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A residual intra-articular varus after medial opening wedge high tibial osteotomy (HTO) for varus osteoarthritis of the knee

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Abstract

Purpose Varus deformity of knee osteoarthritis was formed by both intra-articular and extra-articular pathologies. Such intra-articular deformities could not be fully corrected by a medial open-wedge high tibial osteotomy (HTO), which was performed as an extra-articular procedure. Therefore, the purpose of this study was to investigate whether any residual varus was left inside the joint after HTO in the patients with knee osteoarthritis, and a correlation of the residual varus could be traced.

Methods This study involved 66 patients (66 knees) undergoing HTO for medial knee osteoarthritis. The percentage of mechanical axis (%MA), mechanical femorotibial angle (mFTA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA) and joint line convergence angle (JLCA) were measured on radiographs of the full-length legs preoperatively and 6 months postoperatively. The relationship between changes in the JLCA and alignment correction was assessed. The postoperative residual JLCA was categorized as the optimal (postoperative JLCA $\leq 2°$), the acceptable ($2° <$ postoperative JLCA $\leq 5°$), and the unacceptable (postoperative JLCA $> 5°$) to analyze its correlation with pre- or intra-operative factors.

Results Average %MA and mFTA were improved from 5.5 to 60% and from 190.2° to 176.4°, respectively. There was no change in mLDFA, whereas mMPTA changed from 80.3° to 91.8°. JLCA changed from 4.2° to 2.7°. The analyses of multiple linear regression showed that the preoperative JLCA and postoperative changes in mechanical alignment (%MA, mFTA and mMPTA) were two important variables dependently associated with differences in JLCAs postoperatively. However, postoperative JLCAs showed a stronger correlation to preoperative JLCAs than to changes in mechanical alignment postoperatively. A Chi-square analysis showed a significantly higher percentage of patients achieved acceptable postoperative JLCAs in the preoperative JLCA $\leq 6°$ group (78.8%) compared to the preoperative JLCA $> 6°$ group (6.1%). Therefore, 6° of JLCA was suggested to be a tipping point.

Conclusions The capability of HTO to correct intra-articular varus deformities, which was represented by JLCAs, is limited. Postoperative residual JLCAs were correlated primarily to preoperative JLCA values and total alignment correction, while the former accounted for most. A preoperative JLCA of 6° was suggested to be a tipping point, and a larger value indicated more than 5° residual JLCA after the HTO.

Keywords Knee osteoarthritis · Varus deformity · High tibial osteotomy · Intra-articular varus deformity · Extra-articular varus deformity · Joint line convergence angle

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Introduction

The medial opening wedge high tibial osteotomy (HTO) was an effective treatment to correct the malalignment of the lower extremity, thus to lateralize the body weight from the degenerated medial joint compartment to the lateral plateau [1]. Transferring the mechanical axis from the degenerated medial joint compartment to the lateral compartment through HTO could be an effective treatment resulting in medial decompression, thereby reducing pain and delaying the progression of osteoarthritis, despite the widespread use of joint replacements [2–4].

Knee osteoarthritis was a progressive degenerative disease characterized by a gradual loss of articular cartilage around the knee [5]. Bone marrow edema (BME), osteophytes, subchondral cysts and meniscal tears could also be associated with osteoarthritis. However, the varus deformity of knee osteoarthritis was formed by both extra-articular and intra-articular pathologies. The extra-articular pathology was usually of bony reason and presents as a varus deformity in tibial metaphysis. The intra-articular deformity, represented by the joint space narrowing and the resultant increase in the joint line convergence angle (JLCA) [6, 7], was believed to be derived from the lateral soft tissue laxity, as well as the compromise of the medial meniscus and osteocartilaginous complex. Undoubtedly, HTO could correct the varus deformity adequately lying in the tibial metaphysis. However, there was medial joint space narrowing in addition to the bone deformity in the knees with varus osteoarthritis, which would increase the JLCA and indicated an "intra-articular varus deformity". Therefore, the lateral joint could not come into contact after the HTO [8], and the reallocation of stress distribution, which was the purpose of the mechanical axis shifting by HTO, could not be achieved (Fig. 1). Even though HTO was deemed to be able to correct the intra-articular varus to a limited extent, there was not any evidence to be found in the current literature concerning the relationship between the postoperative residual intra-articular varus and the pre- or intra-operative factors.

We hypothesized that HTO could not correct intra-articular varus deformities ideally only by transferring the mechanical axis. There would be a kind of relationship between the postoperative residual intra-articular varus and the pre- or intra-operative factors. Therefore, the purpose of this study was to investigate whether any residual varus was left inside the joint after HTO in patients with knee osteoarthritis, and a correlation of the residual varus could be traced. Second, a tipping point was suggested to assess to what extent the intra-articular varus could be corrected by HTO.

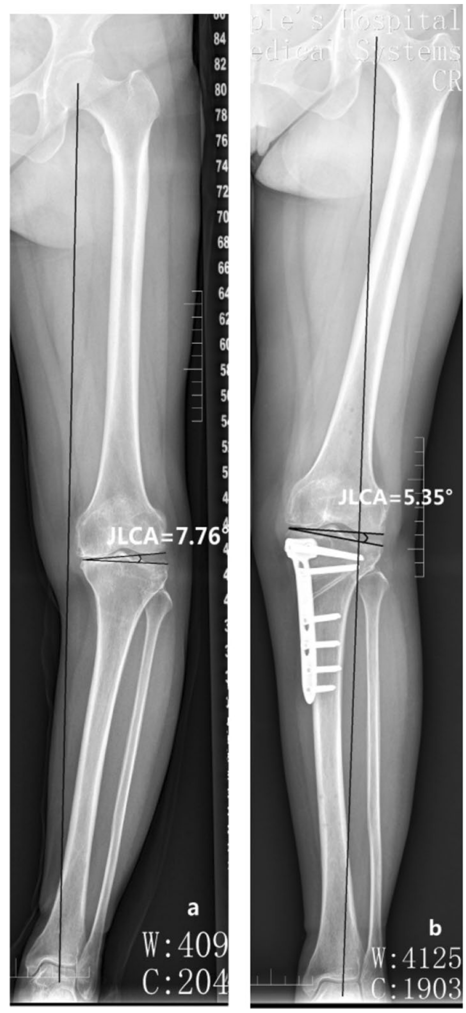

Fig. 1 Advanced cases of varus osteoarthritis of the knee with a large JLCA (**a**). Even when the mechanical axis has been moved to the lateral side by HTO, the intra-articular varus could still not be restored (**b**)

Materials and methods

Study patients

The enrolled patients with medial knee osteoarthritis underwent medial opening wedge HTO from 2015 to 2017. Patients considered ineligible for this research included those aged < 50 years, rheumatoid arthritis, posttraumatic arthritis, severe varus of femoral deformity, a knee range of movement < 100° and a flexion contracture > 10°. In addition, patients were excluded if they experienced complications, such as bone graft collapse, broken screws, or malunion or non-union after surgery, as such conditions could adversely affect limb alignment. After assessing eligibility, 66 patients were enrolled (Table 1). In our study,

Table 1 Preoperative patient characteristics

Parameter	Median (range)
Male/female	29/37
Age (years)	63.2 (51–82)
Height (cm)	167.1 (152.3-176.3)
Weight (kg)	61.1 (46.8–83.1)
Body mass index (kg/m^2)	27.9 (21.2–43.4)

MRI grading system of the osteoarthritis of the knee joint was used [5]. The severity of osteoarthritis was divided into five grades (Table 2). We performed standard HTO in 66 patients, of which 18 knees were Grade 2, 35 knees were Grade 3, and 13 knees were Grade 4. This study was approved by our Institutional Ethics Review Board, and the requirement for informed consent was waived because of its retrospective nature.

Surgical procedure

Anatomical landmarks were drawn, and a skin incision was made from the insertion of the pes anserinus ascending 6–8 cm posterocranially. Carefully releasing the superficial fibers of the medial collateral ligament and exposing the entire medial border of the patellar ligament, the level and direction of the osteotomy were marked with two 2.3-mm guide wires aimed at the upper third of the proximal tibiofibular joint; the wire end exactly at the lateral cortex. Length was measured using the wires and osteotomy depth was marked on the saw blade. Next, a horizontal osteotomy was performed in the posterior 2/3 of the tibia beneath the guide wires, leaving a lateral bone bridge of 10 mm as a hinge. We open the osteotomy with broad flat chisels. Clinical and radiographical evaluation of the leg axis in extension should be performed. The postoperative mechanical axis lay on 60–65% laterally. The plate fixator and locking of proximal screws were later inserted (TomofixSynthes, Bettlach, Switzerland). For an osteotomy gap of 13 mm or more, the gap was filled with autogenous cancellous bone graft. Radiological documentation in both planes and wound closure was performed [9].

Radiographic measurements

For radiological evaluations, an anteroposterior plain radiograph of the full-length leg in a standing position was performed. Radiographs were obtained preoperatively and 6 months after surgery. Patients were instructed to stand straight with both knees fully extended and evenly distribute their body weight between both limbs. The patellas were aligned with the direction of the X-ray beam. The X-ray beam was centered at the distal pole of the patella, aligning the image parallel to the tibial joint line in the frontal plane. Radiographic evaluation was performed in the picture archiving and communication system (PACS, Kingstar Winning Software Co.Ltd, China).

The radiographic assessment was performed by one assessor according to the validated methods [10]. The percentage of mechanical axis (%MA), femorotibial angle (mFTA), mechanical lateral distal femoral angle (mLDFA), and mechanical medial proximal tibial angle (mMPTA) were measured to evaluate leg alignment (Fig. 2) [11]. The joint line convergence angle (JLCA) was measured to evaluate joint congruity, cartilage loss and soft tissue laxity on the coronal plane [12]. JLCA was measured as the angle between the line connecting the distal femur and the proximal tibial articular surfaces on anteroposterior radiographs of standing patients (Fig. 1). A positive JLCA value meant an intra-articular varus deformity due to narrowing of the medial joint space and lateral joint distraction [13, 14].

Statistical analysis

All analyses were conducted using SPSS version 24 (SPSS Inc., Armonk, NY). A P value < 0.05 was considered to be statistically significant. All data were presented as the mean and standard deviation. A one-way analysis of variance (ANOVA) was used to compare postoperative JLCA and variations of JLCAs among the groups of preoperative

Table 2 Proposed MRI grading system of the osteoarthritis of the knee joint

Grade of osteoarthritis	Description
0	No cartilage injury with no or minimal osteophyte (< 5 mm)
1	Cartilage injury grade I and at least one of the following: osteophyte > 5 mm, BME > 10 mm, subchondral cyst > 10 mm
2	Cartilage injury grade II and at least one of the following: osteophyte > 5 mm, BME > 10 mm, subchondral cyst > 10 mm
3	Cartilage injury grade III and at least one of the following: osteophyte > 5 mm, BME > 10 mm, subchondral cyst > 10 mm
4	Cartilage injury grade III and meniscal injury grade III

Cartilage grade: Noyes classification. Meniscal injury grade: Stoller et al. grade

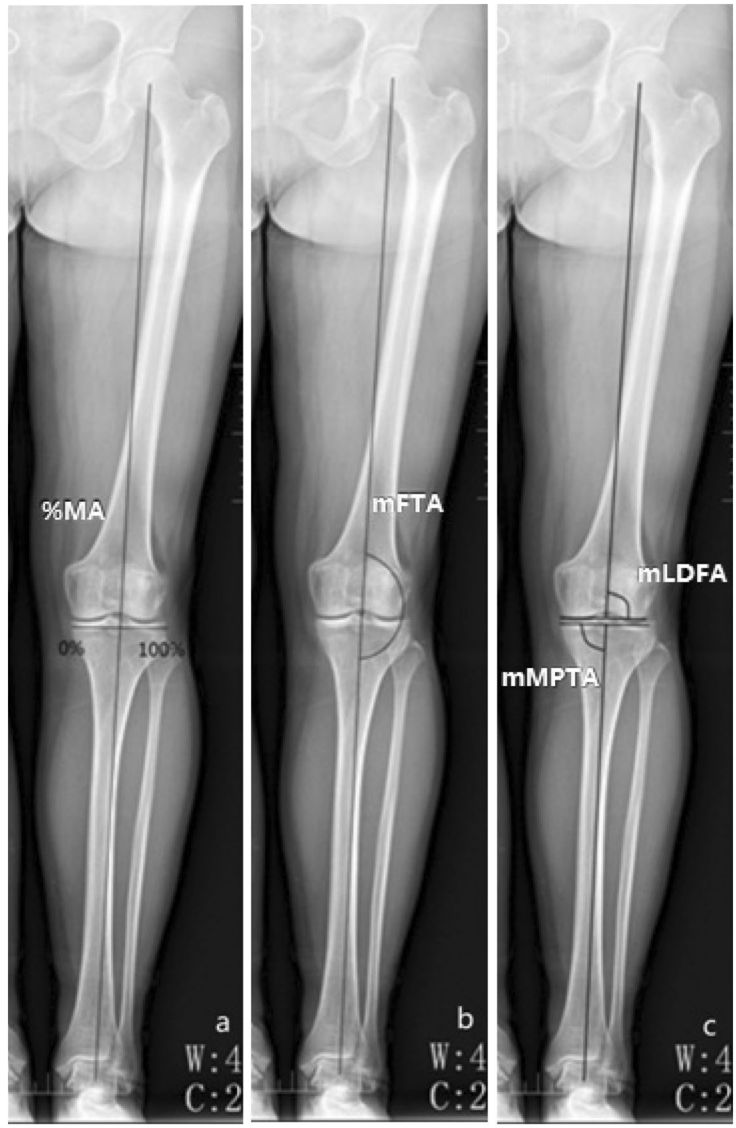

Fig. 2 Percentage of mechanical axis (%MA), mechanical femorotibial angle (mFTA), mechanical lateral distal femoral angle (mLDFA), and mechanical medial proximal tibial angle (mMPTA) were measured to evaluate leg alignment

JLCA ≤ 2° (Group 1), 2° < preoperative JLCA ≤ 4° (Group 2), 4° < preoperative JLCA ≤ 6° (Group 3) and preoperative JLCA > 6° (Group 4), with statistically significant differences being assessed using post hoc Tukey tests to determine which two of the four groups differed significantly. Multiple linear regression analysis was performed to identify which of the factors (preoperative JLCA or changes in mechanical alignment) contributed more to the postoperative JLCA and the difference in JLCA postoperatively. The number of patients corrected, to optimal (postoperative JLCA ≤ 2°), acceptable (2° < postoperative JLCA ≤ 5°) and unacceptable (postoperative JLCA > 5°) JLCA was assessed, respectively, to calculate the tipping point of JLCA. The tipping point of JLCA was tested by means of a Chi-square test.

Results

Patient demographics were summarized in Table 1. A total of 66 patients with varus osteoarthritis of the knee were included with a mean age of 63.2 years (range 51–82), mean height of 167.1 cm (range 152.3–176.3), mean weight of 61.1 kg (46.8–83.1), mean body mass index of 27.9 kg/m^2 (range 21.2–43.4), of which 29 patients (43.9%) were male.

Average %MA improved from 5.5% before the procedure to 60% after the procedure, and mFTA improved from 190.2° to 176.4°, meaning that mechanical alignments of the lower extremities were corrected. There was no change in mLDFA, whereas mMPTA changed from 80.3° to 91.8° after the procedure, meaning that the tibia was corrected to

Table 3 Preoperative and postoperative angle measurement

	Preoperative	Postoperative 6 months	Variation	*P*
%MA	5.5 ± 15.6	60.0 ± 12.7	54.8 ± 15.8	< 0.01
Mfta (°)	190.2 ± 4.0	176.4 ± 3.1	12.8 ± 3.7	< 0.01
mLDFA (°)	87.3 ± 3.0	87.2 ± 3.0	− 0.1 ± 1.9	ns
mMPTA (°)	80.3 ± 4.4	91.8 ± 3.9	11.6 ± 3.3	< 0.01
JLCA (°)	4.2 ± 1.9	2.7 ± 1.7	1.6 ± 0.5	< 0.01

%MA percentage of mechanical axis, *mFTA* mechanical femorotibial angle, *mLDFA* mechanical lateral distal femoral angle, *mMPTA* mechanical medial proximal tibial angle, *JLCA* joint line convergence angle

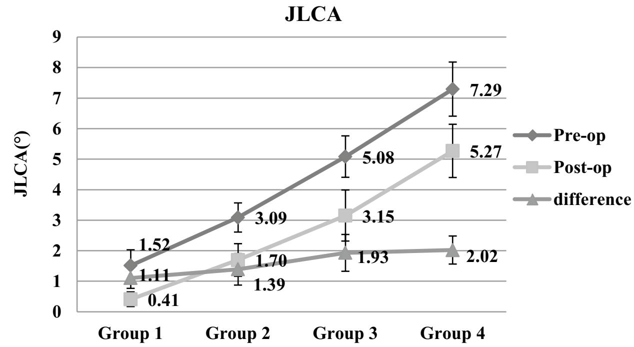

Fig. 3 Preoperative, postoperative JLCA and differences in JLCAs among four groups. Group 1: preoperative JLCA ≤ 2°. Group 2: 2 < preoperative JLCA ≤ 4°, Group 3: 4° < preoperative JLCA ≤ 6° Group 4: preoperative JLCA > 6°

the valgus. JLCA changed from 4.2° to 2.7° after the procedure, meaning the intra-articular varus correction was obtained partly but not satisfactorily (Table 3).

Multiple linear regression analysis was also performed to demonstrate that the preoperative JLCA and the correction of alignment (change in %MA, mFTA and mMPTA) postoperatively were two important variables dependently associated with differences in JLCA postoperatively. However, the preoperative JLCA had many more definite effects on the postoperative JLCA than the correction of alignment (change in %MA, mFTA and mMPTA) postoperatively (Table 4).

Figure 3 shows the average value of preoperative JLCA, postoperative JLCA and differences in JLCA postoperatively in each group. Postoperative JLCA and the differences in JLCA differed significantly between the four groups. ANOVA analyses showed that postoperative JLCA differed significantly among the four groups. Only group 2 (2° < preoperative JLCA ≤ 4°) and group 3 (4° < preoperative JLCA ≤ 6°) differed significantly regarding differences between preoperative and postoperative JLCAs (Table 5).

Reviewing all 66 patients, 40.9% of patients achieved an optimal postoperative JLCA (JLCA ≤ 2°), 43.9% had an acceptable postoperative JLCA (2° < JLCA ≤ 5°), and 15.1% of patients had an unacceptable postoperative JLCA (JLCA > 5°) (Table 6). Due to a higher proportion of patients with an unacceptable postoperative JLCA and a large average value of postoperative JLCA (JLCA = 5.27°, Fig. 3) in Group 4, 6° was suggested as a tipping point of preoperative JLCA, predicting the probability of achieving an acceptable postoperative JLCA.

In the Chi-square analysis, a significantly higher percentage of patients achieved optimal and acceptable postoperative JLCA in the preoperative JLCA ≤ 6° group (78.8%) compared to the preoperative JLCA > 6° group (6.1%). In other words, there was a significantly higher percentage of patients who achieved unacceptable postoperative JLCA in the preoperative JLCA > 6° Group (12.1%). The odds of achieving postoperative JLCA ≤ 5° was 52.0, which indicated that it was much more difficult to achieve an acceptable

Table 4 Multiple linear regression analysis of preoperative JLCA and correction of alignments affecting postoperative JLCA and differences in JLCA

Dependent variable	Explicative variable	Standardized coefficients (β)	*P*	R^2
Preoperative JLCA	Difference in JLCA	0.478	< 0.01	0.590
Difference in %MA		0.490	< 0.01	
Preoperative JLCA	Postoperative JLCA	1.008	< 0.01	0.941
Difference in %MA		− 0.186	< 0.01	
Preoperative JLCA	Difference in JLCA	0.450	< 0.01	0.710
Difference in mFTA		0.604	< 0.01	
Preoperative JLCA	Postoperative JLCA	1.019	< 0.01	0.958
Difference in mFTA		− 0.221	< 0.01	
Preoperative JLCA	Difference in JLCA	0.447	< 0.01	0.560
Difference in mMPTA		0.565	< 0.01	
Preoperative JLCA	Postoperative JLCA	0.975	< 0.01	0.958
Difference in mMPTA		− 0.169	< 0.01	

Table 5 Post hoc multiple comparison test comparing postoperative JLCA and variation in JLCA among the four groups

Measured view	Comparison	Mean difference	SE	95% CI		*P*
				Lower	Upper	
Postoperative	Group 1–2	1.29	0.30	0.70	1.89	< 0.01
	Group 2–3	1.50	0.22	1.06	1.93	< 0.01
	Group 3–4	1.98	0.26	1.46	2.50	< 0.01
Difference	Group 1–2	0.25	0.18	− 0.11	0.60	ns
	Group 2–3	0.44	0.13	0.18	0.70	< 0.01
	Group 3–4	0.14	0.16	− 0.17	0.45	ns

Group 1: preoperative JLCA ≤ 2°, Group 2: 2° < preoperative JLCA ≤ 4°, Group 3: 4° < preoperative JLCA ≤ 6°, Group 4: preoperative JLCA > 6°

Table 6 Preoperative and postoperative JLCA in different groups

	Postoperative JLCA		
	Optimal	Acceptable	Unacceptable
Group 1	8 (12.1%)	–	–
Group 2	16 (24.2%)	7 (10.6%)	–
Group 3	3 (4.5%)	18 (27.0%)	2 (3.0%)
Group 4	–	4 (6.1%)	8 (12.1%)

Optimal: postoperative JLCA ≤ 2°, acceptable: 2° < postoperative JLCA ≤ 5°, unacceptable: postoperative JLCA > 5°

Group 1: preoperative JLCA ≤ 2°, Group 2: 2° < preoperative JLCA ≤ 4°, Group 3: 4° < preoperative JLCA ≤ 6°, Group 4: preoperative JLCA > 6°

Table 7 Predicted probability of achieving an acceptable postoperative JLCA based on preoperative JLCA

	Postoperative JLCA		Chi square	Odds ratio
	≤ 5°	> 5°		
Preoperative JLCA ≤ 6°	52 (78.8%)	2 (3.0%)	< 0.01	52.0
Preoperative JLCA > 6°	4 (6.1%)	8 (12.1%)		

postoperative JLCA when the preoperative JLCA was > 6° (Table 7).

Discussion

The main findings of this study were that JLCA changed from 4.2° to 2.7° postoperatively, which indicated that there was an exact residual varus was left inside the joint after HTO. Postoperative JLCAs showed a stronger correlation to preoperative JLCAs than to changes in mechanical alignment postoperatively. Second, 6° of preoperative JLCA was suggested to be a tipping point in the study. A significantly higher percentage of patients achieved optimal or acceptable postoperative JLCAs in the preoperative JLCA ≤ 6° group (78.8%) compared to the preoperative JLCA > 6° group (6.1%).

Varus deformity of the lower extremity in knee osteoarthritis was the sum of two potential components: (1) the femorotibial geometric alignment, and (2) narrowing of the medial joint space and the separation of the lateral joint space. We defined the former varus deformity as extra-articular varus, including lateral bowing of the femur (increased mLDFA) and varus deformity of the proximal tibia (decreased mMPTA). Correspondingly, the latter varus deformity could be defined as intra-articular varus due to wear and tear of the meniscus and the osteocartilaginous complex or lax lateral soft tissues and ligaments. To the best of our knowledge, the most common pathology was cartilage loss from the medial knee compartments in the patients with varus osteoarthritis. This finding should not be mistaken for lateral ligament laxity [15].

With the advances of osteoarthritis stages, varus occurs in the knee joint with a considerably larger JLCA and a considerably more widened lateral joint than that of the varus resulting from metaphyseal deformity [8]. In our study, the average of the preoperative JLCAs of the 66 patients amounted to 4.2°, including 12 patients (18.2%) with JLCA > 6°. The purpose of valgization osteotomy of the proximal tibia was treatment of medial unicompartmental osteoarthritis with varus deformities by shifting the mechanical weight-bearing axis (Mikulicz line) laterally to relieve the medial compartment [16, 17]. Therefore, JLCA was theoretically likely to be restored to a parallel (postoperative JLCA ≤ 2°) or an acceptable (2° < postoperative JLCA ≤ 5°) position due to valgus alignment following HTO [13, 15]. However, the results of the present study were not consistent with our expectations, showing that the mean JLCA decreased from 4.2° preoperatively to 2.7° postoperatively. Especially, in the patients mentioned above with a large preoperative JLCA (> 6°), the mean postoperative JLCA even achieved a mean of 5.2° (Fig. 3).

Although an appropriate valgus position of alignment of the lower limbs could be beneficial to restoration of

JLCA, it was generally accepted that the postoperative axis of the leg should cross through 62% of the width of the tibial plateau or achieving mFTA valgus positioning of 3° [18]. Therefore, the capacity of the restoration of JLCA by shifting the alignment should be limited. Furthermore, our results in Table 5 identified that the preoperative JLCA and the correction of alignment expressed as changes in %MA, mFTA and mMPTA postoperatively were two nearly equally important variables dependently associated with differences in JLCA postoperatively. However, the preoperative JLCA played considerably more important roles in the postoperative JLCA than the correction of alignment postoperatively. All in all, postoperative residual JLCA primarily correlated to preoperative JLCA value and total alignment correction, while the former accounted for most.

In regard to varus osteoarthritis of the knee usually with a large JLCA, standard HTO only manipulating the proximal tibia to the valgus position could not achieve a satisfied change in JLCA. Therefore, we observed that correcting alignment of the extra-articular varus deformity by medial opening wedge HTO would work better than correcting an intra-articular varus manifested as an increased JLCA. Chiba, Yonekura and Miyamoto [8] described the concept of tibial condylar valgus osteotomy (TCVO). These researchers believed that TCVO could alter JLCA in addition to mMPTA, making it suitable for cases with a large JLCA and widened lateral joint. However, these researchers also acknowledged that the disadvantage of TCVO was the limited angle of valgus correction. Other authors also suggested unicompartmental knee arthroplasty (UKA) to be an effective treatment for isolated medial compartment knee osteoarthritis [19, 20]. However, most patients with a preoperative mechanical axis angle (MAA) of > 10°of varus could not be corrected to neutral, indicating that patients with large preoperative varus deformities might be at risk of undercorrection [21]. A consequence of excessive residual varus alignment increased compartment forces by overloading medially, which could ultimately lead to UKA failure from polyethylene wear or aseptic loosening [22, 23]. Therefore, it could be argued that medial UKA might be the ideal treatment option for patients with medial knee osteoarthritis.

The purpose of this study was also to determine to what extent patients with a large preoperative JLCA could be correctable to optimal or acceptable postoperative JLCA and evaluate the feasibility of achieving an optimal or acceptable postoperative JLCA based on the preoperative JLCA in varus osteoarthritis knees. In accordance with our observations in Fig. 3 and Tables 6, 7, we recommend a preoperative JLCA of 6° as a tipping point. In regard to the patients with a preoperative JLCA below the tipping point, a standard HTO could be recommended because an optimal or acceptable JLCA could be obtained by shifting the mechanical weight-bearing axis (Mikulicz line) laterally. In contrast, we recommend an intra-articular osteotomy, such as TCVO mentioned above, to the patients with a preoperative JLCA above 6° to achieve a significant restoration of JLCA.

The primary limitation of this study was that HTO for varus joint aimed for correction in the frontal plane (varus/valgus), whereas the sagittal plane (flexion/extension) remained unconsidered [24]. In addition, dynamic soft tissue laxity was not assessed on varus/valgus stress radiographs. However, the reliability and accuracy of stress radiography were not very high, due to technical limitations or poor cooperation by patients [25]. Furthermore, as mentioned above, MRI grading system of the osteoarthritis of the knee joint was used for each patient in our study. Cartilage lesions, meniscal tears and laxity of collateral ligament could also be assessed by use of MRI visually and easily. Future studies might be directed towards incorporating stress view data into evaluation of JLCAs after medial open-wedge HTO. A further limitation was the sample distribution with Group 1 (preoperative JLCA ≤ 2°), which was represented by few patients. However, the patients with a varus osteoarthritis knee usually had a large JLCA due to severe lax lateral soft tissues or wear of the medial meniscus and the osteocartilaginous complex of the knee joints.

Conclusions

We found that the capability of HTO to correct the intra-articular varus deformity, which was represented by JLCA, is limited. Postoperative residual JLCAs correlated primarily to preoperative JLCA values and total alignment correction, while the former accounted for most. A preoperative JLCA of 6° was suggested to be a tipping point, and a larger value indicated more than 5° residual JLCA after the HTO.

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Compliance with ethical standards

Conflict of interest Project supported by the National natural Science Foundation of China (Grant no. 81572118).

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