The severity of preoperative varus deformity affects the feasibility of correcting lower limb alignment with medial unicompartmental knee arthroplasty

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Title

The Severity of Preoperative Varus Deformity Affects the Feasibility of Correcting Lower Limb Alignment with Medial Unicompartmental Knee Arthroplasty

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COI Statement

The authors declare that they have no conflict of interest.

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IRB approval

The hospital ethics committee approved the study protocol (No. 1510, Data of Approval: 02 Dec 2013) of this study.

Title

The Severity of Preoperative Varus Deformity Affects the Feasibility of Correcting Lower Limb Alignment with Medial Unicompartmental Knee Arthroplasty

Abstract

Background

The relationship between the severity of preoperative varus deformity and the amount of its correction in unicompartmental knee arthroplasty (UKA) as well as the thickness of the insert has not been well known.

Methods

One hundred and three patients who underwent medial fixed-bearing UKA with the use of the spacer block method were assessed. After the component gap in extension was measured using a UKA tensor, the pre-osteotomy gap was calculated from the thickness of the bone cuts. The relationship between the preoperative hip–knee–ankle (HKA) angle as well as the pre-osteotomy gap and the amount of change in HKA angle were analysed. Also, preoperative HKA angle and the thickness of the bone cuts were compared among groups by the insert thickness.

Results

The mean preoperative HKA angle was 7.7 ± 3.1° varus. Patients with more varus deformity and those with a wider pre-osteotomy gap showed a more valgus change in HKA angle. As for the thickness of the insert, the preoperative HKA angle of the patients with the thinnest insert was significantly smaller (less varus) than that of those with the thicker insert while no statistically significant difference was found among the insert groups regarding the amount of the bone cuts.

Conclusions

The severity of the preoperative varus deformity as well as the intraoperative pre-osteotomy gap related to the amount of change in HKA angle. As thick inserts tended to be used in severe varus knees, the tibial bone cut can be reduced in such cases.

Keywords

Unicompartmental knee arthroplasty; varus deformity; soft tissue balance; insert thickness; tibial bone cut

1. Introduction

Unicompartmental knee arthroplasty (UKA) has proven to be an effective treatment for isolated medial compartment knee osteoarthritis, while it has been reported that UKA has a lower survival rate and more complications postoperatively than total knee arthroplasty (TKA) [1]. Careful selection of patients is the key to successful UKA and the correct restoration of limb alignment is one of the major contributors to it. Past studies showed that the mechanical axis was corrected by about 3° to 6° after medial UKA [2, 3]. Classical selection criteria by Kozinn et al [4] was that medial UKA should only be performed in patients with a preoperative varus deformity of 15° or less as it is normally impossible to restore the mechanical axis to close to neutral in patients who have not fulfilled this condition. Recently, this selection criteria has come under renewed scrutiny and selected patients with severe deformity were reported to be able to achieve good function and quality of life with UKA if satisfactory mechanical alignment is restored [5] while it has not been clear under what conditions this is possible thus far.

Recently, Nakano et al [6] reported a positive correlation between the severity of varus deformity in the preoperative knee and the pre-osteotomy medial joint gap in fixed-bearing UKA using a specially designed UKA tensor. However, there is a paucity of literature evaluating the relationship between the severity of preoperative varus deformity and the amount of its correction in UKA. In this study, we considered the degree of preoperative varus deformity and assessed its impact on the amount of correcting mechanical axis with medial fixed-bearing UKA in connection with the soft tissue balance, i.e, the medial joint gap. We hypothesise that the amount of valgus correction is greater in the knee with more varus deformity.

Also, we assessed the thickness of the insert and tried to find if there is any relationship between the degree of the preoperative varus deformity and the thickness of the insert used in each operation. In fixed-bearing UKA, the amount of proximal tibial bone cut is normally determined at the surgeon's discretion regardless of the severity of varus deformity. As for the femoral side, the amount of distal bone cut was set to the same as the thickness of the femoral component with the spacer block method referring to the surface of the proximal tibial cut. The pre-osteotomy medial joint gap was reported to be wider in more varus knees [6], therefore, we hypothesised that the thicker insert tends to be used in the knee with more varus deformity in medial fixed-bearing UKA.

2. Materials and Methods

This research has been approved by the IRB of the authors' affiliated institutions. One hundred and three consecutive patients underwent medial UKA using the Persona Partial Knee System (Zimmer Biomet inc., Warsaw, IN, USA) from September 2017 to August 2019 and informed consent was obtained from all the patients, and the obtained data were retrospectively collected and analysed. The inclusion criteria for UKA were a radiographic diagnosis of isolated medial compartment osteoarthritis or idiopathic osteonecrosis with an active ROM of > 90°, a fixed flexion deformity of < 10°, and a varus deformity of < 15°. Magnetic resonance imaging (MRI) was performed for all the cases before surgery and the cases without the intact anterior cruciate ligament (ACL) and articular surface of the lateral compartment were excluded from the study. As a result, no case was excluded and a total of 103 UKAs were finally included in the study. Senior doctors with > 15 years of experience performed the surgery. Patient demographics are shown in Table 1.

After inflating the tourniquet to 250 mmHg, a mini-medial parapatellar approach was performed. Following the macroscopic observation of an intact articular surface of the lateral and patellofemoral compartments, the minimal soft tissue release of the medial structures as well as the osteophyte removal was performed. A proximal tibial osteotomy was then performed using an accelerometer-based portable navigation system (OrthAlign Plus®, UniAlign™; OrthAlign Inc., Aliso Viejo, CA, USA), which helps the surgeon to precisely perform tibial bone cut in UKA with coronal and sagittal alignment. It provides measurement accuracy of ± 0.5° when measuring the angle between the OrthAlign Plus® unit and the reference sensor (manufacturer's data). The target value of preoperative planning in coronal alignment of the tibial osteotomy was set to 1.0° in varus. The accuracy of tibial implant alignment using this system in UKA was examined and it was reported that it decreased the outliers of tibial coronal and sagittal alignment [7]. Sagittal alignment was set regarding the original slope. The original posterior tibial slope was measured with reference to the perpendicular line of the sagittal axis, which was defined as the line connecting the anterior one-third of the medial tibial plateau and midpoints of the tibial plafond. The sagittal alignment was set to 6.0° and 8.0° when the angle was ≤ 6.0° and ≥ 8.0°, respectively, and the target value was set as the target value of preoperative planning when the angle was between 6.0° and 8.0° as in previous studies [6, 7]. The amount of the tibial bone cut was decided using a stylus and was set to 4 mm in all the cases. Following the tibial osteotomy, a distal femoral osteotomy was performed with the spacer block method referring to the surface of the proximal tibial cut. The femoral rotation was carefully adjusted to the mechanical axis of the tibia using the spacer block method, and the remaining (posterior and chamfer part) osteotomies of the femur were performed to be parallel to the tibial bone cut. The thickness of the tibial and femoral bone cut was measured at the most thickness part for femur and the lowest (thinnest) point on the articular surface for tibia using a calliper and the actual osteotomies were calculated by adding the thickness of the bone saw blades (1.27 mm).

Following the femoral osteotomies, a trial prosthesis was placed in the distal femur, and the component gap between the medial tibial osteotomy surface and the femoral trial prosthesis was measured using a UKA tensor. Reports on the design and the methodology of the UKA tensor have previously been published [8]. The UKA tensor consists of 3 parts - an upper plate, a lower platform plate with a spike, and an extra-articular main body. Upper and lower plates are to be placed at the medial compartment of the knee. By using this device, surgeons can measure the joint component gap while applying a constant joint distraction force. Joint distraction force was exerted between the upper and lower plates through a specially made torque driver. During the measurement, the medial parapatellar arthrotomy was temporarily repaired with stitches proximal to the connection arm of the UKA tensor. The thigh and knee were aligned in the sagittal plane to eliminate the external load on the knee. The joint distraction forces were preloaded several times to minimise the error due to the creep of the surrounding soft tissues. After the joint distraction force of 20 lb (9.1kg) was applied, the component gap (in mm) between the centre midpoints of the upper surface of the plate and the proximal tibial cut was measured in extension. The joint distraction force was set at 20 lb to reflect the force of 40 lb applied in TKA, in which the force of 20 lb is to be divided into each lateral/medial compartment. The pre-osteotomy gap in extension was then calculated and defined as follows; the pre-osteotomy gap = the component gap + the thickness of the femoral component - the thickness of the tibial bone cut - the thickness of the distal femoral bone cut (Figure 1). Preoperative and postoperative coronal hip–knee–ankle (HKA) angles were measured based on long-leg standing radiographs. Also, the thickness of the selected insert in each patient was recorded and patients were divided into three groups based on the thickness of the insert - group 8 mm (the thinnest insert), group 9 mm, and group ≥ 10 mm.

The data are expressed as means ± standard deviations. The relationship between the preoperative HKA angle as well as the pre-osteotomy gap and the amount of valgus change in the HKA angle were analysed using Pearson's correlation coefficient and simple linear regression analysis. Preoperative HKA angle, the thickness of the tibial bone cut, the thickness of distal femoral bone cut, and the total (= tibial and distal femoral) thickness of the bone cut of each insert group was analysed using Tukey's test. Data analyses were performed using BellCurve for Excel (Social Survey Research Information Co., Ltd., Tokyo, Japan). The sample size calculation was also performed using G*Power 3 (Heinrich Heine Universität Düsseldorf, Germany). Based on our calculations, a minimum sample size of 62 patients was required to observe a moderate correlation with a type I error (α) of 0.01, a power ($1 - \beta$) of 0.80, and a correlation ρ H1 of 0.5. Statistical significance was considered at $P<0.01$.

3. Results

The mean HKA angle was 7.7 ± 3.1° (range, 1.5°–15.5°) varus preoperatively and 3.5 ± 2.7° (range, -3.0°–10.0°) varus postoperatively. Significant positive correlation was found between the preoperative HKA angle and the postoperative HKA angle ($Y = 0.6038 X - 1.1703$, $R^2 = 0.5081$, $P < 0.01$) (Figure 2). The mean values of the thickness of the tibial bone cut and the femoral distal bone cut were 5.0 ± 0.9 mm and 6.1 ± 1.0 mm, respectively. The mean value of the component gap and the pre-osteotomy gap were 10.0 ± 1.3 mm and 5.4 ± 1.6 mm, respectively. The relationships between the preoperative HKA angle and the amount of change in the HKA angle are shown in Figure 3. Patients with more varus deformity in their preoperative knee tended to show a greater amount of valgus change in HKA angle after surgery ($Y = 0.3962 X + 1.1703$, $R^2 = 0.3078$, $P < 0.01$). The relationships between the pre-osteotomy gap and the amount of change in the HKA angle are shown in Figure 4. Patients with a wider pre-osteotomy gap tended to show a greater amount of valgus change in HKA angle after surgery ($Y = 0.6036X + 0.9261$, $R^2 = 0.1863$, $P < 0.01$).

As for the thickness of the insert, groups 8 mm, 9 mm, and ≥ 10 mm included 67 patients, 20 patients, and 16 patients, respectively. The preoperative HKA angle, as well as the thickness of the tibial, distal femoral, and total (distal femur + tibia) bone cut in each group, are summarised in Table 2. Preoperative HKA angle of group 8 mm was significantly smaller (less varus) than that of group 9 mm ($P < 0.01$) and group ≥ 10 mm ($P < 0.01$), while no significant difference was found between group 9 mm and group ≥ 10 mm (Figure 5). There was no statistically significant difference among the three groups as of the thickness of the tibial, distal femoral, and total bone cut.

4. Discussion

The most important finding of the present study was that the degree of preoperative varus deformity correlated with an amount of valgus change in HKA angle after fixed-bearing UKA. Also, we found that the thicker insert tends to be used in the knee with more varus deformity by assessing the thickness of the selected insert in each patient. Both of our hypotheses were proven correct.

UKA is a superior procedure for its low invasiveness, good postoperative range of motion, and early recovery compared with TKA. As postoperative lower extremity alignment is crucial to the outcome of UKA, the varus deformity correction is an important consideration before surgery. Undercorrection could increase the loading force to the medial compartment, which may accelerate polyethylene wear [9, 10]. Also, postoperative large residual varus deformity was reported to contribute to the stress fracture on the medial tibial plateau [11]. However, few studies have reported useful information for surgeons to predict alignment correctability with fixed-bearing UKA with the use of the spacer block method thus far.

Recently, as for the fixed-bearing UKA with the spacer block method, a positive correlation between the severity of varus deformation in the preoperative knee and the pre-osteotomy gap in extension was reported [6]. This result suggested that the medial soft tissue tightness does not exist even in knees with severe varus deformity, which supports our results as not only the degree of preoperative varus deformity but also the pre-osteotomy gap correlated with an amount of valgus change in HKA angle in the current study.

The use of the spacer block method was the important factor for the current result. This method usually involves resection of a fixed amount of the proximal tibia (often 4 mm), then aligns the distal resection of the femur parallel to the tibial resection in extension after the removal of all osteophytes. The amount of osteotomy in the distal femur is always designed to be equal to the thickness of the distal part of the femoral implant. Finally, we determined the thickness of the insert by checking the tension between the femur and tibia using a special spatula, and the same evaluation method were used in all the cases regardless of the degree of the varus deformation. Because the amount of osteotomy in the distal femur and the proximal tibia is fixed, the gap between the distal femoral component and the proximal tibia tends to be wider in more varus knee, which may lead to a greater amount of valgus change in HKA angle.

It has been reported that postoperative HKA angle is difficult to predict precisely. Mullaji et al compared HKA angle after medial UKA with that of the unaffected contralateral lower limb in 123 patients and described that HKA angle was restored to within ±3° of the contralateral lower limb in 87% of the patients after UKA, while it should be noted that they used mobile-bearing insert [12]. To predict the postoperative lower limb alignment, some authors recommended the use of a preoperative valgus stress test using radiographs while it is still controversial [3, 13-16]. One study reported that changes in HKA angle strongly correlated with the femorotibial facet angle value and its change on valgus stress radiographs [3], while another study concluded that because the full extent to which a varus deformity could be corrected could not be determined without the removal of osteophytes, the preoperative valgus stress radiograph tended to be inaccurate [14]. Also, proper bone resection and removal of the medial meniscus and osteophytes could change the HKA angle more, although if these procedures would affect lower limb alignment in UKA is still unclear. Ishibashi et al reported that removing the medial meniscus and osteophyte without damaging the medial collateral ligament might widen the medial joint gap, while the osteophyte size did not affect the postoperative lower-limb alignment, as patients undergoing UKA have a relatively early stage of knee osteoarthritis compared with TKA patients [13]. The results of the current study may partly help to predict the postoperative HKA angle for fixed-bearing UKA.

The other finding of the current study was that the thinnest insert (i.e. 8 mm) tended to be used in preoperatively less varus knee than the thicker insert (i.e. 9 mm and ≥ 10 mm). This result can be explained by the theory that the thickness of the insert is the only variable that can be adjusted to achieve an appropriate tension in fixed-bearing UKA with the use of the spacer block method, i.e., as there was no significant difference in the amount of osteotomy among insert thickness groups, the tension could be maintained constant only by adjusting insert thickness depending on each case. From another point of view, the joint tension can be adjusted by the amount of proximal tibial osteotomy instead of the thickness of the insert although it means the modification of the spacer block method, strictly speaking.

Reducing the tibial bone cut is useful in reducing the tibial bone defect in case of revision surgery. In most cases of UKA failure, bony defects occur only on the tibial side and require special devices including metal augments, bone grafts as well as stems when converting to TKA [17]. A more tibial bone cut in primary UKA might result in a larger bone defect if UKA fails [15]. If the tibial bone defect is larger than 10 mm in depth in the revision, then the revision might need a metal augmentation and a tibial stem. Another advantage of reducing the tibial bone cut is that a smaller tibial cut allows for a larger tibial implant size. A larger amount of bone cut will lead to a smaller tibial bone bed as the proximal tibial bone is shaped like an inverted cone. A small tibial surface can lead to a collapse of the tibial plateau or loosening of the tibial component [18, 19], and also reducing the tibial osteotomy is especially beneficial for patients with small body size, as the only available size of tibial prosthesis is sometimes too large for them [20]. The third merit of reducing the amount of proximal tibial osteotomy is decreased pain by medial stress thanks to increased medial support. As the distance from the subchondral resection surface increases, the bone strength of the proximal tibia decreases [21], thus a more tibial bone cut may lead to a weaker bone bed for the tibial component. Excessive tibial resection was reported to increase the forces on the tibia surface and cause pain in past biomechanical studies [22, 23].

This study has several limitations. Firstly, this study was based only on plain radiographs, which could cause inaccurate measurement of the alignment in the lower extremity. A CT-based study may be more accurate in evaluating the alignment. Secondly, there was only a small group of patients with the use of a thicker insert, i.e., 9 mm or ≥ 10 mm, and this small sample size may have resulted in an inaccurate representation of outcomes for these groups. Thirdly, other factors such as contracture of the quadriceps or patella height might have influenced the assessment of the intraoperative joint gap. Fourthly, tibial coronal inclination and alignment of tibial component may also affect the postoperative knee alignment while the accuracy of tibial osteotomy using the accelerometer-based portable navigation system in UKA was reported to be high [7]. Fifthly, this study did not evaluate any clinical outcomes. Patient-based outcome scores can evaluate and detect changes in knee pain and quality of life in patients undergoing UKA, so they should be investigated in the future. Also, in the absence of data on complications, it is not possible to rule out problems in cases of severe varus deformity or when thick inserts are used.

5. Conclusion

In patients undergoing UKA, the severity of the preoperative varus deformity as well as the intraoperative pre-osteotomy gap positively related to the amount of postoperative alignment correction. Thick inserts tended to be used in severe varus knees, so there is a possibility that the tibial bone mass can be preserved in such cases with the use of thinner inserts.

Statements and Declarations

Ethical approval

All procedures were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to participate

Written informed consent was obtained from all patients.

Consent to publish

Written informed consent was obtained from all patients.

Competing interests

The authors declare that they have no competing interests.

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Availability of data and materials

Authors can confirm that all relevant data are included in the article.

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Figure captions

Figure 1

Definition of the pre-osteotomy gap

The pre-osteotomy gap = the component gap + the thickness of the femoral component - (the thickness of the tibial bone cut + the thickness of distal femoral bone cut)

Figure 2

The relationships between the preoperative HKA angle and the postoperative HKA angle

Figure 3

The relationships between the preoperative HKA angle and the amount of valgus change in HKA angle

Figure 4

The relationships between the pre-osteotomy gap and the amount of valgus change in HKA angle

Figure 5

Preoperative HKA angle by the insert thickness group

Preoperative HKA angle of group 8 mm was significantly smaller (less varus) than that of group 9 mm and group ≥ 10 mm

Figure 1

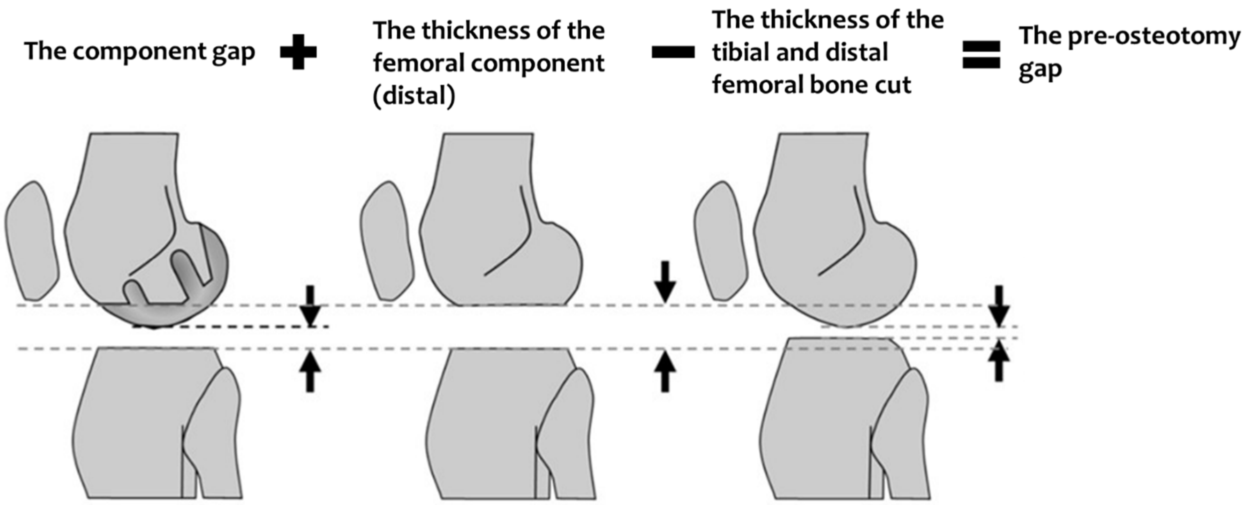
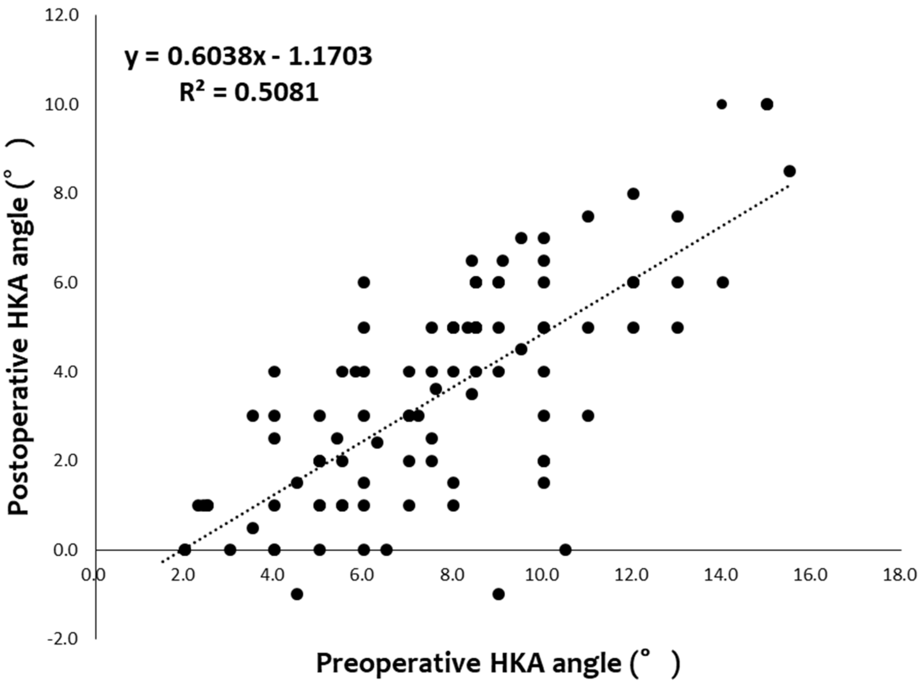

The component gap
The thickness of the femoral component (distal)
The thickness of the tibial and distal femoral bone cut
The pre-osteotomy gap

Figure 2



y = 0.6038x - 1.1703
R² = 0.5081
Postoperative HKA angle (°)
Preoperative HKA angle (°)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0

Figure 3

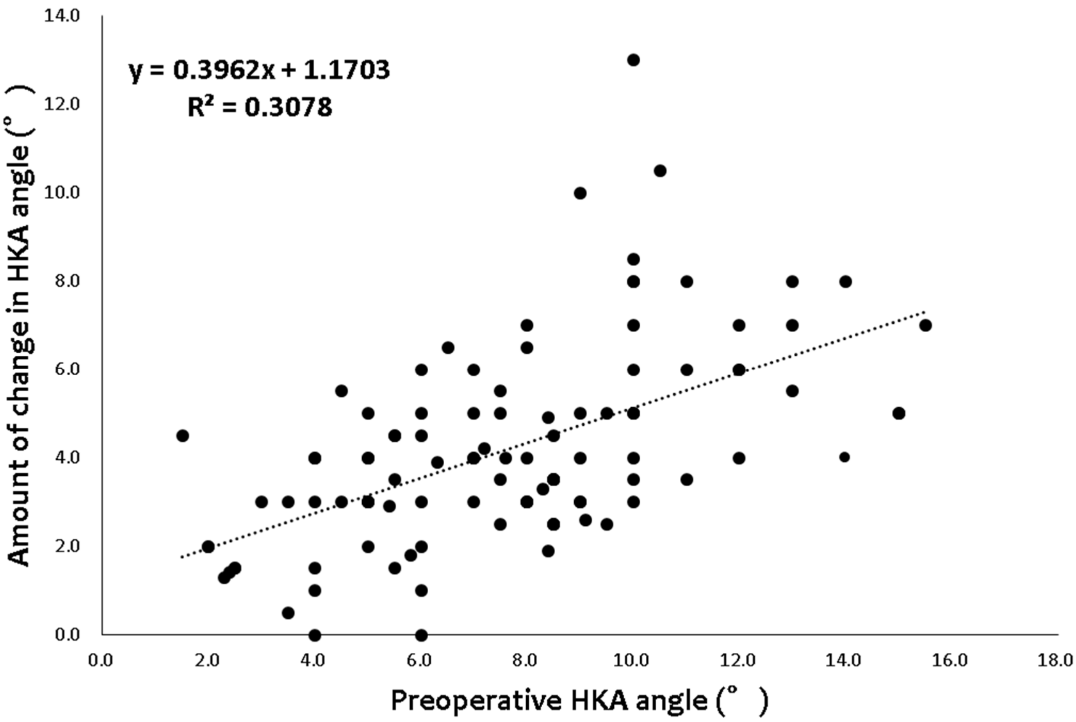
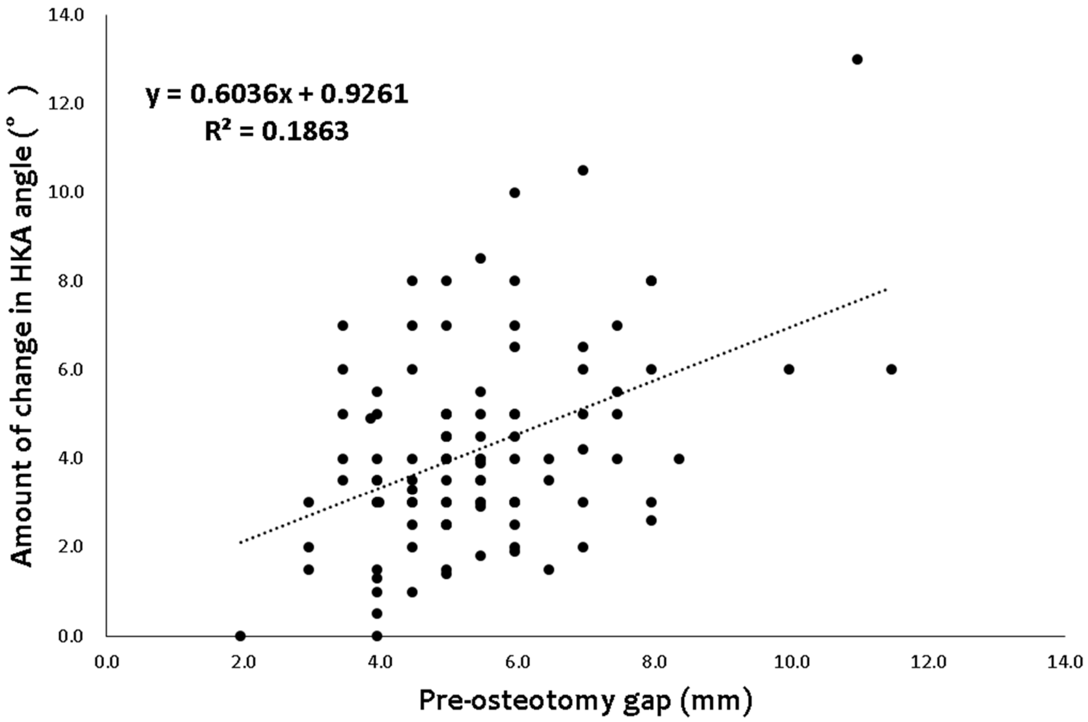
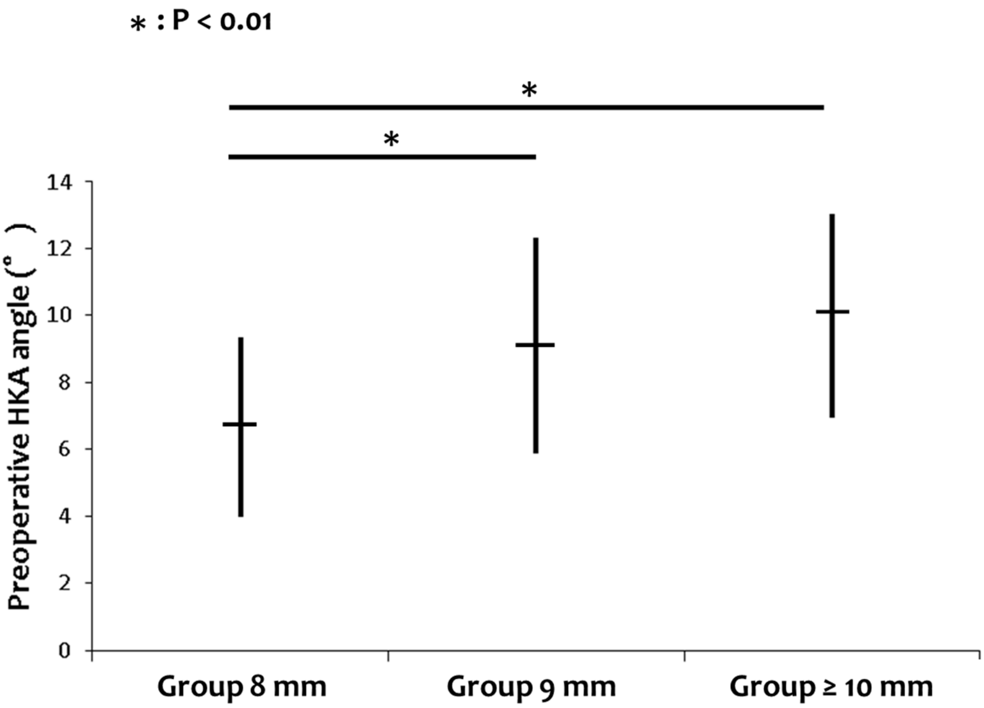

y = 0.3962x + 1.1703
R² = 0.3078
Amount of change in HKA angle (°)
Preoperative HKA angle (°)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0

Figure 4



y = 0.6036x + 0.9261
R^2 = 0.1863
Amount of change in HKA angle (°)
Pre-osteotomy gap (mm)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0

Figure 5



∗ : P < 0.01
*
*
Preoperative HKA angle (°)
14
12
10
8
6
4
2
0
Group 8 mm
Group 9 mm
Group ≥ 10 mm

Table 1

Patient demographics

The values are given as the mean and standard deviation for continuous variables

UKA: unicompartmental knee arthroplasty, HKA: Hip- Knee- Ankle, SD: standard deviation

Age (years)	74.4 (range, 54–95; SD: 8.7)
Gender (male : female)	28 : 75
Side of UKA (left : right)	50 : 53
Preoperative diagnosis	Osteoarthritis: 87, idiopathic osteonecrosis: 16
Preoperative HKA angle (°)	7.7 (range, 1.5–15.5; SD: 3.1)

Table 2

The thickness of the bone cut by the thickness of the insert

The values are given as the mean ± standard deviation

HKA: Hip- Knee- Ankle

Thickness of the insert	The pre-op HKA angle (°)	Distal femur (mm)	Tibia (mm)	Total (distal femur + tibia) (mm)
8 mm	6.7 ± 2.7	6.1 ± 0.6	5.1 ± 0.8	11.1 ± 1.0
9 mm	9.1 ± 3.2	6.1 ± 1.1	4.9 ± 1.0	11.0 ± 1.3
≥ 10 mm	10.0 ± 3.0	6.2 ± 1.8	4.8 ± 0.9	11.0 ± 1.8