Article

AMERICAN ORTHOPAEDIC FOOT & ANKLE SOCIETY

Foot & Ankle Orthopaedics
2021, Vol. 6(4) 1–6

DOI: 10.1177/24730114211061493
journals.sagepub.com/home/fao

Accuracy of Weightbearing CT Scans for Patient-Specific Instrumentation in Total Ankle Arthroplasty

Mitchell J. Thompson, DPM[1], Devon Consul, DPM[1], Benjamin D. Umbel, DO[2], and Gregory C. Berlet, MD[1]

Abstract

Background: Total ankle arthroplasty (TAA) is a popular and viable option for end-stage ankle arthritis. Posttraumatic arthritis is the most common etiology of ankle arthritis, which creates the additional challenge of osseus deformity. Accuracy and reproducibility in placing the implant on the mechanical axis has been shown to be paramount in all joint arthroplasty including total ankle replacement. Patient-specific preoperative navigation is a relatively new technology for TAA, and up until this past year has been based off of nonweightbearing (NWBCT) or simulated weightbearing computed tomography (WBCT). Our institution has created a protocol to use WBCT in the preoperative patient-specific navigation for TAA using the Prophecy system. The purpose of our study was to compare the accuracy and reproducibility of implant alignment and size using WBCT vs prior studies using NWBCT for the Prophecy reports.

Methods: All patients from July 2019 through October 2020 who underwent TAA were evaluated. Inclusion criteria consisted of primary TAA using patient-specific preoperative navigation who had postoperative radiographs in the 4-6-week time frame. Prophecy predictions and measurements were then compared to actual implant placement and size.

Results: Ten patients met our inclusion criteria of WBCT Prophecy preoperative planning using 2 different implant systems. Preoperative deformities in this cohort were small. The average postoperative coronal alignment was 0.84 degrees, range 0.19 to 2.4 degrees. Average postoperative sagittal plane deformity was 1.9 degrees, range 0.33 to 5.05 degrees. Tibial component size was properly predicted in all patients, talar component in 9 of 10.

Conclusion: This initial report supports accuracy and reproducibility in preoperative patient-specific navigation when using WBCT for TAA with these implants. All TAAs were within the intended target of less than 5 degrees varus or valgus.

Level of Evidence: Level III, retrospective comparative analysis.

Keywords: total ankle replacement, patient-specific instrumentation, weightbearing computed topography (CT), accuracy

Introduction

Symptomatic ankle arthritis is a challenging condition, with approximately 1% of the population suffering from ankle arthritis.[2] Contrary to what is seen by orthopaedic surgeons who manage hip and knee arthritis, ankle arthritis is usually posttraumatic and can occur earlier in life than hip and knee arthritis.[9,10] One epidemiologic study demonstrated that roughly 70% of patients with ankle arthritis were posttraumatic in nature.[9] Glazebrook et al[5] reported the major negative effects on the quality of life experienced by patients with significant ankle arthritis. Therefore, reliable and durable treatment options must be continually improved for a younger, more active patient population.

Patient-specific instrumentation (PSI) for total ankle arthroplasty (TAA) with preoperative computed tomography (CT) templating is a relatively new technology. More extensive use and subsequent research studies have been published in the total hip and knee arthroplasty literature with the goal of improving implant alignment, operating room efficiency, and hospital costs, while improving patient

[1]Orthopedic Foot and Ankle Center, Worthington, OH, USA
[2]Department of Orthopedic Surgery, OhioHealth, Columbus, OH, USA

Corresponding Author:
Mitchell J. Thompson, DPM, Orthopedic Foot and Ankle Center, 350 W Wilson Bridge Rd, Suite 200, Worthington, OH 43085, USA.
Email: ThompsonMJ@orthofootankle.com

outcomes. In the total knee arthroplasty literature, it has been generally agreed on that accomplishing a neutral implant alignment is of paramount importance. Hsu and Haddad proposed that coronal implant alignment in TAA should be considered "neutral" if positioned in less than 5 degrees of varus or valgus.[7] The same goals and PSI technologies from total knee arthroplasty have been extrapolated and integrated into TAA surgical planning.

However, several studies previously reporting on the accuracy and reproducibility of the Prophecy system for TAA preoperative planning exclusively used nonweightbearing CT (NWBCT) scans.[1,3,6] Owing to the majority of ankle arthritis being posttraumatic by diagnosis, assessment of concomitant instability or malalignment of the hindfoot, midfoot, or forefoot may be a critical component of preoperative planning for TAA. Accordingly, weightbearing CT (WBCT) scans to assess for foot and ankle pathology and deformity are becoming more popular. If adjunct procedures are considered at the time of TAA or in a staged manner, identifying deformity or instability with WBCT scans can be invaluable to prevent early implant failure. Pyevich et al[8] noted that any incongruencies in TAA components has a significant impact on contact pressures on implants. Their study highlights the importance of accurate implant positioning in TAA. Furthermore, postoperative radiographic alignment of TAA implants has not been found to be superior when comparing standard instrumentation to PSI utilizing NWBCT scans.[4]

To our knowledge, there are currently no published reports defining the role of WBCT scans for preoperative TAA templating and PSI. The purpose of this study was to retrospectively assess accuracy and reproducibility of WBCT scans in determining implant position with preoperative patient-specific guides for TAA.

Methods

This study was a retrospective radiographic analysis measuring the accuracy and reproducibility of PSI in TAA recipients at a single institution (Orthopedic Foot and Ankle Center Worthington, Ohio) performed by the senior author. After receiving our institution's formal institutional review board approval, a retrospective review was done using CPT Code 27702 to identify all TAAs with implant that have been performed since July 2019. This date was chosen as this was the commencement of the WBCT Prophecy scan protocol at our institution. All patient records were then reviewed for the utilization of the prophecy reports for total ankle replacement guidance.

Our inclusion criteria consisted of Wright Medical INFINITY or INBONE II total ankle replacements, implanted using the Prophecy PSI, Prophecy scans must be based off of WBCT, and must have weightbearing radiographs within 4-6 weeks postoperation. Our exclusion criteria consisted of any TAA not using the prophecy guidance, revision TARs, and any TARs that did not have weightbearing radiographs at time of publication. In accordance with our inclusion criteria, all Prophecy reports, along with the CT scans these reports were based on, were then reviewed to ensure the Prophecy reports were based off of WBCT performed at our institution under the aforementioned WBCT Prophecy protocol.

All Prophecy reports generated from WBCT were reviewed for multiple preoperative data points. The prophecy report reports a mechanical axis based on the accepted technique and then reports the current alignment in the arthritic (preimplant) joint. Per Prophecy technique, the INBONE II tibia is aligned with the anatomic axis, and the INFINITY is aligned with the mechanical axis. This information was recorded to reflect the preoperative deformity (Figure 1). First, the axis (anatomic or mechanical) in which the tibial component was based off was recorded; this is found on the first page of the Prophecy report. The differences between these 2 planes in the coronal and sagittal planes were also recorded as the preoperative deformity.

Neutral alignment was considered less than 5 degrees varus or valgus in the coronal plane. Finally, the predicted tibial and talar component sizes from the Prophecy report were recorded for later comparison.

All first postoperative weightbearing radiographs were reviewed and measured by 2 of the authors. The first postoperative weightbearing radiograph most accurately represented the initial position of operative placement. Each set of measurements were done in an anonymized fashion and then the average of these measurements was recorded as the postoperative measurements. The coronal anatomic axis of the tibia in the anterior-posterior weightbearing radiographs was determined by connecting 2 markers located at the center of the tibia at a consistent distance apart in the distal third of the tibia. This line connected these 2 markers and then extended through the center of the ankle joint to represent the anatomic tibial axis (Figure 2). The mechanical axis that is now determined by implant placement was determined by a line connecting 2 markers at the center of the implant a consistent distance apart. These 2 marks were in the proximal stem and base of the stem for the INBONE II implant, and within the distal most and proximal most aspects of the tibial tray for the INFINITY implant. The axis of the implant would be perpendicular to the articular surface of the implant. All measurements were performed using InteleViewer radiographic software. The difference between the tibia axis and axis of the implant was then recorded for each patient. The sagittal plane axis for the tibia and the implant was done in a similar fashion using the lateral weightbearing view radiograph (Figure 3). The difference between these 2 axes was then recorded as dorsiflexion or plantarflexion.

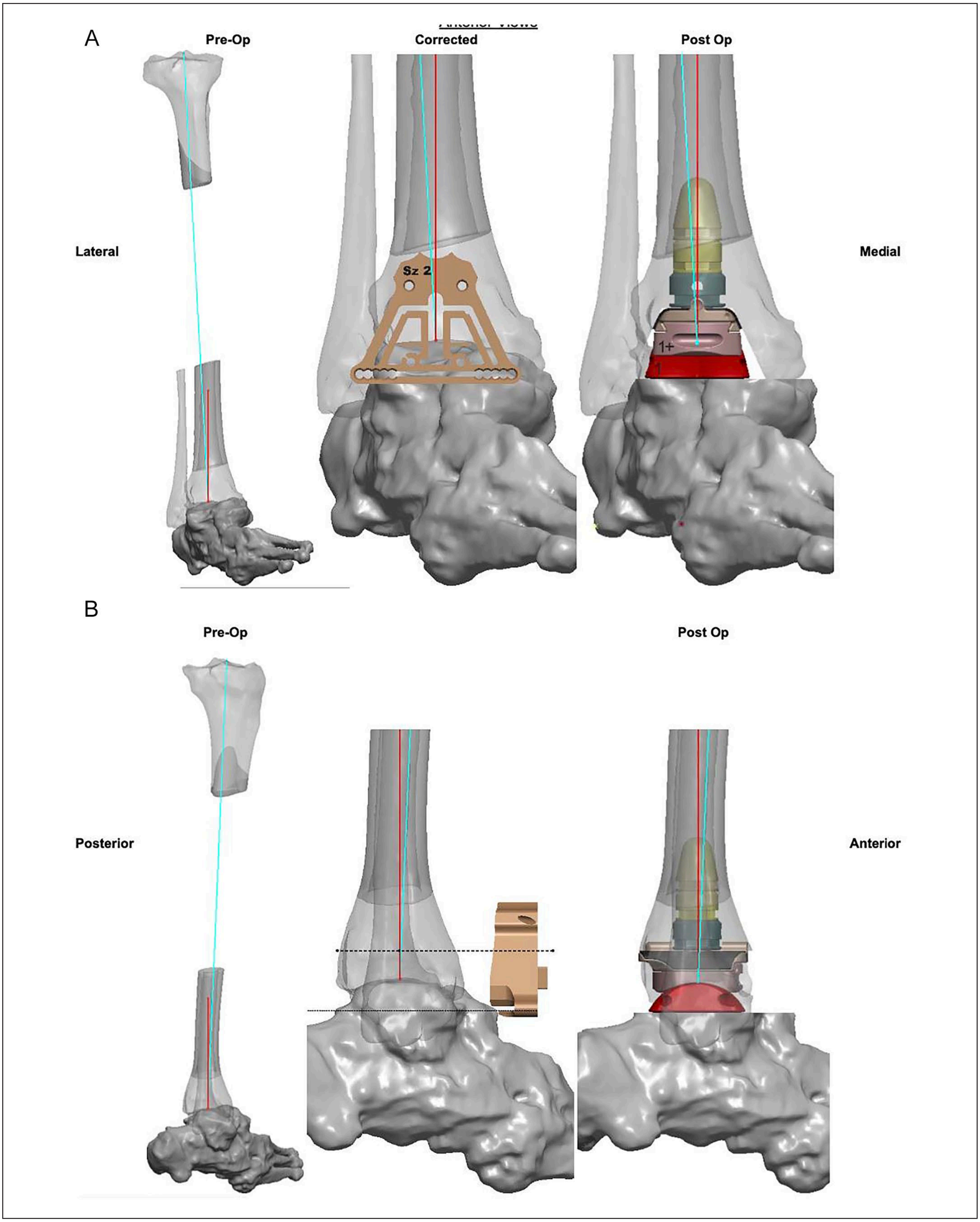

Figure 1. (A) Anterior preoperative and postoperative navigation showing coronal plane deformity and correction. (B) Lateral preoperative and postoperative navigation showing sagittal plane deformity and correction. (Credit Prophecy, Wright Medical).

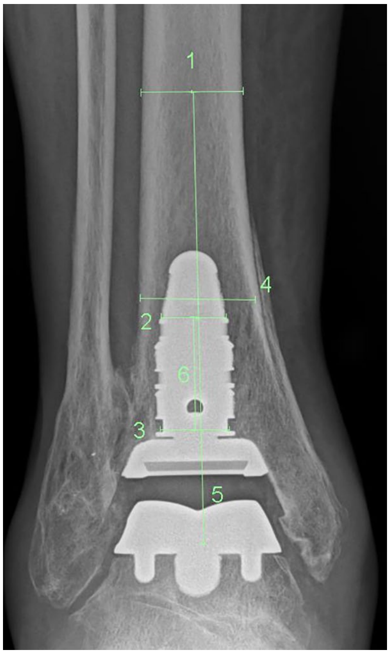

Figure 2. Coronal measurements with line 5 representing tibial axis and line 6 representing implant axis. Line 5 is made by the bisection of lines 1 and 3, and line 6 made of the bisection of lines 2 and 3.

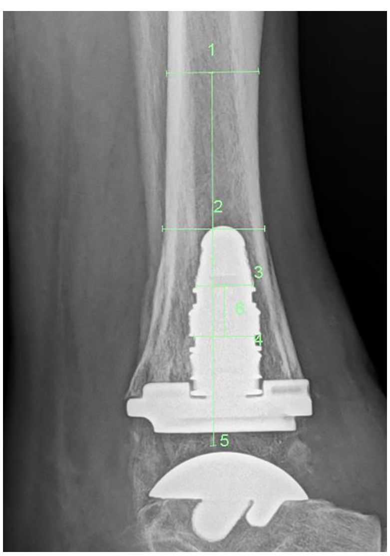

Figure 3. Sagittal plane measurements with line 5 representing tibial axis and line 6 representing implant axis. Line 5 is made by the bisection of lines 1 and 2, and line 6 made of the bisection of lines 3 and 4.

Each operative report was then reviewed for each patient to record the tibial and talar component sizes implanted. These implant sizes, along with the coronal and sagittal plane measurements, were then compared to the predicted sizes and measurements from the Prophecy report.

Results

After review of all TAA done between July 2019 and September 2020, there were 85 TAAs done at our institution. Twenty-seven of the 85 ankle replacements used the Prophecy PSI, and of those 27, 12 were based off of a WBCT done at our institution under our protocol. Two of the 12 included patients were unable to obtain weightbearing radiographs prior to publication and were subsequently excluded from the study, leaving an initial cohort of 10 patients who underwent full chart review and radiographic measurements. There were 7 women (70%) and 3 men (30%). The average age of all participants was 63.9 (range 48-79) years.

Of the 10 patients meeting inclusion criteria, 4 had undergone the INFINITY implant and 6 underwent the INBONE II implant. All 6 of the INBONE II TAA had the Prophecy guidance align with the tibial anatomic axis, and all 4 of the INFINITY implants had the Prophecy guidance aligned with the mechanical axis.

Postoperative Alignment: Tibial Component

There was minimal coronal plane deformity noted in our 10 patients, with the average coronal plane difference between mechanical and anatomic axis being 0.94 (range 0-2.10) degrees. The average postoperative coronal plane deformity between the implant and tibial axis was 0.84 degrees (Table 1). This results in a 0.10-degree difference between the preoperative Prophecy report and our postoperative implant placement. Patient with a preoperative varus deformity were corrected to an average postoperative 1 degree of varus, with 2 of the patients ending in 0.69 and 0.24 degrees of valgus. Four patients had preoperative valgus deformity, 2 of which ended in varus, 2.44 and 0.35 degrees, respectively. The other 2 patients with preoperative valgus was corrected from 0.8 to 0.4 degrees valgus and 2.60 to 0.93 degrees valgus. The final patient had no difference between the anatomic and mechanical axis on the preoperative CT imaging, and at the first weightbearing radiograph, the implant was at 0.37 degrees of valgus. All patients, regardless of preoperative varus or valgus, were in neutral alignment postoperatively. The largest postoperative degree measurement was 2.44 degrees of varus, which is still well within the 5 degrees needed to be considered neutral alignment (Table 1).

The average preoperative sagittal plane deformity as measured by the Prophecy reports was 0.79 (range 0-3) degrees. The average postoperative sagittal plane deformity was 1.88 (range 0.3-3.63) degrees. This results in a

Table 1. Preoperative and Postoperative Measurements in Coronal and Sagittal Planes.

Patient	Implant Type	Axis Alignment	Preop Difference Between Axes	Postop. Difference Between Axes	Preop. Varus	Preop. Valgus	Postop. Varus	Postop. Valgus	Sagittal Preop.	Sagittal Postop.	Predicted Implant Size (Tibial, Talar)	Implant Used (Tibial, Talar)
1	Infinity	Mechanical	0	0.375	0	0	–	0.375	0.2	0.33 (df)	1, 1	1, 1
2	Inbone2	Anatomic	0.5	0.81	0.5	–	0.81	–	3	5.05 (df)	3, 3	3, 3
3	Inbone2	Anatomic	0.2	2.01	0.2	–	2.01	–	0.7	3.59 (pf)	4, 3	4, 3
4	Inbone2	Anatomic	0.5	2.44	–	0.5	2.44	–	0.7	1.52 (df)	3, 2	3, 2
5	Infinity	Mechanical	0.8	0.4	–	0.8	–	0.4	0.1	0.56 (df)	2, 1	2, 1
6	Infinity	Mechanical	0.9	0.185	0.9	–	0.18	–	0.6	1.52 (df)	4, 3	4, 3
7	Infinity	Mechanical	2.1	0.355	–	2.1	0.35	–	0	0.25 (pf)	1, 1	1, 1
8	Inbone2	Anatomic	0.7	0.695	0.7	–	–	0.69	1.8	1.72 (df)	3, 2	3, 3
9	Inbone2	Anatomic	1.1	0.24	1.1	–	–	0.24	0.7	0.48 (pf)	3, 2	3, 2
10	Inbone2	Anatomic	2.6	0.93	–	2.6	–	0.93	0.1	3.76 (df)	2, 1	2, 1
Average			0.94	0.844	0.567	1.2	1.16	0.527	0.79	1.88		Tibial: 100%; talar: 90%

Abbreviations: df, dorsiflexion; pf, plantarflexion.

difference of 1.09 degrees from the predicted Prophecy report and final implant placement (Table 1).

Instrumentation

The patient-specific navigation template predicts the size of the tibial tray and talar component for each specific patient. The tibial tray was predicated correctly by the preoperative navigation template 100% of the time regardless if it was the INBONE II or INFINITY. The talar component was predicted correctly 90% of the time for the entire cohort. The INBONE II talar component was predicted correctly for each patient it was used on except for 1 (5/6) and the INFINITY talar component was predicted correctly 100% of the time it was implanted.

Discussion

Total ankle replacement surgery continues to rise in popularity as a viable option among patients with end-stage ankle arthritis. The goal of a total ankle replacement is to improve functional activity with decreased pain. To maximize outcomes while trying to limit failure or revision, the ankle implant must be properly aligned within the ankle joint. The importance of this element has led to evolving technology that provides preoperative navigation and prediction of implant placement to better assist the surgeon. In 2017, Daigre and colleagues[3] looked at 44 TAAs that used the preoperative patient-specific guidance to determine accuracy and reproducibility of the implant placement. The preoperative patient-specific guidance was based off of NWBCTs. The coronal alignment was corrected from a mean preoperative 4.6 degrees, to a mean postoperative 1.8 degrees. The range of the postoperative coronal alignment was from 5 degrees varus to 3.6 degrees valgus. Patients with a varus preoperative alignment were corrected to a mean 2.4 degrees of varus postoperatively. Patients with valgus deformity noted preoperative were corrected to a mean 1.9 degrees postoperatively. All patients with a valgus deformity were corrected to neutral (within 5 degrees varus or valgus), and all but 2 patients with a preoperative varus deformity were corrected to a neutral ankle alignment. The authors reported a mean postoperative sagittal alignment of 2.4 (range 6.5 dorsiflexion to 5.0 degrees plantarflexion) degrees. The preoperative navigation correctly predicted the tibial tray size in 97.7% of the patients and the talar component in 79.5% of the patients.[3]

The preoperative navigation templates help create PSI guides based on preoperative CT scans of the patient's ankle. A cadaveric study was performed on 15 specimens using this preoperative templating system. The authors reported accurate implant positioning with less than 2 degrees of difference between preoperative and postoperative implant positioning in all planes of motion.[1] Hsu et al[6] later published on early clinical results using the Prophecy system. The authors used both INFINITY and INBONE II total ankle systems (Wright Medical Technology, Memphis, TN). They reported an average preoperative to postoperative difference of less than 3 degrees in the coronal and sagittal planes for implant positioning.[6] Another study assessing total ankle arthroplasty in 44 patients using INBONE II found that 100% of coronal and sagittal postoperative implant positioning was within 5 degrees of the preoperative template.[3] They also were able to accurately match their preoperatively planned tibial component and talar component coronal size in 98% and 80% of cases, respectively.[3]

Our data using preoperative navigation based off of WBCT showed 100% of patients had postoperative "neutral" alignment, based on the criteria of <5 degrees. The mean postoperative coronal alignment was 0.84 (range 0.19-2.44) degrees. All preoperative varus deformities were corrected to within 2 degrees of neutral and all preoperative valgus deformities were corrected to within 2.44 degrees of neutral. The average postoperative varus deformity was 1.16 degrees and the average postoperative valgus was 0.53

degrees. This average postoperative difference between mechanical and anatomical axis in the coronal plane of 0.84 degrees is less than what has been reported when using NWBCT for preoperative guidance (1.8 degrees) although we do not know if these differences are clinically or statistically significant.[3] Our average postoperative sagittal alignment was 1.88 degrees, which again is 0.52 degrees closer to neutral than what was reported with the NWBCT, and again we do not know if these differences are significant.[3] It should be made clear the goal of the preoperative patient-specific guidance is to create cut guides that will align the implant to as close to neutral (0 degrees) as possible, and when based off of a WBCT, may be more accurate in reaching this goal.

The tibia is the constant point to which the patient-specific navigation is based on. The tibia itself is also a rigid body and should not change morphology regardless of weightbearing status.

Our data suggest the possibility of a more precise alignment in the frontal plane than prior studies using NWBCT. The tibia component size accuracy was comparable in our study to the accuracy in the prior studies using NWBCT; in both groups, there was good accuracy in predicting the tibia component size. Using WBCT for preoperative navigation did also provide good prediction of the talar component size within the current series.

There are limitations of our initial study. The first limitation is the small number of total ankle replacements included, and as such should be seen as a pilot study. Another limitation is the minimal severity of preoperative deformity in this patient cohort. Two different total ankle implants (INBONE II and INFINITY) were involved in this study without direct separation and comparison of only like implants; therefore, this can also be seen as a limitation of this study. We did not directly compare NWBCT vs WBCT scan use in the same patients, so all comments about the differences are inferential at best.

Conclusion

This small series of patients with limited deformity suggests that patient-specific guides based off WBCT scans has potential for reliable postoperative alignment. Further work is needed to compare use of WBCT to NWBCT for PSI ankle replacements.

Ethical Approval

Ethical approval was not sought for the present study because the analysis was conducted on de-identified data and poses minimal risks to participants.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Gregory C. Berlet, MD, is a design consultant for Wright Medical Technology and receives royalty payments on some of the products discussed. He reports receiving all support for the present manuscript (eg, funding, provision of study materials, medical writing, and article processing charges) from Curvebeam, which is currently sponsoring another study with Medshape; royalties from Wright Medical Technology; and consulting fees from Wright Medical Technology. ICMJE forms for all authors are available online.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Benjamin D. Umbel, DO, https://orcid.org/0000-0002-1416-6509

References

1. Berlet GC, Penner MJ, Lancianese S, Stemniski PM, Obert RM. Total ankle arthroplasty accuracy and reproducibility using preoperative CT scan-derived, patient-specific guides. *Foot Ankle Int*. 2014;35(7):665-676.
2. Brown TD, Johnston RC, Saltzman CL, Marsh JL, Buckwalter JA. Posttraumatic osteoarthritis: a first estimate of incidence, prevalence, and burden of disease. *J Orthop Trauma*. 2006;20(10):739-744.
3. Daigre J, Berlet G, Van Dyke B, Peterson KS, Santrock R. Accuracy and reproducibility using patient-specific instrumentation in total ankle arthroplasty. *Foot Ankle Int*. 2017;38(4):412-418.
4. 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):851-858. doi:10.1177/1071100721996379
5. 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.
6. Hsu AR, Davis WH, Cohen BE, Jones CP, Ellington JK, Anderson RB. Radiographic outcomes of preoperative CT scan-derived patient-specific total ankle arthroplasty. *Foot Ankle Int*. 2015;36(10):1163-1169.
7. Hsu AR, Haddad SL. Early clinical and radiographic outcomes of intramedullary-fixation total ankle arthroplasty. *J Bone Joint Surg Am*. 2015;97(3):194-200.
8. Pyevich MT, Saltzman CL, Callaghan JJ, Alvine FG. Total ankle arthroplasty: a unique design. Two to twelve-year follow-up. *J Bone Joint Surg Am*. 1998;80(10):1410-1420.
9. Saltzman CL, Salamon ML, Blanchard GM, et al. Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic center. *Iowa Orthop J*. 2005;25:44-46.
10. SooHoo NF, Zingmond DS, Ko CY. Comparison of reoperation rates following ankle arthrodesis and total ankle arthroplasty. *J Bone Joint Surg Am*. 2007;89(10):2143-2149.