

# Total Ankle Replacement Versus Ankle Arthrodesis for End-Stage Ankle Arthritis: A Comprehensive Evidence-Based Review

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## Abstract

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**Background:** End-stage ankle osteoarthritis affects approximately 29,000 patients annually in the United Kingdom. Total ankle replacement (TAR) and ankle fusion (arthrodesis, AF) represent the two principal surgical interventions when conservative management fails. This comprehensive review synthesizes evidence from randomized trials, systematic reviews, and registry data from six countries.

**Methods:** This review integrates evidence from the TARVA randomized controlled trial (303 patients), multiple systematic reviews and meta-analyses, national joint registry data, and large database studies (>2,500 patients).

**Results:** The TARVA trial showed significant functional improvement in both groups at one year with no statistically significant difference in the primary outcome (adjusted mean difference -5.6, 95% CI -12.5 to 1.4, p=0.12). Fixed-bearing TAR demonstrated superiority over AF in post hoc analysis (p=0.008). Registry data demonstrate TAR survivorship of 90.2% at 5 years and 86.2% at 10 years. TAR complications: wound healing 13.8%, nerve injury 4.3%, revision 9-20% at 5 years. AF complications: nonunion 16% at 3 years, infection 6.2%, progressive adjacent joint arthritis 24-100%. Return to sports: 61.9% for TAR versus limited participation after AF. Cost-utility analysis showed TAR cost-effective over lifetime despite higher initial costs.

**Conclusion:** Both procedures effectively improve pain and function. Patient selection is critical: TAR suits older (>50 years), low-demand patients with preserved motion and good bone stock. AF preferred for younger, high-demand patients, severe deformity, or poor bone quality. Modern TAR implants show improved survivorship; AF offers excellent durability with adjacent joint degeneration concerns.

**Keywords:** Ankle arthritis, Ankle arthrodesis, Complications, Patient selection, Return to sports, Total ankle replacement

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## Introduction

End-stage ankle osteoarthritis represents a significant cause of pain and functional disability comparable to hip arthritis, yet occurring eight times less frequently.<sup>1,2</sup> Post-traumatic etiology accounts for 70-80% of cases, with inflammatory arthropathy and primary osteoarthritis comprising the remainder.<sup>3</sup> When conservative management fails, two principal surgical options exist: TAR preserves ankle motion through prosthetic replacement, while AF eliminates painful motion through bony fusion.<sup>4,5</sup> Historically, AF was considered the gold standard with union rates exceeding 95%; however, TAR has gained acceptance due to advances in implant design and improved registry-documented survivorship.<sup>6,7</sup>

The fundamental difference lies in biomechanical implications. TAR preserves ankle motion, potentially reducing adjacent joint stress; conversely, AF sacrifices mobility but provides exceptional durability, though long-term studies document progressive adjacent joint arthritis approaching 100% at 22-year follow-up.<sup>8,9</sup> Until recently, high-quality comparative evidence was lacking. The TARVA trial represents the first multi-centre randomized controlled trial directly comparing these procedures in 303 patients aged 50-85 years with end-stage ankle arthritis.<sup>10</sup> This comprehensive review synthesizes TARVA findings alongside systematic reviews, meta-analyses, and national joint registry data from six countries to provide evidence-based guidance on surgical selection, indications, outcomes, and complication management.

The pathophysiology of ankle OA is characterized by progressive degeneration of articular cartilage, subchondral bone remodelling, and synovial inflammation. Mechanical malalignment or instability can accelerate cartilage loss, leading to joint space narrowing and osteophyte formation. Unlike the hip or knee, the ankle joint has a highly congruent mortise configuration, which distributes load efficiently; thus, when OA does occur, it is often the result of previous injury that disrupted normal joint mechanics.

Clinically, patients present with pain during weight-bearing, stiffness, reduced range of motion, swelling, and activity limitation. Radiographs typically reveal asymmetric joint space narrowing, subchondral sclerosis, and osteophytes. In advanced cases, bone-on-bone contact leads to severe pain and disability, prompting consideration of surgical intervention such as arthrodesis or total ankle replacement.

### Total Ankle Replacement (TAR)- Surgical Overview

TAR replaces the diseased tibiotalar joint with a prosthesis consisting of tibial, talar, and polyethylene components. The goal is to preserve ankle motion and improve function. Modern implants feature improved fixation methods (cementless designs, porous coatings) and refined kinematics. In total ankle replacement (TAR), implant fixation largely falls into two categories: cemented (using bone cement to secure the prosthesis) and uncemented

(press-fit or biologic ingrowth). Early TAR designs often used cemented fixation, but over time the trend has shifted toward uncemented (cementless) designs. Non-cemented prostheses allow for bony ingrowth or on-growth, require less bone removal, and avoid potential issues with cement fatigue or debonding.

The choice between cemented and uncemented designs has trade-offs. Cemented fixation can provide immediate stability, which may be advantageous in patients with poor bone quality or osteoporosis; however, cemented implants are more rigid, potentially leading to stress shielding, and may make revision more difficult because of the need to remove cement. Uncemented designs rely on achieving initial press-fit and subsequent bone ingrowth; they demand good bone stock and careful surgical technique, and there is a risk of micromotion before integration. Over time, most modern TAR implants are designed for cementless fixation, with porous coatings or porous metals to promote osseointegration.

The key advantage of TAR is motion preservation. Patients often experience a more natural gait compared to those who undergo fusion, with preserved dorsiflexion and plantarflexion facilitating smoother transitions during walking. This preservation of motion also reduces compensatory stress on adjacent joints, lowering the risk of secondary arthritis. Functionally, TAR patients report higher satisfaction levels, better quality-of-life scores, and greater ability to perform activities of daily living. These benefits make TAR particularly attractive for older, lower-demand patients who prioritize mobility and independence.

### Alignment, Restoration, & Soft-Tissue Balancing

A fundamental determinant of TAR success is restoration of joint alignment and proper soft-tissue balancing. The surgeon must correct varus/valgus deformities, ensure neutral frontal plane alignment, restore appropriate axial rotation and sagittal plane alignment and positioned correctly within the mechanical axis of the limb. Malalignment or malrotation can cause asymmetrical loading, accelerated wear, edge-loading of the liner, and early implant failure.

Soft-tissue balancing is equally critical. Ligamentous laxity, asymmetries in ligament tension, or residual deforming forces can lead to instability or uneven stresses on the implant. Sometimes adjunctive procedures: ligament reconstructions, tendon transfers, osteotomies of the tibia/fibula or hindfoot are necessary to achieve a balanced biomechanical environment. Intraoperatively, trial components, fluoroscopy, alignment guides, and sometimes

patient-specific instrumentation are used to confirm alignment. Thus, in TAR the interplay of fixation type, constraint/liner geometry, alignment, and soft-tissue balance determines long-term success, wear rates, and complication risk.

Beyond fixation, TAR implants differ in liner geometry, constraint, and degrees of freedom. A crucial design decision is whether to use a fixed-bearing vs mobile-bearing (or semi-constrained) system. Fixed-bearing designs restrict relative motion of the polyethylene insert relative to one of the metal components; mobile-bearing designs allow the polyethylene to move or rotate slightly between the tibial and talar components. Mobile-bearing designs can better accommodate minor misalignments and reduce shear forces but carry risks of liner dislocation or increased wear at the interfaces. Most modern implants adopted a three-part mobile-bearing concept to better mimic natural ankle kinematics, though two-part fixed bearing implants have recently become more popular.

### **Ankle Fusion (Arthrodesis)- Surgical Overview**

Ankle fusion eliminates painful motion at the tibiotalar joint by surgically uniting the tibia and talus. The procedure may be performed via open, arthroscopic, or minimally invasive techniques, and fixation methods include screws alone or with plates. The primary advantage of ankle fusion lies in its reliability. Patients typically experience predictable pain relief, with union rates surpassing 90% in most clinical series. Fusion also offers long-term durability, since there is no prosthetic device to wear out or fail, making it especially suitable for younger, high-demand patients. Moreover, fusion is cost-effective in the short term and is less technically complex than TAR, reducing early surgical risks in certain patient populations.

Despite its strengths, ankle fusion has several significant disadvantages. The most notable is the complete loss of ankle motion, which alters biomechanics and forces compensatory adaptations in gait. These altered mechanics increase stress on adjacent joints, particularly the subtalar and midfoot joints, leading to accelerated degenerative changes and secondary arthritis over time.

The primary limitation of ankle fusion is the permanent elimination of joint motion, which has biomechanical and clinical consequences. Patients must rely on compensatory motion from the subtalar joint, midfoot, knee, and hip, leading to altered gait mechanics. Over time, this increased load on adjacent joints accelerates secondary arthritis, especially in the subtalar and midfoot regions. Several long-term series report the development of degenerative changes in adjacent joints years or decades after fusion. Another limitation is that fusion may not fully relieve pain in all patients, non-union or symptomatic malalignment can lead to persistent symptoms. Additionally, once fused, options for further joint-preserving interventions (e.g. conversion to replacement) become more complex and technically demanding. The lack of motion also imposes

functional restrictions in mobility over uneven ground or during high-demand tasks. Lastly, recovery is slower: fusion patients must wait for bony union, often several months, before full weight-bearing and safe ambulation. Fusion patients can often return to many ADLs with relief of pain and a stable joint, but their ability to resume sports is more limited. Complications such as non-union, malunion, and infection are additional concerns, with higher risks observed in smokers, patients with diabetes, or those with compromised bone quality. Thus, while ankle fusion is durable, it is not without long-term trade-offs.

### **Evidence from Randomized Controlled Trials and Systematic Reviews**

#### **TARVA Randomized Controlled Trial**

The TARVA trial randomized 303 patients across 17 UK centres between March 2015 and January 2019. Mean age was 68 years (71% male), with 43% having adjacent joint arthritis at baseline. Following baseline attrition, 281 patients completed clinical assessment (138 TAR, 143 AF).<sup>10</sup>

Both groups demonstrated clinically meaningful improvements at 52 weeks: TAR patients improved by 35.4 points and AF patients by 31.1 points on the MOXFQ walking/standing domain (0-100 scale, lower=better).<sup>10</sup> The adjusted difference was -5.6 points (95% CI -12.5 to 1.4,  $p=0.12$ ), showing TAR improvement greater than AF, but not statistically significant. Critical post hoc analysis revealed fixed-bearing TAR achieved statistically significant superiority over AF (mean difference -11.1, 95% CI -19.3 to -2.9,  $p=0.008$ ), while mobile-bearing TAR showed no significant difference from AF. This finding suggests implant selection influences outcomes.

Secondary outcome measures favoured TAR: EQ-5D VAS ( $p<0.001$ ) and FAAM scores ( $p=0.027$ ) both showed statistically significant advantages for TAR.<sup>11</sup> At 52 weeks, 82% of TAR patients and 80% of AF patients achieved the minimal important difference (12-point improvement). Adverse events occurred in similar proportions (109 TAR vs 104 AF cases); however, complication profiles differed significantly. TAR demonstrated higher wound complications (13.8% vs 5.5%) and nerve injuries (4.3% vs <1%). AF showed higher nonunion rates (radiographic 11.8%, symptomatic 6.9%) and thromboembolic events (5% vs 3%). Reoperation rates at 1 year: 7.2% TAR versus 5.2% AF; revision rates: 0.7% versus 2.8%, respectively.<sup>10</sup>

#### **Systematic Reviews and Meta-Analyses**

Zaidi et al. analyzed 58 papers (7,942 TARs), documenting complication rates: intraoperative fractures 7%, iatrogenic nerve injury 1.3%, superficial

infections 2.4%, deep infection 1.1%, 10-year survival 89%.<sup>12</sup> An earlier meta-analysis of 18 papers (1,086 TARs) reported similar deep infection rates (1.6%) but higher superficial infections (10.8%), with 5-year survival of 90.6%.<sup>13</sup>

Patel et al.'s systematic review identified risk factors for AF nonunion: strong evidence for male gender, smoking, and prior infection; moderate evidence for open injury history (OR 5.95); limited evidence for preoperative avascular necrosis (OR 13.16).<sup>14</sup> Kim et al.'s meta-analysis demonstrated significantly increased perioperative complication rates for TAR versus AF, with higher wound problems, nerve injury, and fractures; no difference in infection or amputation rates; higher TAR reoperation rates (21% vs 14%).<sup>15</sup> Ling et al.'s systematic review of 24 manuscripts examining AF and adjacent joint arthritis found reported subtalar arthritis prevalence 24-100%, talonavicular arthritis 18-77%.<sup>16</sup>

### National Joint Registry Evidence

#### UK National Joint Registry

The UK NJR analyzed 5,562 primary TARs with data linkage analysis. Survivorship: 98.8% at 1 year, 90.2% at 5 years (95% CI 89.2-91.1%), and 86.2% at 10 years (95% CI 84.6-87.6%). Mortality rates remained remarkably low: 90-day mortality 0.13%, 1-year mortality 0.72%, with pulmonary embolism at 0.51% within 90 days. Cox regression analysis revealed significant implant variability, with some designs showing substantially worse survivorship than others.<sup>17</sup>

#### Multi-Registry Comparison

Comparative analysis of five national registries (Sweden, Norway, New Zealand, Australia, UK) published in 2019 showed varying survival rates reflecting surgeon experience and implant heterogeneity.<sup>18</sup> Long-term data from Norwegian, Swedish, and New Zealand registries demonstrated 15-year mean survival of 66% (56-78) and 19-year survival of 62% (49-78). Swedish data demonstrated substantial improvement from 70% to 86% survival following surgeons' first 30 arthroplasties, emphasizing the learning curve effect.<sup>19</sup>

#### Large Database Studies

Wong et al. analyzed 2,463 AF patients, demonstrating 1-year non-union probability 11% and 3-year non-union probability 16%. Obesity represented the only independently associated risk factor on multivariable analysis (OR 1.6, 95% CI 1.3-2.0,  $p < 0.001$ ). Infection occurred in 3.9% within 1 year and 6.2% within 3 years; diabetes (OR 1.7) and higher comorbidity indices increased infection risk.<sup>20</sup>

### Complications: Comprehensive Analysis

#### TAR Complications

**Wound complications:** The most common early problem (8-13.8% incidence). The anterior approach exposes patients

to wound healing challenges due to limited soft tissue coverage and watershed vascular anatomy. Risk factors include diabetes, smoking, peripheral vascular disease, and corticosteroid use. Prevention strategies include anteromedial approaches preserving perforators, tranexamic acid administration, negative pressure wound therapy, and optimization of patient risk factors.<sup>21,22</sup>

**Medial Impingement:** Kurup et al. reported 23.5% incidence in their series of 34 Buechel-Pappas replacements, with four requiring surgical revision.<sup>23</sup> Contributing factors include cylindrical talar components, residual gutter arthritis, malalignment, and component subsidence. Prophylactic gutter debridement at primary TAR reduces symptomatic impingement requiring secondary surgery (2% vs 18%).<sup>24</sup> Arthroscopic debridement effectively treats established impingement in 80-100% of cases.<sup>25</sup>

**Malleolar Gutters:** Devos Bevernage et al. provided comprehensive management strategies for painful malleolar gutters, addressing differential diagnosis between osseous impingement, soft tissue pathology, and component malposition.<sup>26</sup>

**Day-case safety:** Kurup et al. demonstrated day-case TAR as safe with appropriate patient selection and protocols, achieving 97% satisfaction, zero 28-day readmissions, and £880 cost savings per case while reducing tissue swelling and wound complications.<sup>27</sup>

**Nerve Injury:** Superficial peroneal and anterior tibial nerve injuries manifest as neuromas or dorsal foot dysesthesia. The TARVA trial documented 4.3% nerve injury rate with TAR versus <1% with AF. Most injuries are temporary; permanent dysesthesia affects 1-2%.

**Infection:** Deep infection occurs in 1.1-1.6% of cases, requiring surgical debridement and prolonged antibiotic therapy. Prevention includes meticulous sterile technique, perioperative prophylaxis, diabetes optimization, and smoking cessation.

**Revision Surgery:** Registry data indicate TAR revision rates of 9-20% at 5 years and 23-32% at 10 years, primarily from aseptic loosening and polyethylene wear.<sup>28</sup> Salvage arthrodesis after failed TAR achieves fusion in 70-90%, lower than primary AF, with higher complication rates.<sup>29</sup>

#### AF Complications

**Non-union:** The most significant AF complication. Wong et al.'s database study documented 16% non-union probability at 3 years.<sup>20</sup> Arthroscopic techniques

demonstrate lower rates (2-3%) versus open procedures (6-8%), attributed to soft tissue preservation.<sup>30</sup> Modern fixation methods achieve >95% union in optimal conditions.

**Infection:** Occurs in 6.2% within 3 years.<sup>20</sup> Diabetes (OR 1.7) and higher comorbidity indices increased risk. Deep infection may result in chronic osteomyelitis requiring multiple debridement.

**Malunion:** Residual deformity >5 degrees occurs in 15-25% of cases, significantly impacting functional outcomes. Equinus malposition >5 degrees associates with increased tibial stress fractures and worse outcomes.

**Adjacent joint arthritis:** Progressive degeneration represents the major long-term concern. Coester et al. at 22-year follow-up found 100% of fusion patients developed adjacent joint OA, 96% had persistent limp, and >33% required walking aids.<sup>8</sup> Biomechanical studies show altered force distribution with compensatory hypermobility in adjacent joints. Clinically symptomatic adjacent joint arthritis requiring surgery occurs in 2.8% of AF patients at 5 years versus 0.7% after TAR.<sup>31</sup> By 10 years post-fusion, up to 26% require subtalar arthrodesis, resulting in more rigid, functionally limiting tibio-talo-calcaneal fusion.

## Patient Selection and Surgical Indications

### Indications for TAR

Optimal candidates are older patients (>50-55 years) with low-to-moderate activity demands, failed conservative management ( $\geq 6$  months), preserved ankle motion (>5-10 degrees dorsiflexion), neutral or correctable deformity (<10-15 degrees), good bone stock, adequate soft tissue, absence of neuropathy/vascular disease, and BMI <35-40.<sup>32,33</sup> Specific indications include primary/post-traumatic arthritis, inflammatory arthropathy (particularly rheumatoid arthritis), and failed prior surgery with adequate bone stock. Patients with adjacent joint arthritis particularly benefit from motion preservation.

### Contraindications

Absolute—active infection, severe vascular disease, Charcot arthropathy, talus avascular necrosis, inadequate bone/ligament support. Relative—age <50 (high-demand), BMI >40, smoking, uncontrolled diabetes with neuropathy, severe osteoporosis, previous ankle infection, severe deformity (>15-20 degrees), high-impact occupational/sports demands.<sup>32,33</sup> Relative contraindications require individualization; selected younger patients with low-demand lifestyles and realistic expectations may be appropriate candidates.

### Indications for AF

AF is preferred for younger, high-demand patients prioritizing durability; severe uncorrectable deformity

(>20 degrees); inadequate bone stock or severe osteoporosis; peripheral neuropathy/vascular disease; prior infection; failed TAR salvage; neuropathic arthropathy; and high-impact occupational/recreational demands.<sup>34</sup> Post-traumatic arthritis with significant talar collapse, septic arthritis sequelae, and multiple failed surgeries favour AF. Patient preference for “permanence” over motion preservation influences selection.

## Functional Outcomes and Return to Sports

Gait analysis consistently shows TAR patients achieve more physiological walking patterns with preserved stride length, improved speed, and symmetric gait compared to AF patients relying on compensatory midfoot motion.<sup>5,35</sup> Ankle range of motion preservation in TAR averages 20-30 degrees versus near-complete motion loss following AF. Long-term AF studies reveal persistent abnormalities: 96% have limp at 22-year follow-up, altered plantar pressure distribution, and increased midfoot stress fracture risk.<sup>8</sup>

### Return to Sports:

Arceri et al.'s systematic review and meta-analysis documented 61.9% mean postoperative sport participation rate after TAR, with some series achieving 92%.<sup>36,37</sup> Low-impact sports (swimming, cycling, golf, recreational walking, dancing) are well-tolerated; moderate-impact activities (tennis doubles, skiing) require individualized assessment; high-impact activities (running, jumping, soccer, basketball) remain contraindicated due to wear concerns.<sup>37</sup>

AF patients face greater limitations: post-fusion Tegner activity scores average 2.67 versus pre-injury 3.82, with FADI-Sport scores of 33.8%.<sup>35</sup> Loss of ankle motion restricts dynamic athletic movements, particularly on uneven terrain. Structured rehabilitation programs optimize return to sports success through proprioception, strength, and activity-specific training.<sup>36</sup>

### Cost-Effectiveness

The TARVA health economic analysis represents the first prospectively captured cost-utility assessment.<sup>38</sup> At 52 weeks: TAR costs £10,247 versus AF £7,893 (difference £2,354); TAR QALYs gained 0.571 versus AF 0.545 (difference 0.026 QALYs).<sup>38</sup> Within-trial ICER was £90,538 per QALY, exceeding UK thresholds; however, lifetime modelling incorporating implant longevity, revision probability, and adjacent joint arthritis suggests TAR becomes cost-effective (ICER <£30,000 per QALY) over the patient's lifetime.<sup>38</sup>

## Discussion and Conclusion

This article demonstrates both TAR and AF effectively improve pain and function in end-stage ankle arthritis. The TARVA trial's finding that fixed-bearing TAR showed superiority over AF ( $p=0.008$ ) in post hoc analysis, while mobile-bearing TAR did not, suggests implant selection significantly influences outcomes.

**TAR offers advantages:** motion preservation, improved gait mechanics, 61.9% return to sports participation, reduced adjacent joint stress, and potential lifetime cost-effectiveness. Disadvantages include higher early wound complications (13.8%), nerve injury (4.3%), and technical demands requiring experienced surgeons. Registry data show 86.2% survival at 10 years.

AF demonstrates exceptional durability with >95% union rates in optimal conditions, lower early complications, lower costs, and suitability for high-demand/complex cases. Disadvantages include complete motion loss, progressive adjacent joint arthritis (radiographically 24-100%), non-union risk (16% at 3 years), and limited sports participation.

### Evidence-based patient selection framework:

TAR preferable for: Patients >50-55 years with low-moderate demands, preserved motion, neutral alignment, good bone stock, multiple joint arthritis, and motion preservation preference.

Ankle-fusion preferable for: Younger high-demand patients, severe deformity (>20 degrees), poor bone quality, neuropathy/vascular disease, or failed TAR requiring salvage.

Complication management requires prophylactic gutter debridement for TAR, meticulous soft tissue handling, patient risk factor optimization, and day-case protocols. Surgeon experience substantially impacts outcomes; centralization to higher-volume centres may improve results. Both procedures should be presented through shared decision-making incorporating patient goals, activity demands, comorbidities, and realistic outcome expectations. The choice between TAR and AF should be individualized based on comprehensive preoperative assessment, with modern third-generation implants demonstrating improved survivorship. Future research including long-term TARVA follow-up, novel implant evaluation, and biological preservation strategies will further refine treatment algorithms.

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