Mobile-bearing total ankle arthroplasty: A fundamental assessment of the clinical, radiographic and functional outcomes

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Chapter 11

Overview of Currently Available Prosthetic Designs and A Review of the Clinical and Radiographic Outcome of Total Ankle Arthroplasty

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11.1 Current Designs of Total Ankle Prostheses

Most designs currently in use throughout the world for TAA are 3-component mobile-bearing designs. Exceptions are: the semi-constrained Agility (DePuy, Warsaw, Indiana, USA) total ankle prosthesis, mainly used in the USA[1]; the ESKA prosthesis, used on a limited scale in Germany[2]; and the TNK ankle prosthesis, used in Japan[3]. Of these 2-component designs, the Agility prosthesis is currently most widely used. Its upper component is designed to obtain support from both the distal tibia and fibula. Consequently, it requires an osseous fusion of the distal tibiofibular syndesmosis. This makes this design different from all other designs, and, from the surgical point of view, somewhat more difficult. In Europe, 2-component prostheses have almost disappeared from the market, and here currently mobile-bearing prostheses are used almost exclusively.

The mobile-bearing design is characterized by the use of a mobile polyethylene bearing in between the tibial and talar component. The major advantage of this concept is the reduction of shear and rotational forces at the bone-prosthesis interface. As a consequence, mechanical stresses on the implant are mostly compressive in nature, and therefore more physiological. Thus, the mobile-bearing concept appears to have biomechanical benefits for the endoprosthetic replacement of the arthritic ankle. This design rationale has proven to be successful in the endoprosthetic replacement of the knee as well[4,5,6]. However, in the knee joint, comparative clinical studies between fixed-bearing and mobile-bearing designs have failed to show superior clinical results with mobile-bearing over fixed-bearing designs[7,8]. In the ankle, no clinical studies comparing fixed-bearing and mobile-bearing have been carried out, although some cadaver and in-vivo studies investigating the kinematics of the replaced ankle exist. Michelson et al[9] in a cadaver experiment found no significant kinematic differences changes between the normal ankle and the ankle replaced by the fixed-bearing Irvine prosthesis (a 2-component spherical design). In contrast to this, Valderrabano et al[10,11,12], in cadaver experiments, showed a better kinematic behavior of two mobile-bearing prostheses: STAR (Waldemar Link, Hamburg, Germany) and Hintegra (NewDeal, Lyon, France), than with the semi-constrained fixed-bearing Agility prosthesis. Surgical advantages of 3-component mobile-bearing prostheses over 2-component designs are that: 1) adequate stability of the replaced ankle can be obtained by the use of a bearing of appropriate thickness; and that 2) in the event of wear or instability, a bearing exchange can easily be done. However, potential disadvantages of mobile-bearing prostheses are: 1) the risk of bearing subluxation or dislocation; and 2) the risk of impingement of the bearing with either flanges on the metallic components or with the malleoli. Impingement could give rise to symptomatic arthritis, accelerated wear and osteolysis.

All current ankle prostheses are designed for implantation without bone cement. A porous microstructure is applied to the osseous surface of most implants, often combined with a hydroxyapatite or similar calcium phosphate coating, in order to enhance the osseointegration process. Mobile-bearing prostheses can be classified in two main categories: symmetrical and asymmetrical. Symmetrical implants have no left-right version. Asymmetrical implants do have a left and right version, in most designs limited to the talar component. Concerning the fixation of the tibial component, there are several options: a stem or small fin(s), pegs or screws. In the past, stemmed tibial components were designed to be implanted with an anterior slope of the articulating surface of between five and seven degrees. Examples are: LCS (DePuy, Warsaw, Indiana, USA; its successor the Buechel-Pappas (Endotec, South Orange, New Jersey, USA); Salto (Tornier, Saint-Ismier, France); and the AES (Biomet, Valence, France) prosthesis. The philosophy behind this anterior slope is two-fold: a more anatomical bone resection and a better dorsiflexion. However, both claims remain to be proven. Newly designed stemmed tibial components have a stem that makes a 90 degree angle to the base plate. Examples are: Mobility (DePuy, Leeds, UK) and Zenith (Corin, Cirencester, UK). The articulating surface of the tibial component is mostly flat. The tibial component of the Salto prosthesis has a small flange to prevent contact of the bearing with the medial malleolus. A novel design, the BOX prosthesis (Finsbury, Leatherhead, UK), has a convex spherical articulating surface of the tibial component, in order to give a better mobility compared to flat-surface designs in both the sagittal and the frontal plane[13]. The talar component can be without (true tibiotalar replacement) or with articulating flanges for the malleoli (mostly hemiarthroplasty of the talarmalleolar joints) and can have a symmetrical curvature (examples: Buechel-Pappas, STAR, AES, Mobility, CCI (VanStratenMedical, Nieuwegein, Netherlands), Taric (Implantcast, Buxtehude, Germany), Zenith or an anatomical configuration with a smaller curvature medially compared to laterally (examples: Salto and Hintegra). Furthermore, the talar component can have either a cylindrical or a trochlear shape of the articulating surface. Most polyethylene bearings are fully congruent with both the tibial and talar component. Such a full-contact bearing will reduce the stresses on the polyethylene, thereby improving their wear characteristics, as has been shown by the endoprosthetic mobile-bearing replacement of the knee[14,15,16]. The bearing of the Salto prosthesis has purposely a slight incongruency, thereby allowing for some inversion-eversion motion, in order to compensate for a loss of motion of the hindfoot. However, it appears to be questionable if this concept is advantageous and, on the contrary, does not have other disadvantages such as accelerated wear.

11.2 Review of the Clinical and Radiographic Outcome of Total Ankle Arthroplasty

11.2.1 Clinical Outcome

A substantial number of reports on the clinical and radiographic outcome of TAA have been published in the last decade. Giannini et al[17] gave a historic overview of all designs that had been developed from the early 1970s until 2000. Feldman and Rockwood[18] gave an overview of 11 currently used fixed and mobile-bearing designs. Recently, Stengel et al[19] gave a literature review on the outcome of three mobile-bearing designs and of the fixed-bearing ESKA prosthesis. They found an increase in ankle score of 45.2 points. As recently new literature on the outcome of TAA has become available, and also to complete the above mentioned outcome reviews, an update of the outcome studies of currently used 2 and 3-component designs is presented. With the exception of the TNK ankle, only results with uncemented prostheses are reported.

Plantarflexion-dorsiflexion of normal ankles, as measured clinically (thus a combined motion of the ankle and hindfoot), varies from 50 to 70 degrees. Level walking, ascending and descending stairs require respectively 24 to 30, 37 and 56 degrees of range of motion. Range of motion during normal gait varies, depending on the method of measuring[20]. In the studies mentioned in Table 1, an increase in range of motion of between 3 to 13 degrees after TAA was found. Mean clinically measured range of motion at follow-up ranged from 23 to 41 degrees, clearly less than the motion of the healthy ankle joint. This range of motion at follow-up is sufficient for level walking, but not for descending stairs in a normal manner. Motion as measured clinically is larger than as measured radiographically, due to soft tissue deformation and motion in adjacent joints.[21] This was indeed observed in some of the studies reported.

Seven different scoring systems have been used in the studies referred to in Table 1: the Evanski[41], Mazur[42], LCS[43], AOFAS[44], Kofoed[45], the Ankle Osteoarthritis Scale (AOS)[46] and the almost similar Foot Function Index (FFI)[47], the latter two being the only self-reporting patient-assessment instruments. Except for the AOS and the FFI, the reliability and validity of the five scoring systems, quantifying subjective (pain) and objective (function, range of motion, etc) parameters has not been established. No gross differences have been observed between the five non-validated systems[48]. The clinical scores of these studies are summarized in Table 1.

TABLE 1 Overview of scores preoperative and at latest follow-up in individual studies

Fixed-bearing Designs*	n (n FU)	Mean FU (yrs)	Mean Clinical score Preoperative	At FU	*p*	Scoring system
Agility[22]	132 (68)*,†	9	--	2.02 PS 3.36 DS	-	AOS
Agility[23]	43 (40)*,†	3.7	33.6	83.3	<.001	AOFAS
TNK[3]	70 (61)*,†	5.2	46.7	80.6	N.D.	Mazur
TNK[24]	21 (21)	2.8	52.0	74.1	<.05	Evanski
ESKA	159 102)*,†,‡	<15	34.3	94.5§	N.D.	Kofoed
Mobile-bearing Designs*						
BP[26]	15 (15)	2	22	80	<.001	AOFAS
BP[27]	31 (28)*,†	8.3	-	81	-	AOFAS
BP[28]	19 (19)	4.4	-	79	-	AOFAS
LCS/BP[29]	93 (57)†	8	36.1 26.5 26.9	83.3 77.0 75.7	<.05	LCS AOFAS Kofoed
STAR[30]	51 (39)†	4.3	39 -	70 74	<.0001	Kofoed AOFAS
STAR[31]	58 (48)†,||	3.1	-	81		AOFAS
STAR[32]	25 (25)	9.5	30	91.9	N.D.	Kofoed
STAR[33]	22 (20)†	2.2	-	75	-	Kofoed
STAR[34]	27 (26)*	1.3	35.4	74.8	N.D.	Kofoed
STAR[35]	22 (19)*	3.1	44.7	86.9	N.D.	Kofoed
STAR[36]	74 (68)*	3.7	24.7	84.3	<.05	AOFAS
STAR[37]	200 (182)†	3.8	28	70¶	N.D.	AOFAS
STAR[38]	49 (45)	2.3	- 59	68 35	<.001	Kofoed FFI
SALTO[39]	98 (93)*,†	2.9	32.3	83.1	<.005	AOFAS
HINTEGRA[40]	278 (271)*	2.8	40.3	85	N.D.	AOFAS

*: referred study; n: total number of ankles in study; n FU: number of ankles evaluated clinically at follow-up; Mean FU (yrs): mean follow-up duration in years; p: level of significance; PS: pain subscale; DS: disability subscale; N.D.: not described; LCS = Low Contact Stress; AOFAS = American Orthopaedic Foot and Ankle Society; AOS = Ankle Osteoarthritis Scale; FFI = Foot Function Index.

Details of some studies: * Some subjects lost-to-follow-up. † Revised prostheses excluded from analysis. ‡ Subjects with follow-up shorter than 10 months excluded. § Score at minimum 5-year follow-up. || Subjects with follow-up shorter than 1 year excluded, 1 subject with deep infection excluded. ¶ Score at 2-year follow-up.

All evaluated studies recording preoperative clinical scores report an increase at latest follow-up. Mean preoperative scores between the studies varied between 22 and 52 points. These differences might be attributable to differences in patient selection. Mean scores at follow-up varied between 70 and 94.5 points. The mean increase in score (weighted to sample size) of the 2-component prostheses is 47.6 points (121%, 39.2 points preoperative to 86.8 points at follow-up; n = 224). The mean increase in score (weighted to sample size) of the 3-component prostheses was 46.4 points (138% increase, from 33.4 points preoperative to 79.8 points at follow-up; n = 795). Clinical scores improved significantly after implantation of both 2 and 3-component total ankle prostheses. With regard to clinical score, 2 and 3-component prostheses showed similar results.

The following intraoperative and early postoperative complications have been reported to either influence the outcome of TAA or to necessitate a secondary intervention: malleolar and distal tibial fracture, persistent instability, persistent deformity, skin necrosis, delayed wound healing, deep infection, heterotopic ossification, persistent pain due to talarmalleolar arthritis, and, for the Agility prosthesis: nonunion of the distal tibiofibular synostosis.

11.2.2 Implant Survival

Adequate survival data with the end point defined as removal or replacement of components, conversion to ankle arthrodesis or below-the-knee amputation, and with a mean follow-up of five years or more are available from only a few of the studies referred to in Table 1. In a retrospective study, Knecht et al[22] reported an 8-year survival rate with the Agility prosthesis of 0.91 (95% CI: 0.84-0.96). The study population consisted of patients with posttraumatic arthritis, primary osteoarthritis and rheumatoid arthritis. All ankles had been operated by the designer of the prosthesis. San Giovanni et al[27] reported an 8-year survival rate with the Buechel-Pappas prosthesis of 0.93 (95% CI: 0.82-1) in a retrospective study of patients with the diagnosis of rheumatoid arthritis. In a prospective study with the LCS and Buechel-Pappas prosthesis combined, Doets et al[29] reported an 8-year survival rate of 0.84 (95% CI: 0.73-0.93) in a patient population with inflammatory joint disease (mainly rheumatoid arthritis). A better survival rate was found in ankles with a neutral alignment preoperatively and in ankles were a tibial component of correct size had been implanted. Kofoed[32] reported a 12-year survival rate with uncemented version of the STAR prosthesis of 0.94 (95% CI: 0.91-1) in a population mainly having osteoarthritis.

Stengel et al[19], in a meta-analysis of six studies, found a mean overall 5-year survival rate of 90.6 (95% CI: 84.1-97.1). Recently, reports from national arthroplasty registers have been published. Henricson et al[49] reported the results with six mobile-bearing designs from the Swedish Ankle Arthroplasty Register implanted between 1993 and 2005. They found a mean overall 5-year survival rate of 0.78 (95% CI: 0.74-0.82). The STAR prosthesis was used most frequently, but its number had decreased significantly in recent years. Aseptic loosening was the most frequent mode of failure, followed by technical errors (implant malposition) and infection. Better results were achieved by experienced surgeons who performed substantial numbers of arthroplasties. Fevang et al[50] reported the results with four designs implanted between 1994 and 2005 from the Norwegian Arthroplasty Register. They found a mean overall 5-year survival rate of 0.89 (95% CI: 0.84-0.93). Also in Norway the STAR prosthesis was the implant used most widely, followed by the 2-component TPR prosthesis. The TPR prosthesis was only used early in the study period, and almost exclusively in patients with inflammatory joint disease. Failure as a result of aseptic loosening of the STAR prosthesis occurred more frequently with the single-coated version (hydroxyapatite) than with the double-coated version (calcium phosphate coating on porous titanium). No other risk factor for failure could be identified. Hosman et al[51] reported the results with four designs from the New Zealand National Joint Registry implanted between 2000 and 2005. They found a mean overall 5-year survival rate of 0.86 (95% CI: 0.78-0.94). The 2-component Agility prosthesis was used most widely in New Zealand, followed by STAR prosthesis. Again, aseptic loosening was the most frequent mode of failure. In their series, patients with an inferior ankle score at six months postoperatively had an increased failure rate.

11.2.3 Radiographic Outcome

Comparison of radiographic loosening and/or migration of the prosthetic components between the studies of this review is difficult due to the fact that non-uniform criteria were used. Furthermore, almost half of the studies did not provide clear criteria for classification of components as being loose or having migrated. Table 2 summarizes the percentage of reported radiographic loosening or migration of the prosthetic components. With a relative short follow-up sometimes high percentages of loose prostheses were observed and there were differences in incidence of loosening with same designs. Partial radiolucent lines at the bone-prosthesis interface, which might indicate future failure, are not included in this overview. They were reported with an incidence ranging from 0 to 85 per cent in the studies referred to. It is surprising to note the difference of radiographically loose STAR-components (3.5% to 29.3%), reported in three studies with similar follow-up (3.6, 3.8 and 4.3 years), with use of the same criteria to assess subsidence and tilting[30,31,37]. Wood and Deakin[37] suggested that the difference in coating before and after 1999 could explain this difference in radiographic outcome, while Carlsson[31] suggested that the main factor probably was the surgical learning curve.

TABLE 2 Radiographic signs of loosening or migration of prosthetic components at follow-up in individual studies

Fixed-bearing Designs*	n (X-FU)	Mean FU (yrs)	Aseptic loosening at FU % (n)	Failed component
Agility[22]	132 (117)*	7.2†	4.2% (5) 7.6% (9) 1.7% (2) 13.6% (16)	Tibial component Talar component Tibial + talar component TOTAL
Agility[23]	43 (40)‡,§	3.7	15% (6) 27.5% (11) 2.5% (1) 45% (18)	Tibial component Talar component Tibial + talar component TOTAL
Agility[53]	306 (85)||	2.7	34.1% (29)	Tibial and/or talar component
TNK[3]	70 (68)§	5.2	11.8% (8) 22.0% (15) 33.8% (23)	Tibial component Talar component TOTAL
Mobile-bearing Designs*				
BP[53]	75 (75)	5	4.0% (3)	Talar component
BP[27]	31 (28)‡,§	8.3	17.9% (5) 14.2% (4) 32.1% (9)	Tibial component Talar component TOTAL
BP[28]	19 (19)	4.4	10.5% (2)	Tibial component
LCS/BP[29]	93 (78)‡	7.2	9.0% (7) 7.6% (6) 16.6% (13)	Tibial component Talar component TOTAL
STAR[30]	51 (51)	4.3	7.8% (4) 13.7% (7) 7.8% (4) 29.3% (15)	Tibial component Talar component Tibial + talar component TOTAL
STAR[31]	58 (52)**	3.6	5.7% (3)	Tibial component
STAR[32]	25 (25)	9.5	4.0% (1)	Tibial component
STAR[33]	22 (22)	2.2	4.5% (1)	Tibial component
STAR[34]	27 (26)§	1.3	3.8% (1)	Talar component
STAR[35]	22 (19)§	3.1	0% (0)	Tibial and/or talar component
STAR[36]	74 (68)§,††	3.7	13.2% (9) 1.4% (1) 14.6% (10)	Tibial component Talar component TOTAL
STAR[37]	200 (200)	3.8	4.0% (8) 0.5% (1) 4.5% (9)	Tibial component Talar component TOTAL
STAR[38]	49 (45)	2.3	4% (2)	Tibial component
SALTO[39]	98 (95)§	2.9	1.0% (1)	Talar component
HINTEGRA[40]	278 (266)‡‡	2.8	0.8% (2) 6.0% (16) 6.8% (18)	Tibial component Talar component TOTAL

*: referred study; n: number of ankles in study; X-FU: number of ankles evaluated radiographically; Mean FU (yrs): mean follow-up duration in years; (n): number of components with signs of loosening.

Details of some studies: * Only ankles with a minimum of 2 years of follow-up. † Mean radiographic follow-up. ‡ Revised prostheses excluded from analysis. § Some subjects lost-to-follow-up. || Only information of reoperated ankles presented. ** Subjects with very short follow-up excluded, 1 subject with deep infection excluded. †† 2 revision arthroplasties (other prosthesis previously implanted) excluded. ‡‡ 5 prostheses revised to arthrodeses excluded.

11.2.4 Radiostereometric Analysis

Radiostereometric analysis (RSA) is a highly accurate technique for measuring micromotion, and an important tool for the assessment of implants[54]. So far, two studies have reported the results of RSA after TAA. Carlsson et al[55] carried out a RSA study with the tibial and talar components of the STAR prosthesis in 10 patients, 5 with a diagnosis of rheumatoid arthritis and 5 with osteoarthritis. Patients were followed for 4 (3-5) years. There was no difference in results between ankles operated on for rheumatoid arthritis or for osteoarthritis. A rapid initial migration was observed for the tibial component at 6 weeks, thereafter all but 1 implant seemed stable. The migration pattern for the talar component was similar. Rotation around the 3 axes was observed for the tibial component at 6 weeks, but not thereafter. The talar component became rapidly stable for rotation around the longitudinal and sagittal axes, but stable fixation around the transverse axis was not always observed. Nelissen et al[26] carried out a RSA study of the stability of the tibial component of the Buechel-Pappas prosthesis in patients with RA. Twelve completed a 1-year and eight a 2-year follow-up. An initial migration was observed during the first 3 months, but the component stabilized at 6-month. Mean lateral-medial migration was 0.8 mm, distal-proximal migration was 0.9 mm, and posteroanterior migration was −0.5 mm. This implies that total resultant migration was a proximal, anterior and valgus tilting of the tibial component. Both studies show that uncemented ankle prostheses can safely be used, and that implant fixation also occurs in the softer rheumatoid bone. No RSA studies have been carried out with 2-component ankle designs. By analogy with the study by Garling et al[56] on micromotion of fixed and mobile-bearing total knee replacements, it can be hypothesized that there is less variability in micromotion with mobile-bearing ankle designs.

11.3 Discussion

Due to their favorable biomechanical characteristics and their surgical advantages, 3-component mobile-bearing prostheses appear to be the most suitable concept for the endoprosthetic replacement of the arthritic ankle. A specific disadvantages of mobile-bearing designs is the risk of bearing subluxation. The incidence of this complication should be reduced by a good patient selection and by proper surgical technique. When comparing the characteristics of the specific designs, until now, no implant can claim that it will perform better than its competitors, and furthermore, randomized clinical studies comparing the outcome of different designs have not been done. However, from a clinical point of view, a deep-sulcus trochlear design of the talar component might have certain advantages, such as a reduced risk of bearing subluxation and also, as the result of the greater thickness of the polyethylene bearing, a reduced risk of fracture and wear of the bearing.

Range of motion of the replaced ankle does not fully normalize. In general, postoperative range of motion will be sufficient for level walking, but certain activities such as stair climbing and descending might still remain compromised. Ankle scores at follow-up show a significant gain compared to the preoperative level, indicating that functional results of TAA are relatively good. Sufficient long-term data of mobile-bearing TAA are still lacking, as only a few studies have a mean follow-up of more than five years. Survival data from the referred clinical studies and from the arthroplasty registers show that an eight-year survival rate of about 90 per cent can be expected with use of mobile-bearing designs and implanted by experienced surgeons. However, overall survival after TAA is somewhat inferior to the survival of total knee and total hip arthroplasty. For example, Robertson et al[57], in a study from the Swedish Knee Arthroplasty Register, found an 8-year survival rate of primary total knee arthroplasty of about 95 percent. A study from the Norwegian Arthroplasty Register showed a 9-year survival rate of around 95 per cent with the cemented Charnley and Exeter total hip prosthesis[58]. And Garrellick et al[59], in a prospective randomized study of two cemented hip prosthesis, found an 11-year survival rate of 96 respectively 93 percent. They also showed, that data from specialized centers tend to be better than data with the same implants from a national register.

Aseptic loosening remains the most important mode of failure of TAA. Radiographic loosening of the metallic components is a secondary end point of failure, and with time will usually lead to revision surgery. Current semiconstrained fixed-bearing designs show a relatively high incidence of component loosening at intermediate term follow-up, whereas most studies with mobile-bearing designs show a lower incidence of loosening. Furthermore, it is encouraging that with improved coating characteristics better osseointegration has been demonstrated[37]. Radiostereometric analysis has demonstrated an early migration of both the tibial[55,26] and talar component[55]. The migration pattern of the tibial component was a tilt in an anterior direction, the talar component sometimes lacked stable fixation around a transverse axis. In general, this migration stabilized at 3 to 6 months after surgery.

Stengel et al[19] concluded from their meta-analysis that TAA with use of a mobile-bearing implant provides an acceptable benefit-risk ratio. Haddad et al[60] carried out a comparative meta-analysis on the outcome of ankle arthrodesis and of currently used ankle prostheses. The main reason for failure after arthrodesis was nonunion, and after arthroplasty it was aseptic loosening. They concluded that the intermediate outcome of TAA appears to be similar to that of ankle arthrodesis, although they also noted that there was a higher risk of below-knee amputation after arthrodesis compared with arthroplasty: 5 versus 1 percent. SooHoo and Kominski[61], in a cost-effectiveness analysis, showed that TAA has the potential to become a cost-effective alternative to ankle fusion. Both Stengel et al[19] and Haddad et al[60] stated that randomized studies comparing ankle arthrodesis with arthroplasty are needed.

In summary, at intermediate term follow-up, TAA with use of a mobile-bearing design has a relatively good clinical outcome, equal to or better than ankle arthrodesis. Currently, the survival rate of this procedure is still lower than that of total hip or total knee arthroplasty. However, it has the potential to become a reliable treatment option for the arthritic ankle, and the more so if carried out by an experienced surgeon and after proper patient selection.

References

1. Alvine FG. The Agility ankle replacement: the good and the bad. Foot Ankle Clin. 2002;7:737-53.
2. Rudigier J, Grundei H, Menzinger F. Prosthetic Replacement of the ankle in posttraumatic arthrosis. European J Trauma. 2001;2:66-74.
3. Takakura Y, Tanaka Y, Kumai T, Sugimoto K, Ohgushi H. Ankle arthroplasty using three generations of metal and ceramic prostheses. Clin Orthop Relat Res. 2004;424:130-6.
4. Callaghan JJ, Squire MW, Goetz DD, Sullivan PM, Johnston RC. Cemented rotating-platform total knee replacement. A nine to twelve-year follow-up study. J Bone Joint Surg Am. 2000;82:705-11.
5. Sorrells RB, Stiehl JB, Voorhorst PE. Midterm results of mobile-bearing total knee arthroplasty in patients younger than 65 years. Clin Orthop Relat Res. 2001;390:182-9.
6. Buechel FF Sr, Buechel FF Jr, Pappas MJ, D'Alessio J. Twenty-year evaluation of meniscal bearing and rotating platform knee replacements. Clin Orthop Relat Res. 2001;388:41-50.
7. Furnes O, Espehaug B, Lie SA, Vollset SE, Engesaeter LB, Havelin LI. Early failures among 7174 primary total knee replacements: a follow-up study from the Norwegian Arthroplasty Register 1994-2000. Acta Orthop Scand. 2002;73:117-29.
8. Bhan S, Malhotra R, Kiran EK, Shukla S, Bijjawara M. A comparison of fixed-bearing and mobile-bearing total knee arthroplasty at a minimum follow-up of 4.5 years. J Bone Joint Surg Am. 2005;87:2290-6.
9. Michelson JD, Schmidt GR, Mizel MS. Kinematics of a total arthroplasty of the ankle: comparison to normal ankle motion. Foot Ankle Int. 2000;21:278-84.
10. Valderrabano V, Hintermann B, Nigg BM, Stefanyshyn D, Stergiou P. Kinematic changes after fusion and total replacement of the ankle. Part 1: Range of motion. Foot Ankle Int. 2003;24:881-7.
11. Valderrabano V, Hintermann B, Nigg BM, Stefanyshyn D, Stergiou P. Kinematic changes after fusion and total replacement of the ankle. Part 2: Movement transfer. Foot Ankle Int. 2003;24:888-96.

12. Valderrabano V, Hintermann B, Nigg BM, Stefanyshyn D, Stergiou P. Kinematic changes after fusion and total replacement of the ankle. Part 3: Talar movement. Foot Ankle Int. 2003;24:897-900.
13. Leardini A, O'Connor JJ, Catani F, Giannini S. Mobility of the human ankle and the design of total ankle replacement. Clin Orthop Relat Res. 2004;424:39-46.
14. Psychoyios V, Crawford RW, O'Connor JJ, Murray DW: Wear of congruent meniscal bearings in unicompartmental knee arthroplasty. J Bone Joint Surg Br. 1998;80:976–82.
15. Murray DW, Goodfellow JW, O'Connor JJ: The Oxford medial unicompartmental arthroplasty: A ten-year survival study. J Bone Joint Surg Br. 1998;80:983–9.
16. McEwen HMJ, McNulty DE, Auger DD, Farrar R, Liao YS, Stone MH, Fisher J. Wear analysis of mobile-bearing knee. In: Hamelynck KJ, Stiehl JD (Ed) LCS® mobile-bearing knee arthroplasty. Springer-Verlag, Berlin Heidelberg New York 2002;67-73.
17. Giannini S, Leardini A, O'Connor JJ. Total ankle replacement: review of the designs and of the current status. Foot Ankle Surg. 2000;6:77-88.
18. Feldman MH, Rockwood JW. Total ankle arthroplasty: A review of 11 current ankle implants. Clin Pod Medicine Surg. 2004;2004:393-406.
19. Stengel D, Bauwens K, Ekkernkamp A, Cramer J. Efficacy of total ankle replacement with meniscal-bearing devices: a systematic review and meta-analysis. Arch Orthop Trauma Surg. 2005;125:109-19.
20. Lewis G. Biomechanics of and research challenges in uncemented total ankle replacement. Review. Clin Orthop Relat Res. 2004 ;424:89-97.
21. Lundberg A. Kinematics of the normal ankle joint. In: Kofoed H, editor. Current status of ankle arthroplasty. Berlin, Heidelberg, New York,Tokyo: Springer-Verlag; 1998, p. 3-7.
22. Knecht SL, Estin M, Callaghan JJ, Zimmerman MB, Alliman KJ, Alvine FG, et al. The Agility total ankle arthroplasty. Seven to sixteen-year follow-up. J Bone Joint Surg Am. 2004;86:1161-71.
23. Kopp FJ, Patel MM, Deland JT, O'Malley MJ. Total ankle arthroplasty with the Agility prosthesis: clinical and radiographic evaluation. Foot Ankle Int. 2006;27:97-103.
24. Nagashima M, Takahashi A, Matsuzaki T, Takenouchi K, Fujimori J, Yoshino S. Total ankle arthroplasty for deformity of the foot in patients with rheumatoid arthritis using the TNK ankle system. Clinical results of 21 cases. Mod Rheumatol. 2004;14:48-53.
25. Rudigier J. Ankle replacement by the cementless ESKA endoprosthesis. Techniques Foot Ankle Surg. 2005;4:125-36.
26. Nelissen RGHH, Doets HC, Valstar ER. Early migration of the tibial component of the Buechel-Pappas total ankle prosthesis. Clin Orthop Rel Res. 2006;448:146-51.
27. San Giovanni TP, Keblish DJ, Thomas WH, Wilson MG. Eight-year results of a minimally constrained total ankle arthroplasty. Foot Ankle Int. 2006;27:418-26.
28. Su EP, Kahn B, Figgie MP. Total ankle replacement in patients with rheumatoid arthritis. Clin Orthop Relat Res. 2004;424:32-8.
29. Doets HC, Brand R, Nelissen RGHH. Total ankle arthroplasty in inflammatory joint disease with use of two mobile-bearing designs. J Bone Joint Surg Am. 2006; 88:1272-84.
30. Anderson T, Montgomery F, Carlsson A. Uncemented STAR total ankle prostheses. Three to eight-year follow-up of fifty-one consecutive ankles. J Bone Joint Surg Am 2003;85:1321-9.
31. Carlsson A. [Single- and double-coated STAR total ankle replacements: A clinical and radiographic follow-up study of 109 cases]. Orthopaede. 2006;35:527-32. German.

32. Kofoed H. Scandinavian total ankle replacement (STAR). Clin Orthop Relat Res. 2004;424:73-9.
33. Murnaghan JM, Warnock DS, Henderson SA. Total ankle replacement. Early experiences with STAR prosthesis. Ulster Med J 2005;74:9-13.
34. Natens P, Dereymaeker G, Abbara M, Matricali G. Early results after four years experience with the STAR uncemented total ankle prosthesis. Acta Orthop Belg. 2003;69:49-58.
35. Schill S, Biehl C, Thabe H. [Ankle prostheses. Mid-term results after Thompson-Richards and STAR prostheses]. Orthopaede. 1998;27:183-7. German.
36. Valderrabano V, Hintermann B, Dick W. Scandinavian total ankle replacement: a 3.7-year average followup of 65 patients. Clin Orthop Relat Res. 2004;424:47-56.
37. Wood PLR, Deakin S. Total ankle replacement. The result in 200 ankles. J Bone Joint Surg Br. 2003;85:334-41.
38. Schutte BG, Louwerens JWK. Short-term results of our first 49 Scandinavian total ankle replacements (STAR). Foot Ankle Int. 2008;29:124-7.
39. Bonnin M, Judet T, Colombier JA, Buscayret F, Graveleau N, Piriou P. Midterm results of the Salto total ankle prosthesis. Clin. Orthop Relat Res. 2004;424:6-18.
40. Hintermann B, Valderrabano V, Knupp M, Horisberger M. [The HINTEGRA ankle: Short- and mid-term results]. Orthopaede. 2006;35:533-45. German.
41. Evanski PH, Waugh TR. Management of arthritis of the ankle. An alternative of arthrodesis. Clin Orthop Relat Res. 1977;122:110-5.
42. Mazur JM, Schwartz E, Simon SR. Ankle arthrodesis. Long-term follow-up with gait analysis. 964-75. J Bone Joint Surg Am. 1979;61:964-75.
43. Buechel FF, Pappas MJ, Iorio LJ. New Jersey low con¬tact stress total ankle re¬placement: Biomechani¬cal ration¬ale and review of 23 cementless cases. Foot Ankle. 1988;8:279-90.
44. Kitaoka HB, Alexander IJ, Adelaar RS, Nunley JA, Meyerson MS, Sanders M. Clinical rating system for the ankle-hindfoot, midfoot, hallux and lesser toes. Foot Ankle Int. 1994;15:349-53.
45. Kofoed H. Cylindrical cemented ankle arthroplasty: a prospective series with long-term follow-up. Foot Ankle Int. 1995;16:474-9.
46. Domsic RT, Saltzman CL. Ankle osteoarthritis scale. Foot Ankle Int. 1998;19:466-71.
47. Kuyvenhoven MM, Gorter KJ, Zuithoff P, Budiman-Mak E, Conrad KJ, Post MW. The Foot Function Index with verbal rating scales (FFI-5pt): a clinimetric evaluation and comparison with the original FFI. J Rheumatol. 2002;29:1023-8.
48. Levi N, Kofoed H. Comparison of five different scoring systems for ankle arthroplasty. In: Kofoed H, editor. Current status of ankle arthroplasty. Berlin, Heidelberg, New York, Tokyo: Springer-Verlag; 1998, p. 135-7.
49. Henricson A, Skoog A, Carlsson Å. The Swedish ankle arthroplasty register. An analysis of 531 cases performed 1993-2005. Acta Orthop. 2007;78:569-74.
50. Fevang BTS, Lie SA, Havelin LI, Brun JG, Skredderstuen A, Furnes O. 257 ankle arthroplasties performed in Norway between 1994 and 2005. Acta Orthop. 2007;78:575-83.
51. Hosman A H, Mason R B, Hobbs T, Rothwell A G. Total ankle replacement: A national joint registry review of 202 total ankle replacements followed up to 5 years. Acta Orthop. 2007;78:584-91.
52. Spirt AA, Assal M, Hansen ST. Complications and failure after total ankle artrhoplasty. J Bone Joint Surg Am. 2004;86:1172-78.

53. Buechel FF Sr, Buechel FF Jr, Pappas MJ. Twenty-year evaluation of cementless mobile-bearing total ankle replacements. Clin Orthop Relat Res. 2004;424:19-26.
54. Karrholm J, Gill RH, Valstar ER. The history and future of radiostereometric analysis. Clin Orthop Relat Res. 2006;448:10-21.
55. Carlsson A, Markusson P, Sundberg M. Radiostereometric analysis of the double-coated STAR total ankle prosthesis. A 3–5-year follow-up of 5 cases with rheumatoid arthritis and 5 cases with osteoarthrosis. Acta Orthop. 2005;76:573–9.
56. Garling EH, Valstar ER, Nelissen RGHH. Comparison of micromotion in mobile bearing and posterior stabilized total knee prostheses: a randomized RSA study of 40 knees followed for 2 years. Acta Orthop. 2005; 76(3):353-61.
57. Robertsson O, Knutson K, Lewold S, Lidgren L. The Swedish Knee Arthroplasty Register 1975–1997. An update with special emphasis on 41,223 knees operated on in 1988–1997. Acta Orthop Scand. 2001;72:503–13.
58. Arthursson AJ, Furnes O, Espehaug B, Havelin LI, Söreide JA. Prosthesis survival after total hip arthroplasty—does surgical approach matter? Analysis of 19,304 Charnley and 6,002 Exeter primary total hip arthroplasties reported to the Norwegian Arthroplasty Register. Acta Orthop. 2007;78:719–29.
59. Garellick G, Malchau H, Herberts P. Survival of hip replacements. A comparison of a randomized trial and a registry. Clin Orthop Rel Res. 2000;375:157-67.
60. Haddad SL, Coetzee JC, Estok R, Fahrbach K, Banel D, Nalysnyk L. Intermediate and long-term outcomes of total ankle arthroplasty and ankle arthrodesis. A systematic review of the literature. J Bone Joint Surg Am. 2007;89:1899-905.
61. SooHoo NF, Kominski G. Cost-effectiveness analysis of total ankle arthroplasty. J Bone Joint Surg Am. 2004;86:2446-55.