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Prognostic Factors Affecting Correction Angle Changes After Supramalleolar Osteotomy Using an Opening Wedge Plate for Varus Ankle Osteoarthritis

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ABSTRACT

Supramalleolar osteotomy (SMO) has been suggested as an effective salvage treatment for varus ankle osteoarthritis. To identify the prognostic factors affecting the correction angle changes after SMO, a total of 53 consecutive patients (58 ankles) were evaluated retrospectively. Clinical and radiologic outcomes were evaluated, and statistical analyses were performed to identify the prognostic factors associated with the clinical and radiologic outcomes. The mean visual analogue scale scores and the American Orthopaedic Foot and Ankle Society scores improved significantly at the final follow-up (both $p < .001$). The mean tibial-ankle surface (TAS), talar tilt (TT), and tibial-lateral surface angles improved significantly after surgery, compared with the preoperative assessments (all, $p < .001$). However, at the final follow-up, these angles had changed significantly, compared with their immediate postoperative values (all $p < .001$), and the changes in the TAS and TT angles significantly influenced the clinical outcomes at the final follow-up (both $p < .05$). Male sex, high body mass index ($\geq$26.4 kg/m^2), and the existence of the lateral cortex breakages were significantly associated with the changes in the TAS and TT angle (all $p < .05$). Therefore, surgeons should consider these prognostic factors before performing SMO.

Supramalleolar osteotomy (SMO), which restores ankle joint orientation and axial alignment, has been used as a realignment surgery to preserve the ankle from articular degeneration and biomechanical dysfunction, as well as to postpone fusion or replacement surgeries in patients with limited medial osteoarthritis and varus malalignment of the ankle (1–7). This surgical procedure is designed to alter the joint mechanics in a varus ankle by correcting the medial displacement of the load line and laterally shifting the medial stress concentration onto the intact articular cartilage of the lateral side within the ankle (8). Thus, SMO has been suggested as an effective salvage treatment for ankle arthritis when only a portion of the articular surface of the joint is involved and when adequate alignment correction of the ankle joint is achieved to redistribute the load line (5,9,10). Therefore, the acquisition and maintenance of an ideal postoperative alignment are very important for achieving satisfactory SMO outcomes and halting progression to degenerative arthritis.

Despite the great care taken during these procedures, correction losses are often experienced over time, resulting in poor outcomes. Hence, understanding the indicators of poor outcomes is essential for identifying ideal SMO candidates. However, studies on the prognostic factors associated with SMO correction losses have rarely been published. In the current study, we investigated the clinical SMO outcomes and evaluated the radiologic changes in SMO correction angles over time. This study aims to identify the prognostic factors affecting the correction angle changes after SMO.

Patients and Methods

Patients and Study Design

The study protocol was approved by our ethics committee, and all patients provided written informed consent. Between February 2009 and November 2015, 53 consecutive patients (58 ankles) with medial ankle osteoarthritis and varus deformity were treated with SMO. The indication for SMO included stage 2 or 3A osteoarthritis, according to the modification of the Takakura classification system by Takakura et al (11). Patients were excluded if they had previous surgical ankle treatments; arthritic changes involving the entire ankle joint; deformities proximal to the ankle, as seen on plain radiographs; or varus deformities of the hindfoot, as seen in the heel alignment view. The average age of the patients was 52.3 (range 39 to 68) years, and the mean follow-up period was 62.4 (range 48 to 72) months. The average preoperative body mass index (BMI) was 26.4 (range 22.5 to 30.2) kg/m^2 (Table 1).

Operative Technique and Postoperative Rehabilitation

The operative technique was identical in all patients. It was performed as described (12). The size of the wedge was determined by the mathematical formula described (Fig. 1) (13). The patient is placed in the supine position on the operating table, and then the technique is applied. After determining the level of the osteotomy by using an image

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Table 1
Patient demographics (N = 53 patients)

Characteristic	
Age (y)	52.3 ± 7.6 (39 to 68)
Gender	
Male	27 (51%)
Female	26 (49%)
Side of involvement	
Right	27 (47%)
Left	31 (53%)
Body mass index (kg/m^2)	26.4 ± 2.0 (22.5 to 30.2)
Follow-up period (mo)	62.4 ± 4.2 (48 to 72)
Preoperative visual analogue scale (points)	7.1 ± 0.8 (6 to 9)
Preoperative AOFAS score (points)	62.8 ± 3.9 (55 to 70)
Preoperative tibial-ankle surface angle (°)	82.8 ± 2.1 (78.3 to 86.8)
Preoperative talar tilt angle (°)	5.4 ± 1.4 (2.9 to 8.3)
Preoperative tibial-lateral surface angle (°)	77.2 ± 1.7 (76.1 to 81.0)

Abbreviation: AOFAS, American Orthopaedic Foot and Ankle Society.
Data are presented as mean ± standard deviation (range) or number of patients, with percentages in parentheses.

intensifier, a skin incision is made on the medial side of the distal tibia, centered over the osteotomy site. Minimal periosteal stripping is performed only to an extent required to complete the osteotomy. To guide the osteotomy plane, a Kirschner wire is placed approximately 4 to 5 cm proximal to the tip of the medial malleolus and inserted obliquely toward the distal tibiofibular joint. The apex of the oblique SMO is placed in the syndesmosis. The osteotomy is made using a broad oscillating saw, to preserve the opposite cortex to act as a fulcrum for the opening wedge and to enhance stability. The fibula is left intact. Careful correction of the deformity is achieved by the stepwise insertion of 2 or 3 osteotomes to avoid far-cortex fractures. Alignment is assessed using an image intensifier. Although there has been an ongoing debate regarding the normal tibial-ankle surface (TAS) angle and correction angle values (8,9,14), Sugimoto et al (15) reported that the mean TAS and tibial-lateral surface (TLS) angles in healthy Japanese individuals are 88° and 81°, respectively. We attempted to achieve these TAS and TLS angles. The osteotomy site was stabilized using 2 single-opening wedge plates and screws (B. Braun Aesculap, Tuttlingen, Germany) (Fig. 1), and the osteotomy gap was filled with cancellous bone allografts. After the surgery, a short leg splint was applied for 2 weeks, and after suture removal, a non-weightbearing short leg cast was applied for 4 weeks. Full weightbearing was permitted at 6 weeks postoperatively. Active and passive ankle range of motion exercises were initiated 6 weeks after the surgery. Sports and high-impact activities were limited for at least 3 months.

Clinical and Radiologic Evaluation

A visual analogue scale (VAS) pain score and the American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot score were used for the clinical evaluations. In addition, patients rated their overall satisfaction with the operation as excellent, good, fair, or poor.

Weightbearing anteroposterior and lateral radiographs were obtained for radiologic evaluations preoperatively and during follow-up assessments. On the weightbearing anteroposterior radiograph, the TAS angle was determined by measuring the angle between the tibial axis and the tibial plafond; the talar tilt (TT) angle was determined by measuring the angle between the tibial plafond and the talar dome. On the weightbearing lateral radiograph, the TLS angle was determined by measuring the angle between the tibial axis and a line drawn between the anterior and posterior margins of the tibial plafond to mark the articular surface of the distal aspect of the tibia. To avoid potential bias, a trained musculoskeletal radiologist, uninvolved in the care of the patients and blinded to the study goals, independently evaluated the radiographs.

Statistical Analysis

The principal dependent clinical outcome variables were the VAS and AOFAS scores at the serial follow-up assessments, and the principal dependent radiologic outcome variables were the TAS, TT, and TLS angles determined during the serial follow-up assessments. Wilcoxon signed ranks tests were conducted to evaluate the differences between the preoperative and immediate postoperative values and between the immediate postoperative and final follow-up values. The Spearman rank-order correlation test was used to analyze the correlations of clinical outcomes with changes in correction angles between the immediate postoperative and final follow-up assessments. The associations of various factors, including patient characteristics and surgical procedure variables, with correction angle changes between the immediate postoperative and final follow-up assessments were also analyzed. Median values were used as the standard values for dividing patients according to age and BMI. Differences between groups were analyzed using the Mann-Whitney *U* test or the Kruskal-Wallis test for multiple comparisons. A p value $< .05$ was considered statistically significant.

Results

The mean VAS score decreased from 7.1 (range 6 to 10) preoperatively to 3.5 (range 1 to 6) at final follow-up ($p < .001$). The mean AOFAS score increased from 62.8 (range 55 to 70) to 82.7 (range 68 to 95) ($p < .001$). Patients were generally satisfied with the operations; 34 (64.2%) patients reported their satisfaction levels as excellent, 14 (26.4%) as good, 4 (7.5%) as fair, and only 1 (1.9%) as poor.

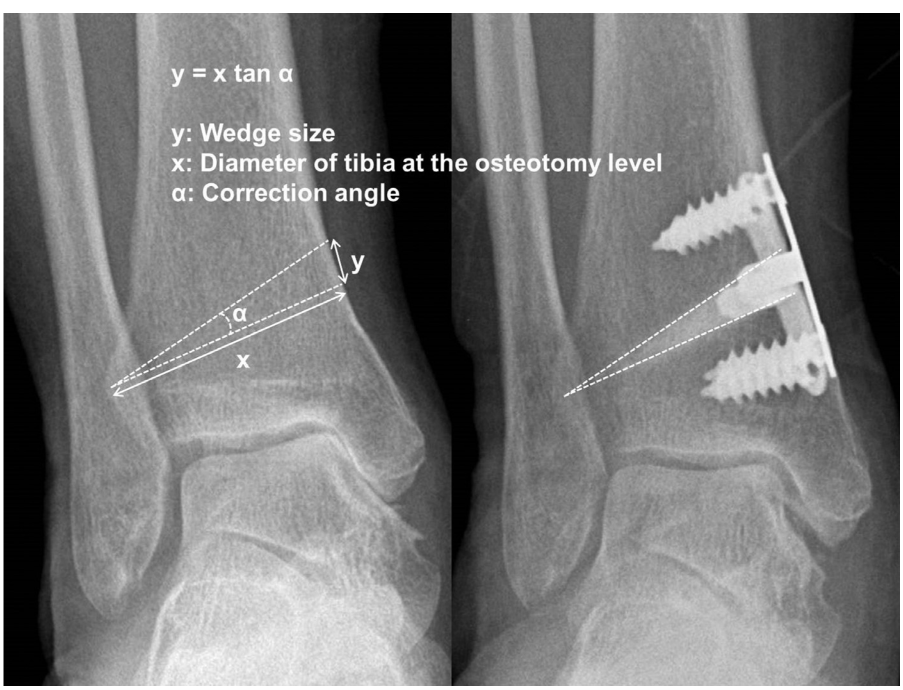

Fig. 1. Method for calculating the size of the opening wedge.

The mean TAS, TT, and TLS angles improved significantly from preoperative values of 82.8° (range 78.3° to 86.8°), 5.4° (range 2.9° to 8.3°), and 77.2° (range 76.1° to 81.0°), respectively, to immediate postoperative values of 89.6° (range 85.3° to 92.7°), 2.6° (range 0.8° to 5.3°), and 78.9° (range 75.6° to 81.2°), respectively (all $p < .001$). However, at the final follow-up (mean 62.4 month after surgery), the mean TAS, TT, and TLS angles significantly changed to 87.3° (range 81.4° to 90.8°), 3.2° (range 1.0° to 6.2°), and 78.2° (range 74.2° to 80.8°), respectively, compared with the values at the immediate postoperative assessment (all $p < .001$). However, they remained significantly better compared with the preoperative assessment values (all $p < .001$) (Fig. 2). Breakage of the lateral cortex was observed in 9 (15.5%) cases.

The mean changes in the correction angles between the immediate postoperative and final assessments were 2.3°, −0.6°, and 0.7°, respectively. The Spearman rank-order correlation test was used to analyze the correlations of clinical outcomes with correction angle changes between the immediate postoperative and final followup assessments. The changes in the TAS and TT angles significantly influenced the clinical outcomes at the final follow-up assessment (VAS: $p = .031$ and $p < .001$, respectively; AOFAS: $p = .018$ and $p = .041$, respectively) (Table 2). However, no significant correlations were found between the preoperative clinical outcomes and correction angle changes.

The independent effects of patient age, sex, BMI, side of involvement, diabetes, smoking habits, the presence of the lateral cortex breakage, and the width of plate wedge on correction angle changes between the immediate postoperative and final follow-up assessments were investigated (Table 3). Median values were used as a standard for dividing patients according to age (<52.3 or ≥52.3 years) and BMI (<26.4 or ≥26.4 kg/m^2). Male sex, high BMIs (≥26.4 kg/m^2), and the presence of the lateral cortex breakage were significantly associated with the changes in the TAS and TT angles (all, $p < .05$), but no association was found between these factors and the changes in the TLS angles. We also investigated the correlations between patient sex and BMI and found good correlation between these factors (Spearman rho = 0.714, $p < .001$). No other factors, including patient age, side of involvement, diabetes, smoking habits, and the width of plate wedge, significantly influenced the correction angle changes between the immediate postoperative and final follow-up assessments (all $p > .05$).

Discussion

Supramalleolar osteotomy is a widely accepted treatment option for medial compartment arthritis of the ankle, particularly in young, active patients. Several surgical techniques, including opening wedge osteotomy (1,5–8,11,16,17), closing wedge osteotomy (18,19), oblique osteotomy (20,21), and dome osteotomy (22), have been described for SMO. Plates (6,8,16,19) and external fixators (20,21) have been used as fixation instruments for the osteotomy site. There has also been debate regarding whether concomitant fibular osteotomy should be performed during SMO (23–26). Recently, Lee and Cho (12) performed an oblique supramalleolar opening wedge osteotomy by using an opening wedge plate (B. Braun Aesculap), without a concomitant fibular osteotomy, and reported that this osteotomy could be performed easily, quickly, and safely, providing correction of varus-deformed ankle joints. They also reported that the presence of an intact fibula could enhance the stability of the osteotomy site, minimizing the adverse effects of mortise distortion and lateral ankle joint impingement. Therefore, we performed SMO by using the same technique in this study. We retrospectively reviewed 53 consecutive patients (58 ankles) with medial ankle osteoarthritis and varus deformity who underwent SMO using opening wedge plates and identified the prognostic factors associated with the correction angles changes between the immediate postoperative and final follow-up assessments.

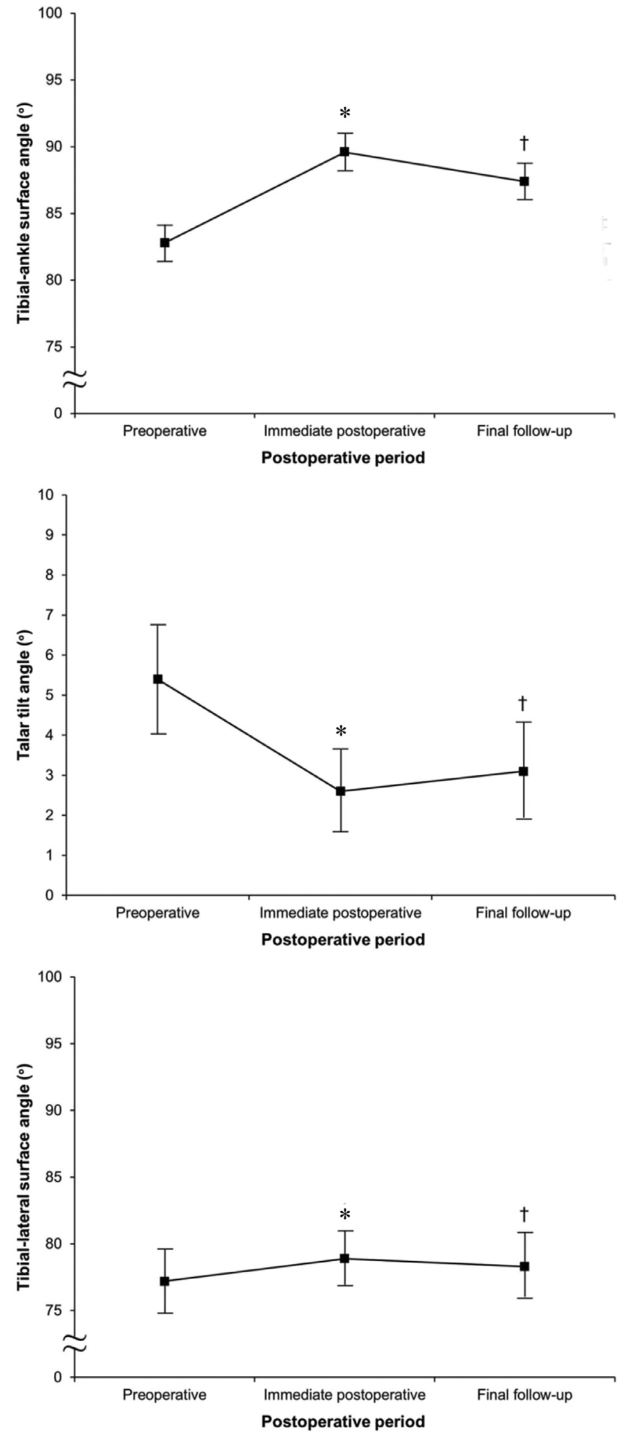

Fig. 2. Time courses of the postoperative tibial-ankle surface, talar tilt, and tibial-lateral surface angle changes. Error bars represent the standard deviation. *Statistically significant differences between preoperative and immediate postoperative values ($p < .001$, Wilcoxon signed-rank test). †Statistically significant differences between the immediate postoperative and final follow-up values ($p < .001$, Wilcoxon signed-rank test).

Several recent studies have reported functional improvements and decreased pain after SMO in patients with varus ankle osteoarthritis (1,3,8,18). Pagenstert et al (3) reported that, after the realignment surgery, the mean VAS and AOFAS scores were improved significantly from 7 to 3 and from 38.5 to 85.4, respectively (both $p = .0001$). Others reported improvements in AOFAS score (from 53.8 to 87; $p < .001$) in

Table 2
Correlations of clinical outcomes with correction angle changes between the postoperative and final follow-up assessments (N = 53)

	TAS Angle		TT Angle		TLS Angle	
	Spearman rho	*p* Value	Spearman rho	*p* Value	Spearman rho	*p* Value
VAS						
Preoperative	0.067	.618	−0.126	.344	0.224	.090
Final follow-up	0.296	.031	−0.487	< .001	0.278	.071
AOFAS score						
Preoperative	−0.003	.982	−0.057	.672	0.206	.122
Final follow-up	−0.412	.018	0.354	.041	0.189	.316

Abbreviations: AOFAS, American Orthopaedic Foot and Ankle Society; TAS, tibial-ankle surface; TLS, tibial-lateral surface; TT, talar tilt; VAS, visual analogue scale.
Data are calculated using the Spearman rank-order correlation test.

Table 3
Association of various factors with correction angle changes between the immediate postoperative and final follow-up assessments (N = 53)

Factors	n (%)	TAS Angle		TT Angle		TLS Angle	
		Mean ± SD	*P* Value[†]	Mean ± SD	*P* Value[†]	Mean ± SD	*P* Value[†]
Age[*] (y)			.317		.624		.418
< 52.3	29 (50)	2.0 ± 1.7		−0.5 ± 0.5		0.8 ± 1.2	
≥ 52.3	29 (50)	2.5 ± 1.8		−0.5 ± 0.6		0.4 ± 0.8	
Gender			.021		.037		.215
Male	30 (51.7)	2.5 ± 1.8		−0.6 ± 0.5		0.8 ± 1.1	
Female	28 (48.3)	1.7 ± 1.5		−0.5± 0.4		0.5 ± 0.9	
BMI[*] (kg/m^2)			.008		.027		.317
< 26.4	27 (46.6)	1.7 ± 1.6		−0.4 ± 0.5		0.6 ± 0.9	
≥ 26.4	31 (53.5)	2.7 ± 1.8		−0.7 ± 0.7		0.7 ± 0.9	
Side of involvement			.745		.683		.613
Right	27 (46.6)	2.1 ± 1.5		−0.5 ± 0.6		0.5 ± 0.9	
Left	31 (53.5)	2.2 ± 1.8		−0.5 ± 0.6		0.7 ± 1.0	
Lateral cortex breakage			.012		.041		.789
Not present	49 (84.5)	1.9 ± 1.5		−0.5 ± 0.5		0.6 ± 1.0	
Present	9 (15.5)	3.6 ± 2.1		−0.8 ± 0.5		0.7 ± 1.1	
Width of plate wedge			.127		.356		.178
5 mm	38 (65.5)	1.8 ± 1.3		−0.4 ± 0.4		0.5 ± 0.8	
7 mm	15 (25.9)	2.7 ± 2.4		−0.6 ± 0.8		1.0 ± 1.2	
9 mm	5 (8.6)	3.8 ± 2.6		−0.8 ± 0.7		1.0 ± 1.1	
Diabetes			.453		.603		.794
Yes	47 (81)	2.5 ± 1.5		−0.5 ± 0.6		0.6 ± 0.8	
No	11 (19)	2.3 ± 1.8		−0.4 ± 0.5		0.6 ± 1.0	
Smoking			.374		.594		.813
Yes	21 (36.2)	2.7 ± 1.9		−0.4 ± 0.5		0.6 ± 0.8	
No	37 (63.8)	2.4 ± 1.7		−0.5 ± 0.6		0.6 ± 1.0	

Abbreviations: BMI, body mass index; SD, standard deviation; TAS, tibial-ankle surface; TLS, tibial-lateral surface; TT, talar tilt.
Data are presented as mean ± standard deviation.
[*] Median values were used as standard values for dividing the groups.
[†] Mann-Whitney *U* test (except for the width of plate wedge; Kruskal-Wallis test).

12 patients who underwent SMO (18) or significant increases in AOFAS scores (from 62.3 to 82.1; $p < .001$) after SMO (15). Similar clinical results were found immediately after SMO surgery in our study, with the mean VAS score improving from 7.1 to 3.6 and the AOFAS score increasing from 62.8 to 83.0 (both $p < .001$). We also found that 48 (90.6%) patients reported good to excellent levels of satisfaction with the surgeries.

Restoration of joint orientation and ankle axial alignment are important factors affecting the clinical outcomes after SMO. Several authors reported that SMO is a reliable procedure that provides excellent correction of varus ankle deformities (1,5,8,18). Tanaka et al (5) reported that the mean TAS and TLS angles were corrected from 82.7° and 78.5°, respectively, preoperatively to 98.2° and 84.7°, respectively, at the follow-up. Although adequate correction of varus deformity is important for achieving normal ankle alignment and, thereby, obtaining good clinical outcomes after SMO, there has been an ongoing debate about the adequate correction of the TAS, TT, and TLS angles (8,9,14). McNicol et al (27) reported that the correction of the TAS angle should be limited to within the normal range, whereas Tanaka (14) and Vichard et al (28) recommended overcorrection to distribute the pressure more evenly on the articular surface. Lee et al (8) attempted to achieve a TAS angle of 95°, and any residual deformity was corrected using calcaneal osteotomy. In addition, Tanaka et al (5) aimed for a TLS angle of 81° to 82° to avoid the restriction of ankle dorsiflexion. In this study, we planned to achieve neutral alignment of the tibial plafond to prevent the hindfoot decompensation or a hypervalgus forefoot and to prevent the formation of a deformity that might lead to subsequent ankle joint degeneration. Therefore, we attempted to achieve the TAS and TLS angles (88° and 81°, respectively) reported by Sugimoto et al (15) in healthy Japanese individuals. As a result, the mean postoperative TAS, TT, and TLS angles in this study were 89.6°, 2.6°, and 78.9°, respectively. However, interestingly, at the final follow-up assessment, the mean TAS, TT, and TLS angles had significantly changed to 87.3°, 3.2°, and 78.2°, respectively (all $p < .001$), despite the very small differences (Fig. 2). The mean changes in the correction angles (TAS, TT, and TLS angles) between the immediate postoperative and final follow-up assessments were 2.3°, −0.6°, and 0.7°, respectively, and there were significant correlations between these correction angle changes and the clinical outcomes (VAS and AOFAS scores) at the final follow-up (Table 2). Previously, several authors showed significant correlations between clinical outcomes and ankle alignment after SMO (1,3,8,11). Takakura et al (11,29) and Cheng et al (1) noted a reversion of joint collapse associated with increased degenerated joint space widths during the follow-up after the correction of TAS angles. Lee et al (8) and Pagenstert et al (3) reported that the postoperative TT angle was correlated with the postoperative AOFAS scores. Hence, we believe that the acquisition and maintenance of an ideal postoperative alignment is very important for achieving satisfactory SMO outcomes and for identifying the factors associated with the correction angle changes after SMO.

We speculated that certain factors were associated with the correction angle changes between the immediate postoperative and final follow-up assessments and attempted to investigate these factors. Accordingly, we found that male sex and high BMI ($\geq$26.4 kg/m^2) were significantly associated with the changes in the TAS and TT angles (both $p < 0.05$) (Table 3). A significant correlation was also found between patient sex and BMI (Spearman rho = 0.714; $p < .001$). We assumed that tibial sizes in the male patients were generally larger than those in the female patients and that the plates used for osteotomy site fixation in this study were not strong enough to prevent the correction angle changes. The plates used in this study in patients with high BMI ($\geq$26.4 kg/m^2) may not have been able to firmly stabilize the osteotomy site, leading to the correction angle changes. Osti et al (30) reported in their high tibial osteotomy study that bone grafting seemed to be essential in osteotomy gaps, especially if conventional nonlocking plates were used. Similarly, Niemeyer et al (31) reported successful osseous consolidation by using locking plate fixators, without bone grafts, after high tibial osteotomy. Therefore, we believe that firmer plates, such as locking plates, are needed, especially in the male patients with high BMI to avoid the correction angle changes after SMO. In addition, in the present study, full weightbearing was permitted at 6 weeks postoperatively. The time to full weightbearing in this study is relatively short compared with other previous studies (12,19,32). Hintermann et al (19) recommended partial weightbearing for 8 to 10 weeks after SMO and permitted full weightbearing at 8 to 12 weeks after the osteotomy site was united. Knupp et al (32) also reported that patients who underwent SMO were not permitted to full weightbearing for 8 weeks after surgery. We considered that relatively short duration of non-weightbearing might influence the correction angle changes after SMO. Therefore, further study comparing the influence of early and delayed weightbearing on the correction angle changes after SMO is needed.

In this study, another poor prognostic factor affecting the TAS and TT angle changes after SMO was the presence of the lateral cortex breakage (Table 3). Several recent studies have indicated that the lateral cortex breakage is a poor prognostic factor in high tibial osteotomies (33–35). Raaij et al (35) reported that an intact lateral cortical hinge is important for providing stability and preventing lateral displacements, which can lead to nonunions. Although nonunions did not occur in this study, we believe that osteotomy site micromotion resulted from the lateral cortex breakage, leading to the dislocation of the osteotomy site, the bending of the fixation plate, and the subsequent changes in the TAS and TT angles after SMO. Therefore, surgeons should carefully avoid the lateral cortex breakage during the SMO and consider using tricortical iliac autografts instead of cancellous bone allografts for firmer osteotomy site fixations when lateral cortical breakages occur.

The present study does have some limitations. First, the data were collected retrospectively. In an attempt to limit bias, an independent musculoskeletal radiologist, uninvolved in the care of the study patients, evaluated the radiographs. However, for more precise assessments, the data on interobserver and intraobserver reliabilities during radiologic evaluations are needed. Second, the number of patients was relatively small. A larger series of cases are required for a more accurate evaluation of the prognostic factors associated with SMO. Third, weightbearing radiographs were taken for the preoperative and final follow-up assessments but could not be taken for the immediate postoperative assessments. Therefore, different settings can cause different radiographic results. Fourth, a control group involving a surgical technique using nonlocking plates with cancellous bone allografts was not used in this study. A randomized comparative study of SMO using different types of plates (nonlocking and locking plates) or bone graft methods (allograft and autograft) would increase the strength of this study and identify the prognostic factors associated with SMO more accurately. Lastly, other factors such as diabetes, differences in bone mineral density, and smoking habits are also likely to affect the correction angle changes, and a multivariate analysis is required to confidently assess these potential prognostic factors.

In conclusion, this study showed improved clinical and radiologic outcomes after SMOs for varus ankle osteoarthritis. Male sex, high BMI ($\geq$26.4 kg/m^2), and the presence of the lateral cortex breakage were the prognostic factors that were significantly associated with the correction angle changes between the immediate postoperative and final follow-up assessments. Therefore, surgeons should consider these prognostic factors before performing SMO, avoid lateral cortex breakage during the SMO, and consider the use of locking plates with tricortical iliac autografts for firmer osteotomy site fixation when lateral cortical breakage occurs.

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