REVIEW ARTICLE

# Total Ankle Replacement

## Indications, Implant Designs, and Results

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## SUMMARY

Background: About 1% of adults suffer from painful osteoarthritis of the ankle. The current literature contains no information on the percentage of such patients who derive long-term relief of symptoms from conservative treatment. Advanced ankle osteoarthritis can be treated with non-joint-preserving measures, such as total ankle replacement and ankle fusion.

Methods: This review is based on selected relevant publications, guidelines from Germany and abroad, and the authors' personal experience.

Results: Before surgery is considered, conservative measures such as physiotherapy and orthopedic aids should be used to the fullest possible extent. No randomized trials have yet been published comparing total ankle replacement with ankle fusion. Total ankle replacement with newer types of prosthesis yields good to very good intermediate-term and long-term results, with mean success rates of up to 90% at 10 years (range, 68–100%). Independent risk factors for the failure of ankle replacement are age over 70 years (odds ratio [OR] 3.84), primary osteoarthritis (OR 7.19), post-traumatic osteoarthritis (OR 6.2), and type of prosthesis (e.g., single hydroxyapatite coating: OR 15.04). The average range of motion of the replaced ankle joint is 25° to 30°, with values as high as 60°.

Conclusion: Total ankle replacement is a good treatment option for complete, end-stage ankle arthritis. It can restore joint function and make the patient mobile with little or no pain. There are, however, many contraindications to be taken into account. There is a need for further studies of the biomechanics of arthritic and replaced ankle joints and for long-term follow-up studies of total ankle replacement.



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Osteoarthritis of the ankle is an increasing issue in the healthcare sector (1, e1, e2). Approximately 1% of the adult population suffers from painful ankle osteoarthritis (2). The psychological and physical limitations associated with advanced ankle osteoarthritis are at least as marked as those of patients with osteoarthritis of the knee or hip (2). Degenerative changes of the ankle, in contrast to osteoarthritis of the knee or hip, are usually posttraumatic *(Table 1, eTable 1)* (3, e3, e4). Both poorly healed fractures to the lower extremity (4, e5) and repetitive ligament injuries (5) can play a major role. The main causes of secondary osteoarthritis of the ankle include rheumatic diseases, hemophilia, hemochromatosis, gout, avascular necrosis, and postinfectious states (1, e1).

This review article uses the current literature to explain the indications and the absolute and relative contraindications for total ankle replacement. It also presents the results of current clinical studies on postoperative functional outcomes and the probability of success of ankle replacement surgery.

### Selective literature search

This review article is based on a selective literature search in established databases. The following medical databases were searched, with no date restriction: Medline, Cochrane, EmbaseTM, Cinahl, Google Scholar, ScienceDirect, and SpringerLink. The search terms used were the following: "total ankle replacement," "total ankle arthroplasty," "ankle replacement," "ankle arthroplasty," and "ankle prosthesis." All articles written in languages spoken by the authors (German, English, and French) were included.

The digital indices of the following orthopedic journals were also searched for the above-mentioned search terms: *Foot and Ankle International*; *Journal of Bone and Joint Surgery, American Volume*; *Bone & Joint Journal* (formerly known as the *Journal of Bone and Joint Surgery, British Volume*); *Clinical Orthopaedics and Related Research*; *Foot and Ankle Clinics of North America*; *Journal of Foot and Ankle Surgery*; and *Der Orthopäde*. In addition, the bibliographies of the identified original and review articles were searched for further studies.

The literature search was performed by two of the authors (AB and MDW), independently of each other.

**TABLE 1**

**Etiology of advanced ankle osteoarthritis, based on a selection of clinical and epidemiological studies***

| Study | Study type | Patients (ankles) | Etiology of ankle osteoarthritis, % (absolute values) | | |
|---|---|---|---|---|---|
| | | | Primary | Secondary | Posttraumatic |
| (e6) | RS, SC, clinical | 45 (51) | 25.5% (13) | 54.9% (28) | 19.6% (10) |
| (6) | PS, SC, clinical | 684 (722) | 9.5% (69) | 11.4% (82) | 79.1% (571) |
| (e7) | PS, SC, clinical | 47 (50) | 6.0% (3) | 8.0% (4) | 86.0% (43) |
| (e8) | PS, SC, clinical | 49 (50) | 16.0% (8) | 18.0% (9) | 66.0% (33) |
| (e9) | PS, MC register, clinical | 245 (257) | 20.6% (53) | 55.3% (142) | 24.1% (62) |
| (e10) | PS, SC, clinical | 80 (83) | 33.7% (28) | 25.3% (21) | 41.0% (34) |
| (e11) | RS, SC, clinical | 111 (123) | 52.8% (65) | 18.7% (23) | 28.5% (35) |
| (e12) | RS, SC, clinical | 61 (62) | 19.4% (12) | 4.8% (3) | 75.8% (47) |
| (e13) | RS, SC, clinical | 45 (52) | 50.0% (26) | 26.9% (14) | 23.1% (12) |
| (e14) | RS, SC, clinical | 126 (132) | 46.2% (61) | 25.0 (33) | 28.8% (38) |
| (e15) | PS, SC, clinical | 43 (50) | 54.0% (27) | 32.0% (16) | 14.0% (7) |
| (e16) | PS, SC, clinical | 396 (404) | 16.6% (67) | 13.6% (55) | 69.8% (282) |
| (e17) | PS, SC, clinical | 80 (84) | 25.0% (21) | 19.0% (16) | 56.0% (47) |
| (e18) | PS, SC, clinical | 82 (82) | 34.2% (28) | 13.4% (11) | 52.4% (43) |
| (e19) | RS, SC, clinical | 95 (100) | 26.0% (26) | 29.0% (29) | 45.0% (45) |
| (e20) | PS, SC, clinical | 229 (229) | 13.8% (32) | 4.0% (9) | 82.2% (188) |
| (e21) | PS, SC, clinical | 106 (106) | 52.8% (56) | 20.8% (22) | 26.4% (28) |
| (e22) | PS, SC, clinical | 233 (240) | 30.8% (74) | 17.9% (43) | 51.3% (123) |
| (3) | PS, SC, epidemiological | 639 (639) | 7.2% (46) | 23.2% (148) | 69.6% (445) |
| (7) | PS, MC, clinical | 593 (593) | 26.5% (157) | 15.3% (91) | 58.2% (345) |
| (e23) | RS, SC, clinical | 100 (100) | 30.0% (30) | 44.0% (44) | 26.0% (26) |
| (e24) | RS, MC, clinical | 501 (517) | 13.9% (72) | 25.9% (134) | 60.2% (311) |
| (e25) | PS, MC register, clinical | 515 (515) | 19.2% (99) | 59.2% (305) | 21.6% (111) |
| (e26) | RS, SC, clinical | 303 (306) | 25.2% (77) | 10.1% (31) | 64.7% (198) |
| (e27) | RS, SC, clinical | 103 (103) | 71.8% (74) | 18.5% (19) | 9.7% (10) |
| (e28) | PS, SC, clinical | 65 (68) | 13.2% (9) | 16.2% (11) | 70.6% (48) |
| (e3) | RS, SC, epidemiological | 390 (406) | 8.9% (36) | 12.8% (52) | 78.3% (318) |
| (e29) | PS, SC, clinical | 66 (66) | 0.0% (0) | 10.6% (7) | 89.4% (59) |
| (e4) | RS, SC, clinical | 226 (233) | 5.6% (13) | 23.2% (54) | 71.2% (166) |
| (e30) | PS, SC, clinical | 96 (100) | 64.0% (64) | 27.0% (27) | 9.0% (9) |
| (e31) | RS, SC, clinical | 90 (99) | 40.4% (40) | 12.1% (12) | 47.5% (47) |
| Total/mean | | 6218 (6389) | 21.5% (1373) | 22.6% (1373) | 56.0% (3575) |

*Clinical (total ankle replacement) and epidemiological (etiology of ankle osteoarthritis) studies with at least 50 patients were included.
MC, multicenter; PS, prospective; RS, retrospective; SC, single-center

## History and implant designs

Most first-generation ankle replacements performed in the 1970s and early 1980s were two-component cemented implants. The rate of aseptic loosening for all first-generation implant types was extremely high, occurring in almost 90% of implants (8).

Second-generation ankle implants (from the mid-1980s onwards) show improved implant shapes and better surgical technique: bone-conserving surgical approach and no cementation. Today there are several commercially available ankle implant types *(Figure 1)*. All implant designs can be classified by surgical technique and implant properties *(eTable 2)* (8).

## Diagnosis and preoperative planning

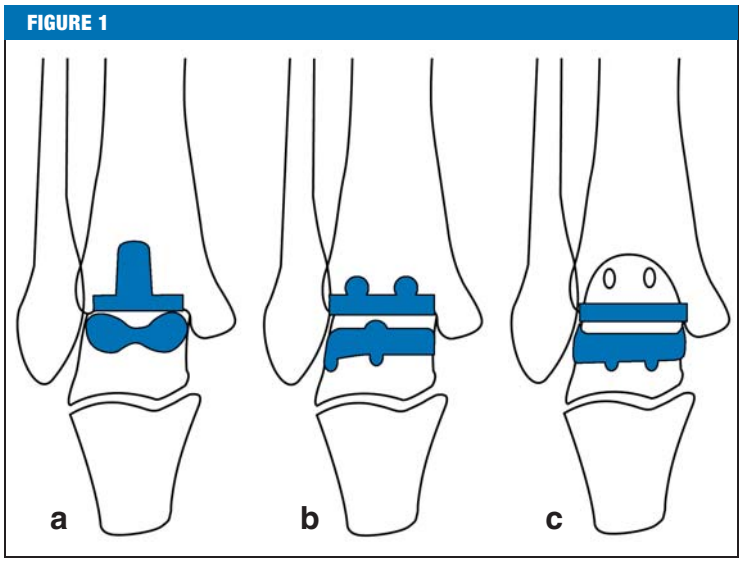
A clinical and radiological diagnosis of osteoarthritis of the ankle can be made by the patient's treating

physician on the basis of clinical and radiological examination, as described.

The first step in preoperative diagnosis is to take a clinical history. All available documents should be evaluated: it is important to note which, if any, treatment options have already been administered. Further information such as BMI (body mass index), physical activity levels, previous and/or current treatment, severity of pain, limitations in everyday private and/or occupational activities, intake of analgesics, and concomitant diagnoses (diabetes mellitus, osteoporosis, polyneuropathy, etc.) should be recorded.

Clinical examination begins with examination of the foot/hindfoot on standing, sitting, and walking. Hindfoot alignment (valgus, varus, or neutral) is assessed from behind, with the patient standing. Stability is determined with the patient seated, using the talar tilt test (examination of medial and lateral ankle inversion) and the anterior drawer test (which tests for increased anterior translation of the talus) (9). Mobility of the subtalar joint is measured using a goniometer under load (10). Mobility of the ankle is measured manually, with the ankle fixed and free (e32).

Radiological examination includes conventional weight bearing radiographs: dorsoplantar and lateral views of the foot, anteroposterior (mortise) and lateral views of the ankle, and Saltzman view (hindfoot alignment view to assess inframalleolar alignment [11]) *(Figure 2)*. Supramalleolar alignment is determined using the of medial distal tibial angle (12, e33). In patients with knee deformities, a whole leg radiograph (orthoradiogram) is also taken. Optionally, computed tomography or magnetic resonance imaging may be performed; these can provide important additional information.




**Modern ankle implant types**
a) Components with tibial stem b) Components with bars c) Flat components

## Indication for surgery

Conservative therapy should be administered before surgery is indicated. This includes intensive physiotherapy (local antiphlogistic therapy, muscle and movement exercises to prevent stiffness of the joint, muscle strength development, gait training) and possibly intra-articular hyaluronic acid viscosupplementation and orthopedic adaptation of footwear (13, 14).

The ideal indication for total ankle replacement is advanced, complete osteoarthritis of the ankle (primary, secondary, or posttraumatic) with good bone quality, neutral alignment, good stability, and preserved mobility of the ankle. Further special indications include patients with bilateral osteoarthritis of the ankle (15, e34).

Total joint replacement can also be performed as revision arthroplasty in patients with failed ankle prosthesis (16, 17, e35). However, revision ankle arthroplasty, like revision joint replacement in general, is a technically demanding surgical procedure. Patients with painful non-union or malunion of previous ankle arthrodesis are another specific indication for total ankle replacement (18, e36, e37).

Absolute contraindications include acute or chronic infections, with or without osteomyelitis or osteitis; severe osteonecrosis of the talus (more than one third of the talus); neuromuscular diseases; neuroarthropathies (e.g. patients with Charcot foot); and patients with severe circulatory disorders (19). In patients with concomitant significant ligament instabilities and/or deformities that cannot be corrected intraoperatively, arthrodesis of the ankle should be performed instead of joint replacement. Metal allergies are also a contraindication (20, 21).

Relative contraindications include severe osteoporosis, poor bone quality (e.g. due to steroid treatment), diabetes mellitus, smoking, and excess weight, although the literature shows that good outcomes can be achieved in some of these cases [22]). There may be an increased rate of aseptic loosening of implant components in patients who engage in high levels of sporting activity (23, 24). Low-impact exercise (walking, swimming, cycling, golf), however, is recommended postoperatively (19, 24).

## Surgical technique

An anterior approach is usually used for ankle replacement surgery *(eFigure 1)*. In patients with a history of previous ankle surgery, the surgical approach can be modified in order not to compromise postoperative wound healing (e38, e39). Depth preparation is performed beneath the tendon of the tibialis anterior muscle in order to preserve the anterior neurovascular bundle, which in most cases lies behind the tendon of the extensor hallucis longus muscle or between the tendons of the extensor hallucis longus and extensor digitorum longus muscles (e40). Bone resection is performed using an oscillating saw. Additional procedures for patients with concomitant deformities and/or instabilities should be performed after insertion of the implant components *(eTable 3)* (25, 26, e41, e42).

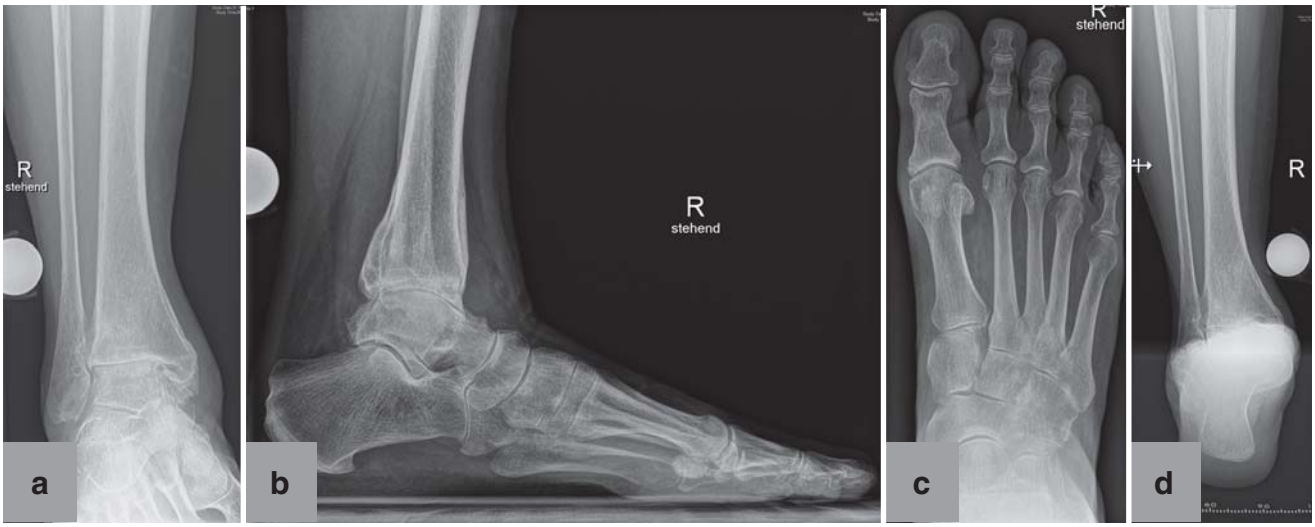



**Figure 2:** Preoperative conventional X-ray in standing position of 67-year-old female patient with posttraumatic ankle osteoarthritis following open reduction and internation fixation for trimalleolar luxation fracture 4 years earlier: a) mortise view of ankle; b) lateral view of foot and ankle; c) dorsoplantar view of foot; d) Saltzman view of hindfoot

## Aftercare

We recommend immobilization using plaster cast of the lower leg or a stabilizing boot for six weeks after surgery. During this period full weight may be borne with the aid of two elbow crutches, depending on the severity of the patient's complaints. In patients with reduced bone quality and/or who have undergone additional procedures such as corrective osteotomy, we recommend 15 kg partial weightbearing for six weeks after surgery. Thromboprophylaxis is administered during immobilization (27). Clinical and radiological follow-up examination is performed after six weeks *(Figure 3)*. After this, intensive outpatient physiotherapy begins: gait training, proprioception exercises, gradual increase to full weightbearing, local antiphlogistic therapy including lymph drainage, active and passive ankle mobility therapy, extension exercises, and therapy to strengthen the triceps surae muscle.

Compression stockings are used for patients with persistent edema or soft-tissue swelling. The following sports can be recommended after full mobilization and full weightbearing ability have been attained: low-impact (e.g. walking, swimming, cycling, golf) or medium-impact (e.g. jogging, tennis, skiing) (24). Contact sports and sports that involve jumping should be avoided (24).

Clinical and radiological follow-up examinations are performed six weeks, three months, six months, and one year after surgery and then annually. The most important tools/questionnaires (28) that can be used to record functional postoperative outcomes following total ankle replacement are the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle–Hindfoot Score (29) (score composed of pain, function, and alignment; minimum score, 0 points; maximum score, 100 points); and the Kofoed Ankle Score (e58) (score composed of pain, function, and range of motion; minimum score, 0 points; maximum score, 100 points). Pain level is determined using the visual analogue scale (VAS) from 0 (no pain) to 10 (worst possible pain) (e59). Quality of life can be analyzed using the SF-36 questionnaire (36-Item Short Form Health Survey) (e60).

## Results/literature review

For a long time arthrodesis of the ankle was the first-line treatment for patients with advanced osteoarthritis of the ankle, which is not surprising given how uniformly disappointing the results of first-generation total ankle replacement were. Precise analysis of failures led to the development of new implant designs, acceptance of which is steadily increasing among orthopedic surgeons.

However, it is difficult to find well conducted, controlled, prospective studies in the literature, and in particular there are no comparisons of two-component and three-component implant types (30). Saltzman et al. (7) published the first results of a prospective study comparing ankle arthrodesis (66 cases) and total ankle replacement (593 patients) and demonstrated that patients with total ankle replacement had less pain and better functional outcomes postoperatively, with comparable postoperative complication rates. Although postoperative complications (poor wound healing, infections) were observed more frequently in patients undergoing ankle replacement than in those undergoing arthrodesis of the ankle—6.2% versus 1.5%— the difference was not statistically significant ($p = 0.087$). The Buechel–Pappas score (score composed of pain, function, deformity, and mobility; minimum score, 0 points; maximum score, 100 points) (e61) was used to assess functional outcome. Patients with total ankle

replacement had significantly better functional outcomes: Buechel–Pappas score 46.7 ± 13.0 versus 26.3 ± 17 ($p$<0.001). The two groups had comparable postoperative pain levels: 1.6 ± 1.8 versus 1.8 ± 2.0 ($p$ = 0.607). Further studies are planned by the authors but have not yet been published (7).

Despite increasing acceptance, total ankle replacement remains a technically demanding procedure with a flat learning curve. Intraoperative complications are not uncommon; they include fractures of the medial and/or lateral malleolus in 0 to 23% of cases and tendon injuries (posterior tibial tendon, flexor hallucis longus, flexor digitorum longus) and nerve injuries (superficial/deep peroneal nerve) in 0 to 10% of cases (31, e62–e66). Difficult steps during surgery include correct component positioning, particularly of talar components (e62, e66). Incorrect tibial component positioning can be found in 0 to 16% of all cases, and incorrect talar component positioning in 0 to 36% of all cases (e62). Numerous *in vitro* biomechanical studies have shown that incorrect positioning of implant components has adverse biomechanical consequences such as reduced ankle mobility, pathological tension of the periarticular ligaments, and unfavorable intra-articular pressure distribution (e67–e70). We have shown in a clinical study that patients with suboptimal positioning of talar components have a higher rate of persisting pain and worse ankle mobility (32).

Postoperative outcomes following total ankle replacement are steadily improving *(Table 2; eTable 4)* but lag behind those of total knee and hip replacements *(Table 3)*. Labek et al. (33) investigated cumulative outcomes on the basis of worldwide joint replacement registers. Outcomes following total hip and knee replacements were comparable, with 1.29 and 1.26 revisions per 100 component years. This means that after 10 years 13 out of every 100 patients need to undergo revision surgery. The outcomes following medial partial replacement were somewhat worse, with 1.53 revisions per 100 component years. Total ankle replacement was associated with the worst outcomes, however, with 3.29 revisions per 100 component years, resulting in revision surgery for 33 out of every 100 patients within 10 years (33). The causes and frequency of failure of total ankle replacement are different from those of hip and knee replacements: the main causes of failure are aseptic loosening of tibial and/or talar components, persisting pain, and septic loosening *(Table 3)* (34).

In 2010, Gougoulias et al. (35) performed a systematic review of the literature including 13 level IV studies with a total of 1105 ankle replacements. Seven different implant types were used. The mean failure rate (defined as replacement of one or both implant components or implant removal and conversion to arthrodesis of the ankle) five years after implantation was 10%, but there was great variation in failure rates between different centers, ranging from 0% to 32%. The percentage of patients in the included studies with persisting complaints was between 27 and 60%.

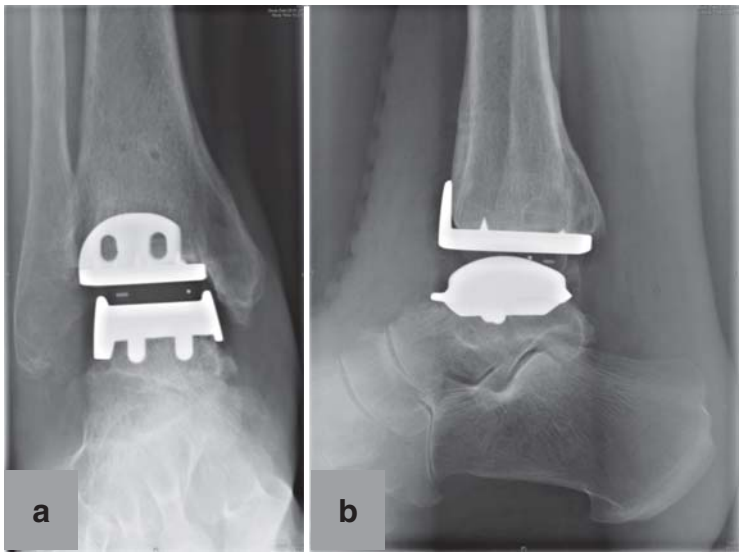



**Figure 3:** Postoperative X-ray of 67-year-old female patient 6 weeks after total ankle replacement: a) mortise view of ankle; b) lateral view of ankle

Postoperative improvement in ankle mobility was relatively low, with values between 0° and 14° (35). Zaidi et al. (36) published a systematic review of the literature and meta-analysis of 58 publications with a total of 7942 ankle replacements. The success rate after 10 years was 89%, with an annual failure rate of 1.2% (95% confidence interval [CI]: 0.7 to 1.6). The mean AOFAS Ankle–Hindfoot Score rose from 40 (95% CI: 36 to 43) preoperatively to 80 (95% CI: 76 to 84) postoperatively. The range of motion of the ankle on which surgery was performed improved from a mean of 23° (95% CI: 19 to 26°) preoperatively to 34° (95% CI: 26 to 41°) postoperatively (36).

We performed a survivorship analysis of implant components in 684 patients who received a total of 722 ankle replacements (6). The mean follow-up time in this prospective study was 6.3 ± 2.9 years. The probability of success of the implant components was 94% after five years and 84% after 10 years. These results are comparable with those of current clinical studies *(Table 2, eTable 4)*. The following factors were identified as independent risk factors for ankle replacement failure:

- Age under 70 years (odds ratio [OR]: 3.84)
- Etiology of ankle osteoarthritis (OR for primary osteoarthritis: 7.19; OR for posttraumatic osteoarthritis: 6.20)
- Implant generation (OR for single hydroxyapatite coating: OR: 15.04) (6).

For a long time a change of approach—removal of the implant components followed by arthrodesis—was the standard procedure in cases of ankle replacement failure. The current literature describes various surgical techniques and fixation methods for such arthrodesis after prosthesis removal: bone allografts, autografts, or replacement materials (e.g. porous metals such as

**TABLE 2**

**Clinical outcomes following total ankle replacement: probability of survival of implant components***

| Study | Study type | Implant type | No. of implants | Probability of survival of implant components |
|---|---|---|---|---|
| (e72) | RS, SC | Agility | 207 | 76% after 9 years |
| (22) | RS, SC | HINTEGRA | 123 | 93% after 6 years |
| (6) | PS, SC | HINTEGRA | 722 | 94% after 5 years, 84% after 10 years |
| (e74) | RS, MC | Salto (388), AES (173), HINTEGRA (22), STAR (9) | 592 | 88% after 71 months |
| (e79) | PS, SC | Buechel–Pappas (normal sulcus 40; deep sulcus 75) | 115 | 74.2% (normal sulcus) after 20 years, 92% (deep sulcus) after 12 years |
| (e9) | PS, MC | STAR (216), TPR (32), HINTEGRA (6), AES (3) | 257 | 89% after 5 years, 76% after 10 years |
| (e85) | PS, MC | BOX | 158 | 96.1% after 4 years |
| (e86) | PS, MC | STAR (318), Buechel-Pappas (92), AES (69), HINTEGRA (29), Mobility (23) | 531 | 78% after 5 years, 62% after 10 years |
| (e87) | PS, MC | STAR (322), Mobility (132), AES (115), Buechel-Pappas (109), CCI (66), HINTEGRA (36) | 780 | 81% after 5 years, 69% after 10 years |
| (e11) | RS, SC | STAR | 123 | 86% (patients with preoperative deformity up to 10°), 75% (patients with preoperative deformity 10 to 30°) after 5 years |
| (e88) | PS, MC | Agility (117), STAR (45), Mobility (29), Ramses (11) | 202 | 86% after 5 years |
| (e90) | RS, SC | Mayo | 204 | 79% after 5 years, 65% after 10 years, 61% after 15 years |
| (e14) | RS, SC | Agility | 132 | 86% after 9 years, 63% after 11 years |
| (e92) | PS, SC | STAR | 100 | 85.7% (patients under 50) and 91.6% (patients over 50) after 5 years, 75% (patients under 50) and 80.6% (patients over 50) after 10 years |
| (e96) | PS, MC | BOX | 189 | 97% after 4 years |
| (e16) | PS, SC | INBONE (211), STAR (122), Salto-Talaris (71) | 404 | 90% and 97.6% after 3.2 years with and without arthrodesis of the hindfoot |
| (21) | RS, MC | Salto (91), HINTEGRA (39), AES (20), Coppelia (17), STAR (11), Ramses (4), Akile (1) | 183 | 86% (88.4% high-volume centers; 84.9% low-volume centers) after 5 years |
| (e22) | PS, SC | Mobility | 240 | 97.7% after 4 years |
| (e102) | RS, SC | Salto | 401 | 86.6% (all patients), 85.1% (posttraumatic osteoarthritis), 95.6% (rheumatoid arthritis), 87.9% (patients under 55) after 5 years |
| (e25) | PS, MC | AES (298), STAR (217) | 515 | 83% after 5 years |
| (e26) | RS, SC | Agility | 306 | 80% (89% in patients over 54) after 5 years |
| (e108) | PS, SC | STAR | 200 | 92.7% after 5 years |
| (e109) | RS, MC | Salto | 109 | 97.5% after 2 years |
| (e111) | PS, SC | STAR | 200 | 93.3% after 5 years, 80.3% after 10 years |
| (e112) | PS, SC | Buechel-Pappas (100), STAR (100) | 200 | 79% (Buechel-Pappas) and 95% (STAR) after 6 years |
| (e30) | PS, SC | Mobility | 100 | 97% after 3 years, 93.6% after 4 years |

*Clinical studies (total ankle replacement) with at least 100 patients were included.
AES: Ankle Evolutive System; BOX: Bologna–Oxford; MC: multicenter; PS: prospective; RS: retrospective; STAR: Scandinavian Total Ankle Replacement; TPR: Thomson, Prichard and Richard; SC: single-center

Trabecular Metal™) can be used to bridge the defect (37, 38, e113–e118). The alternative to converting to ankle arthrodesis is revision ankle arthroplasty (16, 17, e35, e119–e121). If possible, an implant type for which special revision components are available, e.g. a thicker metal plate for tibial components and larger weightbearing area and improved fixation for talar components, should be used. Revision surgery can be performed as one-stage or two-stage procedure. In the two-stage procedure, the goal of the first surgery is to address the bone defect. After bone integration of the autograft is achieved, the revision components can be implanted in a second surgery *(eFigure 2)*.

## Conclusion

There is no gold standard treatment for advanced ankle osteoarthritis. Both, ankle arthrodesis and total ankle replacement are important treatment options in patients with end-stage ankle osteoarthritis. Attaining satisfactory intermediate-term and long-term postoperative outcomes in patients who have undergone total ankle replacement requires thorough preoperative examination and planning, taking careful account of all relative and absolute contraindications, with corresponding patient selection. If modern ankle implant designs are used, 10-year success rates of between 70 and 90% can be achieved.

**TABLE 3**

**Most common causes of failure of total hip, knee, and ankle replacement (given in % according to Sadoghi et al. [34])**

| Cause of failure | Total hip replacement | Total knee replacement | Total ankle replacement |
|---|---|---|---|
| Aseptic loosening | 55.2 | 29.8 | 38 |
| Luxation/instability | 11.8 | 6.2 | 8.5 |
| Septic loosening | 7.5 | 14.8 | 9.8 |
| Periprosthetic fracture | 6 | 3 | 2 |
| Pathological wear | 4.2 | 8.2 | 8 |
| Persistent pain | 3.7 | 9.5 | 12 |
| Implant failure | 2.5 | 4.7 | 5.3 |
| Technical error | 3.8 | 4.6 | 4.6 |

**Conflict of interest statement**
The authors declare that no conflict of interest exists.

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REVIEW ARTICLE

# Total Ankle Replacement

## Indications, Implant Designs, and Results

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**eTABLE 1**

**Etiology of advanced ankle osteoarthritis, based on a selection of clinical and epidemiological studies***

| Study | Study type | Patients (ankles) | Etiology of ankle osteoarthritis, % (absolute values) | | |
|---|---|---|---|---|---|
| | | | Primary | Secondary | Posttraumatic |
| (e6) | RS, SC, clinical | 45 (51) | 25.5% (13) | 54.9% (28)<br>– Rheumatism: 54.9% (28) | 19.6% (10) |
| (6) | PS, SC, clinical | 684 (722) | 9.5% (69) | 11.4% (82) | 79.1% (571) |
| (e7) | PS, SC, clinical | 47 (50) | 6.0% (3) | 8.0% (4)<br>– Rheumatism: 4.0% (2)<br>– Tuberculosis: 2.0% (1)<br>– Hemophilia: 2.0% (1) | 86.0% (43)<br>– State following fracture: 50.0% (25)<br>– State following ligament injuries: 36.0% (18) |
| (e8) | PS, SC, clinical | 49 (50) | 16.0% (8) | 18.0% (9)<br>– Rheumatism: 14.0% (7)<br>– Necrosis of the talus: 4.0% (2) | 66.0% (33) |
| (e9) | PS, MC register, clinical | 245 (257) | 20.6% (53) | 55.3% (142) | 24.1% (62)<br>– State following fracture: 22.1% (57)<br>– State following ligament injuries: 1.9% (5) |
| (e10) | PS, SC, clinical | 80 (83) | 33.7% (28) | 25.3% (21)<br>– Rheumatism: 25.3% (21) | 41.0% (34) |
| (e11) | RS, SC, clinical | 111 (123) | 52.8% (65) | 18.7% (23) | 28.5% (35) |
| (e12) | RS, SC, clinical | 61 (62) | 19.4% (12) | 4.8% (3)<br>– Clubfoot: 3.2% (2)<br>– Postpolio: 1.6% (1) | 75.8% (47) |
| (e13) | RS, SC, clinical | 45 (52) | 50.0% (26) | 26.9% (14) | 23.1% (12) |
| (e14) | RS, SC, clinical | 126 (132) | 28.8% (38) | 25.0 (33)<br>– Rheumatism: 23.5% (31)<br>– Postinfection: 1.5% (2) | 46.2% (61) |
| (e15) | PS, SC, clinical | 43 (50) | 54.0% (27) | 32.0% (16) | 14.0% (7) |
| (e16) | PS, SC, clinical | 396 (404) | 16.6% (67) | 13.6% (55) | 69.8% (282) |
| (e17) | PS, SC, clinical | 80 (84) | 25.0% (21) | 19.0% (16)<br>– Rheumatism: 17.9% (15)<br>– Hemochromatosis: 1.2% (1) | 56.0% (47)<br>– State following fracture: 39.3% (33)<br>– State following ligament injuries: 16.7% (14) |
| (e18) | PS, SC, clinical | 82 (82) | 34.2% (28) | 13.4% (11) | 52.4% (43) |
| (e19) | RS, SC, clinical | 95 (100) | 26.0% (26) | 29.0% (29)<br>– Rheumatism: 26.0% (26)<br>– Postinfection: 2.0% (2)<br>– Psoriasis: 1.0% (1) | 45.0% (45) |
| (e20) | PS, SC, clinical | 229 (229) | 13.8% (32) | 4.0% (9) | 82.2% (188) |
| (e21) | PS, SC, clinical | 106 (106) | 52.8% (56) | 20.8% (22) | 26.4% (28) |
| (e22) | PS, SC, clinical | 233 (240) | 30.8% (74) | 17.9% (43)<br>– Rheumatism: 15.0% (36)<br>– Hemochromatosis: 2.9% (7) | 51.3% (123) |
| (3) | PS, SC, epidemiological | 639 (639) | 7.2% (46) | 23.2% (148)<br>– Rheumatism: 11.9% (76)<br>– Neuropathy: 4.9% (31)<br>– Hemophilia: 1.9% (12)<br>– Postinfection: 1.6% (10)<br>– Gout: 0.8% (5) | 69.6% (445)<br>– State following fracture: 46.6% (298)<br>– State following ligament injuries: 19.7% (126)<br>– Traumatic osteochondral lesions: 3.3% (21) |
| (7) | PS, MC, clinical | 593 (593) | 26.5% (157) | 15.3% (91) | 58.2% (345) |
| (e23) | RS, SC, clinical | 100 (100) | 30.0% (30) | 44.0% (44) | 26.0% (26) |
| (e24) | RS, MC, clinical | 478 (489) | 15.3% (75) | 25.8% (126) | 58.9% (228) |
| (e25) | PS, MC register, clinical | 515 (515) | 19.2% (99) | 59.2% (305) | 21.6% (111) |
| (e26) | RS, SC, clinical | 303 (306) | 25.2% (77) | 10.1% (31) | 64.7% (198) |
| (e27) | RS, SC, clinical | 103 (103) | 71.8% (74) | 18.5% (19) | 9.7% (10) |

| Study | Study type | Patients (ankles) | Etiology of ankle osteoarthritis, % (absolute values) | | |
|---|---|---|---|---|---|
| | | | Primary | Secondary | Posttraumatic |
| (e28) | PS, SC, clinical | 65 (68) | 13.2% (9) | 16.2% (11)<br>– Rheumatism: 7.4% (5)<br>– Hemochromatosis: 4.4% (3)<br>– Psoriasis: 1.5% (1)<br>– Lupus erythematosus: 1.5% (1)<br>– Sclerodermia: 1.5% (1) | 70.6% (48)<br>– State following fracture: 60.3% (41)<br>– State following ligament injuries: 10.3% (7) |
| (e3) | RS, SC, epidemiological | 390 (406) | 8.9% (36) | 12.8% (52)<br>– Rheumatism: 5.4% (22)<br>– Hemochromatosis: 2.7% (11)<br>– Hemophilia: 1.5% (6)<br>– Clubfoot: 1.0% (4)<br>– Avascular necrosis of the talus: 0.7% (3)<br>– Osteochondral lesions: 0.7% (3)<br>– Postinfection: 0.7% (3) | 78.3% (318)<br>– State following fracture: 62.3% (253)<br>– State following ligament injuries: 16.0% (65) |
| (e29) | PS, SC, clinical | 66 (66) | 0.0% (0) | 10.6% (7)<br>– Necrosis of the talus: 4.5% (3)<br>– Hemophilia: 3.0% (2)<br>– Rheumatism: 1.5% (1)<br>– Hemochromatosis: 1.5% (1) | 89.4% (59)<br>– State following fracture: 72.7% (48)<br>– State following ligament injuries: 16.7% (11) |
| (e4) | RS, SC, clinical | 226 (233) | 5.6% (13) | 23.2% (54)<br>– Flatfoot: 8.2% (19)<br>– Rheumatism: 7.3% (17)<br>– Clubfoot: 3.4% (8)<br>– Osteochondral lesion: 1.7% (2)<br>– Postinfection: 1.3% (1.3)<br>– Charcot–Marie–Tooth disease: 0.9% (2)<br>– Hemophilia: 0.4% (1) | 71.2% (166)<br>– State following fracture: 59.2% (138)<br>– State following ligament injuries: 12.0% (28) |
| (e30) | PS, SC, clinical | 96 (100) | 64.0% (64) | 27.0% (27)<br>– Rheumatism: 27.0% (27) | 9.0% (9)<br>– State following fracture: 9.0% (9) |
| (e31) | RS, SC, clinical | 90 (99) | 40.4% (40) | 12.1% (12) | 47.5% (47) |
| **Total** | | 6218 (6389) | 21.5% (1373) | 22.6% (1441) | 56.0% (3575) |

*Clinical (total ankle replacement) and epidemiological (etiology of ankle osteoarthritis) studies with at least 50 patients were included.
MC: multicenter; PS: prospective; RS: retrospective; SC: single-center

**eTABLE 2**

**Classification of current ankle implant types**

| | Surgical access | Inlay type | Replaced surfaces | Internal implant surfaces | Inlay materials | Sulcus type | Surface morphology |
|---|---|---|---|---|---|---|---|
| **AAA** | Anterior | Mobile | Superior | HA | UHMWPE | None | Trapezoidal |
| **AES** | Anterior | Mobile | Superior | HA | UHMWPE | Deep | Trapezoidal |
| **Agility** | Anterior | Fixed | Superior/medial/ lateral | Titanium | UHMWPE | None | Trapezoidal |
| **BOX** | Anterior | Mobile | Superior | HA | UHMWPE | Normal | Ellipsoidal |
| **Buechel-Pappas** | Anterior | Mobile | Superior | Titanium | UHMWPE | Deep | Ellipsoidal |
| **ESKA** | Lateral/medial | Fixed | Superior | Titanium | UHMWPE | Normal | Ellipsoidal |
| **INBONE** | Anterior | Fixed | Superior | Titanium | UHMWPE | Normal | Spheroidal |
| **HINTEGRA** | Anterior | Mobile | Superior/medial | HA | UHMWPE | None | Conical |
| **Mobility** | Anterior | Mobile | Superior | Titanium | UHMWPE | Deep | Trapezoidal |
| **Ramses** | Anterior | Mobile | Superior | HA | UHMWPE | None | Ellipsoidal |
| **Salto** | Anterior | Mobile | Superior/medial | HA | UHMWPE | Normal | Conical |
| **STAR** | Anterior | Mobile | Superior | HA | UHMWPE | None | Cylindrical |
| **TNK** | Anterior | Fixed | Superior | HA | UHMWPE, ceramic | None | Cylindrical |
| **TM Total Ankle** | Lateral | Fixed | Superior | Porous metal | Highly cross-linked UHMWPE | None | Conical |

AAA: Alpha Ankle Arthroplasty; AES: Ankle Evolutive System; BOX: Bologna–Oxford; HA: hydroxyapatite; STAR: Scandinavian Total Ankle Replacement; TM: Trabecular Metal; UHMWPE: ultra-high-molecular-weight polyethylene

**eTABLE 3**

**Additional procedures in patients with concomitant valgus or varus hindfoot deformity**

| | |
|---|---|
| **Patients with valgus hindfoot deformity** | |
| Supramalleolar valgus deformity | Supramalleolar tibial osteotomy:<br>– Medial closing tibial osteotomy (e43–e45) |
| Isolated valgus defective heel position | Corrective calcaneal osteotomy:<br>– Medial sliding calcaneal osteotomy (e46) |
| Flexible pes planovalgus et abductus deformity | Corrective calcaneal osteotomy:<br>– Lateral sliding calcaneal osteotomy (e47)<br>Tendon transfer:<br>– Flexor digitorum longus to tibialis posterior (e48) |
| Rigid pes planovalgus et abductus deformity | Corrective arthrodesis of the hindfoot:*<br>– Subtalar arthrodesis (e49)<br>– Triple arthrodesis with or without calcaneocuboidal joint (e50) |
| Medial instability | Medial ligament stabilization:<br>– Anatomical reconstruction with transosseous sutures (e51)<br>– Reconstruction with tendon autograft (e52) |
| **Patients with varus hindfoot deformity** | |
| Supramalleolar varus deformity | Supramalleolar tibial osteotomy:<br>– Medial opening tibial osteotomy (with supramelleolar deformity <10°) (e44, e45, e53)<br>– Lateral closing tibial osteotomy (with supramelleolar deformity >10°) (e44, e45, e53) |
| Flexible varus abnormal heel position | Corrective calcaneal osteotomy:<br>– Dwyer calcaneal osteotomy (e54)<br>– Z-shaped calcaneal osteotomy (e55) |
| Rigid inframalleolar varus alignment | Corrective arthrodesis of the hindfoot:<br>– Subtalar arthrodesis (e49) |
| Lateral instability | Lateral ligament stabilization:<br>– Anatomical reconstruction with transosseous stitches (e56)<br>– Reconstruction with tendon autograft (e57) |

*Depends on extent of deformity and degenerative changes

**eTABLE 4**

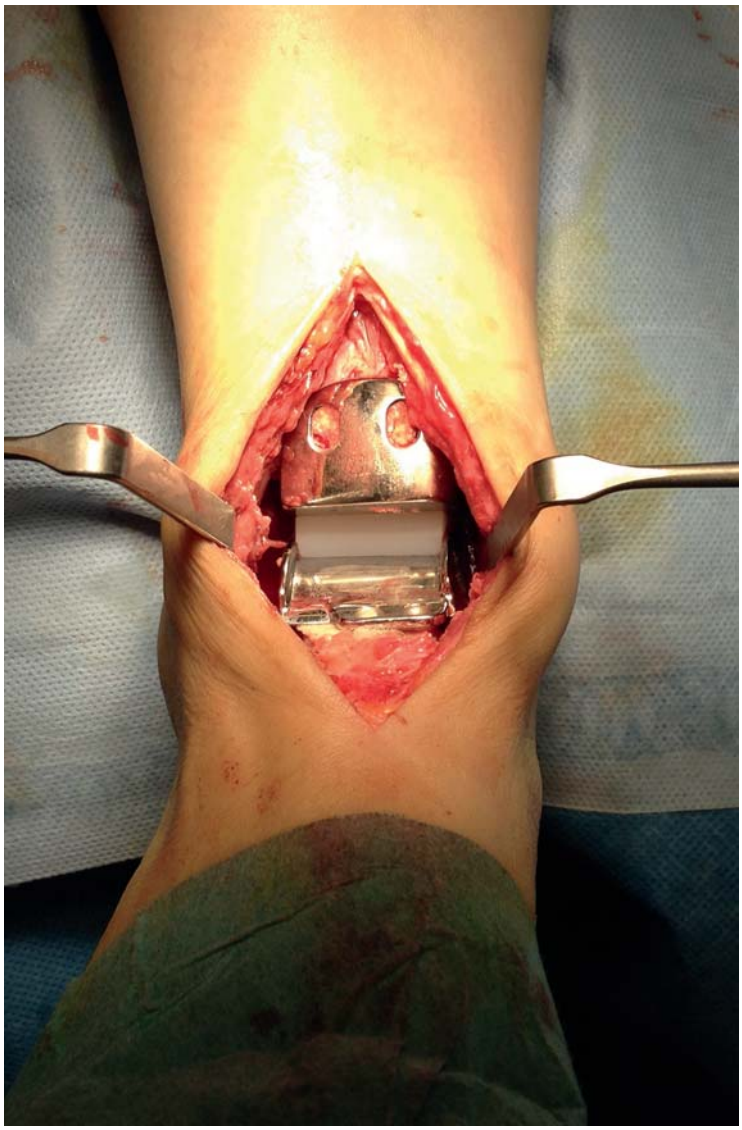
**Clinical outcomes following total ankle replacement: probability of survival of implant components and postoperative range of ankle motion***

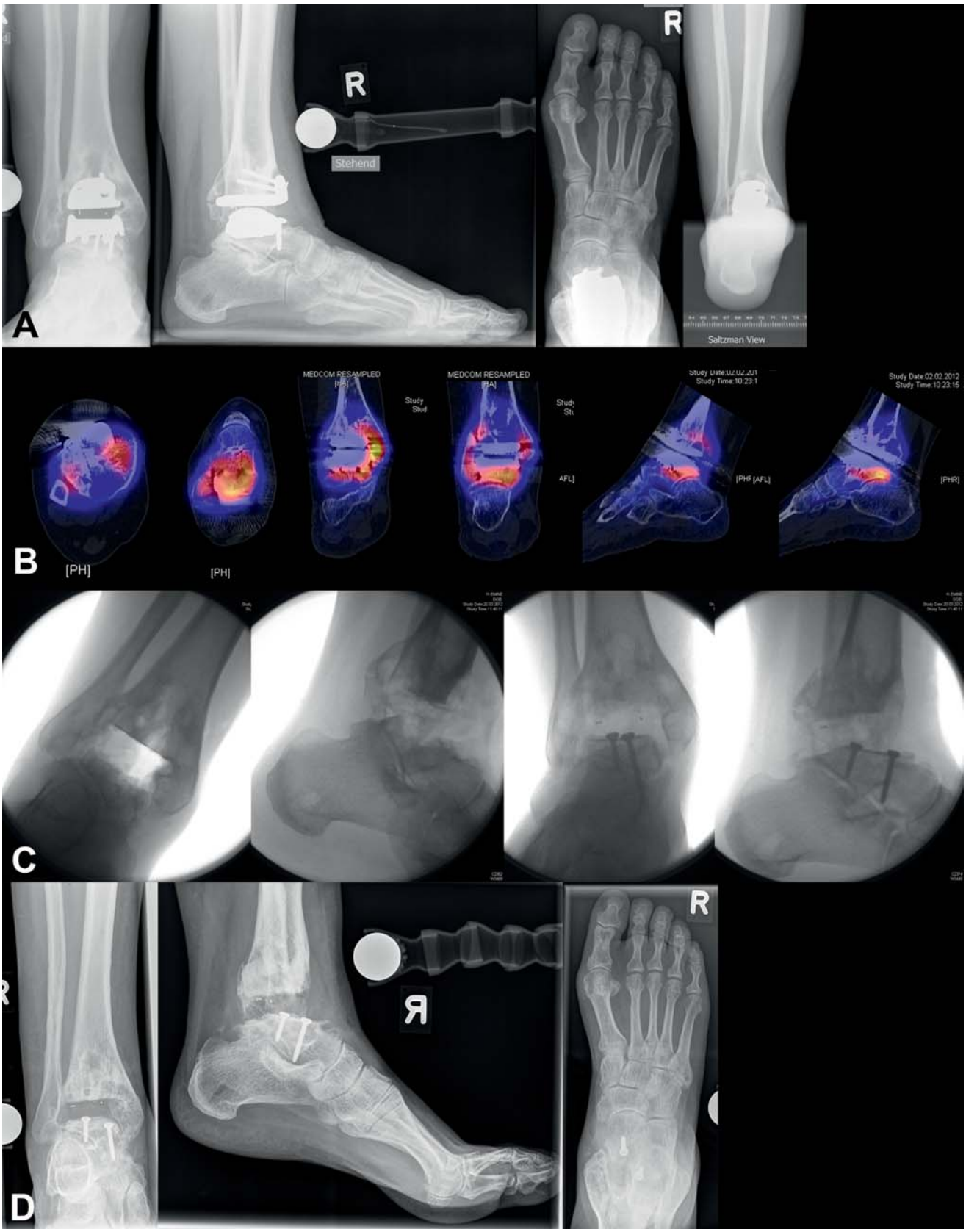
| Study | Study type | Implant type | No. of implants | Probability of survival of implant components | Mean follow-up time | Postoperative range of motion |
|---|---|---|---|---|---|---|
| (e71) | RS, SC | Buechel–Pappas | 35 | 97% after 5 years | 5 years (3 to 150 months) | N/A |
| (e72) | RS, SC | Agility | 207 | 76% after 9 years | N/A | N/A |
| (e73) | RS, SC | AES | 93 | 90% after 5 years | 42 months (13 to 73 months) | N/A |
| (e6) | RS, SC | STAR | 51 | 70% after 5 years | 52 months (36 to 97 months) | Total 28° (10 to 55°) |
| (22) | RS, SC | HINTEGRA | 123 | 93% after 6 years | 67.7 ± 27.0 months (29 to 126 months) | Total 35.3°± 8.1° |
| (e34) | PS, SC | HINTEGRA | 52 | 91% after 5 years, 78% after 8 years | 5 years (2 to 10 years) | Total 38°± 9° |
| (6) | PS, SC | HINTEGRA | 722 | 94% after 5 years, 84% after 10 years | 6.3 ± 2.9 years (2 to 12.2 years) | N/A |
| (e74) | RS, MC | Salto (388), AES (173), HINTEGRA (22), STAR (9) | 592 | 88% after 71 months | Min. 1 year | N/A |
| (e75) | PS, SC | BOX | 62 | 91.9% after 42.5 months | 42.5 months (24 to 71 months) | DF 8.4° ± 4.8° (0 to 20°); PF 17.1° ± 8.3° (0 to 30°) |
| (e76) | RS, SC | Salto | 98 | 98% after 5 years | 35 months (24 to 68 months) | Total 28.3° ± 7° |
| (e77) | RS, SC | Salto | 98 | 85% after 10 years | 8.9 years (6.8 to 11 years) | DF 8.6° ± 5.3° (−5 to 20°); PF 18.1° ± 7.8° (5 to 40°) |
| (e78) | PS, SC | STAR | 77 | 70.7 after 10 years, 45.6% after 14 years | 12.4 years (10.8 to 14.9 years) | Total 22.8°±3.5° |
| (e8) | PS, SC | Buechel–Pappas | 50 | 93.5% after 10 years | 5 years (2 to 10 years) | Total 28° (12 to 46°) |
| (e79) | PS, SC | Buechel–Pappas (normal sulcus 40; deep sulcus 75) | 115 | 74.2% (normal sulcus) after 20 years, 92% (deep Sulkus) after 12 years | 12 years (2 to 10 years, normal sulcus), 5 years (2 to 12 years, deep sulcus) | Total 25° (10 to 47°, normal sulcus), total 29° (10 to 50°, deep sulcus) |
| (e80) | PS, SC | BOX | 20 | N/A | 12 months (7 to 14 months) | Total 28.8° ± 11.3° (10 to 50°) |
| (e81) | RS, SC | Agility | 42 | 62% after 9 years | 8 years (0.5 to 11 years) | |
| (e82) | RS, SC | Buechel–Pappas | 30 | 87.6% after 5 years | 5.1 ± 4 years (1 to 13 years) | DF 5°; PF 30° |
| (e83) | PS, SC | LCS (19), Buechel–Pappas (74) | 93 | 84% after 8 years | 7.2 years (0.4 to 16.3 years) | DF 7.1° (5.8 to 8.4°); PF 24.8° (22.6 to 27.2°) |
| (e9) | PS, MC | STAR (216), TPR (32), HINTEGRA (6), AES (3) | 257 | 89% after 5 years, 76% after 10 years | 4 years (5 days to 12 years) | N/A |
| (e84) | PS, MC | BOX | 51 | 97.2% after 3 years | 30 months (24 to 48 months) | Total 27.4° (16 to 53°) |
| (e85) | PS, MC | BOX | 158 | 96.1% after 4 years | 17 months (6 to 48 months) | Total 26.5° (14 to 53°) |
| (e86) | PS, MC | STAR (318), Buechel–Pappas (92), AES (69), HINTEGRA (29), Mobility (23) | 531 | 78% after 5 years, 62% after 10 years | 1 to 11 years | N/A |

| Study | Study type | Implant type | No. of implants | Probability of survival of implant components | Mean follow-up time | Postoperative range of motion |
|---|---|---|---|---|---|---|
| (e87) | PS, MC | STAR (322), Mobility (132), AES (115), Buechel–Pappas (109), CCI (66), HINTEGRA (36) | 780 | 81% after 5 years, 69% after 10 years | 10 years | N/A |
| (e11) | RS, SC | STAR | 123 | 86% (patients with preoperative deformity up to 10°) and 75% (patients with preoperative deformity 10 to 30°) after 5 years | 4 years (2 to 8 years) | N/A |
| (e88) | PS, MC | Agility (117), STAR (45), Mobility (29), Ramses (11) | 202 | 86% after 5 years | 28 to 75 months | N/A |
| (e12) | RS, SC | Agility | 65 | 91% after 1 year, 70% after 3 years, 67% after 5 years | 3.3 years (2 to 5.9 years) | N/A |
| (e89) | RS, SC | TPR | 33 | 85% after 10 years | 10 to 23 years | N/A |
| (e13) | RS, SC | STAR | 52 | 90% after 5 years, 84% after 8 years | 80 months (60 to 110 months) | Total 23° ± 12° (0 to 55°) |
| (e90) | RS, SC | Mayo | 204 | 79% after 5 years, 65% after 10 years, 61% after 15 years | 9 years (2 to 17 years) | k. A. |
| (e14) | RS, SC | Agility | 132 | 86% after 9 years, 63% after 11 years | 9 years | DF 0° (−24 to 16°); PF 19° (−1 to 36°) |
| (e58) | PS, SC | STAR | 28 | 70% after 12 years | 1 to 12 years | N/A |
| (e91) | PS, SC | STAR | 52 | 72.7% (primary osteoarthritis) and 75.5% (rheumatoid arthritis) after 14 years | 9 years (6 to 14 years) | N/A |
| (e92) | PS, SC | STAR | 100 | 85.7% (patients under 50) and 91.6% (patients over 50) after 5 years, 75% (patients under 50) and 80.6% (patients over 50) after 10 years | 6.8 years (1 to 15 years) | N/A |
| (e93) | PS, SC | STAR (33 cemented, 25 uncemented) | 58 | 70% (cemented) and 95.4% (uncemented) after 12 years | 9.4 ± 2.7 years | N/A |
| (e94) | PS, SC | AES | 38 | 79% after 2 years | 28 months (2 to 70 months) | N/A |
| (e95) | PS, SC | LCS (19), Buechel–Pappas (74) | 93 | 80% after 15 years | 14.8 years (10.7 to 22.8 years) | N/A |
| (e96) | PS, MC | BOX | 189 | 97% after 4 years | 21 months | Total 14 to 53° |
| (e16) | PS, SC | INBONE (211), STAR (122), Salto-Talaris (71) | 404 | 90% and 97.6% after 3.2 years with and without arthrodesis of the hindfoot | 3.2 years (2 to 6 years) | N/A |
| (e17) | PS, SC | STAR | 84 | 96% after 5 years, 90% after 10 years | 9.1 years (2.6 to 11 years) | DF 4.5°; PF 34.7° |
| (e97) | RS, SC | AES | 38 | 94.7% after 6 years | 57.8 months (48 to 80 months) | N/A |
| (e98) | RS, SC | TNK | 27 | 77% after 14.1 years | 72 months (15 to 169 months) | DF 7.5° (0 to 20°); PF 8.5° (−10 to 20°) |
| (e99) | RS, SC | Salto | 75 | 98% after 3.6 years | 43 months (27 to 73 months) | DF 8.7° ± 5.6°; PF 29° ± 7° |
| (21) | RS, MC | Salto (91), HINTEGRA (39), AES (20), Coppelia (17), STAR (11), Ramses (4), Akile (1) | 183 | 86% (high-volume sites 88.4%; low-volume sites 84.9%) after 5 years | 39 ± 29 months (6 to 132 months) | N/A |

| Study | Study type | Implant type | No. of implants | Probability of survival of implant components | Mean follow-up time | Postoperative range of motion |
|---|---|---|---|---|---|---|
| (e100) | RS, MC | STAR | 59 | 88% after 3 years | 36 months (12 to 65 months) | DF 10.2° ± 6.3°; PF 11.3° ± 7.9° |
| (e22) | PS, SC | Mobility | 240 | 97.7% after 4 years | 32.8 ± 15.3 months (12 to 63 months) | DF 8.3° ± 5.3°; PF 13.6° ± 6.4° |
| (e101) | RS, SC | Buechel–Pappas | 28 | 93% after 8.3 years | 8.3 years (5 to 12.2 years) | Total 23° (8 to 40°) |
| (e102) | RS, SC | Salto | 401 | 86.6% (all patients), 85.1% (posttraumatic osteoarthritis), 95.6% (rheumatoid arthritis), 87.9% (patients under 55) after 5 years | 29 months (1 to 84 months) | Total 33.1° ± 13.6° |
| (e103) | PS, SC | TPR (20), STAR (19) | 39 | 87% (TPR) after 12 years, 94.3% (STAR) after 6 years | 8.6 years (TPR: 3 to 13 years), 3.1 years (STAR: 1 to 6 years) | Total (TPR) 37°. Total (STAR) 33.5° |
| (e104) | PS, SC | Salto Talaris | 75 | 96% after 2.8 years | 2.8 years (2 to 4.5 years) | N/A |
| (e25) | PS, MC | AES (298), STAR (217) | 515 | 83% after 5 years | 3.2 years (0.1 to 9.6 years) | N/A |
| (e26) | RS, SC | Agility | 306 | 80% (89% in patients over 54) after 5 years | 33 ± 18 months (4 to 75 months) | N/A |
| (e105) | PS, MC | Mobility | 88 | 89.6% after 3 years, 88.4% after 4 years | 40 months (30 to 60 months) | N/A |
| (e106) | RS, SC | Mobility | 58 | 84% after 4 years | 32 months (14 to 49 months) | N/A |
| (e107) | RS, SC | AES (16), Salto (4), New-Jersey (1) | 21 | 91% after 3 years, 57% after 5 years | 38 ± 26 months | N/A |
| (e108) | PS, SC | STAR | 200 | 92.7% after 5 years | 46 months (24 to 101 months) | N/A |
| (e109) | RS, MC | Salto | 109 | 97.5% after 2 years | 21.7 months (12 to 65 months) | Total 32° |
| (e110) | RS, SC | HINTEGRA | 16 | 66.7% after 5 years | 61.8 months (7 to 116 months) | Total 23.7° (12.0 to 47.5°) |
| (e111) | PS, SC | STAR | 200 | 93.3% after 5 years, 80.3% after 10 years | 88 months (60 to 156 months) | N/A |
| (e112) | PS, SC | Buechel–Pappas (100), STAR (100) | 200 | 79% (Buechel–Pappas) and 95% (STAR) after 6 years | Min. 36 months | N/A |
| (e30) | PS, SC | Mobility | 100 | 97% after 3 years, 93.6% after 4 years | 43 months (4 to 63 months) | DF 7.5° (−5 to 22°), PF 14° (1 to 41°) |

*All available clinical studies (total ankle replacement) were included.
AES: Ankle Evolutive System; BOX: Bologna–Oxford; DF: dorsiflexion; N/A: information not available; LCS: low-contact stress; MC: multicenter; PF: plantar flexion; PS: prospective; RS: retrospective; STAR: Scandinavian Total Ankle Replacement; TPR: Thomson, Prichard and Richard; SC: single-center

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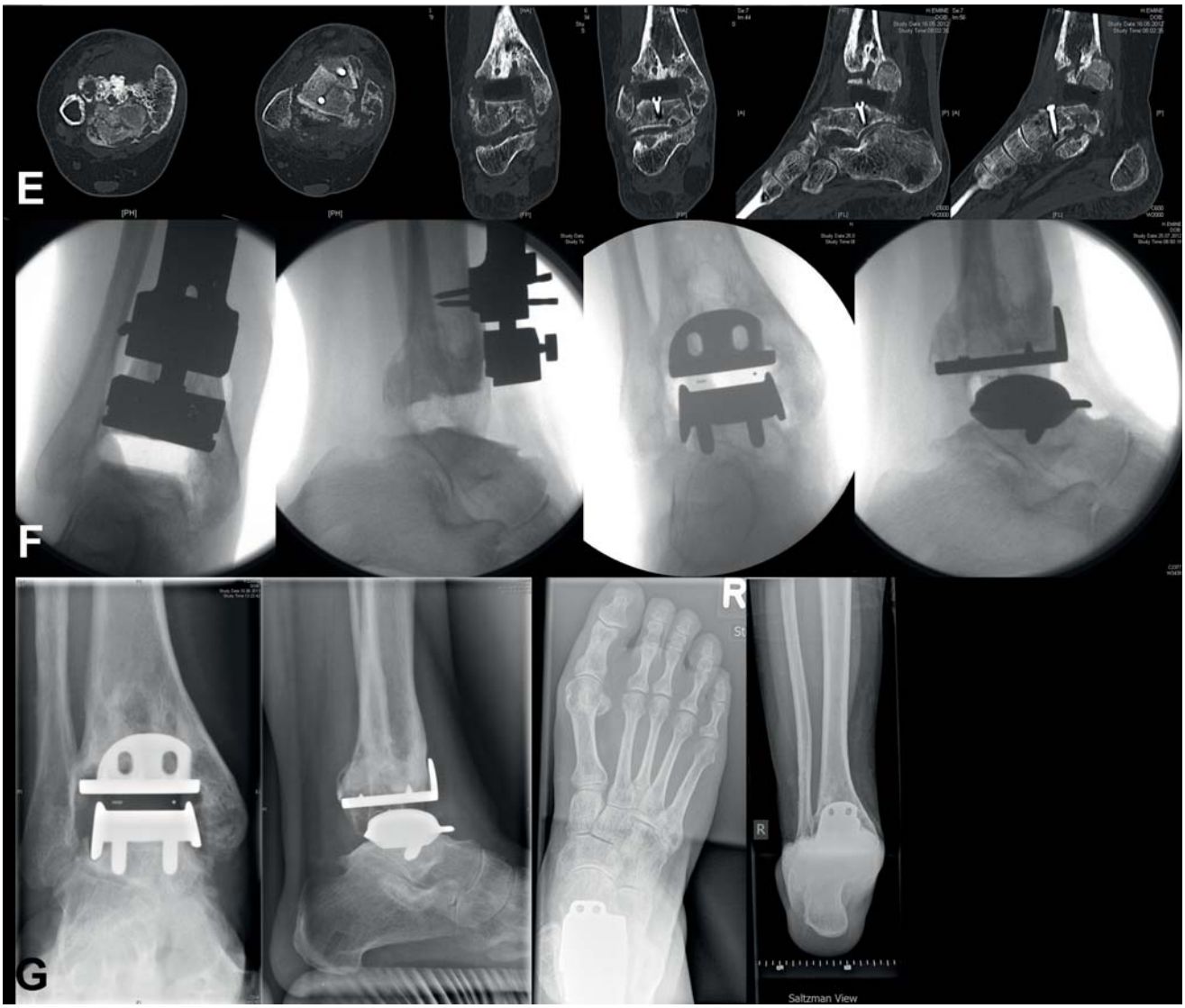
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