Joint Diseases and Related Surgery

Jt Dis Relat Surg
2026;37(2):442-453

ORIGINAL ARTICLE

Ankle arthrodesis with arthroscopic fibular osteotomy for varus ankle arthritis

Mehmet Orçun Akkurt, MD[1], Batuhan Bahadir, MD[2], Nurettin Mantı, MD[2]

[1]Department of Orthopedics and Traumatology, Sincan Research and Training Hospital, Ankara, Türkiye
[2]Department of Orthopedics and Traumatology, Ankara Bilkent City Hospital, Ankara, Türkiye

The ankle joint is less frequently affected by primary osteoarthritis (OA) compared to the hip and knee joints, accounting for approximately 1% of all OA cases, and the arthrosis is tolerated relatively better.[1] Previous clinical and epidemiological studies have identified post-traumatic etiology as the most common cause of ankle OA,[2-5] with varus malalignment being the most frequently associated deformity.[6] Varus ankle OA is a progressive and degenerative condition characterized by asymmetric joint space narrowing, medial deviation of the talus, and mechanical malalignment.[7] This pathology eventually results in pain, joint instability, and functional limitations in affected individuals.[8,9] Although ankle arthroplasty has gained increasing popularity in the treatment of end-stage ankle OA, particularly with the advent of new-generation implants,[10] ankle arthrodesis remains a widely accepted and effective treatment option. This is largely due to concerns regarding implant longevity,

Received: October 14, 2025
Accepted: November 18, 2025
Published online: November 26, 2025

Correspondence: Mehmet Orçun Akkurt, MD. Sincan Araştırma ve Eğitim Hastanesi, Ortopedi ve Travmatoloji Bölümü, 06909 Sincan, Ankara, Türkiye.

E-mail: mehorcun@gmail.com

Citation: Akkurt MO, Bahadir B, Mantı N. Ankle arthrodesis with arthroscopic fibular osteotomy for varus ankle arthritis. Jt Dis Relat Surg 2026;37(2):442-453. doi: 10.52312/jdrs.2026.2680.

© 2026 Joint Diseases and Related Surgery. This is an open access article published under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0), which permits non-commercial use, distribution, reproduction, and adaptation in any medium, provided the original work is properly cited. http://creativecommons.org/licenses/by-nc/4.0/

ABSTRACT

Objectives: The aim of this study was to assess the clinical outcomes of a novel, single-stage arthroscopic ankle arthrodesis employing complete arthroscopic fibular osteotomy in patients exhibiting significant varus malalignment (≥ 10°) and severe osteoarthritis (OA) and to compare these results with those of patients undergoing arthroscopic ankle arthrodesis with mild deformity.

Patients and methods: Between August 2018 and May 2023, a total of 49 patients (23 males, 26 females; mean age: 50.00 ± 14.72 years; range, 21 to 71 years) who underwent arthroscopic ankle arthrodesis for tibiotalar arthrosis with a minimum postoperative follow-up of two years were retrospectively analyzed. The patients were divided into two groups: Group A (n = 20) consisted of end-stage tibiotalar OA patients with ≥ 10° varus alignment and Group B (n = 29) consisted of those with < 10° varus alignment. An arthroscopic fibular osteotomy at the level of ankle joint was performed using an osteotome introduced through the anteromedial portal in Group A, resulting in fibula shortening equivalent to the thickness of the osteotome. Fixation in both groups was achieved using two or three 6.5-mm cannulated screws. Outcomes were evaluated utilizing the Visual Analog Scale (VAS) for pain, the 36-item Short Form Survey (SF-36), and the American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Score (AOFAS) at baseline and at three, six, 12, and 24 months postoperatively.

Results: There was no statistically significant difference between the groups in terms of age, sex, or the affected sides between the groups ($p = 0.210$, $p = 0.348$, and $p = 0.906$, respectively). All the patients had Takakura Stage IIIB and IV ankle OA with a trauma-related etiology. The mean duration of the operation was 85.50 ± 9.72 min in Group A which included arthroscopic fibular osteotomy and 57.59 ± 5.61 min in Group B, indicating a statistically significant difference ($p < 0.001$). The mean fusion times and complication rates were comparable between the groups ($p = 0.064$ and $p = 1.000$, respectively). All patients demonstrated significant and consistent improvements in VAS, AOFAS, and SF-36 scores, compared to baseline ($p < 0.001$). At three months, the VAS scores in Group A were significantly higher ($p = 0.020$); however, later evaluations showed comparable scores between the groups. Group B exhibited significantly higher AOFAS scores at three, six, and 24 months. The SF-36 scores indicated no significant differences between the groups in any time points in the postoperative period.

Conclusion: This study provides the novel, initial clinical evidence for a single-stage arthroscopic procedure which incorporates complete arthroscopic ankle arthrodesis and arthroscopic fibular osteotomy in severe varus deformities. It can be effectively used with similar fusion and recovery times, by eliminating mechanical obstruction caused by the fibula in varus OA without necessitating additional surgical incisions.

Keywords: Ankle, ankle arthrodesis, arthroscopic arthrodesis, arthroscopy, arthrosis, fibular osteotomy, osteoarthritis, varus deformity.

financial barriers to access implants, and patient preference.[11]

In arthrodesis surgery, both open and arthroscopic techniques can be used for joint preparation and cartilage resection. In patients with varus deformities exceeding 10 degrees, conventional surgical options such as open ankle arthrodesis with or without realignment osteotomy pose considerable technical challenges and increase the risk of soft tissue complications, particularly in the presence of comorbidities or prior surgical intervention.[12,13] Arthroscopic ankle arthrodesis, in contrast, offers several advantages over open techniques according to recent comparative studies; enhanced intra-articular visualization, lower morbidity and complication rates, shorter hospital stay, faster recovery, superior union rates, and more favorable functional outcomes.[14,15] However, the effective correction of severe varus deformities remains a challenge in arthroscopic techniques, primarily due to the limited access and realignment capabilities inherent to arthroscopy.[16] Specifically, the impinging distal fibula acts as a mechanical block, preventing adequate reduction of the talus and complete apposition of the tibiotalar joint surfaces, which is a limitation inherent to the standard arthroscopic portals.

To overcome this mechanical block, various solutions have been proposed. While traditional open procedures, such as transfibular approaches or realignment osteotomies, are effective, they negate the primary advantages of arthroscopy by requiring larger incisions and increasing soft tissue morbidity.[12] More recently, arthroscopic techniques to decompress the lateral side have been developed. Although arthroscopic intra-articular fibular resection using a burr has been technically described,[17] this method can be time-consuming, may generate thermal heat, and poses challenges in achieving a precise, planar osteotomy for controlled shortening. In this context, the intra-articular fibular osteotome technique was described as an innovative procedure developed to enhance deformity correction during arthroscopic ankle arthrodesis.[18] This method enables controlled lateral decompression, allowing for improved apposition of the joint surfaces, and offers a less invasive solution for varus ankle OA. Crucially, while the osteotome technique itself has been described, its clinical outcomes have not yet been explored.

In the present study, we hypothesized that single-stage arthroscopic technique, by removing the fibular mechanical block, would allow patients with severe varus deformity to achieve clinical outcomes and fusion times comparable to those in patients with mild deformity who do not need angular correction. We, therefore, aimed to evaluate the outcomes of arthroscopic ankle arthrodesis with intra-articular fibular osteotomy in patients with ≥ 10° varus malalignment and compare the results with those with < 10° deformity.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Ankara Bilkent City Hospital, Department of Orthopedics and Traumatology between August 2018 and May 2023. Initially, patients who underwent arthroscopic ankle arthrodesis for tibiotalar arthrosis and operated were screened. We began utilizing the arthroscopic fibular osteotomy technique described below in our clinic in August 2018, and all patients who underwent surgery using this technique, completed the necessary two-year follow-up period, and did not meet the exclusion criteria were included in the study. Exclusion criteria were as follows: patients with uncontrolled diabetes mellitus (DM), Charcot neuroarthropathy, active infection or a history of osteomyelitis, and concomitant arthrodesis of neighboring joints (including the subtalar joint). From the initial list of 59 patients who met the inclusion criteria, 10 patients were excluded: six for having concomitant subtalar arthrodesis and five for incomplete follow-up or missing records (with one patient meeting both criteria). Finally, a total of 49 patients (23 males, 26 females; mean age: 50.00 ± 14.72 years; range, 21 to 71 years) were recruited. The patients were divided into two groups based on the severity of varus deformity: Group A, which included end-stage tibiotalar OA patients with ≥ 10° varus alignment in the joint (n = 20), and Group B, which included end-stage tibiotalar OA without ≥ 10° varus alignment (n = 29). Written informed consent was obtained from each patient. The study protocol was approved by the Ankara Bilkent City Hospital Clinical Research Ethics Committee (Date: 14.05.2025, No: TABED 2-25-1206). The study was conducted in accordance with the principles of the Declaration of Helsinki.

All procedures were performed by a single senior orthopedic surgeon. The following variables were retrieved from the hospital database: age, sex, operated side, body mass index (BMI) category, smoking habits, preoperative and postoperative ankle radiographs, patient history related to etiology

of ankle arthrosis, previous surgeries, comorbid conditions, duration of surgery, length of hospital stay, complications, additional postoperative interventions (if there was), time to partial and full weight-bearing (in weeks), Short Form-36 (SF-36), Visual Analog Scale (VAS), and American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Scores (AOFAS) at baseline and at three, six, 12, and 24 months postoperatively. Takakura Classification was conducted through preoperative X-rays.

Preoperative evaluation

All patients included in the study underwent an ankle physical examination, as well as weight-bearing anterior-posterior and lateral radiographs of the ankle during the diagnosis of tibiotalar arthrosis and surgical decision-making process. The patients who were recommended for arthrodesis and agreed to the treatment received functional evaluation tests as part of the institution's standard protocol after obtaining surgical consent. These assessments included the SF-36, VAS for pain, and AOFAS, and they served as the baseline for our retrospective study.

Surgical technique

All patients underwent surgery under spinal anesthesia in supine position and tourniquet control, utilizing standard anterolateral and anteromedial portals. A 4.0-mm arthroscope was used; in 12 cases with narrow joint spaces, a 2.7-mm scope was used for initial visualization.

Standard arthroscopic joint preparation was performed in both groups. In Group B, in accordance with the current literature, no fibular osteotomy was performed. In Group A, in addition to standard joint preparation, lateral gutter debridement was carried out followed by an arthroscopic intra-articular fibular osteotomy. An osteotome with 10-mm width, 5-mm thickness was introduced through the anteromedial portal under fluoroscopic guidance, and the osteotomy was performed at the level of the distal tibial joint surface, shortening the fibula by the osteotome's thickness (Figure 1). Coronal alignment was then controlled under fluoroscopy. If varus correction was insufficient, the proximal fibula was further shortened 2 to 5 mm utilizing a burr. The entire procedure was visualized through the standard anterior portals without additional incisions.

Fixation in both groups was achieved under arthroscopic and fluoroscopic guidance, in neutral ankle flexion with 10° of external rotation, using two or three 6.5-mm cannulated screws (Figure 2). The incisions were closed and a short leg splint was then applied.

Postoperative protocol

All patients were allowed to mobilize without weight-bearing in postoperative day one. All splints were removed at the beginning of the fourth postoperative week, and patients were allowed partial weight-bearing as tolerated. Both groups were allowed to bear their full weight by the end of the second postoperative month.

Time to mobilization with partial and full weight-bearing and complications were documented at each scheduled follow-up visit. Additionally, SF-36, VAS and AOFAS scores were evaluated at three, six, 12, and 24 months.

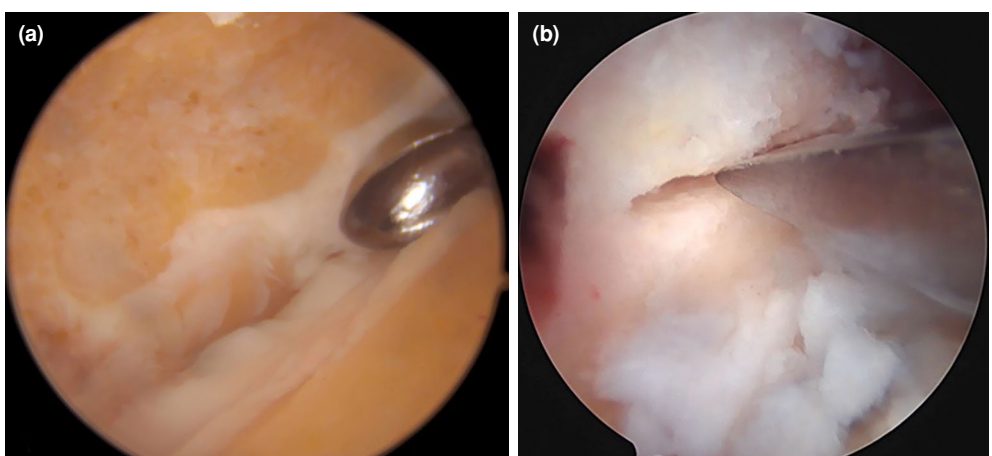


FIGURE 1. (a) Arthroscopic view through the anteromedial portal showing the debrided lateral gutter and removal of the fibular articular cartilage. **(b)** Fibular osteotomy performed through an osteotome introduced through the anteromedial portal and viewed through the anterolateral portal.

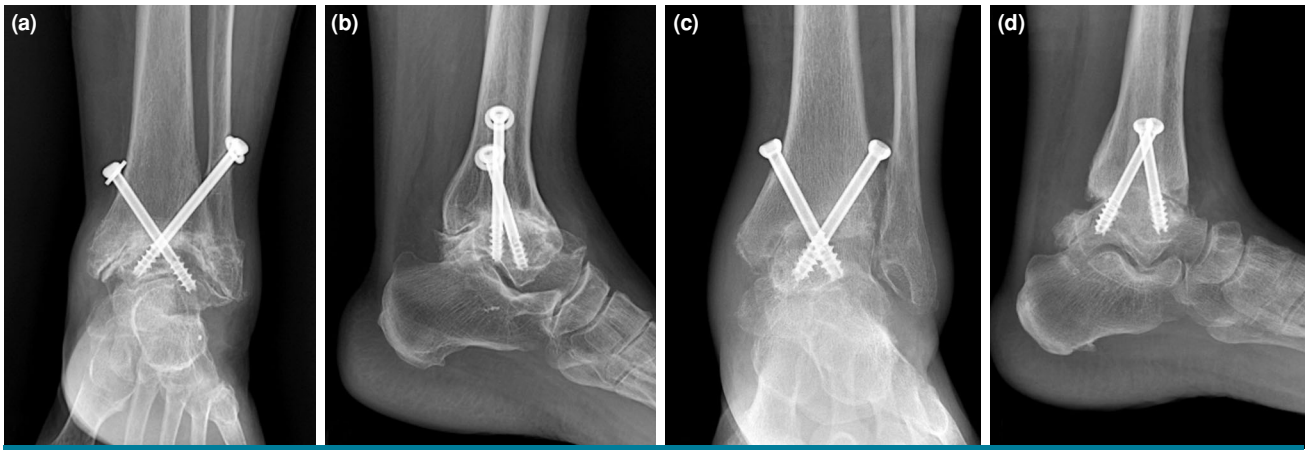


FIGURE 2. Radiographs **(a)** (anterior-posterior) and **(b)** (lateral) are from early postoperative visit of a patient with significant preoperative ankle varus deformity. Note that radiograph A shows the correction of the coronal deformity and the fibular osteotomy line. Radiographs **(c)** (anterior-posterior) and **(d)** (lateral) illustrate the early postoperative condition of a patient in Group B with a preoperative mild coronal deformity.

Radiological assessment

As of the first postoperative month, anteroposterior, lateral, and mortise radiographs were taken at each subsequent visit. Complete fusion was defined as the closure of the joint space with a complete cortical bone bridge over the fusion site. Radiographs obtained during follow-up visits were evaluated by two orthopedic surgeons to determine the time to fusion (in weeks). The evaluators were not blinded to the patient groups or surgical technique. In case of disagreement, the senior surgeon made the final decision.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). Continuous data were expressed in mean ± standard deviation (SD) or median (min-max), while categorical data were expressed in number and frequency. The relationship between two categorical variables was analyzed using the chi-square test. The Fisher exact test was utilized for the comparison of categorical distribution of BMI in groups. The Mann-Whitney U test was utilized for comparison of continuous variables between groups. The 95% confidence intervals (CIs) for the mean difference were also calculated for key perioperative and clinical outcomes. For significant findings from the Mann-Whitney U test, the rank-biserial correlation (rB) was calculated to determine the effect size. A p value of < 0.05 was considered statistically significant.

RESULTS

Of the 49 patients included in the study, Group A consisted of 20 patients with end-stage tibiotalar OA with ankle joint alignment of ≥10° varus and Group B consisted of 29 patients with less alignment disturbance.

There was no statistically significant difference between the groups in terms of age, sex, or the affected sides between the groups ($p = 0.210$, $p = 0.348$, and $p = 0.906$, respectively). While all the patients had a follow-up duration that longer than two years, 61.22% had more than three years and 28.57% had more than four years. There was also no significant difference between groups in terms of smoking ($p = 0.938$). The details of the demographic data are presented in Table I.

According to the BMI category, more than half of the patients in both groups were overweight or had obesity. However, there was a trend toward higher BMI categories in Group A compared to Group B, indicating a statistically significant difference ($p = 0.048$). According to Takakura Classification, 19 patients had Stage IIIB and 30 had Stage IV arthrosis. There was a significantly higher proportion of Stage IV cases in Group A compared to Group B ($p = 0.025$).

The etiology of the ankle arthrosis was related to trauma in all patients with a heterogenous distribution of directly affected structures (Table I). Although all patients reported a history of trauma in their anamnesis, the length of time that had elapsed made it difficult to pinpoint the precise

TABLE I
Distribution of patients' demographic characteristics and related medical conditions according to groups.

	Group A (≥ 10° varus)			Group B (< 10° varus)			Total		
	n	%	Mean ± SD	n	%	Mean ± SD	n	%	Mean ± SD
Age (year)			46.75 ± 15.65			52.24 ± 13.87			50.00 ± 14.72
Sex									
Male	11	55.00		12	41.38		23	46.94	
Female	9	45.00		17	58.62		26	53.06	
Side									
Right	10	55.00		15	51.72		25	51.02	
Left	10	55.00		14	48.28		24	48.98	
Follow-up time (year)									
≥ 2	20	100.00		29	100.00		49	100.00	
≥ 3	14	70.00		16	55.17		30	61.22	
≥ 4	7	35.00		7	24.14		14	28.57	
Cigarette smoking									
No	14	70.00		20	68.97		34	69.39	
Yes	6	30.00		9	31.03		15	30.61	
Body mass index (kg/m^2)									
Underweight (< 18.5)	0	0.00		4	13.79		4	8.16	
Normal (18.5-24.9)	7	35.00		8	27.59		15	30.61	
Overweight (25-29.9)	10	50.00		15	51.72		25	51.02	
Obese (≥ 30)	3	15.00		2	6.90		5	10.20	
Takakura staging									
IIIB	4	20.00		15	51.72		19	38.78	
IV	16	80.00		14	48.28		30	61.22	
Etiology of ankle arthrosis									
Ankle instability	1	5.00		2	6.90		3	6.12	
Pilon fracture	2	10.00		5	17.24		7	14.29	
Bimalleolar fracture	2	10.00		0	0.00		2	4.08	
Calcaneus fracture	2	10.00		0	0.00		2	4.08	
Motor deficit	2	10.00		0	0.00		2	4.08	
Trauma history with unknown details	11	55.00		22	75.86		33	67.34	
Failed arthroscopic tibiotalar arthrodesis	2	10.00		1	3.45		3	6 .12	
Diabetes mellitus	1	5.00		5	17.24		6	12.24	
Other comorbidities	9	45.00		6	20.69		15	30.61	
Total knee arthroplasty	1	5.00		2	6.90		3	6.12	
Hip arthroplasty	0	0.00		1	3.45		1	2.04	
Hammer toe	1	5.00		0	0.00		1	2.04	

SD, standard deviation.

position of the fracture or the afflicted component in many of them. In two patients in Group A, the arthrosis was related to walking disturbances and motor deficit with drop foot. Additionally, two patients in Group A and one in Group B had a history of unsuccessful arthroscopic arthrodesis. One patient in Group A and five in Group B had DM and 15 patients in total had other comorbid conditions such as hypertension, coronary artery disease, and early-stage renal insufficiency.

The mean duration of the operation was 85.50 ± 9.72 min in Group A which included arthroscopic fibular osteotomy and

TABLE II
Comparison of perioperative and postoperative parameters according to preoperative varus angle severity

	Group A (≥ 10° varus)			Group B (< 10° varus)			Total			
	Mean ± SD	Min-Max	IQR	Mean ± SD	Min-Max	IQR	Mean ± SD	Min-Max	IQR	*p*
Duration of surgery (min)	85.50 ± 9.72	75-115	10	57.59 ± 5.61	50-70	5	68.98 ± 15.75	50-115	25	**< 0.001**
Length of hospital stay (days)	1.95 ± 0.69	1-3	0	1.48 ± 0.57	1-3	1	1.67 ± 0.66	1-3	1	0.017
Time to partial weight bearing (weeks)	6.65 ± 0.75	6-8	1	6.76 ± 1.19	6-11	1	6.71 ± 1.02	6-11	1	0.821
Time to full weight bearing (weeks)	9.10 ± 0.85	8-11	1	9.45 ± 1.68	8-16	2	9.31 ± 1.36	8-16	2	0.581
Time to union (weeks)	9.60 ± 2.14	8-16	2	10.41 ± 2.26	8-18	2	10.08 ± 2.23	8-18	2	0.064

SD, standard deviation; IQR, interquartile range.

57.59 ± 5.61 min in Group B. The difference was statistically significant ($p < 0.001$; 95% CI 22.97 to 32.85). The median length of hospital stay was also significantly longer in Group A (1.95 *vs.* 1.48 days, $p = 0.017$; 95% CI 0.09 to 0.85). The mean fusion time was 10.08 ± 2.23 weeks, with values of 9.6 ± 2.14 weeks in Group A and 10.41 ± 2.26 weeks in Group B; however, the difference was not statistically significant ($p = 0.064$; 95% CI –2.10 to 0.47). The time ranges were eight to 16 weeks in Group A and eight to 18 weeks in Group B. One patient in Group A and three patients in Group B with longest fusion durations were smokers. There was no statistically significant difference in the length of time between the surgery and either partial or full weight-bearing. In Group B, the implants of a patient with a history of tibia fracture and infection were removed utilizing a stab incision, and asymptomatic nonunion was observed at that patient (Table II).

There were two incidents of postoperative superficial wound infection in each group which were all treated within the first three months with conservative measures without requiring surgical intervention. Also, there was one case of asymptomatic nonunion in Group B mentioned before, according to our radiological criteria. Due to the low number of different complications in the groups, statistical analysis was performed by evaluating all complications together including asymptomatic nonunion (Table III). No significant difference was found in the comparison performed ($p = 1.000$).

Comparisons of preoperative and postoperative three-, six- 12-, and 24-month VAS scores between the groups revealed no significant differences, with the exception of the postoperative three-month (Table IV). The three-month VAS scores were markedly higher in the group that had arthroscopic fibula osteotomy (p = 0.020). In the assessment of AOFAS scores, significant differences were observed between the groups at three, six, and 24 months in favor of Group 2 ($p = 0.011$, $p = 0.008$, and $p = 0.027$, respectively). The only significant difference between the groups for SF-36 scores was observed in the preoperative period, where Group A exhibited higher scores ($p = 0.037$). In comparison to the preoperative condition, there was significant and consistent improvements in all three scores for every postoperative measurement time ($p < 0.001$).

TABLE III
The relationship between the complications and preoperative varus angle severity

	Group A (≥ 10° varus)		Group B (< 10° varus)		Total		
	n	%	n	%	n	%	*p*
Asymptomatic non-union	0	0.00	1	3.45	1	2.04	-
Superficial wound infection	2	10.00	2	6.90	4	8.16	-
All complications	2	10.00	3	10.35	5	10.20	1.000

DISCUSSION

In the present study, we evaluated the outcomes of arthroscopic ankle arthrodesis with intra-articular fibular osteotomy in patients with ≥ 10° varus malalignment and compared the results with those with < 10° deformity. To the best of our knowledge, this is the first clinical study to demonstrate the effectiveness of this specific single-stage arthroscopic procedure using intra-articular fibular osteotomy without an additional incision in varus deformities greater than 10°. The main finding of this study was that this technique could yield favorable clinical outcomes. In addition, functional AOFAS scores were higher in the mild deformity group, while the overall quality of life as assessed by the SF-36 for patients with significant varus deformity was comparable, highlighting the effectiveness of the procedure for complex cases.

The ankle acts as an important pivot point for human mobilization and trauma is the most common etiology for ankle OA among other causes like chronic instability, rheumatological diseases and septic arthritis.[19,20] The clinical progression of ankle OA is described by the Takakura classification, which delineates an order of severity from minimal joint narrowing in Stage I to extensive degeneration and talus tilt in Stage IV.[21] In Takakura Stages III or IV of varus OA, previous research has indicated favorable outcomes with ankle arthrodesis or ankle replacement.[22,23] In our study, all patients were classified as Stage IIIB (n = 19) and Stage IV (n = 30). In our cohort, the etiologic factors were trauma, associated instability, and motor deficits.

From a biomechanical standpoint, varus and valgus abnormalities accelerate the development of OA by altering the load distribution throughout the joint. Varus deformity, in particular, causes increased stress on the medial joint compartment, leading to asymmetrical degeneration of cartilage.[7] The progression of varus deformity is characterized by the medial shift of the mechanical axis and the medial displacement of the talus; this condition not only exacerbates pain, but also directly influences the results of surgical intervention.[2,8] Consequently, the precise diagnosis of varus deformity and reassurance of proper anatomical alignment during the surgical planning phase are essential for enhancing fusion success and improving long-term clinical outcomes.[24-26] While our technique addresses the fibula as a mechanical block, its primary biomechanical advantage is likely the creation of a lateral space, which permits the medially subluxated talus to be reduced and re-centered under the tibial mechanical axis. This lateralization is critical to maximize the tibiotalar contact surface area, which is a known prerequisite for successful and durable fusion.[27] Zanolli et al.[28] and Jennison et al.[29] showed in their study on subtalar arthrodesis, which is frequently combined with ankle arthrodesis, that the biomechanical alterations connected to varus deformities led to complications. This emphasizes the vital importance of correcting deformities, particularly in the coronal plane, in patients with varus OA. According to Lawton et al.,[24] improper alignment may expose adjacent joints at risk for degenerative changes postoperatively.

Arthroscopic ankle arthrodesis was initially described by Schneider.[30] It yields higher success rates when careful patient selection and the correct surgical techniques are employed, in cases of ankle arthritis along with complex anatomical abnormalities such varus deformity. Literature findings indicate that arthroscopic treatments diminish complication rates, shorten the healing process, while improving patient satisfaction relative to conventional open approaches.[14,31,32] The advantages of arthroscopic techniques contribute to sooner postoperative mobilization and enhance quality of life in a reduced timeframe. A literature review on healing outcomes indicates that arthroscopic arthrodesis usually decreases healing

TABLE IV

Comparison of VAS, AOFAS and SF-36 scores' improvements according to preoperative varus angle severity

	Group A (≥ 10° varus)			Group B (< 10° varus)			Total			
	Mean ± SD	Min-Max	IQR	Mean ± SD	Min-Max	IQR	Mean ± SD	Min-Max	IQR	*p**
VAS										
Preoperative	7.90 ± 0.91	7-10	2	7.90 ± 0.90	6-10	1	7.90 ± 0.90	6-10	1	0.906
Third month	5.10 ± 0.97	4-7	2	4.34 ± 1.11	2-7	1	4.65 ± 1.11	2-7	1	**0.020**
Sixth month	3.55 ± 1.00	2-6	1	3.79 ± 0.82	2-5	1	3.69 ± 0.90	2-6	1	0.213
First year	2.95 ± 0.83	1-4	1	2.79 ± 0.90	1-4	1	2.86 ± 0.87	1-4	1	0.576
Second year	1.30 ± 0.47	1-2	1	1.28 ± 0.46	1-2	1	1.29 ± 0.46	1-2	1	0.856
AOFAS										
Preoperative	35.80 ± 8.65	20-50	11	41.34 ± 12.08	24-62	22	39.08 ± 11.06	20-62	18	0.178
Third month	64.90 ± 9.18	42-80	11	72.86 ± 8.63	58-88	15	69.61 ± 9.62	42-88	12	**0.011**
Sixth month	67.00 ± 6.54	54-80	10	73.72 ± 9.53	52-92	12	70.98 ± 9.00	52-92	12	**0.008**
First year	71.50 ± 6.80	58-84	9	76.17 ± 8.72	62-94	12	74.27 ± 8.25	58-94	10	0.108
Second year	72.70 ± 6.91	60-86	10	78.52 ± 8.69	66-98	14	76.14 ± 8.44	60-98	11	**0.027**
SF-36										
Preoperative	57.88 ± 7.87	40-70	8.8	53.72 ± 7.17	42-68	10	55.42 ± 7.67	40-70	12	**0.037**
Third month	74.38 ± 7.43	62.5-85	12.5	77.83 ± 6.23	62-88	7	76.42 ± 6.89	62-88	6	0.112
Sixth month	83.50 ± 5.67	70-90	8	83.45 ± 5.84	68-92	5	83.47 ± 5.71	68-92	8	0.984
First year	84.95 ± 4.49	76-92	6	84.76 ± 5.05	74-94	5	84.84 ± 4.78	74-94	6	0.984
Second year	86.50 ± 3.55	80-92	5	86.62 ± 4.44	78-94	4	86.57 ± 4.06	78-94	6	0.649

VAS, Visual Analog Scale for pain; AOFAS, American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Score; SD, standard deviation; IQR, interquartile range; SF-36, Short Form-36; * Rank-Biserial Correlation (effect size).

time, while concerns persist regarding postoperative pain management and the risk of nonunion.[26,33]

Sufficient contact between bone surfaces is a crucial requirement for successful arthrodesis and fusion.[34] The fibula's involvement with the varus ankle joints could hinder the necessary adequate contact. Smith and Wood described fibula excision during open ankle arthrodesis in individuals with varus OA.[35] Fibula resection during open ankle arthrodesis by a transfibular technique has been recognized for its optimal joint exposure.[36] However, the choice between open and arthroscopic correction in severe deformity remains a critical point of debate. Many surgeons still prefer an open transfibular or anterior approach for severe varus (> 15°), arguing it provides superior visualization and mechanical control to ensure anatomic reduction, with some evidence suggesting that attempted arthroscopic correction of such large deformities carries a higher risk of malunion.[37] Our study, which used a 10° threshold, challenges this by demonstrating that an arthroscopic-only approach, when augmented by our osteotomy technique, can successfully correct the deformity without the significant soft-tissue morbidity associated with open procedures. Fibula excision in ankle arthrodesis is typically examined in comparison with supramalleolar tibial osteotomy with a lateral approach.[17] Mehdi et al.[38] conducted fibular shortening osteotomy during open ankle arthrodesis in varus, valgus, and normal ankles, reporting a 97.6% union rate in 42 arthrodesis patients. de Leeuw et al.[39] indicated that arthroscopic techniques yielded comparable fusion rates to conventional open arthrodesis while reducing hospital durations, therefore expediting the rehabilitation process. Advanced arthroscopic procedures and instruments facilitate joint preparation while reducing soft tissue trauma, thus establishing an optimal environment for fusion.[40]

Our study revealed remarkable clinical enhancement in both groups. Despite the extended duration of surgery in severe varus group due to fibular osteotomy, no statistically significant difference was observed in the recovery duration. Based on these findings, we can speculate that arthroscopic fibular osteotomy can achieve removal of the mechanical obstruction posed by the fibula in varus OA without necessitating further surgical incisions.

In the current study, there were three patients with previously failed arthroscopic ankle arthrodesis. Nonunion refers to the inability of bone to unite after surgical intervention, potentially resulting in functional restrictions, increased morbidity, and the necessity for further surgical procedures.[26,33] Numerous factors affect the likelihood of nonunion following arthroscopic ankle arthrodesis. Smoking is a well-recognized risk factor that markedly elevates the likelihood of nonunion.[41] Moreover, factors such as male sex, neuropathic arthropathy, or a prior infection in the surgical site have been linked to nonunion.[26,42] The rates of nonunion following ankle arthrodesis exhibit significant variability. While literature indicates failure rates as high as 40%,[26] a recent study has demonstrated that these rates vary from 3 to 15% for arthroscopic techniques and from 7.4 to 12.1% for conventional open surgical methods.[43] Patel et al.[26] and Colman et al.[44] similarly observed that fusion rates of up to 100% could be attained using arthroscopic arthrodesis. Our study showed fusion times were between eight to 16 weeks in Group A and eight to 18 weeks in Group B. We assume that the minimal stimulation of bone marrow during fibular osteotomy, along with the autografts from the osteotomy site, aids in the healing process.

The union periods were longer in the four patients who persisted in smoking. Research indicates that smoking adversely impacts bone repair and fusion outcomes.[45] The results of this study reaffirm the detrimental impact of smoking on bone healing. Gutteck et al.[16] showed that nonunion rates following arthrodesis were markedly elevated in individuals with a history of diabetes-related complications. There were six patients with DM, and they were not the ones with longer fusion durations. Another study indicated that diabetes mellitus impeded fracture healing; nevertheless, this study argued that DM alone was not a critical risk factor, as factors including uncontrolled hyperglycemia and infection significantly contribute as mentioned in the literature.[46] In our study, two patients from each group had a superficial infection at the fixation sites, which recovered with simple medical treatment.

In our study, the durations for partial and full weight-bearing were comparable among the groups. The application of fibular osteotomy via arthroscopic portals does not prolong recovery time, even though pain scores at the three-month assessment were elevated in the osteotomy group. Subsequent evaluations indicated that VAS scores were comparable in both groups.

Furthermore, the AOFAS scores were higher in Group B at three, six, and 24 months. Yet, there was a substantial improvement in postoperative scores aligning with the results of Semenistyy's work which was a minimally invasive transfibular approach conducted on 12 ankles.[47] Our study revealed that SF-36 scores exhibited no significant differences between groups in any postoperative assessments, which encourages us to believe that this technique can achieve similar quality of life outcomes to those seen in patients with less varus deformity who do not require corrective osteotomy.

Previous infections are also known to potentially influence long-term bone healing. This risk can be minimized with the application of suitable surgical methods and stable fixation. Asymptomatic nonunion occurred in a patient in Group B with a history of infection at the previously operated tibial fracture site, indicating that a two-stage surgical approach may be a safer option in such circumstances. These findings highlight the critical necessity of a comprehensive assessment of the patient's systemic diseases, vascular status, and previous surgical history prior to surgery to improve surgical outcomes.

The present study has certain limitations. First, we compared patients with significant varus angulation who underwent correction with arthroscopic fibular osteotomy with the patients having less varus deformity with no need for bony correction. An ideal control group would be patients with similar varus angles who underwent arthroscopic arthrodesis along with open fibular osteotomy to correct the deformity. As we did not have a comparable group of patients who underwent open fibular osteotomy by the same surgeon, we compared them with patients who did not have deformities requiring surgical correction during arthroscopic arthrodesis. Second, the retrospective design of the study inherently predisposes the findings to bias and precludes the uniform application of standardized follow-up protocols despite the existence of strict institutional documentation standards for follow-up. The lack of explicit blinding of clinical evaluators to patient data or clinical outcomes introduces an additional risk of assessment bias. Third, the single-center and single-surgeon setting with a relatively small sample size and a follow-up duration of less than five years further constrains the external validity and the long-term interpretability of the results, thereby limiting their applicability to broader, more heterogeneous clinical populations. Finally, while our two-year follow-up is sufficient to assess fusion and early clinical improvement, the primary long-term concern following ankle arthrodesis is the development of symptomatic adjacent joint arthritis. Longer-term studies with 10- and 20-year follow-ups consistently demonstrate a high rate of progressive subtalar and talonavicular degeneration, a complication our study is not powered to address.[48]

In conclusion, this study offers meaningful contributions to the current understanding of single-stage arthroscopic ankle arthrodesis via intra-articular fibular osteotomy for varus ankle arthritis. To the best of our knowledge, this is the first study to demonstrate that arthroscopic ankle arthrodesis with arthroscopic fibular osteotomy can achieve good clinical outcomes in patients with significant varus deformity. Taken together, we believe that arthroscopic fibular osteotomy eliminates the mechanical obstruction caused by the fibula in varus OA without the need for additional surgical incisions. Future multi-center, large-scale, prospective, randomized-controlled trials with larger cohorts and extended follow-up periods are required to validate and expand these findings.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Conceptualization, writing-original draft preparation: M.O.A., B.B.; Methodology: M.O.A., N.M.; Data curation: B.B., N.M.; Writing-review and editing: N.M., B.B.; Supervision: M.O.A. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

AI Disclosure: The authors declare that artificial intelligence (AI) tools were not used, or were used solely for language editing, and had no role in data analysis, interpretation, or the formulation of conclusions. All scientific content, data interpretation, and conclusions are the sole responsibility of the authors. The authors further confirm that AI tools were not used to generate, fabricate, or 'hallucinate' references, and that all references have been carefully verified for accuracy.

REFERENCES

1. Valderrabano V, Horisberger M, Russell I, Dougall H, Hintermann B. Etiology of ankle osteoarthritis. Clin Orthop Relat Res 2009;467:1800-6. doi: 10.1007/s11999-008-0543-6.
2. Takakura Y, Takaoka T, Tanaka Y, Yajima H, Tamai S. Results of opening-wedge osteotomy for the treatment of a post-traumatic varus deformity of the ankle. J Bone Joint

Surg Am 1998;80:213-8. doi: 10.2106/00004623-199802000-00008.
3. Thomas RH, Daniels TR. Ankle arthritis. J Bone Joint Surg Am 2003;85:923-36. doi: 10.2106/00004623-200305000-00026.
4. Monroe MT, Beals TC, Manoli A 2nd. Clinical outcome of arthrodesis of the ankle using rigid internal fixation with cancellous screws. Foot Ankle Int 1999;20:227-31. doi: 10.1177/107110079902000404.
5. Herrera-Pérez M, González-Martín D, Vallejo-Márquez M, Godoy-Santos AL, Valderrabano V, Tejero S. Ankle osteoarthritis aetiology. J Clin Med 2021;10:4489. doi: 10.3390/jcm10194489.
6. Liang JQ, Wang JH, Zhang Y, Wen XD, Liu PL, Liang XJ, et al. Fibular osteotomy is helpful for talar reduction in the treatment of varus ankle osteoarthritis with supramalleolar osteotomy. J Orthop Surg Res 2021;16:575. doi: 10.1186/s13018-021-02732-8.
7. Kurokawa H, Taniguchi A, Ueno Y, Miyamoto T, Tanaka Y. Risk factors for the progression of varus ankle osteoarthritis. Foot Ankle Orthop 2023;8:24730114231178763. doi: 10.1177/24730114231178763.
8. Barg A, Pagenstert GI, Hügle T, Gloyer M, Wiewiorski M, Henninger HB, et al. Ankle osteoarthritis: Etiology, diagnostics, and classification. Foot Ankle Clin 2013;18:411-26. doi: 10.1016/j.fcl.2013.06.001.
9. Takakura Y, Tanaka Y, Kumai T, Tamai S. Low tibial osteotomy for osteoarthritis of the ankle. Results of a new operation in 18 patients. J Bone Joint Surg Br 1995;77:50-4.
10. Schenk K, Lieske S, John M, Franke K, Mouly S, Lizee E, et al. Prospective study of a cementless, mobile-bearing, third generation total ankle prosthesis. Foot Ankle Int 2011;32:755-63. doi: 10.3113/FAI.2011.0755.
11. Hennessy C, Abram S, Loizou C, Brown R, Sharp B, Kendal A. Long-term consequences of total ankle arthroplasty versus ankle fusion: a 25-year national population study of 41,000 patients. Orthop Procs 2025;107-B(Supp_1):4-4. doi:10.1302/1358-992X.2025.1.004
12. Tanaka Y, Takakura Y, Hayashi K, Taniguchi A, Kumai T, Sugimoto K. Low tibial osteotomy for varus-type osteoarthritis of the ankle. J Bone Joint Surg Br 2006;88:909-13. doi: 10.1302/0301-620X.88B7.17325.
13. Daniels TR, Younger AS, Penner M, Wing K, Dryden PJ, Wong H, et al. Intermediate-term results of total ankle replacement and ankle arthrodesis: A COFAS multicenter study. J Bone Joint Surg Am 2014;96:135-42. doi: 10.2106/JBJS.L.01597.
14. Chen B, Tan F, Li X. An assessment of ankle function, oxidative damage, and Inflammatory factor levels in minimally invasive ankle joint fusion surgery for the treatment of traumatic ankle osteoarthritis. Int J Morphol 2024;42:462–9.
15. Bai Z, Yang Y, Chen S, Dong Y, Cao X, Qin W, et al. Clinical effectiveness of arthroscopic vs open ankle arthrodesis for advanced ankle arthritis: A systematic review and meta-analysis. Medicine (Baltimore) 2021;100:e24998. doi: 10.1097/MD.0000000000024998.
16. Gutteck N, Delank KS, Schilde S. Comparative results of arthroscopic ankle arthrodesis vs. open arthrodesis in patients with diabetes-associated Charcot Neuro-Arthropathy. Eur J Orthop Surg Traumatol 2023;33:3577-84. doi: 10.1007/s00590-023-03592-0.
17. Bernasconi A, Mehdi N, Lintz F. Fibular intra-articular resection during arthroscopic ankle arthrodesis: The surgical technique. Arthrosc Tech 2017;6:e1865-70. doi: 10.1016/j.eats.2017.07.007.
18. Harada S, Teramoto T, Takaki M, Asahara T, Katoh N, Takenaka N, et al. Radiological assessments and clinical results of intra-articular osteotomy for traumatic osteoarthritis of the ankle. Injury 2021;52:3516-27. doi: 10.1016/j.injury.2021.08.022.
19. Harrington KD. Degenerative arthritis of the ankle secondary to long-standing lateral ligament instability. J Bone Joint Surg Am 1979;61:354-61.
20. Liu N, Zhang M, Feng SM, Bi YL, Zhai HW, Meng Q. Effect of hip strategy-based motion control training on walking function restoration after ankle joint injury. Jt Dis Relat Surg 2024;35:54-61. doi: 10.52312/jdrs.2023.1277.
21. Kim H, Choi J, Jang CY, Lee JW, Kim S, Han SH. Automatic grading of ankle osteoarthritis based on takakura staging system: a deep learning- based approach. Foot Ankle Orthop 2019;4. doi: 10.1177/2473011419S00246.
22. Trajkovski T, Pinsker E, Cadden A, Daniels T. Outcomes of ankle arthroplasty with preoperative coronal-plane varus deformity of 10° or greater. J Bone Joint Surg Am 2013;95:1382-8. doi: 10.2106/JBJS.L.00797.
23. Maenohara Y, Taniguchi A, Tomiwa K, Tsuboyama D, Kurokawa H, Kumai T, et al. Outcomes of bilateral vs unilateral ankle arthrodesis. Foot Ankle Int 2018;39:530-4. doi: 10.1177/1071100717749505.
24. Lawton CD, Butler BA, Dekker RG 2nd, Prescott A, Kadakia AR. Total ankle arthroplasty versus ankle arthrodesis-a comparison of outcomes over the last decade. J Orthop Surg Res 2017;12:76. doi: 10.1186/s13018-017-0576-1.
25. Xu Y, Li XC, Guo CJ, Xu XY. Intra-articular opening osteotomy combined with lateral ligament reconstruction for varus ankle arthritis. J Orthop Surg Res 2021;16:7. doi: 10.1186/s13018-020-02143-1.
26. Patel S, Baker L, Perez J, Vulcano E, Kaplan J, Aiyer A. Risk factors for nonunion following ankle arthrodesis: A systematic review and meta-analysis. Foot Ankle Spec 2023;16:60-77. doi: 10.1177/1938640021998493.
27. Thordarson DB, Motamed S, Hedman T, Ebramzadeh E, Bakshian S. The effect of fibular malreduction on contact pressures in an ankle fracture malunion model. J Bone Joint Surg Am 1997;79:1809-15. doi: 10.2106/00004623-199712000-00006.
28. Zanolli DH, Nunley JA 2nd, Easley ME. Subtalar fusion rate in patients with previous ipsilateral ankle arthrodesis. Foot Ankle Int 2015;36:1025-8. doi: 10.1177/1071100715584014.
29. Jennison T, Dalgleish J, Taher S, Chadwick C, Blundell C, Davies M, et al. Subtalar arthrodesis union rates with and without adjacent ankle arthrodesis. Foot Ankle Int 2022;43:1295-9. doi: 10.1177/10711007221110873.
30. Collman DR, Kaas MH, Schuberth JM. Arthroscopic ankle arthrodesis: Factors influencing union in 39 consecutive patients. Foot Ankle Int 2006;27:1079-85. doi: 10.1177/107110070602701214.
31. Bloch B, Srinivasan S, Mangwani J. Current concepts in the management of ankle osteoarthritis: A systematic review. J Foot Ankle Surg 2015;54:932-9. doi: 10.1053/j.jfas.2014.12.042.
32. Honnenahalli Chandrappa M, Hajibandeh S, Hajibandeh S. Ankle arthrodesis-open versus arthroscopic: A systematic review and meta-analysis. J Clin Orthop Trauma 2017;8:S71-7. doi: 10.1016/j.jcot.2017.03.010.

33. Park JJ, Son WS, Woo IH, Park CH. Combined transfibular and anterior approaches increase union rate and decrease non-weight-bearing periods in ankle arthrodesis: Combined approaches in ankle arthrodesis. J Clin Med 2021;10:5915. doi: 10.3390/jcm10245915.
34. Winson IG, Robinson DE, Allen PE. Arthroscopic ankle arthrodesis. J Bone Joint Surg Br 2005;87:343-7. doi: 10.1302/0301-620x.87b3.15756.
35. Smith R, Wood PL. Arthrodesis of the ankle in the presence of a large deformity in the coronal plane. J Bone Joint Surg Br 2007;89:615-9. doi: 10.1302/0301-620X.89B5.18109.
36. Verhelst MP, Mulier JC, Hoogmartens MJ, Spaas F. Arthrodesis of the ankle joint with complete removal of the distal part of the fibula: Experience with the transfibular approach and three different types of fixation. Clin Orthop Relat Res 1976;(118):93-9.
37. Yasui Y, Hannon CP, Seow D, Kennedy JG. Ankle arthrodesis: A systematic approach and review of the literature. World J Orthop 2016;7:700-8. doi: 10.5312/wjo.v7.i11.700.
38. Mehdi N, Bernasconi A, Laborde J, Lintz F. An original fibular shortening osteotomy technique in tibiotalar arthrodesis. Orthop Traumatol Surg Res 2017;103:717-20. doi: 10.1016/j.otsr.2017.03.023.
39. de Leeuw PA, Hendrickx RP, van Dijk CN, Stufkens SS, Kerkhoffs GM. Midterm results of posterior arthroscopic ankle fusion. Knee Surg Sports Traumatol Arthrosc 2016;24:1326-31. doi: 10.1007/s00167-015-3975-z.
40. Marsh A, Kooner S, Conlin C, Hussain R, Yeganeh KM, Lau J. Arthroscopic ankle arthrodesis: a review of current concepts and technique. Tech Foot Ankle Surg 2020;19:19-25.
41. Fragomen AT, Borst E, Schachter L, Lyman S, Rozbruch SR. Complex ankle arthrodesis using the Ilizarov method yields high rate of fusion. Clin Orthop Relat Res 2012;470:2864-73. doi: 10.1007/s11999-012-2470-9.
42. Chalayon O, Wang B, Blankenhorn B, Jackson JB 3rd, Beals T, Nickisch F, et al. Factors affecting the outcomes of uncomplicated primary open ankle arthrodesis. Foot Ankle Int 2015;36:1170-9. doi: 10.1177/1071100715587045.
43. Cottino U, Collo G, Morino L, Cosentino A, Gallina V, Deregibus M, et al. Arthroscopic ankle arthrodesis: A review. Curr Rev Musculoskelet Med 2012;5:151-5. doi: 10.1007/s12178-012-9119-x.
44. Colman AB, Pomeroy GC. Transfibular ankle arthrodesis with rigid internal fixation: An assessment of outcome. Foot Ankle Int 2007;28:303-7. doi: 10.3113/FAI.2007.0303.
45. Patel RA, Wilson RF, Patel PA, Palmer RM. The effect of smoking on bone healing: A systematic review. Bone Joint Res 2013;2:102-11. doi: 10.1302/2046-3758.26.2000142.
46. Loder RT. The influence of diabetes mellitus on the healing of closed fractures. Clin Orthop Relat Res 1988;(232):210-6.
47. Semenistyy AA, Kehayov RI. Ankle arthrodesis through minimally-invasive transfibular approach: A new surgical technique. Eur J Orthop Surg Traumatol 2024;34:2483-92. doi: 10.1007/s00590-024-03950-6.
48. Coester LM, Saltzman CL, Leupold J, Pontarelli W. Long-term results following ankle arthrodesis for post-traumatic arthritis. J Bone Joint Surg Am 2001;83:219-28. doi: 10.2106/00004623-200102000-00009.