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# Comparison of Mechanical Axis of the Limb Versus Anatomical Axis of the Tibia for Assessment of Tibiotalar Alignment in End-Stage Ankle Arthritis

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**Abstract**

**Background:** Coronal plane ankle joint alignment is typically assessed using the tibiotalar angle (TTA), which relies on the anatomical axis of the tibia (AAT) and the articular surface of the talus as landmarks. Often, the AAT differs from the mechanical axis of the lower limb (MAL). We set out to test our hypothesis that the TTA using the MAL would differ from the TTA measured using the AAT in patients with ankle osteoarthritis.

**Methods:** Standardized standing long leg radiographs of 61 ankles with end-stage osteoarthritis were analyzed. We measured the MAL and the AAT. A line was drawn along the talar articular surface (TA) and the TTA was calculated using both the MAL (MAL-TA) and the AAT (AAT-TA). The mechanical axis of the tibia (MAT) was also recorded and the MAL-MAT angle calculated. The difference between MAL-TA and AAT-TA and its correlation with the MAL-MAT angle were assessed. Intra- and interobserver agreement were measured for MAL-TA and AAT-TA.

**Results:** The mean MAL-TA was 91.4 degrees (95% CI, 88.5-94.4) and the mean AAT-TA was 91.2 degrees (95% CI, 88.6-93.9). The difference ranged from −8.1 to 7.8 degrees, and was greater than 2 and 3 degrees in 42% and 18% of the patients, respectively. The difference, as an absolute value, also strongly correlated with the MAL-MAT angle ($r = 0.91$, $P < .001$). Intra- and interobserver reliability were excellent for both MAL-TA (intraclass correlation coefficient [ICC], 0.93 and 0.91, respectively) and AAT-TA (ICC, 0.91 and 0.89, respectively).

**Conclusion:** We recommend that surgeons consider using the MAL-TA, which relies on long leg radiographs, especially with proximal deformity, to more accurately measure coronal plane ankle joint alignment.

**Level of Evidence:** Level III, retrospective comparative study.

**Keywords:** ankle, alignment, axis, mechanical, osteoarthritis, MAL-TA

## Introduction

The assessment of ankle alignment is an essential part of the physical examination of patients with foot and ankle pathology. The imbalance of intra-articular forces in malaligned joints leads to the onset and progression of arthritis. Specifically, in the setting of total ankle replacement, the surgeon seeks to balance forces across a resurfaced joint in order to optimize the longevity of the implant. Neutral ankle alignment is key to ensuring normal postoperative biomechanics,[6] while malalignment is a recognized risk factor for failure of total ankle replacement.[6,13]

Measurement of the tibiotalar angle (TTA) using weight-bearing radiographs is routinely used to assess the coronal

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**Table 1.** Demographics.

| | Total ($n$ = 61) | Varus ankle ($n$ = 24) (MAL-TA, <90 deg) | Valgus ankle ($n$ = 30) (MAL-TA, >93 deg) | $P$ value |
|---|---|---|---|---|
| Sex, n (%) | | | | |
| Male | 39 (63.9) | 19 (79.1) | 17 (56.7) | .072[a] |
| Female | 22 (36.1) | 5 (20.9) | 13 (43.3) | |
| Age, y | | | | |
| Mean (SD) | 63.8 (11.5) | 66.6 (9.9) | 61.4 (13.3) | .058[b] |
| Minimum-maximum | 29-82 | 46-82 | 29-80 | |
| Side, n (%) | | | | |
| Right | 34 (56) | 12 (50) | 20 (66.7) | .27[a] |
| Left | 27 (44) | 12 (50) | 10 (33.3) | |

Abbreviations: MAL-TA, mechanical axis of the limb to talar articular surface angle.
[a]Fisher's exact test.
[b]Student $t$ test.

plane alignment of the ankle joint.[17,26,30] The tibial arm of the angle can be drawn using different methods (ie, anatomical axis, mechanical axis, lateral border, or a line passing through the anterior tibial tuberosity)[12,16,20,24,26,30]; however, the anatomical axis of the tibia (AAT) is most commonly used. Najefi et al[16] have recently demonstrated that the TTA measured using the AAT is a reliable measurement in both anteroposterior and mortise radiographs of patients with arthritis and those without. However, AAT differs from the mechanical axis of the lower limb (MAL) by more than 2 degrees in 27% of patients with end-stage ankle arthritis in the absence of any proximal deformity, and in 52% of patients with a proximal deformity.[17]

In this context, we aimed to test our hypothesis that the TTA using the MAL would differ from the TTA measured using the AAT in a cohort of patients with end-stage ankle osteoarthritis.

## Methods

### Study Design

In this retrospective comparative study (level III), we analyzed data recorded as part of routine clinical care at the Foot and Ankle Unit of a tertiary referral center. All procedures performed followed the ethical standards of both institutional research committees and the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study also followed STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

### Study Population

Patients presenting between March 2015 and June 2018 with symptomatic end-stage ankle osteoarthritis prior to their TAR were retrieved. Data were stored on the computer systems at the Royal National Orthopaedic Hospital, Stanmore, UK. Those who had standing long leg radiographs were selected. Patients with chronic inflammatory arthropathies were excluded since their diffusely destructive pattern may have affected the correct identification of the line along the axis of the talar articular surface (TA). Medical notes were searched for sex, age, and side.

Seventy-three ankles (from 71 patients) were screened. After exclusion of 12 cases for inflammatory arthropathy, 61 ankles were included in the analysis (39 from men and 22 from women). The mean age was 63.8 years (range, 29-82 years) (Table 1). Images were reviewed by a foot and ankle fellowship-trained orthopedic surgeon (A.B.), who repeated the measurements twice on a subcohort of 20 patients 2 weeks apart in order to assess the intraobserver (same observer) reliability. A senior foot and ankle resident (A.A.N.) also performed the measurements on the same subcohort to calculate the interobserver (different observer) reliability.

### Measurement of Angles

Weightbearing long leg anteroposterior radiographs were used to measure the MAL, the mechanical axis of the tibia (MAT), the AAT, and a line along the TA (Figure 1 and Table 2). All radiographs were standardized, taken with the patient standing with their feet a comfortable distance apart with their patellae facing forward. The MAL was measured from the center of the femoral head to the center of the tibiotalar joint in the coronal plane. The MAT was represented by a line from the center of the knee joint to the center of the tibiotalar joint. In order to measure the AAT, a line was drawn connecting the tibial shaft center to a point located 10 cm above the surface of the ankle joint, midway between the medial and lateral surfaces (middiaphyseal line) (Table 2).

The alignment of the ankle joint was calculated in 2 ways: (1) as the mechanical axis of the limb to talar articular surface angle (MAL-TA), defined as the medial angle

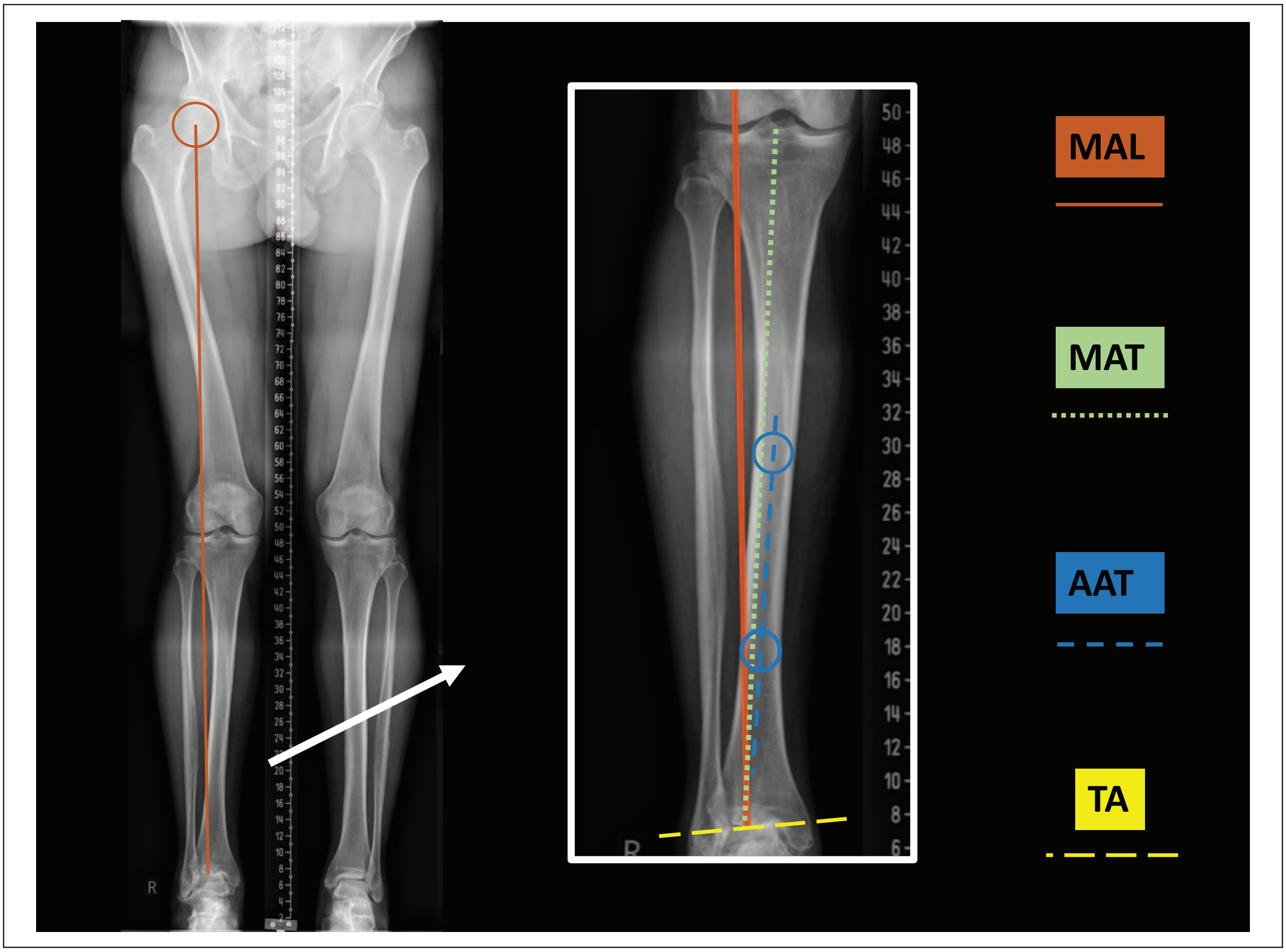


**Figure 1.** Example of anteroposterior long leg alignment radiograph with assessment of the mechanical axis of the lower limb (MAL; continuous line), the mechanical axis of the tibia (MAT; narrow dotted line), the anatomical axis of the tibia (AAT; large dotted line), and the talar articular surface (TA; horizontal very large dotted line).

subtended by the MAL and the TA, and (2) as the classical TTA, defined as the medial angle subtended by the AAT and the TA (AAT-TA) (Figure 2 and Table 2).[18] Additionally, the angle defined by the MAL and MAT (MAL-MAT angle) was calculated since it is the most common parameter used in the literature to describe lower limb alignment (Table 2).[2] This was then correlated with the difference between MAL-TA and AAT-TA to demonstrate whether a greater proximal deformity led to greater differences between the 2 angles.

The lines and angles were measured and calculated using a digital picture archiving and communication system (PACS; McKesson, UK). The accuracy of the line was 0.1 mm. Normal values for TTA have been reported at 91.5 ± 1.2 degrees[11]; therefore, in this study varus alignment was reported as a value <90 degrees, and valgus alignment as a value >93 degrees.

### *Statistical Analysis*

Data were reported as a percentage, mean value, and 95% confidence interval (CI). A regression analysis model with a relative scatterplot was used to evaluate whether the difference between MAL-TA and AAT-TA correlated with the MAL-MAT angle. Intra- and interobserver agreement were measured for MAL-TA and AAT-TA measurements using the intraclass correlation coefficient (ICC).

A sample size calculation was performed considering the difference in TTA as the primary outcome measure. In previous literature, Najefi et al[17] found a difference of 2 degrees between MAL and MAT in 27% of patients. Therefore, we determined a priori that a sample of 52 subjects was sufficient to detect a 2 degree difference (with an estimated SD of 5.1)[16] in TTA (effect size) for a power of 0.80 and type I error (alpha) of 0.05.

**Table 2.** Main Abbreviations Used in the Text and Their Description.[a]

| Abbreviation | Meaning | Description |
|---|---|---|
| TTA | Tibiotalar angle | Generic term commonly used in the literature to describe the angle between the tibial axis (either mechanical or anatomical) and the talar articular surface |
| MAL | Mechanical axis of the lower limb | Line from the center of the femoral head to the center of the tibiotalar joint |
| MAT | Mechanical axis of the tibia | Line from the center of the knee joint to the center of the tibiotalar joint |
| AAT | Anatomical axis of the tibia | Line drawn connecting the tibial shaft center to a point located 10 cm above the surface of the ankle joint, midway between the medial and lateral surfaces (middiaphyseal line) |
| TA | Talar articular surface (dome) | Line along the articular surface of the talar dome |
| MAL-TA | Mechanical axis of the limb to talar articular surface angle | Medial angle subtended by the MAL and the TA |
| AAT-TA | Anatomical axis of the tibia to talar articular surface angle | Medial angle subtended by the AAT and the TA |
| MAL-MAT angle | Mechanical axis of the limb to mechanical axis of the tibia angle | Angle defined by the MAL and MAT; the most common parameter used in the literature to describe lower limb alignment |

[a]All the axes and angles are drawn in the coronal plane.

All statistical analysis was performed using the STATA statistical software package (version 12.0; StataCorp, College Station, TX).

## Results

The mean MAL-TA was 91.4 degrees (95% CI, 88.5-94.4) and the mean AAT-TA was 91.2 degrees (95% CI, 88.6-93.9) (Figure 3). The difference ranged between −8.1 and 7.8 degrees, and was greater than 2 and 3 degrees in 42% and 18% of patients, respectively (Figure 4). In 5 patients, the difference was greater than 5 degrees, and in 2 patients greater than 8 degrees. The mean MAL-MAT angle was 0.6 degrees (95% CI, 0.1-1.2) and correlated almost perfectly with the difference between MAL-TA and AAT-TA ($r = 0.91$, $P < .001$) (Figure 5). The intra- and interobserver reliability were excellent for MAL-TA (ICC, 0.93 and 0.91, respectively) and AAT-TA (ICC, 0.91 and 0.89, respectively).

## Discussion

In this cohort, the MAL-TA and AAT-TA differed by more than 2 degrees in 42% of patients affected by severe ankle osteoarthritis. In fact, the difference was as high as 8 degrees in some patients and strongly correlated with the presence of proximal deformity assessed through the MAL-MAT angle. This suggests that the MAL-TA accounts for the presence of proximal deformities, better representing the biomechanical forces exerted through the ankle. To the best of our knowledge, this is the first study to assess the ankle alignment in the coronal plane using the mechanical axis of the whole lower limb rather than just the distal extent of the tibia.

The ankle joint is an incongruent articulation at light load (due to the sinusoidal radius of the talus as opposed to the constant radius of the tibia) with incomplete and separate contact areas (medially and laterally), but increasing loads cause the transition from incongruence to complete congruence with a continuous stress distribution area, allowing the joint to withstand large pressures.[29] Compressive forces of up to 5.5 times one's body weight go through this relatively small surface area.[22] Osteoarthritis of the ankle, especially after trauma, may result from chronic cartilage overload from articular incongruity and instability.[15] This incongruency needs to be corrected when performing replacement or reconstructive procedures of the ankle and hindfoot. Bearing this in mind, the correct assessment of the TTA appears essential for the preoperative planning of reconstructive procedures of the hindfoot,[10,11,24] joint-sparing procedures such as distal tibia osteotomies,[25,26] and joint-sacrificing surgeries such as total ankle replacement.[3-5,17,20] In particular, postoperative coronal malalignment has been proven to be a risk factor for failure after total ankle replacement[23] and correlates with the development of periprosthetic osteolysis.[28] As such, coronal plane alignment needs to be accurately measured to predict failure of total ankle replacements and prevent postoperative edge loading of the implant.[7,14]

There have been multiple papers reviewing operative outcomes after total ankle replacement in patients with coronal plane deformity,[19,27] where the AAT-TA has been measured on short leg ankle radiographs to calculate the

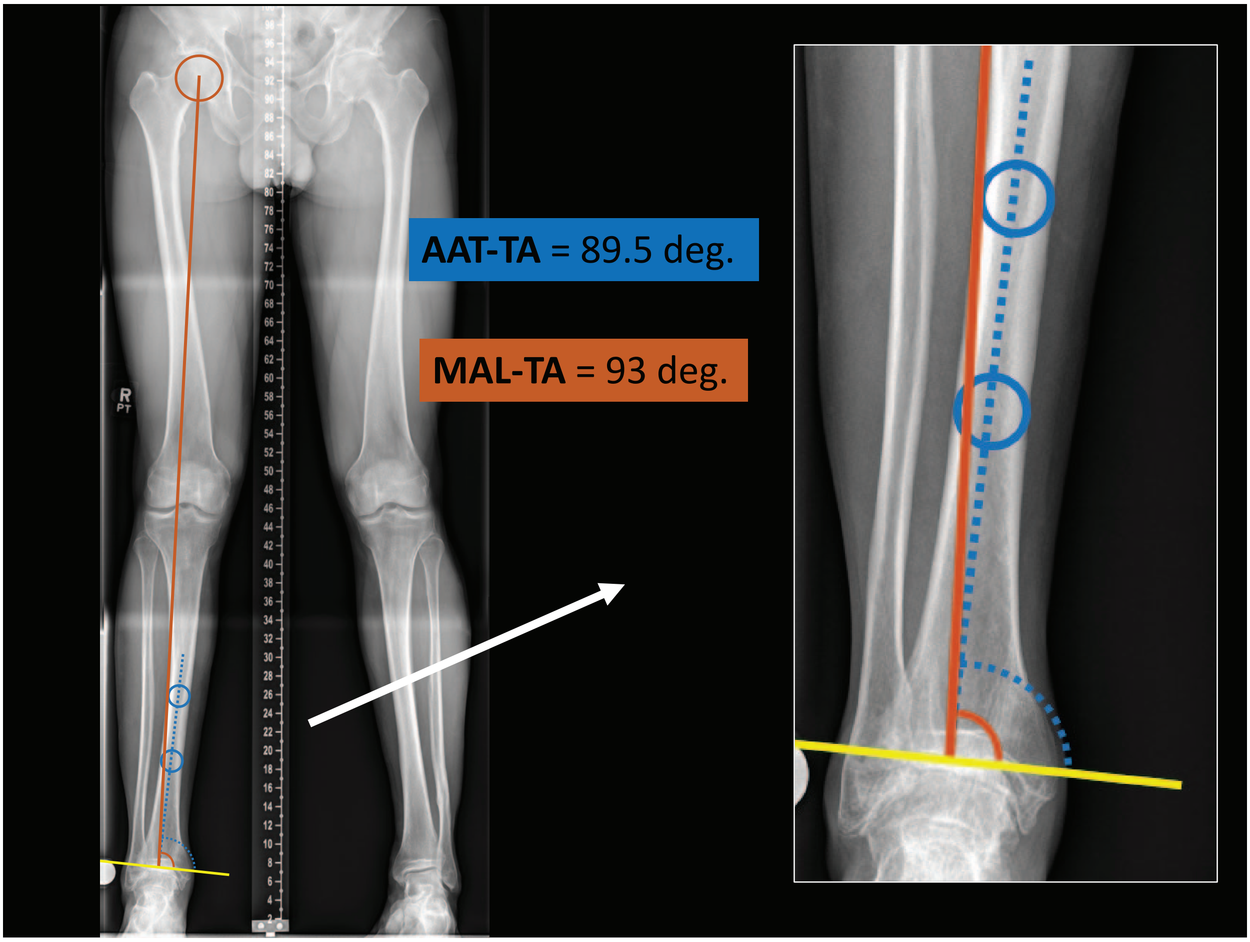


**Figure 2.** In this patient, the assessment of ankle alignment through the MAL-TA (93 degrees) and the AAT-TA (−89.5 degrees) revealed a difference of 3.5 degrees between the 2 methods. AAT-TA, anatomical axis of the tibia to talar articular surface angle; MAL-TA, mechanical axis of the limb to talar articular surface angle.

alignment. A large number of patients with coronal plane deformity have had extensive soft tissue stabilization procedures as a result of their correction to neutral. However, in those patients who have had failures of their implants, it would be interesting to know if their MAL-TA was far greater than the AAT-TA, suggesting that perhaps the coronal plane deformity was not fully corrected.[7] In this case, these patients would require corrective supramalleolar osteotomies to ensure the alignment is corrected and the forces through the ankle are balanced.

Current methods for ankle replacement alignment use the AAT or MAT to align the implant. Interestingly, a significant difference between the AAT and the MAL has been reported, with 27% of patients without known proximal deformity having a difference greater than 2 degrees, and 52% of those with a proximal deformity having a difference of more than 2 degrees.[17] These differences highlight important questions about the appropriateness of using the AAT to gauge the mechanical forces acting at the tibiotalar joint. Without assessing the whole MAL, it is possible to incorrectly estimate the biomechanical stresses around the joint and miscalculate the amount of correction needed.

Furthermore, while most authors use the AAT to measure the TTA, there is heterogeneity with regard to the landmarks adopted to define it. In a 2006 study, Tanaka et al[26] suggested orienting the beam at 30 degrees from posterior and superior to anterior and inferior and using the midpoints of the tibial shaft 8 cm and 13 cm above the medial corner of the tibial plafond to draw the AAT. The authors stressed that a minimum distance of 6 cm from the tibial plafond was necessary to eliminate the influence of tibial bowing on the final measurement.[26] In the majority of other studies, anteroposterior views are recommended with slightly different points marked on the tibia (7.5 cm and 15 cm proximal from the surface of the ankle joint[24] and 8 cm and 15 cm

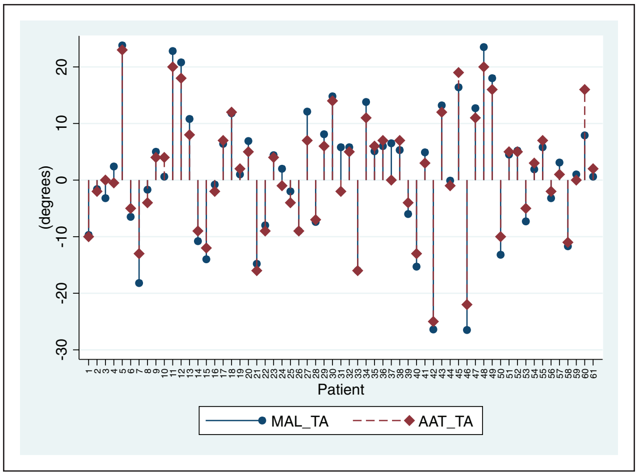


**Figure 3.** Two-way dropline plot reporting MAL-TA (circles) and AAT-TA (diamonds) values (*y*-axis) for each patient in our cohort (*x*-axis). AAT-TA, anatomical axis of the tibia to talar articular surface angle; MAL-TA, mechanical axis of the limb to talar articular surface angle.

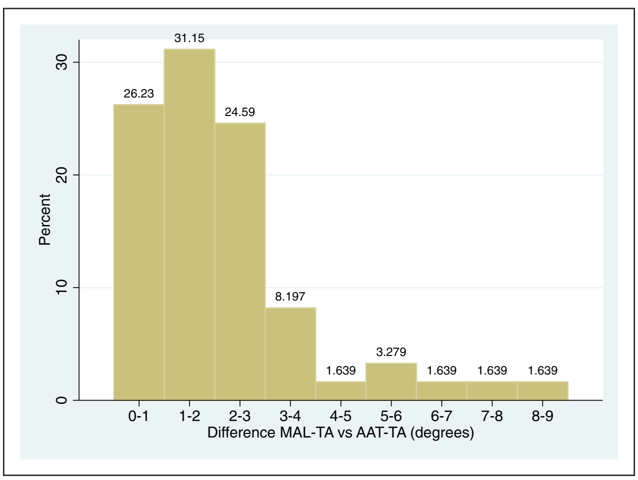


**Figure 4.** Histogram depicting the difference between the MAL-TA and AAT-TA in various proportions of our cohort. In 42% of patients the 2 measurements differed by >2 degrees, in 18% by > 3 degrees, and in 9.8% by >4 degrees. AAT-TA, anatomical axis of the tibia to talar articular surface angle; MAL-TA, mechanical axis of the limb to talar articular surface angle.

proximal[11]). In other studies, generic definitions are adopted, such as "tibial axis"[20] or "line passing through two points of the diaphysis."[16] Also, while the angle is generally considered on the medial side (so that angles of >90 degrees are defined as valgus and those <90 degrees as varus[16]), debate also exists regarding normal values. We believe that establishing a clear gold standard to measure ankle alignment will enable the collection of larger amounts of data and allow us to define "normality."

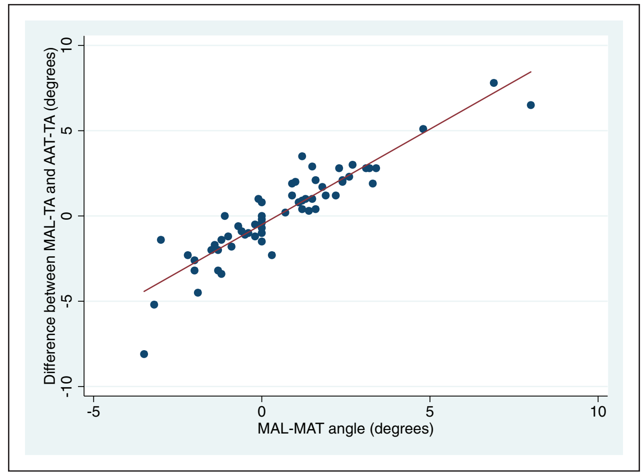


**Figure 5.** Scatterplot showing the strong positive correlation between the MAL-MAT angle (*x*-axis) and the difference between the MAL-TA and the AAT-TA (*y*-axis) ($r = 0.91$, $P < .001$). AAT-TA, anatomical axis of the tibia to talar articular surface angle; MAL-MAT, mechanical axis of the limb to mechanical axis of the tibia; MAL-TA, mechanical axis of the limb to talar articular surface angle.

We acknowledge some limitations of the current study, including the retrospective design, along with the limited sample size and the lack of normal controls. However, the power analysis suggested that our cohort was adequate to verify whether the TTA significantly differed using the MAL and the AAT as reference in patients with end-stage disease, the very patients that will receive an ankle replacement. While we believe this to be the first study to assess TTA using the mechanical axis of the limb as opposed to just the distal extent of the tibia, we did not consider sagittal or axial plane alignment, which is a weakness. The mechanical and anatomical axes of the lower limb could differ significantly when assessed on 2-dimensional and 3-dimensional imaging,[21] mostly because of factors of error inherently related to radiographs (eg, limb rotation and the presence of joint deformity). Due to the physiological procurvatum of the femur in the sagittal plane, it has been shown that a change in the position of the femur might lead to a variation in the measurement of its mechanical axis and in the assessment of the whole lower limb.[21] In order to overcome these limitations, 3-dimensional cone beam computed tomography in a standing position has been introduced.[1,8,9] The potential for scanners to include the hips (already produced for research goals) may help us obtain more accurate and reliable measurements of the lower limb axes.

## Conclusion

In this study, TTA assessed using MAL-TA was shown to be a reliable measurement of ankle joint alignment. The difference between MAL-TA and AAT-TA was greater than 2 degrees in 42% of patients and was as high as 8 degrees, correlating strongly with the degree of malalignment of the lower limb. TTA measured using the AAT could mislead surgeons with respect to biomechanical forces transmitted at the ankle. We recommend that surgeons consider using the MAL-TA, which relies on long leg radiographs, especially with proximal deformity, to more accurately measure coronal plane ankle joint alignment.

## Declaration of Conflicting Interests

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