Arthroplasty versus arthrodesis for end-stage ankle arthritis: decision analysis using Markov model

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Abstract

Background Total ankle arthroplasty and arthrodesis are the two mainstreams of treatment for end-stage ankle arthritis. This study was performed to determine which is a better choice for ankle arthritis, using a decision analysis and Markov model to reflect the repetitive nature of revision arthroplasty.

Methods Based on current published evidence, a decision tree was constructed to compare the clinical outcomes of total ankle arthroplasty and arthrodesis, which contained the possible clinical events and the probabilities. Total ankle arthroplasty was subject to revision arthroplasty, and a Markov model was adopted for this branch to reflect this repetitive trait of the procedure. Arthrodesis could cause adjacent arthritis, and a conventional decision analysis model was adopted for this branch. Quality well-being index score was used for clinical outcome assessment, which was the utility in the decision tree. Sensitivity analysis was performed to test the stability of the decision tree and the threshold values.

Results The model favoured total ankle arthroplasty over arthrodesis in terms of quality well-being index score.

Sensitivity analysis showed that the model was considerably stable, unaffected by the changes in probabilities of failure after total ankle arthroplasty and adjacent arthritis after arthrodesis.

Conclusions Based on current evidence, total ankle arthroplasty was found to be a better treatment than arthrodesis for ankle arthritis. Future development in the implant materials, improved understanding of ankle biomechanics, and surgical techniques will further enhance the clinical outcome of total ankle arthroplasty.

Introduction

End-stage degenerative joint disease of the ankle secondary to trauma, metabolic joint disease, or some other identified or idiopathic aetiology typically results in a debilitating loss of mobility. Primary surgical treatment for ankle arthritis was tibiotalar arthrodesis. Despite the reduced ankle mobility, arthrodesis improved patients' clinical score markedly, inducing pain relief, better walking ability and easier daily activities [1]. Therefore, arthrodesis has been the main treatment of end-stage ankle arthritis. However, this procedure could cause several complications, such as nonunion, malalignment, infection, and the development of osteoarthritis in the neighbouring joint [1].

Another surgical option for end-stage arthritis of the ankle is total ankle arthroplasty. Previously, total ankle arthroplasty was discarded because of the poor clinical results and high rates of prosthetic loosening. However, recently, total ankle arthroplasty has re-emerged with the advent of more anatomically sound designs and improved surgical techniques. This procedure could preserve ankle motion and relieve pain, although revision surgery for prosthetic loosening still remains problematic.

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Total ankle arthroplasty and ankle arthrodesis have their advantages and disadvantages that clinicians should consider when deciding on a treatment. A randomised controlled trial is believed to be able to provide a useful guideline in the choice between the procedures, but needs a long-term follow-up period which is not always possible. Alternatively, decision analysis can be used to determine which treatment would be better according to current evidence. Decision analysis is a tool to analyse the information quantitatively and optimise the decision making process to provide the most benefit to the patients and population health using finite resources [2].

Total ankle arthroplasty is subject to a revision procedure during follow-up. Although a previous study compared total ankle arthroplasty with arthrodesis using decision analysis [3], it did not sufficiently consider the repetitive nature of total ankle arthroplasty for prosthetic loosening. To represent this event that necessarily occurs over time, the Markov model needs to be designed to repeat the cycle of events during the time period of interest [4].

Therefore, this study examined which procedure is more favourable—total ankle arthroplasty or ankle arthrodesis—for patients with end-stage ankle arthritis using the Markov model incorporated into decision analysis and current published evidence.

Materials and methods

Approval of our institutional review board was waived because the study materials did not involve human subjects.

Model design

In this study, a decision analysis model was formulated based on two options for the treatment of patients with the end-stage ankle arthritis: ankle arthrodesis or total ankle arthroplasty. This model can address any aged patient with arthritis refractory to conservative treatment. In the decision tree, the root node (where the decision is made) is divided into two arms: total ankle arthroplasty and ankle arthrodesis (Fig. 1). The total ankle arthroplasty branch of the decision node is then followed by Markov models [4], which could reflect the repetitive nature of total ankle arthroplasty, i.e., revision arthroplasty for aseptic loosening. The decision tree was constructed using decision analysis software (TreeAge Pro 2009, Williamstown, Massachusetts).

Some assumptions were made in the construction of the model. First, the surgeon did not consider the difference between revision and redo-revision total ankle arthroplasties. Redo-revision total ankle arthroplasty is technically more difficult than revision ankle arthroplasty due to insufficient bone stock and lack of a suitable implant

design. However, our decision model did not reflect this situation. Second, the procedure chosen in a septic revision had the same probability in an aseptic revision. Generally, a septic revision is performed by two-stage procedure. Infection control is performed first, and when there are no signs of infection, the revision procedure is considered second. Therefore, the preoperative condition of septic and aseptic revision was similar, even though outcome of a septic revision arthroplasty could be worse than an aseptic revision. Third, the patients with end-stage ankle arthritis were over the age of 45 years. Fourth, the patients undergoing total ankle arthroplasty were subject to repeat revision arthroplasty every ten years.

Total ankle arthroplasty arm

A literature review was performed to construct the possible events and their probabilities in a Markov cycle tree after total ankle arthroplasty. In total ankle arthroplasty, the ten-year implant survival rate was 77% (95% confidence interval, 63.3–90.8%) [5–16]. A revision during the follow-up period was required in 9.8% (95% confidence interval, 3.1–16.5%) of patients who had undergone total ankle arthroplasty [17, 18], which meant clinical failure. A total of 63% of failure cases were salvaged with a revision of the total ankle arthroplasty, and 36% were converted to arthrodeses [5–15, 17–20]. A below-knee amputation was performed in 1% of patients treated with total ankle arthroplasty [5–15, 17, 18, 20]. A deep infection rate was 1.7% of articles reporting the complication [8–11, 20, 21] (Table 1).

Ankle arthrodesis arm

This arm was subjected to complication and healing without complication, where complication included nonunion and amputation (Fig. 1). In cases of achieved union, adjacent arthritis could be a problem [1, 22–25]. Nonunion rate after ankle arthrodesis was 10% (95% confidence interval, 7.4–12.1%) [3, 17, 18], and 9% (95% confidence interval, 5.5–11.6%) of the nonunion patients underwent revision arthrodesis [17]. Fifty percent of the patients were assumed to suffer from adjacent arthritis after ankle arthrodesis, based on previous studies [1, 23]. Five percent of the patients were reported to undergo below-the-knee amputation after ankle arthrodesis [17] (Table 1).

Utility

The utility used in this model was based on the quality well-being index scores reported in the literature [26]. The quality well-being index is a widely used preference-based instrument, which has demonstrated high construct validity,

Fig. 1 Decision analysis tree with probability and utility variables. The decision node branches into total ankle arthroplasty and ankle arthrodesis. The total ankle arthroplasty branch adopts the Markov model

appropriate responsiveness to intervention, and high test–retest reliability [27]. The reference case guidelines define the utility along a continuum, with a factor of 1.0 representing perfect health and a factor of 0.0 representing death. A longitudinal cohort study demonstrated quality well-being index scores of 0.72 for patients with arthritis who were between 45 and 54 years of age, and 0.77 for patients without arthritis in the same age group. The intermediate and long-term outcome and relative utility of total ankle arthroplasty and arthrodesis has been documented. It was reported that arthroplasty was more favourable than arthrodesis showing a better functional outcome [19]. In this study, utility values of 0.76 and 0.75

were used for successful total ankle arthroplasty and arthrodesis, respectively, which were quality well-being scores of the subjects without arthritis.

There is limited data available with which to assign utility values to septic revision or aseptic revision arthroplasty. Therefore, it was assumed that only a 50% improvement in the quality-adjusted life year value would be observed in patients who had undergone revision arthroplasty. In addition, a utility value of 0.73 was used for septic revision because patients with septic revision were reported to have 40–90% of the postoperative function or clinical score of those who had undergone an aseptic revision in knee arthroplasty [28, 29]. Previous data was

Table 1 Probabilities of variables in decision tree

Variable	Baseline	Range	Studies
Total ankle arthroplasty			
Failed total ankle arthroplasty	0.23	0.046–0.37	Haddad et al. [17] Gougoulas et al. [18]
Revision	0.1	0.03–0.17	Haddad et al. [17] Gougoulas et al. [18] Pyeovich et al. [19]
Conversion to arthrodesis	0.05	0.02–0.08	Haddad et al. [17] Gougoulas et al. [18] Pyeovich et al. [19]
Below knee amputation	0.01	0.00–0.03	Knecht et al. [8] Kopp et al. [10] Gougoulas et al. [18]
Infection	0.01	0.00–0.046	Anderson et al. [5] Bonnin et al. [6] Buechel et al. [7]
Ankle arthrodesis			
Nonunion	0.1	0.00–0.41	SooHoo et al. [3] Haddad et al. [17] Gougoulas et al. [18]
Adjacent arthritis	0.5	0.1–1.00	Coester et al. [1] Mazur et al. [23] Ahlberg et al. [25]
Below knee amputation	0.05	0.00–0.15	Haddad et al. [17]

used to assign a utility value of 0.6 to a below-knee amputation [26, 30]. Utility values of 0.72 and 0.73 were assigned to adjacent arthritis and nonunion after arthrodesis, respectively. The utilities were arranged according to age, and the averaged value between utilities at the initial operation and at the age of interest was used in the ankle arthrodesis arm because the ankle arthrodesis arm did not employ the Markov model (Table 2).

Roll back

In the total ankle arthroplasty arm, the duration of each cycle in the Markov model was ten years. Because the mean life span in the United States is approximately 80

years, patients with 40 years of age would undergo the cycle four times. In the same manner, a patient 50 years of age would undergo the cycle three times. The utility was applied according to the patient's age (Tables 2 and 3).

Sensitivity analysis

The uncertainty and stability of the decision tree model were assessed using a sensitivity analysis tool. The variables of greatest uncertainty were analysed over their range of plausibility one at a time or in conjunction with other variables to examine the effects of the uncertainty on the results of the model. A threshold value in which the point of intersection occurs with each variable could then

Table 2 Age-specific scores on the quality of well-being index (QWB)

Age range(years)	Without arthritis	TAA	Arthrodesis	Aseptic revision	Septic revision	Nonunion	BKA	Arthritis
45–54	0.77	0.76	0.75	0.74	0.73	0.73	0.6	0.72
55–64	0.77	0.76	0.75	0.74	0.73	0.73	0.6	0.70
65–74	0.76	0.75	0.74	0.72	0.71	0.71	0.6	0.69
75–84	0.71	0.70	0.69	0.68	0.67	0.67	0.6	0.65
85 or older	0.69	0.68	0.67	0.66	0.65	0.65	0.6	0.64

TAA total ankle arthroplasty, BKA below knee amputation

Table 3 The final outcomes (quality of well-being index) during the time period of interest

	Cycle	Age at procedure (years) and option							
		45–54		55–64		64–74		75–84	
		TAA	Arthrodesis	TAA	Arthrodesis	TAA	Arthrodesis	TAA	Arthrodesis
One cycle is the duration of ten years after surgery TAA total ankle arthroplasty	One cycle	0.76	0.73	0.75	0.72	0.72	0.69	0.69	0.66
	Two cycles	0.75	0.72	0.73	0.70	0.71	0.68		
	Three cycles	0.74	0.70	0.73	0.69				
	Four cycles	0.74	0.69						

be determined. The threshold represented the point where the preference between the ankle arthroplasty and arthrodesis was changed.

The variables of the greatest uncertainty and debate in this study were the probabilities of failed total ankle arthroplasty and the adjacent arthritis following arthrodesis. The failure rates of total ankle replacement and the rates of adjacent arthritis after arthrodesis were tested in one-way sensitivity analysis. The failure rates of total ankle replacement ranged from 4.6% to 32.3% [17, 18], and the prosthetic survival rates were tested. The rates of adjacent arthritis were tested between 10% and 100% in one-way sensitivity analysis based on previous reports [1, 23, 25].

Sensitivity analysis was also performed for the utilities of total ankle arthroplasty and ankle arthrodesis because higher outcome scores in arthroplasty might be controversial. The utility of arthroplasty ranged from the value of revision arthroplasty to the value of ‘without arthritis’, and the utility of arthrodesis ranged from the value of arthritis to the value of ‘without arthritis’.

Statistical methods

No statistical analysis was used other than a decision analysis and sensitivity analysis.

Results

The decision model showed that total ankle arthroplasty was superior to arthrodesis in terms of the final outcome score (quality well-being index) when performing the roll back tool. All age groups showed better outcomes in total ankle arthroplasty (Table 3). When the age of surgery was between 45 and 54 years old, total ankle arthroplasty showed a higher quality well-being index score (0.76) than that of ankle arthrodesis (0.73) at first cycle of ankle arthroplasty, and the superiority of total ankle arthroplasty was maintained through subsequent revisions (cycles) of ankle arthroplasty performed every ten years. When surgery was performed in those aged between 75 and 84 years, total ankle arthroplasty also showed higher quality well-being

index score (0.69) than ankle arthrodesis (0.66). The baseline quality well-being index decreased according to the age of surgery and repetition of arthroplasty, but total ankle arthroplasty showed higher quality well-being index scores than ankle arthrodesis regardless of the age and cycle of arthroplasty (Table 3). Furthermore, one-way sensitivity analysis showed that total ankle arthroplasty was superior to ankle arthrodesis, unaffected by the probabilities of adjacent arthritis after arthrodesis and the prosthetic failure after arthroplasty (Fig. 2). One-way and two-way sensitivity analyses on the utilities showed that total ankle arthroplasty was superior to ankle arthrodesis regardless of the changes in the utility of each procedure (Fig. 3).

Discussion

Using the decision analysis model based on current published evidence, this study demonstrated that total ankle arthroplasty in patients with end-stage ankle arthritis is a better choice than ankle arthrodesis in terms of the quality well-being index scores. The Markov circle tree for total ankle arthroplasty made it possible to simulate long-term processes incorporating the revision arthroplasty into the decision model. Therefore, the long-term outcome of total ankle arthroplasty and ankle arthrodesis could be compared.

Before discussing the findings of the study, some limitations need to be addressed. First, there was limited data available with which to assign utility values to some conditions, such as revision arthroplasty and arthrodesis after arthroplasty. Therefore, some assumptions have been made to determine the probability or utility, although most of them were evidence-based. Second, the Markov model was used only in the total ankle arthroplasty branch. Although a standard decision tree was applied to the ankle arthrodesis branch, the utility used in this arm was compensated for with age related values. Third, there are limited data regarding the longevity of total ankle arthroplasty, and the failure rates were somewhat wide according to the previous studies [17, 18]. Further evidence will be needed for total ankle replacement.

Fig. 2 One-way sensitivity analysis showing that the model favours total ankle arthroplasty over ankle arthrodesis in terms of the quality of well-being index scores. **a** One-way sensitivity analysis for the probability of adjacent arthritis after arthrodesis. The decision model always favours the total ankle arthroplasty based on the reported

ranges of the probability of adjacent arthritis after arthrodesis. **b** One-way sensitivity analysis for the probability of prosthetic survival in the total ankle arthroplasty. The total ankle arthroplasty was superior to ankle arthrodesis between the prosthetic survival rate of 65% and 95%, which was based on the previous reports

Orthopaedic surgeons are believed to be in the situation frequently, where they need to determine which procedure

is a better choice for end-stage ankle arthritis, total ankle arthroplasty or ankle arthrodesis. Patients' characteristics,

Fig. 3 These graphs show one-way and two-way sensitivity analyses within a single cycle in patients aged between 45 and 54 years. **a** One-way sensitivity analysis on the utility of ankle arthrodesis. The decision model favours total ankle replacement in terms of the quality of well-being index scores regardless of the changes in the utility of ankle arthrodesis, of which the ranges were determined between the quality of well-being index scores with ankle arthritis and that without ankle arthritis. **b** One-way sensitivity analysis on the utility of total ankle replacement. The decision model favours total ankle replacement in terms of the quality of well-being index scores regardless of the changes in the utility of total ankle replacement, of which the ranges were determined between the quality of the well-being index scores with ankle arthritis and that without ankle arthritis. **c** Two-way sensitivity analysis showed that the decision model always favours total ankle replacement regardless of the changes in both utilities of ankle arthrodesis and total ankle replacement

such as activity level, obesity, and underlying diseases should be considered. However, the debate on the issue has been focussed on the following considerations: (1) capacity of failure of total ankle replacement prosthesis at a given time and (2) loss of mobility in patients undergoing ankle arthrodesis.

In a previous study, arthroplasties produced more favourable results, showing lower complication rate [3]. In particular, there were no cases of subtalar degeneration, which was common after arthrodesis. The level of pain was lower and the function was better (even without mobility ratings) in the arthroplasty group. This study showed consistent results with previous studies, i.e., total ankle arthroplasty had a better outcome than ankle arthrodesis. We believe that the clinical outcome of total ankle arthroplasty could be further improved through increased understanding of ankle biomechanics, surgical technique, and development of a new durable materials.

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References

- Coester LM, Saltzman CL, Leupold J, Pontarelli W (2001) Long-term results following ankle arthrodesis for post-traumatic arthritis. *J Bone Joint Surg Am* 83-A(2):219–228
- Bernstein J (1997) Decision analysis. *J Bone Joint Surg Am* 79(9):1404–1414
- SooHoo NF, Kominski G (2004) Cost-effectiveness analysis of total ankle arthroplasty. *J Bone Joint Surg Am* 86-A(11):2446–2455
- Hunink MG GP, Siegel JE, Weeks JC et al. (2001) Decision making in health and medicine: integrating evidence and values. Cambridge University Press
- Anderson T, Montgomery F, Carlsson A (2003) Uncemented STAR total ankle prostheses. Three to eight-year follow-up of fifty-one consecutive ankles. *J Bone Joint Surg Am* 85-A(7):1321–1329
- Bonnin M, Judet T, Colombier JA et al (2004) Midterm results of the Salto total ankle prosthesis. *Clin Orthop Relat Res* 424:6–18
- Buechel FF Sr, Buechel FF Jr, Pappas MJ (2004) Twenty-year evaluation of cementless mobile-bearing total ankle replacements. *Clin Orthop Relat Res* 424:19–26
- Knecht SI, Estin M, Callaghan JJ et al (2004) The Agility total ankle arthroplasty. Seven to sixteen-year follow-up. *J Bone Joint Surg Am* 86-A(6):1161–1171
- Hurowitz EJ, Gould JS, Fleisig GS, Fowler R (2007) Outcome analysis of agility total ankle replacement with prior adjunctive procedures: two to six year followup. *Foot Ankle Int* 28(3):308–312
- Kopp FJ, Patel MM, Deland JT, O'Malley MJ (2006) Total ankle arthroplasty with the Agility prosthesis: clinical and radiographic evaluation. *Foot Ankle Int* 27(2):97–103
- San Giovanni TP, Kiblish DJ, Thomas WH, Wilson MG (2006) Eight-year results of a minimally constrained total ankle arthroplasty. *Foot Ankle Int* 27(6):418–426
- Naal FD, Impellizzeri FM, Loibl M et al (2009) Habitual physical activity and sports participation after total ankle arthroplasty. *Am J Sports Med* 37(1):95–102
- Valderrabano V, Pagenstert G, Horisberger M et al (2006) Sports and recreation activity of ankle arthritis patients before and after total ankle replacement. *Am J Sports Med* 34(6):993–999
- Kofoed H (2004) Scandinavian total ankle replacement (STAR). *Clin Orthop Relat Res* 424:73–79
- Wood PL, Prem H, Sutton C (2008) Total ankle replacement: medium-term results in 200 Scandinavian total ankle replacements. *J Bone Joint Surg Br* 90(5):605–609
- Takakura Y, Tanaka Y, Kumai T et al (2004) Ankle arthroplasty using three generations of metal and ceramic prostheses. *Clin Orthop Relat Res* 424:130–136
- Haddad SL, Coetzee JC, Estok R et al (2007) Intermediate and long-term outcomes of total ankle arthroplasty and ankle arthrodesis. A systematic review of the literature. *J Bone Joint Surg Am* 89(9):1899–1905
- Gougoulis N, Khanna A, Maffulli N (2010) How successful are current ankle replacements?: a systematic review of the literature. *Clin Orthop Relat Res* 468(1):199–208
- Pyeovich MT, Saltzman CL, Callaghan JJ, Alvine FG (1998) Total ankle arthroplasty: a unique design. Two to twelve-year follow-up. *J Bone Joint Surg Am* 80(10):1410–1420
- Tallon C, Coleman BD, Khan KM, Maffulli N (2001) Outcome of surgery for chronic Achilles tendinopathy. A critical review. *Am J Sports Med* 29(3):315–320
- Glazebrook MA, Arsenaault K, Dunbar M (2009) Evidence-based classification of complications in total ankle arthroplasty. *Foot Ankle Int* 30(10):945–949
- Thomas RH, Daniels TR (2003) Ankle arthritis. *J Bone Joint Surg Am* 85-A(5):923–936
- Mazur JM, Schwartz E, Simon SR (1979) Ankle arthrodesis. Long-term follow-up with gait analysis. *J Bone Joint Surg Am* 61(7):964–975
- Jackson A, Glasgow M (1979) Tarsal hypermobility after ankle fusion—fact or fiction? *J Bone Joint Surg Br* 61-B(4):470–473
- Ahlberg A, Henricson AS (1981) Late results of ankle fusion. *Acta Orthop Scand* 52(1):103–105
- Fryback DG, Dasbach EJ, Klein R et al (1993) The Beaver Dam Health Outcomes Study: initial catalog of health-state quality factors. *Med Decis Making* 13(2):89–102
- Coons SJ, Rao S, Keininger DL, Hays RD (2000) A comparative review of generic quality-of-life instruments. *Pharmacoeconomics* 17(1):13–35
- Centers for Medicare and Medicaid Services (2005) Physician fee schedule relative value file. CMMS, Baltimore, Maryland. www.cms.hhs.gov. Accessed 18 May 2009
- Centers for Medicare and Medicaid Services (2004) Revisions to payment policies under the physician fee schedule for calendar year. CMMS, Baltimore, Maryland. www.cms.hhs.gov. Accessed 18 May 2009
- Tengs TO, Wallace A (2000) One thousand health-related quality-of-life estimates. *Med Care* 38(6):583–637