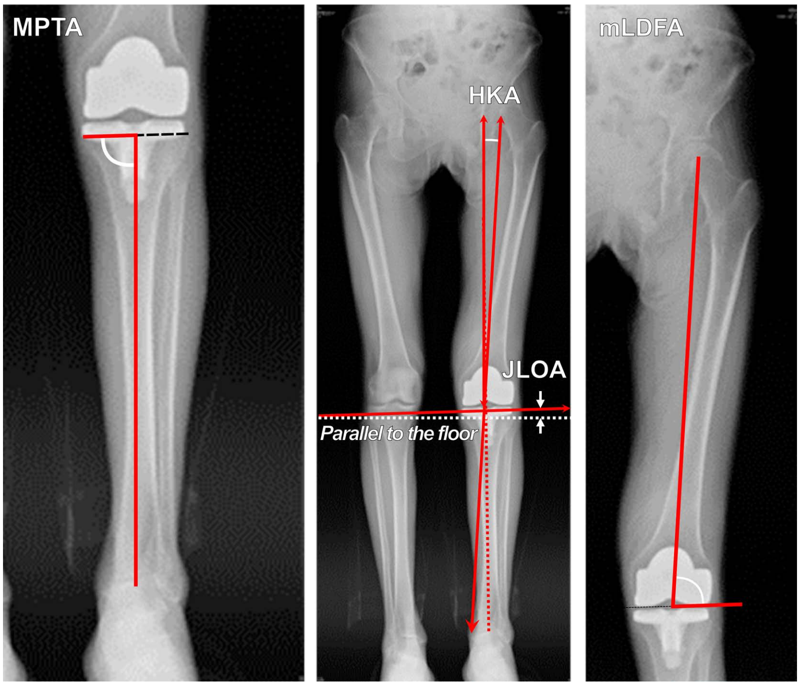

Figure 1. Radiographic data of Coronal Alignment. Measurements of coronal alignment from standing long leg radiographs. MPTA, medial proximal tibial angle; JLOA, joint line orientation angle; HKA, hip knee ankle angle; mLDFA, mechanical lateral distal femoral angle.

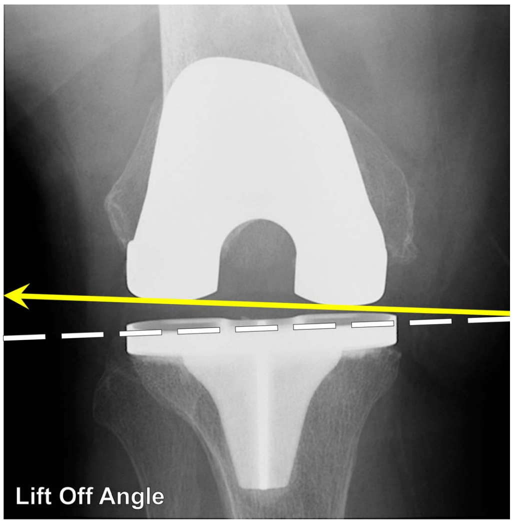

Figure 2. Evaluation of Flexion Stability. Lift-off angle (the angle between the tibial implant surface and distal femoral articular surface; the lateral joint opening was positive) was measured using the Axial Radiography (*Kanekasu's view*) [9].

Next, we moved to the tibial cut. Several methods have been used to determine the varus-valgus inclination of the joint line. The first method involves performing manual in-line traction without a femoral trial component after the femoral cut and drawing a resection level on the proximal tibia parallel to the distal femoral cut surface to determine the inclination of the joint line.

The second method involves attaching a femoral trial component, performing manual in-line traction, measuring the lateral joint gap, and determining the resection level using a stylus. Although these two methods are common, in the case of a laterally deformed knee, osteophyte formation does not generally occur in the lateral direction of the tibial joint, and the area around the center of the articular surface is often worn in a mortar-like shape. Therefore, the lateral edge of the lateral articular surface of the tibia often remains and can be observed on X-ray. A joint line may be established from the remaining lateral edge to the medial articular surface of the tibia, and a resection line may be made parallel to this line according to the thickness of the component implying that it is the first cut of the tibia. In this case, a tibial trial implant was placed after tibial osteotomy, and manual in-line traction was performed to measure the lateral joint gap and determine the amount of wear on the distal femur. This wear was compensated laterally, and the distal femur was cut. Resection was also performed parallel to the posterior condylar axis in the flexed position with equivalent compensation.

In the case of an externally deformed knee, the contralateral knee is sometimes not deformed. In such cases, it is possible to determine the resection line of the affected tibia by referring to the inclination of the joint line on the unaffected side. The tibia first cut follows the more resurfacing concept, the basic philosophy of KA, and is fundamentally different from the inverse KA technique. [13] We also used a traction technique to utilize the medial and lateral soft tissue function rather than applying varus and valgus stress to the knee joint to determine the varus-valgus inclination. In both cases, we used a native slope cut to achieve posterior tibial inclination and did not replace the patella. A lateral soft tissue procedure was added in cases where the extension limitation remains or the balance could be corrected.

3. Results

3.1. Surgical Time

The surgical time ranged from 47 to 74 minutes, with an average of 60 minutes. The average time for all KA TKA in our department was 64 minutes.

1) Range of motion

The mean preoperative extension was −9.4˚ ± 8.1˚ and flexion was 124.4˚ ± 10.0˚; at 3 weeks postoperatively, the mean extension was −1.9˚ ± 2.9˚ and flexion was 115.1˚ ± 8.8˚. The achievement rate of postoperative flexion was 93% compared with preoperative flexion and that of the total arc of range of motion was up to 98% of the preoperative values at 3 weeks postoperatively.

2) Additional Soft Tissue Treatment

After implanting the femoral component trial, the iliotibial band (ITB) was cut transversely only in one patient because of residual extension limitation, not valgus deformity.

3) Intraoperative gap and balance measurements

Varus measurements were negative (Figure 3). CG at 0˚, 30˚, 60˚, 90˚, and 120˚ of knee flexion averaged (mean ± SD), 11.4 ± 1.2, 11.9 ± 2.2, 11.5 ± 1.1, 11.9

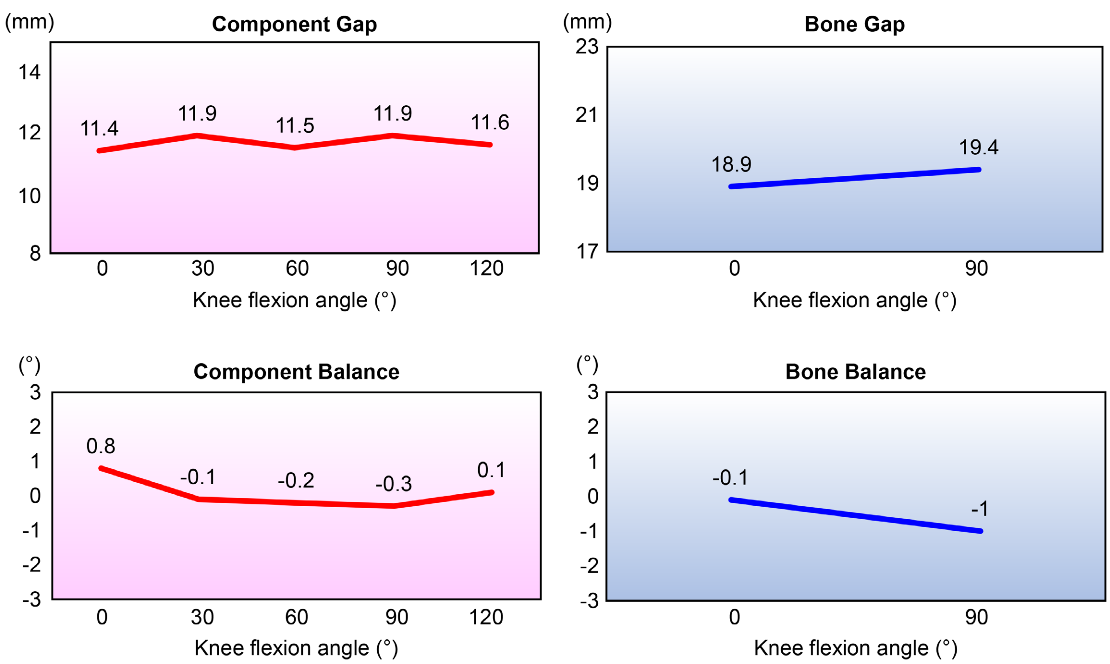

Figure 3. Intraoperative gap and balance measurements. Intraoperative gap (CG and BG) and balance (CB and BB) were stable, with little variation throughout the entire range of motion (varus measurements were negative). BB: bone balance; BG: bone gap; CB: component balance; CG: component gap.

± 2.4, and 11.6 ± 1.8 mm, respectively. CB averaged (mean ± SD) was 0.8˚ ± 1.2˚, −0.1˚ ± 1.9˚, −0.2˚ ± 1.6˚, −0.3˚ ± 1.7˚, and 0.1˚ ± 2.5˚, respectively. There were no statistically significant differences at any flexion angle in either the CG or CB (paired Student's t-test). BG at 0˚ and 90˚ of knee flexion averaged (mean ± SD) were 18.9 ± 2.2 mm and 19.4 ± 3.0 mm, respectively, and BB averaged (mean ± SD) were −0.1˚ ± 3.2˚ and −1.0˚ ± 2.3˚, respectively. There were no statistically significant differences at any flexion angle in either the BG or BB (paired Student's t-test). In addition, the gap values for CG and BG were stable, with little variation throughout the entire range of motion. Likewise, the balance was stable for both CB and BB, with little variation throughout the entire range of motion.

4) Postoperative radiographic evaluation

Coronal Alignment Evaluation

The measured values of the MPTA, JLOA, HKA, and mLDFA are listed in Table 2. In addition, the distribution of MPTA and HKA was also examined, and 95% (16 of 21 cases) of MPTA and 76% (16 of 21 cases) of HKA were within ±3˚ (Figure 4).

The distribution (frequency) of CPAK classification is shown in Table 3. There were no Type I, IV, VII, VIII, or IX; however, they were Type II, 33% (n = 7); III, 29% (n = 6); V, 24% (n = 5); and VI, 14% (n = 3). In arithmetic HKA, there was no varus, although there were 57% neutral and 43% valgus knees, and joint line obliquity was apex distal in 62% and neutral in 38%. Type V was neutral in 24% of the cases.

3.2. Evaluation of Flexion Stability

The lift-off angle was stable at 1.4˚ ± 2.5˚ of the lateral joint opening.

Table 2. Radiographic data of coronal alignment.

	MPTA	JLOA	HKA	mLDFA
Mean	89.0	0.1	2.4	86.7
SD	±1.6	±0.8	±2.4	±1.5

MPTA, medial proximal tibial angle; JLOA, joint line orientation angle; HKA, hip-knee-ankle-angle; mLDFA, mechanical lateral distal femoral angle.

Table 3. CPAK classification after kinematically aligned TKA for the severe valgus knee (HKA ≥ 10˚).

	N = 21	Arithmetic HKA		
		Varus	Neutral	Valgus
Joint line obliquity	Apex distal	0	33	29
	Neutral	0	24	14
	Apex proximal	0	0	0
				%

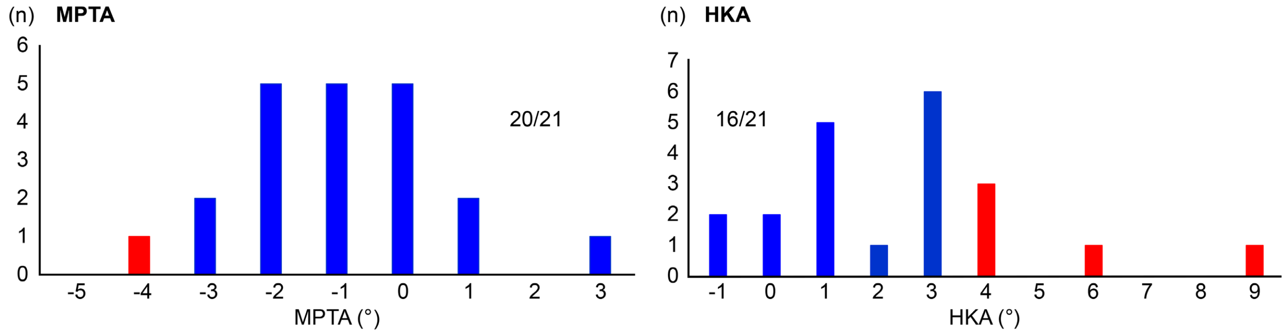

Figure 4. Distribution of MPTA and HKA. The distribution of MPTA: 95% (20 of 21 cases) and HKA: 76% (16 of 21 cases) were in range (within ±3˚). MPTA: medial-proximal-tibial-angle; HKA: hip-knee-ankle-angle.

4. Discussion

The pathology of valgus deformity is complex, with a wide variety of conditions, such as hypoplasia of the lateral femoral condyle and contracture of the lateral soft tissues. Therefore, in TKA, various soft tissue procedures are thought necessary to achieve good alignment and balance. In addition, in some cases, implant selection must be considered. Due to the complexity of the pathology and surgical technique, TKA for ectopically deformed knees has long been described as a "*challenging* surgery", [1]-[6] wherein the MA method was used in all these reported cases.

In this study, the surgical time was the same as or slightly shorter than that of the ordinal varus osteoarthritic knee. We speculated that this might be because the medial osteophyte resection procedure was unnecessary in valgus deformity. However, the range of motion was restored early, especially in the range of extension. Since the preoperative range of motion is often relatively preserved in valgus knees, there was no difficulty in gaining the range of motion. All implants were of the CR type, except for one case in which we used a semi-constrained type because of significant lateral instability in a patient with flaccid paralysis due to polio. We preserved the posterior cruciate ligament (PCL) as a stabilizer because we believe that the effect of PCL resection on stability, such as gap and balance, is unpredictable; furthermore, resection was unnecessary. Additional lateral soft tissue procedures were performed in only one case (5%; 1 of 21 cases) in which sufficient extension could not be obtained after implantation of the femoral component trial, and the ITB was cut transversely. The valgus deformity was corrected in this case, but the extension limitation remained.

The significance of intraoperative evaluation using a seesaw-type tensor is a matter of opinion; however, both the gap and balance were stable throughout the full range of motion. Naturally, no mid-flexion instability was observed. Although the postoperative radiographic evaluation revealed a slight valgus alignment of the HKA (2.4˚) when the CPAK classification was considered, the native alignment of patients who transitioned to a valgus deformity was not constitutional varus (0%) but constitutional valgus (43%), and the postoperative valgus HKA was mild. Therefore, it is reasonable to assume that postoperative HKA is mildly valgus. Furthermore, TKA using the KA technique [14] [15] [16] for valgus deformity does not require or rarely requires any additional soft tissue treatment, the operative time is short, the intraoperative and postoperative balance is stable, and good postoperative alignment is achieved, suggesting that the surgery is not a "*challenging* surgery" but instead a "simple surgery".

TKA with the MA method was invented by Freeman *et al.* [17] and Insall *et al.* [18] in the 1970s, aiming for the long-term survival of knee joint prostheses by performing osteotomies perpendicular to the functional axis of both the femur and tibia and achieving neutral alignment. Currently, this is considered the gold standard. Subsequently, the concept of obtaining neutral alignment and gap and balance adjustment was introduced, and the concept of performing soft tissue dissection to obtain the same rectangular gap [19] in flexion and extension was the target of surgeons until recently.

Although MA methods are simple to understand in theory, they can be difficult to achieve perfectly in practical surgery; therefore, surgeons must establish an "acceptable range" to confirm their judgment. Therefore, in recent years, attempts have been made to achieve these goals by introducing computer-assisted surgery (patient specific instruments, navigation, and robot) and other technologies. Unfortunately, although the introduction of these new technologies may have improved the precision of implant placement, it has not yet led to an improvement in patient satisfaction rates, [20] implying that an inaccurate goal has been achieved precisely.

Since the recent report on constitutional alignment by Bellemans *et al.*, [21] the diversity of lower-limb alignment has been advocated and is becoming recognized. Furthermore, reports by Lin, [22] Hirschman, [23] and MacDessi [8] on phenotype classification, which clearly expresses the difference in morphology between TKA with MA methods and biological knees, have indicated the diversity of alignment and the inconsistency of MA.

In contrast, the KA method adapts to the diversity of individual patient alignments. Howell *et al.* continue to advocate the KA technique to restore individual native joint lines based on the concept of more resurfacing and soft tissue respecting without placing restrictions of preoperative deformity worldwide. [7]

This does not denigrate the MA method, which has many excellent long-term results. [24] [25] [26] It is clear that the KA method is not inferior to the MA method in the short term; however, the long-term durability needs to be investigated in the future.

Therefore, the fact that TKA using MA methods has been called a "challenging surgery" for a long time remains questionable. Assuming that the native morphology is reproduced by the KA method, the perception that "the lateral soft tissue is contracted in the valgus deformity" must be changed.

When comparing the angles of each implant placement for TKA using our department's KA method for valgus knees with HKA of 10˚ or more (severe valgus; the subject of this study) and those with HKA < 10˚ (n = 35; mild valgus), the distal femoral joint inclination was similar regardless of the degree of deformity (mLDFA: 86.7˚ ± 1.6˚ in severe vs. 86.3˚ ± 1.5˚ in mild; not a significant difference); however, with more severe valgus deformity (HKA > 10˚), the tibial joint inclination differed from that in mild valgus deformity and was observed to be closer and perpendicular to the bone axis (MPTA: 89.0˚ ± 2.1˚ in severe vs. 87.6˚ ± 2.3˚ in mild; statistically significant difference, $p < 0.01$).

In other words, for mild valgus deformity, the balance may be achieved by chance in the extended position, and soft tissue release may be unnecessary or minimal when corrected with the MA technique. However, if the valgus deformity is more severe, the tibial joint line is less inclined, resulting in a high degree of overstuffing at the lateral joint at the time of implantation, which requires extensive soft tissue release (**Figure 5(a)**).

Furthermore, if the femoral component is placed parallel to the surgical epicondylar axis (SEA), which is currently common, almost the same phenomenon occurs in the flexed position (**Figure 5(b)**). If the osteotomy is performed perpendicular to the mechanical axis, as described above, the lateral soft tissue is naturally strained by the implant placement; however, this condition is misinterpreted as a "contraction of the lateral soft tissue," and the ITB, lateral collateral ligament (LCL), and the popliteal tendon need to be lengthened, separated, or cut completely to obtain good balance. However, currently, it is evident medically that lateral soft tissue injury cases (ITB, LCL, or popliteal tendon injury) have significant varus instability (**Figure 6**). This raises the question of whether

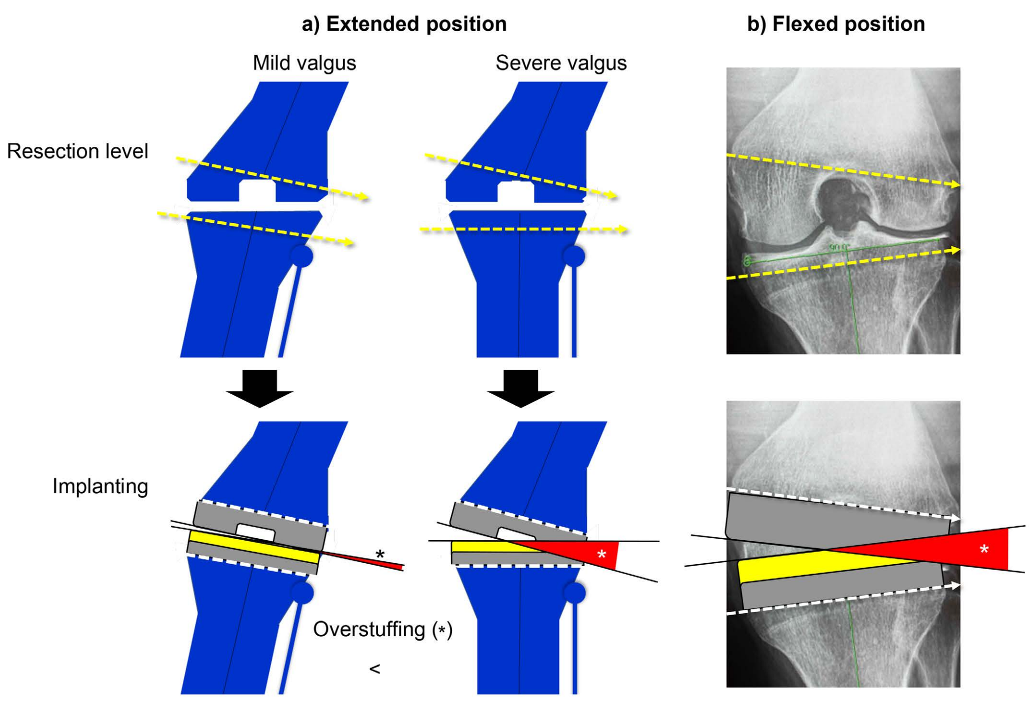

Figure 5. Prosthetic overstuffing at the lateral joint. (a) In the mild valgus deformity, soft tissue release may be unnecessary or minimal to achieve a good balance in the extended position. However, in severe valgus deformity, a less inclined tibial joint line results in a high degree of overstuffing at the lateral joint when implanting components, requiring extensive soft tissue releases. (b) Femoral component is placed parallel to SEA; extensive soft tissue releases are required in the flexed position. SEA: surgical epicondylar axis.

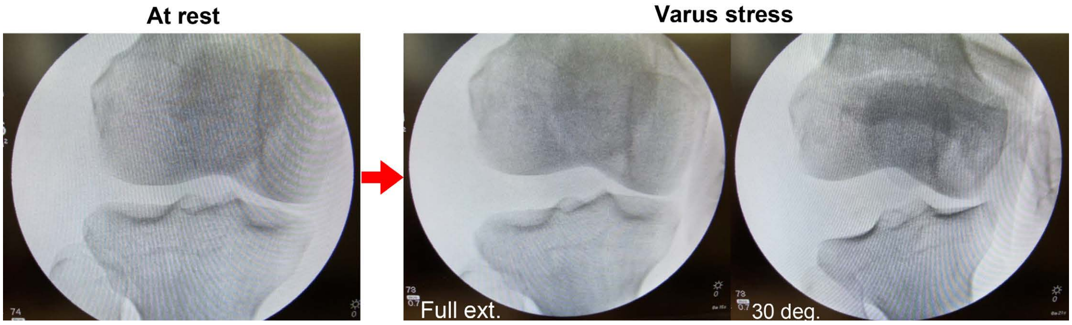

Figure 6. Lateral soft tissue injury (ITB, LCL, and popliteal tendon). Lateral joint space opening at 30˚ of knee flexion under varus stress is more remarkable than that at rest and at an extended position in the case of lateral soft tissue injury (ITB, LCL, and popliteal tendon). ITB: iliotibial band; LCL: lateral collateral ligament.

extensive soft tissue management required to correct the "imbalance" caused by the MA technique's bony resection and the resulting "instability" should be addressed by a constrained implant. However, these assumptions are highly dubious, and surgeons are incapable of correcting their own errors.

Some KA surgeons consider valgus deformity difficult and exclude them as an indication for TKA surgery. However, following the fundamental principles of the KA method, we believe that the concept and technique should be the same for all types of knee deformities.

As shown in this study, TKA using the KA method for valgus deformity could be performed in a short time without special surgical instruments or techniques, and good gap and balance could be obtained. However, it is unrealistic to systematically achieve the same shape and balance in all knees, as evidenced by the results of the Phenotype classification. Moreover, achieving neutral alignment in all cases after TKA surgery is difficult, with the final alignment of varus osteoarthritis being mildly varus, and the final alignment of valgus OA being mild valgus seems a natural result. Clinically, it is well known that the medial side of the joint is tight in varus knees and the lateral side of the joint is tight in valgus knees, and the MA method, which adjusts the balance measured by stress and distraction, does not always achieve good balance, forcing the surgeon to make allowances. The same may be true for the joint dynamics. Just as the same rectangular gap was the ideal goal in the past, [18] the medial pivot motion may be misinterpreted [27] as the standard for all knees. The fact that the center of rotation varies with the degree of deformity has been mentioned in several papers. [28] [29] [30] However, it has not received much attention. Therefore, individualized goals should be set for patients rather than aiming for a uniform or average goal.

Admittedly, we realize that not all cases of valgus deformity can be treated with true KA. For example, even if a bony resection similar to component thickness is performed, soft tissue management may be required in more severe fixed valgus cases with strong residual limitation of extension or in cases with clearly remarkable valgus deformity. In addition, in cases where the medial soft tissues are stretched and lax as per Ranawat's Classification Type II, the KA technique is not indicated because soft tissues cannot be respected, and constrained-type implants are necessary to compensate for these conditions. [31]

In other words, the advantage of the KA method over the MA method is that it does not require processing of soft tissues for alignment and balance adjustment.

A limitation of this study is that the degree of valgus deformity and soft tissue contracture in our study participants may have been mild. In addition, the results may have been different in severe valgus cases; however, such cases are very rare. Finally, our study was based only on static alignment evaluation in the short postoperative period and did not consider the long-term results and dynamic alignment.

5. Conclusions

Current study introduced our kinematically aligned TKA for valgus osteoarthritic knees and evaluated objective clinical data.

Our surgical technique for valgus osteoarthritic knee was technically simple to achieve good postoperative alignment and balance. In other words, this technique would improve patient satisfaction and have the possibility to relieve the surgeons from the "challenging surgery".

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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List of Abbreviations

BB: bone balance
BG: bone gap
CB: component balance
CG: component gap
CPAK: Coronal Plane Alignment of the Knee
CR: cruciate retaining
HKA: hip-knee-ankle-angle
ITB: iliotibial band
KA: kinematic alignment
LCL: lateral collateral ligament
MA: mechanical alignment
mLDFA; mechanical lateral distal femoral angle
MPTA: medial-proximal-tibial-angle
OA: osteoarthritis
PCL: posterior cruciate ligament
SEA: surgical epicondylar axis
TKA: total knee arthroplasty