—**Original**—

Relationship between Severity of Varus Osteoarthritis of the Knee and Contracture of Medial Structures

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Background: Knees with severe varus osteoarthritis can develop medial structure contracture. However, there is no report on the relationship between severity of varus deformity and contracture of the medial structure. We aimed to determine the threshold angle that could be corrected in proportion to the width of medial osteophyte removal and to examine correction differences between angles larger and smaller than the threshold angle in total knee arthroplasty.

Methods: This study included 27 varus osteoarthritic knees scheduled for total knee arthroplasty (TKA). A navigation system was used to measure hip-knee-ankle angle (HKA) in all knees at maximum extension and 30° and 60° flexion, before and after osteophyte removal and with and without external 10 N-m valgus torque loads. Subsequently, resected osteophyte widths were measured. Mean correction angle per 1 mm of osteophyte removal was calculated, and the threshold angle was calculated with the receiver operating characteristic curve. HKA differences were compared against deformities larger and smaller than the threshold angle.

Results: Mean osteophyte width was 7.1±2.20 mm. Osteophyte removal produced a mean 3.1° correction, which equaled a 0.4° correction per 1 mm of osteophyte width removal. The varus deformity threshold angle was 9.5°. However, when comparing groups with angles larger and smaller than the threshold angle, there was no significant difference in HKA difference between each step and flexion angle.

Conclusions: The threshold angle for expected correction with medial osteophyte removal was 9.5°. However, because there were no differences in correction between those with angles larger or smaller than this, medial structure contracture seemed to be unrelated to the severity of deformity.

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Key words: total knee arthroplasty, osteophyte, correction of varus deformity, receiver operating characteristic curve (ROC), threshold angle

Introduction

When performing total knee arthroplasty (TKA) for varus osteoarthritic knee, the deformity is corrected by releasing the deep medial collateral ligament (dMCL) and then removing the osteophyte[1,2]. Clinically mild varus deformity can be satisfactorily corrected by medial osteophyte removal alone. In contrast, correction was reported to be difficult when osteophyte removal alone was used to treat severe varus deformity[3].

To preserve valgus and rotatory stability, medial knee structures such as the dMCL and posterior oblique ligament should be retained without release[4]. A 0.4° correction can be achieved per 1 mm of osteophyte removal without medial release[5]. However, this 0.4° correction is a mean value based on reported cases of osteoarthritis of varying severity. In severe varus deformity, some studies reported the possibility of contracture in medial structures[6,7], whereas others reported no such contracture[8,9].

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Thus, the relationship between contracture of medial structures and severity of varus osteoarthritis of the knee requires clarification.

We hypothesized that severe varus deformity is associated with contracture of the medial structures and that there is a critical threshold varus angle between the expected and actual correction with osteophyte removal. Therefore, the present study aimed to identify the threshold varus angle at which medial osteophyte removal produces the expected limb correction and to examine the difference in the amount of correction between angles that were larger and smaller than the threshold angle.

Materials and Methods

Among 93 patients who underwent primary TKA performed by the same surgeon in the period from January 2015 to October 2018, 27 medial osteoarthritic knees of 22 patients were included after excluding simultaneous bilateral TKA, surgeries combining augmentation (including planned), and patients with comorbidities (e.g., diabetes, kidney disease, and heart disease).

The surgical and experimental methods were the same as in a previous report[5]. In all surgeries, the knee joint was exposed by using a medial parapatellar approach, and a navigation system (KNEE3 2.6.0, BrainLab, Munich, Germany) was set and registered. Without any soft tissue release or meniscus removal, the first measurement was performed before removing the osteophytes at maximum extension and 30° and 60° flexion, without loading (Step 1), and with 10.0-N-m valgus loads using a Ligament Tensioner (Meira Corp., Japan) (Step 2). All surgeries, loading, and measurements were performed by a single surgeon. Two parameters were recorded with the navigation system: maximum extension angle and the angle created by the thigh axis and lower leg axis on the navigation system (i.e., the hip-knee-ankle angle [HKA]). Next, osteophytes on the femoral and tibial sides were removed to the extent possible while protecting the dMCL, and a 10.0-N-m valgus load was applied at the same measurement angle (Step 3) to record the parameters. Maximum osteophyte widths on the femoral and tibial sides were measured with a vernier caliper.

The expected correction angle was defined as the calculated mean correction angle per 1 mm of osteophyte removal multiplied by the width of the removed osteophyte. To calculate the preoperative varus threshold angle for which the expected correction angle could be achieved, knees were classified according to whether their actual correction angles were larger or smaller than the expected correction. After the threshold angle was calculated, knees were classified as those with lesser (Group A) and greater deformity (Group B) than the threshold angle. Then, the variables below were compared between the 2 groups.

Osteophyte width, maximum angle of extension before and after osteophyte removal, and HKA at each step were extracted from the database. Then, using these data, HKA difference before and after osteophyte removal (corrected angle) and the amount of correction achieved per removal of 1 mm of osteophyte were calculated as the mean corrected angle/mean osteophyte width.

This study was approved by the institutional review board of Nippon Medical School (R1-05-1122). Informed consent was obtained from all participants.

Statistical Analysis

The receiver operating characteristic (ROC) curve was used to calculate the threshold angle, and the paired t-test and chi-square for independence test were used to compare various measured parameters. The Pearson's correlation coefficient test was used to examine correlations. All statistical analyses were performed with JMP 10.0.2 (SAS Institute Inc, Cary, NC, USA), and statistical significance was set at $P < 0.05$. Assuming an area under the ROC curve (AUC) of 0.8, a statistical power of 0.8, and a significance level of 0.05, the required sample size was 20.

Results

The mean age of patients was 76.4±5.9 years (range: 64-87 years). There were 3 knees from 3 men and 24 knees from 19 women (13 right knees and 14 left knees). The mean preoperative lateral femorotibial angle (FTA) was 188.7° ± 6.7, the HKA (where negative angles represent varus deformity) was −12.1° ± 5.7, and there were 6 Kellgren-Lawrence (K-L) scale Grade 2 knees, 12 Grade 3 knees, and 9 Grade 4 knees (**Table 1**).

Correction Angles and Threshold Angle

The mean osteophyte widths on the femoral and tibial sides were 7.0 ± 2.1 (3.0-11.0) mm and 5.2 ± 2.2 (2.1-10.0) mm, respectively. Tibial osteophyte width was greater than femoral osteophyte width in 4 knees. Maximum femoral or tibial osteophyte width was 7.1 ± 2.2 (3.0-11.0) mm. Maximum extension angles were −10.7° ± 7.4 (1.0 to −23.0) in Step 1, −10.5° ± 8.0 (4.5 to −24.0) in Step 2, and −8.9° ± 8.2 (5.5 to −24.7) in Step 3. There were no significant differences in maximum extension angle, regardless of load or osteophyte removal. The mean HKA difference at maximum extension angles was 3.0°±1.6

Table 1 Demographic data of study patients

Age, y, mean ± SD (range)	76.4±5.87 (64-87)
Gender (male/female)	3 (3 knees)/19 (24 knees)
Side (right/left)	13/14
Preoperative FTA, degrees, mean ± SD (range)	186.5±5.97 (180.1-203.4)
Preoperative HKA angle, degrees, mean ± SD (range)	–12.1±5.70 (–5.3- –25.7)
K-L scale (knees)	Grade 2:6
	Grade 3:12
	Grade 4:9

FTA: lateral femorotibial angle, HKA: hip-knee-ankle, K-L; Kellgren-Lawrence

Table 2 HKA in each knee flexion angle and each step in all cases (degrees, mean ± SD [range]), and differences between each step (degrees, mean ± SD)

Flexion angles	Step 1	Step 2	Step 3	Differences	
				Steps 1 to 2	Steps 2 to 3
Maximum extension	–9.0±5.75 (–22.0- –0.5)	–6.0±5.46 (–20.0-3.0)*	–3.3±5.02 (–15.2-5.8)*	3.0±1.63	2.7±2.93
30°	–7.2±5.50 (–20.0-1.0)	–4.0±4.93 (–15.8-3.8)*	–0.9±3.97 (–7.5-5.7)*	3.2±1.64	3.1±2.77
60°	–6.8±5.62 (–19.5-3.0)	–3.7±5.23 (–14.0~5.5)*	–0.8±5.03 (–10.8-7.2)*	3.2±1.52	2.8±3.14

*significant difference vs previous step at same angle

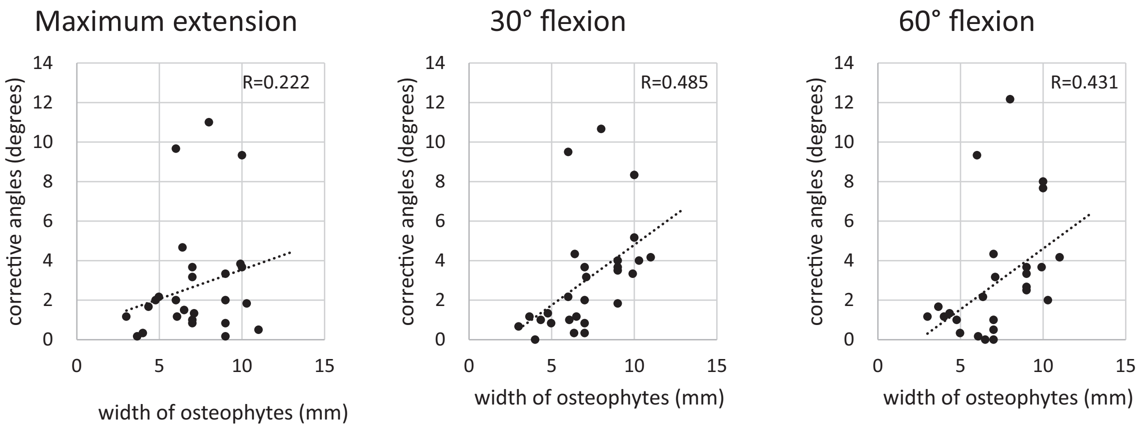

Fig. 1 Correlations between corrective angle and osteophyte width.

with a valgus load only (Steps 1 to 2), and 2.7 °± 2.9 correction was obtained by osteophyte removal (Steps 2 to 3). At 30 ° flexion, the mean HKA differences in Steps 1 to 2 and Steps 2 to 3 were 3.2 ° ± 1.6 and 3.1 ° ± 2.8, respectively (**Table 2**). The correlation was strongest between osteophyte width and corrected angle by osteophyte removal at 30 ° of flexion (r = 0.485) (**Fig. 1**). A mean 3.1 ° correction was obtained by osteophyte removal at 30 ° flexion, where the strongest correlation was found and from which a 0.4 ° correction was achieved per 1 mm of osteophyte width removal. The threshold angle for HKA using ROC analysis was –9.5 ° at both 30° flexion (AUC 0.57; sensitivity 60.0%; specificity 58.8%) and 60 ° flexion (AUC 0.71; sensitivity 71.4%; specificity 76.9%) (**Fig. 2**).

Comparison between the 2 Groups

The demographic data of the 2 groups are shown in **Table 3**. There were significant differences between the groups in FTA, HKA, and K-L scale. There were no significant differences between the groups in mean femoral and tibial osteophyte widths (**Table 4**). The maximum osteophyte widths on the femoral or tibial sides of Groups A and B were 6.4 ± 2.34 mm and 7.8 ± 1.9 mm, respectively. There were no significant differences in maximum extension, except at Step 2 (**Table 5**). The mean difference in HKA after osteophyte removal with a valgus load (Steps 2 to 3) in maximum extension and 30 ° and 60 ° flexion was 2.3 ° ± 2.6, 2.6 ° ± 2.6, and 3.1 ° ± 2.8 for

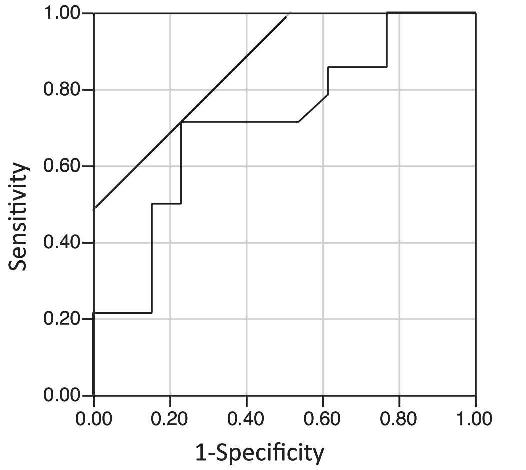

Fig. 2 A ROC curve for HKA in relation to corrective angle, which determined a threshold HKA value of –9.5° at 60° flexion (sensitivity 71.4%; specificity 76.9%).
ROC: receiver operating characteristic, HKA: hip-knee-ankle angle

Group A and 3.1° ± 3.3, 3.5° ± 2.9, and 2.6° ± 3.5 for Group B. There were no significant differences between Groups A and B in any HKA difference between steps at the same angle (**Table 6**). A 0.4° correction was achieved per 1 mm of osteophyte removal at 30° of flexion in both Groups A and B.

Discussion

The most important finding of the present study was that the threshold of varus angle at which medial osteophyte removal produced an expected limb correction was 9.5° of varus deformity. Several studies have classified a varus deformity of less than 10° as mild[9,10]; however, no study provided concrete evidence to support this threshold. The mean HKA of patients with less than 9.5° varus deformity (Group A) was 7.3°, and a mean 5.6° correction was possible with a valgus load and osteophyte removal only. Bellmans et al.[11] reported a varus knee of 3° or more in 32% of healthy men and 17% of healthy women, and Shetty et al.[12] reported that the rates were 40% and 28% for Asian men and women, respectively. These findings suggest that, at least for varus knees

Table 3 Demographic data of each group

	Group A n=13	Group B n=14
Age, y, mean ± SD (range)	76.0±6.92 (64-87)	76.9±4.94 (70-85)
Gender (male/female)	3 (3 knees)/8 (10 knees)	0/11 (14knees)
Side (right/left)	8/5	5/9
Preoperative FTA, degrees, mean ± SD (range)*	182.0±1.91 (180.1-185.3)	190.7±5.36 (186.0-203.4)
Preoperative HKA angle, degrees, mean ± SD (range)*	–7.3±1.35 (–5.3- –9.5)	–16.6±4.34 (–11- –25.7)
K-L scale (knees)*	Grade 2:6	Grade 2:0
	Grade 3:5	Grade 3:7
	Grade 4:2	Grade 4:7

FTA: lateral femorotibial angle, HKA: hip-knee-ankle, K-L; Kellgren-Lawrence
*significant difference between Groups A and B

Table 4 Widths of resected osteophytes of each group (mm, mean ± SD [range])

Group	Femoral side	Tibial side	Larger side (femoral or tibia)
A	6.2±2.25 (3.0-9.0)	5.0±2.40 (2.1-10.0)	6.4±2.34 (3.0-10.0)
B	7.7±1.77 (5.0-11.0)	5.3±2.10 (2.4-10.0)	7.8±1.88 (5.0-11.0)

No significant differences between Groups A and B.

Table 5 Maximum extension angles of each group (degrees, mean ± SD [range])

Group	Step 1	Step 2*	Step 3
A	–12.8±7.06 (–1.0- –23.0)	–14.0±7.34 (–2.0- –24.0)	–11.7±8.12 (–3.0- –24.7)
B	–8.7±7.45 (1.0- –22.5)	–7.3±7.44 (4.5- –22.7)	–6.3±7.63 (5.5- –21.7)

*significant difference between Groups A and B smaller than 9.5˚, osteophyte removal without medial release suffices for correcting varus angles.

Cases of severe deformity often involve contracture of both the MCL itself and the articular capsule. In those reports, contracture of the medial structures occurred at varus angles larger than 10˚ to 15˚ [6,7]. The threshold angle obtained in the present study was 9.5˚, which was very close to the 10˚ borderline value that has been used to provide the threshold between mild and moderate, or for severe, varus deformity[8,10].

Okamoto et al.[8] and Ushio et al.[9] reported that even severe varus osteoarthritis does not involve actual medial soft tissue shortening and attributed any shortening to the mere appearance of contracture due to compression of the MCL by structures such as osteophytes. In the present study, only medial and posterior osteophytes were removed, to the extent possible, and measured without release of the deep and superficial MCL, and without additional surgical intervention involving other femorotibial joint parts. This suggests that only the effects of osteophytes removal were measured. As the correction angle expected by removing osteophytes alone was not influenced by the severity of the deformity, we assumed that contracture of the medial structure was absent even in cases where varus deformity was severe.

This study has several limitations. First, because the actual AUC was lower than the assumed AUC, statistical power decreased to 0.62. Thus, more samples were needed to increase the power. The similarity in correction angle for angles larger and smaller than the threshold angle might be attributable to the lower statistical power. Second, the medial to posteromedial osteophytes on tibia were thoroughly removed, but posterior osteophyte removal was not complete in some cases, which may have affected the data. However, medial osteophytes directly under the d/sMCL have the greatest effect on varus and valgus deformity near the extended position, and the effects on the measured angles were minimal. Third, only the relationship between osteophyte width and correction angle was calculated. The relationship between osteophyte length and volume should also be examined. Furthermore, the maximum HKA was −26˚, and it is unclear whether medial compartment shortening occurs in more severe deformity. Factors associated with severe deformity (e.g., the effects of osteophytes on other areas, such as the posterior femoral condyle) and histological assessment of the articular capsule and MCL should be investigated in further studies.

This study found that a varus knee deformity less than 9.5˚ requires less medial release to correct.

Conclusions

The varus deformity angle at which the expected correction was obtained with medial osteophyte removal was 9.5˚ or less. Release of the medial knee structures, including the dMCL, may be unnecessary in patients with a varus angle deformity less than 9.5˚. As there were no significant differences in correction of cases between those with angles larger or smaller than this, contracture of medial structures seemed to be unrelated to the severity of the deformity.

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Authors' contribution: N. Iizawa performed the operative procedures, analyzed the data, drafted the manuscript, and is the corresponding author.

Y. Oshima, T. Kataoka, and H. Watanabe have made substantial contributions to data acquisition and interpretation.

T. Majima and S. Takai supervised the study and helped draft the manuscript.

Conflict of Interest: None declared.

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