ORIGINAL ARTICLE

Gap Pattern in Valgus Knee: An Assessment with TKA Navigation

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Background: Valgus knee is a challenge of ligament balance in total knee arthroplasty (TKA). A lateral release is often recommended to achieve symmetric extension gaps in valgus deformity, due to the traditional requirements of tight lateral gap. However, the gap pattern valgus osteoarthritis knee has not been studied.

Materials and Methods: The present study was a retrospective study on navigated TKA with 89 valgus osteoarthritis knees. The gap measurement, bone cut, and component rotation values were collected from navigation and the data were analyzed.

Results: Only 6.70% of valgus knees in the present series had a narrower lateral flexion gap than medial flexion gap and 7.90% had narrower lateral extension gap than medial extension gap. Conversely, most of valgus cases were seen in bigger lateral flexion gaps than medial flexion gaps at 76.4%. This was consistent with the extension gap patterns of 80.9%. The degree of valgus deformity positively correlated with all gaps, except for flexion lateral gap. The present study demonstrated a mean external rotation of 2.25±2.09° in the femoral component rotation and the degree of valgus deformity had no significant correlation with femoral rotation.

Conclusion: The lateral distal femoral condyle hypoplasia might have more important role in the extension gap than the ligament tension. The lateral ligament might influence the lateral flexion gap more than the lateral femoral condyle deficiency. Lateral structural release for correction of valgus deformity during extension could lead to instability in flexion especially for gap patterns with a lateral flexion gap that is wider than the medial flexion gap.

Keywords: Valgus knee; Navigated TKA; Gap pattern

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The surgical goal of total knee arthroplasty (TKA) is to provide symmetric balanced flexion and extension gaps[1,2]. A valgus knee is a challenge in the creation of symmetrical soft tissue balance. This is associated with contracture of lateral soft tissue and laxity of medial soft tissue[3,4]. The valgus knee may combine with bone abnormalities, such as a hypoplasia of distal femur, femoral or tibial rotational deformity, and patellar maltracking[4]. Joint line elevation and excessive soft tissue release can occur after TKA in valgus knee[1]. Peter et al. showed that gap balancing required more soft tissue release in valgus knees than in others[5]. In cases with rigid and severe valgus deformities, an extensive release of posterolateral structures or epicondylar osteotomy may be required during TKA[6]. However, the surgical approach and how to release soft tissue in the valgus knee remain controversially[7-9].

Krackow et al. and Ranawat et al. classified valgus knees into three types[3,10]. A typical type-I deformity had a minimal substantial deformity of less than 10° and was passively correctable. A type II was defined as fixed valgus deformity with a more substantial deformity of more than 10°. A type III was a severe osseous deformity after a prior osteotomy with an incompetent medial soft-tissue sleeve[3,10]. While multiple surgical approaches have been introduced to correct each type of valgus deformities[3], conventional techniques may not accurately restore soft tissue balance to correct the valgus deformities. Therefore, computer assisted surgery (CAS) has been developed to improve the accuracy of bone resection, ligament balancing, and

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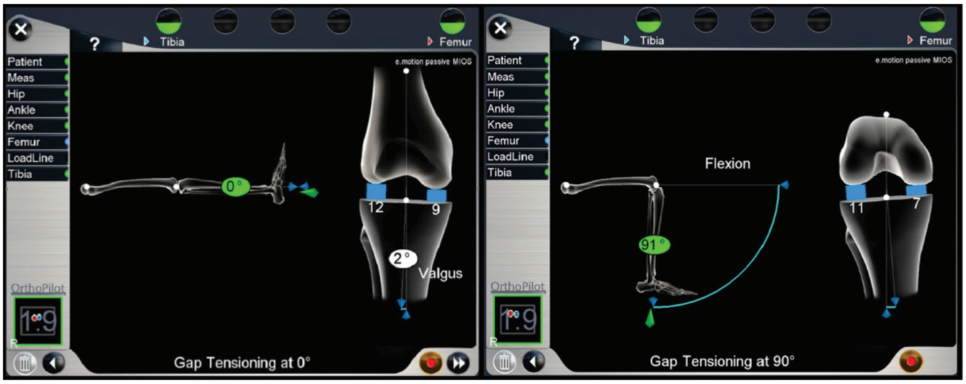

Figure 1. Snapshot from navigation screen displaying gap measurement in 0° extension and 90° flexion after tibial resection.

PCA=posterior condylar axis

limb and prosthesis alignment[11-13]. The CAS TKA increases the precision of intraoperative angular and tibiofemoral gap measurements with an accuracy of less than 1° or 1 mm, respectively[13]. The literature showed that lateral structure release was necessary in valgus deformity to increase the lateral extension gap[1,3,10], however the knowledge of flexion gap is still lacking. Therefore, the authors primary aim was to examine the medial-lateral flexion gap pattern in valgus knee deformity. The secondary aim was to determine correlation between degree of valgus deformity and gap configuration including femoral component rotation in valgus knees using CAS.

Materials and Methods

Banphaeo Ethics Committee approved the present study. The authors retrospectively reviewed 89 patients with type I and II valgus osteoarthritis knees according to the Krackow et al. and Ranawat et al.[3,10] classification undergoing primary navigated TKA using the same surgical approach between January 2008 and December 2014 for the present study.

Navigated TKA was performed by one orthopedic surgeon (PS). A mini-midvastus approach was used in all cases. All patients received the posterior-stabilized mobile bearing prosthesis and posterior-stabilized fixed bearing prosthesis with modified gap technique. The OrthoPilot® knee navigation system (B Braun Aesculap, Tuttlingen, Germany) with soft tissue management program was also used. Briefly, the surgery was performed as follows. After the knee was exposed, the deep medial collateral ligament (MCL) was released subperiosteally to show approximately half of proximal part of the tibial plateau. The osteophyte, anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) were resected respectively. The knee was registered using the OrthoPilot workflow, relying on anatomical and kinematic registration. After registration, leg alignment in extension as well as in full flexion was performed as a reference for all of the following measurements. The proximal tibial plateau resection was a plan perpendicular with respect to the tibial mechanical axis and there was a 0° posterior slope under navigation guidance. The thickness of bone resection was verified after the tibial cut was made and this information was transferred to navigation system. To measure the gap in extension and flexion, a spreading device was put into knee joint during full leg extension and 90° knee flexion with patellar eversion. This was then spread up to the medial and lateral gaps with equal maximum force. The resulting leg axes as well as the medial and lateral gaps were calculated via the navigation system (Figure 1). Next the plan for femoral cutting was displayed on the navigation screen. The authors planed for a distal femoral cut of 0° to 3° valgus to femoral mechanical axis to achieve balanced medial and extension gap. The amount of bone resection was not more than 2 mm reference to thickness of the femoral component to avoid joint line elevation. If a rectangular extension gap was not achieved by femoral resection planning from navigation, then the authors performed lateral soft tissue release. This was performed with Ranawat's pie-crusting technique[3] whereby tight lateral structures are palpated when the lamina spreaders were inserted. Then, they released over multiple transverse incisions with a No. 15 surgical blade. To balance the flexion gap during femoral planning, the authors adjusted the femoral

Table 1. Intraoperative data collected from navigation

Data from navigation	Mean±SD
Pre-operative mechanical axis (°)	6.18±5.62 (valgus)
Post-operative mechanical axis (°)	1.29±1.81 (valgus)
Tibial cut angle (°)	0.05±0.90
Thickness of medial tibial plateau resection (mm)	4.63±2.38
Thickness of lateral tibial plateau resection (mm)	5.90±2.48
Medial extension gap at 0° extension after tibial resection (mm)	9.47±2.62
Lateral extension gap at 0° extension after tibial resection (mm)	11.33±2.93
Medial flexion gap at 90° flexion after tibial resection (mm)	9.66±2.62
Lateral flexion gap at 90° flexion after tibial resection (mm)	11.89±2.73
Thickness of medial distal femoral resection (mm)	9.93±2.26
Thickness of lateral distal femoral resection (mm)	6.94±2.61
The actual medial extension gap (mm)	4.88±3.20
The actual lateral extension gap (mm)	5.47±3.93
The actual medial flexion gap (mm)	5.03±2.89
The actual lateral flexion gap (mm)	6.00±3.51
The total medial extension gap (mm)	19.54±2.76
The total lateral extension gap (mm)	18.20±2.61
The total medial flexion gap (mm)	19.74±3.08
The total lateral flexion gap (mm)	18.80±3.08
Femoral component rotation respect to PCA (°)	2.25±2.29

SD=standard deviation; PCA=posterior condylar axis

Table 2. The incidence of gap pattern in fully extension and 90° flexion gap measurement after tibial resection

Gap pattern	Frequency (cases)	Percentage (%)
Extension gap at 0° extension		
Lateral gap < medial gap	7	7.90
Lateral gap = medial gap	10	11.2
Lateral gap > medial gap	72	80.9
Flexion gap at 90° flexion		
Lateral gap < medial gap	6	6.70
Lateral gap = medial gap	15	16.90
Lateral gap > medial gap	68	76.40
Total	89	100

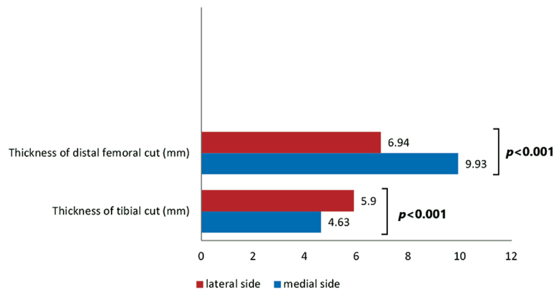

Figure 2. Comparison of tibial cut thickness between medial plateau and lateral plateau (lower bars). Comparison of distal femoral cut thickness between medial and lateral side (upper bars). p<0.05 is significant.

component rotation related to the posterior condylar axis (PCA) of the femur.

There were 68 patients (76.40%) with a typical type-I valgus deformity, and 21 (23.59%) with a type-II valgus deformity. The average of the coronal plane alignment was 6.18±5.62° of the valgus (1 to 26) at pre-operation. Information regarding mechanical axis alignment, gap measurement, and femoral component rotation during operation were collected from the navigation data.

Statistical analysis

Descriptive data were expressed as the mean, standard deviation, and range. Paired sample t-tests were used to determine the differences between medial and lateral gap measurements. Spearman correlation coefficient was used to assess the relationships between mechanical axis with femoral component rotation and medial-lateral gap, during flexion and extension. Differences were considered statistically significant at p-value less than 0.05. All analyses were performed using SPSS Statistics, version 16.0 (SPSS Inc., Chicago, IL, USA).

Results

There were 70 women and 19 men with a mean pre-operative mechanical axis alignment of 6.18±5.62° valgus (1 to 26), as shown in Table 1. The navigated TKAs improved the postoperative mechanical axis to a mean of 1.29±1.81° valgus (–4 to 7), which was significantly different from pre-operative value (p=0.001). In terms of tibial resection, the mean of tibial cut angle was 0.05±0.90° varus (–3 to 4) respect to tibial mechanical axis (Table 1). The results in terms of gap pattern after tibial resection are shown in Table 2.

The mean of medial and lateral tibial plateau resections were 4.63±2.38 mm (0 to 10) and 5.90±2.48 mm (0 to 11), respectively (Table 1), and the lateral plateau resection was larger than medial one significantly (p<0.001) (Figure 2). In addition, the mean of distal femoral resection in medial side was significantly higher than the lateral cut (9.93±2.26 mm and 6.94±2.61 mm) significantly (p<0.001) (Figure 2).

In terms of gap measurement during navigated TKA, Extension gap was wide on the lateral side and narrow on the medial side after tibial resection

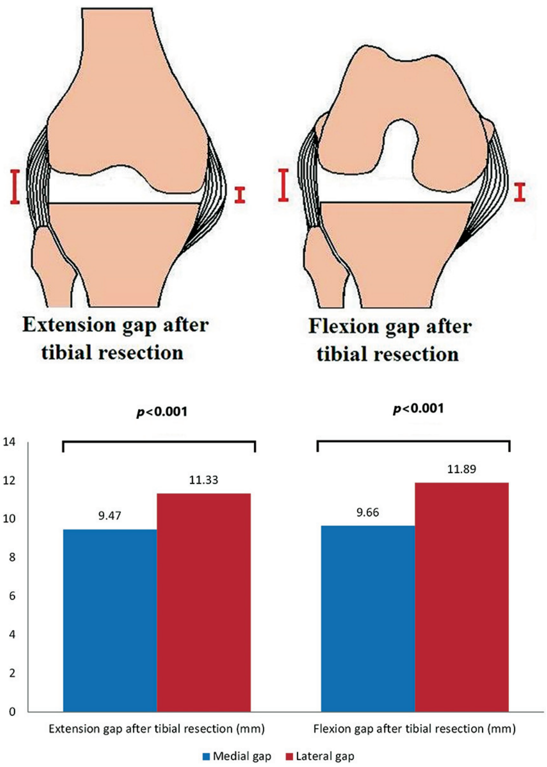

Figure 3. Comparison of gap widths in 0° extension and 90° flexion gap measurement after tibial resection between medial gap and lateral gap. p<0.005 is significant.

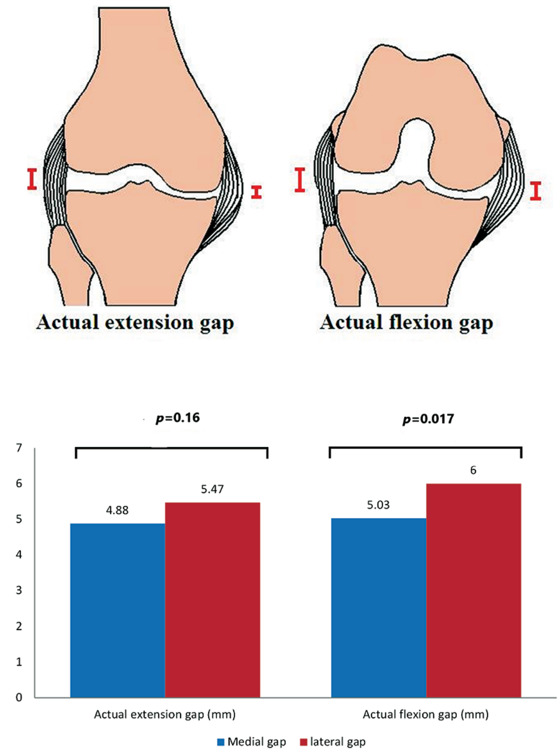

Figure 4. Comparison of actual gap widths in 0° extension and 90° flexion between medial gap and lateral gap. p<0.005 is significant.

(Table 1). There was significantly greater in lateral extension gap than in the other (p<0.001) (Figure 3). The flexion gap had a similar pattern to the extension gap with bigger gap in the lateral side (Figure 3). No significant differences between extension and flexion gaps were detected during side-by-side comparisons, (p=0.626 in medial side and p=0.1893 in lateral side). The "actual gap" was calculated by the extraction of the thickness of the tibial resection (mm) from the gap tension values (mm) after tibial resection. The actual gap referenced the natural joint space no significant differences were noted between medial and lateral extension gap. Conversely, the actual gap in flexion for the lateral flexion gap was significantly wider than the medial flexion gap (Figure 4). The amount of gap after correction of valgus deformity for ligament tension and amount of bone resection, defined as "total gap", showed an average of total extension gaps wider in medial than lateral sides significantly (Figure 5).

The degree of valgus alignment significantly correlated with all extension gaps (r=0.293, p=0.005 in the lateral extension gap, r=0.242, p=0.022 in the medial extension gap) and medial flexion gap (r=0.356, p=0.001). However, there was no correlation in the lateral flexion gap (r=0.170, p=0.110).

An average value of femoral component rotation was 2.25±2.29° external rotation at 3° internal rotation to 7° external rotation, respect to PCA as presented in Table 1. The authors observed no additional relationships between femoral component rotation and degree of valgus alignment (r=0.973, p=0.600).

Discussion

The valgus deformity consists of two components divided into bone anatomical deficiencies and soft tissue contracture[3]. The contracted lateral soft tissue and medial soft tissue laxity are more obvious in extension[14]. Although numerous techniques for ligament balance have been proposed[3,6,10,15,16], no consensus has emerged on the best sequence or best method for release of lateral soft tissue. The most common reported complications in patients with valgus knee that underwent TKA are tibiofemoral instability, as high as 70%[4]. Therefore, a thorough understanding of gap kinematics is critical to effective

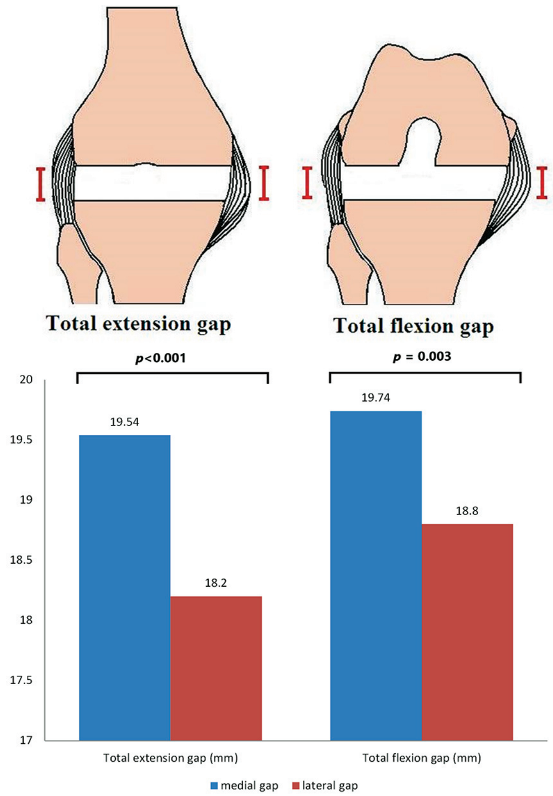

Figure 5. Comparison of total gap widths (gap after tibial and distal femoral resection) in 0° extension and 90° flexion between medial gap and lateral gap. p<0.005 is significant.

surgical management. The CAS TKA offers highly precise intraoperative angular and tibiofemoral gap measurements with an accuracy of less than 1° or 1 mm[17]. Luring et al. analyzed the effect of sequential lateral soft-tissue release in cadavers to evaluate the flexion gap change using CT-free knee navigation system[13]. Only 6.70% of valgus knees in the present series had a narrower lateral flexion gap than medial flexion gap and 7.90% had narrower lateral extension gap than medial extension gap. Conversely, most valgus cases were seen in bigger lateral flexion gaps than medial flexion gaps (76.4%). This is consistent with the extension gap patterns (80.9%). Several studies have confirmed the present study findings of the lateral gap laxity data[18,19]. Tokuhara et al. demonstrated that the lateral flexion gap is significantly wider than the medial flexion gap (6.7±1.9 mm versus 2.1±1.1 mm) in normal knee[18]. Deep et al. observed a kinematic pattern of arthritic knee prior to TKA navigation and found only 8.33% of valgus knee cases had a consistent valgus deformity that remained the same throughout extension to maximum flexion prior to making any bony cuts or ligamentous releases where 32.40% of valgus deformities become varus during knee extension to 30°, 60°, 90°, and maximum flexion[19]. These findings indicated that the dynamic behavior of arthritis knee should be assessed before making soft tissue release, especially when the deformity has opposite deformity after knee flexion. Here, collateral release in extension might be the underlying cause of flexion instability.

Bone morphology in valgus knee is another important finding. The authors found that the thickness of the tibial bone cut shows a small but significant difference between the medial and lateral sides at 4.63 mm in medial versus 5.90 mm in lateral. The thickness of the distal femoral cut had quite larger in the distal medial femoral condylar resection than the lateral side at 9.93 mm versus 6.94 mm. This finding indicated that the origin of the valgus knee deformity is the femoral side similar to Thienpont et al.[20]. They found that the mean tibial joint line of the valgus osteoarthritis knee was 90° to the tibial mechanical axis. The distal femoral joint line had a substantial valgus to femoral mechanical axis (5°). In contrast to the varus deformity, the pathology comes from the tibial intra-articular deformity if the varus deformity is more substantial. Here, the deformity is sometimes intra-articular on the femoral side[20]. This data suggest that correction of the valgus deformity should be performed on femoral side. The case of severe valgus deformity, the distal femoral cut perpendicular to the femoral mechanical axis might not be sufficient to balance the gap. In the authors' practice, it is allowed to make minor degrees of valgus cut, but not more than 3°, before making the decision to perform the lateral ligament release in extension.

The present study data showed that the gap in lateral structures is slightly wider than those in prior cuts and post bone cuts. The wider lateral flexion gap had larger values (Table 2), and this contrasted with established concepts of the valgus knee. Mediolateral flexion gaps have never been reported in valgus knee. The flexion gap in the normal knee has only been reported by Tokuhara et al.[18]. Their results challenge the traditional concept of using MRI. There was more laxity in the lateral joint gap (6.7 mm versus 2.1 mm) at 90° flexion. This represented a non-rectangular normal knee and it agreed with the present study. There was a significant difference of 4.6 mm between both sides of the mediolateral gap in normal knee. There was a 1.32 mm difference seen in the valgus knee. These results indicated that a tighter gap in the lateral side of the valgus knee than normal knee.

Here, the actual tension gap was calculated from the difference between the thickness of the tibial resection and gap tension values. Gap tensions were measured after tibial resection with no distal femoral cut. The authors actually assumed that the gap of the lateral structure must be tighter than the medial structure of the valgus knee. Interestingly, the actual tension gap has no significant difference between both sides during full extension at 5.47 mm in lateral versus 4.88 mm in medial (p=0.172), while the wider actual gap was detected on the lateral side at 90° flexion at 6.00 mm versus 5.03 mm (p=0.016). The lateral extension gap was larger than the medial extension gap (11.33 mm versus 9.47 mm). This indicated that hypoplasia of the lateral distal femoral condyle might have a more important role in the extension gap than ligament tension. The flexion gap measurements after tibial resection revealed a lateral gap that was wider than the medial gap (11.89 mm versus 9.66 mm). This finding indicated that the lateral ligament might influence the lateral flexion gap more than the lateral extension gap. This result was consistent with a cadaveric study, which showed that the complete lateral structural release affected the flexion gap more than the extension gap[13]. The present study data show that lateral structural release for correction of valgus deformity during extension could lead to instability in flexion, especially for gap patterns with a lateral flexion gap that is wider than the medial flexion gap. Joint gap measurements are recommended during surgery to prevent a component malrotation. This is an unequal gap and results in constrained prosthesis using[21]. Whiteside et al. concluded that a standard lateral release sequence is not applicable to all valgus cases[16]. They recommended selective soft tissue release. An iliotibial band and posterolateral capsule should be released when the knee is tighter during extension. The lateral collateral ligament and popliteus are appropriate to release the knee that is tight during flexion. The present study results in navigated TKA with a modified gap technique demonstrated that the total medial extension and flexion gap were wider than the total lateral extension and flexion gap. However, there were no clinically significant outcome differences.

Lateral condylar hypoplasia is a common component of valgus knee deformity. Therefore, using posterior femoral condyles (PCA) as a rotational alignment landmark can offer internal malrotation of the femoral component. The epicondylar axis (EPA) can determine femoral component rotation[22,23]. However, the epicondylar axis and the epicondyle peaks are difficult to localize[24]. The anteroposterior axis (AP axis) may be the most reliable landmark for femoral rotational alignment in the valgus knee[24]. A component malrotation using the AP axis was significantly lower than the PCA in the valgus TKA[25]. However, in cases of severe trochlear dyspepsia, the AP axis could be extremely difficult to identify. Other group have recommended a gap-balancing technique in which the femoral component rotation is positioned parallel to the tibial cut with each collateral ligament equally tensioned[2,26]. Ranawat et al. determined the flexion gap and femoral rotation via an anteroposterior (AP) cutting block fixed to the distal aspect of the femur. A lamina spreader was then placed into the 90° flexion gap, and the medial and lateral flexion gaps were measured. If the gaps are unequal, then the AP cutting block can be rotated, raised, or lowered to create a symmetric gap. Walede et al. compared the anatomical landmarks and ligament tension-based methods in navigation. They showed that the ligament tension-based method is more accurate and reliable than anatomical landmark for determining femoral rotation in TKA[27]. The authors found that the average of femoral rotation was 2.25° for external rotation with respect to PCA. The wide range of femoral rotation was 3° internal rotation to 7° external rotation. Clearly, the femoral rotation in gap technique depends on ligament tension during flexion and the posterior femoral condyle surface morphology. The present study findings showed that the lateral flexion gap is wider than the medial flexion gap. These results in external rotation of the femoral component with respect to PCA. However, degree of valgus deformity did not correlate with femoral component rotation. This is consistent with the findings that the lateral flexion gap did not correlate with the degree of valgus deformity.

The present study has limitations. There were a high percentage type I valgus cases at 76.4% with only 23.6% type II. This is likely selection bias. However, the incidence of type II was only 15% in the literature[1]. The sample size was not sufficient for separate analysis. The applied joint distraction forces during the gap measurements could be due to differences among surgeons, but there is no consensus on how much the joint distraction force affects gap measurements[28,29]. The data were obtained from two designs, PS-mobile and PS-fixed bearing, but they used the same surgical technique. The gaps were measured after PCL resection. Thus, the results may differ from the data obtained from the retained PCL.

Conclusion

The extension and flexion gap are not rectangular. It has high lateral tightness in contrast to the traditional concept of the valgus knee. Most valgus subjects had a wider lateral gap than medial gap. The degree of valgus deformity has a significant correlation with all tension gaps, except for the lateral flexion gap. The extension and flexion gap measurement are recommended before performing lateral ligament release. This determines femoral component rotation. Navigation with gap balance technique can minimize excessive femoral component rotation via bone resection and ligament balancing as well as limb and prosthesis alignment.

What is already known on this topic?

The valgus knee deformity consists of two components that are divided into bone anatomical deficiencies and soft tissue contracture. The bone abnormalities are a hypoplasia of distal femur, femoral or tibial rotational deformity. The contracted lateral soft tissue and medial soft tissue laxity are more obvious in extension. However, the knowledge of both extension and flexion gap pattern is still lacking.

What this study adds?

According to the results from navigation assessment found that most of valgus knees in this series had a wider lateral gap than medial gap. The degree of valgus deformity has a significant correlation with all tension gaps, except for the lateral flexion gap. The extension and flexion gap assessment are recommended before performing bone cutting and lateral ligament release.

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Conflicts of interest

The authors declare no conflict of interest.

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