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Original Article

Varus kinematics at knee flexion affect clinical outcomes of unicompartmental knee arthroplasty: Intraoperative navigation-based kinematics evaluation

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ABSTRACT

Background: The aim of the study was to investigate the effects of navigation-based varus or axial rotational alignment through knee flexion on patient reported outcomes or the maximum flexion angle of unicompartmental knee arthroplasty (UKA).

Methods: Data were retrospectively collected from 46 knees that underwent UKA for medial unicompartmental knee osteoarthritis. An image-free knee navigation system was used in all cases, and intraoperative varus and axial rotational alignment at every knee flexion angle were recorded before and after implantation. All patients completed the Knee injury and Osteoarthritis Outcome Score (KOOS) at final follow-up. By varus or valgus at 0° knee flexion, the knees were subdivided into two groups (varus at 0° group, varus above the median value; neutral at 0° group, varus equal to or below the median value). By varus or valgus at 90° knee flexion, patients were similarly subdivided into two groups (varus at 90° group; neutral at 90° group). The maximum knee flexion angle was measured 3 months after surgery.

Results: There were no differences in the KOOS between the neutral at 0° group and the varus at 0° group. However, the KOOS activity score (79 ± 17 vs 69 ± 16, $p = 0.02$) and the KOOS total score (72 ± 17 vs 65 ± 15, $p = 0.03$) of the neutral at 90° group were better than those of the varus at 90° group. The alignment and the maximum knee flexion angle 3 months after surgery were not correlated.

Conclusion: Varus at 0° knee flexion and axial rotational alignment did not affect the clinical outcomes of UKA. Patient reported outcomes was better for the neutral knees with less varus at 90° knee flexion than for varus knees.

Introduction

Unicompartmental knee arthroplasty (UKA) to treat isolated medial compartment osteoarthritis has become a good option to relieve knee pain and obtain function.[1,2] Several publications about the alignment of UKA have been reported using a variety of evaluation methods to achieve better clinical outcomes.[3–6] Compared to these methods, navigation-based alignment have advantages because they can provide detailed intraoperative alignment data.

In total knee arthroplasty (TKA), many studies of navigation-based alignment have been reported. One of the representative themes about the alignment of TKA is the correlation between axial rotational alignment and the maximum flexion angle. Tibial internal rotation at 90° of flexion or from 90° to maximum flexion has been reported to correlate with the postoperative maximum flexion angle.[7,8] The medial pivot pattern was also reported as a predictor of better postoperative maximum flexion angle and subjective outcomes.[9] Although these data were reported, to the best of our knowledge, there have been no reports about UKA that

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investigated the correlation between axial rotational alignment and the maximum flexion angle.

There have been a few studies of the navigation-based alignment of UKA that focused on varus alignment at knee extension.[10,11] Grant et al.[10] reported that clinical outcomes did not differ according to postoperative varus alignment at knee extension. However, whether varus alignment at knee flexion correlate with clinical outcomes has not yet been investigated.

The aim of this study was to investigate the effect of navigation-based varus or axial rotational alignment through knee flexion on patient reported outcomes or the maximum flexion angle of UKA and the correlation between the alignment and the maximum knee flexion angle 3 months after surgery. We hypothesized that alignment affect clinical outcomes and the alignment and the maximum knee flexion angle 3 months after surgery were not correlated.

Materials and methods

Patients

Data were retrospectively collected from 44 patients (46 knees) who underwent UKA for medial unicompartmental osteoarthritis by a single surgeon between July 2012 and May 2016. The indications for UKA were knee pain with medial compartmental osteoarthritis, intact anterior cruciate ligament, intact posterior cruciate ligament, and collateral ligaments, and flexion contracture of less than 10 degree, correctable varus deformity, and the coronal anatomical femoro-tibial angle (FTA) in maximal extension during weight-bearing of less than 190°. Exclusion criteria were a history of previous knee surgery, refusal to participate, and rheumatoid arthritis. There were 34 female and 10 male patients (average age 74.2 (61–86) years, average body mass index of 26.0 ± 4.5 (16.5–41.8) kg/m^2), with Kellgren-Lawrence grade 3 in 37 knees and 4 in 9 knees. The implant used in all knees was the Triathlon Partial Knee Resurfacing System (Stryker, Mahwah, NJ, USA). An image-free knee navigation system (Precision Knee Navigation System Ver.4.0, Stryker) was used in all cases. This research has been approved by the IRB of the authors' affiliated institutions. All subjects gave informed consent prior to participating in the study. All patients completed the Knee injury and Osteoarthritis Outcome Score (KOOS) at final follow-up; the mean final follow-up period was 36 (12–56, standard deviation was 13.5) months.

Surgical technique

After medial parapatellar arthrotomy with minimal medial release, placement of the tracker pins, and the registration of the trackers, the degrees of varus or valgus and internal or external rotational alignment were calculated by the navigation system. The alignment before implantation were recorded at knee flexion angles of 0°, 30°, 45°, 60°, 90°, and 120°. The tibial extramedullary cutting guides were attached aiming to match the alignment of 0° varus and 3° posterior slope using the navigation system. A tibial sagittal cut was done parallel to Akagi's line, in the middle of the medial intercondylar eminence of the tibia. Then, a tibial axial cut was done according to the tibial extramedullary cutting guides. The femoral cutting guides integrated with a spacer block were attached, aiming to match the alignment of 0° varus and 3° flexion using the navigation system. By using spacer blocks, the amounts of the distal and posterior femoral bone cuts were adjusted to acquire a balanced flexion and extension space. After the bone cuts and selecting the sizes of the implants classically using sizing templates, the procedures of implantations were carried out. The thickness of the insert was selected in order to achieve mild varus alignment at knee extension and flexion using the navigation system. The alignment after implantation were recorded at knee flexion angles of 0°, 30°, 45°, 60°, 90°, and 120°.

Intraoperative alignment evaluation

A standard registration of the navigation system was done according to the manufacturer's protocol. Before and after implantation, degrees of varus or valgus and internal or external rotational alignment were calculated by the navigation system. The alignment were recorded at knee flexion angles of 0°, 30°, 45°, 60°, 90°, and 120° during passive flexion placing the patient's heel on the examiner's palm and touching the distal of the thigh with the opposite hand for support by the surgeon (S.N.). The varus alignment were calculated by the angle of the femoral and tibial mechanical axis. The varus alignment at 0° knee flexion are similar to the hip-knee-ankle angle (HKA). The schema of varus alignment at 90° knee flexion is shown in Fig. 1. The axial rotational alignment were calculated by the angle of the transepicondylar axis of the femur and the Akagi line of the tibia.[12] Additionally, the knees were subdivided into two subgroups by varus or valgus at 0° and 90° knee flexion, respectively. The knees were subdivided into two groups by varus or valgus at 0° knee flexion (varus at 0° group, varus above the median value; neutral at 0° group, varus equal to or below the median value). Similarly, patients were subdivided into two groups by varus or valgus at 90° knee flexion (varus at 90° group, varus above the median value; neutral at 90° group, varus equal to or below median value).

Radiographic evaluation

Preoperatively and postoperatively (6 weeks after surgery), the coronal FTA in maximal extension during weight-bearing was calculated in each knee. The HKA on radiographs of the whole limb during weight-bearing was also calculated preoperatively and postoperatively.

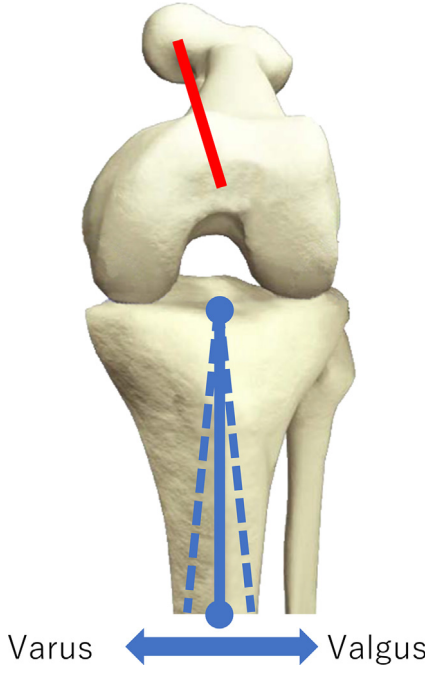

Fig. 1. The schema of varus alignment at 90° knee flexion.

Clinical outcomes

The maximum knee flexion angle was measured 3 months after surgery. All patients completed the KOOS at final follow up. The KOOS has 5 subscales: pain, other symptoms, function of daily living (ADL), function in sport and recreation (Sport), and quality of life related to knee function (QoL). Each subscale was scored separately from zero (extreme knee problems) to 100 (no knee problems). KOOS is internationally accessible, being free of charge and translated into >45 different language versions, including Japanese.[13]

Statistical analysis

The FTA, HKA, maximum knee flexion angle, and varus or valgus alignment between the two periods of each knee flexion angle were compared using Student's *t*-test. The correlations between the maximum knee flexion angle and alignment were evaluated using Pearson's correlation coefficient. KOOS values between subgroups at 0° and 90° knee flexion were compared using the Mann-Whitney *U* test. These analyses were performed using SPSS version 24.0 (IBM Corp., Armonk, NY). A p-value of <0.05 was considered significant.

A post hoc power analysis was performed to assess the correlations using G*Power version 3.1.9.2. Each power of the parameters was calculated as follows: 0.91, to detect a significant difference of FTA, HKA, maximum knee flexion angle, and varus or valgus alignment between the two periods of each knee flexion angle; 0.97, to detect the correlations between the maximum knee flexion angle and alignment were evaluated using Pearson's correlation coefficient; 0.73, to detect a significant difference KOOS values between the subgroups at 0° and 90° knee flexion.

Results

Intraoperative alignment evaluation

Fig. 2 shows that varus alignment decreased after implantation at every knee flexion angle ($p < 0.01$). Table 1 (a, b) shows that all alignment were significantly correlated between before and after implantation ($p < 0.01$).

Radiographic evaluation

The FTA was 179.2 ± 3.3° (standard deviation) preoperatively and 174.8 ± 2.6° at final follow-up ($p < 0.001$). The HKA was 6.9 ± 3.7° varus preoperatively and 1.7 ± 1.5° varus at final follow-up ($p < 0.001$).

Clinical outcomes

The maximum knee flexion angle was 123.9 ± 9.7° preoperatively and 134.2 ± 7.2° at final follow-up ($p < 0.01$). The results of the KOOS were: symptom score 76.7 ± 14.3, pain score 75.7 ± 18.6, ADL score 74.7 ± 17.4, sport score 38.4 ± 24.5, QoL score 52.2 ± 25.3, and total score 68.7 ± 16.3.

Correlations between alignment and maximum knee flexion angle

Table 2 shows that the alignment and the maximum knee flexion angle 3 months after surgery were not correlated.

Subgroup analyses

The median value of varus or valgus at 0° knee flexion was 2.5° varus. The knees above 2.5° varus at 0° knee flexion were subdivided into the varus at 0° group, and the knees equal to or below 2.5° varus were subdivided into the neutral at 0° group. Similarly, the median value of varus or valgus at 90° knee flexion was 2.0° varus. The knees above 2.0° varus at 90° knee flexion were subdivided into the varus at 90° group, and the knees equal to or below 2.0° varus were subdivided into the neutral at 90° group.

There were no differences in KOOS values between the neutral at 0° group and the varus at 0° group (Fig. 3). However, KOOS ADL scores and KOOS total scores were better in the neutral at 90° group than in the varus at 90° group ($p = 0.02, 0.03$, Fig. 4).

Discussion

The most important finding of this study is that patient reported outcomes was better among the knees that were less varus at 90° knee flexion than those that were above 2.0° varus. In addition,

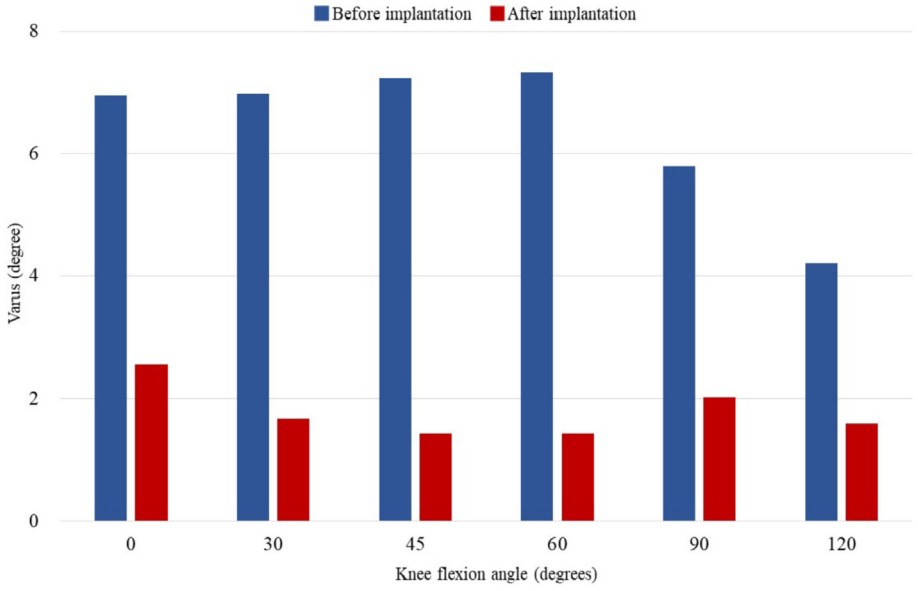

Fig. 2. Varus or valgus alignment at knee flexion angles of 0°, 30°, 45°, 60°, 90°, and 120° before and after implantation.

Table 1

a.) Correlation between varus or valgus alignment before and after implantation				
	Before	After	R^2	P value
0°	6.86	2.57	0.730	<0.001
30°	6.98	1.68	0.829	<0.001
45°	7.24	1.43	0.888	<0.001
60°	7.33	1.43	0.910	<0.001
90°	5.79	2.03	0.930	<0.001
120°	4.21	1.59	0.872	<0.001
b.) Correlation between internal or external alignment before and after implantation				
0°	−7.14	−5.09	0.935	<0.001
30°	−1.32	−1.94	0.898	<0.001
45°	−2.36	−1.79	0.902	<0.001
60°	−3.87	−1.92	0.912	<0.001
90°	−2.20	−2.22	0.881	<0.001
120°	3.29	1.26	0.929	<0.001

Table 2
Correlations between alignment and maximum knee flexion angle.

Knee flexion angle	Varus or valgus alignment before implantation		Varus or valgus alignment after implantation		Internal or external alignment before implantation		Internal or external alignment after implantation	
	R^2	P value	R^2	P value	R^2	P value	R^2	P value
0°	−0.218	N.S.	−0.064	N.S.	−0.096	0.53	−0.054	N.S.
30°	−0.156	N.S.	−0.090	N.S.	0.007	0.96	−0.016	N.S.
45°	−0.073	N.S.	−0.106	N.S.	−0.019	0.90	−0.045	N.S.
60°	−0.035	N.S.	−0.104	N.S.	−0.014	0.93	−0.109	N.S.
90°	0.02	N.S.	−0.052	N.S.	−0.157	0.30	−0.148	N.S.
120°	−0.012	N.S.	−0.039	N.S.	−0.068	0.65	−0.136	N.S.

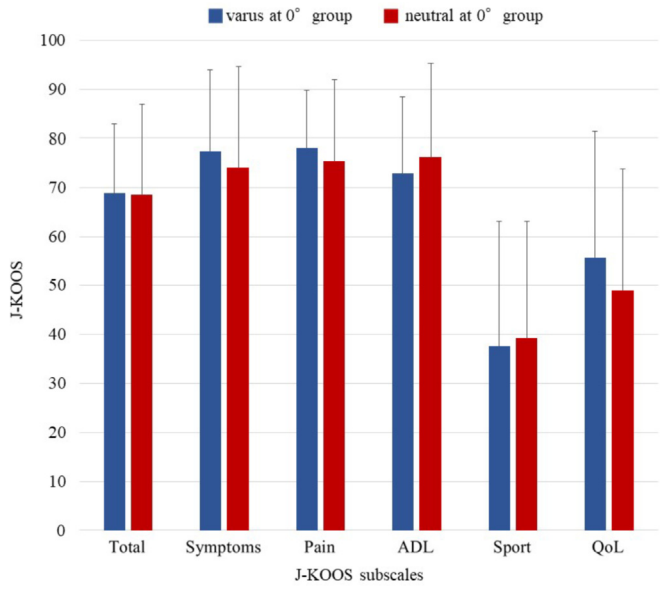

Fig. 3. Comparison of KOOS values between the varus at 0° group and the neutral at 0° group (mean values with error bars reporting standard deviations).

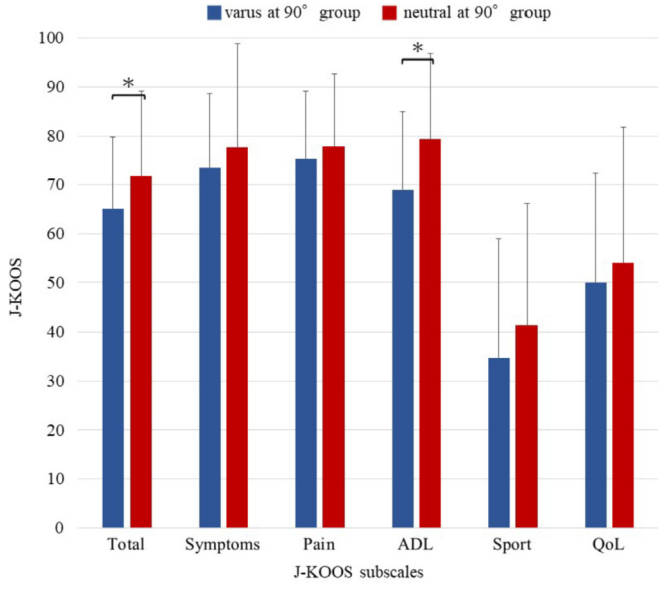

Fig. 4. Comparison of KOOS values between the varus at 90° group and the neutral at 90° group (mean values with error bars reporting standard deviations).

varus at 0° knee flexion and axial rotational alignment did not affect clinical outcomes.

Several papers have reported the association between varus alignment at knee extension and the clinical outcomes of UKA surgery.[14–16] Kennedy et al.[16] reported that clinical outcomes were better in the knees in which the mechanical axis passed through the centre of the tibial plateau or slightly medial to the centre. Zuiderbaan et al.[15] reported that an HKA angle between 1° and 4° correlated with better clinical outcomes. However, other publications reported clinical outcomes that did not differ depending on varus alignment at knee extension.[17,18] The results of the present study that varus alignment at knee extension did not affect clinical outcomes were in agreement with the latter reports.

Patient reported outcomes was better among the knees that were less varus at 90° knee flexion than those that were above 2.0° varus. To the best of our knowledge, no previous reports

investigated the effects of varus alignment at knee flexion on patient reported outcomes. Not only the effects on patient reported outcomes, but also varus alignment at knee flexion itself was not previously discussed. The result of the present study that varus alignment only at knee flexion affected patient reported outcomes might suggest that varus alignment at knee flexion could be a more sensitive factor affecting clinical outcomes than varus alignment at knee extension. Although we surmise that varus alignment at knee flexion depends on the amount of bone cut and ligament balance and so on, further studies of varus alignment at knee flexion are expected to improve UKA surgery.

In cadaver or navigation-based alignment studies, UKA preserved normal axial rotational alignment while TKA changed axial rotational alignment.[11,19] In a similar way, the axial rotational alignment of the present study before and after implantation were strongly correlated. Regarding TKA, several papers reported the correlation between axial rotational alignment and maximum knee flexion angle.[7,9,20,21] However, in the present study, axial rotational alignment were not correlated with maximum knee flexion angle. This may be because the average postoperative maximum knee flexion angle in the present cases, which was 134.2°, may be higher than that for usual TKA knees, and it might be difficult to identify risk factors for worse maximum knee flexion angle for statistical reasons.

The present study has several limitations. First, although the number of the patients in this study, 46, was not enough, the two previous reports about the navigation kinematics of the UKA were 20 and 53. So, the number of the patients in this study was comparable with the previous reports. Second, there were no control group like mobile type UKA. This was associated with the retrospective design and single institution research. Third, the reliability of kinematics obtained during the surgery was not investigated. It was reported that measurement of intraoperative passive knee kinematics using a navigation system has a high inter-rater reliability as described previously. However, this is the first study investigating the effects of navigation-based varus or axial rotational alignment through knee flexion on patient reported outcomes or the maximum flexion angle of UKA. The result that varus at knee flexion affected patient reported outcomes may be a new perspective to consider in UKA surgery.

Conclusions

In conclusion, varus at 0° knee flexion and axial rotational alignment did not affect the clinical outcomes of UKA. Patient reported outcomes was better in the neutral knees with less varus at 90° knee flexion than in varus knees. These data might be a suggestion to improve the surgical technique and clinical outcomes of UKA.

Funding

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Study design

Case series.

Declaration of competing interest

All authors have no conflict of interest.

This study was approved by the institutional review board of the Hakodate Goryoukaku Hospital (Reference number: 2016-072).

Appendix

Table 1
Post-op maximum knee flexion angle between the Varus at 90°group Neutral at 90° group

	Varus at 90°group (more varus than median value post-op)	Neutral at 90° group (less varus than median value post-op)	P value (unpaired *t*-test)
Post-op Flexion angle	133.4	134.8	0.23

Table 2a
Comparison of Varus at 0° pre-op, Varus at 0° post-op, Varus at 90° pre-op between Varus at 90° group and Neutral at 90° group

	Varus at 90°group (more varus than median value post-op)	Neutral at 90° group (less varus than median value post-op)	P value (unpaired *t*-test)
Varus at 0° pre-op	8.19	5.74	0.01
Varus at 0° post-op	4.02	1.34	0.007
Varus at 90° pre-op	9.57	2.62	<0.001

Table 2b
Correlation of Varus at 90° post-op re-op, Varus at 0° post-op, and Varus at 90° pre-op between Varus at 90° group and Neutral at 90° group

	R^2	P value (Pearson's correlation coefficient)
Varus at 0° pre-op	0.509	<0.001
Varus at 0° post-op	0.521	<0.001
Varus at 90° pre-op	0.930	<0.001

Table 3a
The difference in varus alignment pre and post arthroplasty at every knee flexion angle

	Difference	SD
0°	4.29	2.48
30°	5.29	2.34
45°	5.80	2.04
60°	5.90	1.91
90°	3.76	1.71
120°	2.62	2.10

Table 3b
The difference in internal or external alignment pre and post arthroplasty at every knee flexion angle

	Difference	SD
0°	2.05	2.72
30°	−0.63	3.33
45°	0.57	3.22
60°	1.95	3.45
90°	−0.02	4.05
120°	−2.02	3.37

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