

Ankle Distraction Arthroplasty: Indications, Technique, and Outcomes

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Abstract

Ankle distraction is an alternative to ankle arthrodesis or total ankle arthroplasty in younger patients with arthritis. Ankle distraction involves the use of external fixation to mechanically unload the ankle joint, which allows for stable, congruent range of motion in the setting of decreased mechanical loading, potentially promoting cartilage repair. Adjunct surgical procedures are frequently done to address lower-extremity malalignment, ankle equinus contractures, and impinging tibiotalar osteophytes. Patients can bear full weight during the treatment course. The distraction frame frequently uses a hinge, and patients are encouraged to do daily range-of-motion exercises. Although the initial goal of the procedure is to delay arthrodesis, many patients achieve lasting clinical benefits, obviating the need for total ankle arthroplasty or fusion. Complications associated with external fixation are common, and patients should be counseled that clinical improvements occur slowly and often are not achieved until at least 1 year after frame removal.

Ankle osteoarthritis is generally a progressive condition, most commonly the result of high-energy tibial plafond fractures, bimalleolar ankle fractures, recurrent ankle instability, and neuropathy.¹⁻³ Lower-extremity posttraumatic arthritis has an estimated cost of \$12 billion annually in the United States.⁴ It is often disabling, predominantly affects young, active persons, and has a negative effect on quality-of-life measures that is comparable to that of hip and knee arthritis.¹ The mainstay of surgical treatment of advanced ankle arthritis has traditionally included ankle arthrodesis or total ankle arthroplasty (TAA).

Ankle arthrodesis reliably provides pain relief. However, loss of ankle motion, increased stress at adjacent joints that leads to degeneration, and increased energy expenditure with

ambulation do occur.⁵ Unlike fusion, TAA does not affect range of motion (ROM); however, its use in young active patients may be contraindicated because of wear, failure, and subsequent revisions.⁶

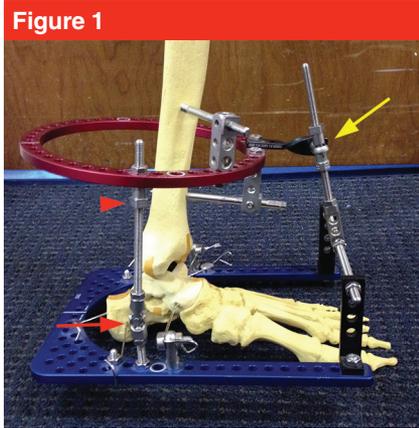
In contrast to the aims of TAA and ankle fusion, the aim of distraction arthroplasty is to optimize the body's regenerative capacity and the function of the diseased joint.^{7,8} An external fixator is used to mechanically unload the ankle to relieve pain, preserve ROM, and potentially delay or even partially reverse the effects of arthritis (Figure 1). The surgeon should be aware of this treatment option, as well as its indications, outcomes, and potential adverse effects for ankle arthritis. Recent short- and intermediate-term evidence suggests that distraction arthroplasty may be a viable surgical

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Figure 1

Ankle distraction frame mounted on an extremity model demonstrating our current assembly method. The red (circular) and blue (U-shaped) rings are secured with 6-mm hydroxyapatite-coated half pins and 1.8-mm bayonet Kirschner wires to the tibia and foot, respectively. The hinge (red arrow) is aligned with the Inman axis. The acute and gradual distraction is achieved with clockwise rotations of the square nuts (red arrowhead), which are attached to the tibial ring. Range-of-motion exercises occur with unlocking the connection between the two rings (yellow arrow). Gradual dorsiflexion of the ankle, in the setting of chronic ankle equinus, is achieved by gradually increasing the distance between the square nut (yellow arrow) and the proximal end of the rod. (Copyright Mitchell Bernstein, MD, FRCSC, Chicago, IL.)

option with the use of appropriate patient selection criteria.^{9,10}

Anatomy and Biomechanics of the Ankle Joint

The ankle is a highly constrained and congruent weight-bearing joint. Its

ability to withstand up to 5.5 times body weight during ambulation depends on a stable relationship among the bony and ligamentous structures of the distal tibia, fibula, and talus.¹¹ The tibial plafond has a central ridge oriented in the sagittal plane that is complementary to a concavity on the talar dome. The relationship between the distal fibula, tibiotalar joint, and the medial malleolus is maintained by the stout ligaments that make up the ankle syndesmosis.

One study demonstrated that even a 1-mm displacement of the talus in the ankle mortise generates a 42% decrease in available joint contact area.¹² Consequently, the remaining cartilage is exposed to compressive forces over a smaller surface area, potentially leading to degeneration and arthritis.

The orientation of the ankle joint, as described by a line perpendicular to the diaphysis of the tibia, is in slight valgus. Named the lateral distal tibial angle, it measures on average 89° (range, 86° to 92°). The axis of the ankle joint is created through the relationship between, and the geometric constraints of, the talar dome, tibial plafond, and the lateral and medial malleoli.¹³ The traditionally accepted theory, proposed in the 1950s, suggests that the ankle rotates with one-degree of freedom about an axis (ie, the Inman axis) that lies between the tips of the medial and lateral malleoli.¹⁴⁻¹⁶ This axis is the basis for total ankle prosthesis designs¹⁷ and forms the basis on which the hinge is built when distraction arthroplasty is performed

with a circular fixator.^{18,19} The concept of the hinge is based on the theory that the talar dome is a frustum of a cone with its apex medially directed.

Articular cartilage, or hyaline cartilage, lacks blood supply, nerve innervation, and lymphatic drainage. It receives nutrition and expels waste via diffusion and imbibition. Its high tensile strength and elasticity function to withstand high loads, protect subchondral bone, and decrease friction between the two opposing surfaces. Hyaline cartilage is primarily composed of type II collagen, water, and chondrocytes. Chondrocytes, which produce enzymes, proteins, and collagen, are responsible for the normal and pathologic state of the articular surface.^{20,21} Chondrocytes are metabolically controlled via the surrounding mechanical environment and thus, can upregulate the synthesis of degradative cytokines, increasing catabolic enzymes in the local milieu—a concept referred to as mechanochemical events.²²

Arthritis in the ankle is most often secondary, usually resulting from trauma.^{2,3} The energy dissipated through the articular surface and the ensuing inflammatory response is thought to be critical in post-traumatic arthritis.^{23,24} It has been demonstrated that the inflammation resulting from the energy loss causes the production of dysfunctional cellular elements and chondrocyte apoptosis.²⁵ In the subacute phase, articular cartilage changes its composition, increasing its water content and decreasing its proteoglycan

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concentration. Furthermore, type II collagen is weakened by a combination of decreased production by chondrocytes and increased concentration of proinflammatory cytokines. To restore normal homeostasis, deeper layers containing “resting” chondrocytes proliferate to increase anabolic activities. The exact cellular mechanisms, signaling molecules, genetic factors, and the role of mechanical influences currently are not fully understood.

As the catabolic processes overwhelm resident chondrocytes, “full-thickness” chondral involvement ensues, exposing subchondral bone. Healing is possible, albeit unpredictably. This spontaneous healing occurs in part because of the release of growth factors from exposed marrow spaces.²⁶ The resultant local inflammatory response recruits pluripotent mesenchymal stem cells, which, depending on the local environment, can be manipulated to develop fibrocartilage.²⁷⁻³⁰ This is one potential pathway that distraction arthroplasty and adjunct procedures may use to exploit the formation of hyaline cartilage.³¹

For younger patients with posttraumatic lesions, a durable, joint-sparing solution is desirable. Concurrently addressing all pathology, including equinus contracture, tibiotalar osteophytes, supramalleolar or hindfoot malalignment, and instability, is central to treatment. Cartilage regeneration is more reliable when it occurs in the setting of a congruent, stable limb in anatomic alignment.^{19,32}

Distraction Arthroplasty

The success of ankle distraction depends on proper patient selection and appropriate management of expectations. The ideal candidate for ankle distraction arthroplasty is a motivated patient who seeks an alternative to ankle fusion or TAA

and has recalcitrant pain in the setting of a congruent joint with preserved motion of $>20^\circ$.³³ Relative contraindications include complex regional pain syndrome, inflammatory arthritides, previous infection, neuropathic joint, and older age with low functional demands. Patients with a painful stiff ankle (ie, $<20^\circ$ of motion) are less likely to do well with distraction because the procedure does not reliably increase ROM, and thus, these patients may be better candidates for arthrodesis or TAA.¹⁰

Extra-articular deformity, located in the hindfoot or distal tibia, is not a contraindication if the deformity is addressed concurrently.³⁴ Patients with marked intra-articular deformity or a flat-top talus, however, are felt to be poor candidates for ankle distraction. Asymmetric arthritis of the ankle is not a contraindication for ankle distraction. For example, patients with varus deformity at the distal tibia and asymmetric joint wear on the medial side may benefit from a supramalleolar osteotomy, with correction of the varus deformity and ankle distraction to offload the diseased segment. Finally, anterior joint space narrowing associated with impinging anterior osteophytes should be identified. In these patients, arthroscopic or open decompression, possibly in conjunction with gastrocnemius recession, should be considered.

The success of ankle distraction is predicated on a thorough history, physical examination, and ancillary tests. Our evaluation includes a review of patients’ reasons for consultation and their perception of their disability in addition to the basic elements of a thorough patient history: the location and quality of the pain, aggravating and alleviating factors, subjective description of instability, previous nonsurgical and surgical treatments, and other musculoskeletal complaints. Because inflammatory arthritides are relative contraindications to

distraction, the etiology of ankle arthritis is critical. A history of injury or repetitive instability is therefore carefully elucidated.

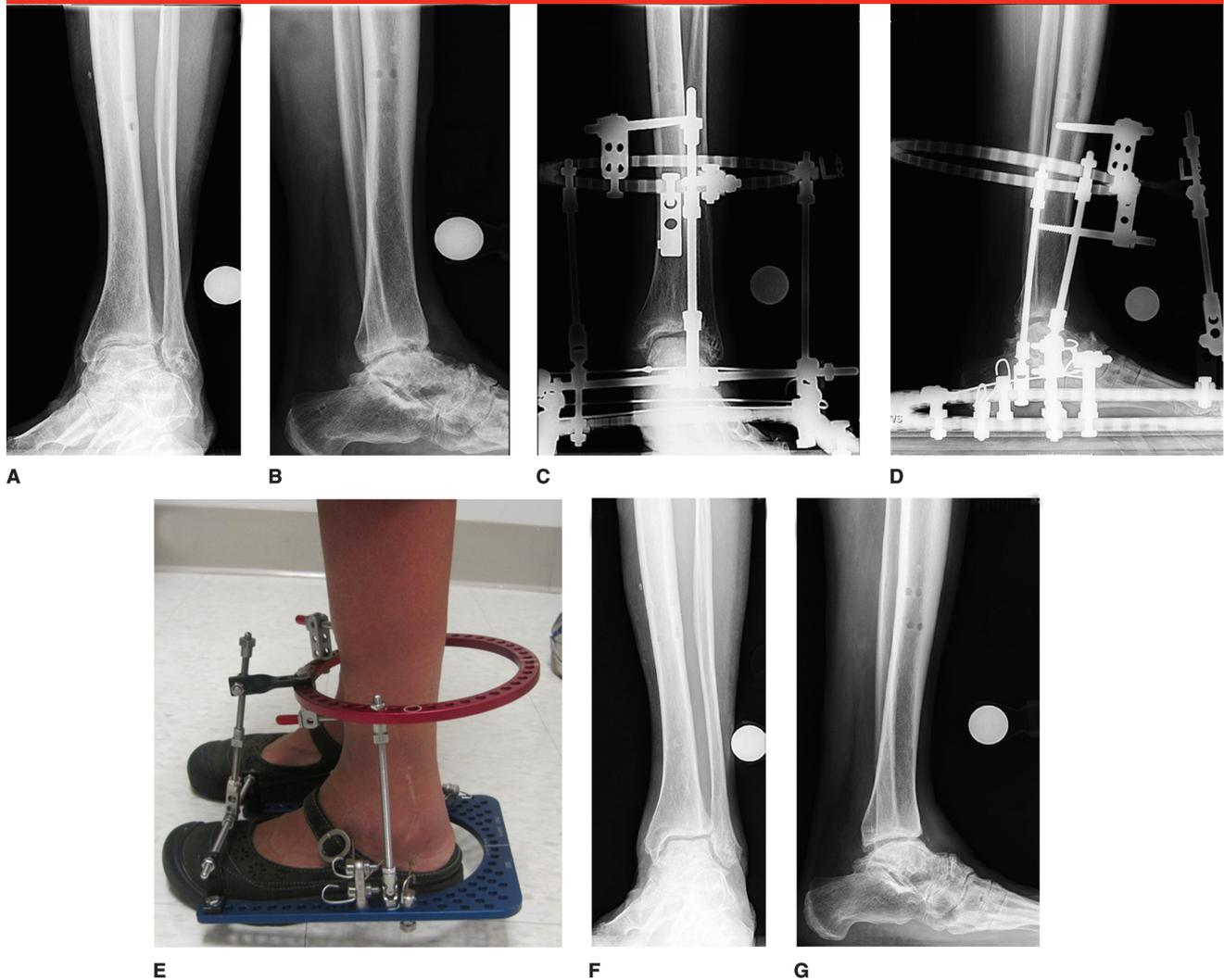
The physical examination begins with an assessment to identify any ipsilateral (or contralateral) extremity malalignment, such as tibial malunion, knee hyperextension, or tibia vara. The patient is screened for limb length inequality by comparing the heights of the iliac crests. Dynamic extremity instability, malalignment, and foot progression angle are determined by observing the patient ambulate. A focused assessment of the ankle and foot, including stability and ROM testing, completes the physical examination.

No routine laboratory tests are required. Infectious markers, such as white blood cell count and erythrocyte sedimentation rate and C-reactive protein level, are ordered when active infection is suspected or needs to be ruled out.

Radiographic evaluation includes AP, lateral, and mortise weight-bearing views of the ankle (Figure 2). Radiographs of the tibia and/or a standing hindfoot alignment (Saltzman) view of the foot are obtained in the case of pathology and/or malalignment. CT scans of the ankle are not routinely ordered. MRI is used when osteochondral lesions need to be delineated or in the case of nonosseous pathology (eg, lateral ankle ligament pathology, posterior tibial tendinosis).

The ankle radiographs are also used to measure the weight-bearing preoperative joint space in preparation for the required increase of 5 mm during distraction to effectively unload the ankle joint.^{10,35} The presence of subchondral sclerosis and subchondral cysts are noted. In addition, the ankle joint should be scrutinized for asymmetric wear. This wear should be correlated to an associated deformity. For example, if the medial aspect of the ankle joint demonstrates arthritis with relative

Figure 2



Preoperative AP (A) and lateral (B) standing radiographs of the ankle joint in a 53-year-old woman with posttraumatic arthritis. Subchondral sclerosis and cysts, as well as decreased joint space are noted. Mild flattening of the talar dome is evident anteriorly on the lateral radiograph. AP (C) and lateral (D) standing radiographs obtained immediately postoperatively after distraction arthroplasty and osteophyte excision. Note the 1-inch calibration ball to measure the joint space E, Photograph of the patient wearing the frame. AP (F) and lateral (G) standing radiographs of the ankle joint demonstrating joint space and remodeling of the joint at an 18-month follow-up visit. (Copyright Mitchell Bernstein, MD, FRCSC, Chicago, IL.)

preservation of the lateral joint and the patient has a posttraumatic varus deformity with an apex at the distal tibial metaphysis, joint distraction in addition to a supramalleolar osteotomy may be indicated.

History of the Procedure

In 1978, seeking alternatives to TAA for joint arthritis, Judet and

Judet³⁶ described a technique using external fixation to mechanically separate opposing joint surfaces to allow “for fibrous tissue between the bone ends.” Their histologic analysis of regenerated tissue in dogs was done after the tibiotarsal joints were devoid of articular cartilage and distracted for 30 days with a 4- to 8-mm gap. At 1 year, they reported metaplastic changes in the joint surface resembling

those of normal hyaline cartilage.³⁶ Aldegheri et al³⁷ reported on the use of a hinged distractor for hip arthritis in 80 patients. Based on good results achieved in 46 patients at a minimum follow-up of 5 years, the authors concluded that radiographic results do not always correlate with clinical outcomes. Patients aged >45 years with or without inflammatory arthritis had uniformly poor results.

Mechanism of Action

The exact mechanism of action for distraction arthroplasty is unknown; however, it is based on the belief that the biologic aspects of cartilage regeneration are most likely to occur in a mechanically unloaded, well-aligned limb.^{38,39} The stiffness of the circular ring fixator may allow for sufficient stress shielding at the ankle joint to allow subchondral bone remodeling, which has been shown to be of clinical benefit.⁴⁰ However, this phenomenon, and its clinical correlation to pain relief, is still controversial.

In addition, weight bearing, stability, and motion—crucial for promoting durable articular cartilage—are possible for an extended period in the external fixator.⁴¹⁻⁴³ van Valburg et al⁴³ measured intra-articular hydrostatic pressure during distraction by inserting a pressure-sensitive catheter into the ankle. Recordings demonstrated intra-articular pressure fluctuations, and the authors suggested that these fluctuations combined with the absence of mechanical stress were instrumental in articular cartilage repair.⁴³⁻⁴⁵ They theorized that the intermittent fluid flow inside the joint caused by pressure fluctuations effectively mimics normal physiologic processes in the absence of load and shear and that this promotes cartilage repair. In a study of knee arthritis (induced by anterior cruciate ligament resection) in a canine model, van Valburg et al³¹ observed that, in addition to the intermittent fluid flow caused by an articulated knee hinge on the Ilizarov device, a change occurred in the proteoglycan metabolism that resembled the nonarthritic control knee.

Factors that have been associated with cartilage repair include a decrease in joint reactive forces (shear), an

increase in proteoglycan synthesis, recruitment of mesenchymal stem cells, and optimization of the mechanical environment.^{22,31,45} Furthermore, an improvement is seen in the density of the subchondral bone with a decrease in sclerosis.⁴⁰ This subchondral change may improve the biomechanical environment of the arthritic joint. In addition, resorption of subchondral cysts and improvement in edema may contribute to the clinical improvement that we have observed.

Outcomes

In 1995, van Valburg et al⁴⁴ published a preliminary retrospective study on the use of ankle distraction in 11 patients with severe post-traumatic arthritis scheduled for ankle arthrodesis. The patient cohort was relatively young (mean age, 35 years). An Ilizarov distraction apparatus was used for a mean of 15 weeks. Their technique, which has since been slightly modified, consisted of ensuring a postoperative distraction gap of 5 mm and the addition of hinges between 6 and 12 weeks postoperatively. At a mean follow-up of 20 months (range, 10 to 60 months), all patients reported a decrease in pain, and five patients (45%) reported a complete resolution of pain.⁴⁴ Six patients (55%) had increased ROM, and five (50%) had radiographic evidence of increased tibiotalar joint space. Encouraged by their results, the authors published a prospective study with a minimum 2-year follow-up.⁴⁶ The study included 17 patients (mean age, 39.6 years) who underwent annual evaluations for functional ability, mobility, and pain scores. Ankle distraction failed in four patients, who ultimately proceeded with arthrodesis. Of the remaining 13 patients, clinical outcome scores at 2-year follow-up

were better ($P < 0.004$) than those obtained at 1-year follow-up. Although poorly understood, several studies support the process of ankle joint remodeling after frame removal.^{10,40,46,47} The restoration of preinjury ankle architecture and mechanics is thought to be instrumental for prolonged benefit. The notion that improvements may occur over 12 to 24 months subsequent to frame removal should be considered when counseling patients in their recovery period.

In 2008, Paley et al⁴⁸ published their results on a modified distraction frame that was being used in Europe. Motion during distraction was stressed, and an anatomically located hinge based on the Inman axis became the foundation of the frame. Adjunctive procedures, such as osteophyte resection, gastrocnemius-soleus complex recession, and extremity realignment with osteotomy, were also done to maximize clinical outcomes.⁴⁸ Nine males and 14 females were available for retrospective chart review after a mean 17 weeks with external fixation. Preoperative and postoperative ankle motion was 28° and 27°, respectively. At a mean follow-up of 64 months (range, 24 to 157 months), 77% patients reported ambulation for pleasure, and 33% reported an ability to run. Radiographic analysis revealed that the joint space after frame removal did not remain distracted, although this did not affect clinical results. The authors claimed that the purpose of articular cartilage repair was to “seal cartilage cracks and defects,”⁴⁸ which was supported by an MRI study of three patients who were treated with ankle distraction.⁴⁹ Of note, 33% were not satisfied with the outcome of the procedure. Treatment failed in two patients (11%); one patient underwent ankle fusion and another underwent TAA.⁴⁸

Table 1**Summary of Outcomes and Adverse Events From Studies on Distraction Arthroplasty**

Study	No. of Patients	Follow-up ^a	Age ^a (yr)	Outcomes	Adverse Events
Marijnissen et al ⁹	111	2 yr minimum	42.7 ± 9.8	Pain and disability scores decreased from 67% and 68% to 38% and 36%, respectively, at 2 yr	48 patients (44%) had subsequent arthrodesis
Tellisi et al ¹⁰	23	30.5 mo (12–60 mo)	43 (16–73)	Decrease in pain in 91% of patients	Pin-site infection in all patients; 2 of 23 patients (9%) went on to arthrodesis
Saltzman et al ³²	29	2 yr	Fixed: 42.4 (18–53) Motion: 42.7 (27–59)	Better pain improvement in motion group at 2 yr; both groups better at 2 yr than baseline	19 of 29 patients (66%) had recurrent pin-site infections; 2 of 29 patients (7%) had osteomyelitis. 8 of 29 patients (28%) had nerve injury of medial calcaneal branch of the tibial nerve and deep peroneal nerve; 1 of 29 patients (3%) had deep vein thrombosis
Intema et al ⁴⁰	26	2 yr	41 ± 9	Decrease in AOS pain and disability scores; correlation with subchondral bone remodeling and clinical improvement	Not reported
Ploegmakers et al ⁴⁷	22	10 yr (7–15 yr)	37 ± 11	Decrease in pain scores from 78% to 30%; increase in function scores from 20% to 73%	6 of 22 patients (27%) had arthrodesis; 1 of 22 patients (5%) had complex regional pain syndrome
van Valburg et al ⁴⁴	11	20 wk (10–60 wk)	35 (20–70)	Pain decreased in all patients 5 patients pain free	Not reported
van Valburg et al ⁴⁶	17	2 yr	40 (17–55)	Decrease in physical, functional, and pain disability scores at 2 yrs ($P < 0.003$)	4 of 17 patients (24%) had arthrodesis; 4 of 17 patients (24%) had broken Kirschner wires
Paley et al ⁴⁸	23	64 mo (24–157 mo)	45 (17–62)	71% of patients ambulating for pleasure; 33% can run, 22% using assistive devices; 11% with severe limitations	17 of 23 patients (74%) had pin-site infection; 1 of 23 patients (4%) had arthrodesis; 1 of 23 patients (4%) had total ankle arthroplasty; 10 of 23 patients (43%) returned to operating room for unplanned procedure
Nguyen et al ⁵⁰	36	8.3 yr (6.1–10.5 yr)	Fixed: 42.4 (18–53) Motion: 42.7 (27–59)	AOS score < 43; age at time of distraction, and fixed versus motion ankle distraction predictive of failure at 2 yr postoperatively	16 of 36 patients (45%) failed treatment; 8 of 16 patients (50%) had ankle fusion, 5 of 16 patients (31%) had total ankle arthroplasty
Marijnissen et al ⁵¹	57	2.8 yr (2.5–3.1 yr)	44 (18–65)	Decrease in pain scores by 38% ($P < 0.0001$); 69% increase in function ($P < 0.0001$); increase in clinical condition by 120% ($P < 0.0001$)	16 of 57 patients (28%) had pin-site infections; 8 of 57 patients (14%) had broken Kirschner wires

AOS = Ankle Osteoarthritis Scale

^a The values are given as the mean with the range in parentheses.

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A hinge allows for ROM during rehabilitation, but ROM will not likely increase after frame removal.^{10,32} In

addition, while hinge distraction in animals supports robust and durable articular-like cartilage regener-

ation, histologic proof of hyaline cartilage regeneration in humans is lacking.^{8,31} In a prospective

randomized controlled trial, Saltzman et al³² compared 36 patients who underwent distraction arthroplasty with or without a hinge. Two years after frame removal, clinical scores were better in the hinge group, although ankle motion was similar in both groups. However, in a subsequent report on the same cohort with longer follow-up, the authors reported that patients without a hinge had improved outcomes.⁵⁰ The authors could only speculate on the reason for the contradictory results, and further research on the benefit of a hinge is necessary. In a retrospective study of 23 patients with hinged distraction arthroplasty, Tellisi et al¹⁰ reported that all patients in the hinge group had severe posttraumatic arthritis and were being considered for ankle arthrodesis. At a mean follow-up of 30.5 months (range, 12 to 60 months), no patient demonstrated a change in ankle motion. At the latest follow-up, 21 of 23 patients (91%) reported improved pain, and 17 patients (74%) had notable improvement in American Foot and Ankle Society scores.

The initial enthusiasm for ankle distraction focused on the ability to delay arthrodesis or TAA. Proponents of distraction arthroplasty cite several advantages, including the minimally invasive nature of the procedure, no required internal fixation, and no interference with future reconstructive efforts.¹⁰ However, studies of ankle arthrodesis and TAA after distraction arthroplasty are lacking.

Nevertheless, clinical failures in the form of ankle fusion or TAA do occur following distraction.^{9,10,46,50} As noted, van Valburg et al⁴⁶ reported on 17 patients with a mean age of 39.6 years who were treated with fixed ankle joint distraction. Four patients (24%) required ankle fusion within 1 year postoperatively because of the recurrence of severe

pain.⁴⁶ Similar rates of failure were reported by Marijnissen et al⁵¹ and Ploegmakers et al⁴⁷ (24% and 27%, respectively), who reported that clinical recurrence of pain 1 year after frame removal was the reason for ankle arthrodesis.⁵¹ Marijnissen et al⁹ recently updated their clinical results with data from a 12-year follow-up, noting a 44% rate of conversion to ankle arthrodesis. In the same study, Cox regression analysis revealed that female sex was predictive of failure, whereas preoperative ankle motion permitting distraction was protective.⁹ Nguyen et al⁵⁰ reported on their cohort of 36 patients who underwent ankle distraction for end-stage osteoarthritis. At a mean follow-up of 8.3 years, 29 patients (81%) were available for follow-up. Treatment failed in 13 patients (45%), requiring either ankle fusion or TAA. The authors reported that age, Ankle Osteoarthritis Scale score, and the presence of a hinge to allow ankle ROM were predictors of failure at 2 years.⁵⁰

Finally, it is important to note that published results primarily analyze patients with severe ankle arthritis who otherwise would be considered candidates for arthrodesis (Table 1). Selection of patients with moderate arthritis could lead to improved long-term outcomes. Further research is necessary.

Authors' Preferred Surgical Technique

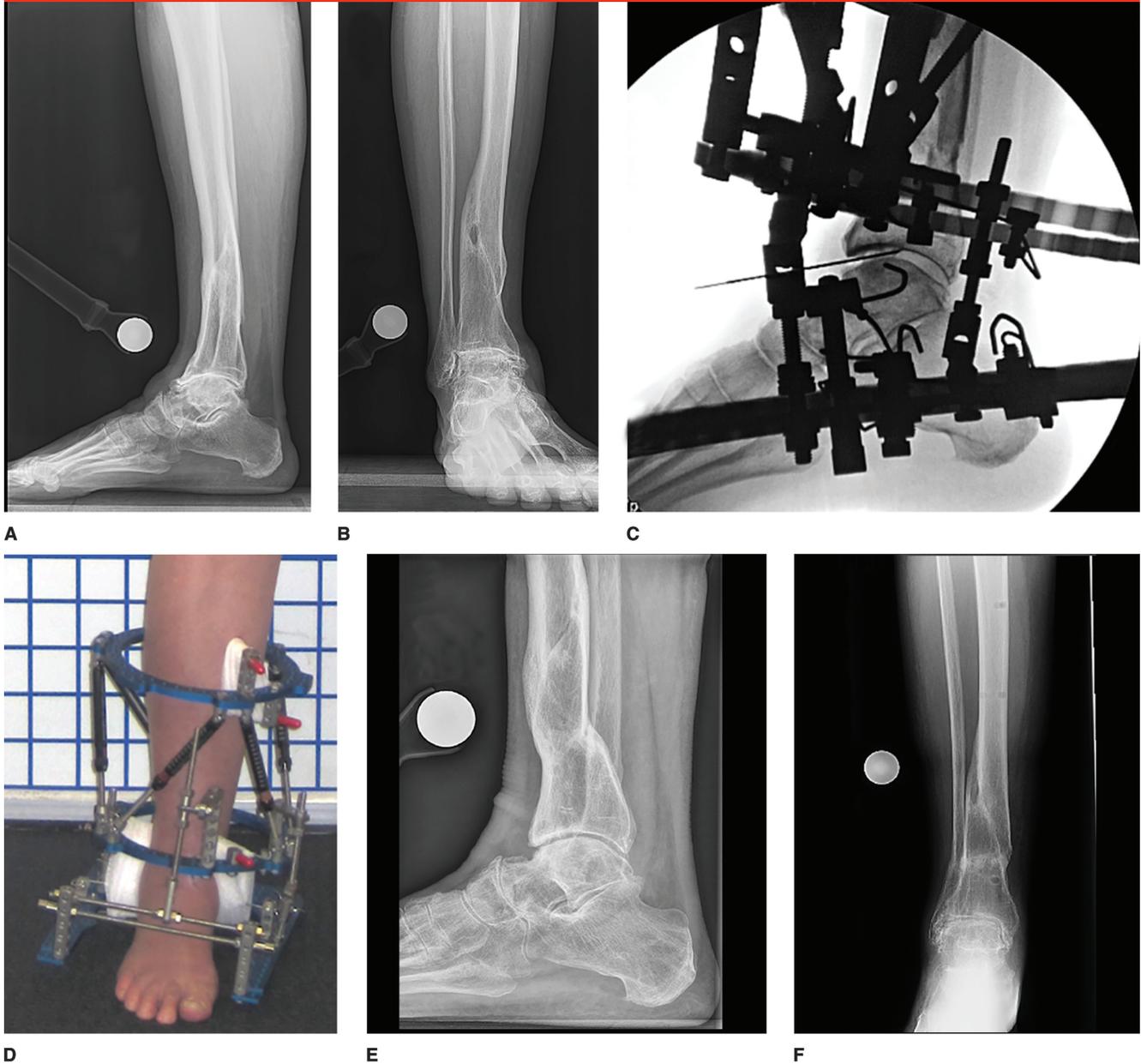
The patient's history and physical examination, as well as the results of appropriate imaging studies will dictate which, if any, adjunct surgical treatments are required before the circular frame is mounted to the leg. Ankle equinus contracture with a positive Silfverskiöld test is treated with a gastrocnemius Strayer or Vulpius recession through a posteromedial or direct posterior surgical

approach, respectively. An arthrotomy is used to remove impinging anterior osteophytes. A supra-malleolar osteotomy is added to correct concomitant coronal or sagittal malalignment.^{19,34} This procedure requires placement of an additional circular ring at the proximal tibia, with the distraction tibial ring closer to the ankle joint (Figure 3). The supramalleolar osteotomy begins with the patient in a supine position on a radiolucent table. A bump is placed under the ipsilateral buttock to ensure the limb is in neutral rotation (ie, patella facing upward).

In addition to mechanical distraction, we prefer to inject bone marrow autograft concentrate (BMAC) from the ipsilateral iliac crest as described by Hernigou et al.⁵² An aspirate of 60 mL of marrow yields approximately 7 mL of BMAC. This aspirate contains pluripotent stem cells, which are injected into the ankle joint. We inject this percutaneously at the end of the case, after the acute distraction has been performed. We routinely administer this aspirate as part of the ankle distraction procedure. Although clinical evidence is lacking, compelling basic science and animal studies support the use of BMAC to augment the cartilage regeneration.^{8,29,53-55}

The application of the ankle distraction frame begins by choosing a tibial ring that allows for two finger-breadths of space circumferentially between the skin and the ring. The medial malleolus and the anterior and posteromedial border of the distal tibia are marked. The proximal ring is secured with two 6-mm hydroxyapatite-coated pins.^{56,57} The first pin is placed approximately 6 cm proximal to the medial malleolus directly anterior in the tibial crest using a 4.8-mm drill bit. The pin is placed perpendicular to the shaft of the tibia and secured to the ring with a three-hole cube. Before

Figure 3



Preoperative AP (A) and lateral (B) standing radiographs of the ankle joint in a 62-year-old woman who sustained a closed right distal tibia fracture in a skiing accident. Note the decreased joint space, subchondral sclerosis, cysts, and anterior ankle osteophytes. Lateral translation, recurvatum, and anterior subluxation of the talus also are evident. Supramalleolar osteotomy was performed to correct extremity malalignment, and ankle distraction arthroplasty was done in conjunction with arthrotomy, excision of tibiotalar osteophytes, microfracture of the talar dome and tibial plafond, and gastrocnemius-soleus complex recession. C, Intraoperative fluoroscopic image demonstrating bone marrow aspirate injection into the ankle joint. D, Clinical photograph of the lower extremity after frame application. Note the additional ring and struts used to correct supramalleolar malalignment. Lateral (E) and AP (F) radiographs of the ankle joint at 6 months postoperatively. Reduction of the tibiotalar joint and restoration of coronal and sagittal alignment have been achieved. Joint space is increased on weight-bearing radiographs. Clinical examination demonstrated 10° of dorsiflexion and 25° of plantar flexion. (Copyright Mitchell Bernstein, MD, FRCSC, Chicago, IL.)

final tightening, intraoperative fluoroscopy is used to confirm that the ring is positioned perpendicular to

the axis of the tibial shaft. Universal hinges are then applied in line with a Kirschner wire, inserted from the tip

of the lateral malleolus and exiting at the tip of the medial malleolus, in a posterolateral-to-anteromedial

direction¹⁸ (Figure 4). This approximates the Inman axis. A footplate is secured 1 inch proximal and parallel to the plantar aspect of the foot. A locking rod connects the footplate to the proximal adjustable ring, which allows for gradual dorsiflexion to correct equinus contractures. The ring is unlocked four times daily for ROM exercises (15 repetitions/session). Typically, the ankle is acutely distracted 3 mm in the operating room by turning the square nuts on the proximal ring. Acute distraction beyond that is discouraged to avoid neurologic traction injury; acute correction of equinus contracture is avoided for the same reason. Once normal postoperative plantar sensation is confirmed, an additional 2 mm of distraction is usually done on postoperative day 1 and another 1 mm on postoperative day 2. At the 2-week clinic visit, another 1 to 2 mm of distraction is done. Fluoroscopy is used to confirm that a congruent distraction gap exists on the AP and lateral views.

Postoperatively, the patient is allowed full weight bearing as tolerated, with crutches. The neutral position (ie, ankle dorsiflexion) is marked on the hinge, and the physical therapist teaches the patient how to unlock the hinge and do active-assisted ROM exercises with a foot strap. Once patients are comfortable, they are encouraged to ambulate with the frame's hinge unlocked. Any residual distraction beyond what was done in the operating room is undertaken by the physician in the hospital or 2 weeks later at the first clinical visit. We typically do not distract >3 mm acutely. Based on a recent biomechanical study, a relative increase of 5 mm of joint space should be obtained relative to the preoperative standing radiograph to ensure that the articular surfaces of the tibial plafond and talar body do not come in contact during weight bearing.³⁵ Animal models support

the use of the frame in distraction for at least 8 weeks, and no added benefit has been seen beyond 12 weeks.^{8,31} We prefer to use the frame for 12 weeks.

In addition to distraction, the senior authors (A.T.F., S.R.R.) currently inject autologous bone marrow aspirate into the ankle joint and routinely affect microfracture. Although the mechanism of action of hyaline cartilage regeneration remains elusive, and clinical data are lacking, we feel that these adjunctive procedures may optimize the local healing environment.

Complications

The most common complication associated with ankle distraction arthroplasty is a superficial pin-site infection, which typically resolves with a course of oral antibiotics. The reported incidence ranges from 14% to 100%.^{10,32,48,50,51,58} Osteomyelitis that requires hospital admission and intravenous antibiotics is less common, with a reported incidence of 1.2% to 5.5%.^{32,48,51} Pin breakage does occur, usually in the mid-foot because of the motion-induced cyclic fatigue of the Kirschner wire. Likely underreported, the estimated incidence is 14% to 24% in two studies of 74 patients.^{51,58} Typically, this breakage occurs at the junction of the wire connection onto the ring and therefore is rectified by modifying the connection of the wire-fixation bolt closer to the skin.

Complications are best avoided with stringent and consistent patient selection, meticulous surgical technique, and close clinical follow-up. Patients should be screened at the initial clinical visit for the inability to comply with postoperative regimens. Educational level, ability to take time off work, living situation, and the availability of supportive family and/or friends are determined. Patients

Figure 4



AP fluoroscopic image of the ankle demonstrating insertion of a Kirschner wire to approximate the Inman axis during application of an ankle distraction frame. The wire is inserted from the tip of the lateral malleolus aiming toward the distal aspect of the medial malleolus in a posterolateral-to-anteromedial direction. (Copyright Mitchell Bernstein, MD, FRCSC, Chicago, IL.)

are educated preoperatively and in the hospital before discharge regarding the appropriate use of their external fixation device. We recommend daily pin-site care using a solution of 50% normal saline and 50% hydrogen peroxide applied with sterile cotton-tipped swabs. To protect the soft tissues, each group of pins should be wrapped with 2-inch cotton gauze.

A thorough knowledge of cross-sectional anatomy in the lower extremity is required to avoid inadvertent perforation or incarceration of neurovascular structures. Specifically, when placing the tibial ring, the tibialis anterior tendon and anterior neurovascular bundle are at risk of injury. The surgeon should have access to new, sharp 4.8-mm

bits to drill pilot holes for the 6-mm half pins in each case. This precaution avoids thermal damage to bone, premature loosening, and pin-site infection. The foot ring is applied with care taken to avoid the medial neurovascular structures. However, in our experience, patients report heel numbness, which can be attributed to medial calcaneal branch nerve irritation from the crossed hindfoot wires. These symptoms should not be mistaken for plantar numbness at the forefoot consistent with tibial nerve injury because the former should resolve, whereas the latter requires urgent release of distraction and possible tarsal tunnel decompression. Posterior tibial nerve neurapraxia often occurs with larger, acute distraction (>5 mm) in patients with contracted postero-medial soft tissues.

Summary

Ankle distraction arthroplasty is a surgical procedure whereby the ankle joint is temporarily mechanically unloaded with an external fixator and is performed in conjunction with osteophyte removal, microfracture, soft-tissue release, and deformity correction, if necessary. Although robust clinical evidence is lacking, studies using animal models support the theory that the addition of mechanical unloading and alignment correction improves the inherent ability of human cartilage repair to occur. The goals of the procedure are to provide pain relief, preserve motion, and to generate hyaline cartilage or a durable hyaline-like cartilaginous substance. Although clinical studies have demonstrated good short- to intermediate-term clinical outcomes, the mechanisms for success and failure remain unknown. Further clinical research on this procedure and the histologic

composition of the resultant generated tissue is needed.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 1, 9, 32, and 57 are level I studies. Reference 51 and 55 are level II studies. References 5, 6, 11, and 33 are level III studies. References 2-4, 7, 10, 17, 18, 24, 34, 37, 39, 40, 44, 46-50, and 53 are level IV studies. References 15, 19, and 38 are level V expert opinion.

References printed in **bold type** are those published within the past 5 years.

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