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KNEE ARTHROPLASTY

Slight under-correction following total knee arthroplasty for a valgus knee results in similar clinical outcomes

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Abstract

Background Restoration of correct coronal alignment is one of the main goals of total knee arthroplasty (TKA). Traditionally, TKA has been considered successful when a neutral mechanical hip–knee–ankle (HKA) axis within 3° is achieved. Recent studies have reported no differences or improved clinical outcomes following a slight under-correction of the HKA axis for a varus knee. However, the influence of under-correction of a valgus knee has not been reported. This study investigated the influence of post-operative HKA alignment in TKA patients with valgus deformity on clinical outcomes.

Methods Ninety-three knees (93 patients) with pre-operative valgus alignment were evaluated with a mean follow-up period of 60 months. All patients were classified into three groups based on post-operative HKA alignment: neutral ($0 \pm 3°$), mild valgus (3°–6°), and severe valgus ($> 6°$). These groups were compared using the Western Ontario and McMaster Universities osteoarthritis (WOMAC) index, the Knee Society (KS) knee score, KS function score, α-angle, β-angle, patella tilt angle, and the congruence angle.

Results Sixty-nine knees were included in the neutral group, seventeen knees in the mild valgus group, and seven knees in the severe valgus group. In all cases, post-operative clinical and functional scores significantly improved compared to pre-operative scores. There were no differences between the three groups in post-operative clinical and functional scores. More post-operative patellar tilt angle outliers ($> 10°$) and congruence angle outliers ($> 16°$) were apparent in the severe valgus group (patellar tilt angle, 13 vs. 17 vs. 57.1%, $p = 0.022$; congruence angle, 32 vs. 47 vs. 71%, $p = 0.035$).

Conclusions Slight under-correction following TKA for a valgus knee resulted in similar clinical outcomes. A residual valgus angle of more than 6° can induce patellar maltracking.

Level of evidence III, Retrospective comparative study.

Keywords Alignment · Neutral alignment · Total knee replacement · Knee valgus · Patellar maltracking

Introduction

Traditionally, restoration of neutral limb alignment is considered a successful outcome with total knee arthroplasty (TKA) [1, 2]. The general consensus is to aim to achieve a mechanical hip–knee–ankle (HKA) axis within 3° of neutral, with femoral and tibial component positions perpendicular to the neutral mechanical axis [2–6]. However, recent studies suggest that evidence regarding the importance of neutral post-operative alignment is weak in knee varus TKA [7–9]. Some studies have reported that slight under-correction of varus alignment does not result in inferior outcomes. Moreover, in some studies, TKA performed in patients with pre-operative varus deformity had superior clinical outcomes when the alignment was left in residual varus [7, 8, 10, 11]. Many studies have investigated the correlation between residual deformity and clinical outcomes in TKA with pre-operative varus deformity. As far as known, no study has investigated the correlation between TKA clinical outcomes and pre-operative valgus deformity. Among all TKA cases, about 10% of patients have a valgus deformity [12]. Compared with TKA for varus deformity, TKA with knee valgus deformity has different concerns for several reasons, including lateral condylar hypoplasia, lateral soft-tissue contracture, and peroneal nerve injury [13, 14]. Patellar maltracking is also one of the concerns when performing TKA with

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a valgus knee deformity due to the excessive Q-angle and the tightness of the lateral retinaculum [15]. Unlike residual varus deformity in patients undergoing TKA with pre-operative varus, patellofemoral issues can alter the outcome of residual valgus deformity.

The purpose of this study was to assess the relationship between post-operative HKA alignment in TKA patients with a pre-operative valgus deformity and clinical outcomes. It was hypothesized that, in patients with a valgus deformity, a slight under-correction of the valgus deformity might show better clinical outcomes compared to a neutral correction.

Materials and methods

This study was a retrospective review of prospectively collected data performed at by one surgeon. Data collected from 2387 consecutive TKAs performed between January 2005 and November 2015 were reviewed. All patients who had pre-operative valgus deformity with lateral compartment arthritis were included in the study, resulting in 165 TKAs. From these, patients were excluded if pre-operative radiographs or clinical scores were unavailable or inadequate, if the follow-up period was shorter than 24 months, or if they had received a constraint-type implant. One hundred and thirteen cases remained following exclusion criteria. There were 20 bilateral cases. In bilateral cases, one side (left or right) was selected by simple random sampling. This resulted in a study population consisting of 93 TKAs performed on 93 patients. The 93 TKAs were divided into three groups based on post-operative HKA alignment (the mechanical axis deviation of the femur and the tibia). Consequently, there were 69 knees in the "neutral group" (3° varus–3° valgus), 17 knees in the "mild valgus group" (3°–6° valgus), and 7 knees in the "severe valgus group" (> 6° valgus), (Fig. 1). Among all the patients, 85 were diagnosed with primary osteoarthritis and 8 with rheumatoid arthritis. There were no diagnoses of post-traumatic osteoarthritis or any previous procedures involving high tibial osteotomy. The mean follow-up period was 60 months (range 24–135 months). Detailed demographic data are represented in Table 1. The study protocol was approved by the Institutional Review Board (SMC-2017-06-008).

Surgical techniques and management

All the surgical procedures were conducted by one experienced surgeon. The operations were performed with the use of a tourniquet. A posterior-stabilized prosthesis (Scorpio Superflex or NRG; Stryker Orthopedics, Mahwah, NJ, USA) was implanted. All surgeries were performed to obtain neutral alignment of lower limb and balanced gap. To obtain a rectangular gap, soft-tissue release was performed in some instances as described in the previous studies. First, the iliotibial band was released, and then, if necessary, the posterolateral corner was released [12, 16]. The popliteus tendon was preserved as far as possible. However, in one knee, a popliteus tendon release was performed due to severe lateral tightness. The constraint prosthesis was used in mediolateral gap balancing failure. A distal femoral resection was performed using an intramedullary cutting guide. The intramedullary rod for the distal femoral cut was inserted at an angle of 4°–6° valgus to compensate for metaphyseal–diaphyseal valgus remodeling that has usually taken place and to avoid under-correction of the underlying deformity, based on the pre-operative radiograph [12, 17]. Proximal tibial cutting followed using a device that created a rectangular extension gap until the mediolateral and flexion–extension gaps were balanced. After implantation was completed, temporary repair of the arthrotomy site was performed to check patellar tracking. If poor patellar tracking was evident, patellofemoral tracking was rechecked under tourniquet deflation. In situations where poor tracking was apparent despite deflation of the tourniquet, a lateral retinacula release was performed.

To avoid peroneal neuropraxia, the patients' knees were placed in a position of 30° flexion until ranges of motion (ROM) exercises were commenced. All the patients began active and passive ROM exercises on the second day post-operatively.

Clinical and radiographic assessment

Clinical assessments including ROM, the Western Ontario, and McMaster Universities Osteoarthritis index (WOMAC) [18] and Knee Society (KS) scores [19] were evaluated pre-operatively and at the final follow-up and compared. In addition, clinical outcomes were compared between the "neutral group", "mild valgus group", and "severe valgus group", pre-operatively and at the final follow-up.

The pre-operative and final follow-up radiographs, including a whole-leg radiograph with the patella oriented in a forward-facing position, a standing anteroposterior view of the knee, lateral knee full extension view, and a Merchant view [20], were analyzed and measured. Pre- and post-operative HKA alignment (the mechanical axis deviation between the femur and the tibia) was measured using the whole-leg radiograph. The mechanical femoral axis was considered as the line connecting the center of the hip, determined using concentric Moose circles, with the midpoint of the widest dimension of the distal femur. After TKA, the midpoint of the femoral component replaced the midpoint of the widest dimension of the distal femur. The mechanical tibial axis was defined as the line connecting the center of the tibial spines to the center of the talus. After TKA, the mechanical tibial axis was determined using the line connecting the

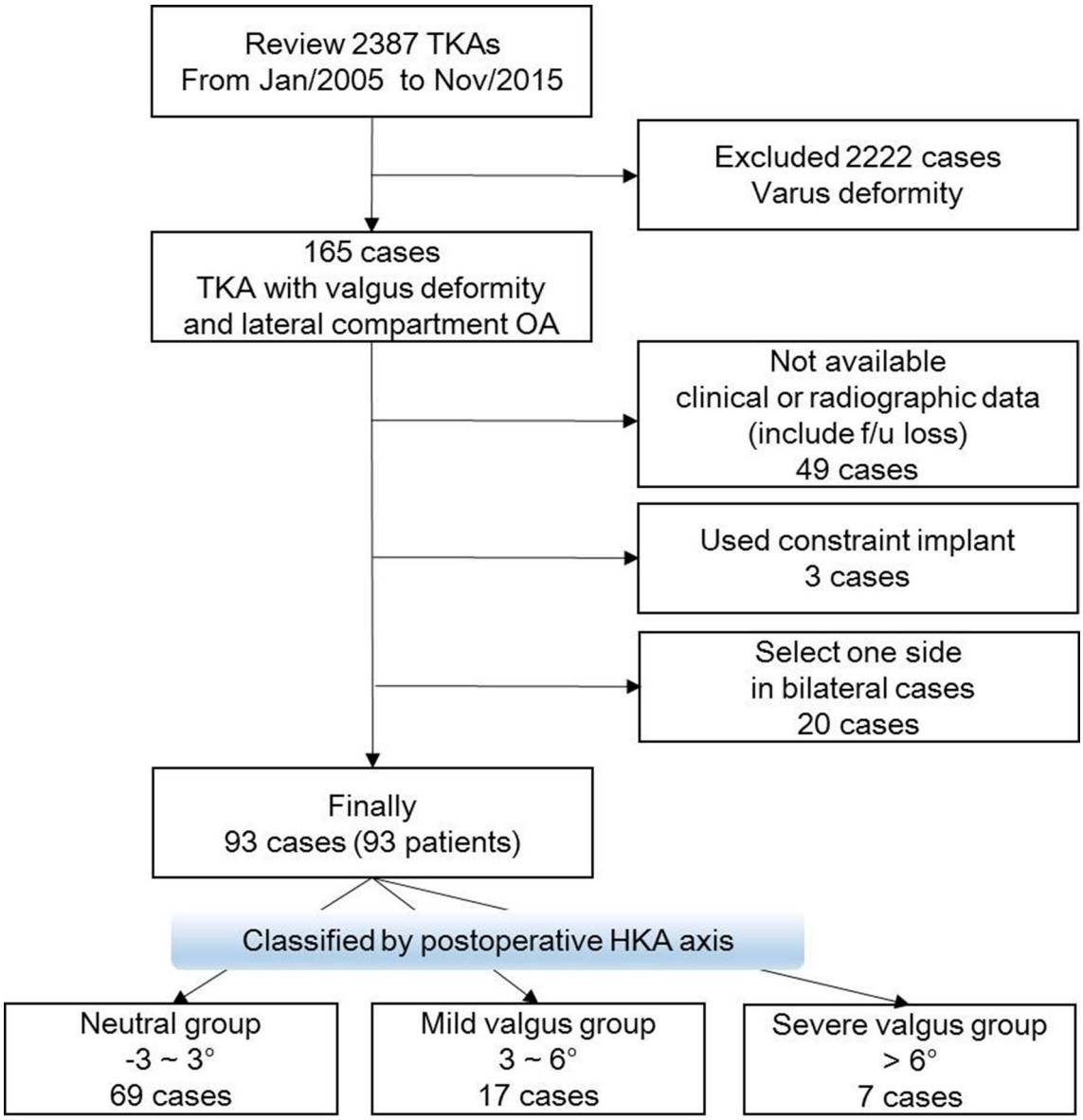

Fig. 1 Flowchart of patients included in the study

center of the polyethylene insert to the center of the talus [21]. A positive value indicated a valgus deformity. To investigate the implant position in the coronal and sagittal plane, alpha (α), beta (β), gamma (γ), and delta (δ) angles were measured using the standing anteroposterior knee view and lateral knee full extension view [22], (Fig. 2). The α-angle was the medial angle between a line parallel with the femoral component condyles and the anatomical axis of the femur, the β-angle was the medial angle between a line parallel to the tibial component and the anatomical axis of the tibia. The γ and δ angles were the angle between femoral or tibial component and anatomical axis of femur or tibia in sagittal plane. To check pre- and post-operative patellofemoral alignment, patellar tilt angle [23] and congruence angle [24] were measured using the Merchant view (Fig. 3a, b). The patellar tilt angle was defined as the angle between the line from one corner of the patella to the other and the line connecting the anterior limits of the femoral condyles or femoral component. A positive value indicated patellar lateral translation and a patellar tilt angle greater than 10° was considered as an outlier based on the results from a previous study [23]. The congruence angle was considered as the angle between the bisector of the sulcus angle and the line connecting the lowest point of the intercondylar sulcus with the articular ridge of the patella. Patellar resurfacing was not performed during surgery; therefore, the post-operative congruence angle was able to be measured. A positive value indicated patellar lateral translation and a congruence angle value greater than

Table 1 Demographic data and pre-operative clinical and radiographic results for neutral, mild valgus, and severe valgus post-operative HKA alignment

	Neutral (0 ± 3°) *n* = 69	Mild valgus (3–6°) *n* = 17	Severe valgus (> 6°) *n* = 7	*p* value	Neutral vs. mild	Neutral vs. severe	Mild vs. severe
Age (years)	68.2 ± 7.6	69.2 ± 9.8	67.0 ± 11.5	n.s			
BMI (kg/m^2)	25.5 ± 3.4	27.2 ± 4.4	27.3 ± 5.7	n.s			
Sex (M:F)	12:57	1:16	0:7	n.s			
Range of motion (°)	122 ± 21.7	113.8 ± 22.6	122.1 ± 12.9	n.s			
WOMAC index	59.4 ± 12.8	59.2 ± 15.5	54.7 ± 10.1	n.s			
KS knee score	54.2 ± 15.9	56.8 ± 17.6	60.7 ± 8.2	n.s			
KS functional score	49.0 ± 15.4	44.4 ± 16.2	45.7 ± 7.9	n.s			
HKA alignment (°)	5.3 ± 4.7	9.7 ± 8.5	12.5 ± 5.6	**0.001**	***p* = 0.005**	***p* = 0.014**	n.s
Patellar tilt angle (°)	6.0 ± 3.7	6.7 ± 6.9	8.8 ± 2.9	n.s			
Number of patellar tilt angle outliers	9 (13%)	2 (11.8%)	2 (14.3%)	n.s			
Congruence angle (°)	7.9 ± 16.4	7.9 ± 23.3	15.1 ± 22.1	n.s			
Number of congruence angle outliers	18 (26.1%)	5 (29.4%)	3(42.9%)	n.s			

Statistically significant values are in bold

n.s non-significant difference

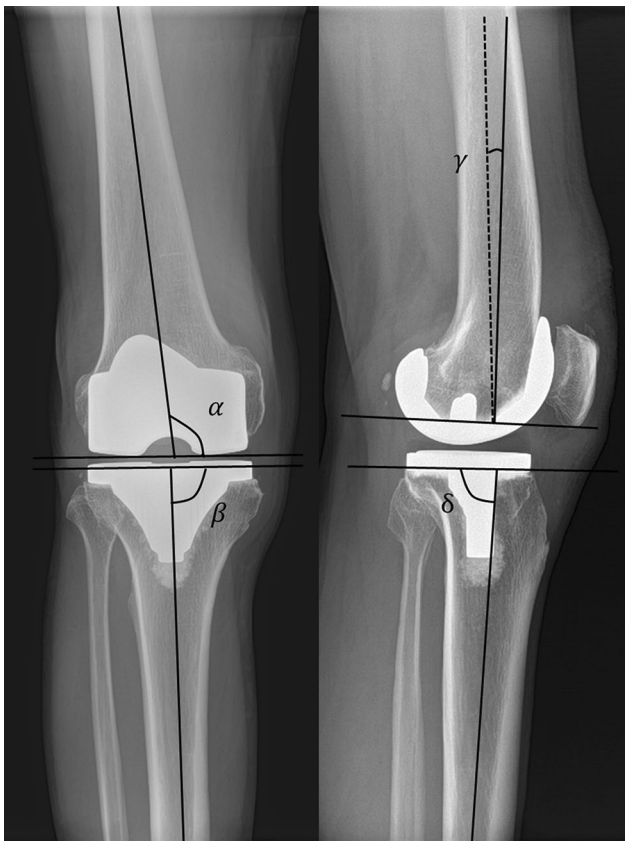

Fig. 2 Post-operative radiographs demonstrating measurement of the α-, β-, γ-, and δ-angles

16° was defined as an outlier [25]. The above variables were measured using a PACS system (Centricity; General Electric, Chicago, IL, USA). The radiographs were evaluated by two independent orthopedic surgeons for inter-observer reliability. Two observers performed the measurements twice at 6-week intervals to ensure intra-observer reliability.

Similar to the clinical outcomes, the pre-operative and final follow-up results including HKA alignment, patellar tilt angle, and congruence angle were compared. The pre-operative and final follow-up radiographic results were also compared between the three groups.

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences software version 20.0 (SPSS, Inc., Chicago, IL, USA). An intra-class correlation coefficient (ICC) was used to examine inter- and intra-observer reliability of radiographic measurements. Student *t* tests for continuous variables and Chi-square tests for categorical variables were used to compare the pre-operative and final follow-up results. To compare post-operative HKA alignment or the correction angle amount between the three groups, the Kruskal–Wallis test for continuous variables and the linear by linear association method for categorical variables were used. The Mann–Whitney *U* test with a Bonferroni correction or the Chi-square test was used for post hoc pairwise comparisons. A post hoc power analysis was performed to address the research question that under-correction of valgus alignment might show different post-operative clinical

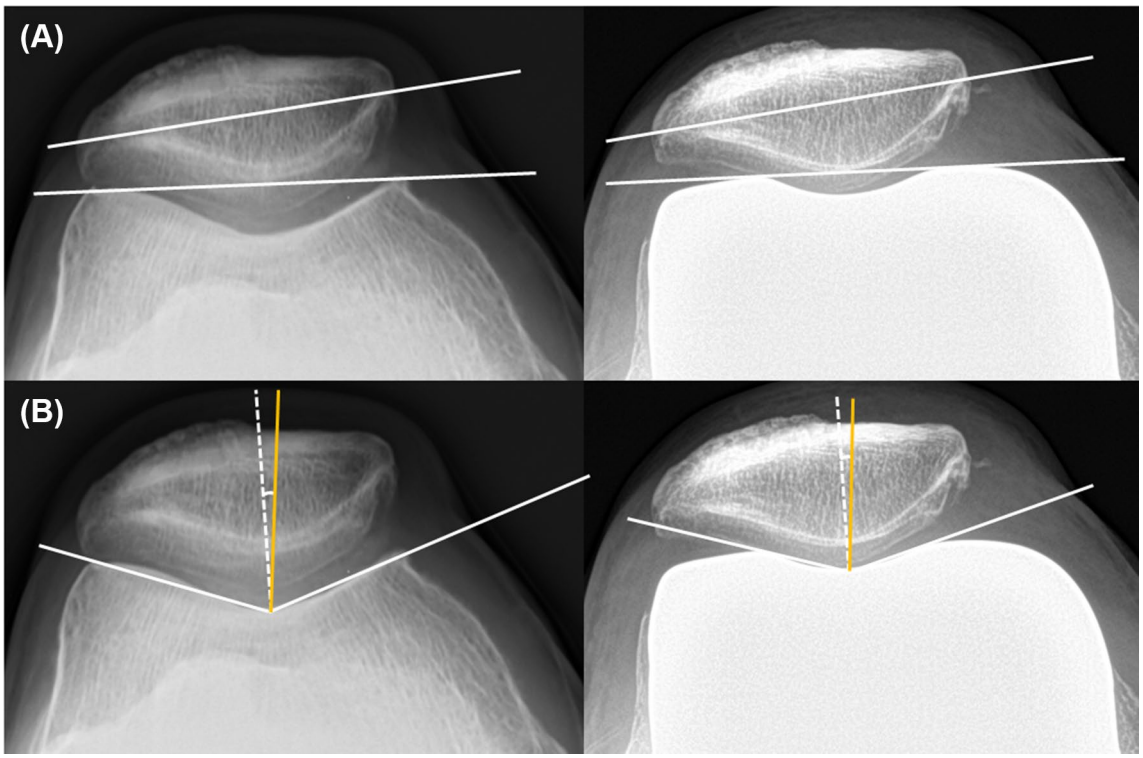

Fig. 3 Pre- and post-operative Merchant view radiograph demonstrating measurement of **a** patellar tilt angle and **b** congruence angle: angle between the dotted line and the orange line. The dotted line indicates the bisector of the sulcus angle; the orange line indicates the connection at the lowest point of the intercondylar sulcus with the articular ridge of the patella

outcomes. In our study, 69 patients were in a neutral post-operative alignment and 17 patients were in a mild valgus post-operative alignment. A six-point difference in the Knee Society scores reported to be a minimal clinically important difference [26]. It would be 80.7% power to detect a difference of at least six points in the mean KSS scores ($\alpha = 0.05$).

Results

All inter- and intra-observer ICCs of radiographic measurements showed good agreement regarding radiographic measurement reliability (> 0.80). In all cases, ROM, WOMAC index, KS knee score, KS functional score, and HKA alignment showed a significant improvement after surgery. The patellar tilt angle and the congruence angle were similar between the pre-operative and final follow-up periods (Table 2).

Regarding comparisons of pre-operative results between the three groups which were classified using post-operative HKA alignment, there were no significant differences except for pre-operative HKA alignment. Pre-operative HKA alignment in the neutral group was less than in the mild valgus group or in the severe valgus group ($p = 0.001$) (Table 1). Post-operatively, the severe valgus group showed slightly decreased scores; however, there was no statistical significance between the three groups in terms of clinical outcomes. The α-angle in the neutral group (95.3°) was smaller than in the mild (96.7°, $p < 0.001$) or severe groups (98.8°, $p = 0.007$); however, the β-angle was similar. Patellar tilt angle outliers (13 vs. 57.1%, $p = 0.003$) and congruence angle outliers (31.9 vs. 71.4%, $p = 0.037$) were significantly greater in the severe group than in the neutral group. The number of lateral

Table 2 Comparison of clinical and radiographic outcomes between the pre-operative and final follow-up period (Mean ± standard deviation)

	Pre-operative	Post-operative	*p* value
Range of motion (°)	120.7 ± 21.4	132.8 ± 13.8	**< 0.001**
WOMAC index	59.0 ± 13.1	9.8 ± 7.6	**< 0.001**
KS knee score	55.2 ± 15.8	90.8 ± 7.2	**< 0.001**
KS functional score	47.9 ± 15.1	71.0 ± 14.9	**< 0.001**
HKA alignment (°)	6.6 ± 6.0	1.8 ± 2.9	**< 0.001**
Patellar tilt angle (°)	6.4 ± 4.4	8.1 ± 5.1	n.s
Congruence angle (°)	8.8 ± 17.4	9.6 ± 26.5	n.s

Statistically significant values are in bold

n.s non-significant difference

retinacula releases was similar between the three groups (Table 3).

Two knees (included in the neutral group) with rheumatoid arthritis demonstrated instability (at 66 and 60 months post-operatively, respectively). These knees required revision and replacement of the polyethylene insert for a thicker one and have since performed well. The other cases were not revised or considered for revision.

Discussion

The most important finding of the current study was that a slight under-correction of valgus deformity showed similar clinical outcomes and patellar tracking to neutral alignment in patients who received a TKA for pre-operative valgus deformity. However, a large amount of under-correction showed a high incidence of patellofemoral incongruence.

Earlier studies reported that malalignment post-TKA resulted in inferior clinical outcomes [2, 27]. However, recent studies have contradicted this, since similar or superior clinical outcomes have been shown with mild under-correction of varus deformity during TKA in varus knees [8, 28]. It was suggested that under-correction to an approximate alignment which related to the pre-arthritic status, possibly causes less release of knee soft tissues. Slevin et al. [6] proposed that the influence of post-operative alignment on functional outcomes was dependent on pre-operative alignment, because soft-tissue tension was important for providing neurosensory feedback. This is very close to the concept of kinematic alignment technique that is introduced to preserve normal knee kinematics and minimize soft-tissue releasing based on pre-arthritic joint status, shows to better or similar clinical outcomes [29, 30]. Similar reasons could be considered to have affected the clinical outcomes of residual valgus deformity in patients undergoing TKA with pre-operative valgus deformity in this study. However, the "mild valgus group" did not demonstrate superior clinical outcomes compared to the "neutral group". This may be attributed to the higher pre-operative valgus deformity presenting post-operatively in the "mild valgus group" (mean 9.7°) compared to the "neutral group" (mean 5.3°). Some studies have demonstrated that post-operative patellofemoral incongruence induced anterior knee pain and lower satisfaction post-TKA [31–33]. Inferior clinical outcomes were expected in the severe valgus group due to the high incidence of post-operative patellofemoral incongruence, in contrast to the severe varus group following knee varus TKA [7, 8]. When the three groups were compared based on post-operative HKA alignment (neutral vs. mild vs. severe), inferior clinical outcomes were obtained in the severe group; however, these were not statistically significant. First, this may be explained by the fact that although the knee society score and the WOMAC index are highly valid scoring systems and widely used, these systems are not specific to the patellofemoral joint compared to Feller or Kujala scores [34, 35]. Keshmiri et al. reported that similar knee society scores but poorer Feller scores were shown in patients with patellar

Table 3 Post-operative clinical and radiographic results for neutral, mild valgus, and severe valgus post-operative HKA alignment

	Neutral (0 ± 3°) $n = 69$	Mild valgus (3–6°) $n = 17$	Severe valgus (> 6°) $n = 7$	p value	Neutral vs. mild	Neutral vs. severe	Mild vs. severe
Range of motion (°)	135.2 ± 10.7	127.6 ± 19.4	122.1 ± 18.7	n.s			
WOMAC index	9.4 ± 7.6	9.1 ± 7.9	15.1 ± 5.8	n.s			
KS knee score	91.2 ± 7.5	91.1 ± 4.9	86.1 ± 8.4	n.s			
KS functional score	71.9 ± 15.7	70.0 ± 12.7	64.3 ± 11.3	n.s			
α-angle (°)	95.3 ± 2.1	96.7 ± 1.0	98.8 ± 2.4	**< 0.001**	**$p < 0.001$**	**$p = 0.007$**	n.s
β-angle (°)	89.7 ± 1.9	90.8 ± 2.1	90.1 ± 2.0	n.s			
γ angle (°)	2.5 ± 1.7	2.1 ± 2.0	2.6 ± 2.1	n.s			
δ angle (°)	85.8 ± 2.4	85.4 ± 2.5	85.9 ± 1.4	n.s			
Patellar tilt angle (°)	7.3 ± 3.2	8.0 ± 4.5	15.7 ± 12.2	n.s			
Number of patellar tilt angle outliers	9 (13%)	3 (17.6%)	4 (57.1%)	**0.011**	n.s	**$p = 0.003$**	n.s
Congruence angle (°)	7.1 ± 27.9	11.8 ± 18.4	28.9 ± 22.9	n.s			
Number of congruence angle outliers	22 (31.9%)	8 (47.1%)	5 (71.4%)	**0.035**	n.s	**$p = 0.037$**	n.s
Number of lateral retinacula releases	19 (27.5%)	10 (58.8%)	3 (42.9%)	n.s			

Statistically significant values are in bold

n.s non-significant difference

maltracking post-TKA [31]. Second, the number of patients in the severe valgus group was not large, and this may be a reason that statistical differences were not obtained.

Several factors affect post-operative patellofemoral incongruence following TKA, including residual limb malalignment and internal rotation of the femoral or tibial component [36]. Karachalios et al. stated that patellar maltracking with residual valgus malalignment post-TKA for a valgus knee was associated with inadequate soft-tissue release and greater Q-angle rather than femoral component malrotation [27]. Slevin et al. demonstrated that valgus orientation post-TKA was the factor most correlated with patellar maltracking [37]. In the current study, a post-operative CT scan was not performed routinely. This was one limitation of the current study, since component rotation was not evaluated. Lateral femoral condylar hypoplasia in knee valgus deformity is well understood. Hence, particular attention was paid to adjusting the femoral component rotational axis, checking the trans-epicondylar axis and the Whiteside line during surgery. In the current study, the femoral malrotation component was not considered a major factor in patellofemoral congruency. In future studies, a post-operative CT scan will be required to effectively address this limitation.

The number of outliers in the patellar tilt angle (from 13 to 16 cases) and in the congruence angle (from 26 to 35 cases) increased slightly from the pre-operative to the final follow-up period despite performing lateral retinacula releases (32 knees, 34%) in the current study. This may be due to the use of a medial parapatellar approach in all of the TKAs. Keshmiri et al. [31] demonstrated that increased capsular dehiscence occurred (range 0–6 mm) following TKA using a medial parapatellar approach in more than half of the study population. Greater force for medial dehiscence might be applied to the patients who remain with valgus alignment. It could cause an increased patellar tilt angle or a congruence angle post-TKA.

Longevity problem is one of the concerns in TKA with residual deformity. Ritter et al. investigated the correlation between malalignment of the limb or implant and the revision rate in 6070 knees [38]. These authors reported that overall lower extremity varus outliers (anatomical femorotibial angle (FTA) < 2.5° valgus) showed a greater failure rate compared to neutral (2.5 < FTA < 7.4°) or valgus alignment (FTA > 7.4°) post-TKA. In addition, varus alignment of the tibial component (< 90°) and valgus alignment of the femoral component (> 8°) produced while compensating for the tibial varus cut were also related to implant failure. According to Ritter and colleagues [35], the mean femoral component alignment of the mild valgus group (α angle = 96.7°) in the current study would be classified as "neutral alignment". The mean femoral component alignment of the severe valgus group would be classified as a "valgus outlier" (α angle = 98.8°); however, this was not due to the compensation of the varus tibial component (mean β angle = 90.1°). All the current study outliers were classified as "overall valgus alignment" which showed a similar failure rate to those classified as "overall neutral alignment". The mean follow-up period in this study was not long term; therefore, it was difficult to conclude whether there was a correlation between alignment and implant failure in valgus knee TKA. A longer follow-up period would be required for this evaluation, especially regarding the survival period of the implant in the severe valgus group.

Other study limitations include the use of a retrospective study design with prospectively collected data. Randomization was, therefore, not performed, making comparisons less reliable. Second, the sample size was relatively small; however, statistical power was sufficient to evaluate the differences between the three groups. Third, HKA alignment was measured from standing whole-leg radiographs which might be less reliable than 3D-reconstructed CT scans. Despite several limitations, a few studies have evaluated the correlation between clinical outcomes and post-operative alignment following knee valgus TKA. Therefore, this study makes a valuable contribution to this research area.

Conclusion

Slight under-correction following total knee arthroplasty for a valgus knee showed similar clinical outcomes compared with neutral alignment. The results of this study correspond with the current concepts of under-correction in TKAs performed on varus knees. However, a residual valgus angle of more than 6° can induce patellar maltracking.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors. The protocol used to evaluate radiographic findings and intraoperative navigation data was approved by our institution's investigational review board (SMC2017-06-008).

Informed consent Informed consent was obtained from all individual participants included in the study.

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