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ORIGINAL ARTICLE

Tibiotalocalcaneal arthrodesis with retrograde intramedullary nailing: What differs only approach change?

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Ankle arthrodesis has been successfully applied in many cases, including primary or secondary arthritis affecting the ankle, neuromuscular and congenital deformities, avascular necrosis of the talus, and Charcot arthropathy.[1,2] Retrograde intramedullary nails are one of the most preferred methods in daily practice in patients who are candidates for ankle arthrodesis and also have subtalar joint pathology due to their biomechanical advantages, such as increased rotational stability and load sharing.[1] It provides a plantigrade foot by fixing the subtalar and tibiotalar joint in a slight valgus position, significantly improving patients' functional capacity.[3] Despite favorable clinical outcomes and increased primary stability, complications such as infection, tibial fracture, nonunion, and implant failure have also been reported at non-negligible rates.[4]

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ABSTRACT

Objectives: This study aims to compare the clinical and radiographic outcomes of open (lateral transfibular) and arthroscopic joint debridement techniques in tibiotalocalcaneal arthrodesis (TTCA) using the same nail system.

Patients and methods: Between January 2011 and December 2022, a total of 62 patients (21 males, 41 females; mean age 53.81±16.68 years; range 18 to 82 years) who underwent TTCA with retrograde intramedullary nail were retrospectively analyzed. The patients were classified as open (n=30) or arthroscopy (n=32) based on the method used for joint debridement. Data including demographic characteristics, pre-and postoperative radiographs, skin-to-skin operative times, and fluoroscopy times were recorded. Tibiotalar and subtalar union rates, coronal and sagittal ankle alignment examined through coronal tibiotalar (CTT) and sagittal tibiotalar (STT) angles were also noted. Functional outcomes were measured using the American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Score (AOFAS-AHS) and Visual Analog Scale (VAS). Complications were evaluated.

Results: A total of 34 ankles (n=30) underwent open TTCA, while 34 ankles (n=32) had arthroscopic TTCA. Baseline characteristics and follow-up duration were similar between the groups (p>0.05). The overall fusion rate (tibiotalar and subtalar) was 94.1% in the open group and 85.3% in the arthroscopic group (p=0.425). Both open and arthroscopy groups achieved satisfactory coronal and sagittal ankle alignment. The median CTT angles were 94° and 91°, and STT angles were 109° and 112°, respectively. The arthroscopy group had significantly shorter operative time, fluoroscopy time, and hospital stay (p<0.001, p=0.019, p<0.001, respectively). No significant differences were found in complication rates, postoperative AOFAS-AHS, and VAS scores (p>0.05).

Conclusion: Both open and arthroscopic TTCA approaches yielded similar radiographic and clinical outcomes. Based on these findings, we can speculate that the arthroscopic technique may offer advantages in perioperative efficiency, suggesting it is a viable alternative in appropriately selected patients.

Keywords: Ankle arthrodesis, arthroscopic, hindfoot arthrodesis, intramedullary nail, open, tibiotalocalcaneal arthrodesis.

In tibiotalocalcaneal arthrodesis (TTCA), it is crucial to prepare the joint surfaces to create a stable environment that facilitates union. Traditionally, TTCA arthrodesis has been performed with open joint debridement, which achieves full access to the joint surfaces through arthrotomy, involving the mechanical removal of all cartilage tissues.[5] This open debridement technique allows for extensive surface preparation under direct vision and simplifies the correction of accompanying deformities. In contrast, recent trends highlight the benefits of arthroscopic techniques for joint debridement, which offer minimally invasive surgical options.[6] Open surgeries tend to have higher rates of complications such as infection, skin necrosis, and delayed wound healing due to the large incisions required.[7] While these complications are less common with arthroscopic surgery, challenges such as the potential for inadequate joint debridement due to limited visibility and improper alignment in advanced deformities may still arise.[8]

Surgical success is evaluated not only by radiological union, but also by how well the patient can resume daily living activities. Therefore, beyond the technical success of the surgery, the balance of functional gain and complication risk affecting the quality of life of the patient directly affects which method to choose. Given that less invasive surgeries are associated with more rapid recovery, previous studies have suggested that arthroscopic ankle arthrodesis has slightly more favorable functional outcomes and a superior fusion rate.[9,10] However, for TTCA, it has not been clearly demonstrated that either method is superior to the other in terms of fusion rates and functional outcomes.[11]

The length of surgery influences tissue exposure which, in turn, impacts the likelihood of complications and the healing process.[12] Additionally, the duration of fluoroscopy is crucial for safe surgical practices, as it dictates the level of radiation exposure for both the patient and the surgical team.[13] In previous publications, the operative time in open TTCA has been reported to be between 53 and 168 min; however, there is not enough data on fluoroscopy time.[8,14,15] To the best of our knowledge, no current study compares the surgical time and radiation exposure of two different joint debridement methods within a similar group, along with the clinical outcomes of these two methods.

In the present study, we aimed to evaluate patients who underwent TTCA using the same retrograde intramedullary nail, following either open or arthroscopic joint debridement. The primary objective was to compare clinical and radiographic outcomes between the two approaches, with a specific emphasis on union rates, coronal and sagittal ankle alignments, operative time, fluoroscopy duration, length of hospital stay, functional outcomes, and complication profiles.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Ankara University Faculty of Medicine, Department of Orthopedics and Traumatology between January 2011 and December 2022. Medical data of the patients who underwent TTCA with a retrograde intramedullary nail were reviewed. We identified 93 ankles operated by two surgeons, each with over 10 years of dedicated experience in foot and ankle surgery, as confirmed by institutional case logs that reflect comparable surgical volume. The patients were referred based on the date of hospital admission, without triage based on pathology severity or surgeon preference. The choice of surgical technique (open *vs.* arthroscopic joint debridement) corresponded with the assigned surgeon, as each surgeon consistently utilized only one technique. Both surgical approaches followed standardized and institutionally approved protocols, which are consistent with current practices.[16] Operative records confirmed devotion to these predefined steps in all cases. Although no randomization or matching was performed due to the limited sample size, baseline demographic and clinical characteristics between groups were statistically comparable, and no systematic differences in patient selection were present. Only patients aged over 18 years and with a minimum of 12 months of follow-up were included. All patients in this study had end-stage tibiotalar arthritis along with varying degrees of subtalar joint arthritis. Radiographic signs of the tibiotalar and subtalar joint osteoarthritis were graded based on the Kellgren classification.[17] Exclusion criteria were as follows: having previous talectomy surgery due to malignancy or osteomyelitis, deformities necessitating corrective osteotomies or soft tissue releases, nailing due to fracture without joint debridement, and missing follow-up data. Twenty-five of the 93 cases who underwent surgery were excluded from the study including eight patients with additional pathologies, 13 with no joint debridement due to acute geriatric fracture, and four with missing follow-up data. Finally, a total of 62 patients 21 males, 41 females; mean age 53.81±16.68 years; range 18 to 82 years) whose demographic characteristics, pre-and postoperative radiographs, skin-to-skin operative times, and fluoroscopy times were available were recruited. After the selection was completed, the patients were classified as open (n=30) or arthroscopy (n=32) based on the method used for joint debridement. The study flowchart is shown in Figure 1. Written informed consent was obtained from each patient. The study protocol was approved by the Ankara University, Faculty of Medicine, Ethics Committee (Date: 20.07.2022, No: İ06-385-22). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Surgical procedure

Open and arthroscopic arthrodesis procedures were conducted using a similar standardized technique, but only the operative approaches differed. All procedures were performed under general or spinal anesthesia, with the patient placed prone and a tourniquet applied to the thigh. The draping was done above the knee for limb alignment assessment. The feet and ankles were positioned away from the operating table to facilitate better control, and no traction was applied.

The standard lateral transfibular approach was used in the open technique, and the distal fibular segment of about 5 cm was resected. The articular cartilages of the tibiotalar and subtalar joints were resected using an oscillating saw, osteotomes, and curettes under fluoroscopic imaging to expose bleeding subchondral bone surfaces. Periarticular osteophytes and the medial malleolus were removed through the same incision, and the resected fibula was utilized as an autograft. In the arthroscopic technique, standard posteromedial and posterolateral portals were created 1 cm above the intersection of the horizontal line drawn from the lateral and medial malleoli and the longitudinal lines from the medial and lateral borders of the Achilles tendon. These portals were used to reach both the tibiotalar and subtalar joints. After the diagnostic arthroscopy was conducted and debridement of the synovial tissue was accomplished, the posterior talofibular

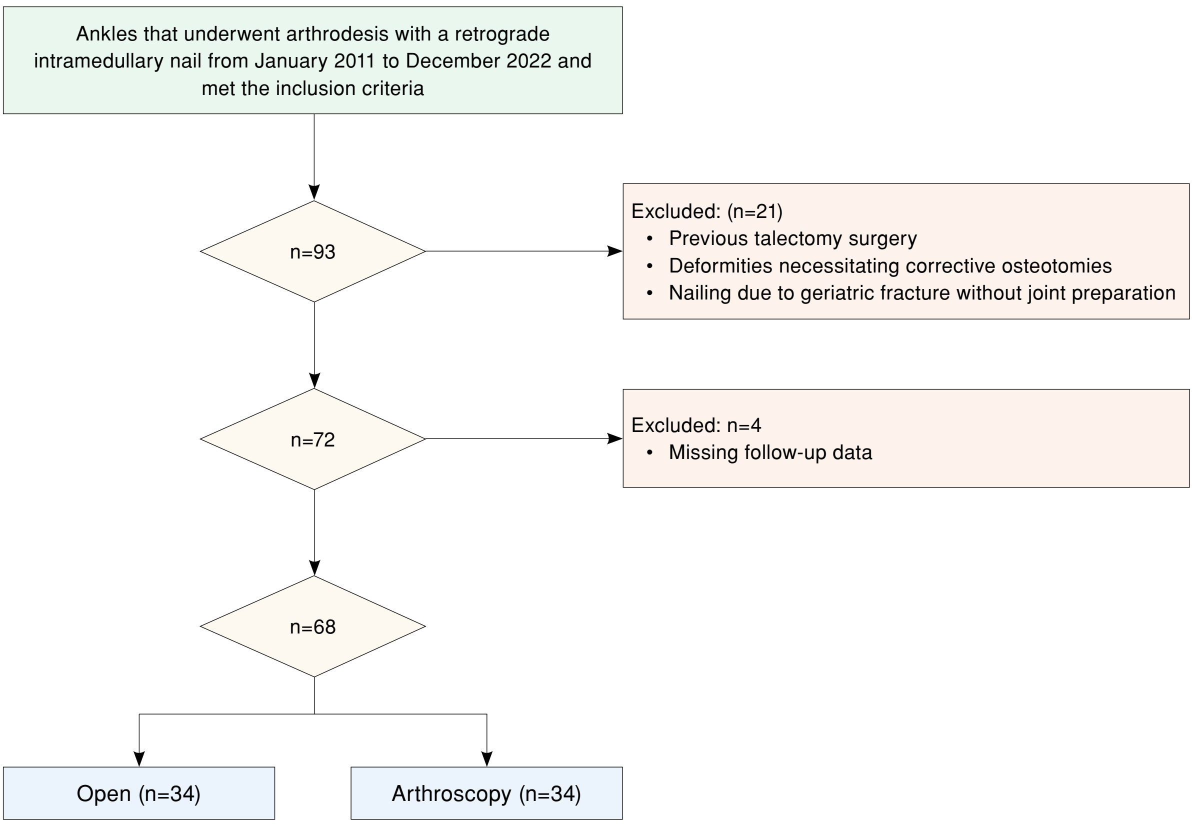

FIGURE 1. Study flowchart.

and transverse tibiofibular ligament tissues were resected from the posterior capsule. Subsequently, articular cartilage removal with the use of a shaver, curettes, and high-speed burr was made, until it reached the cancellous subchondral bone of both the tibiotalar and subtalar joints. The ankle was positioned in maximum dorsiflexion, particularly to excise cartilage in the anterior portion of the talus. The anterior capsule served as a reference to preserve the anterior vascular nerve bundle. To prevent damage to the tibialis posterior artery and nerves, meticulous care was exerted to avoid distorting the subtalar joint line.

When joint debridement was completed, the same fixation steps were followed for both groups. Once proper hindfoot alignment, neutral flexion, 0-5° hindfoot valgus, 0-5° external rotation, and contact of bony surfaces were provided, the ankle was temporarily fixed using multiple Kirschner wires (K-wires). Under intraoperative C-arm fluoroscopy, the long axis of the ankle/tibia for the anteroposterior (AP) and lateral plane was determined, and a longitudinal plantar incision of about 3 cm was centered on it. The guidewire placement, medullary preparation, and nail insertion and locking were performed as instructed by the manufacturer. A straight nail (Trigen Hindfoot Fusion Nail; Smith & Nephew) was used in all cases.

The postoperative protocol for both groups remained the same; the patients were instructed to be non-weight-bearing in a cast for three weeks until wound healing. Subsequently, progressive weight-bearing was allowed on the operated side, gradually increasing from partial to full as tolerated, in accordance with the literature.[11,18-20] Subsequent routine follow-ups were scheduled at six weeks, three months, six months, 12 months, and annually thereafter, with functional and radiographic evaluations conducted at each follow-up visit.

Patient evaluation and definitions

All patients' characteristics, including age, sex, body mass index (BMI), skin-to-skin operative time, fluoroscopy time, Charlson Comorbidity Index (CCI), and length of hospital stay, were collected pre- and perioperatively. The records were reviewed for complications and adverse events. Preoperative and postoperative functional status were evaluated with the Visual Analog Scale (VAS) and the American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Score (AOFAS-AHS).[21] Due to the restricted ankle and subtalar joint movements of patients after surgery, the highest AOFAS-AHS score was set at 86.

Radiographic evaluation was conducted using AP and lateral ankle radiographs taken preoperatively and during routine follow-up visits and computed tomography scans which were ordered solely to evaluate potential nonunion. Union was defined as constant bone bridging that crosses the joint surfaces in at least three of four cortices. The union of the tibiotalar and subtalar joints was assessed individually and documented; fusion was accepted as the union of both joints. Failure of fusion was defined as nonunion of one or both joints 12 months after surgery.[22] The two authors of the study, who did not perform the procedures, evaluated the radiographs and reached a consensus. Various studies in the literature have employed this definition to assess union.[23-25] Ankle alignment in the coronal plane was assessed using a weight-bearing AP ankle radiograph. This was done by measuring the superomedial angle, formed by the long axis of the tibia and the line defining the talar shoulders. The obtained angle was defined as the coronal tibiotalar (CTT) angle with optimal measurements between 90 and 93 degrees (neutral to 3 degrees valgus).[26] Sagittal alignment on lateral ankle radiographs was assessed using the sagittal tibiotalar (STT) angle recommended by prior literature on ankle arthrodesis.[27] The CTT and SST angle measurements are demonstrated in Figure 2.

Statistical analysis

Statistical analysis was performed using the Stata/MP version 13.0 software (StataCorp LLC, Texas, UT, USA). The Shapiro-Wilk test was used to assess the normal distribution of the data. Continuous variables were expressed in mean ± standard deviation (SD) or median and interquartile range (IQR), while categorical variables were expressed in number and frequency. The chi-square test and Fisher exact test were used to analyze categorical variables. The t-test was utilized for parametric data in independent group comparisons, while the Mann-Whitney U test was applied for non-parametric data. The Wilcoxon test was used for dependent group comparisons. Due to the retrospective nature of the study, sample size calculation was unable to be performed. However, the *post-hoc* power analysis showed that the statistical power for comparing union rates at 12 months between open and arthroscopic groups was 23.1% with the current sample size, suggesting

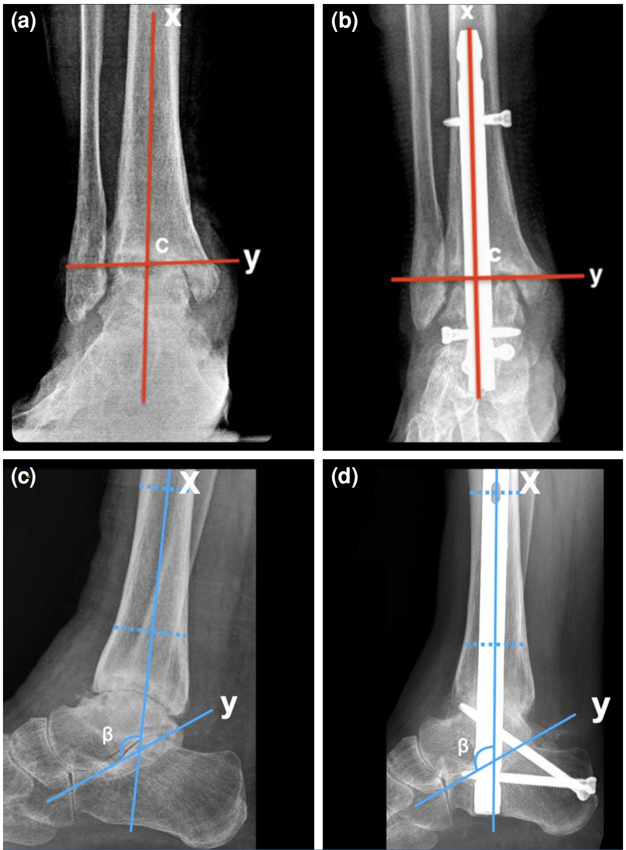

FIGURE 2. Coronal tibiotalar (CTT) angle measurements on preoperative **(a)** and postoperative **(b)** ankle radiographs. In both radiographs, this was done by measuring the superomedial angle (c), formed by the long axis of the tibia (x) and the line defining the talar shoulders (y). The obtained angle was used to determine coronal alignment, which was defined as the CTT angle. Sagittal tibiotalar (STT) angle measurements on preoperative **(c)** and postoperative **(d)** ankle radiographs. In both radiographs, this was done by measuring the angle between the two axes, formed by the long axis of the tibia, created by connecting two points in the middle of the proximal and the distal tibial shaft (x) and the line defining the axis of the talus, defined by a line drawn from the inferior aspect of the posterior tubercule of the talus to the most inferior aspect of the talar neck (y). The obtained angle was used to determine sagittal alignment, which was defined as the STT angle.

that the sample size may have hindered achieving statistical significance in some comparisons. A *p* value of <0.05 was considered statistically significant.

RESULTS

Thirty patients and 34 ankles underwent open TTCA, while 32 patients and 34 ankles underwent arthroscopic TTCA. There was no significant differences in the age, sex, BMI, or CCI between the groups (Table I). The indications for surgeries included primary and secondary post-traumatic osteoarthritis, neurocongenital deformities, and Charcot neuroosteoarthropathy, with no significant group differences (p=0.217). Among all ankles with end-stage (Grade 4, severe) tibiotalar arthritis, there was no significant difference in subtalar arthritis grade between the two groups (p=0.747). The median follow-up was 41 (range, 28 to 64) months in the open group and 46 (range, 36 to 66) months in the arthroscopic group, indicating no significant difference (p=0.462).

Union rates for both tibiotalar and subtalar joints were assessed at intervals of ≤3 months, ≤6 months, and ≤12 months in patients who underwent either arthroscopic or open TTCA. Statistical analysis indicated no significant difference in tibiotalar union rates between the arthroscopic and open techniques at any interval (p=0.807 for ≤3 months; p=0.775 for ≤6 months; p=0.425 for ≤12 months). Likewise, no statistically significant difference was found in subtalar union rates between these groups (p=1.000 for ≤3 and ≤6 months; p=0.425 for ≤12 months). The union rates for the tibiotalar and subtalar joints by surgical approach are presented in Figure 3 and Table II. The fusion rate in the open group was 94.12%, compared to 85.29% in the arthroscopy group. Despite the open group exhibiting a slightly higher fusion rate, no statistically significant difference

TABLE I
Baseline characteristics of the patients

	All (n=62)			Open (n=30)			Arthroscopy (n=32)			
	n	%	Mean±SD	n	%	Mean±SD	n	%	Mean±SD	*p*
Age (year)			53.8±16.7			50.8±17.5			56.7±15.7	0.167
Sex										0.652
Female	41	66.12		19	63.33		22	68.75		
Body mass index (kg/m^2)			29.32±4.37			29.83±5.21			28.84±3.27	0.377
Charlson comorbidity index			1.8±1.6			1.5±1.6			2.1±1.6	0.150

SD: Standard deviation.

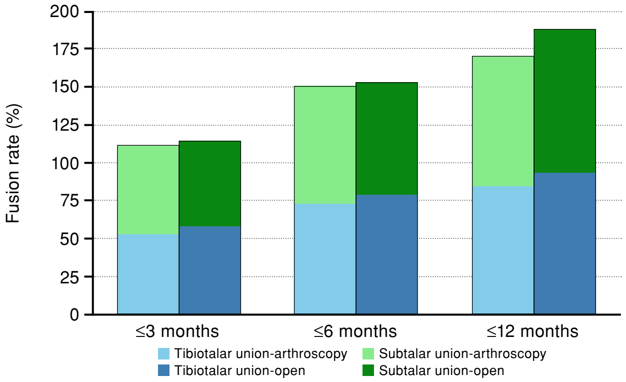

FIGURE 3. Fusion rates tibiotalar *vs.* subtalar by surgical technique.

was noted between the two groups (p=0.425) (Figure 4). The median preoperative CTT angles were 89.0° (range, 72 to 105°) in the open group and 87.5° (range, 70 to 101°) in the arthroscopy group, indicating no significant difference between the groups (p=0.531). Meanwhile, the median postoperative CTT angles for open and arthroscopy were 94.0° (range, 89 to 96°) and 91.0° (range, 85 to 98°), respectively (p<0.001). Statistically significant improvements in coronal alignment were observed in both groups (p<0.001 for both); however, no significant difference in the degree of improvement was noted between the groups (p=0.632). The median preoperative STT angles were 112.0° (range, 91 to 129°) and 111.0° (range, 100 to 120°) for open and arthroscopy groups, respectively, indicating no statistically significant difference (p=0.990). Overall median postoperative STT angle was 111.0° (range, 101 to 125°), neither the median postoperative STT angle between groups nor the angle difference for both groups individually was statistically significant (p=0.158, p=0.701 and p=0.900, respectively). The radiographic characteristics are shown in Table III.

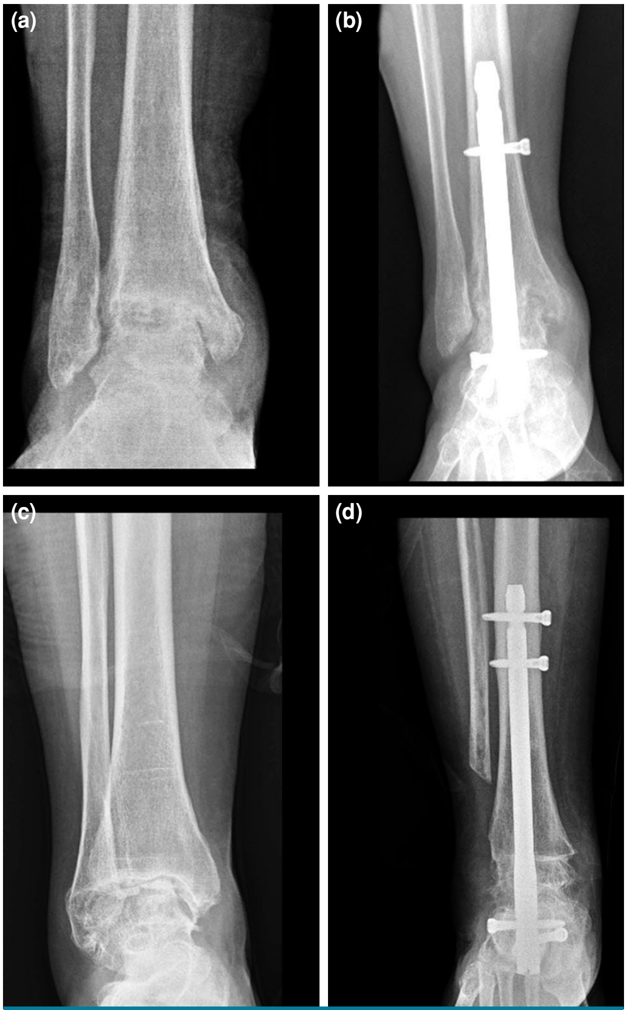

FIGURE 4. Preoperative anteroposterior **(a)** views of a 61 years old female who has end-stage ankle arthritis, along with anteroposterior **(b)** radiographs of the same ankle six months after tibiotalocalcaneal arthrodesis performed with arthroscopic joint preparation. Preoperative anteroposterior **(c)** views of a 69 years old female who has end-stage ankle arthritis, along with anteroposterior **(d)** radiographs of the same ankle after six months following open tibiotalocalcaneal arthrodesis.

TABLE II

Details on union rates by joint debridement technique for tibiotalar and subtalar joints at certain time points

	TT total (n=68)		TT open (n=34)		TT arthroscopy (n=34)			ST total (n=68)		ST open (n=34)		ST arthroscopy (n=34)		
	n	%	n	%	n	%	*p*	n	%	n	%	n	%	*p*
Union (month)														
≤3	38	55.9	20	58.8	18	52.9	0.807	39	57.4	19	55.9	20	58.8	1.000
≤6	52	76.5	27	79.4	25	73.5	0.775	51	75.0	25	73.5	26	76.5	1.000
≤12	61	89.7	32	94.1	29	85.3	0.425	61	89.7	32	94.1	29	85.3	0.425

TT: Tibiotalar joint; ST: Subtalar joint.

The mean operative time and the median fluoroscopy time were significantly longer in the open group (p<0.001 and p=0.019, respectively) (Table IV). The mean length of hospital stay for all patients was 2.43±1.48 days. This duration was 3.5±1.13 days for the open and 1.35±0.88 days for the arthroscopy group. A statistically significant shorter hospital stay was observed in the arthroscopy group (p<0.001).

Complications were thoroughly evaluated and compared between patients who had arthroscopic and open TTCA, categorized as minor or major. The distribution of complications is presented in Table V. The overall complication rates were similar across both groups, with no statistically significant difference found in the occurrence of either minor or major complications (p>0.05 for both). The most prevalent minor complication in both groups was screw loosening, affecting six (17.6%) patients in the arthroscopic group and five (14.7%) patients in the open group. For major complications, the most common was deep infection necessitating

TABLE III
Details on coronal and sagittal alignment measurements

	Total			Open			Arthroscopy			
	Median	IQR	Range	Median	IQR	Range	Median	IQR	Range	*p*
CTT										
Preoperative angles	89.0	83.0-91.0	70-105	89.0	83.5-91.0	72-105	87.5	83.0-90.75	70-101	0.531
Postoperative angles	93.0	91.0-95.0	85-98	94.0	92.0-94.75	89-96	91.0	89.0-92.0	85-98	**<0.001**
p		**<0.001**			**<0.001**			**<0.001**		
Difference	4.0	1.0-8.2	–10-23	4.5	1.0-8.8	–10-23	3.5	1.0-7.0	–10-22	0.632
STT										
Preoperative angles	111.0	105.0-117.25	91-129	112.0	104.0-118.0	91-129	111.0	106.5-118.0	100-120	0.990
Postoperative angles	111.00	108.0-114.0	101-125	109.0	106.0-111.0	101-125	112.0	110.0-114.0	105-115	0.158
p		0.704			0.701			0.900		

IQR: Interquartile range; CTT: Coronal tibiotalar angle; STT: Sagittal tibiotalar angle.

TABLE IV
Details on operating and fluoroscopy times

	All (n=68)				Open (n=34)				Arthroscopy (n=34)				
	Mean±SD	Median	IQR	Range	Mean±SD	Median	IQR	Range	Mean±SD	Median	IQR	Range	*p*
Operating time (min)	103.81±16.54				111.03±17.47				96.59±11.94				<0.001
Fluoroscopy time (sec)		31	28-35	24-46		32.5	29-38	24-46		29.5	27-34	25-39	0.019

SD: Standard deviation; IQR: Interquartile range.

TABLE V
Distribution of complications

	Open (n=34)		Arthroscopy (n=34)	
Complications	n	%	n	%
Minor				
Screw loosening	5	14.7	6	17.6
Superficial infection	4	11.8	1	2.9
Fracture non-operatively	0	0.0	2	5.9
Major				
Deep infection requiring reoperation	3	8.8	2	5.9
Symptomatic non-union	1	2.9*	2	5.9‡
Asymptomatic non-union	1	2.9†	0	0.0
Fracture	1	2.9	1	2.9

* Non-septic ankle and subtalar; † Non-septic subtalar; ‡ 1× non-septic ankle and 1x non-septic subtalar.

TABLE VI
Details on patient-reported outcome measures from baseline to final follow-up

	Preoperative score			Postoperative score			Difference			
Outcome variable	Median	IQR	Range	Median	IQR	Range	Median	IQR	Range	*p*
VAS										
Open	9	8.00-9.00	3-10	1	0.25-2.00	0-5	8	6.00-8.00	2-10	<0.001
Arthroscopy	8	7.25-9.00	6-10	1	1.00-2.00	0-4	7	6.00-7.75	4-10	<0.001
p		0.486			0.589			0.361		
AOFAS-AHS										
Open	17	12.00-20.00	0-35	68	58.00-75.00	46-80	51	44.24-57.50	18-78	<0.001
Arthroscopy	18.5	13.00-28.00	0-48	67.50	61.00-75.00	42-83	48	42.25-55.50	9-65	<0.001
p		0.087			0.382			0.305		

IQR: Interquartile range; VAS: Visual Analog Scale; AOFAS-AHS: American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Score.

reoperation, occurring in two (5.9%) patients in the arthroscopic group and three (8.8%) patients in the open group.

Both arthroscopic and open TTCA techniques resulted in statistically and clinically significant improvements in functional outcomes at the final follow-up. The VAS scores showed a significant decrease in both the arthroscopic (p<0.001) and open (p<0.001) groups. Additionally, the AOFAS-AHS scores showed a significant improvement in both groups (p<0.001). While assessing the extent of improvement between the two techniques, no statistically significant difference was noted in the change of VAS scores (p=0.361) or AOFAS scores (p=0.305). Furthermore, both pre- and postoperative scores were similar between the groups (p>0.05), suggesting comparable baseline and final functional statuses across both groups. Details of functional scores are given in Table VI.

DISCUSSION

In the present study, we compared the clinical and radiographic outcomes of open (lateral transfibular) and arthroscopic joint debridement techniques in TTCA using the same nail system. Our study results showed that TTCA performed with the same intramedullary nail resulted in comparable outcomes with either arthroscopic or open-lateral transfibular joint debridement. The arthroscopic method offered several advantages, such as reduced operative time, fluoroscopy time, and shorter hospital stays. Given the scarcity of comparative studies, the findings of this research provide valuable insights into the arthroscopic versus open methods.

The use of retrograde intramedullary nails with open joint debridement in TTCA procedures has been extensively discussed in the literature, with the use of anterior, posterior, and lateral approaches or combinations having yielded satisfactory fusion rates reported in the literature, ranging from 55 to 100%.[4,23,25,28-37] Our study utilized the lateral transfibular approach in 34 ankles undergoing TTCA with open joint debridement and achieved a fusion rate of 94.12%. Open joint debridement has been assumed as the mainstay of treatment for TTCA with retrograde intramedullary nails. However, it can lead to wound healing complications due to the requirement for large incisions, particularly in patients with coagulopathies, steroid use, rheumatoid arthritis, diabetes, or peripheral vascular disease.[20] The TTCA performed with joint debridement through arthroscopic portals is considered a less invasive method that protects the periosteum and surrounding soft tissue. Its potential advantages include reduced postoperative hemorrhage and swelling, fewer wound complications, and shorter hospital stays. Although all of these appear to promote healing and union, there is a possible concern regarding whether joint debridement is sufficient with this method.[8,11,38] Although not as widely studied as open arthrodesis, arthroscopic joint debridement has shown promising results, with reported fusion rates ranging between 57.1 and 100% through anterior, posterior, or combined portals.[20,38-41] In our study, we performed TTCA in all 34 ankles through posterior ankle and subtalar arthroscopy and achieved an 85.29% fusion rate.

The wide range of fusion rates reported in the literature suggests that TTCA is a reliable, but technically demanding procedure. Although the choice of approach is affected by many factors, searching for and comparing approaches is essential to obtaining more favorable outcomes. In a comparative study of high-risk patients, Baumbach et al.[38] reported 75% and 67% fusion rates for the open and arthroscopic groups, respectively. Our study achieved fusion rates of 94.12% for the open group and 85.29% for the arthroscopy group. Although the union rate we achieved with the arthroscopic technique was comparable to what is reported in the literature, it lagged behind the open technique. Previous studies have highlighted that the arthroscopic method is superior to the open method in terms of union rates for isolated tibiotalar arthrodesis.[42] While comparative studies are still lacking in the literature, satisfactory fusion rates have been reported for both open and arthroscopic TTCA separately, but superiority could not be claimed.[11] In our study, potential reasons for the relatively high union rate in the open group include the advantage of using the fibula as an autograft, the capability to perform more aggressive joint debridement, and the ability to access a larger surface area. Although the open group showed slightly higher fusion rates, this variation lacked statistical significance within this sample and may not indicate a clinically relevant difference.

Achieving proper alignment in the coronal and sagittal planes during TTCA is essential for ensuring long-term functional results and patient satisfaction. Malalignment, whether varus or valgus, in the coronal plane can disrupt load distribution and cause degeneration in adjacent joints. Similarly, misalignment in the sagittal plane can adversely impact gait patterns and the propulsion phase.[43] The ideal ankle arthrodesis position in the coronal plane is considered to be 5° valgus.[3] In open arthrodesis cases, the ability to manage preoperative varus or valgus deformities can be achieved through bone cuts, so arthroscopic arthrodesis is traditionally not recommended for cases with preoperative deformities.[44,45] However, successful outcomes have been reported in cases where arthroscopic ankle arthrodesis was performed on deformities greater than 15°.[20,26] Both groups in our study achieved the desired coronal alignment with comparable preoperative CTT angles and similar improvements, reaching 94° for open procedures and 91° for arthroscopy, respectively. Furthermore, both groups also achieved acceptable sagittal alignment, with postoperative STT angles of 109° and 112° for open surgery and arthroscopy, respectively.[46] Given these results, arthroscopic joint debridement may be a reliable option for patients without significant deformities who do not require corrective osteotomy to achieve adequate ankle alignment. Although there is insufficient data on coronal and sagittal alignment in the literature for arthroscopic TTCA, the data we obtained is comparable to open TTCA.[47]

Operative times are critical concerning the productive use of the operating room and the patient's exposure to anesthesia.[48] In the literature, there is a limited number of data regarding surgical time related to joint debridement methods in TTCA.[8,49] In the current study, the arthroscopic group had an average operative time that was approximately 15 min shorter than that of the open group. Although there is limited data in the literature regarding the operative time in TTCA with retrograde nails, there is no data on fluoroscopy time. It is stated in the literature that radiation exposure has been linked to an increased risk of cancer, cataracts, and cardiovascular disease, and the surgical treatment method can be changed by taking into consideration the increasing fluoroscopy time.[50] In this study, shorter fluoroscopy times were achieved with arthroscopic joint debridement compared to open joint debridement. However, the efficiencies of shorter operating and fluoroscopy durations should not outweigh the treatment's overall success. While shorter operative times and reduced radiation exposure offer certain advantages, such as lowering intraoperative risks and optimizing resources, they are secondary to achieving stable fusion, alleviating pain, and enhancing functionality. As a result, surgical decisions should prioritize the effectiveness and long-term outcomes of the procedures rather than intraoperative data. Of note, additional research is needed to determine whether these time-related benefits result in significant clinical advantages.

The study by Rammelt et al.[23] reported that patients who underwent open TTCA were discharged on average 8.4 days postoperatively, with 92% of patients discharged within the first two weeks. In our study, the mean length of hospital stay was 1.35±0.88 days for the arthroscopy group and 3.5±1.13 days for the open group. The shorter hospital stay of the arthroscopic technique may be related to the use of smaller incisions and cause less soft tissue damage, leading to reduced postoperative pain, swelling, and wound problems.[9] Moreover, the minimally invasive nature possibly allowed the lowered requirement for opioid analgesics and earlier mobilization. As predicted by Lameire et al.,[11] the length of hospital stay was significantly reduced with the less invasive arthroscopic method in our study.

The literature reports complication rates ranging from 1 to 56% for open TTCA despite high fusion rates and stability.[25,32-37] The main complications include nonunion, fractures, implant failure, infection, and amputation.[29] In their systematic review, Lameire et al.[11] reported a 38.5% complication rate for arthroscopic TTCA. In this study, the complication rates, which include both minor and major events, were similar between patients undergoing arthroscopic and open TTCA. In detail, complications were recorded in 15 out of 34 patients (44.1%) in the open group and 14 out of 34 (41.2%) patients in the arthroscopic group. Statistical analysis indicated that this difference was not statistically significant. These findings imply that both surgical methods present a similar risk of postoperative complications in the context of TTCA. Since screw loosening and irritation occurred after the union was achieved in our study, it can be considered that they do not directly have a clinically significant effect on the union rates. However, in cases where symptoms caused by screw irritation could not be relieved by non-operative methods necessitating removal, it may negatively affect functional results by causing pain and reducing patient comfort. Although the effect of screw removal on functional results has not been fully addressed in the literature, it has been suggested that removal procedures performed due to prominent screw may increase patient satisfaction.[8,51] Although deep infections requiring surgery were observed at low rates of 8.8 and 5.9% for the open and arthroscopy groups in our study, respectively, they might relate to long-term adverse outcomes such as union failure, increased morbidity, and poor functional results.[7] Additionally, the need for further surgeries for implant removal and revision arthrodesis may significantly affect the quality of life of the patient. Notably, the relatively high complications noted in both groups highlight the complex nature of tibiotalocalcaneal fusion surgeries and the difficulties of achieving successful results in this high-risk patient population, which often involves patients with multiple comorbidities and compromised bone quality.[3] Despite the similar patient characteristics and CCI scores of both groups, the less invasive arthroscopic technique did not result in a statistically significant reduction in complication rates. This may be related to the fact that the number of participants in each group was limited to 34. While there were some numerical differences, the study might not have had sufficient power to identify a statistically significant difference in complication rates. Certain complications, such as hardware-related problems or fusion failure, might be more closely related to patient biology rather than the surgical technique used. Consequently, even while utilizing a minimally invasive approach, the total burden of complications may still be similar. Still, the complication rates for both groups are comparable to those reported in the literature.

The findings of the current study indicate that open and arthroscopic TTCA procedures yield reasonable functional results with no significant difference in pain relief and patient-reported outcomes as measured by the VAS and the AOFAS-AHS. Although some studies have suggest that TTCA frequently leads to deficits in functional outcomes, others have reported notable improvements in the AOFAS score linked to TTCA, similar to our results.[15,52-54] While arthroscopic surgery could provide additional perioperative advantages, such as decreased operative time or minimized soft tissue damage, the long-term clinical results seem to be equivalent. This supports the idea that the selected surgical method must be customized for each patient, considering their specific condition and the surgeon's experience, rather than depending on presumed functional superiority.

Nonetheless, our study has several limitations. First, the retrospective design naturally restricts our ability to manage all possible confounding variables and increases the risk of selection bias. Second, the smaller sample size reduces the statistical power of the analysis and limits the generalizability of the findings. In a *post-hoc* power calculation for the fusion rate statistic (94.1% *vs.* 85.3%, with 34 subjects in each group and an alpha of 0.05), the calculated power is 23.1%. This indicates a beta (the likelihood of a false negative) of 77%. Consequently, it is challenging to conclude that there is no significant difference between the fusion rates of the two groups. Third, the lack of randomization, along with the exclusive performance of each surgical technique by a single surgeon, creates potential confounding related to the surgeon's impact. While both surgeons were highly experienced and followed standardized, protocol-driven approaches to joint debridement, differences in surgical execution, decision-making, or intraoperative judgment could still influence the outcomes. This prevents us from fully isolating the effect of the surgical technique itself. Future studies with randomized or crossover designs involving multiple surgeons performing both techniques may better address this potential source of bias. Another limitation is that only plain radiographs were used to assess union, as no routine computed tomography scan was performed. Although some studies indicate that conventional radiographs may be comparable to CT scans for evaluating bone fusion, they are usually less precise, particularly in procedures such as TTCA, where the risk of nonunion is a major issue.[33] Future research employing routine CT scans could provide more reliable data and enhance the accuracy of fusion evaluations. While open arthrodesis is well-represented in the literature with large patient numbers, the literature on arthroscopic TTCA is more limited, with smaller patient cohorts. On the other hand, the main strength of our study is its highest number of reported cases of arthroscopic TTCA and directly comparing it to the open technique in the same study. Another significant strength of our study is the comparison of two standard approaches performed by two surgeons using the same nail in the two groups with similar patient characteristics and comorbidities.

In conclusion, open and arthroscopic joint debridement methods yielded similar fusion and complication rates, functional improvement, and ankle alignment. Based on these findings, it can be concluded that, despite the arthroscopic method having a shorter hospital stay, reduced operative time, and fluoroscopy time, both techniques have comparable outcomes for TTCA with a retrograde intramedullary nail in experienced hands. Nevertheless, further multi-center, large-scale, prospective, randomized studies are warranted to confirm these findings and to ensure the merits of the arthroscopic technique. Furthermore, it is essential to examine the effects of surgical methods on outcomes across distinct subgroups exhibiting varying degrees of arthritis or deformities.

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

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