



# Radiographic Evaluation of Anterior Ankle Soft Tissue Thickness

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## ABSTRACT

**Objective:** To evaluate radiographic methods for measuring anterior ankle soft tissue thickness and its relation to patient characteristics. We hypothesize there will be differences between x-ray and CT measurements, and that there will be noticeable trends between measurements of anterior ankle soft tissue thickness and patient habitus.

**Methods:** A retrospective cohort of patients who underwent total ankle arthroplasty between 2017 and 2023 at our institution were analyzed. Preoperative x-rays and CT scans were utilized to measure anterior ankle soft tissue thickness, with a novel CT-based technique introduced. Additionally, correlations of anterior soft tissue envelope thickness to patient body habitus were evaluated.

**Results:** The study included 307 patients, 51.8% were women. The analysis demonstrated significantly different soft tissue measurements between x-ray and CT. There was a moderate relationship between x-ray and CT measurements ( $R=0.50$ ), while interrater reliability was strong for x-ray ( $ICC=0.67$ ), and very strong for CT ( $ICC=0.92$ );  $p<0.001$ ). Patient characteristics such as height, weight, and BMI showed weak relationships with soft tissue thickness across x-ray and CT.

**Conclusion:** The anterior ankle soft tissue envelope is an emerging and important predictor of outcomes following total ankle arthroplasty in the literature. Our study describes a new, highly reliable method of estimating anterior ankle soft tissue thickness. Future studies correlating these findings to in-vivo measurements are imperative to establishing an accurate and precise measurement technique, with the hope of optimizing patient outcomes following TAA.

**KEYWORDS:** Musculoskeletal imaging, Radiography, CT, Comparative imaging, Ankle arthritis.

## INTRODUCTION

Total ankle arthroplasty (TAA) has emerged as a preferred surgical option for managing end-stage ankle arthritis, offering significant improvements in pain relief and functional outcomes. However, complications following TAA remain a concern, particularly those

related to soft tissue healing, prosthetic joint infections (PJIs), and eventual implant failure.<sup>1,2</sup> A growing body of evidence underscores the critical role of perioperative factors, including preoperative soft tissue thickness in influencing postoperative outcomes.<sup>3</sup> Despite the fact that the ankle soft tissue envelope is emerging as an important surgical consideration for total ankle arthroplasty, there currently exists no standardized method to radiographically evaluate anterior soft tissue thickness in patients.

Previous work by our group has shown an association between preoperative anterior ankle soft tissue thickness and superficial infection after TAA. This relationship was independent of patient weight and body mass index.<sup>4</sup> Wu et al. demonstrated an association between increased soft tissue thickness and higher revision rates at a minimum five-year follow-up, emphasizing the importance of preoperative assessment.<sup>3</sup> Conversely, Kalma et al. identified that decreased soft tissue thickness was associated with increased incidence of wound complications.<sup>5</sup> They support the idea that decreased soft tissue thickness may be a predictor of wound complications after TAA. Similarly, evidence by Matson et al. found obesity was associated with fewer wound healing issues following open reduction internal fixation of ankle fractures.<sup>6</sup> They hypothesized that the ankle presents a unique anatomic situation where obesity and thicker soft tissue envelopes may be protective, rather than conducive, against wound complications.

There are several ways that soft tissue thickness has been measured radiographically. This has included x-ray, computerized tomography (CT), magnetic resonance imaging (MRI), and ultrasound. MRI is the gold standard for soft tissue detail, supported by LiMarzi et al. with their exploration of different imaging modalities for diagnosis of ankle impingement syndromes.<sup>7</sup> However, the cost expenditure and associated time is more significant regarding MRI compared to other imaging modalities. Wu et al. has suggested methods to assess anterior ankle soft tissue thickness utilizing simple x-ray measurement techniques.<sup>3</sup> However, no analogous technique using CT has been described.

The aim of this study was to evaluate the reproducibility of x-ray based and CT based methods of estimating the anterior ankle soft tissue envelope. We relied on a unique cohort of patients who underwent patient specific instrumentation (PSI) for total ankle arthroplasty and therefore had both preoperative x-ray and CT information available. We further sought to identify the relationship between patient habitus and anterior ankle soft tissue thickness. We hypothesize that noticeable trend between measurements of anterior ankle soft tissue thickness and patient habitus.

## METHODS

### Database

Our imaging database was constructed using studies and demographic information from patients who underwent total ankle arthroplasty at our institution under a single surgeon from 2017-2023. These patients all obtained pre-operative computed tomography scans in order to design their patient-specific instrumentation. This database was chosen because this is a unique patient population in which all-comers would have routine CT scans of their ankle, in

addition to preoperative radiographs. In addition to radiographic measurements, we collected routine demographic information on our patients including age, sex, height, weight and body mass index (BMI). All patients received patient specific instrumentation utilizing the *Infinity® Total Ankle System* implant (Stryker, 1941 Stryker Way, Portage, MI, USA, 49002).

### Radiographic Analysis

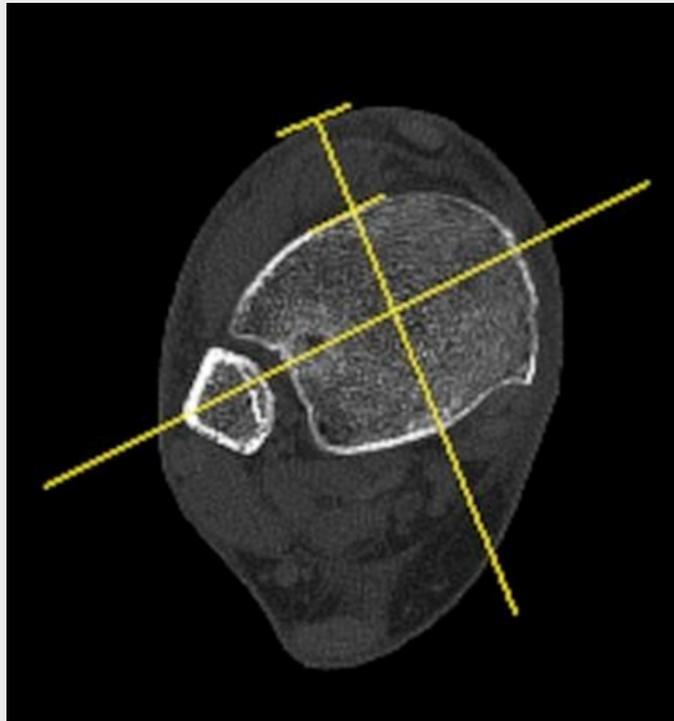
Soft tissue thickness on both lateral weight bearing radiographs of the ankle and preoperative CT scans were compared. In determining thickness on lateral radiographs, we utilized the strategy employed by Wu et al.<sup>3</sup> In short, a line was drawn through the anterior and posterior lips of the distal tibia in the region of the plafond. Soft tissue thickness was measured along this line, anterior to the anterior lip of the plafond.

Regarding ankle soft tissue thickness measurements on CT, we required a novel strategy. Axial and sagittal CT scans with functional slice thickness of 1.00 mm were utilized in this study. Through a linear line bisecting the medial and lateral malleoli at the maximum point of the plafond, we established a standard reference point to ensure all axial measurements were obtained utilizing the same region. The widest point of the plafond was determined through slice cut analysis of axial CT imaging, in which the plafond reached its maximum width. A separate line was then drawn perpendicularly, bisecting the plafond along the previously drawn line. Anterior ankle soft tissue was measured based on soft tissue on this axis anterior to the anterior border of the plafond. (Figure 1) Radiographic measurements were recorded by a single orthopaedic surgeon. To evaluate for the reproducibility of measurements, we also performed a separate review by another investigator to calculate interrater reliability. Power analysis for this study indicated a minimum comparison of 99 patients to detect a correlation of .40 or greater, assuming an alpha of .05 and a beta of .80. All measurements were performed with investigators blinded to the patient demographic information including weight and BMI, and with blinding of the other investigator's measurements. Furthermore, differences in lateral ankle soft tissue thickness between preoperative and first clinical postoperative films were assessed for swelling. These postoperative films were obtained at the 2-weeks postoperative interval. Differences between pre- and postoperative thickness were evaluated using paired t-test, with a statistical significance level set at .05.

### Data Analysis

Demographic information was reported with percentages for binomial variables, and medians with interquartile ranges for continuous variables when appropriate.

Correlation of height, weight, and BMI to both x-ray as well as CT derived measurements was evaluated using Pearson R correlation coefficient. Analysis was based on standard assessments of correlation, in which 0.0 to 0.19 was considered very weak, 0.20 to 0.39 was considered weak, 0.40 to 0.59 was considered moderate, 0.60 to 0.79 was considered strong, and 0.80 and greater was considered very strong. Intraclass correlation coefficients were also used to evaluate inter-rater reliability between both methods of anterior ankle soft tissue measurement and interpreted using the same scale.



**Figure 1.** Computed tomography-based assessment strategy of anterior ankle soft tissue thickness using axial sequence

### Inclusion and Exclusion Criteria

Patients that were included for this study were over the age of eighteen at the time of surgery, those that had undergone total ankle arthroplasty between the years 2017-2023 by the senior orthopaedic author, a minimum follow-up of six months postoperatively, alongside viewable preoperative and postoperative x-ray and CT scans.

Patients were excluded if they met any one of the following criteria: under the age of eighteen at the time of surgery, no or missing preoperative or postoperative imaging, did not undergo TAA, had concomitant injuries at the time of surgery, or failed to follow-up postoperatively or did not follow-up within six months postoperatively.

### Ethical Considerations

This study was approved by our hospital's institutional review board, IRB #2022-148. No informed consent was required for this project.

## RESULTS

### Cohort Information

In total, 434 patients were initially assessed for fit in this study. Of this preliminary population, 307 patients who underwent patient specific instrumentation for total ankle arthroplasty from 2017 to 2023 met inclusion for this study. All patients had preoperative x-rays and CT scans within six months of the date of surgery. 51.8% of patients were women. Mean weight and BMI were 88.1 kg and 30.3

kg/m<sup>2</sup>; respectively. Full demographic information is contained within Table 1.

**Table 1.** Patient Cohort Demographics.

Category	Overall
n	307
Sex, n (%)	
F	159 (51.8)
M	148 (48.2)
Height in cm, mean (SD)	169.8 (11.4)
Weight in kg, mean (SD)	88.1 (21.1)
BMI (kg/m <sup>2</sup> ), mean (SD)	30.3 (5.2)
Xray Soft Tissue Thickness in mm, mean (SD)	18.7 (4.4)
CT Soft tissue Thickness in mm, mean (SD)	16.7 (4.0)

cm=centimeter. Kg=kilogram. BMI. mm=millimeter. SD=standard deviation.

### Radiographic Measurement of Anterior Soft Tissue Thickness

The average ankle soft tissue thickness measured on x-ray was 18.7mm, compared to 16.7mm when measured using the axial cut from CT scans at the level of plafond. These values were significantly different ( $p < 0.001$ ). Through standardized measurement calibration within the PACS© imaging system, errors of magnification within plain film x-rays were accounted for and controlled.

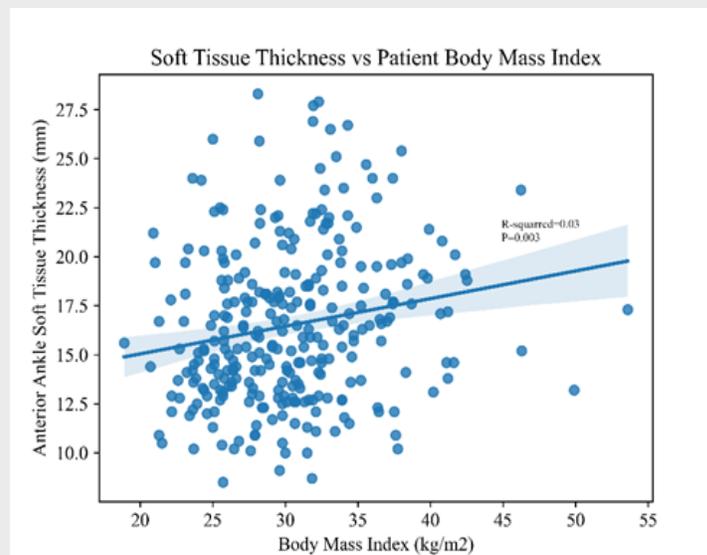
When looking at the relationship between patient body habitus and ankle soft tissue thickness, height was very poorly correlated to measurement on both x-ray and CT ( $R = 0.18$  and  $0.15$ ; respectively). Weight was poorly correlated ( $R = 0.31$  and  $0.23$ ; respectively). Furthermore, BMI was poorly correlated ( $R = 0.27$ ) on x-ray and very poorly correlated ( $R = 0.18$ ) to soft tissue thickness on CT. There was a moderate correlation between soft tissue thickness when measured on x-ray versus the same value when measured on CT ( $R = 0.50$ ). All p-values for correlation coefficients were  $< 0.01$  and were significant even when accounting for multiple comparisons. Table 2 contains the full correlation matrix showing results of these comparisons. When comparing pre- and postoperative soft tissue thickness using lateral x-rays, there was an increase of on average 2.2mm between pre- and postoperative films ( $P = .01$ ). Figure 2 shows the direct correlation between anterior ankle soft tissue thickness and patient BMI was also calculated. The  $R^2$  value for this relationship was 0.03 ( $p = 0.003$ ), indicating a negligible relationship.

When looking at the interrater reliability of our measurement techniques, measurement of anterior ankle soft tissue thickness on x-ray was found to have strong interrater reliability,  $R = 0.67$ . Our novel method of CT derived anterior ankle soft tissue measurement had very strong interrater reliability between our two reviewers,  $R = 0.92$ . Both these results were significant ( $P < .001$ ).

**Table 2.** Correlation matrix of patient demographic data and radiographic measurements

Categories	Xray Soft Tissue Thickness in mm, mean (SD)	CT Soft tissue Thickness in mm, mean (SD)
Height (cm)	0.18	0.15
Weight (kg)	0.31	0.23
BMI (kg/m <sup>2</sup> )	0.27	0.18
Xray Soft Tissue Thickness in mm, mean (SD)	1	0.5
CT Soft tissue Thickness in mm, mean (SD)	0.5	1
All p-values <0.01		

mm=millimeter. cm=centimeter. Kg=kilogram. BMI = body mass index. SD=standard deviation

**Figure 2.** Correlation between anterior ankle soft tissue thickness and patient body mass index

## DISCUSSION

Our study found remarkable differences between measurements of anterior ankle soft tissue thickness with CT and x-ray. Anterior ankle soft tissue thickness, when measured utilizing x-ray, were overall thicker than when measured using CT. Indicating that the thickness observed on x-ray is greater than that of the measurements obtained utilizing computerized tomography. We did not find significant relationships between height, weight, and BMI with anterior ankle soft tissue thickness. There was a significantly greater soft tissue thickness comparing pre- and postoperative films when measured on x-ray. There was greater interrater reliability through the use of CT when compared to x-ray.

Previous studies have not addressed the comparison between CT and x-ray measurements for anterior ankle soft tissue thickness. We proposed that CT may be a better predictor of precise preoperative measurements, supported by our greater interrater reliability through the use of CT. While this technique has shown to be a precise and effective method, its accuracy remains unanswered. Through the utilization of intraoperative and calibrated measurements during

arthroplasty, the accuracy of utilizing CT scans as a preoperative measurement tool of anterior ankle soft tissue thickness, can be further clarified. While we cannot comment on the rate of complications based on soft tissue thickness, this adds context to the existing literature in regards to imaging reliability, as x-rays were utilized as the main way to determine soft tissue thickness.<sup>3,5</sup>

The anterior ankle soft tissue envelope is emerging as an important predictor in outcomes after foot and ankle surgery, including in the increasingly common procedure of total ankle arthroplasty. In this study, we demonstrated a novel method of estimating anterior ankle soft tissue thickness using computed tomography imaging obtained prior to surgery. Our method was shown to have high interrater reliability, and also consistently estimates a lower soft tissue thickness when compared to utilizing plain lateral ankle radiographs. Despite obesity (BMI > 30 kg/m<sup>2</sup>) being a known risk factor for TAA failure, its applicability in measuring anterior ankle soft tissue thickness has been controversial at best due to unique adipose distribution and inaccurate measurement techniques.<sup>3,8-10</sup> In this study, we also demonstrated that standard numeric evaluators of patient habitus

such as weight and body mass index are poorly correlated to the thickness of the anterior ankle soft tissue envelope.

This study provides important commentary in the discussion initiated by Wu et al. in their paper regarding radiographic soft tissue thickness and its association with revision rates in total ankle surgery.<sup>3</sup> They found that increased soft tissue anterior to the tibia and talus both were independent predictors of revision at 5 years for total ankle arthroplasty. Similar to our work, they also demonstrated that the body mass index alone was an imperfect predictor of failure after ankle replacement, and that soft tissue thickness may provide an important adjunct to risk analysis. They postulated that a larger anterior soft tissue envelope would provide challenges in intraoperative correction of deformity and malalignment. Our study differed from theirs in that it focused solely on the anterior soft tissue thickness at the level of the tibial plafond, as opposed to both at the tibial and talar level independently. Similarly, we utilized the advantage of relying on both x-ray and CT in our estimation of the soft tissue envelope. Our standardized method of CT evaluation was shown to be both higher in interrater reliability than using x-ray, and also yielded consistently lower estimates of soft tissue thickness than x-ray, suggesting that employing lateral plain radiographs may be overestimating the true thickness of the soft tissue envelope. We did find that postoperative radiographs obtained in our clinic demonstrates a significant increase of on average 2.2 mm of soft tissue thickness of ankle soft tissue thickness when measured on lateral x-rays. This difference may be attributable to post-operative swelling and inflammation; concerns for impact of film magnification are addressed through the calibration design of *PACS*© imaging, in which standard measurement lengths are established. Future study should investigate whether the change in thickness on pre and post-operative films has a correlation with eventual patient outcomes, including pain score and infection.

It is important to consider the accuracy of soft tissue thickness measurements in both x-ray and CT. We report a significant difference between these measurements, with x-ray calculations being consistently higher than CT. One possible explanation lies in a lack of standardization between x-ray techniques. While all patients had recent preoperative standing radiographs, our clinical x-rays did not standardize lower extremity rotation of beam position. Rotation and beam positioning has already been shown to be consequential in radiographic calculation of ankle and hindfoot alignment.<sup>11</sup> There is a possibility that with a higher standardized x-ray protocol that controls for lower extremity rotation and foot position, as well as beam position and exposure, may actually provide a more consistent estimation of ankle soft tissue thickness than what has been represented in this study. It may offer a much more cost-effective strategy than preoperative CT. Due to the novelty of our CT measurement methods, and similar recentness of x-ray measurement protocols, further research needs to be investigated into the true accuracy of these imaging derived measurements compared to true intraoperative thicknesses.

Innovative approaches to mitigating soft tissue complications following TAA have also been explored. Wallace et al. investigated the efficacy of noninvasive soft tissue expansion strips in reducing

wound complications, providing a novel adjunct to enhance healing in high-risk patients.<sup>12</sup> Additionally, Noguchi et al. reported successful outcomes with early resection of the tibialis anterior tendon in cases of tendon exposure, suggesting a proactive strategy to prevent deep infections in rheumatoid arthritis patients undergoing TAA.<sup>13</sup>

Comparative studies have further elucidated the impact of surgical techniques on wound outcomes. Reb et al. found a higher incidence of anterior incision wound complications in patients undergoing total ankle arthroplasty compared to ankle arthrodesis, emphasizing the need for targeted interventions to address this disparity.<sup>14</sup> Gross et al. provided a comprehensive overview of soft tissue reconstruction techniques post-TAA, offering valuable insights into optimizing outcomes in cases of severe wound complications.<sup>15</sup>

## LIMITATIONS

The present study has several limitations. As a single-institution retrospective chart review of TAA's performed by a single surgeon, the generalizability to patient populations, surgical techniques, and outcomes is hindered. Furthermore, provided as a retrospective analysis, the capacity to ensure full data collection for all patients and tailored research investigations were limited. Additionally, we utilize CT as a radiographic surrogate of anterior ankle soft tissue thickness. While the present data demonstrates that this method is consistent and reproducible, it remains an estimate and cannot correlate perfectly with in-vivo measurements performed in the operative theater at time of arthroplasty. Future studies should employ an intraoperative direct measurement of anterior soft tissue thickness techniques in order to directly establish the precision and accuracy necessary to rely upon preoperative x-ray films and CT scans and their role as effective predictive measurement tools.

## CONCLUSIONS

Total ankle arthroplasty is an increasingly common strategy to manage end-stage ankle osteoarthritis. The ankle soft tissue envelope is emerging as an important predictor of outcomes following these surgeries. Our study describes a new, highly reliable method of estimating anterior ankle soft tissue thickness. Our goal is for this measurement strategy to be used in further research on outcomes following total ankle arthroplasty, in order to better risk-stratify patients and to optimize outcomes following this increasingly common procedure.

## ETHICAL APPROVAL

Ethical approval for this study was obtained through institutional review board approval at Oakland University William Beaumont hospital (IRB#2022-148). Research was performed in accordance with the Declaration of Helsinki as described by the World Medical Association (WMA).

## CONSENT TO PARTICIPATE

Data was collected retrospectively using deidentified patient demographic and radiologic information. Individual patient consent was not required per discretion of our hospital's Institutional Review Board.

## CONFLICT OF INTEREST STATEMENT

The above authors have no conflicts of interest to declare with regard to this project. All authors have complete conflict of interest forms available through the American Academy of Orthopaedic Surgeons website at [www.aaos.org](http://www.aaos.org).

## FUNDING

No funding sources were obtained for this project

## DATA AVAILABILITY

Data for this project is derived from non-publicly available patient health information compiled in secure database for research purposes. De-identified cohort data available on request from corresponding author.

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