# Management of Periprosthetic Bone Cysts After Total Ankle Arthroplasty

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**KEYWORDS**

• Total ankle arthroplasty • Bone cysts • Osteolysis • Revision arthroplasty

**KEY POINTS**

- Periprosthetic bone cysts are common after total ankle arthroplasty and can often be asymptomatic.
- The exact cause of bone cyst formation is likely multifactorial with contributing factors including polyethylene wear, implant micromotion, and implant design.
- Nonoperative management includes observation with annual clinical and radiographic follow-up to assess for cyst progression, implant stability, and patient symptoms.
- Operative treatment of isolated periprosthetic bone cysts without implant compromise consists of cyst debridement and grafting, whereas treatments for unstable implants in the setting of bone cysts include revision total ankle arthroplasty and arthrodesis.

## INTRODUCTION

End-stage ankle arthritis is a debilitating condition that results in pain, loss of function, and an impaired quality of life.[1] The 2 major surgical treatment options to address this condition include tibiotalar arthrodesis and total ankle arthroplasty (TAA). TAA was introduced in the 1970s with the goal of providing pain relief while preserving range of motion to maintain optimal function. Unfortunately, initial attempts at TAA resulted in poor outcomes with high rates of failure including implant loosening and subsidence.[2,3] Given the poor outcomes of early-generation TAA, tibiotalar arthrodesis became the gold standard treatment of end-stage ankle arthritis. However, concerns regarding adjacent joint degeneration and altered gait mechanics following arthrodesis have led to an increasing interest in the optimization of TAA.[4–9] Modern advancements in implant design and surgical technique have demonstrated improved outcomes after TAA with comparable results to tibiotalar arthrodesis.[10–12] These improvements have resulted in a large increase in the number of TAAs being performed, especially when compared with tibiotalar arthrodesis.[13,14]

Despite improvements with TAA, postoperative complications requiring revision surgery remains a clinical problem. Hauer and colleagues[15] investigated revision rates after TAA by analyzing 43 clinical studies including 5806 primary TAAs and found a 7-year revision rate of 12.6%. In this study, implant loosening and subsidence was the cause of 49% of the revision TAAs. The formation of periprosthetic bone cysts is a common radiographic finding and can be a contributing factor to implant loosening and subsidence. The reported prevalence of periprosthetic bone cysts formation after TAA has been variable, but can be as high as 81% at an average follow-up of 44.6 months.[16] Along with implant loosening and subsidence, periprosthetic bone cysts can result in persistent pain and periprosthetic fracture. With the

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increasing volume of patients having undergone TAA, it is crucial for providers to understand the cause, proper evaluation, and subsequent management when periprosthetic bone cysts are encountered following TAA.

## CAUSE

The cause of periprosthetic bone cysts after TAA is not entirely understood. The most commonly described process of periprosthetic bone cyst formation is osteolysis secondary to polyethylene (PE) wear, as has been seen with total hip and total knee arthroplasties.[17] Phagocytosis of debris from PE wear by macrophages can stimulate the release of cytokines resulting in the activation of osteoclasts causing bone resorption and cyst formation.[18,19] The rate of PE wear can be affected by the type of PE implanted. The use of conventional PE may produce increased wear particles when compared with highly cross-linked PE.[20,21] In addition, implant design may contribute to PE wear. The 2 major implant designs are a 3-component mobile-bearing prosthesis and a 2-component fixed-bearing prosthesis. The concern with a mobile-bearing prosthesis is the possibility of increased PE wear given 2 bearing surfaces and risk of PE subluxation resulting in edge loading. Assal and colleagues[22] compared reoperation rates between mobile-bearing and fixed-bearing implants at 3 years and found higher rates of reoperation with mobile-bearing implants. Specifically, mobile-bearing implants had higher rates of reoperations attributed to PE wear and cyst formation when compared with the fixed-bearing group. Similar findings of increased periprosthetic bone cysts with mobile-bearing implants have been observed in other studies as well.[23–25]

Although PE wear is a commonly reported cause for periprosthetic bone cyst formation, histologic evaluation of cystic tissue is conflicting. Schipper and colleagues[26] analyzed 57 pathology samples from areas of osteolysis after TAA and found large quantities of PE particles in osteolytic tissue. However, Gross and colleagues[27] found PE debris in only 7 of the 26 tissue samples taken from periprosthetic cysts with other findings including chronic inflammation, calcium pyrophosphate dehydrate crystals, unspecified foreign body reaction, ganglion cyst material, metal histiocytosis, and granulomatous reactions. These findings are similar to those of other studies with mixed histologic results, which may represent other causes of periprosthetic bone cysts.[28,29] Last, histologic analysis has identified hydroxyapatite as a contributing factor.[29,30]

In addition to PE wear, other explanations for the formation of periprosthetic bone cysts have been described. Micromotion between the bone and implant may contribute to cyst formation, and 1 factor contributing to increased micromotion is component malalignment.[31,32] In addition, component malalignment may increase PE wear in TAA due to increase in joint contact forces.[33,34] Lintz and colleagues[16] performed a retrospective review of patients with weight-bearing computed tomographic (CT) images following TAA and found that patients with residual hindfoot malalignment had an increased volume of periprosthetic cysts. With concerns regarding component malalignment, there is an increased focus on accurate and reliable positioning of components using patient-specific instrumentation (PSI). Escudero and colleagues[35] compared 51 patients undergoing TAA using PSI with 16 patients undergoing TAA using standard techniques and found no difference in osteolysis rates on plain radiographs at 2-year follow-up.[35] However, it is important to consider that PSI may not be superior to standard referencing techniques for component positioning.[36,37] Furthermore, there is some concern regarding the use of PSI increasing the risk of osteolysis secondary to greater soft tissue stripping, which may lead to ischemic necrosis and cyst formation.[35] If this is true, surgical approach may be a factor in osteolysis; however, to our knowledge this has not been evaluated.

In addition, patient factors may increase the risk of periprosthetic bone cyst formation including age, activity level, body mass, and even differences in cellular response to implant wear particles.[19] Lee and colleagues[38] evaluated if preoperative bone density of distal tibia and talus was associated with periprosthetic osteolysis following TAA, but found no association. Similarly, Cho and colleagues[39] found no difference in implant loosening between patients with rheumatoid arthritis and end-stage osteoarthritis after TAA. Additional research is required to determine patient risk factors for periprosthetic bone cyst formation.

Ultimately, the cause of periprosthetic bone cysts after TAA is not well understood and is likely multifactorial in nature. Other explanations are related to stress shielding,[40] implant material science,[41] high synovial fluid pressures,[42] and presence of preexisting cysts.[43] Further investigations are required to better understand the development of periprosthetic bone cysts, identification of risk factors, optimal implant design, ideal surgical technique, and subsequent prevention of this complication.

## PATIENT EVALUATION OVERVIEW

Evaluation of patients with a painful TAA has been described previously.[44,45] First, a detailed history should be obtained. Questions regarding startup pain should be asked because this is often the first symptom of a problematic periprosthetic bone cyst. Other questions regarding trauma, infection, and other causes of pain should be asked to rule out other causes of symptoms. A thorough physical examination should be performed, and evidence of a ballooning bone cyst may be evident upon inspection and palpation (Fig. 1). Laboratory studies should be ordered to rule out infection.

In addition to history and physical examination, plain radiographs of the ankle should be obtained and detailed inspection of these radiographs should be performed to detect periprosthetic bone cysts, which is often defined as a radiolucent lesion measuring greater than 2 mm.[25] Radiographs should be compared with previous films to evaluate for interval change such as cyst progression, periprosthetic fracture, implant loosening, or subsidence (Fig. 2). In addition, Besse and colleagues[46] described 10 zones to classify the location of bone cyst formation with zones 1 to 5 viewed on the anteroposterior radiograph and zones 6 to 10 on the lateral radiograph. The clinical relevance of this classification system is not known but has been used in other investigations.[47,48]

Advanced imaging is useful for further evaluation of periprosthetic bone cysts. Specifically, CT imaging is more accurate at cyst detection and allows for volumetric assessment of these lesions when compared with plain radiographs.[47,48] In addition, weight-bearing CT may provide additional information regarding implant position and malalignment that may need to be corrected.[16] MRI is often limited in the setting of TAA given artifact from implants; however, metal artifact reduction sequencing can improve imaging quality and provide information regarding osteolytic cysts and bony edema.[49] Finally, nuclear medicine imaging can be obtained such as single-photon emission CT to assess biologic activity at the bone cyst and bone-implant interface. However, these findings can be nonspecific because increased activity may be seen in osteolysis, component loosening, infections, stress fractures, or a normal response in the early postoperative period.[50]

## MANAGEMENT

### Nonoperative Treatment

Nonoperative treatment is reserved for patients found to have small periprosthetic bone cysts without any symptoms. Although the presence of periprosthetic bone cysts can be common, patients are often asymptomatic.[51] These patients should be followed with clinical observation and evaluated for development of symptoms such as startup pain. Routine

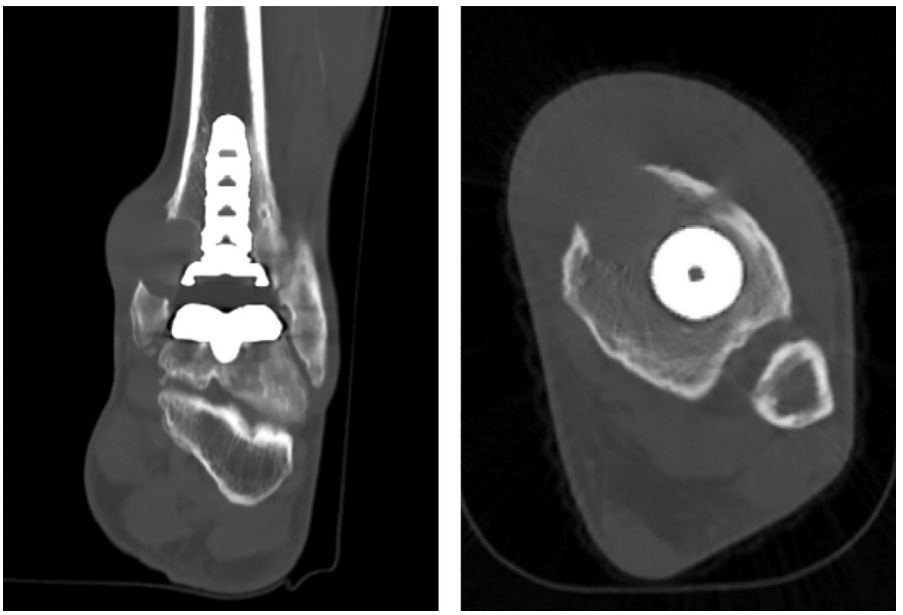

Fig. 1. Coronal and axial CT images representing a ballooning periprosthetic bone cyst of the medial malleolus that was evident on physical examination 5 years after TAA.

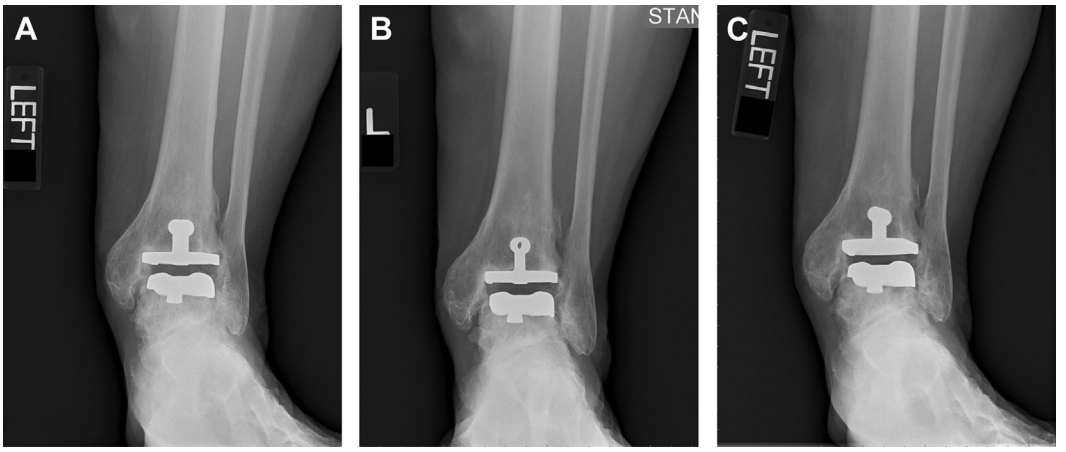


Fig. 2. (*A*) Anteroposterior radiograph of the left ankle 7 years after TAA. Progressive cyst formation can be seen inferior to the lateral aspect of the talar component at (*B*) 8 years and (*C*) 9 years postoperatively. (*Images courtesy* of Dr. James W. Brodsky.)

radiographs of the ankle should be obtained on an annual basis to assess for cyst progression, implant loosening, component subsidence, or impending fracture (Fig. 3). Advanced imaging should be obtained if any concerns are found on history, physical examination, or plain radiographs. Patients should be counseled regarding monitoring and instructed to return for repeat evaluation if symptoms develop.

## Bone Cyst Debridement and Grafting

The primary surgical treatment of isolated bone cysts without implant compromise is cyst debridement with grafting. Indications to pursue surgical treatment in the setting of stable implants include large cysts, progressive increase in cyst size, and symptomatic cysts. Thresholds for surgical treatment regarding cyst size have been suggested as cysts greater than 10 mm,[27,52] but minimal evidence exists to support this cutoff. The goal of cyst debridement and grafting is elimination of the cyst to relieve pain, provide implant stability, and prevent implant loosening or subsidence in the future.

Outcomes regarding cyst debridement and grafting have been variable. Yang and colleagues[53] reported promising results with this procedure by reviewing 210 consecutive mobile-bearing TAA where 19 cases (9%) required reoperation with cyst debridement, grafting, and PE liner exchange. This was the most common reoperation procedure observed, and they found no further progression of any of the lesions after the grafting procedure. In addition, Naude and colleagues[29] reported outcomes of cyst debridement, bone grafting, and PE liner exchange of 9 cystic lesions in 8 patients measuring at least 1.75 $cm^3$ on CT scan. The investigators demonstrated that 8 of the 9 lesions had successful graft incorporation when

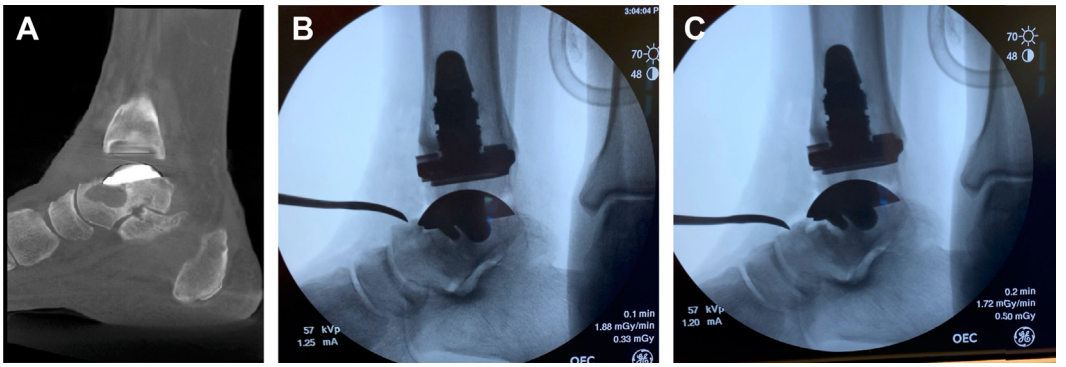


Fig. 3. (*A*) Sagittal CT imaging demonstrating periprosthetic bone cyst within the talar neck 7 years following TAA. (*B* and *C*) Intraoperative fluoroscopy demonstrating subsequent periprosthetic fracture of the talus and implant loosening.

evaluated postoperatively on CT at an average follow-up of 3 years. Last, Gross and colleagues[27] analyzed a total of 726 primary TAAs and reported outcomes of 31 patients who underwent bone cyst debridement and grafting. Failure of this procedure was defined as conversion to an arthrodesis or requiring future component revision. In this series, 27 (87%) patients had a successful outcome with 4 patients requiring arthrodesis or component revision, although 1 patient in the successful cohort did require a repeat bone grafting procedure. The investigators also use bisphosphonates for cysts greater than 10 mm.[27]

In contrast, Besse and colleagues[54] reported isolated cyst debridement and grafting in 14 patients who underwent TAA with poor results including a radiographic failure of 92% and need for arthrodesis in 28% of patients at an average of 34 weeks following grafting. Similarly, Kohonen and colleagues[52] performed a retrospective review of 65 periprosthetic bone cysts in 34 cases of TAA that underwent reoperation with cyst debridement and grafting.[52] The investigators found that 68% of the grafted lesions demonstrated continued progression of the cyst on postoperative CT with only 28% demonstrating radiographic success at an average follow-up of 3.8 years. One possible explanation for these conflicting findings between studies may be related to the specific TAA implant. Most of patients in these 2 studies had primary TAA with an implant that was discontinued due to high rates of early osteolysis, which may have an impact on the success of grafting procedures.

Additional considerations for patients undergoing cyst debridement and grafting include graft choice, role of PE exchange, assessment for possible cause of cyst formation, and optimal surgical technique. A variety of grafts have been used including autograft, allograft, supplementation with biologics, and use of bone cement; however, it is not clear what the optimal choice is. Also, concomitant PE liner exchange has been recommended at the time of cyst debridement and grafting given concerns of PE wear contributing to cyst formation.[29] However, Kohonen and colleagues[52] found no difference in cyst progression in those who underwent cyst grafting with or without PE exchange. Furthermore, patients should be assessed for component malposition and hindfoot malalignment because these may need to be addressed to reduce PE wear and implant micromotion. Finally, technical differences exist regarding this procedure. Lundeen and colleagues[55] described an endoscopic-assisted technique for cyst debridement and grafting. The investigators advocate for this method due to improved visualization of the cyst and superior debridement of cystic material, but this has not been proven.

In conclusion, the optimal management of periprosthetic bone cysts without implant compromise is not known. Cyst debridement and grafting appears to be a reasonable option for large cysts, progressive cysts, or painful cysts. Outcomes of this procedure are variable in terms of long-term radiographic success and avoidance of future arthrodesis or TAA component revision. However, treatment alternatives include nonoperative treatment with risk of further cyst progression and catastrophic implant failure in the future. In addition, revision TAA or conversion to arthrodesis can be performed instead, but these larger surgical procedures can be difficult to justify in an asymptomatic patient with stable implants. Further research is required to determine the success of this procedure and optimal techniques.

## Revision Arthroplasty

Periprosthetic bone cysts may ultimately affect the integrity of a TAA prothesis causing implant loosening or component subsidence. In these clinic situations, revision of the tibial, talar, or all components is a potential treatment option. Large periprosthetic cysts remains a challenge during revision TAA because significant bone loss can limit the ability to revise either component. However, with the addition of revision TAA systems and modern primary TAA using minimal bone resection, revision TAA can a feasible surgical option.

With regard to the tibial component, adequate medial and lateral osseous structural support is needed, and standard tibial components often rely on a minimum of 50% osseous coverage at the distal tibia for fixation.[56,57] For large osseous defects of the distal tibia, implants with an intramedullary stem or custom tibial implants may be required to provide adequate fixation.[57–59] Bone defects should be addressed with techniques such as impaction grafting to improve the structural support for the implant and limit the possibility of periprosthetic cyst development following revision TAA.[57,59] Although grafting of bone defects can be performed at the time of revision TAA, some advocate for a staged procedure in which bone defects are first grafted followed by revision TAA approximately 3 to 4 months later.[60] Last, large PE liners can be used to help accommodate for a loss of distal tibial height.[57]

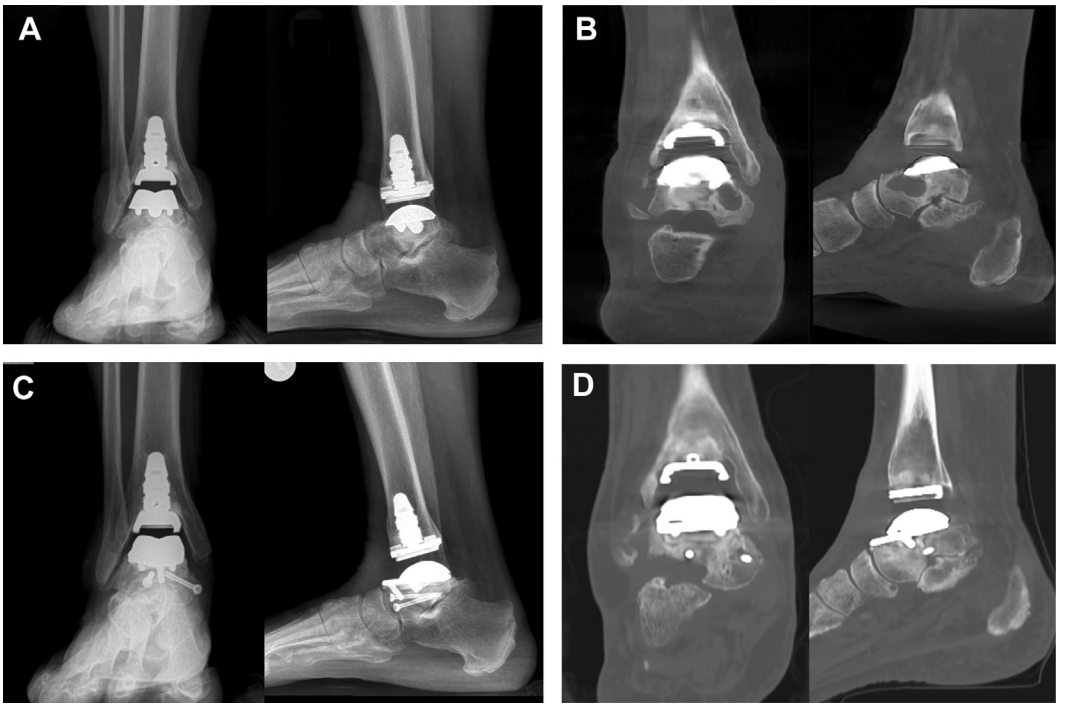


Fig. 4. (*A*) Preoperative radiographs and (*B*) CT images of a patient with recurrent right ankle pain 7 years after TAA demonstrating periprosthetic cysts of the talus. A periprosthetic talus fracture through the bone cyst and unstable talar component was seen intraoperatively (see Fig. 2). (*C*) Postoperative radiographs and (*D*) CT images 19 months after staged talar component explanation, cyst debridement, iliac crest bone grafting, and talar neck open reduction internal fixation followed by revision of the talar component 2 months later.

Periprosthetic cysts of the talus resulting in talar subsidence is a common cause for revision TAA.[61,62] Bone defects can be addressed in several ways for talar component revision. Grafting of bone defects and use of a revision talar component may be a viable option for small cysts or in cases of minimal subsidence (Fig. 4). The use of custom long-stemmed talar implants has been reported to improve fixation in the setting of greater bone loss and implant subsidence.[61,63] If the talus is unable to be salvaged, the use of a custom total talus implant in conjunction with a TAA may be a viable option for severe talar bone loss.[64–66]

Outcomes following revision TAA can be difficult to interpret in the setting of periprosthetic bone cysts because most studies contain small sample sizes or heterogeneous indications for revision. Behrens and colleagues[67] performed a retrospective review of 18 patients who underwent revision TAA for aseptic implant loosening or talar subsidence. Four patients (22.2%) required additional component revision at an average follow-up of 57.3 months, one of whom was for infection. Despite progression of osteolysis in 27.8% of patients following revision TAA, patient-reported outcomes (PROs) remained comparable to primary TAA with similar implants. Lachman and colleagues[68] reviewed a larger cohort of 52 patients who underwent revision TAA for aseptic causes at an average of 5.5 years following primary TAA. Eleven patients (21.2%) required additional surgery with 6 converting to arthrodesis and the remaining 5 undergoing a second revision surgery. Otherwise, PROs improved following revision TAA but not to the level after primary TAA.

A larger series evaluating outcomes of revision TAA was published by Hintermann and colleagues[69] who reported a series of 117 revision TAAs with indications including implant loosening, subsidence, malposition, cyst formation, instability, and infection. At an average follow-up of 6.2 years following revision TAA, 17 patients (15%) required additional revision of components or arthrodesis. The remaining 100 patients demonstrated improvement in PROs with 81 patients obtaining good or excellent American Orthopedic Foot and Ankle Society hindfoot scores. The investigators deemed revision TAA as a viable treatment option for failure of primary TAA. Last, Egglestone and

colleagues[70] performed a retrospective review of 31 cases of failed TAA undergoing surgical treatment with 21 proceeding with a revision TAA and 10 converting to arthrodesis. Patients undergoing revision TAA had superior PROs with an 87% implant survival at 4 years and arthrodesis was found to have a 20% nonunion rate.

The results of revision TAA may not be as promising as that of primary TAA[71]; however, it remains a viable option for patients with periprosthetic bone cysts that cause implant loosening or subsidence, especially if they desire to maintain range of motion and avoid the potential disadvantages of an arthrodesis.[69,72]

## Arthrodesis

Massive expansion of periprosthetic bone cysts may cause dramatic bone loss and component subsidence, which can severely compromise the ability to perform a revision TAA. In addition, patients may fail multiple attempts at revision TAA resulting in soft tissue compromise, which further contributes to clinical decision making. In these scenarios, arthrodesis is the treatment of choice. Kotnis and colleagues[73] evaluated 14 patients undergoing surgical treatment of TAA aseptic loosening of which 5 patients underwent revision TAA and 9 proceeded with hindfoot arthrodesis. One of the revision TAAs required conversion to arthrodesis and another had evidence of radiographic failure, but declined surgery. Also, a higher proportion of patients undergoing revision TAA had persistent pain postoperatively compared with the hindfoot arthrodesis cohort. With these results, the investigators recommend arthrodesis as the preferred method for management of the failed TAA.

However, arthrodesis following failed TAA should not be viewed the same as a primary arthrodesis with longer time to union and inferior PROs related to pain and function.[74] In addition to bone loss, poor bone quality making rigid fixation difficult and compromise of the surrounding soft tissues creates a challenge for conversion of the failed TAA to an arthrodesis.[45] Union rates following arthrodesis for failed TAA have been variable with rates ranging from 58% to 95%.[75–82] Varying surgical techniques, patient factors, graft choice, and severity of bone loss likely contributes to the wide range of reported union rates. Gross and colleagues[83] performed a systematic review including 16 studies to determine the outcomes following conversion of a failed TAA to arthrodesis. A total of 193 patients were included, and an 84% union rate was observed after first attempts at arthrodesis with improved union rates seen with isolated tibiotalar arthrodesis compared with tibiotalocalcaneal (TTC) arthrodesis.

When possible, a tibiotalar arthrodesis should be performed to preserve the motion of the subtalar joint. In addition, TTC arthrodesis after failed TAA appears to have inferior union rates when compared with isolated tibiotalar arthrodesis.[78,83] However, TTC arthrodesis may be indicated in the setting of severe talar bone loss limiting adequate fixation, severe talar subsidence involving the subtalar joint, or symptomatic subtalar arthritis.[84]

To address issues with bone loss and union during arthrodesis, graft is often required with options including autograft, allograft, and metal cage implants. Autograft can be used for smaller bone defects without need for significant structural support, although these patients may be better suited with attempted revision TAA. When bone loss is greater than 2 cm, a graft that provides structural support is necessary.[45] The most common allograft used in this scenario is a bulk femoral head allograft, which provides adequate bone stock and structural support for arthrodesis (Fig. 5). Coetzee and colleagues[85] reviewed outcomes of 45 cases of failed TAAs undergoing tibiotalar and TTC arthrodesis using femoral head allograft with an average of

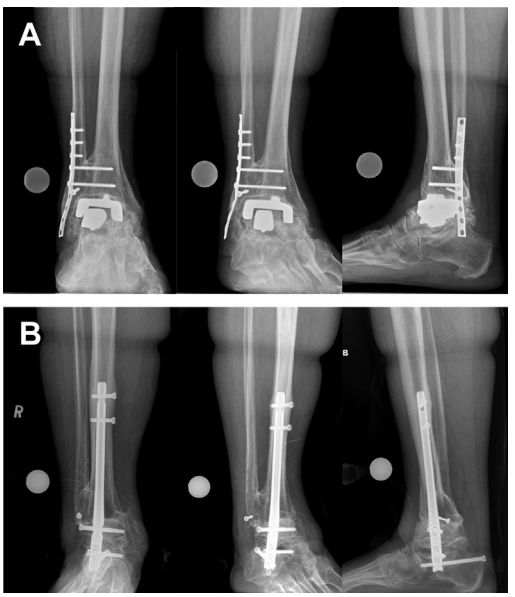


Fig. 5. (*A*) Weight-bearing radiographs 12 years following a right TAA in a patient with increasing right ankle pain demonstrating periprosthetic cyst formation involving the tibia and talus and with talar component subsidence. (*B*) Postoperative radiographs following conversion to a TTC arthrodesis with use of a femoral head allograft.

42.8 months follow-up. All 15 patients who underwent tibiotalar arthrodesis achieved union with high patient satisfaction. However, 5 (17%) of the 30 patients in the TTC arthrodesis group experienced nonunion.

In addition to bulk femoral head allograft, metal cage implants can be used to assist in the management of severe bone loss.[86] Potential advantages of these implants include customization to the specific patient and lower risk of collapse with improved mechanical properties.[87] Steele and colleagues[87] compared outcomes of patients who underwent TTC arthrodesis with either a femoral head allograft or a custom spherical implant. Eight patients underwent arthrodesis with a custom spherical implant, and 7 patients received a femoral head allograft. The spherical implant cohort had significantly higher rates of successful union and less graft resorption when compared with femoral head allograft. It is important to note that these procedures were not exclusively performed in patients with failed TAA. When looking at the use of metal cage implants specifically for failed TAA, outcomes are not as encouraging.[88] Aubret and colleagues[89] investigated union rates in 10 patients who underwent arthrodesis using a noncustom Trabecular Metal (Zimmer Biomet, Warsaw, IN, USA) implant with the use of iliac crest autograft. One patient underwent isolated tibiotalar arthrodesis and achieved union. Nine patients underwent TTC arthrodesis with 7 achieving tibiotalar union (78%), 5 achieving subtalar union (56%), and a total of 4 patients who had union at both the tibiotalar and subtalar joint (44%). Three patients (33%) went on to revision surgery.

## SUMMARY

Periprosthetic bone cysts are common following TAA. Cysts can range from small asymptomatic cyst to large cysts causing catastrophic failure of TAA. Further investigation is needed to better understand the cause, risk factors, prevention, and optimal surgical treatment of this condition.

## CLINICS CARE POINTS

- Periprosthetic bone cysts after TAA are a common radiographic finding with a wide range of clinical consequences
- Patients with small, asymptomatic cysts and stable TAA implants can be monitored on an annual basis with assessment for development of symptoms, progression of cysts size, periprosthetic fracture, or implant loosening or subsidence.
- Patients with large, progressive, or symptomatic cysts and stable implants can be treated with cyst debridement and grafting. However, the success of this procedure is variable.
- Patients with implant loosening or subsidence can be treated with revision TAA or salvage arthrodesis depending on the severity of bone loss and soft tissue compromise.

## DISCLOSURE

The authors have nothing to disclose.

## REFERENCES


1. Glazebrook M, Daniels T, Younger A, et al. Comparison of health-related quality of life between patients with end-stage ankle and hip arthrosis. J Bone Joint Surg Am 2008;90(3):499–505.
2. Cracchiolo A 3rd, Deorio JK. Design features of current total ankle replacements: implants and instrumentation. J Am Acad Orthop Surg 2008; 16(9):530–40.
3. Henne TD, Anderson JG. Total ankle arthroplasty: a historical perspective. Foot Ankle Clin 2002;7(4): 695–702.
4. Sanders AE, Kraszewski AP, Ellis SJ, et al. Differences in gait and stair ascent after total ankle arthroplasty and ankle arthrodesis. Foot Ankle Int 2021;42(3):347–55.
5. Singer S, Klejman S, Pinsker E, et al. Ankle arthroplasty and ankle arthrodesis: gait analysis compared with normal controls. J Bone Joint Surg Am 2013;95(24):e191, 191-110.
6. Thomas R, Daniels TR, Parker K. Gait analysis and functional outcomes following ankle arthrodesis for isolated ankle arthritis. J Bone Joint Surg Am 2006;88(3):526–35.
7. Coester LM, Saltzman CL, Leupold J, et al. Long-term results following ankle arthrodesis for post-traumatic arthritis. J Bone Joint Surg Am 2001; 83(2):219–28.
8. Fuchs S, Sandmann C, Skwara A, et al. Quality of life 20 years after arthrodesis of the ankle. A study of adjacent joints. J Bone Joint Surg Br 2003; 85(7):994–8.
9. Hendrickx RP, Stufkens SA, de Bruijn EE, et al. Medium- to long-term outcome of ankle arthrodesis. Foot Ankle Int 2011;32(10):940–7.
10. Haddad SL, Coetzee JC, Estok R, et al. 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(9):1899–905.
11. Kim HJ, Suh DH, Yang JH, et al. Total ankle arthroplasty versus ankle arthrodesis for the treatment of end-stage ankle arthritis: a meta-analysis of comparative studies. Int Orthop 2017;41(1):101–9.
12. Stavrakis AI, SooHoo NF. Trends in Complication Rates Following Ankle Arthrodesis and Total Ankle Replacement. J Bone Joint Surg Am 2016;98(17): 1453–8.
13. Pugely AJ, Lu X, Amendola A, et al. Trends in the use of total ankle replacement and ankle arthrodesis in the United States Medicare population. Foot Ankle Int 2014;35(3):207–15.
14. Vakhshori V, Sabour AF, Alluri RK, et al. Patient and practice trends in total ankle replacement and tibiotalar arthrodesis in the united states from 2007 to 2013. J Am Acad Orthop Surg 2019;27(2):e77–84.
15. Hauer G, Hofer R, Kessler M, et al. Revision rates after total ankle replacement: a comparison of clinical studies and arthroplasty registers. Foot Ankle Int 2022;43(2):176–85.
16. Lintz F, Mast J, Bernasconi A, et al. 3D, Weight-bearing topographical study of periprosthetic cysts and alignment in total ankle replacement. Foot Ankle Int 2020;41(1):1–9.
17. Mehta N, Serino J, Hur ES, et al. Pathogenesis, evaluation, and management of osteolysis following total ankle arthroplasty. Foot Ankle Int 2021;42(2):230–42.
18. Besse JL. Osteolytic cysts with total ankle replacement: frequency and causes? Foot Ankle Surg 2015;21(2):75–6.
19. Espinosa N, Klammer G, Wirth SH. Osteolysis in total ankle replacement: how does it work? Foot Ankle Clin 2017;22(2):267–75.
20. Schipper ON, Haddad SL, Fullam S, et al. Wear characteristics of conventional ultrahigh-molecular-weight polyethylene versus highly cross-linked polyethylene in total ankle arthroplasty. Foot Ankle Int 2018;39(11):1335–44.
21. Bischoff JE, Fryman JC, Parcell J, et al. Influence of crosslinking on the wear performance of polyethylene within total ankle arthroplasty. Foot Ankle Int 2015;36(4):369–76.
22. Assal M, Kutaish H, Acker A, et al. Three-year rates of reoperation and revision following mobile versus fixed-bearing total ankle arthroplasty: a cohort of 302 patients with 2 implants of similar design. J Bone Joint Surg Am 2021;103(22):2080–8.
23. Gaudot F, Colombier JA, Bonnin M, et al. A controlled, comparative study of a fixed-bearing versus mobile-bearing ankle arthroplasty. Foot Ankle Int 2014;35(2):131–40.
24. Nunley JA, Adams SB, Easley ME, et al. Prospective randomized trial comparing mobile-bearing and fixed-bearing total ankle replacement. Foot Ankle Int 2019;40(11):1239–48.
25. Arcangelo J, Guerra-Pinto F, Pinto A, et al. Periprosthetic bone cysts after total ankle replacement. A systematic review and meta-analysis. Foot Ankle Surg 2019;25(2):96–105.
26. Schipper ON, Haddad SL, Pytel P, et al. Histological analysis of early osteolysis in total ankle arthroplasty. Foot Ankle Int 2017;38(4):351–9.
27. Gross CE, Huh J, Green C, et al. Outcomes of bone grafting of bone cysts after total ankle arthroplasty. Foot Ankle Int 2016;37(2):157–64.
28. van Wijngaarden R, van der Plaat L, Nieuwe Weme RA, et al. Etiopathogenesis of osteolytic cysts associated with total ankle arthroplasty, a histological study. Foot Ankle Surg 2015;21(2):132–6.
29. Naude JJ, Saragas NP, Ferrao PNF. CT scan assessment and functional outcome of periprosthetic bone grafting after total ankle arthroplasty at medium-term follow-up. Foot Ankle Int 2022;43(5): 609–19.
30. Singh G, Reichard T, Hameister R, et al. Ballooning osteolysis in 71 failed total ankle arthroplasties. Acta Orthop 2016;87(4):401–5.
31. Sundfeldt M, Carlsson LV, Johansson CB, et al. Aseptic loosening, not only a question of wear: a review of different theories. Acta Orthop 2006; 77(2):177–97.
32. Mondal S, Ghosh R. Effects of implant orientation and implant material on tibia bone strain, implant-bone micromotion, contact pressure, and wear depth due to total ankle replacement. Proc Inst Mech Eng H 2019;233(3):318–31.
33. Espinosa N, Walti M, Favre P, et al. Misalignment of total ankle components can induce high joint contact pressures. J Bone Joint Surg Am 2010;92(5): 1179–87.
34. Fukuda T, Haddad SL, Ren Y, et al. Impact of talar component rotation on contact pressure after total ankle arthroplasty: a cadaveric study. Foot Ankle Int 2010;31(5):404–11.
35. Escudero MI, Symes M, Bemenderfer TB, et al. Does patient-specific instrumentation have a higher rate of early osteolysis than standard referencing techniques in total ankle arthroplasty? A radiographic analysis. Foot Ankle Spec 2020;13(1): 32–42.
36. Escudero MI, Le V, Bemenderfer TB, et al. Total ankle arthroplasty radiographic alignment comparison between patient-specific instrumentation and standard instrumentation. Foot Ankle Int 2021;42(7): 851–8.
37. Heisler L, Vach W, Katz G, et al. Patient-Specific Instrumentation vs standard referencing in total ankle arthroplasty: a comparison of the radiologic outcome. Foot Ankle Int 2022;43(6):741–9.

38. Lee GW, Seo HY, Jung DM, et al. Comparison of preoperative bone density in patients with and without periprosthetic osteolysis following total ankle arthroplasty. Foot Ankle Int 2021;42(5):575–81.
39. Cho NH, Kim S, Kwon DJ, et al. The prevalence of hallux valgus and its association with foot pain and function in a rural Korean community. J Bone Joint Surg Br 2009;91(4):494–8.
40. Waizy H, Behrens BA, Radtke K, et al. Bone cyst formation after ankle arthroplasty may be caused by stress shielding. A numerical simulation of the strain adaptive bone remodelling. Foot (Edinb) 2017;33:14–9.
41. Kormi S, Kohonen I, Koivu H, et al. Low rate of periimplant osteolysis in trabecular metal total ankle replacement on short- to midterm follow-up. Foot Ankle Int 2021;42(11):1431–8.
42. Aspenberg P, van der Vis H. Fluid pressure may cause periprosthetic osteolysis. Particles are not the only thing. Acta Orthop Scand 1998;69(1):1–4.
43. Bonnin M, Gaudot F, Laurent JR, et al. The Salto total ankle arthroplasty: survivorship and analysis of failures at 7 to 11 years. Clin Orthop Relat Res 2011;469(1):225–36.
44. Henry JK, Rider C, Cody E, et al. Evaluating and managing the painful total ankle replacement. Foot Ankle Int 2021;42(10):1347–61.
45. Hsu AR, Haddad SL, Myerson MS. Evaluation and management of the painful total ankle arthroplasty. J Am Acad Orthop Surg 2015;23(5):272–82.
46. Besse JL, Brito N, Lienhart C. Clinical evaluation and radiographic assessment of bone lysis of the AES total ankle replacement. Foot Ankle Int 2009;30(10):964–75.
47. Viste A, Al Zahrani N, Brito N, et al. Periprosthetic osteolysis after AES total ankle replacement: Conventional radiography versus CT-scan. Foot Ankle Surg 2015;21(3):164–70.
48. Kohonen I, Koivu H, Pudas T, et al. Does computed tomography add information on radiographic analysis in detecting periprosthetic osteolysis after total ankle arthroplasty? Foot Ankle Int 2013;34(2):180–8.
49. de Cesar Netto C, Fonseca LF, Fritz B, et al. Metal artifact reduction MRI of total ankle arthroplasty implants. Eur Radiol 2018;28(5):2216–27.
50. Serino J, Kunze KN, Jacobsen SK, et al. Nuclear medicine for the orthopedic foot and ankle surgeon. Foot Ankle Int 2020;41(5):612–23.
51. Yoon HS, Lee J, Choi WJ, et al. Periprosthetic osteolysis after total ankle arthroplasty. Foot Ankle Int 2014;35(1):14–21.
52. Kohonen I, Koivu H, Tiusanen H, et al. Are periprosthetic osteolytic lesions in ankle worth bone grafting? Foot Ankle Surg 2017;23(2):128–33.
53. Yang HY, Wang SH, Lee KB. The HINTEGRA total ankle arthroplasty: functional outcomes and implant survivorship in 210 osteoarthritic ankles at a mean of 6.4 years. Bone Joint J 2019;101-B(6):695–701.
54. Besse JL, Lienhart C, Fessy MH. Outcomes following cyst curettage and bone grafting for the management of periprosthetic cystic evolution after AES total ankle replacement. Clin Podiatr Med Surg 2013;30(2):157–70.
55. Lundeen GA, Barousse PS, Moles LH, et al. Technique tip: endoscopic-assisted curettage and bone grafting of periprosthetic total ankle arthroplasty bone cysts. Foot Ankle Int 2021;42(2):224–9.
56. Myerson MS, Won HY. Primary and revision total ankle replacement using custom-designed prostheses. Foot Ankle Clin 2008;13(3):521–38, x.
57. Jonck JH, Myerson MS. Revision total ankle replacement. Foot Ankle Clin 2012;17(4):687–706.
58. Devries JG, Berlet GC, Lee TH, et al. Revision total ankle replacement: an early look at agility to INBONE. Foot Ankle Spec 2011;4(4):235–44.
59. Gaden MT, Ollivere BJ. Periprosthetic aseptic osteolysis in total ankle replacement: cause and management. Clin Podiatr Med Surg 2013;30(2):145–55.
60. Horisberger M, Henninger HB, Valderrabano V, et al. Bone augmentation for revision total ankle arthroplasty with large bone defects. Acta Orthop 2015;86(4):412–4.
61. Li SY, Myerson MS. Management of Talar component subsidence. Foot Ankle Clin 2017;22(2):361–89.
62. Glazebrook MA, Arsenault K, Dunbar M. Evidence-based classification of complications in total ankle arthroplasty. Foot Ankle Int 2009;30(10):945–9.
63. Ketz J, Myerson M, Sanders R. The salvage of complex hindfoot problems with use of a custom talar total ankle prosthesis. J Bone Joint Surg Am 2012;94(13):1194–200.
64. Bejarano-Pineda L, DeOrio JK, Parekh SG. Combined total talus replacement and total ankle arthroplasty. J Surg Orthop Adv 2020;29(4):244–8.
65. Kurokawa H, Taniguchi A, Morita S, et al. Total ankle arthroplasty incorporating a total talar prosthesis: a comparative study against the standard total ankle arthroplasty. Bone Joint J 2019;101-B(4):443–6.
66. Kanzaki N, Chinzei N, Yamamoto T, et al. Clinical outcomes of total ankle arthroplasty with total talar prosthesis. Foot Ankle Int 2019;40(8):948–54.
67. Behrens SB, Irwin TA, Bemenderfer TB, et al. Clinical and radiographic outcomes of revision total ankle arthroplasty using an intramedullary-referencing implant. Foot Ankle Int 2020;41(12):1510–8.

68. Lachman JR, Ramos JA, Adams SB, et al. Revision surgery for metal component failure in total ankle arthroplasty. Foot Ankle Orthop 2019;4(1). 2473011418813026.
69. Hintermann B, Zwicky L, Knupp M, et al. HINTEGRA revision arthroplasty for failed total ankle prostheses. J Bone Joint Surg Am 2013;95(13):1166–74.
70. Egglestone A, Kakwani R, Aradhyula M, et al. Outcomes of revision surgery for failed total ankle replacement: revision arthroplasty versus arthrodesis. Int Orthop 2020;44(12):2727–34.
71. Lachman JR, Ramos JA, Adams SB, et al. Patient-reported outcomes before and after primary and revision total ankle arthroplasty. Foot Ankle Int 2019;40(1):34–41.
72. Hordyk PJ, Fuerbringer BA, Roukis TS. Sagittal ankle and midfoot range of motion before and after revision total ankle replacement: a retrospective comparative analysis. J Foot Ankle Surg 2018;57(3):521–6.
73. Kotnis R, Pasapula C, Anwar F, et al. The management of failed ankle replacement. J Bone Joint Surg Br 2006;88(8):1039–47.
74. Rahm S, Klammer G, Benninger E, et al. Inferior results of salvage arthrodesis after failed ankle replacement compared to primary arthrodesis. Foot Ankle Int 2015;36(4):349–59.
75. Deleu PA, Devos Bevernage B, Maldague P, et al. Arthrodesis after failed total ankle replacement. Foot Ankle Int 2014;35(6):549–57.
76. Kamrad I, Henricson A, Magnusson H, et al. Outcome after salvage arthrodesis for failed total ankle replacement. Foot Ankle Int 2016;37(3):255–61.
77. Culpan P, Le Strat V, Piriou P, et al. Arthrodesis after failed total ankle replacement. J Bone Joint Surg Br 2007;89(9):1178–83.
78. Berkowitz MJ, Clare MP, Walling AK, et al. Salvage of failed total ankle arthroplasty with fusion using structural allograft and internal fixation. Foot Ankle Int 2011;32(5):S493–502.
79. Hopgood P, Kumar R, Wood PL. Ankle arthrodesis for failed total ankle replacement. J Bone Joint Surg Br 2006;88(8):1032–8.
80. Kitaoka HB, Romness DW. Arthrodesis for failed ankle arthroplasty. J Arthroplasty 1992;7(3):277–84.
81. Carlsson AS, Montgomery F, Besjakov J. Arthrodesis of the ankle secondary to replacement. Foot Ankle Int 1998;19(4):240–5.
82. Ali AA, Forrester RA, O'Connor P, et al. Revision of failed total ankle arthroplasty to a hindfoot fusion: 23 consecutive cases using the Phoenix nail. Bone Joint J 2018;100-B(4):475–9.
83. Gross C, Erickson BJ, Adams SB, et al. Ankle arthrodesis after failed total ankle replacement: a systematic review of the literature. Foot Ankle Spec 2015;8(2):143–51.
84. Adams SB. Salvage Arthrodesis for Failed Total Ankle Replacement. Foot Ankle Clin 2020;25(2):281–91.
85. Coetzee JC, Den Hartog BD, Stone McGaver R, et al. Femoral Head Allografts for Talar Body Defects. Foot Ankle Int 2021;42(7):815–23.
86. Bullens P, de Waal Malefijt M, Louwerens JW. Conversion of failed ankle arthroplasty to an arthrodesis. Technique using an arthrodesis nail and a cage filled with morsellized bone graft. Foot Ankle Surg 2010;16(2):101–4.
87. Steele JR, Kadakia RJ, Cunningham DJ, et al. Comparison of 3D printed spherical implants versus femoral head allografts for tibiotalocalcaneal arthrodesis. J Foot Ankle Surg 2020;59(6):1167–70.
88. Carlsson A. Unsuccessful use of a titanium mesh cage in ankle arthrodesis: a report on three cases operated on due to a failed ankle replacement. J Foot Ankle Surg 2008;47(4):337–42.
89. Aubret S, Merlini L, Fessy M, et al. Poor outcomes of fusion with Trabecular Metal implants after failed total ankle replacement: early results in 11 patients. Orthop Traumatol Surg Res 2018;104(2):231–7.