


CLINICAL ARTICLE

Effectiveness of Ilizarov Ankle Arthrodesis in the Treatment of End-Stage Varus Ankle Osteoarthritis: A Retrospective Study

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Objective: To evaluate the outcomes of Ilizarov ankle arthrodesis in the treatment of end-stage varus ankle osteoarthritis (OA).

Methods: This was a retrospective study of 63 patients with varus ankle OA who underwent Ilizarov ankle arthrodesis between June 2013 and December 2018. There were 24 males and 39 females with an average age of 56.57 ± 4.45 years (range, 47–64 years). Thirty-six cases were affected on the left side, and 27 were affected on the right side. The patients' mean body mass index (BMI) was 25.18 ± 2.93 kg/m². According to the modified Takakura staging criteria, there were 18 cases of stage 3b (28.57%) and 45 cases of stage 4 (71.43%). Nine patients were primary (14.29%), 48 were traumatic (76.19%), and six were caused by rheumatoid OA (9.52%). Functional assessments were performed according to the American Orthopedic Foot and Ankle Society (AOFAS) ankle-hindfoot score, Ankle Osteoarthritis Scale (AOS), and visual analogue scale (VAS). The tibial anterior surface angle (TAS), coronal plane tibial-talar angle (CPT), talar tilt angle (TT), deformity angle (DA), and tibial lateral surface angle (TLS) were assessed on X-ray films.

Results: The average operation time was 147.84 ± 13.67 min (range, 135–168 min). The average follow-up time was 34.24 ± 8.72 months (range, 24–61 months). Bony fusion was achieved in all ankles, and the fusion time was 12.43 ± 1.99 weeks on average. The average AOFAS score at the final follow-up increased from 42.14 ± 8.66 to 80.90 ± 6.80 . The average VAS score and AOS pain and disability scores at the final follow-up decreased from 7.29 ± 1.27 to 2.24 ± 0.94 , from 67.94 ± 7.68 to 27.92 ± 5.82 , and from 71.64 ± 9.37 to 41.32 ± 8.99 , respectively. The average TAS, CPT, and TLS at the final follow-up increased from $77.76^\circ \pm 4.44^\circ$ to $89.81^\circ \pm 1.25^\circ$, from $69.04^\circ \pm 3.73^\circ$ to $90.43^\circ \pm 1.80^\circ$, and from $82.14^\circ \pm 3.77^\circ$ to $88.67^\circ \pm 2.50^\circ$, respectively. The average TT and DA at the final follow-up decreased from $8.76^\circ \pm 4.30^\circ$ to $2.05^\circ \pm 1.28^\circ$ and from $20.95^\circ \pm 3.73^\circ$ to $1.57^\circ \pm 0.93^\circ$, respectively. Three patients developed superficial pin tract infections, all settled with local dressing and antibiotic treatment. Two patients were found to have subtalar arthritis and underwent conservative treatment.

Conclusion: Ankle arthrodesis using the Ilizarov technique is efficient in treating end-stage varus ankle OA.

Key words: Ankle arthrodesis; Ankle osteoarthritis; Deformity correction; Ilizarov; Varus deformity

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Introduction

The ankle joint is a complex structure comprising a diarthrosis between the tibia and talus and an interosseous syndesmosis between the tibia and fibula.¹ It is one of the joints bearing the largest biomechanical load; it bears approximately five times the body weight during normal walking and up to 13 times the body weight during running.² Ankle osteoarthritis (OA) is a constantly growing problem, and approximately 1% of the world's adult population is affected by ankle OA.³ It is a progressive disease that often develops asymmetrically with concomitant varus or valgus deformities of the hindfoot.⁴ Varus malalignment tends to result from chronic lateral ligamentous insufficiency and also inflammatory joint disease.⁵ Apart from other degenerative characteristics of ankle OA, such as degeneration of cartilage, subchondral bone sclerosis, and formation of osteophytes, malpositioning of the talus, such as talus medial translation, talar internal rotation along its longitudinal axis, and/or talus varus tilt, is a typical characteristic of a varus ankle.^{6,7} As malalignment of the talus results in unbalanced stress distribution of the ankle articular surface and further promotes the development of ankle OA,⁷ compared with other types of lower extremity OA, ankle OA develops earlier and more rapidly into the end-stage, which often affects young patients and causes substantial pain and impairment of ankle function.^{8,9} End-stage ankle OA with varus deformity is still a challenging condition to treat.⁷ Fundamental surgical correction of varus malalignment plays a crucial role during treatment to eliminate pain and deformity of the degenerated ankle joint and achieve painless mobilization.¹⁰ Currently, the optimal management for advanced ankle OA with varus deformity remains controversial.

Total ankle arthroplasty (TAA) and ankle arthrodesis are the two primary surgical options for end-stage ankle OA. The first TAA was performed in 1970 by Lord and Marrott in France,¹¹ and the results of the primary implantation are still unsatisfactory; it has a high failure and revision rate. The overhaul failure rate has been reported to be as high as 32.9%–42%, with a 5-year revision rate of more than 20% and a 10-year revision rate of more than 40%.^{12,13} After more than 40 years of refinement, TAA has made continuous progress in ankle joint biomechanical analysis, prosthesis design, and simulation technology. However, TAA has not been popularized in China because of the types, prices, and surgical techniques of artificial ankle prostheses. Moreover, for deformity correction, it is suggested that preoperative varus deformity greater than 15° is the relative contraindication of TAA, and greater than 20° is the absolute contraindication; if the varus deformity is between 10° and 15°, it may lead to early surgical failure, and the incidence of complications and revision rate is relatively higher, and auxiliary surgeries are often required.^{5,10,14,15} Joo *et al.*¹⁰ reported that 48 of 105 ankles with coronal plane deformity required additional surgical procedures for TAA, such as osteotomy and soft tissue release, and the incidence of complications was 43.8%.

Austrian surgeon, Eduard Albert, described ankle arthrodesis in 1878 when he performed a surgical procedure for the fusion of both knees and ankles in a 14-year-old child who had severe palsy of the lower extremities.¹⁶ For almost a century, ankle arthrodesis has been considered the gold standard for surgically treating end-stage ankle OA because of its wide indications, definite clinical effect, and low revision rate.^{7,17–19} Various fixation methods have been developed along with continuous improvements in surgical techniques for ankle arthrodesis. To date, more than 40 techniques have been used for arthrodesis and have shown positive effects, such as open reduction and internal fixation, arthroscopic fusion using screws, external fixation, and/or the application of iliac bone grafts. However, each method has certain disadvantages; for example, traditional open fusion and arthroscopic fusion usually require additional surgeries, such as hardware removal, external fixation usually hampers patients' daily activities, and applying iliac bone grafts requires another incision. There is still no consensus on the optimal method to achieve bony fusion, minimal invasiveness, deformity correction, functional recovery, and pain relief. Ankle arthrodesis using the Ilizarov technique was first introduced in 1976.²⁰ It has been proven to be viable even in many complicated cases and has a favorable effect on improving patients' quality of life.^{21,22} However, only a few studies have focused on varus deformity correction.^{9,17,19,23–25} Moreover, to the best of our knowledge, studies on Ilizarov arthrodesis to manage advanced varus ankle OA are still lacking.

This study aimed: (i) to evaluate the effectiveness of Ilizarov ankle arthrodesis in treating end-stage varus ankle OA on bony fusion, functional recovery, pain relief, and deformity correction; and (ii) to analyze the advantages of ankle arthrodesis using the Ilizarov method and to summarize the complications and prevention measures.

Methods and Patients

The present study obtained approval from the review board of our hospital, and the Ethics Code was 2021 Review 251. Informed consent for data use was obtained from all participants.

Inclusion and Exclusion Criteria

The inclusion criteria followed the PICOS principle. Patients: (i) diagnosed with ankle OA of stage 3b or 4 according to the modified Takakura staging criteria;²⁶ (ii) ankle OA with varus deformity, coronal plane tibial-talar (CPT) angle less than 90°;⁹ (iii) age over 18 years old, less than 60 years old; (iv) with clinical symptoms, such as pain, limping and using crutches; (v) conservative treatment ineffective for more than 6 months; (vi) unilateral lesions; and (vii) follow-up more than 24 months. Intervention: patients were treated with Ilizarov ankle arthrodesis. The study design was a retrospective study.

The exclusion criteria were as follows: (i) ankle OA with valgus deformity; (ii) unclosed tibial epiphysis;

TABLE 1 Baseline characteristics of 63 patients

Variable	
Age (years)	56.57 ± 4.45 (range, 47–64)
Gender	
Male	24
Female	39
BMI (kg/m ²)	25.18 ± 2.93
Side	
Left	36
Right	27
Stage	
3b	(18, 28.57%)
4	(45, 71.43%)
Cause	
Primary	(9, 14.29%)
Traumatic	(48, 76.19%)
Rheumatoid	(6, 9.52%)
Follow-up (months)	34.24 ± 8.72 (range, 24–61)

Abbreviation: BMI, body mass index.

(iii) acute ankle infections; (iv) severe systemic diseases; and (v) neurologic disorders.

General Information

Between June 2013 and December 2018, 63 patients who met the criteria were enrolled in this study, their baseline characteristics were listed in Table 1. There were 24 males and 39 females with an average age of 56.57 ± 4.45 years (range, 47–64 years). Thirty-six patients were affected on the left side, and 27 on the right side. Their mean body mass index (BMI) was 25.18 ± 2.93 kg/m². According to the modified Takakura staging criteria, there were 18 cases of stage 3b (28.57%) and 45 cases of stage 4 (71.43%). Nine patients were primary (14.29%), 48 were traumatic (76.19%), and six were caused by rheumatoid OA (9.52%).

Operative Technique

Anesthesia and Position

The surgery was performed under general anesthesia by a single surgical team. The patient was placed in the supine position, and the hip was padded 20–30° higher to correct the pronation of the lower limb. A proximal thigh tourniquet was also applied.

Approach and Exposure

A conventional anterior median ankle approach was used (Fig. 1A). The skin, subcutaneous tissue, and fascia were dissected layer-by-layer. The ankle was exposed after incising the joint capsule.

Ankle Debridement and Osteotomy

Synovectomy was performed, and the articular cartilage and sclerotic subchondral bone were debrided until fresh blood oozed to form a bony fusion surface. Osteotomy was

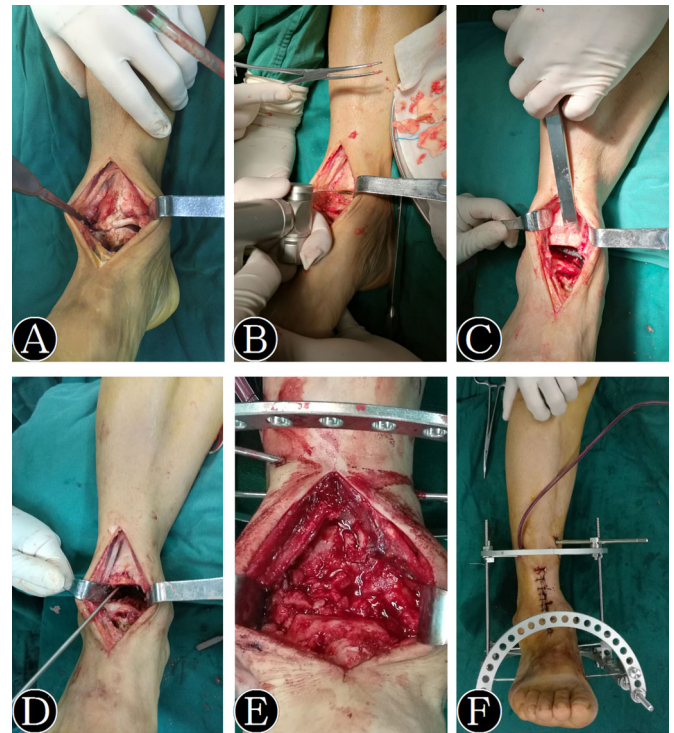


Fig. 1 (A) The incision and obvious osteophyte. (B) Repair the articular surface. (C) Bone harvest. (D) Drill holes. (E) Implanted bones in the joint space. (F) The fixed ankle

performed to preliminarily correct the varus misalignment according to the preoperative radiographic assessment (Fig. 1B), and the length of the tibia was maintained as long as possible.

Reconstruction and Fixation

A cancellous bone block was harvested from the distal tibia using an osteotome (Fig. 1C). Then, a 4.0-mm Kirschner wire was used to drill holes in the articular surface (Fig. 1D), and the harvested bone block was divided into small segments and implanted in the joint space (Fig. 1E). Lastly, the Ilizarov fixator was assembled in the order of the tibia, ankle, and foot (Fig. 1F). The external apparatus was further adjusted to correct the varus misalignment according to the C-arm examination, and the ankle was fixed in a neutral dorsiflexion position, with 0° to 5° of hindfoot valgus, and external rotation equal to the opposite side if normal, or approximately 5° to 10° if abnormal.^{17,19,23,27}

Postoperative Care

Postoperative pain, antibiotic management, and wound and pin tract care were regularly performed. The drainage was removed 24–48 h after surgery. On the second postoperative day, functional training of the lower extremity was guided, and early weight-bearing was encouraged if tolerated. The follow-up timeline was performed every month before

removing the external apparatus and once a year thereafter. According to radiographic examinations performed at each follow-up, the frame could be modulated and compressed if needed. The indications for removal of the external apparatus were as follows: (i) radiographic examination showed bone fusion; and (ii) the patient could step with no pain after temporarily undoing the frame. When removing the Ilizarov external fixator, an ankle brace was used for 6 weeks as an auxiliary for weight-bearing. The patients were also asked about complications and treated during each follow-up.

Outcome Assessment

The preoperative and postoperative radiographic and functional outcomes were evaluated and compared.

Radiographic Evaluation

Radiographic evaluation included the tibial articular surface (TAS) angle, talar tilt (TT) angle, coronal plane tibial-talar (CPT) angle, deformity angle (DA), and tibial lateral surface (TLS) angle, all measured on ankle radiographic films (Fig. 2). The TAS angle, TT angle, DA, and CPT angle could reflect the details of the deformity in the coronal plane. The CPT angle is the angle between the axis of the tibia and the articular surface of the talus, which can be seen as the degree close to the neutral axis. The TAS angle was defined as the angle between the axis of the tibia and its distal articular surface to evaluate the degree of varus deformity of the distal TAS. The TT angle is the angle between the articular surface of the distal tibia and the articular surface of the talus to evaluate the degree of talus tilt. The DA is the angle between the anatomical axis of the tibia and a line perpendicular to

the talus articular surface to illustrate degrees deviating from the neutral axis, and the DA is equal to 90° minus the CPT angle. The TLS angle is defined as the angle between the anatomical axis of the tibia and its distal articular surface, which was measured in the sagittal plane.

Functional Evaluation

The American Orthopedic Foot and Ankle Society (AOFAS) ankle-hindfoot score, visual analogue scale (VAS), and ankle osteoarthritis scale (AOS) were used to evaluate functional outcomes.

The AOFAS ankle-hindfoot score system includes nine aspects: pain, function, maximum walking distance (blocks), walking surfaces, gait abnormality, sagittal motion (flexion plus extension), hindfoot motion (inversion plus eversion), ankle-hindfoot stability (anteroposterior, varus-valgus), and alignment. The maximum value of the AOFAS ankle-hindfoot score is 100 points; however, it reaches only 92 points in patients with ankle arthrodesis owing to the limited range of ankle motion.

The VAS is the most frequently used instrument to measure pain intensity. It is measured using a 10-cm line with 0 on the left indicating “no pain” and 10 on the right indicating “worst possible pain.” Patients were instructed to place a mark on the line to report the intensity of pain experienced.

The AOS is a reliable and valid self-assessment instrument that specifically measures symptoms and disabilities related to ankle arthritis. It comprises 18 items. Patients responded by placing a mark along a 100-mm horizontal line to depict their level of pain or disability for the described condition. Each subscale, pain (A) or disability (B), comprises nine items. The sums of the responses for the nine-item subscales were tallied to generate each subscale’s total and overall scores. In cases of “not applicable,” the responses were dropped so that normalized total scores were calculated.

Statistical Analysis

Statistical analyses were performed using SPSS 24.0 statistical software (IBM Corp., Armonk, NY, USA). Data normality was checked with Kolmogorov–Smirnov test. The paired *t*-test and Wilcoxon signed-rank test were used to compare preoperative and postoperative data of AOFAS score, VAS score, AOS score, TAS, CPT, TT, DA, and TLS of normal and nonnormal distribution, respectively. *P*-value of less than 0.05 was set statistically significant.

Results

General Results

The average operation time of 63 patients was 147.84 ± 13.67 min (range, 135–168 min). The average follow-up time was 34.24 ± 8.72 months (range, 24–61 months). All ankles achieved bony fusion, and the fusion time was 12.43 ± 1.99 weeks on average (range, 10–18 weeks). They also achieved significant functional and radiographic results (listed in Table 2). Typical cases were shown in Figs 3–5.

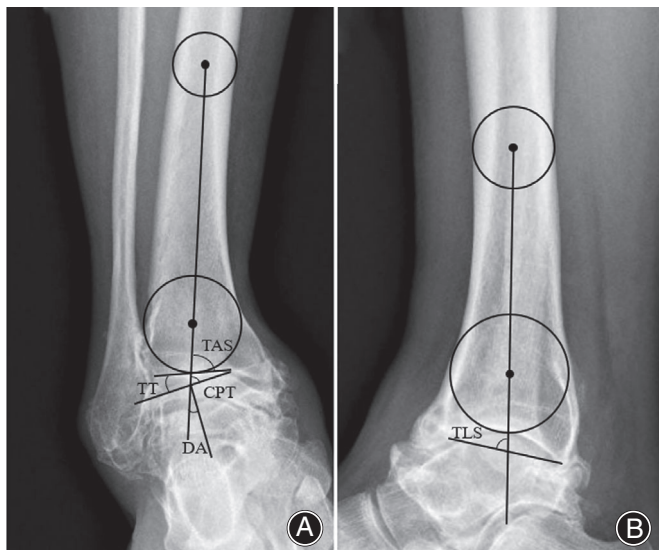


Fig. 2 Radiographic parameters of the ankle. (A) Anterior–posterior view: tibial articular surface angle (TAS), talar tilt angle (TT), and coronal plane tibial-talar angle (CPT). (B) Lateral view: tibial lateral surface angle (TLS)

TABLE 2 Results of preoperative and final follow-up parameters

	Pre-operation	Final follow-up	t-value	P-value
AOFAS score	42.14 ± 8.66	80.90 ± 6.80	-32.490	<0.001
VAS score	7.29 ± 1.27	2.24 ± 0.94	16.165	<0.001
AOS pain	67.94 ± 7.68	27.92 ± 5.82	28.419	<0.001
AOS disability	71.64 ± 9.37	41.32 ± 8.99	12.241	<0.001
TAS	77.76° ± 4.44°	89.81° ± 1.25°	-12.960	<0.001
CPT	69.04° ± 3.73°	90.43° ± 1.80°	-28.466	<0.001
TT	8.76° ± 4.30°	2.05° ± 1.28°	8.370	<0.001
DA	20.95° ± 3.73°	1.57° ± 0.93°	23.366	<0.001
TLS	82.14° ± 3.77°	88.67° ± 2.50°	-10.217	<0.001
Operation time (min)		147.84 ± 13.67 (range, 135–168)		
Union time (weeks)		12.43 ± 1.99		
Union rate		100%		
Complication		Nonunion 0 Pin tract infection 3 Subtalar arthritis 2		

Abbreviations: AOFAS, American Orthopedic Foot and Ankle Society; AOS, Ankle Osteoarthritis Scale; CPT, coronal plane tibial-talar angle; DA, deformity angle; TAS, tibial articular surface angle; TLS, tibial lateral surface angle; TT, talar tilt angle; VAS, Visual Analog Scale.



Fig. 3 Example of a 55-year-old female patient. (A) The preoperative TAS, CPT, TT, and DA were 68°, 58°, 10°, and 32°, respectively. (B) Preoperative TLS was 72°. (C) and (D) X-rays 1 month after the operation. (E) and (F) X-rays 3 months after the operation. (G) and (H) X-rays 12 months after the operation. The postoperative TAS, CPT, TT, DA, and TLS were 89°, 88°, 1°, 2°, and 82°, respectively. CPT, tibial anterior surface angle; DA, deformity angle; TAS, tibial anterior surface angle; TLS, tibial lateral surface angle; TT, talar tilt angle

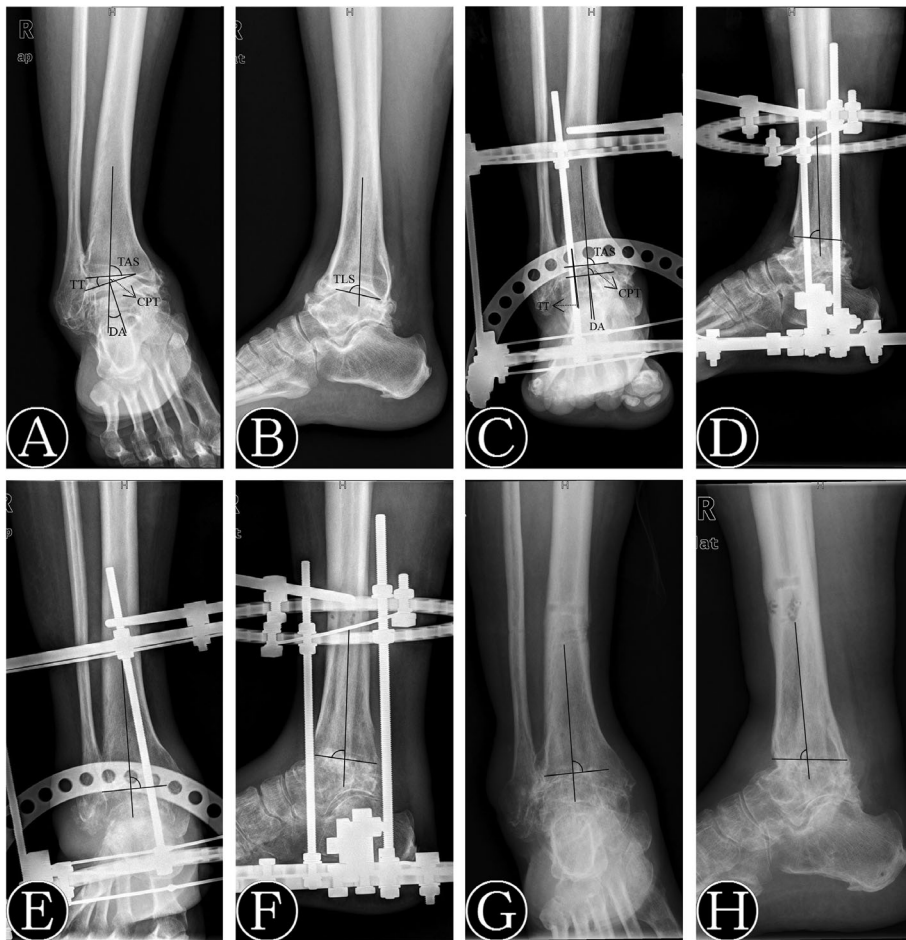


Fig. 4 Example of a 51-year-old female patient. (A) The preoperative TAS, CPT, TT, and DA were 83°, 68°, 15°, and 22°, respectively. (B) Preoperative TLS was 79°. (C) and (D) X-rays 1 month after the operation. (E) and (F) X-rays 3 months after the operation. (G) and (H) X-rays 12 months after the operation. The postoperative TAS, CPT, TT, DA, and TLS were 89°, 87°, 2°, 3°, and 84°, respectively. CPT, tibial anterior surface angle; DA, deformity angle; TAS, tibial anterior surface angle; TLS, tibial lateral surface angle; TT, talar tilt angle

Intraoperative Recommendations

First, to fix the ankle in the optimal position, osteophytes around the entire talus should be removed as much as possible when performing ankle debridement.

Second, when performing the osteotomy, insufficient or excessive osteotomy should be avoided because this may result in uncorrected ankle joint varus or ankle joint valgus; at the same time, the tibia and talus should also be kept perpendicular. Preoperative and intraoperative radiographic assessment and the use of Kirschner wires help achieve these goals.

Third, excessive osteotomy may result in limb shortening. Two thin pieces of bone were removed from the tibial and talar articular surfaces when performing the osteotomy to keep the length of the tibia as long as possible. We also harvested the cancellous bone block from the anterodistal tibia instead of the prepared bone contact surface and implanted it in the joint space; therefore, the limb length did not shorten significantly.

Functional Results

For functional evaluation, the average AOFAS score at the final follow-up increased significantly compared with the

preoperative score ($t = -32.490$, $P < 0.001$), from 42.14 ± 8.66 (range, 15–57) to 80.90 ± 6.80 (range, 69–92). The average VAS score and AOS pain and disability scores at the final follow-up decreased significantly compared with the preoperative scores ($t = 16.165$, $P < 0.001$; $t = 28.419$, $P < 0.001$; $t = 12.241$, $P < 0.001$), from 7.29 ± 1.27 (range, 5–9) to 2.24 ± 0.94 (range, 0–4), from 67.94 ± 7.68 (range, 43.8–81.4) to 27.92 ± 5.82 (range, 21.2–39.4), and from 71.64 ± 9.37 (range, 48.6–88.2) to 41.32 ± 8.99 (range, 27.3–56.7), respectively.

Radiographic Results

For radiographic evaluation, the average TAS, CPT, and TLS angles at the final follow-up increased significantly compared with the preoperative values ($t = -12.960$, $P < 0.001$; $t = -28.466$, $P < 0.001$; $t = -10.217$, $p < 0.001$), from $77.76^\circ \pm 4.44^\circ$ (range, 68°–86°) to $89.81^\circ \pm 1.25^\circ$ (range, 88°–92°), from $69.04^\circ \pm 3.73^\circ$ (range, 58°–79°) to $90.43^\circ \pm 1.80^\circ$ (range, 87°–93°), and from $82.14^\circ \pm 3.77^\circ$ (range, 72°–88°) to $88.67^\circ \pm 2.50^\circ$ (range, 82°–92°), respectively. The average TT angle and DA at the final follow-up decreased significantly compared with the preoperative values ($t = 8.370$, $P < 0.001$; $t = 23.366$, $P < 0.001$), from $8.76^\circ \pm 4.30^\circ$ (range, 3°–20°) to



Fig. 5 Example of a 67-year-old female patient. (A) The preoperative TAS, CPT, TT, and DA were 86° , 79° , 8° , and 11° , respectively. (B) Preoperative TLS was 76° . (C) and (D) X-rays 1 month after the operation. (E) and (F) X-rays 3 months after the operation. (G) and (H) X-rays 12 months after the operation. The postoperative TAS, CPT, TT, DA, and TLS were 89° , 88° , 2° , 2° , and 80° , respectively. CPT, tibial anterior surface angle; DA, deformity angle; TAS, tibial anterior surface angle; TLS, tibial lateral surface angle; TT, talar tilt angle

$2.05^\circ \pm 1.28^\circ$ (range, 0° – 4°) and from $20.95^\circ \pm 3.73^\circ$ (range, 11° – 32°) to $1.57^\circ \pm 0.93^\circ$ (range, 0° – 3°), respectively.

Complications

Complications such as wound and deep infections, nerve injury, deep venous thrombosis, pin breakage, peroneal bleeding, and malunion were not observed during the follow-up. Two patients had subtalar arthritis at the 60-month follow-up, manifested mild pain in the foot when walking on uneven ground, and conservative treatment was administered, following which both patients were relieved of their symptoms. Three patients developed superficial pin tract infection, which resolved within 7 days with local dressing and oral antibiotic treatment.

Discussion

The Effectiveness of Ilizarov Ankle Arthrodesis for End-Stage Varus Ankle OA

The primary aim of this study was to evaluate the effectiveness of Ilizarov ankle arthrodesis in treating end-stage varus ankle OA in terms of bony fusion, functional recovery, pain relief, and deformity correction. The average AOFAS, VAS, and AOS pain and disability scores at the final follow-up

improved significantly compared with the preoperative scores. The average TAS angle, CPT angle, TLS angle, TT angle, and DA at the final follow-up also improved significantly compared with the preoperative values. Bony fusion was achieved in all 63 ankles, and the overall complication rate was 7.9%. The results were analyzed as below.

Bony Fusion

The key point for arthrodesis is whether ankles can be successfully fused, especially in patients with large deformities. Smith and Wood²⁵ reported 25 cases of ankle OA with severe coronal deformity treated with open arthrodesis, with a nonunion rate of 4%. A report by Dannawi *et al.*¹⁷ showed the fusion rate of 55 patients with ankle deformities treated with arthroscopic arthrodesis was 91% overall and 88% in the severe deformity group. Saiga *et al.*²⁴ reported 38 patients with varus deformity who underwent arthroscopic arthrodesis, of which one case showed nonunion with screw loosening. These studies showed good overall fusion rates for ankles with deformities; however, there were still cases of nonunion with relatively small samples, especially those with large deformities treated with arthroscopic arthrodesis. In the present study, 60 ankles had a large varus deformity, and the fusion rate was 100%, which is comparable to or better

than that reported in other studies. We believe that the Ilizarov method has several theoretical advantages compared with the internal fixation and arthroscopic methods. First, compression is the basic principle of arthrodesis, and the fixator itself can be adjusted to provide dynamic axial compression, even after surgery. Second, circumferential rigid fixation allows early weight-bearing to exert additional axial compression. Third, early axial compression allows micro-movement between cancellous bone blocks and the fusion contact surface to promote bony fusion.²¹

Different studies have also reported different fusion times, even differences occurred in the same article. For example, Dannawi *et al.*¹⁷ reported arthroscopic ankle arthrodesis (AAA) for ankles with different deformity angles. The time to union in Group A (varus or valgus deformity of $<15^\circ$) was 8.8 weeks compared with 12.7 weeks for Group B (varus or valgus deformity $\geq 15^\circ$). The deformity angle of 60 ankles was more than 15° in this study, and the time to fusion was 12.43 ± 1.99 weeks on average (range, 10–18 weeks), which was comparable to that of patients in Group B of Dannawi's study. In addition, some studies, such as that by Schmid *et al.*,⁹ did not even mention the fusion time in their study. More in-depth research is needed to clarify whether the fusion time of Ilizarov ankle arthrodesis differs with or without coronal deformity.

Functional Recovery and Pain Relief

For functional recovery and pain relief, Smith and Wood²⁵ reported that the mean AOFAS pain and function scores improved from 10.5 to 35.2 and from 25.5 to 43.7, respectively. Schmid *et al.*⁹ demonstrated 62 arthroscopic and 35 open ankle fusions for ankles with coronal deformity, both of which led to postoperative improvements in the AOS and ankle arthritis scores. In the present study, the AOFAS, VAS, and AOS scores also achieved satisfactory results at the final follow-up compared with the preoperative scores; thus, we believe this method was as effective as other arthrodesis methods.

Deformity Correction

Deformity correction is an essential part that we focus on. In previous studies,^{9,17,19,23–25} the DA was defined as the angle between the anatomical axis of the tibia and a line perpendicular to the talus articular surface, which illustrated the degree of deviation from the neutral axis. Usually, an angle of 15° is considered the borderline of severe deformity in the coronal plane.^{10,17,23} Both open and arthroscopic arthrodesis can achieve satisfactory deformity correction. AAA has been widely used in recent years as a minimally invasive method; however, some authors have suggested that advanced ankle arthritis with a large deformity is better treated with an open procedure that allows correctional osteotomy rather than AAA.^{9,25,27–29} In this study, the deformity angle of the 60 ankles was $>15^\circ$, and all angles in the coronal plane revealed satisfactory varus correction (Table 2). TLS was also increased; we believed this was not to correct the deformity

but to fix the ankle in a neutral position. Compared with other methods, we believe that Ilizarov fixation is more suitable for varus correction. First, the adjustability of the apparatus allowed the correction of any residual deformities according to radiographic examinations, even in the postoperative period. Second, bone contact can be maintained by dynamic compression of the bone grafts and fusion surface after angle adjustment. Third, as illustrated in this study, Ilizarov fixation could be used in cases of a large varus deformity and achieved a good fusion rate and deformity correction.

The Advantages and Complications of Ilizarov Ankle Arthrodesis

The other aim of this study was to analyze the advantages of ankle arthrodesis using the Ilizarov method and summarize the complications and preventive measures. Apart from good results on bony fusion, functional recovery, pain relief, and deformity correction, Ilizarov ankle arthrodesis is also a less invasive method that allows early weight-bearing. Although Ilizarov ankle arthrodesis has complications, its incidence is not high. We analyzed these points as follows:

Less Invasive

Ilizarov external fixation causes less damage to the soft tissue, periosteum, and blood supply to the bone. It is feasible even in many complicated cases and has a favorable effect on patient quality of life.^{21,22} Traditional open fusion and arthroscopic fusion usually require additional surgeries.^{9,17,19,23–25} Smith and Wood²⁵ reported that 13 of 20 varus ankles required lateral malleolus osteotomy to correct the deformity. Schmid *et al.*⁹ reported that seven patients (10%) in the arthroscopic group and five patients (14%) in the open group required reoperations that mainly comprised hardware removal. In this study, all patients underwent a one-stage surgery without additional surgery, and the external frame was removed under sedation. Second, we did not want to increase the trauma, expense, and complications caused by iliac bone harvesting or allogeneic bone; therefore, we obtained the bone graft from the anterodistal tibia (Fig. 1C) instead of making another incision. Ilizarov ankle arthrodesis is less invasive.

Early Weight-Bearing

The Ilizarov frame can be used as an ultimate treatment for fractures, deformity, and other diseases, and its structure is strong enough to maintain limb length, allow angle correction, allow early weight-bearing, and reduce complications due to prolonged bed rest. However, previous studies reported that other methods require non-weight-bearing protocols.^{9,17,19,23,24} For example, Saiga *et al.*²⁴ suggested that non-weight-bearing with short leg orthosis was maintained for 10 days. Winson *et al.*¹⁹ mobilized patients with non-weight-bearing protocols for 2 weeks, followed by partial weight-bearing for 6 weeks; two cases reported complications of deep vein thromboses/pulmonary emboli in that study. In

the present study, patients were encouraged to begin tolerable weight-bearing on the second postoperative day; thus, no complications due to prolonged bed rest occurred.

Complications

Subtalar degeneration is a common complication of arthrodesis, and long-term results of ankle fusion show subtalar degenerative changes in 10%–60% of patients; however, the incidence rate of subtalar arthritis is usually not high, and the symptoms are not obvious.^{17,23} SooHoo *et al.*¹⁵ reported the 5-year subtalar fusion rate of 4705 ankle fusions as 2.8%. In the present study, only two patients had subtalar arthritis, and they were satisfied with conservative treatment. Another common complication is pin tract infection, which can usually be cured with timely treatment. In addition, although not a complication, the Ilizarov fixator often causes inconvenience to patients; thus, it is extremely important to communicate to them clearly before admission, during hospitalization, and after discharge to increase compliance.

Limitations of the Study

We acknowledge that there are several limitations in this study. First, the sample size was small, and the follow-up

period was not long enough. Second, this is a retrospective case series, and further studies, especially RCTs, are still needed to compare the efficacy of different methods. However, to our knowledge, this is the first study about Ilizarov ankle arthrodesis in treating end-stage varus ankle OA that focuses on deformity correction.

Conclusion

According to functional scoring systems, the results of bony fusion, varus deformity correction, and pain relief, ankle arthrodesis using the Ilizarov technique is less invasive and effective in treating end-stage varus ankle OA. This provides an option for managing end-stage varus ankle arthritis.

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