ORIGINAL RESEARCH

Midterm Results of Ankle Distraction Arthroplasty as a Salvage Option for Ankle Osteoarthritis in Young Patients: A Retrospective Cohort Study

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Abstract

Background: Arthroplasty and arthrodesis, which are the most widely used surgical modalities available for the treatment of ankle osteoarthritis (OA), are associated with a high rate of complications due to increased stresses on adjacent joints, leading to wear, failure, nonunion, and subsequent revisions. Ankle distraction arthroplasty (ADA) using a hinged external fixator facilitates intermittent, intra-articular flow of synovial fluid, thereby promoting cartilage regeneration by relieving the mechanical overload. This study aimed to alleviate pain, improve ankle function, and obviate the need for ankle arthroplasty or fusion in young individuals with symptomatic ankle OA.

Materials and methods: Twelve patients with a unilateral, painful, and arthritic ankle underwent ADA using a hinged two-ring external fixator, coupled with adjuvant procedures, such as joint debridement, microfracturing, cheilectomy, percutaneous tendo-Achilles lengthening (TAL), and bone marrow aspirate concentrate (BMAC) infiltration. The following parameters were assessed preoperatively and at 6- and 12-month postoperative: joint range of motion (ROM), American Orthopaedic Foot and Ankle Society—ankle hindfoot (AOFAS-AH) scores, and visual analog scale (VAS) scores.

Results: The mean external fixator duration was 12.5 (±1.9) weeks, and the mean follow-up was 19 (±7.7) months. Mean dorsiflexion preoperative was 11.3° (±4.8), which improved marginally to 14.6° (±3.9) postoperative (p-value = 0.013), whereas mean plantarflexion improved from 24.5° (±7.5) preoperative to 27.9° (±7.2) postoperative (p-value = 0.0045). Mean AOFAS-AH scores improved from 56.6 (±8.1) preoperative to 81.3 (±6.2) postoperative, which were statistically significant ($p < 0.05$). The mean preoperative VAS score was 4.8 (±1.5), which reduced to 1.8 (±0.5) postoperatively ($p < 0.05$). Follow-up CT and MRI scans showed improved joint space and cartilage thickness, with resolution of subchondral cysts. Complications included superficial pin tract infections in two cases and complex regional pain syndrome (CRPS) in one case. There were no conversions to arthroplasty or fusion.

Conclusion: Ankle distraction arthroplasty is a low-risk, promising joint-preserving surgery, offering a simple solution to a complex problem.

Keywords: Ankle osteoarthritis, Cartilage regeneration, Ilizarov, Joint preservation, Mechanical distraction.

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Introduction

Ankle osteoarthritis (OA) is a slowly progressive, degenerative joint disorder that is often diagnosed late due to the delayed onset of clinical symptoms.[1] Several etiological factors have been implicated in the development of OA in young individuals; however, high-energy trauma, as seen in trimalleolar or tibial plafond fractures, and recurrent ligamentous instability remain the foremost contributory factors.[2] Since patients with posttraumatic ankle OA present at a much younger age, as compared to hip and knee joint OA, joint-preserving surgeries are highly desirable to improve the quality of life, delay the disease progression, and defer or circumvent the need for joint-sacrificing procedures.[3,4] Total ankle arthroplasty (TAA) and ankle arthrodesis relieve pain and provide good short-term results.[5] However, both are associated with potential complications such as increased stresses on adjacent joints; leading to degeneration; increased energy expenditure; malunion and nonunion with TAA; and wear, failure, and subsequent revisions with ankle fusion.[6,7] Ankle distraction arthroplasty (ADA) has gradually gained acceptance and recognition as a lucrative joint-preserving option, dramatically reducing pain and improving ankle function, thereby obviating the need or delaying the time to arthroplasty or fusion.[8] The goal of the procedure is to increase the joint space and refurbish the articulating surfaces by applying an external fixator and distracting the joint. In doing so, the mechanical overload on the cartilage is relieved, allowing reparative processes to take place. Additionally, the frame allows the patient to bear weight, causing cyclical fluctuations

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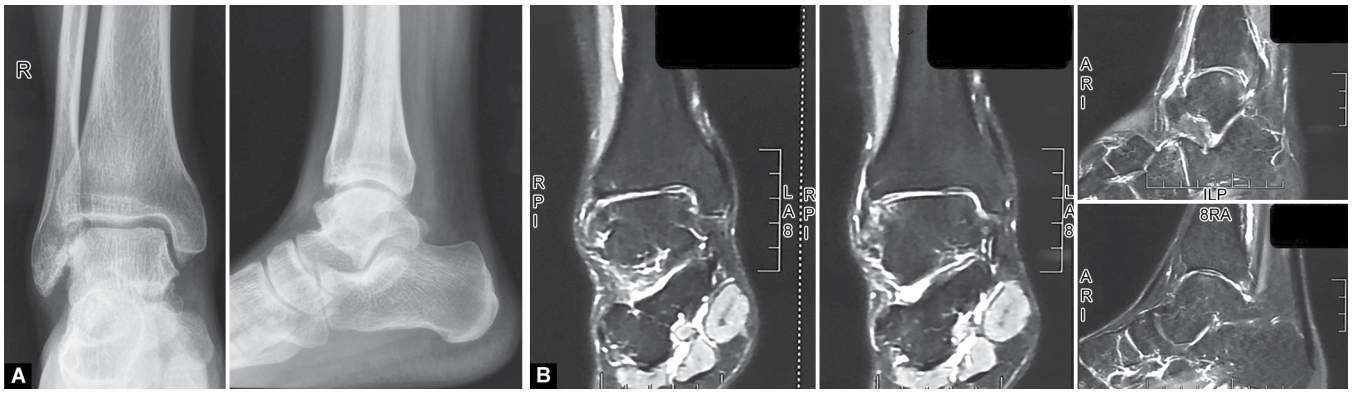
in the intra-articular hydrostatic pressures, thereby improving the local "milieu." Concomitant procedures such as cheilectomy, microfracturing, and bone marrow aspirate concentrate (BMAC) infiltration potentiate the local inflammatory response, influencing hyaline or fibrocartilage formation by increasing proteoglycan synthesis.[8,9] The present study aimed to evaluate the functional outcome of ADA in treating symptomatic ankle OA in young individuals. The primary objective was to assess the intervention's outcome on joint range of motion (ROM), American Orthopaedic Foot and Ankle Society—ankle hindfoot (AOFAS-AH) scores, and visual analog scale (VAS) scores. The secondary objective was to document any radiological improvement in joint space or articular congruity following the intervention.

Materials and Methods

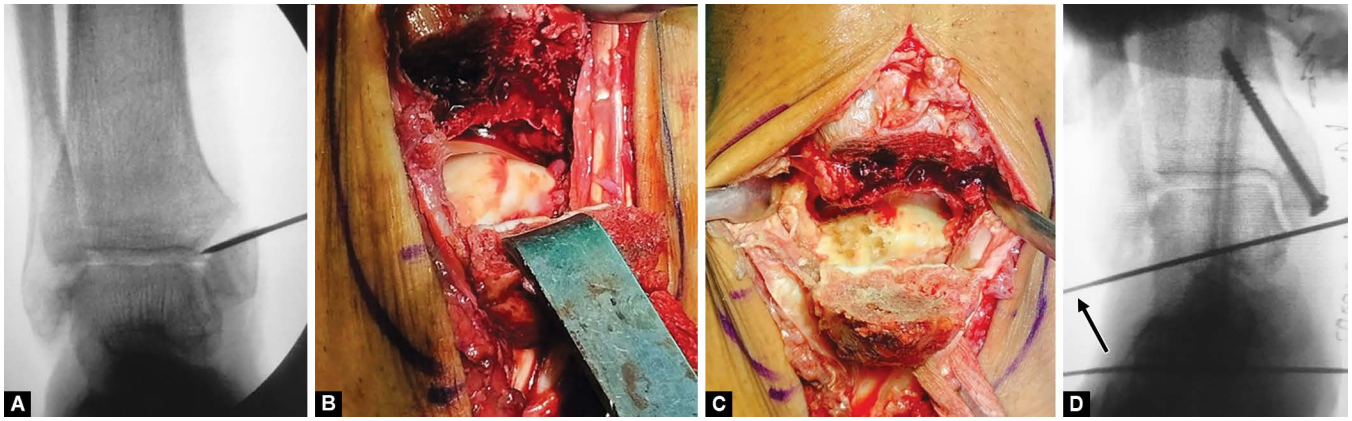
Ours was a retrospective cohort study in 12 patients, aged ≤60 years, presenting to a tertiary orthopaedic center in North India, with a unilateral, painful, and arthritic ankle and fulfilling the inclusion criteria[10]: (a) failed conservative treatment for >1 year, (b) preserved arc of motion of ≥20°, (c) no serious contraindications to surgical treatment, (d) not on anticoagulation or discontinuing them as recommended before surgery, and (e) no history of compensated hormonal disorders, not pregnant or lactating. Exclusion criteria[11] included: (a) severe ankle varus or valgus >10°, (b) acute or chronic infections, (c) neuropathic arthropathy, and (d) arterial or venous insufficiency. Asymmetrical arthritis with a mild varus or valgus deformity, obesity, and inflammatory arthritis were relative contraindications.[8] The data were collected retrospectively from a computerized hospital database, and all patients fulfilling the criteria mentioned above were included in the study. Ankle joint ROM was recorded using a goniometer. Preoperative weight-bearing anteroposterior and lateral radiographs of both ankle joints were performed. CT and MRI scans were obtained preoperatively and at the final follow-up visit, to evaluate the status of cartilage and subchondral bone (Fig. 1). Routine laboratory investigations, such as ESR (erythrocyte sedimentation rate) and CRP (C-reactive protein), were done to rule out active/subclinical infection. AOFAS-AH and VAS scores were obtained preoperatively. The Institutional Ethics Committee (IEC) granted a waiver for obtaining individual patient consents; however, a telephonic consent was obtained for the individuals whose clinical images have been included below.

Surgical Technique

The patient was positioned supine on a radiolucent operating table. Anterior impingement was addressed first by performing a cheilectomy, with adequate resection of offending osteophytes, using the anterior approach.[12] Concomitant procedures such as synovectomy and joint debridement, including clearance of medial and lateral gutters, were performed in selected cases. Loose osteochondral fragments were addressed either from an anterior or a medial approach, through a medial malleolar osteotomy (Figs 2A and B), followed by microfracturing using a microawl, to open up the subchondral marrow spaces (Fig. 2C). If restriction of dorsiflexion persisted, a percutaneous tendo-Achilles lengthening (TAL) was performed.[13]



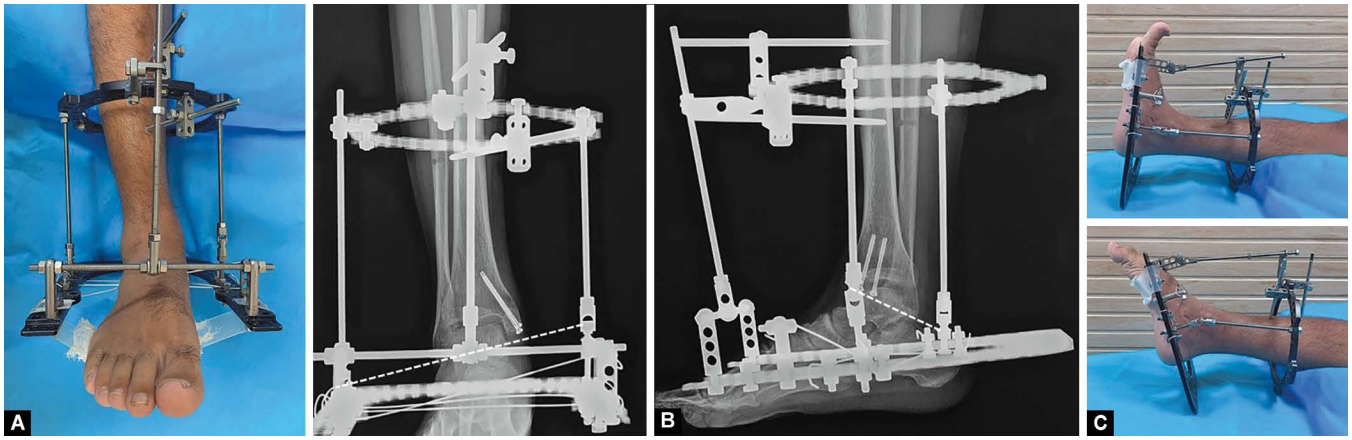
Figs 1A and B: (A) AP and lateral ankle radiographs of a 35-year-old male, with grade 2 ankle OA; (B) T2-weighted MRI images showing delaminated areas of articular cartilage



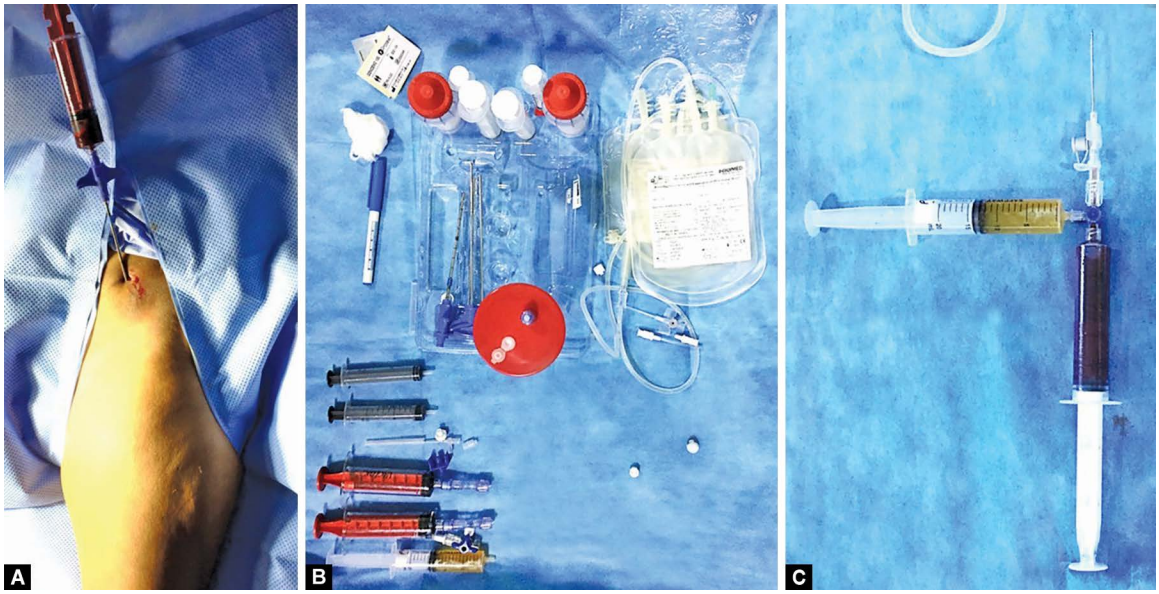
Figs 2A to D: (A and B) Medial malleolar osteotomy performed for joint debridement and excision of loose chondral fragments; (C) Microfracturing of talar surface using angled microawl; (D) Wire representing the Inman axis (marked in black), for hinge positioning

The external frame consisted of two rings: one foot ring and one full ring over the distal third tibia, perpendicular to the anatomical axis. The foot frame, which was a commercially available foot plate (Pitkar Orthotools, Pune, India, or Taylor Spatial Frame, Smith & Nephew, Tennessee, USA), was affixed using one midfoot wire, two counteropposed olive wires through the calcaneum, and one wire through the talus. Two universal hinges connected the two rings, placed along the axis of rotation of the ankle (Inman axis),[14] under intraoperative fluoroscopic assistance (Fig. 2D). An anterior flexion–extension distraction assembly completed the montage (Fig. 3). In all cases, acute distraction of the joint to approximately 5 mm was performed under fluoroscopic control, and the foot was moved through its range-of-motion to confirm the precise hinge placement. Select patients, with severe cartilage wear on preoperative MRI, additionally underwent a percutaneous BMAC infiltration into the ankle joint, under fluoroscopic guidance at the end of the surgery. Two milliliters of BMAC mixed with 1 mL of platelet-rich plasma (PRP), prepared using a commercially available kit (Concemo®, Soluciones Bioregenerativas SL, Gava, Spain), was injected using a two-way cannula, as shown in Figure 4.

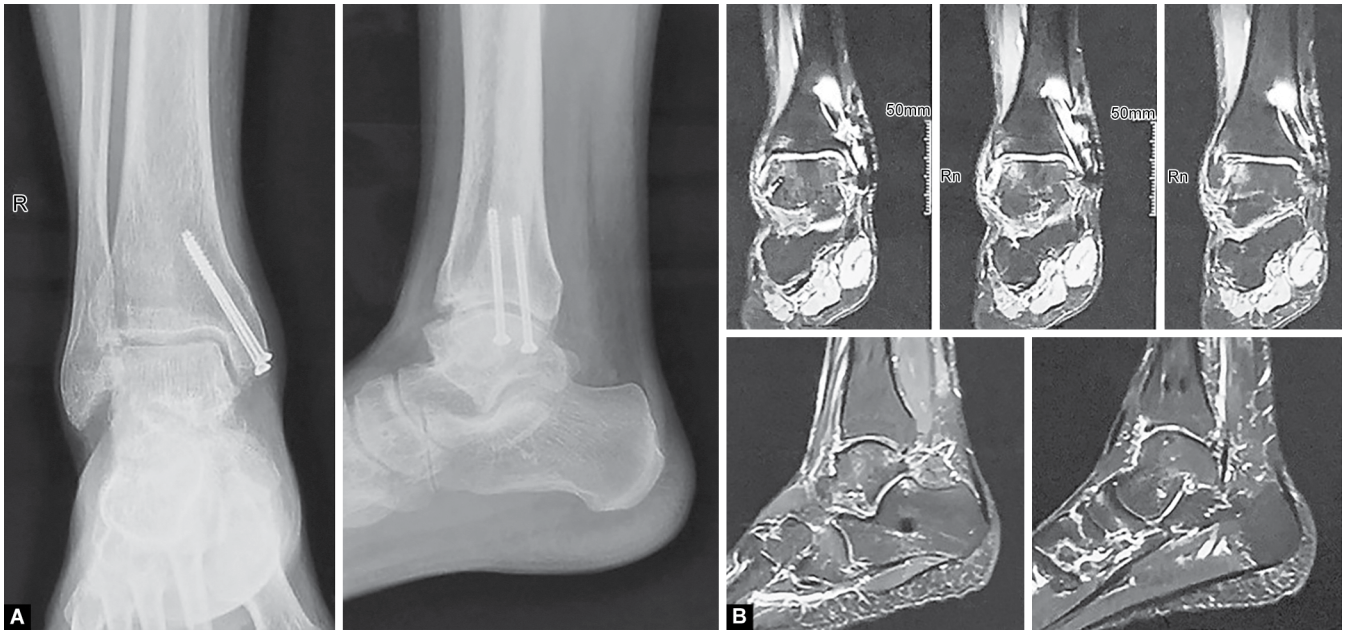
Postoperative care protocol comprised of partial weight bearing ambulation with a walking frame and active ankle ROM exercises for 6 weeks, progressing to unrestricted weight bearing with two crutches for the next 6 weeks. Tablet aspirin 150 mg was prescribed for deep vein thrombosis (DVT) prophylaxis for 3 weeks, and pin tract care was taught to all patients. Frame removal was considered at an average of 12 weeks, or thereafter. No footwear modification was required in any patient. Follow-up radiographs were taken at 6 and 12 months; CT and MRI were repeated on completion of a minimum follow-up of 12 months (Fig. 5). Functional outcome of the intervention was measured by comparing pre- and postoperative AOFAS-AH scores, VAS scores, and ankle ROM. Descriptive statistics were calculated as mean ± standard deviation (SD). Statistical analysis was performed with Microsoft Excel 2024 (v.16), using Student's *t*-test, with the level of significance set at $\alpha = 0.05$, and 95% confidence interval (CI).



Figs 3A to C: (A) Final frame assembly showing the anterior distractor; (B) Postoperative AP and lateral radiographs showing the joint distraction and the hinge axis (marked with white dashed line); (C) Active ROM with frame *in situ*



Figs 4A to C: (A) Harvesting of 50 mL bone marrow from multiple sites of iliac crest. 10 mL is aspirated from each site; (B) Constituents of commercially available BMAC kit; (C) BMAC and PRP injection apparatus using a two-way cannula



Figs 5A and B: (A) Six-month postoperative AP and lateral radiographs of the same patient; (B) 12-month follow-up MRI showing increased thickness of talar articular cartilage

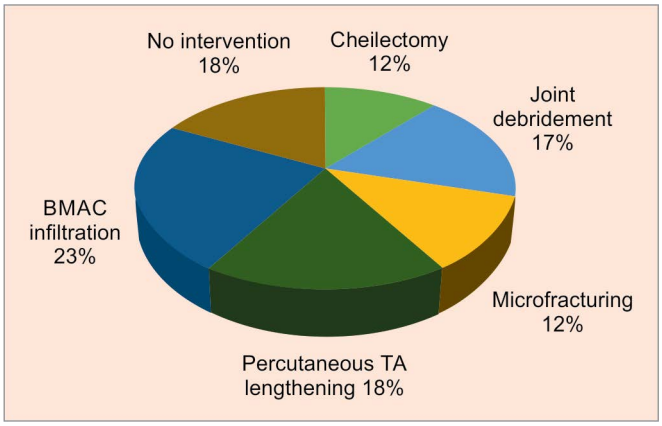


Fig. 6: Pie chart depicting the proportion of adjuvant procedures performed in 12 cases

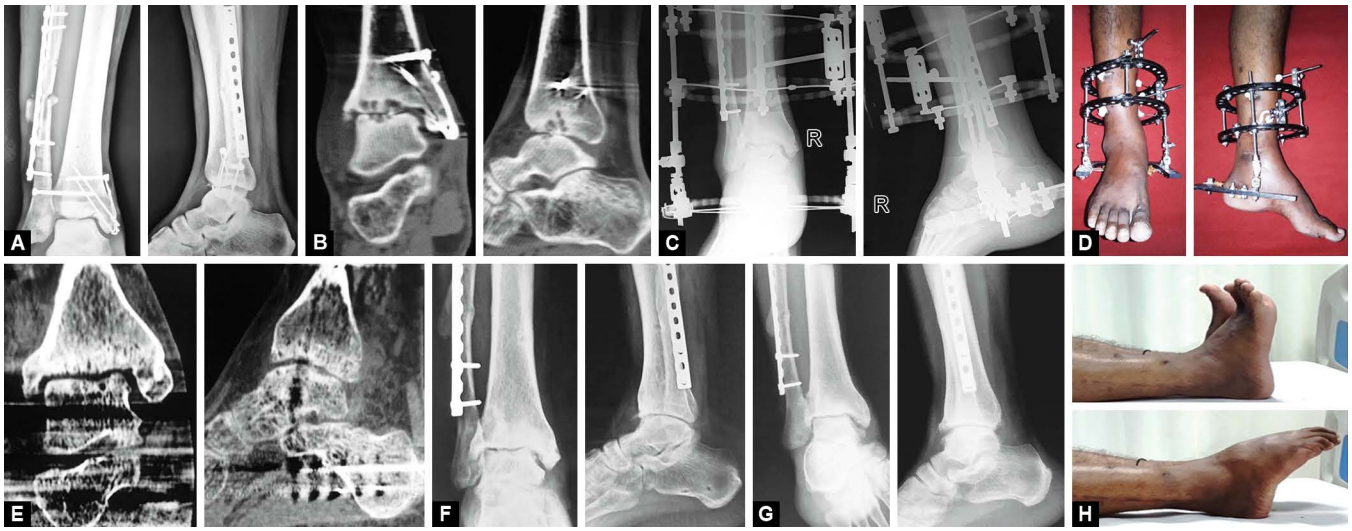
Results

Of the 15 patients initially shortlisted, who met the selection criteria, three patients had incomplete follow-up; hence, the sample size included in the participant data was 12 patients. Of the 12 patients, 3 were females and the remaining, males. The mean age was 46.33 years (range 35–56 years). Comorbidities included type 2 diabetes in one case and rheumatoid arthritis in another case. The predisposing factors for OA were trauma in 11 patients and rheumatoid arthritis (RA) (presumably) in one patient. Six patients had grade 2, three patients had grade 3A, and two patients had grade 3B OA, according to the Takakura–Tanaka classification.[15,16] Adjuvant procedures included cheilectomy in two patients, joint debridement in three patients, microfracturing in two patients, percutaneous TAL in three patients, and BMAC infiltration in four patients (Fig. 6). The mean external fixator duration was 12.5 (±1.9) weeks, and the mean follow-up was 19 (±7.7) months. The longest follow-up was 38 months (Fig. 7). The mean dorsiflexion preoperative was 11.3° (±4.8), which improved marginally to 14.6° (±3.9) postoperative, with a p-value = 0.013, while the mean plantarflexion improved from 24.5° (±7.5) preoperative to 27.9° (±7.2) postoperative, with a p-value = 0.0045, which was significant. Mean AOFAS-AH scores improved from 56.6 (±8.1) preoperative to 81.3 (±6.2) postoperative, which were statistically significant ($p < 0.05$). The mean preoperative VAS score was 4.8 (±1.5), which reduced to 1.8 (±0.5) postoperative ($p < 0.05$). Postoperative CT or MRI scans were compared with preoperative ones to document improvement in joint congruency, joint space, and resolution of subchondral cysts, which was present in all cases. We encountered minor complications, namely, superficial pin tract infections (Checketts–Otterburn grade 2) in two cases, which responded to local dressings and antibiotics, and complex regional pain syndrome (CRPS) in one case, which subsided with gabapentin and vitamin-C supplementation. There were no conversions to arthroplasty or fusion. A summary of demographic parameters and results is outlined in Tables 1 and 2.

Discussion

Conventional methods of treating severe ankle OA include TAA and ankle arthrodesis. Though the time-tested method of arthrodesis has demonstrated excellent, reliable, and reproducible results, it is associated with various complications, such as increased stress on adjacent joints, resulting in degeneration, increased energy expenditure, malunion, and nonunion.[17–19] TAA was designed to supersede arthrodesis as the preferred treatment of severe ankle OA. First- and second-generation TAA implants were characterized by unacceptably high failures and complications; however, the newer semiconstrained designs are more compatible with ankle kinematics, resulting in lower wear rates and subsequent failures.[20] Although TAA may be an acceptable alternative to arthrodesis in certain situations, consensus is that TTA is contraindicated in young patients because of wear, failure, and subsequent revisions.[21]

The term "arthrodiastasis" was first described by Volkov in 1975 for the knee and elbow and later by Aldegheri in 1981 for the hip. It literally means "arthro" (joint), "dia" (through), and "tasis" (to stretch out).[22,23] The aim of joint distraction is to neutralize muscle



Figs 7A to H: (A) AP and lateral radiographs of a 45-year male, with grade 2 OA and mild anterior subluxation of the ankle; (B) NCCT images showing focal full-thickness cartilage denudation, with subchondral cysts; (C and D) Individual underwent hinged ADA for 16 weeks; (E and F) Follow-up NCCT images and radiographs at 12 months showing a congruent tibiotalar joint with increased joint space and resorption of subchondral cysts; (G and H) 38-month follow-up of the same patient, showing a well-maintained joint space and a decent ROM

Table 1: Compilation of demographic parameters and results

Patients	*Age*	*Sex*	*Comorbidities**	*OA grade (Takakura–Tanaka)*	*Adjuvant interventions**	*External fixator duration (weeks)*	*Follow-up (months)*	*Complications**
Case 1	37	M	Nil	2	BMAC	12	14	Nil
Case 2	45	M	Nil	2	Nil	16	38	Nil
Case 3	54	M	DM2	3A	Cheilectomy, percutaneous TAL	10	15	Superficial pin tract infection
Case 4	51	F	Nil	3A	Joint debridement, BMAC	16	20	Nil
Case 5	35	M	Nil	2	Joint debridement, microfracturing	12	16	Nil
Case 6	52	F	Nil	2	Nil	12	24	Nil
Case 7	49	M	Nil	3B	BMAC	12	12	CRPS
Case 8	42	M	Nil	2	Nil	12	13	Nil
Case 9	36	F	RA	3B	BMAC, percutaneous TAL	12	28	Nil
Case 10	52	M	Nil	2	Joint debridement	10	18	Superficial pin tract infection
Case 11	47	M	Nil	2	Nil	12	12	Nil
Case 12	56	M	Nil	3A	Cheilectomy, microfracturing, and percutaneous TAL	14	18	Nil

*BMAC, bone marrow aspirate concentrate injection; TAL, tendo-Achilles lengthening, DM2, diabetes mellitus type2; RA, rheumatoid arthritis; CRPS, complex regional pain syndrome

Table 2: Functional outcome assessment

Parameter	*Value (expressed as mean ± SD)*	*p-value*
Preoperative dorsiflexion	11.3° (±4.8)	0.013
Final dorsiflexion	14.6° (±3.9	
Preoperative plantar flexion	24.5° (±7.5)	0.0045
Final plantarflexion	27.9° (±7.2)	
Preoperative AOFAS-AH score	56.6 (±8.1)	<0.05
Final AOFAS-AH score	81.3 (±6.2)	
Preoperative VAS score	4.8 (±1.5)	<0.05
Final VAS score	1.8 (±0.5)	

forces and simultaneously permit protected weight bearing, to promote creeping substitution in subchondral bone.[24] ADA was first introduced by Judet and Judet in 1978,[25] and popularized by van Valburg.[26] ADA addresses the articular cartilage damage by recruiting pluripotent mesenchymal cells, which differentiate into hyaline/fibrocartilage, thereby preserving natural joint surfaces and ankle motion. Weight-bearing ambulation in the frame bypasses the axial loading and shear stresses on the joint, promotes cyclical fluctuations in the intra-articular hydrostatic pressure, and releases growth factors from the exposed marrow spaces, aiding in cartilage healing. The biomechanical stability of the Ilizarov fixator and its variants enables sufficient stress-shielding to allow subchondral bone to remodel, resulting

in resorption of cysts, which is of clinical benefit.[27] In their series of 17 patients, Van Valburg et al. reported a substantial reduction in pain and significant clinical improvement at 3 months.[26] ROM increased by 55% in all patients. Marjinissen et al. performed a randomized controlled trial of 57 patients comparing ankle distraction with ankle debridement and found substantial pain relief and improved function at 3-year follow-up in both groups.[28] Tellisi et al. applied the Ilizarov apparatus for ankle distraction in 23 patients and found substantial pain relief in 91% of patients and a significant improvement in AOFAS scores at 30-month follow-up.[11] Paley et al. designed an ankle distractor with hinges placed along the anatomical axis, permitting ROM while walking, thereby achieving a positive outcome in 71% of patients.[4] The long-term survival of ADA was analyzed

Table 3: Summary of outcomes and complications from studies on ankle distraction arthroplasty (ADA)

Study	*Number of cases*	*Follow-up*	*Mean age (years)*	*Outcome*	*Complications*
Tellisi et al.[11]	23	30.5 months(range: 12–60)	43 (16–73)	Decrease in pain in 91% of patients	Pin-site infection in all patients Arthrodesis: 2/23 (9%)
Saltzman et al.[31]	29	2 years	Fixed group: 42.4 (18–53) Motion group: 42.7 (27–59)	Better pain reduction in motion group as compared to fixed group at 2 years from baseline	Recurrent pin-site infections: 19/29 (66%) Osteomyelitis: 2 /29 (7%) Nerve injuries: 8/29 (27.5%) DVT: 1/29 (3.5%)
van Valburg et al.[32]	17	2 years	40 (17–55)	Decrease in physical disability and pain scores at 2 years	Arthrodesis: 4/17 (24%) Broken K-wires 4/17 patients (24%)
Paley et al.[4]	23	64 months (24–157)	45 (17–62)	71% of patients ambulate for pleasure; 33% can run, 22% use assistive devices; and 11% severe limitations	Pin tract infections: 17/23 (74%) Arthrodesis: 1/23 (4%) TAA: 1/23 (4%) Returned to OR for unplanned procedure: 10/23 (43%)
Marijnissen et al.[28]	57	2.8 years (2.5–3.1)	44 (18–65)	Decrease in pain scores by 38% ($p = 0.0001$); 69% increase in function ($p = 0.0001$); and increase in clinical condition by 120% ($p = 0.0001$)	Pin tract infections: 16/57 (28%) Broken K-wires: 8/57 (14%)
Wang et al.[16]	34	45.3 months (13–143)	42.3	AOFAS-AH and VAS scores were significantly improved compared to preoperative values ($p < 0.05$). Five cases had no pain, 13 cases had moderate, 9 cases had mild, and 7 cases had no obvious pain relief	Pin tract infection: 12/34 (35%)
Zhao et al.[6]	46	42.8 months (24–68)	54.8 (42–71)	AOS and AOFAS scores significantly improved ($p < 0.01$). The ankle joint space distance improved in 61% of patients and was significant ($p < 0.01$)	Failure rate was 21.7% Patients with large talar tilt (≥5°) angle (RR = 3.81, 95% CI 1.28–11.33, $p = 0.02$), and obesity (RR = 3.58, 95% CI 1.30–9.89, $p = 0.01$) were found to have positive correlation with failure
Herrera-Pérez et al.[30]	50	46 months (36–78)	40.0 (± 8.5)	Overall survival rates were 19 of 25 (74%) and 15 of 25 (59%) at 3 and 5 years, respectively AOFAS score in preoperative group was 38 ± 8.6 and improved to 55.6 ± 19.1 at 3 years follow-up (p = 0.073)	Pin tract infections: 4/50 (8%)(two pins being removed before 3 months) Type I reflex sympathetic dystrophy syndrome: 1/50
Greenfield et al.[29]	258	55 months	48.9 (±14.1)	5-year survival was 84% (95% CI: 78–91%)	Failure: 24/144 (16.7%)
Present study	12	19 months (12–38)	46.3 (35–56)	Mean AOFAS-AH scores improved from 56.6 (±8.1) preoperative to 81.3 (±6.2) postoperative ($p < 0.05$) Mean preoperative VAS score was 4.8 (±1.5), which reduced to 1.8 (±0.5) postoperative ($p < 0.05$)	Pin tract infection: 2/12 (16.7%) CRPS: 1/12 (8.3%) Conversions to TAA or fusion: Nil

by Greenfield et al.[29] and Herrera-Pérez et al.[30] Both studies demonstrate excellent intermediate-long-term survival data for the described technique. Table 3 summarizes our results with similar studies based on ADA.

The ankle rotates with one degree of freedom about an axis (Inman axis) that can be plotted along a line joining the tips of the medial and lateral malleoli.[14,33] This concept is based on the theory that the talar dome constitutes a frustum of a cone, with its apex directed medially.[8] Therefore, the hinges of the frame should be meticulously placed along this axis to permit smooth gliding between the opposing surfaces. Two distraction methods have been reported in literature: gradual distraction starting on the first postoperative day, of 0.5 mm twice daily, for 5 days, totaling 5 mm[8,28,32]; or acute distraction on table to approximately 5 mm, under fluoroscopic guidance, as performed in our study.[6,31,34] Based on a recent biomechanical study, a recommendation of a 5 mm increase in joint space should be obtained to ensure that the articulating surfaces do not come in contact during weight bearing.[35] In addition to mechanical distraction, we also employed biological adjuvants, such as BMAC from the ipsilateral iliac crest, along with PRP, as described by Hernigou et al.[36] An aspirate of 50–60 mL of bone marrow yields approximately 6–7 mL of BMAC, rich in pluripotent stem cells. This is percutaneously injected at the end of the case, following acute distraction. For an appropriate assessment of its clinical implication on cartilage repair, a larger number of patients would need to be recruited in a multicenter randomized controlled trial. We did not find any significant improvement in joint mobility after the intervention, which, by far, is not the primary aim of ADA. Complications can range from minor pin tract infections to severe, debilitating pain (CRPS) and late collapse, warranting ankle fusion. The surgeon must exercise caution in using ADA in obese patients and those with a large talar tilt angle because of high failure rates.[8] Although literature cites RA as a relative contraindication to ADA, our personal experience in one case was encouraging, and recent studies suggest good clinical results in young patients with RA.[37]

The limitations of the current study include (1) a small sample size, (2) retrospective study design, (3) lack of a control group for comparison, and (4) a longer duration of follow-up would have been desirable.

Conclusion

Ankle distraction arthroplasty offers a promising solution for a potentially debilitating condition with its unique concept of mechanical unloading of a joint with preservation of motion. Although the functional outcomes of ADA remain a dynamic entity, our midterm results corroborate this technique as a successful joint-sparing option in young individuals. Patient perspectives are mostly positive, with majority reporting significant pain relief and functional improvement. Clinically, ADA shows decent survival rates and maintenance of joint space, highlighting its potential long-term benefits.

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References

1. Daniels T, Thomas R. Etiology and biomechanics of ankle arthritis. Foot Ankle Clin 2008;13:341–352. DOI: 10.1016/j.fcl.2008.05.002
2. Saltzman CL, Salamon ML, Blanchard GM, et al. Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic centre. Iowa Orthop J 2005;25:44–46. PMID: 16089071.
3. Barg A, Amendola A, Beaman DN, et al. Ankle joint distraction arthroplasty: why and how? Foot Ankle Clin 2013;18:459–470. DOI: 10.1016/j.fcl.2013.06.005
4. Paley D, Lamm BM, Purohit RM, et al. Distraction arthroplasty of the ankle—how far can you stretch the indications? Foot Ankle Clin 2008;13:471–484. DOI: 10.1016/j.fcl.2008.05.001
5. Stavrakis AI, SooHoo NF. Trends in complication rates following ankle arthrodesis and total ankle replacement. J Bone Joint Surg Am 2016;98:1453–1458. DOI: 10.2106/JBJS.15.01341
6. Zhao H, Yang Y, Yu G, et al. A systematic review of outcome and failure rate of uncemented Scandinavian total ankle replacement. Int Orthop 2011;35:1751–1758. DOI: 10.1007/s00264-011-1339-y
7. Hayes BJ, Gonzalez T, Smith JT, et al. Ankle arthritis: you can't always replace it. J Am Acad Orthop Surg 2016;24:e29–e38. DOI: 10.5435/JAAOS-D-15-00354
8. Bernstein M, Reidler J, Fragomen A, et al. Ankle distraction arthroplasty: indications, technique, and outcomes. J Am Acad Orthop Surg 2017;25(2):89–99. DOI: 10.5435/JAAOS-D-14-00077
9. Im GI, Kim DY, Shin JH, et al. Repair cartilage defect in the rabbit with cultured mesenchymal stem cells from bone marrow. J Bone Joint Surg Br 2001;83(2):289–294. DOI: 10.1302/0301-620x.83b2.10495
10. Smith NC, Beaman D, Rozbruch SR, et al. Evidence-based indications for distraction ankle arthroplasty. Foot Ankle Int 2012;33(8):632–636. DOI: 10.3113/FAI.2012.0632
11. Tellisi N, Fragomen AT, Kleinman D, et al. Joint preservation of the osteoarthritic ankle using distraction arthroplasty. Foot Ankle Int 2009;30(4):318–325. DOI: 10.3113/FAI.2009.0318
12. Hoppenfeld S, DeBoer P, Buckley R. Surgical Exposures in Orthopaedics: The Anatomic Approach. Philadelphia: Lippincott Williams & Wilkins; 2012.
13. Hatt RN, Lamphier TA. Triple hemisection: a simplified procedure for lengthening the Achilles tendon. N Engl J Med 1947;236(5):166–169. DOI: 10.1056/NEJM194701302360502
14. Inman VT. Inman's Joints of the Ankle, 2nd edition. Baltimore, MD: William and Wilkins; 1991.
15. Takakura Y, Tanaka Y, Kumai T, et al. Low tibial osteotomy for osteoarthritis of the ankle: results of a new operation in 18 patients. Bone Joint Sung (Br) 1995;77(1):50–54. PMID: 7822395.
16. Wang J, Wang C, Ding X, et al. Effect of distraction arthroplasty in the treatment of moderate-to-severe ankle arthritis. Orthop Surg 2024;16(9):2167–2172. DOI: 10.1111/os.14233
17. Thomas R, Daniels TR, Parker K. Gait analysis and functional outcomes following ankle arthrodesis for isolated ankle arthritis. J Bone Joint Surg Am 2006;88(3):526–535. DOI: 10.2106/JBJS.E.00521
18. Abuhantash M, Veljkovic A, Wing K, et al. Arthroscopic versus open ankle arthrodesis: a 5-year follow up. J Bone Joint Surg Am 2022;104(13):1197–1203. DOI: 10.2106/JBJS.21.01088
19. Tay KS, Langit M, Fenton C, et al. Complex ankle fusion with circular frames: factors influencing outcomes, complications, and patient satisfaction. Foot Ankle Int 2023;44(5):403–414. DOI: 10.1177/10711007231157710
20. Guyer AJ, Richardson EG. Current concepts review: total ankle arthroplasty. Foot Ankle Int 2008;29(2):256–264. DOI: 10.3113/FAI.2008.0256
21. Brunner S, Barg A, Knupp M, et al. The Scandinavian total ankle replacement: long-term, eleven to fifteen-year, survivorship analysis of the prosthesis in seventy-two consecutive patients. J Bone Joint Surg Am 2013;95(8):711–718. DOI: 10.2106/JBJS.K.01580

22. Volkov MV, Oganesian OV. Restoration of function in the knee and elbow with a hinge-distractor apparatus. J Bone Joint Surg Am 1975;57:591–600. PMID: 1150697.
23. Aldegheri R. Arthrodiatasis of the hip. Ortopedia Traumatologia Oggi 1981;1:103–109.
24. Aldegheri R, Trivella G, Saleh M. Articulated distraction of the hip: conservative surgery for arthritis in young patients. Clin Orthop Relat Res 1994;301:94–101. PMID: 8156703.
25. Judet R, Judet T. The use of a hinge distraction apparatus after arthrolysis and arthroplasty (author's transl). Rev Chir Orthop Reparatrice Appar Mot 1978;64:353–365. PMID: 152944.
26. van Valburg AA, van Roermund PM, Lammens J. Can Ilizarov joint distraction delay the need for an arthrodesis of the ankle? A preliminary report. J Bone Joint Surg Br 1995;77:720–725. PMID: 7559696.
27. Intema F, Thomas TP, Anderson DD. Subchondral bone remodeling is related to clinical improvement after joint distraction in the treatment of ankle osteoarthritis. Osteoarthritis Cartilage 2011;19(6):668–675. DOI: 10.1016/j.joca.2011.02.005
28. Marijnissen ACA, Roermund PMV, Melkebeek JV, et al. Clinical benefit of joint distraction in treating severe osteoarthritis of the ankle: proof of concept in an open prospective study and in a randomized controlled study. Arthritis Rheum 2002;46:2893–2902. DOI: 10.1002/art.10612
29. Greenfield S, Matta KM, McCoy TH, et al. Ankle distraction arthroplasty for ankle osteoarthritis: a survival analysis. Strategies Trauma Limb Reconstr 2019;14(2):65–71. DOI: 10.5005/jp-journals-10080-1429
30. Herrera-Pérez M, García-Paños JP, González-Martín D, et al. Hinged motion distraction surgery for ankle osteoarthritis. Tech Foot Ankle Surg 2020;19(1):14–18. DOI: 10.1097/BTF.0000000000000262
31. Saltzman CL, Hillis SL, Stolley MP, et al. Motion versus fixed distraction of the joint in treating ankle osteoarthritis: a prospective randomized controlled trial. J Bone Joint Surg Am 2012;94:961–970. DOI: 10.2106/JBJS.K.00018
32. van Valburg AA, van Roermund PM, Marijnissen AC, et al. Joint distraction in treatment of osteoarthritis: a two-year follow-up of the ankle. Osteoarthritis Cartilage 1999;7:474–479. DOI: 10.1053/joca.1998.0242
33. Barnett CH, Napier JR. The axis of rotation at the ankle joint in man. Its influence upon the form of the talus and the mobility of the fibula. J Anat 1952;86(1):1–9. PMID: 14907546.
34. Zhao H, Qu W, Li Y, et al. Functional analysis of distraction arthroplasty in the treatment of ankle osteoarthritis. J Orthop Surg Res 2017;12:1–7. DOI: 10.1186/s13018-017-0519-x
35. Fragomen AT, McCoy TH, Meyers KN, et al. Minimum distraction gap: How much ankle joint space is enough in ankle distraction arthroplasty? HSS J 2014;10(1):6–12. DOI: 10.1007/s11420-013-9359-3
36. Hernigou P, Mathieu G, Poignard A, et al. Percutaneous autologous bone-marrow grafting for nonunions. Surgical technique. J Bone Joint Surg Am 2006;88(Suppl. 1 Pt 2):322–327. DOI: 10.2106/JBJS.F.00203
37. Nakasa T, Adachi N, Kato T, et al. Distraction arthroplasty with arthroscopic microfracture in a patient with rheumatoid arthritis of the ankle joint. J Foot Ankle Surg 2015;54(2):280–284. DOI: 10.1053/j.jfas.2014.11.016