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Original article

Impact of preoperative varus deformity on postoperative mechanical alignment and long-term results of "mechanical" aligned total knee arthroplasty

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ABSTRACT

Purpose: Preoperative varus deformity may affect postoperative mechanical alignment and outcomes of total knee arthroplasty (TKA). In this study, we aimed to determine whether (1) greater degrees of preoperative varus deformity increase the incidence of varus-aligned TKAs and (2) residual varus alignment improves the long-term survival rate in TKAs with preoperative varus deformity.
Methods: We retrospectively reviewed 905 primary TKAs for varus-type osteoarthritis from November 1998 to June 2009. The mean follow-up was 8.23 years (± 3.47 years). We measured pre- and postoperative mechanical hip-knee-ankle axis angle (HKA) on full-length standing radiographs to assess the severity of preoperative varus deformities, defined as mild ($0° < HKA \leq 5°$), moderate ($5° < HKA \leq 10°$), severe ($10° < HKA \leq 15°$), and very severe ($HKA > 15°$). Postoperative alignment was divided to four groups: valgus ($HKA < -3°$), neutral ($-3° \leq HKA \leq 3°$), mild varus ($3° < HKA \leq 6°$), and severe varus ($HKA > 6°$). We performed survival analysis in all cases for mechanical failure.
Results: Varus-aligned TKAs increased proportionally to increasing preoperative varus deformity ($p < 0.001$). The survival rate showed no significant difference according to the preoperative varus deformity ($p = 0.147$). However, the survival time for postoperative neutral alignment (16.13 ± 0.10 years, 95% CI 15.94–16.33 years) was longer than the survival time for mild varus (15.32 ± 0.35 years, 95% CI 14.64–16.00 years) and severe varus (13.38 ± 0.53 years, 95% CI 12.35–14.42 years) alignment ($p < 0.001$).
Conclusion: Postoperative varus malalignment appears to increase proportionally to the severity of preoperative varus deformity. Also, postoperative neutral alignment results in longer TKA survival time than residual varus alignment.
Level of evidence: III, Retrospective comparative cohort study.

1. Introduction

Postoperative neutral mechanical alignment has been considered the gold standard for total knee arthroplasty (TKA) procedures [1,2]. In knees with severe varus deformity, achieving neutral alignment may be difficult because of such problems as medial compartment bone loss, excessive contracture of the medial collateral ligament (MCL), and relative laxity of the lateral structures [3]. As the severity of preoperative varus malalignment increases, more extensive medial soft tissue release and more complex bone cuts are required to restore neutral mechanical alignment [4,5]. These measures may make postoperative residual varus malalignment and cause worse TKA survival rate.

However, a substantial portion of the normal population has constitutional varus, defined as (HKA) hip-knee-ankle axis angle > 3°[6]. Kinematic alignment aims to reproduce the prearthritic or native constitutional alignment; [7–9] good long-term results have been reported regardless of postoperative alignment [10,11]. The postoperative varus alignment of the patients with preoperative constitutional varus could be a false malalignment, as opposed to true malalignment in patients with preoperative neutral axis. The effect of residual varus alignment in TKAs had been reported in several studies [3,12–20]. However, most studies used short knee radiographs to evaluate preoperative or postoperative

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alignment [3,18–20], or only reported the results of short-term follow-up (less than 5 years) [12,14,15]. To the best of our knowledge, there has been no investigation of the survivorship of TKA according to the severity of the pre- and postoperative varus deformity using full-length standing films and a large number of patients followed for longer periods (over 5 years on average).

This study was designed to investigate whether (1) increasing degrees of varus deformity are associated with a higher incidence of postoperative varus malalignment and (2) residual varus alignment results in better arthroplasty survival rates than neutral alignment in TKAs with preoperative varus deformity. We hypothesized that (1) knees with severe varus deformities would have more postoperative varus malalignment and that (2) residual varus alignment would result in better TKA survival rates in patients with preoperative varus deformity.

2. Materials and methods

This study was approved by our institutional review board (IRB N° 2017–1124). Between November 1998 and June 2009, we performed 1,299 cemented posterior cruciate ligament-substituting knee arthroplasties in 867 patients with primary osteoarthritis. Preoperative full-length standing films were taken in all patients. We excluded 105 patients with no postoperative full-length standing film available; 58 whose preoperative and postoperative films were not true anterior-posterior (AP) views and were thus inappropriate for measuring mechanical alignment; 10 with a history of osteotomy, hip arthroplasty, or extra-articular deformity that could affect ipsilateral limb alignment; 14 with prosthetic joint infection, periprosthetic infection, or periprosthetic fractures; and 158 who were lost to follow-up before a minimum of 24 months. We also excluded 38 patients who had preoperative valgus or neutral alignment (mechanical hip-knee-ankle axis angle). Consequently, the records of 508 patients (with 905 varus-type osteoarthritic knees) were reviewed for this study. Mechanical alignment was determined by measuring the HKA between the mechanical axes of the femur and tibia. Varus angles were expressed as positive values (HKA > 0°) and valgus angles as negative values (HKA < 0°).

The knees were classified into four groups based on the preoperative HKA: mild ($0° < HKA \leq 5°$, $n = 116$), moderate ($5° < HKA \leq 10°$, $n = 323$), severe ($10° < HKA \leq 15°$, $n = 287$), and very severe ($HKA > 15°$, $n = 179$) varus deformity (Fig. 1) [3,12,16,17,21]. The patients' knees were also divided into four postoperative alignment groups: valgus ($HKA < -3°$), neutral ($-3° \leq HKA \leq 3°$), mild varus ($3° < HKA \leq 6°$), and severe varus alignment ($HKA > 6°$) [12,13,15]. Four patients died during follow-up without having undergone revision surgery. Demographics of the groups are presented in Tables 1 and 2.

2.1. Surgical technique

All operations were performed by one senior surgeon. A conventional technique without computer assistance was used exclusively, employing a NexGen system (LPS or LPS-Flex system; Zimmer, Warsaw, IN, USA). A standard anterior midline skin incision and medial parapatellar arthrotomy were performed. After release of the deep MCL and posteromedial capsule, the distal femoral and proximal tibial bones were cut using an intramedullary alignment guide. After the tibia was cut, the posterior cruciate ligament was resected. Posterior capsular release was done according to the degree of flexion contracture, and additional posteromedial capsular release was performed according to the degree of varus deformity with use of a thicker polyethylene inlay. In cases of severe varus deformity, the semimembranosus tissue and posterior oblique portions of the superficial MCL along the medial tibial flare were also released. Neither the pie crust technique for release of the superficial MCL nor medial epicondylectomy were performed. Components were cemented in all cases, and patelloplasty was performed in all patients without resurfacing the patella.

2.2. Radiologic assessment

Preoperative (within 1 month before the index operation) and postoperative (within 1 year after the index operation) full-length standing films (14×51 inch cassette) of the legs were obtained with the patients standing barefoot with the patella oriented forward.

Routine weight-bearing AP and lateral knee radiographs (14×17 inch cassette) were also taken at 6 weeks, 3 months, 6 months, 1 year, and every 2–3 years thereafter. Radiolucent lines progressing beyond 2 mm and gross shifting of the component causing subsidence or tilting were defined as aseptic loosening [22]. Mechanical failures, including aseptic loosening, polyethylene wear, and instability requiring revision surgery, were considered the endpoint of implant survival.

To test the reliability of the measurements, the films of 50 patients were randomly selected, and all variables were measured twice at an interval of 2 weeks by two orthopedic surgeons. The intraclass correlation coefficients for intra-observer and interobserver reliability were > 0.90 and > 0.85, respectively. Because all measurements were highly reproducible, measurements made by one researcher were used for all subsequent analyses.

2.3. Statistical analysis

Descriptive statistics were summarized as means and standard deviations for the four pre- and postoperative groups. Analysis of variance or a Kruskal–Wallis test (ANOVA on ranks) with a post hoc test were used to compare continuous variables including age, body mass index, follow-up length, and pre- and postoperative HKA. A chi-square test and pairwise comparisons were used to compare categorical variables including sex, side, and groups stratified for pre- and postoperative alignments. The linear-by-linear association method was used to evaluate the relationship between categorical variables. Kaplan–Meier survival analysis was performed using TKA revision for mechanical failure as an endpoint. Comparison of revision rates was performed using a log rank test. Statistical analysis was performed using SPSS software (version 21.0; SPSS, Inc., Chicago, IL, USA), and a value of $p < 0.05$ was considered statistically significant.

3. Results

The mean patient age at the time of surgery was 66.87 ± 6.36 years (range, 43–83 years), and the mean body mass index was $27.38 \pm 3.49\ kg/m^2$ (range, 16.7–42.2 kg/m^2). The mean duration of follow-up was 8.23 ± 3.47 years (median, 8.33 years; range, 2.00–16.75 years). There were no significant differences among the groups regarding age, side, body mass index (BMI), or follow-up periods. The postoperative HKA increased with increasing severity of the preoperative varus deformity ($p < 0.001$) (Table 3). As the severity of the preoperative varus deformity increased, the proportion of varus-aligned TKAs increased, and the proportion of neutral- and valgus-aligned TKAs decreased ($p < 0.001$) (Table 4). Mechanical failures in the preoperative mild, moderate, severe, and very severe varus deformity groups occurred in 2 (1.7%), 8 (2.5%), 12 (4.2%), and 13 (7.3%) TKAs, respectively. Mechanical failures in the postoperative valgus, neutral, mild varus, and severe varus alignment groups occurred in 2 (5.4%), 10 (1.6%), 14 (8.0%), and 9 (16.1%) TKAs, respectively. Survival rates according to the severity of preoperative varus deformity did not show any significant differences in the log rank test ($p = 0.147$) (Fig. 2). Survival rates according to the

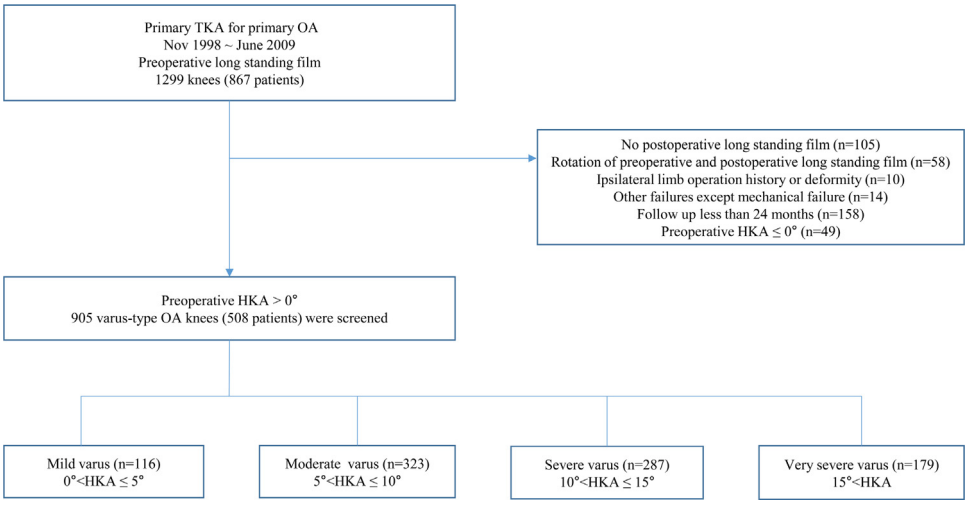

Fig. 1. Flowchart. TKA: total knee arthroplasty; OA: osteoarthritis; HKA: hip-knee-ankle axis angle.

Table 1
Demographics: pre operative alignement.

Varus	Mild($n=116$)	Moderate($n=323$)	Severe($n=287$)	Very severe($n=179$)	p-value
Age, years	67.52 ± 5.84	66.43 ± 6.54	67.02 ± 6.33	67.02 ± 6.33	0.388
Female (%)	105 (90.5%)	303 (93.8%)	279 (97.2%)	174 (97.2%)	0.014
Right/Left	55/61	161/162	151/136	83/96	0.570
BMI, kg/m^2	27.07 ± 3.44	27.36 ± 3.44	27.52 ± 3.36	27.35 ± 3.81	0.694
Follow-up, years	8.30 ± 3.36	7.83 ± 3.27	8.25 ± 3.64	8.74 ± 3.65	0.091

HKA: hip-knee-ankle axis angle; BMI: body mass index; The severity of preoperative varus deformities was defined as mild ($0^\circ < HKA \leq 5^\circ$), moderate ($5^\circ < HKA \leq 10^\circ$), severe ($10^\circ < HKA \leq 15^\circ$), and very severe ($HKA > 15^\circ$).

Table 2
Demographics: postoperative alignment.

	Valgus($n=37$)	Neutral($n=636$)	Mild varus($n=176$)	Severe varus($n=56$)	p-value
Age, years	67.24 ± 5.37	66.89 ± 6.32	66.93 ± 6.54	66.25 ± 6.70	0.845
Female (%)	37 (100%)	598 (94.0%)	174 (98.9%)	52 (92.9%)	0.023
Right/Left	20/17	329/307	79/97	22/34	0.145
BMI, kg/m^2	28.31 ± 3.32	27.41 ± 3.52	27.35 ± 3.36	26.38 ± 3.49	0.263
Follow-up, years	8.83 ± 3.71	7.99 ± 3.43	8.62 ± 3.55	8.87 ± 3.65	0.078

HKA: hip-knee-ankle axis angle; BMI: body mass index; The postoperative alignment was defined as valgus ($HKA < -3^\circ$), neutral ($-3^\circ \leq HKA \leq 3^\circ$), mild varus ($3^\circ < HKA \leq 6^\circ$), and severe varus ($HKA > 6^\circ$).

Table 3
Postoperative mechanical axis angle according to the severity of preoperative varus deformity.

Varus	Mild($n=116$)	Moderate($n=323$)	Severe($n=287$)	Very severe($n=179$)	p-value
Preoperative HKA, degree	3.76 ± 1.24	8.11 ± 1.3	12.69 ± 1.46	19.5 ± 3.56	< 0.001
Postoperative HKA, degree	−0.24 ± 2.51	0.77 ± 2.86	2.20 ± 2.83	3.96 ± 3.13	< 0.001

HKA: hip-knee-ankle axis angle; The severity of preoperative varus deformities was defined as mild ($0^\circ < HKA \leq 5^\circ$), moderate ($5^\circ < HKA \leq 10^\circ$), severe ($10^\circ < HKA \leq 15^\circ$), and very severe ($HKA > 15^\circ$); Varus angles were expressed as positive values and valgus angles as negative values.

Table 4
Postoperative mechanical alignment type according to the severity of the preoperative varus deformity.

Varus		Moderate($n=323$)	Severe($n=287$)	Very severe($n=179$)	Total ($n=905$)
Valgus, $HKA < -3^\circ$	11 (9.5%)	19 (5.9%)	6 (2.1%)	1 (0.6%)	37 (4.1%)
Neutral, $HKA -3^\circ$ to $\leq 3^\circ$	98 (84.5%)	257 (79.5%)	197 (68.6%)	84 (46.9%)	636 (70.3%)
Mild varus, $3^\circ < HKA \leq 6^\circ$	7 (6.0%)	43 (13.3%)	70 (24.4%)	56 (31.3%)	176 (19.4%)
Severe varus, $HKA > 6^\circ$	0 (0.0%)	4 (1.2%)	14 (4.9%)	38 (21.2%)	56 (6.2%)

HKA: hip-knee-ankle axis angle; The severity of preoperative varus deformities was defined as mild ($0^\circ < HKA \leq 5^\circ$), moderate ($5^\circ < HKA \leq 10^\circ$), severe ($10^\circ < HKA \leq 15^\circ$), and very severe ($HKA > 15^\circ$); Varus angles were expressed as positive values and valgus angles as negative values.

postoperative alignment showed significant differences in the log rank test ($p < 0.001$) (Fig. 3). The mean survival time, standard error, and 95% CI of valgus, neutral, mild varus, and severe varus-aligned TKAs are described in Table 5. The survival time for postoperative neutral alignment was longer than the survival time for mild and severe residual varus alignment ($p < 0.001$). High BMI (> 30 kg/m^2), sex, and operated side did not affect the survival rates on log rank testing ($p = 0.148$, $p = 0.659$, and $p = 0.674$, respectively).

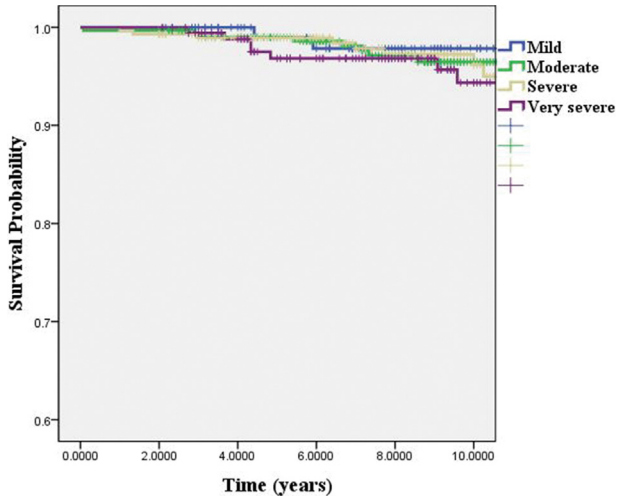

Fig. 2. Kaplan–Meier survival curve showing the influence of preoperative varus severity on implant survival rates in patients with pre operative varus osteoarthritis. HKA: hip-knee-ankle axis angle; Severity of the varus deformity was defined by the hip-knee-ankle (HKA) axis angle: mild ($0^\circ < HKA \leq 5^\circ$), moderate ($5^\circ < HKA \leq 10^\circ$), severe ($10^\circ < HKA \leq 15^\circ$), and very severe ($HKA > 15^\circ$).

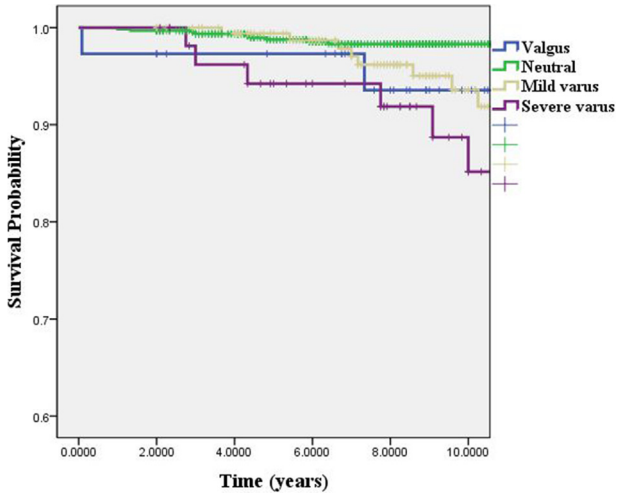

Fig. 3. Kaplan–Meier survival curve showing the influence of postoperative alignment on implant survival rates in patients with pre operative varus osteoarthritis. HKA: hip-knee-ankle axis angle; Postoperative alignment was divided by the hip-knee-ankle (HKA) axis angle: valgus ($HKA < -3^\circ$), neutral ($-3^\circ \leq HKA \leq 3^\circ$), mild varus ($3^\circ < HKA \leq 6^\circ$), severe varus alignment ($HKA > 6^\circ$).

Table 5
Survival time according to the postoperative alignment.

	Mean survival time (years)	Standard error (years)	95% CI (years)	
			Lower	Upper
Neutral	16.13	0.10	15.94	16.33
Valgus	15.71	0.54	14.65	16.78
Mild varus	15.32	0.35	14.64	16.00
Severe varus	13.38	0.53	15.72	16.24

HKA: hip-knee-ankle axis angle; BMI: body mass index; The postoperative alignment was defined as valgus ($HKA < -3^\circ$), neutral ($-3^\circ \leq HKA \leq 3^\circ$), mild varus ($3^\circ < HKA \leq 6^\circ$), and severe varus ($HKA > 6^\circ$).

In subgroup analysis (each preoperative varus deformity group divided by the postoperative alignment), there were no survival rate differences among the preoperative mild and very severe varus deformity groups divided by postoperative alignment ($p = 0.805$, $p = 0.597$, respectively). In the preoperative moderate varus deformity group, postoperative neutral and severe varus alignment showed a higher survival rate than the other types ($p = 0.001$) (Fig. 4). In the preoperative severe varus deformity group, postoperative neutral and valgus alignment showed a higher survival rate than the other types ($p < 0.001$) (Fig. 5).

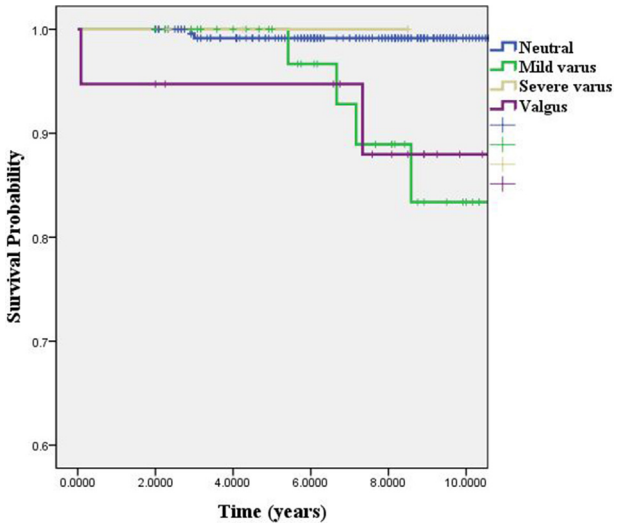

Fig. 4. Kaplan–Meier survival curve showing the influence of postoperative alignment on implant survival rates in patients with moderate varus osteoarthritis. HKA: hip-knee-ankle axis angle; Postoperative alignment was divided by the hip-knee-ankle (HKA) axis angle: valgus ($HKA < -3^\circ$), neutral ($-3^\circ \leq HKA \leq 3^\circ$), mild varus ($3^\circ < HKA \leq 6^\circ$), severe varus alignment ($HKA > 6^\circ$).

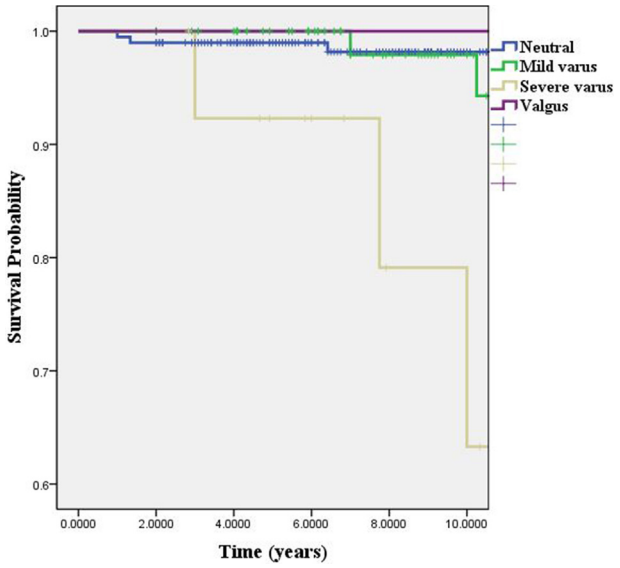

Fig. 5. Kaplan–Meier survival curve showing the influence of postoperative alignment on implant survival rates in patients with severe varus osteoarthritis. HKA: hip-knee-ankle axis angle; Postoperative alignment was divided by the hip-knee-ankle (HKA) axis angle: valgus ($HKA < -3^\circ$), neutral ($-3^\circ \leq HKA \leq 3^\circ$), mild varus ($3^\circ < HKA \leq 6^\circ$), severe varus alignment ($HKA > 6^\circ$).

4. Discussion

It is known that increasing severity of preoperative varus deformity necessitates more extensive soft tissue release and more complex bone cuts to restore a neutral mechanical alignment [4,5]. Hence, the severity of preoperative varus deformity is a possible risk factor for postoperative varus malalignment and poorer

long-term results of TKA. However, a considerable number of patients have constitutional varus [6] and kinematic alignment, which aims to restore pre-arthritic kinematics, has been proposed [7,23]. In addition, the effect of residual varus deformity in TKAs with preoperative varus deformity was unclear especially in terms of long-term follow-up using full-length standing films.

Our most important finding is that the incidence of varus-aligned TKAs increased with worsening preoperative varus deformity. The proportions of varus-aligned TKAs within the groups were 6.0%, 14.6%, 29.3%, and 52.5%, respectively ($p < 0.001$). Our first hypothesis is confirmed.

In a previous study [3], we reported that 86 knees with mild (HKA $\leq 5^\circ$) and 82 knees with severe (HKA $\geq 15^\circ$) varus deformity did not differ in terms of postoperative anatomical femorotibial angle (FTA) or the proportion of outliers exceeding 3° of varus or valgus deviation as measured on short knee radiographs. Three studies have reported on postoperative mechanical alignment as measured on full-length films in knees with preoperative severe varus deformity [14,16,17]. Bae et al. [17] compared 204 knees with a preoperative HKA of $\leq 15^\circ$ with 32 knees with an HKA > 15°, finding that the postoperative HKAs after conventional TKA were 1.1° and 3.2°, respectively. Postoperative varus malalignment (HKA > 3°) was present in 20.5% (42/204) and 53.1% (17/32), respectively, similar to our results. Ozturk et al. [16] compared posterior cruciate ligament-substituting TKA with posterior cruciate ligament-retaining TKA among patients with a preoperative varus deformity >10°, reporting an average postoperative HKA of −0.4° in 27 knees with the first procedure and of 0.3° in 33 knees undergoing the second type. Magnussen et al. [14] also reported that 7.9% (21/266) of knees with a preoperative varus deformity $\geq 10^\circ$ had postoperative varus malalignment of > 3°, compared with 1.0% (3/287) in knees with a lesser degree of preoperative varus deformity. These previous investigations had various limitations, such as relatively small numbers of patients with severe varus deformity preoperatively [16,17] or comparison of only two categories of preoperative varus severity [14]. In contrast, we analyzed a large number of patients stratified more precisely by different degrees of preoperative varus deformity.

Our second important finding is that the survival time for postoperative neutral alignment was longer than the survival time for other alignment types, including mild and severe residual varus alignment in TKAs with preoperative varus deformity ($p < 0.001$). Our second hypothesis is not confirmed.

There have been several studies of clinical scores and TKA survival rates in patients with preoperative varus and postoperative residual varus deformities [12–15,24]. Magnussen et al. reported that there was no difference in survival rate and clinical scores between postoperative neutral alignment and residual varus alignment in 553 knees after a mean follow-up period of 2 years [14]. Rames et al. reported that there was no difference in clinical scores among 4 alignment groups (postoperative neutral, mild varus, severe varus, and valgus) in 256 TKAs after a mean follow-up period of 1.3 years [12]. Nishida et al. also reported that there was no significant difference in clinical outcomes among alignment groups of 220 knees after a mean follow-up period of 3.6 years [15]. Vanlommel et al. reported better clinical outcomes for postoperative mild varus alignment than postoperative neutral alignment, without failures in 143 TKAs after 7.2 years of follow-up [13]. Zhang et al. reported that postoperative mild varus alignment showed the same functional outcomes as neutral alignment in 219 knees with preoperative varus deformity after 5.2 years of follow-up [24]. In our study, a large number of patients with more extended follow-up was analyzed and postoperative neutral alignment showed better survival than residual varus deformity in TKAs with preoperative varus deformity. In the subgroup analysis, there was no survival rate difference among postoperative alignment groups with preoperative mild and very severe varus deformity, and postoperative severe varus alignment showed no relationship to failure in the preoperative moderate varus deformity group. The small sample size of these groups seemed to affect the results.

Our study has several limitations. First are its retrospective nature and low enrollment. We excluded patients who were lost to follow-up within 2 years of the surgery and patients who did not have full-length standing films or had them taken in the wrong position. This may have introduced selection bias because a large number of patients were excluded. Second, the effects of intra-articular and extra-articular deformity were not evaluated respectively. Preoperative varus alignment is caused not only by intra-articular deformity including cartilage wear but also by extra-articular deformity including bowing and joint laxity; further study distinguishing the two conditions is needed. Third, not accounting for the amount of release could contribute to confusion bias. However, because we did not record the amount of release during operation, we could not include this factor in the subgroup analysis. Fourth, we did not analyze patient-reported outcomes including pain, range of motion, function, or satisfaction. These factors should also be addressed in future studies. Fifth, most of the patients were female (861, 95.1%) and the number of male patients (44, 4.9%) was small. Also, because of the relatively small number of patients in the preoperative mild varus deformity and postoperative valgus alignment groups, the sex ratio imbalance became statistically considerable. Because of this sample size limitation, the difference in TKA survival rate between male and female patients could not be described.

5. Conclusion

With increasing degrees of preoperative varus deformity, the incidence of postoperative mechanical varus malalignment also increases, and even in the patients with preoperative varus deformity, TKA survival rate is superior with postoperative neutral alignment. Understanding the risk conferred by increasing degrees of varus malalignment is important; with higher degrees of varus deformity, more attention should be paid intraoperatively to avoiding insufficient correction.

Disclosure of interest

The authors declare that they have no competing interest.

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Contributions

Sung-Mok Oh: Protocol and manuscript writing, data-gathering and analysis.
Jae-Young Kim: Data-gathering, manuscript review.
Bum-Sik Lee: Data-gathering, manuscript review.
Jong-Min Kim: Data-gathering, manuscript review.
Seong-Il Bin: Data provision, manuscript review.

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