Ankle arthrodesis: A systematic approach and review of the literature

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Ankle arthrodesis is a common treatment used for patients with end-stage ankle arthritis (ESAA). The surgical goal of ankle arthrodesis is to obtain bony union between the tibia and talus with adequate alignment [slight valgus (0°-5°)], neutral dorsiflexion, and slight external rotation positions) in order to provide a pain-free plantigrade foot for weightbearing activities. There are many variations in operative technique including deferring approaches (open or arthroscopic) and differing fixation methods (internal or external fixation). Each technique has its advantage and disadvantages. Success of ankle arthrodesis can be dependent on several factors, including patient selection, surgeons' skills, patient comorbidities, operative care, etc. However, from our experience, the majority of ESAA patients obtain successful clinical outcomes. This review aims to outline the indications and goals of arthrodesis for treatment of ESAA and discuss both open and arthroscopic ankle arthrodesis. A systematic step by step operative technique guide is presented for both the arthroscopic and open approaches including a postoperative protocol. We review the current evidence supporting each approach. The review finishes with a report of the most recent evidence of outcomes after both approaches and concerns regarding the development of hindfoot arthritis.

Key words: Ankle; Osteoarthritis; Arthrodesis; Review; Ankle fusion

Core tip: Ankle arthrodesis is an effective treatment option for end stage arthritis. There is no current consensus on the most optimal approach and fixation method. It is thus important for the surgeon to understand both the open and arthroscopic approach and when each approach is indicated. Joint alignment must be slightly valgus (0°-5°), neutrally dorsiflexed and slightly in an externally rotated
INTRODUCTION

Ankle arthrodesis and ankle arthroplasty are the two common operative treatments used in end stage ankle arthritis (ESAA)\(^1,2\). Recent clinical evidence suggests that ankle arthroplasty leads to superior functional outcomes over ankle arthrodesis\(^3-7\). However, ankle arthroplasty is associated with higher rates of postoperative complications and revision surgeries\(^8,9\). Despite the increasing popularity of ankle arthroplasty, a large database has indicated that ankle arthrodesis still remains the most common surgical treatment for ESAA\(^9,10\).

There are several operative techniques for ankle arthrodesis including open or arthroscopic approaches\(^11-15\). Although successful clinical outcome can be achieved following both approaches\(^11-15\), reported outcomes have varied and are conflicted\(^16\). The differences in techniques, surgeon skill, patient selection and populations, and outcome measurements utilized all contribute to the variability in outcome after arthrodesis. Ankle arthrodesis should be performed judiciously in young patients, highly active patients, and patients with advanced foot and ankle deformity.

The purpose of this manuscript is to provide: (1) to provide an evidence-based review of ankle arthrodesis for ESAA; and (2) to describe a standardized approach to both open and arthroscopic ankle arthrodesis.

INDICATIONS AND GOALS OF ARTHRODESIS

Ankle arthrodesis is indicated for patients with ESAA that failed a minimum of 3 mo of conservative treatment. The goal of ankle arthrodesis is to provide a pain-free plantigrade foot during weightbearing activities\(^17\). Alignment following ankle arthrodesis must be slight valgus (0°-5°), neutral dorsiflexion, and slightly externally rotation. Equinus position of the ankle joint can accompany genu recurvatum and a varus position of hindfoot can develop painful callosities to the lateral forefoot\(^18\), which may cause hindfoot pain\(^19,20\). Additionally, the surgeon should attempt to minimize limb length discrepancies (less than 2.5 cm or 1.0 inch)\(^21-23\). Limb length discrepancies can result in a symptomatic malalignment with altered gait pattern\(^24\).

Arthroscopic ankle arthrodesis is typically reserved for patients with little to no joint deformity (less than 15° of varus or valgus in the coronal plane). Open arthrodesis is best utilized for patients with moderate to severe deformity as this allows for better visualization for malalignment correction. Additionally, as fusion of the ankle joint will inevitably lead to a lack of motion, preoperative balance of the forefoot is essential. Therefore, careful examination of forefoot balance without excessive pronation or supination is needed\(^25\). Arthroscopic or open debridement with subsequent external fixation would be preferred by the authors in patients with significant malalignment, comprised skin, limbs discrepancies, and active/previous infection.

TYPES OF ANKLE ARTHRODESIS

Numerous surgical techniques for ankle arthrodesis have been described\(^11-15\). The technique should be selected based on patient characteristics, function and goal of treatment, as well as the preference of the surgeon.

Approach

The approach to ankle arthrodesis is broadly divided into open and arthroscopic techniques. The open approach is further subdivided into the anterior approach, posterior approach, lateral approach, medial approach, and combined medial and lateral approach. Compared with the arthroscopic approach, the main benefit of an open approach includes less difficulty in correcting malalignment, and ease in applying plates and bone grafts. However, open arthrodesis is associated with higher rates of wound complications due to the extensive amount of soft tissue dissection required\(^3-7\). This can subsequently lead to longer hospitalization and recovery. Therefore, open approaches are generally reserved for patients with moderate to severe ankle deformities with healthy skin.

Arthroscopic ankle arthrodesis is a less invasive procedure enabling shorter operative time with comparable union rates\(^26-28\). This procedure is most commonly performed using anterior ankle arthroscopy, however recent studies have suggested that posterior ankle arthroscopic arthrodesis may provide better fusion rates\(^29\). Arthroscopic ankle arthrodesis is indicated for patients with minimal ankle joint deformity (less than 15° of varus or valgus in coronal plane) or patients who are at higher risk of wound complications (e.g., immunosuppressed, diabetics, rheumatoid arthritis patients). Although arthroscopic arthrodesis is increasingly becoming popular, open ankle arthrodesis remains the mainstay procedure.
for ESAA in the United States of America\textsuperscript{[9,10]}.

**Fixation methods**

Both internal and external fixation may be used in ankle arthrodesis. Each has its unique advantages; successful outcomes having been demonstrated with both fixation methods\textsuperscript{[11-15]}.

Various methods of internal fixation have been described, including screws, plates, and retrograde intramedullary nails. Many surgeons prefer to use screw fixation as the primary means of internal fixation, because screws are easy to use, have low morbidity (they only require small percutaneous incisions) and are cheaper compared to most other methods. However, higher nonunion rates of the ankle joint have been reported with screw fixation especially in osteoporotic bone\textsuperscript{[30,31]}. Plates are advantageous for ankle arthrodesis because there are many options when using plates. The surgeon has choices with regard the type of plate needed (e.g., conventional or locking), how many plates and where to place the plates. While some surgeons prefer plates because they are stiffer constructs than screws that may achieve better union rates, the extensive dissection needed to place the plate can lead to a higher risk of infection and morbidity\textsuperscript{[32-34]}. A combination of plates and screws may also be used. A recent biomechanical study found that a combination of plate and screw fixation provided significantly greater stiffness than plates or screws alone. In this study there were no significant difference between 3 compression screws, anterior plate and lateral plate fixation\textsuperscript{[34]}. Retrograde intramedullary arthrodesis is typically reserved for arthrodesis of both the ankle and subtalar joints\textsuperscript{[35-38]}.

Patients with ESAA typically have concomitant subtalar arthritis. In these patients, it is difficult to delineate whether the pain is coming solely from the tibiotalar joint, the subtalar joint or a combination of both. The surgeon must determine this preoperatively because it is best to avoid arthrodesis of the subtalar joint whenever possible especially when the ankle will be fused. In the setting of a subtalar arthrodesis the subtalar joint is critical for gait stability\textsuperscript{[20,39,40]}. The subtalar joint allows for inversion and eversion of the ankle joint and therefore, this can compensate for a more stable gait when joint motion is permanently reduced post-arthrodesis.

External fixation is typically indicated for complex patients with significant bone defects, limb length discrepancies, poor bone quality, and active or previous infection\textsuperscript{[31]}. Overall, union rates and outcomes measures of external fixation are inferior to internal fixation (Table 1).

**OPERATIVE TREATMENT**

Two standardized methods of ankle arthrodesis for ESAA is described here: Open and arthroscopic. For both methods, the joint is fixed with two or more screws. Patients are placed in a short leg cast and immobilized for 6 wk. Patients have achieved successful outcomes following either approach in our experience\textsuperscript{[16]}.

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### Table 1  Open ankle arthrodesis

| investigator | year | method | no. of patients | union rate | outcome(s) |
|--------------|------|--------|----------------|------------|------------|
| charnley     | 1981 | internal and external fixation | 37 | 84% | N/A |
| kennora      | 1986 | external fixation | 26 | 69% | N/A |
| sowa         | 1989 | compression blade plate | 17 | 94% | 10 excellent; 2 good; 2 fair (out of 14; mazur) |
| helm         | 1990 | charnley compression | 47 | 85% | N/A |
| mann         | 1991 | screws from talus to tibia | 18 | 94% | N/A |
| kitaoka      | 1992 | external fixation and bone graft | 26 | 77% | N/A |
| wang         | 1993 | t plate on lateral side | 11 | 91% | n/a |
| chen         | 1996 | cross screws | 40 | 95% | n/a |
| patterson    | 1997 | anterior sliding graft with screws | 27 | 93% | N/A |
| levine       | 1997 | internal fixation and bone graft | 22 | 92% | N/A |
| mann         | 1998 | internal fixation and fibular graft | 81 | 88% | 74 (aofas) |
| dereymaeker  | 1998 | internal and external fixation | 14 | 64% | N/A |
| ben-amor     | 1999 | 80% internal fixation, 20% external fixation | 36 | 97% | 56.2 (duquennoy) |
| takakura     | 1999 | anterior sliding graft with screws | 43 | 93% | 77.9 (takakura) |
| coester      | 2001 | internal or external fixation | 23 | n/a | 27 limitation, 38 pain, 47 disability (foot function index) |
| bertrand     | 2001 | 84% internal fixation, 16% external fixation | 23 | 87% | 69.7 (duquennoy) |
| andersson    | 2002 | internal and external fixation | 29 | 89% | N/A |
| fuchs        | 2003 | 22% internal fixation, 78% external fixation | 18 | 95% | 59.4 (olerud and molander) |
| buchner      | 2003 | 38% internal fixation, 62% external fixation | 45 | 92% | 73.6 (aofas) |
| kopp         | 2004 | internal fixation with staples and screws | 41 | 95% | 72.8 (mazur) |
| kennedy      | 2006 | internal fixation with screws | 41 | 95% | 80.6 (aofas) |
| thomas       | 2006 | internal fixation with transfixil approach | 26 | 100 | 74 (aofas) |
| trichard     | 2006 | 60% internal fixation, 40% external fixation | 25 | n/a | 64.7 (duquennoy) |
| smith        | 2007 | internal fixation | 25 | 96% | 43.7 (aofas) |
| colman       | 2007 | transfixil approach with grafting | 48 | 96% | 69 (aofas) |
Open arthrodesis with screw fixation

Patient positioning and equipment: The patient is placed in the supine position with the feet at the edge of the bed. A tourniquet is typically used at the level of the thigh and applied before the start of the case. All equipment should be confirmed prior to the onset of the case. Osteotomes, a bone saw, and curettes are needed for the osteotomy and debridement of the joint surface. A large fragment cannulated drill set and screws (4.0/6.5/7.3 mm) are required to fuse the ankle joint. Fluoroscopy should be used to confirm ankle alignment and screw positions.

Steps of the procedure: (1) Marking anatomical landmarks: Anatomical landmarks are marked using a sterile surgical marker. In this procedure, the lateral malleolus (LM), medial malleolus (MM), ankle joint line, fourth metatarsal, fifth metatarsal, superficial peroneal nerve, and sural nerve are all identified and marked. Then, a hockey-stick-shaped incision is outlined over the lateral aspect of the LM, starting approximately 7.0 cm above the tip of the LM and extending distally to the base of the fourth metatarsal. Additionally, a longitudinal medial skin incision line is marked over medial gutter of ankle joint; (2) Skin incision and osteotomy of distal fibula: The first skin incision is made over the fibula along the previously described outline. Once distal tibiofibular joint is identified, soft tissues including the anterior inferior talofibular ligament, interosseous ligament, and interosseous membrane are resected. An osteotomy of the distal fibula is then made in a beveled fashion approximately 2.5 cm proximal to the ankle joint using a sagittal oscillating saw. The resected bone block (medial side of fibula) should be kept for local autologous bone grafting later on in the case (Figure 1). After the osteotomy is complete, the lateral aspect of the fibula is retracted posteriorly. It is important to preserve the fibula as best as possible to minimize the risk of non-union; (3) Debridement of joint surface cartilage: After the fibular osteotomy, the ankle joint is distracted using a lamina spreader. Any inflammation or scar tissue within the ankle joint is debrided and/or removed carefully to fully expose the joint surface. Careful attention during exposure of the joint surface is essential to avoid injury to the neurovascular bundle located anterior of the ankle joint capsule. If the full joint surface cannot be visualized at this point, a medial incision with arthrotomy may be needed to reduce the future potential of saphenous nerve damage. After fully exposing the joint surface, cartilage is removed from both the tibia and talus to expose the subchondral bone. The authors prefer to use an osteotome and curette rather than a bone saw or burrs to minimize the risk of thermal necrosis of the subchondral bone. The debridement should also be minimalized to maintain joint congruency; (4) Fusion of tibiotalar joint: The tibiotalar joint is fixed typically using two to three 7.3 mm cannulated screws after adequate alignment is obtained. The alignment of tibiotalar joint should be slightly valgus (0°–5°), neutrally dorsiflexed, and slightly external rotated. The talus should be reduced in a posterior position to obtain the largest possible contact area of joint surfaces. This is to reduce the lever arm of the foot on the mechanical construct. The alignment is evaluated using fluoroscopy in two planes. Two to three guide wires are then inserted in the inferolateral aspect of the base of the talus neck. This technique is similar to what was previously described by Mann et al.[22]. The positions of the guide wires should be confirmed using fluoroscopy. Three 7.3 mm cannulated screws are then inserted through the guide wires starting at the talus through the ankle joint and into the tibia. The authors believe that two to three screws are optimal to fuse the joint, as too few screws results in the inadequate compression of the bony surfaces and too many screws reduces the availability of bony surface for osseous integration[14]; (5) Fusion of lateral malleolus to tibia (Figure 2): Two 4.0 mm screws are used to fix the lateral malleolus and distal tibia into place. Guide wires may be placed before insertion of the screws to ensure adequate alignment. The position of the screws/guide wires should be confirmed with fluoroscopy. Bone graft may be placed around the fusion site to facilitate union. This is especially recommended when there might be factors that could complicate the union such as osteonecrosis of the talus, previous non-union or bony defects[41–45]. Bone graft can be prepared through the morselization of bone acquired...
Arthroscopic arthrodesis with screw fixation

Steps of the procedure: (1) Marking anatomical landmarks and establishing portals: The careful identification of anatomical landmarks is critical for any arthroscopic procedure of the ankle. The most commonly injured nerve following anterior ankle arthroscopy is the superficial peroneal nerve (up to 2.9%). Anterior ankle arthrodesis is performed using anteromedial (AM), anterolateral (AL) and occasionally posterolateral (PL) portals. The lateral malleolus (LM), medial malleolus (MM), peroneus tertius, tibialis anterior tendon (TAT), superficial peroneal nerve, and sural nerve are all identified and marked. At the level of ankle joint, the AM portal is established just medial to the medial border of tibia in a similar orientation aiming toward the central talar dome. These Kirschner wires should be altogether inserted at the tibial joint surface. The location of the Kirschner wires should be confirmed by both arthroscopy (Figure 4A) and fluoroscopy. Following the confirmation of adequate talocrural joint alignment, the wires are then advanced into talus (Figure 4B). Screws are then inserted over these Kirschner wires (Figure 4C). A countersink may be required to reduce the prominence of the screw heads.

BIOLOGICS

Biologics may be used to aid in fusion of the ankle in both the open and arthroscopic techniques. Two types of biologics are currently available: Osteoconductive and osteoinductive agents. Osteoconductive agents, e.g., bone allografts, demineralized bone matrix and various apatitic pastes, are agents that serve as a scaffold at the site of fusion. This scaffold acts as a tissue network to facilitate autologous cell interaction for osteogenesis. Osteoinductive agents, e.g., bone morphogenetic proteins, platelet-rich plasma or concentrated bone marrow aspirate, are agents that directly facilitate osteogenesis. This may be in the form of containing growth factors (platelet-rich plasma) or stem cells (concentrated bone marrow aspirate) to stimulate the formation of osteoblasts. Biologics should be placed into the fusion site before and after the final seating of screws.

POSTOPERATIVE REHABILITATION

The ankle joint is immobilized in a non-weightbearing leg cast for 6 wk. The cast is then removed and
the patient is transferred over to a Controlled Ankle Movement Walker Boot. Radiographs should be taken at intervals of 6 wk, 3 mo, 6 mo and 1 year to assess the position of fusion and adequacy of union. A gradual 10% increase every two weeks in weightbearing is advised. However, as soon as complete union is evident on radiographs, patients may be allowed to fully weightbear.

OUTCOMES AFTER ANKLE ARTHRODESIS: A SYSTEMATIC REVIEW

Clinical studies on ankle arthrodesis were searched for on the MEDLINE and EMBASE databases using the terms: (open OR arthroscopic) AND (ankle) AND (arthrodesis OR fusion). The search revealed 463 papers from MEDLINE and 695 papers from EMBASE. The inclusion criteria were: (1) the studies’ intervention included the use of arthrodesis; (2) clinical studies; and (3) published in a peer-review journal. Exclusion criteria were: (1) review studies; (2) cadaver studies; and (3) animal studies. This resulted in the inclusion of 26 studies on open ankle arthrodesis and 16 studies on arthroscopic ankle arthrodesis (Table 2).

Union rate has been shown to be a popular outcome measure following arthrodesis, as indicated by its prevalent use in the current literature. Other popular measures included the AOFAS, Duquennoy, Mazur, Takakura, Foot Function Index and Olerud and Molander scoring systems.

The average union rate following open arthrodesis was 89% (range: 64%-100%) and following arthroscopic arthrodesis was 94% (range: 70%-100%). In the cohort of patients in the four comparative studies, the average union rate in the open group was 89% and in the arthroscopic group was 91%. However, in the only comparative study reporting clinical outcomes, Townshend et al demonstrated that clinical outcomes only mildly improved following the use of the arthroscopic technique.

In regards to the effects of ankle arthrodesis on the automobile breaking. Jeng et al demonstrated that ankle arthrodesis can significantly decreased the total break reaction time. However, this delay does not exceed the safe reaction brake timing criteria by the United States Federal Highway. Schwienbacher et al demonstrated that ankle arthrodesis can significantly decreased the total break reaction time.

## Table 2  Arthroscopic ankle arthrodesis

| Investigator          | Year | Method                          | No. of patients | Union rate | Outcome(s)          |
|-----------------------|------|---------------------------------|-----------------|------------|---------------------|
| Ogilvie-Harris et al  | 1993 | Tibiotalar and fibulotalar screws | 19              | 89%        | N/A                 |
| Dent et al            | 1993 | Crossed tibiotalar, charney clamp | 8               | 100%       | N/A                 |
| De Vriese et al       | 1994 | Arthroscopic arthrodesis        | 10              | 70%        | N/A                 |
| Tuzan et al           | 1995 | Arthroscopic arthrodesis        | 8 (10 ankles)   | 100%       | N/A                 |
| Corso et al           | 1995 | Tibiotalar and fibulotalar screws | 16              | 100%       | N/A                 |
| Crosby et al          | 1996 | Arthroscopic arthrodesis        | 42              | 93%        | N/A                 |
| Glick et al           | 1996 | Cannulated screws               | 34              | 97%        | N/A                 |
| Jerosch et al         | 1996 | Tibiotalar and fibulotalar screws | 26              | 85%        | N/A                 |
| Cameron et al         | 2000 | Arthroscopic arthrodesis        | 15              | 100%       | N/A                 |
| Zvijac et al          | 2002 | Arthroscopic arthrodesis        | 21              | 95%        | N/A                 |
| Cannon et al          | 2004 | Arthroscopic arthrodesis        | 36              | 100%       | N/A                 |
| Saragas              | 2004 | Arthroscopic arthrodesis        | 26              | 96%        | 63.9 (modified AOFAS out of 78 points) |
| Winson et al          | 2005 | Arthroscopic arthrodesis        | 116 (118 ankles)| 92%        | N/A                 |
| Ferkel et al          | 2005 | Arthroscopic arthrodesis        | 35              | 97%        | 73.9 (Mazur)        |
| Gougoulias et al      | 2007 | Arthroscopic arthrodesis        | 74 (78 ankles)  | 97%        | N/A                 |
| Dannawi et al         | 2011 | Arthroscopic arthrodesis        | 55              | 91%        | 81.5 (Mazur)        |
performed comparative case series in a driving simulator and found that patients receiving ankle arthrodesis had less of an ability to brake under emergency circumstances compared to healthy volunteers.

**Relationship between ankle arthrodesis and adjacent-joint arthritis in the hindfoot**

The development of adjacent hindfoot arthritis following tibiotalar arthrodesis remains a concern. A recent systematic review by Ling et al. investigated the relationship between ankle arthrodesis and adjacent-joint arthritis and demonstrated that there was insufficient evidence to support either that ankle arthrodesis caused adjacent-joint arthritis or that pre-existing joint arthritis could have already existed in those cohort of patients. As the current postulation include that there may be inherent pre-existing adjacent joint arthritis in the majority of patients requiring fusion, no clear consensus can be made on whether ankle arthrodesis can cause or predispose to hindfoot arthritis.

Recently, Yasui et al. published a large retrospective cohort study that investigated the postoperative adjacent-joint hindfoot arthritis following ankle arthrodesis. The authors found that there was significant higher rate of subsequent adjacent-joint arthrodesis in the open cohort than the arthroscopic cohort (7322 open procedures vs 1152 arthroscopic procedure, reoperation rate: 5.6% vs 2.6%, odds ratio: 2.17, 95% confidence level: 1.49-3.16). Regardless of whether adjacent hindfoot arthritis is present before or develops after arthrodesis the authors believe that these patients more commonly have open procedures. The authors hypothesized that open ankle arthrodesis leads to degenerative OA of the adjacent joints more frequently than does the arthroscopic procedure; or, patients undergoing open ankle arthrodesis develop concurrent degenerative arthritis in the adjacent joints more frequently than does the arthroscopic group. To address this subject, further investigation is necessary (Table 3).

**CONCLUSION**

Ankle arthrodesis is an effective treatment for ESAA that may be achieved through either the open or arthroscopic approach. Several fixation options exist, however the authors prefer two to three screws. It is difficult to generate a clear consensus on whether open or arthroscopic arthrodesis should be the mainstay of treatment for ESAA because conflicting evidence currently exists. As the current success of arthrodesis continues to depend on a variety of factors, the current review aims to summarize an up-to-date knowledge for optimizing the outcomes of ankle arthrodesis.

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