Original Article
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Parallel versus Angulated Screw Configuration in Subtalar Arthrodesis for Posttraumatic Arthritis

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Background: To compare radiographic union and clinical outcomes between parallel and angulated screw configurations (SCs) for patients undergoing subtalar arthrodesis due to posttraumatic subtalar arthritis (PSA) after displaced intra-articular calcaneal fractures.

Methods: This study retrospectively reviewed 140 consecutive PSA cases from March 2011 to November 2021 (parallel SC: group 1, n = 80; angulated SC: group 2, n = 60). Radiographic union, Foot and Ankle Outcome Score (FAOS), and visual analog scale (VAS) scores were among the outcome assessments. Six months after surgery, nonunion was confirmed based on plain radiographs, clinical evaluation, and computed tomography.

Results: Groups 1 and 2 included 14 (17.5%) and 3 (5.0%) nonunion cases, respectively ($p = 0.035$). There was no significant difference in preoperative FAOS and VAS scores between the groups. However, group 2 had significantly better clinical outcomes in 2 of the 5 FAOS domains (sports and quality of life), as well as VAS scores at 3 and 6 months postoperatively and at the final follow-up ($p < 0.05$).

Conclusions: Using the angulated SC for PSA had a lower nonunion rate and superior clinical outcomes than the parallel SC. Obtaining better radiological and clinical outcomes when using the angulated SC, rather than the parallel SC, would be advantageous.

Keywords: *Subtalar joint, Osteoarthritis, Arthrodesis, Bone screws*

Subtalar arthrodesis (SA) is a widely known and commonly performed surgical treatment for patients with posttraumatic subtalar arthritis (PSA) due to displaced intra-articular calcaneal fracture (DIACF).[1)] The principle of SA is to prevent movement of the affected subtalar joint. Union is believed to be promoted by compression and minimal motion at the arthrodesis site.[2)] For a successful functional outcome, it is essential to achieve a stable bony fusion of the SA construct in a physiological position.[3)]

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Although SA is the preferred treatment for PSA, significant postoperative complications have been reported including nonunion.[4-6)] Reported rate of nonunion in SA varies significantly, ranging from 5% to 45%,[5,7-9)] and shows inconsistencies for many reasons, depending on the population of patients, quality of joint preparation, and quality of fixation.[10,11)] History of smoking, peripheral vascular disease, diabetes, alcoholism, mental problems, previous ankle arthrodesis, recent infection, and revision procedures have been reported to cause nonunion.[5,11-13)] Recently, the use of freeze-dried iliac bone as an interpositional graft or the traditional 2-screw fixation with the parallel screw configuration (SC) through the posterior facet, compared to the angulated SC, has been reported to be a surgeon-related risk factor for nonunion.[11)]

Among the several options for fixation in SA, fixation with screws has been considered the standard method throughout the past few decades.[5,14,15)] Although the 2-SC may be the most widely used technique in clinical practice,[2,5,10,16-18] there is a controversy over the number of screws and the type of SC for the proper initial stability of the SA construct.[5,14,15,19,20] Biomechanical studies have reported that the SC affects the mechanical characteristics of the SA construct[2,3,21,22] and shown that the angulated SC reduces joint movement in SA and shows better resistance to cyclic loading than the parallel SC.[3,17,23]

Burgi and Hintermann[16] first reported the radiological and clinical outcomes of the angulated SC using 2 screws. Union was achieved within 12 weeks in all 13 patients. They found that the angulated SC provided better initial stability, thereby allowing early weight-bearing. Boffeli and Reinking[10] reported a 100% union rate in 15 patients who underwent the angulated SC, where the angulated SC enhanced the raw bone surface contact area and improved the resistance to rotational forces, inducing SA union. However, only a few studies have evaluated the utility of the angulated SC versus parallel SC fixation constructs for SA *in vivo*. We hypothesized that compared with the parallel SC, the angulated SC would provide significantly better stability and increased resistance to rotational forces, thus improving radiological and clinical outcomes. Therefore, we compared the outcomes of SA treatment with the parallel SC and the angulated SC.

METHODS

Study Population

This study was approved by the Institutional Review Board of Pusan National University Yangsan Hospital (IRB No. 05-2023-051). Informed consent was waived due to the retrospective nature of this study. This study reviewed all patients who underwent SA for PSA with the parallel SC and angulated SC between March 2011 and November 2021. The inclusion criteria were SA performed for PSA after DIACF using 2 screws, complete radiographs, and a minimum of 12-month postoperative follow-up. The exclusion criteria were SA for primary subtalar arthritis, revision SA, persistent infection, using 1 or more than 2 screws during SA, and < 12 months of follow-up. Overall, 181 patients underwent 191 SA, of which 140 SA in 130 patients satisfied the inclusion criteria. A total of 51 cases were excluded, including 12 for primary subtalar arthritis, 6 with revision SA, 2 with persistent infection, 18 with 1 (n = 10) or more than 2 screws (n = 8) in SA, and 13 with < 12 months of follow-up.

Operative Techniques

Between 2011 and 2016, the parallel SC for SA was performed in 80 cases (group 1). However, the angulated SC[10] was performed from 2017 to 2021 in 60 cases (group 2). Two orthopedic surgeons (SHW and TSG) trained in foot and ankle surgery from the 2 institutions affiliated with the same school of medicine conducted SA using the same surgical technique. The subtalar joint was exposed during surgery using an extended lateral approach[24] or a sinus tarsi approach.[14] The approaches were the same as those used for patients who underwent open reduction and internal fixation for DIACF. After approaching the subtalar joint, the cartilage of the middle and posterior facet was removed, and the subchondral bone was peeled off until fresh surfaces came out.[11] Bone grafting was performed in all patients using an autologous iliac bone or cancellous allograft.[6] When there was limited ankle dorsiflexion, anterior ankle impingement, and a talar declination angle of < 20° on the preoperative radiograph, distraction subtalar arthrodesis (DSA) was performed.[5,25] We used two 6.5-mm partially or fully threaded cannulated screws for fixation of the SA construct.

For the parallel SC (group 1), the first screw was placed perpendicular to the subtalar joint at the plantar surface of the calcaneus, just posterior to the weight-bearing surface. The second screw was placed anterior to the first screw in the same manner. For the angulated SC (group 2), the first screw was placed in the same manner as for the first screw of the parallel SC. The second screw was oriented from the plantar lateral aspect of the anterior calcaneus in a dorsomedial trajectory (typically 45° angle from plantar lateral) to the talar head of the neck (Fig. 1).[10,16]

Postoperatively, a short leg splint was applied for 2 weeks, and intermittent passive and active ankle motions were allowed. After 2 weeks, a short leg cast was applied without weight-bearing for another 4 weeks. At 6 weeks following surgery, ambulation with partial weight-bearing was permitted and at 8 weeks, full weight-bearing.

Radiological and Clinical Outcome Assessments

All patients underwent serial radiological and clinical assessments for at least 12 months postoperatively. Following surgery, patients came to the outpatient department at 6 weeks, and 3, 6, and 12 months. Radiographic union was determined by the presence of osseous trabecular bridging involving over half of the joint, with intact cortical borders and without a visible radiolucent line on radiographs obtained before 6 months postoperatively.[26] Although computed tomography (CT) scans are the best method for confirming union,[27] this study only assessed CT scans in those who had equivocal radiographic findings. For a definitive finding of the union or nonunion status, CT was required in 29 cases. Six months following surgery, non-

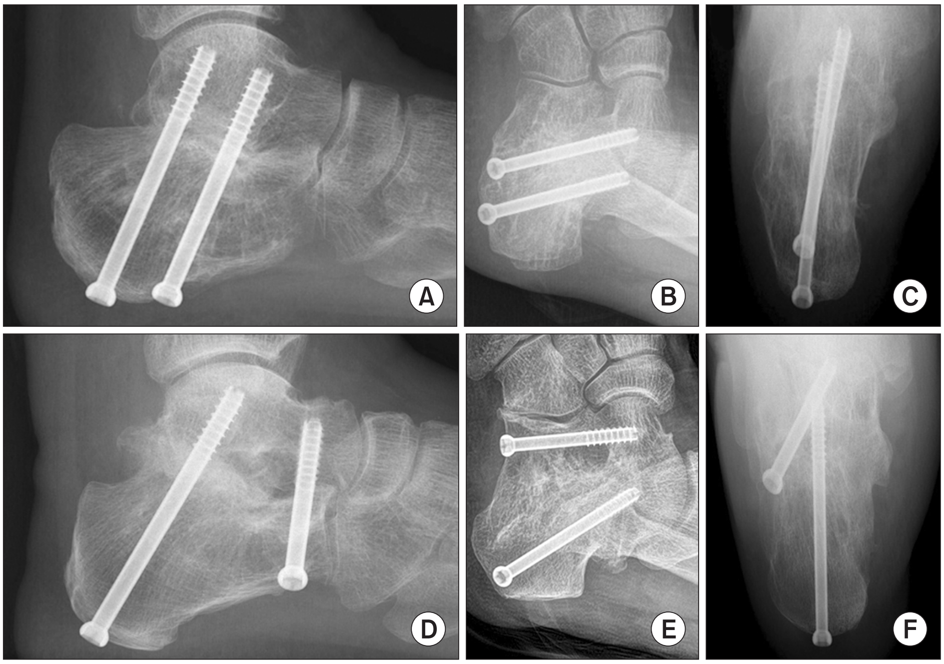

Fig. 1. Screw configurations. Lateral (A), medial oblique (B), and axial (C) radiographs of the parallel screw configuration. Lateral (D), medial oblique (E), and axial (F) radiographs of the angulated screw configuration.

union was identified based on results from plain radiographs and CT scans.

For clinical assessments, the Foot and Ankle Outcome Score (FAOS) questionnaire and visual analog scale (VAS) scores were used. To avoid potential bias, clinical evaluation was performed by an independent nurse who was not a member of the surgical team. All clinical outcomes were evaluated at the time of admission, 3 and 6 months postoperatively, and at the last follow-up visit.

Statistical Analysis

IBM SPSS software version 20.0 (IBM Corp.) was used for statistical analyses. For normality analysis, the Kolmogorov-Smirnov test was used. For comparisons of continuous variables, the Mann-Whitney *U* and independent *t*-tests were used for nonparametric and parametric variables, respectively. For categorical variables (sex, type of approach, type of surgery, type of screws, type of bone graft, comorbidities, nonunion, and complications), the chi-square or Fisher's exact test ($n < 40$ or $t < 1$) was used to identify significant parameters between the groups. A *p*-value of < 0.05 was considered statistically significant.

RESULTS

In Table 1, the demographic, surgical, and medical information of the study population is presented. Among the 140 SA cases, 108 (77.1%) were men and 32 (22.9%) were women (mean age, 50.9 ± 11.6 years; range, 23–73 years). The average follow-up period was 18.6 ± 8.3 months (range, 12–48 months). The mean body mass index of the patients was 26.1 ± 2.8 kg/m^2 (range, 18.2–33.3 kg/m^2). The initial treatment for DIACF included 106 (75.7%) operative treatments and 34 (24.3%) conservative casting approaches. No significant differences were detected between the groups with regard to demographics, operative information, or comorbidities ($p > 0.05$).

The rate of nonunion was significantly higher in group 1 (n = 14, 17.5%) compared to group 2 (n = 3, 5.0%) ($p = 0.035$). The mean time to union was 12.9 ± 3.4 weeks (range, 10–22 weeks). Eight patients of group 1 and 2 patients of group 2 underwent revision surgery with an autologous iliac bone graft ($p = 0.556$). All 9 cases of surgical wound dehiscence occurred after SA via the extended lateral approach and were treated with local wound care and antibiotics. Eleven patients required hardware removal due to irritation while walking postoperatively. There were no significant differences between the groups with regard to time to union and complications ($p > 0.05$) (Table 2).

Although SA was performed using the same method, the 2 surgeons did not perform the surgery in the exact same way. The detailed operative techniques, radiologic unions, and complications were compared between the surgeons. There were no significant differences between the surgeons with regard to the operative techniques, radiologic union, and complications (Table 3). The preoperative all domains of FAOS did not significantly differ between the groups ($p > 0.05$). Although no significant differences were shown between the 2 groups in the 3 domains of FAOS (symptoms, pain, and activities of daily

Table 1. Demographics and Surgical and Medical Characteristics of the Patients in Both Groups

Variable	Entire SA group	Group 1	Group 2	*p*-value
Number	140 (100)	80 (57.1)	60 (42.9)	-
Sex				0.066
Male	108 (77.1)	67 (83.8)	41 (68.3)	
Female	32 (22.9)	13 (16.3)	19 (31.7)	
Age (yr)	50.9 ± 11.6	49.1 ± 13.7	52.6 ± 9.2	0.384
Follow-up period (mo)	18.6 ± 8.3	19.9 ± 8.7	18.6 ± 8.3	0.277
Body mass index (kg/m^2)	26.1 ± 2.8	25.2 ± 2.9	26.1 ± 2.8	0.103
Treatment of previous calcaneus fracture				1.000
Operative treatment	106 (75.7)	61 (73.8)	45 (75)	
Conservative treatment	34 (24.3)	19 (26.2)	15 (25)	
Type of approach				0.390
Extended lateral approach	83 (59.3)	50 (62.5)	33 (55.0)	
Sinus tarsi approach	57 (40.7)	30 (37.5)	27 (45.0)	
Type of surgery				0.375
Distraction subtalar arthrodesis	92 (65.7)	50 (62.5)	42 (70.0)	
Isolated subtalar arthrodesis	48 (34.3)	30 (37.5)	18 (30.0)	
Type of screw				0.106
Partially threaded screw	118 (84.3)	71 (88.8)	47 (78.3)	
Fully threaded screw	22 (15.7)	9 (11.3)	13 (21.7)	
Type of bone graft				0.244
Autologous iliac bone	69 (49.3)	44 (55.0)	25 (41.7)	
Cancellous allograft	71 (50.7)	36 (45.0)	35 (58.3)	
Comorbidity				
Diabetes	30 (21.4)	19 (23.8)	11 (18.3)	0.534
Hypertension	29 (20.7)	16 (20.0)	13 (21.7)	0.836
Cardiovascular disease	19 (13.6)	11 (13.8)	8 (13.3)	1.000
Chronic kidney disease	4 (2.9)	3 (3.8)	1 (1.7)	0.635
Liver disease	14 (10.0)	8 (10)	6 (10.0)	1.000
Osteoporosis	7 (5.0)	4 (5.0)	3 (5.0)	0.103
History of current smoking	54 (38.6)	18 (22.5)	19 (31.7)	0.164

Values are presented as number (%) or mean ± standard deviation.
SA: subtalar arthrodesis.

living), group 2 had significantly better scores in the 2 domains (sports and quality of life) of FAOS at all postoperative assessments ($p < 0.05$) (Table 3). Likewise, there were no significant differences in the preoperative VAS score between the groups ($p = 0.695$); however, the VAS scores were significantly lower in group 2 at all postoperative as-

Table 2. Comparison of Radiologic Union and Complications between Both Groups

Variable	Entire SA group (n = 140)	Group 1 (n = 80)	Group 2 (n = 60)	*p*-value
Nonunion	17 (12.1)	14 (17.5)	3 (5.0)	0.035
Time to union (wk)	12.9 ± 3.4	13.6 ± 3.5	12.0 ± 3.1	0.271
Revision surgery	10 (7.1)	8 (10.0)	2 (3.3)	0.556
Wound dehiscence	9 (6.4)	6 (7.5)	3 (5.0)	0.732
Hardware removal	6 (6.1)	5 (6.3)	1 (1.7)	0.238

Values are presented as number (%) or mean ± standard deviation.
SA: subtalar arthrodesis.

sessments ($p < 0.05$) (Table 4).

DISCUSSION

This study investigated differences in the radiological and clinical outcomes of posttraumatic SA with the parallel and angulated SCs. In our experience of using the parallel SC for SA from 2011 to 2016, nonunion was found in 14 of 80 cases (17.5%). Because of this relatively high nonunion rate, we changed the fixation method to the angulated SC. Our hypothesis was that compared with the parallel SC, the angulated SC would provide better stability and increased resistance to rotational forces, thus improving radiological and clinical outcomes.

Table 3. Comparison of Operative Techniques, Radiologic Union, and Complications between 2 Surgeons

Variable	Entire SA group	Surgeon 1	Surgeon 2	*p*-value
Number	140 (100)	80 (57.1)	60 (42.9)	-
Treatment of previous calcaneus fracture				0.155
Operative treatment	106 (75.7)	57 (71.3)	49 (81.7)	
Conservative treatment	34 (24.3)	23 (28.7)	11 (18.3)	
Type of approach				0.843
Extended lateral approach	83 (59.3)	48 (60.0)	35 (58.3)	
Sinus tarsi approach	57 (40.7)	32 (40.0)	25 (41.7)	
Type of surgery				0.472
Distraction subtalar arthrodesis	92 (65.7)	55 (68.8)	37 (61.7)	
Isolated subtalar arthrodesis	48 (34.3)	25 (31.2)	23 (38.3)	
Type of screw				0.503
Partially threaded screw	118 (84.3)	66 (82.5)	52 (86.7)	
Fully threaded screw	22 (15.7)	14 (17.5)	8 (13.3)	
Type of bone graft				0.063
Autologous iliac bone	69 (49.3)	45 (56.3)	24 (40.0)	
Cancellous allograft	71 (50.7)	35 (43.7)	36 (60.0)	
Nonunion	17 (12.1)	7 (8.8)	10 (16.7)	0.194
Time to union (wk)	12.9 ± 3.4	12.6 ± 2.9	13.3 ± 3.9	0.771
Revision surgery	10 (7.1)	5 (6.3)	5 (8.3)	0.745
Wound dehiscence	9 (6.4)	5 (6.3)	4 (6.7)	0.921
Hardware removal	6 (6.1)	4 (5.0)	2 (3.3)	0.700

Values are presented as number (%) or mean ± standard deviation.
SA: subtalar arthrodesis.

Table 4. Comparison of Clinical Outcomes between Both Groups

Variable	Group 1	Group 2	*p*-value
FAOS			
Preoperative			
Symptoms	32.2 ± 6.8	32.0 ± 6.8	0.801
Pain	35.0 ± 5.0	35.4 ± 5.1	0.673
Activities of daily living	44.2 ± 4.7	44.3 ± 5.7	0.606
Sports	30.7 ± 6.3	29.9 ± 6.2	0.476
Quality of life	24.7 ± 5.8	24.1 ± 6.0	0.522
Postoperative 3 months			
Symptoms	65.9 ± 12.8	68.0 ± 11.6	0.329
Pain	62.4 ± 15.1	65.9 ± 13.7	0.131
Activities of daily living	64.2 ± 9.5	66.3 ± 8.7	0.159
Sports	54.6 ± 17.0	61.4 ± 13.2	0.007
Quality of life	58.7 ± 18.7	65.1 ± 15.1	0.045
Postoperative 6 months			
Symptoms	78.2 ± 18.6	80.6 ± 15.3	0.555
Pain	77.1 ± 20.0	80.1 ± 16.6	0.807
Activities of daily living	79.1 ± 16.5	82.3 ± 15.5	0.125
Sports	66.0 ± 21.7	74.2 ± 19.9	0.021
Quality of life	67.9 ± 22.4	77.1 ± 21.0	0.004
Final follow-up			
Symptoms	82.7 ± 16.7	87.7 ± 8.9	0.230
Pain	80.8 ± 19.6	86.1 ± 11.7	0.617
Activities of daily living	83.7 ± 15.9	88.8 ± 10.1	0.093
Sports	70.6 ± 21.2	79.2 ± 15.3	0.020
Quality of life	73.9 ± 20.1	81.1 ± 16.1	0.023
VAS scores			
Preoperative	7.8 ± 0.8	7.7 ± 1.0	0.695
Postoperative 3 months	4.1 ± 2.1	3.0 ± 1.4	< 0.001
Postoperative 6 months	2.6 ± 2.5	1.6 ± 1.5	0.009
Final follow-up	2.2 ± 2.4	1.4 ± 1.6	0.032

Values are presented as mean ± standard deviation.
FAOS: Foot and Ankle Outcome Score, VAS: visual analog scale.

SCs used for SA fixation are well known in the orthopedic foot and ankle literature. The selection of optimal SC is important because it improves the initial stability of the SA, resulting in a higher postoperative union rate.[28] Several biomechanical studies have compared different kinds of SC using 2-screw fixation constructs.[2,3,17,23] Hungerer et al.[17] reported that compared to the parallel SC, the angulated SC provides greater stability to the arthrodesis construct because it covers a larger area. Since the screw shanks must move laterally through the bone for rotation to occur, increasing the distance between the screws prevents relative rotation.[17] Because of the relatively small corridor that can be used to place screws for SA, the parallel SC is less stable against rotational forces.[17] Eichinger et al.[3] emphasized that resistance to cyclic loading and initial stability are important for successful SA. In comparison to the parallel SC, they found that the angulated SC led to decreased joint motion in the SA construct immediately after fixation and cyclic loading. Jastifer et al.[23] reported that the angulated SC is biomechanically superior to the parallel SC. They reported that the angulated SC, which is inserted perpendicular to the subtalar joint axis, better controls the forces of motion than the parallel SC, which is inserted nearly parallel to the subtalar joint axis of motion. The angulated SC minimizes rotational forces while providing optimal compression from a biomechanical viewpoint.

The angulated SC was first introduced in 2003 by Burgi and Hintermann[16] with a union rate of 100% (13 of 13 patients). They reported that the angulated SC provides high initial stability and effectively neutralizes the rotational forces acting on the subtalar joint, allowing for earlier functional aftercare, including weight-bearing. In 2004, Baravarian[29] reported the outcomes of DSA with the angulated SC. They reported a 100% union rate (12 of 12 patients) and observed satisfactory results in all but 1 patient. In 2012, Boffeli and Reinking[10] reported a 100% union rate in 15 patients who underwent the angulated SC. According to them, the angulated SC enhanced the raw bone surface contact area and improved the resistance to rotational forces, which helped induce SA osseous fusion.

Although our total number of patients was relatively small (n = 180), the overall nonunion rate of 12.9% (18 of 80 patients) was within the range described in recent studies.[15,30] Although many well-known risk factors can cause nonunion,[5,6,11] both groups were well-matched based on demographics and surgical and medical characteristics, without significant difference (Table 1). The nonunion rate was significantly higher in group 1 (17.5%) than in group 2 (5.0%). This statistical difference noted in the high union rate indicates that the angulated SC is more protective against nonunion than the parallel SC. Biomechanical studies[3,17,23] have shown superior initial stability and resistance to rotational forces, suggesting that the angulated

SC improves the union rate in SA. It is possible that the high nonunion rate in group 1 contributed to the notable difference in the clinical outcomes between the 2 groups. Six of 14 patients in group 1 and 1 of 3 patients in group 2 opted against revision surgery owing to discomfort in daily activities at 6 months postoperatively (Table 2). Consequently, a significant difference between the groups was observed only in the 2 domains (sports and quality of life) of FAOS at all postoperative assessments (Table 3).

Although the parallel SC creates sufficient compression and stability in the SA construct, there is always a concern about decreasing the raw bone surface area available for bony union, because 2 large 6.5-mm compression screws are placed through the small posterior facet.[10,23] Additional clinical advantage of the angulated SC over the parallel SC is the larger raw bone surface area obtained with only 1 screw passing through the posterior facet.[3] In addition, the possibility of pain with weight-bearing and the need for hardware removal can increase owing to 2 screw heads on the plantar side of the calcaneus.[10] Although the difference was not statistically significant, hardware removal was more frequently performed in group 1 (6.3%) than in group 2 (1.7%). One possible concern regarding the angulated SC is the anatomical consideration.[23] The second screw is inserted through the anterior process of the calcaneus into the talar head or neck. However, the current study showed a potentially safe pathway for the sural nerve and peroneal tendon, and no complications associated with talar blood flow inhibition were observed.

This study has several limitations. It was performed retrospectively, with a relatively small patient population and a minimum of 12 months of follow-up. There are several different techniques for SA, varying in the operative approach, type of screw, SC, and the selection of graft material. Additionally, patient-specific factors, such as specific comorbidities, smoking status, and previous infection can influence the nonunion rate of SA. Although these factors did not show a significant difference between the 2 groups, it is believed that selection bias would still exist. However, midway through the study period, the SC technique was changed from the parallel SC to the angulated SC, which was supposed to lessen selection bias. This allowed for the observation of the 2 independent groups without selection bias based on other confounding variables. In addition, both clinical and radiographic confirmations of union are inherently subjective. Despite CT scans are the best method for confirming union in arthrodesis of the hindfoot,[27] we evaluated CT scans to classify SA as union or nonunion only if clinical and radiographic evaluations were equivocal. It is possible that some patients who were diagnosed with nonunion at 6 months after surgery may have been determined to have union later. It is thought that prospective studies using routine CT scans in the assessment of radiographic union during follow-up will be needed in the future.

To the best of our knowledge, this is the first study that compares the outcomes of 2 different SCs for posttraumatic SA. Using the angulated SC for PSA had a significantly lower nonunion rate and superior clinical outcomes than the parallel SC. Obtaining better radiological and clinical outcomes when using the angulated SC, rather than the parallel SC, would be advantageous.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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Tae Sik Goh, MD, PhD, assistant professor at the Department of Orthopedic Surgery, Pusan National University Hospital, Pusan National University School of Medicine, Yangsan, Korea, performed surgery and follow-up in 54 of the 140 cases included in the study.

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