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Role of Rotation in Total Ankle Replacement

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Abstract

Background: The importance of total ankle replacement (TAR) implant orientation in the axial plane is poorly understood with major variation in surgical technique of implants on the market. Our aim was to better understand the axial rotational profile of patients undergoing TAR.

Methods: In 157 standardized computed tomography (CT) scans of patients with end-stage ankle arthritis planning to undergo primary TAR surgery, we measured the relationship between the knee posterior condylar axis, the tibial tuberosity, the transmalleolar axis (TMA), and the tibiotalar angle. The foot position was measured in relation to the TMA with the foot plantigrade. The variation between the medial gutter line and the line bisecting both gutters was assessed.

Results: The mean external tibial torsion was 34.5 ± 10.3 degrees (11.8-62 degrees). When plantigrade, the mean foot position relative to the TMA was 21 ± 10.6 degrees (0.7-38.4 degrees) internally rotated. As external tibial torsion increased, the foot position became more internally rotated relative to the TMA (Pearson correlation, 0.6; $P < .0001$). As the tibiotalar angle became more valgus, the foot became more externally rotated relative to the TMA (Pearson correlation, −0.4; $P < .01$). The mean difference between the medial gutter line and a line bisecting both gutters was 4.9 ± 2.8 degrees (1.7-9.4 degrees). More than 51% of patients had a difference greater than 5 degrees. The mean angle between the medial gutter line and a line perpendicular to the TMA was 7.5 ± 2.6 degrees (2.8-13.7 degrees).

Conclusion: There was a large variation in rotational profile of patients undergoing TAR, particularly between the medial gutter line and the TMA. Surgeon designers and implant manufacturers should develop consistent methods to guide surgeons toward judging the appropriate axial rotation of their implant on an individual basis. We recommend careful clinical assessment and preoperative CT scans to enable the correct rotation to be determined.

Level of Evidence: Level IIc, outcomes research.

Keywords: deformity, alignment, gutter, impingement, loosening, biomechanics, arthritis

Inadequate correction of alignment in the coronal, sagittal, or axial planes and failure to address soft tissue imbalances increase the risk of failure of total ankle replacement (TAR).[8,11,24] Indeed, the failure rates of TAR are twice as high as those in total hip and knee replacements.[16] In the preoperative assessment of alignment, typically standard anteroposterior and lateral weightbearing radiographs are used to evaluate lower limb alignment and plan the position of TAR in the coronal and sagittal planes. Axial plane alignment is still poorly understood and difficult to determine on 2-dimensional radiographs. In some centers, computed tomography (CT) or magnetic resonance imaging (MRI) is used for preoperative diagnosis and planning, although their use is not routine.[8] Tibial torsion is defined as the angle between the line connecting both posterior condyles of the tibia (proximal posterior condylar axis) and the line bisecting the medial and lateral malleolus, also known as the transmalleolar axis (TMA).[17] A number of methods have been used to measure tibial torsion. These include goniometry, ultrasound, and CT.[4,12,27] CT is generally regarded as the most accurate.[4]

Alignment of implants during TAR typically involves the use of extramedullary referencing, using a rod that lines

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Table 1. Overview of the Methods Used by Different TAR Systems to Guide Axial Rotation Intraoperatively.[a]

TAR System	Method to Guide TAR Alignment in the Axial Plane
• STAR (Stryker, FL) • Vantage (Exactech, FL) • INFINITY (Wright Medical Technology, Memphis, TN)	Alignment is set by an osteotome or shim placed in the medial gutter
• PROPHECY INFINITY (Wright Medical Technology, Memphis, TN)	PROPHECY designers set alignment as a bisection of the medial and lateral gutters
• Salto (Tornier, France) • Cadence (Integra, TX)	Bisection of medial and lateral gutter pins
• Hintegra (Integra, France)	Medial surface of tibial jig lined up with medial talus
• Salto Talaris (Integra, TX) • AAA (Implantcast, Germany)	Pin on tibial alignment jig that lines up to 2nd metatarsal
• Zenith (Corin, UK)	Guide pin on talar trial lined up to 2nd metatarsal
• BOX (Matortho, UK)	Rotation is not specifically dealt with in surgical technique, but a tongue is inserted into the joint centered between malleoli
• Trabecular Metal (ZimmerBiomet, IN)	Based on radiographic assessment of medial clear space using an image intensifier and external frame

Abbreviation: TAR, total ankle replacement.
[a]The methods are taken from the technical guide for each respective TAR system.

up with the tibial tuberosity of the knee. Most TAR systems reference the tibial tuberosity initially for the proximal end of the alignment frame, and then use fluoroscopy to confirm the position in the coronal plane. In the presence of tibial torsion, this method might be inaccurate, also leading to coronal plane malalignment. There is a lack of consensus on what the most appropriate position should be of an implant in the axial plane, with some implant techniques recommending reference to gutter surfaces, and others using the second metatarsal as a primary or secondary reference. The different methods of aligning TAR in the axial plane in their respective surgical technique guides are described in Table 1.

The aim of this study was to define the rotational profile in patients with end-stage ankle arthritis undergoing TAR. We aimed to determine the range and relationship between the proximal posterior condylar axis at the knee, the tibial tuberosity, and the TMA at the ankle. In addition, we measured the medial and lateral gutter angles and the foot position (as determined by the alignment of the second metatarsal). We also reviewed the literature on axial plane alignment and provided some case studies to illustrate some important learning points.

Methods

This study was a retrospective analysis of prospectively captured data on 157 consecutive patients with end-stage ankle osteoarthritis undergoing patient-specific instrumentation (PSI) planning. Data were stored on the computer systems at Royal National Orthopaedic Hospital, Middlesex, UK. Patient demographics, body mass index, medical comorbidities, and any previous fractures or trauma were recorded. Institutional review board approval was sought. As part of our standard of care, all patients underwent preoperative long leg radiographs capturing hips to feet, with the tibial tuberosity of both knees facing anteriorly with the feet a comfortable distance apart. All patients also underwent preoperative CT scans captured using a standardized protocol for PSI (PROPHECY), which included slices through the knee, ankle, and foot capturing 2-mm slices at 1-mm increments at the knee (5 cm proximal and distal to the knee joint line) and 1-mm slices at 0.5-mm increments from 10 cm above the ankle joint to the sole of the foot. For each scan, the foot was positioned in a holder in the neutral dorsiflexion position (90 degrees) relative to the leg unless the patient had fixed equinus. Individual patient CT data were converted into 3-dimensional computer models to create a virtual operative procedure with implant sizes, positioning, and alignment (PROPHECY, Solidworks software, Dassault Systèmes, Boston, MA).[13,18,22]

This series was of all consecutive patients undergoing PROPHECY scans using a Philips (Amsterdam, The Netherlands) Ingenuity Core 128 Scanner between October 2014 and December 2017. Patients were excluded if they had fixed equinus or ipsilateral total knee arthroplasty, as these exclusions would lead to inaccurate tibial torsion and foot position measurements. One hundred fifty-seven consecutive patients were included. Seven patients with total knee arthroplasty were excluded, leaving 150 for analysis of all measurements. However, in 25 patients fixed equinus prevented us from measuring the alignment of the second

Table 2. Outline of Different Measurements in Relation to the TMA, Based on CT Scans.[a]

Relationship to TMA	Medial 1/3 Tibial Tuberosity (Internal Rotation)	External Tibial Torsion	Medial Gutter Line	Bisection of Gutter Line (Internal Rotation)	2nd Metatarsal Position (Internal Rotation)
Mean ± SD, deg	16.4 ± 9.3	34.5 ± 10.3	7.5 ± 2.6	1.3 ± 2.6	21.0 ± 10.6
Total range, degrees	1.0-44.6	11.8-62.0	2.8-13.7	0.1-4.7	0.7-38.4

Abbreviations: CT, computed tomography; SD, standard deviation; TMA, transmalleolar axis.
[a]The foot position as measured by the second metatarsal was always internally rotated relative to the TMA when the foot was plantigrade.

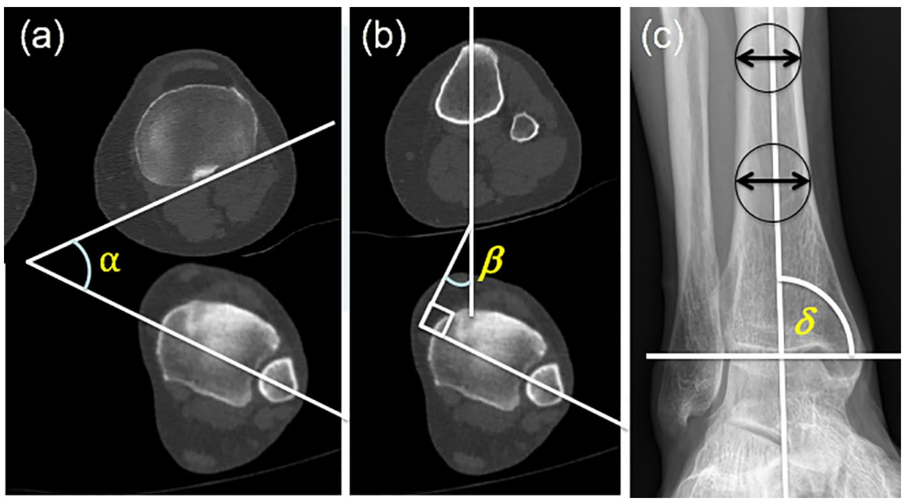

Figure 1. Axial computed tomography scans at a cross section of the knee and ankle used to calculate tibial torsion. (A) Tibial torsion is defined as the angle between the line connecting both posterior condyles of the tibia and the line bisecting the articular surfaces of the medial and lateral malleoli (the transmalleolar axis [TMA]) (α). (B) The middle picture demonstrates the angle between a line drawn along the most prominent point of the medial third of the tibial tuberosity, and the TMA (β). (C) Measurement of the tibiotalar angle on plain radiographs. The center point of the medial and lateral margins of the diaphysis of the tibia was plotted at 2 points of the diaphysis and a circle was drawn. A central line was drawn connecting these 2 points, and this was called the anatomical axis of the tibia. A separate line was drawn along the top of the articular surface of the talus. The medial angle was calculated to give the tibiotalar angle (δ).

metatarsal, and hence only 125 scans were analyzed for the foot alignment measurement. There were 71 females and 79 males. The mean age was 63.4 (range, 24-80) years. There were 73 left and 77 right ankles. All data were normally distributed. The measurements are outlined in Table 2.

Measurements

Tibial torsion was defined as the angle between the line connecting both posterior condyles of the tibia (proximal posterior condylar axis) and the TMA.[17] Tibial torsion was manually evaluated on the standardized CT scans using the PACS system (McKesson, Coventry, UK). It was measured using previously described methods (Figure 1).[9,10,13,22] The medial third of the tibial tuberosity was used as a reference point relative to the TMA, as the medial third is recommended in knee arthroplasty systems.[3,19] A line was drawn along the medial third of the tibial tuberosity, and at the distal end of the tibia (the last axial scan that shows the tibial plafond prior to entering the joint space) a line was drawn along the TMA. The angle between these 2 lines was calculated (Figure 1).[2,13]

The tibiotalar angle was measured on the long leg anteroposterior weightbearing radiographs preoperatively using previously published methods (Figure 1).[15] The center point of the medial and lateral margins of the diaphysis of the tibia was plotted at 2 points on the diaphysis. A line was drawn connecting these 2 points, and this was called the anatomical axis of the tibia. A separate line was drawn along the top of the articular surface of the talus. The medial angle was calculated to give the tibiotalar angle.

An axial slice 4 mm below the tibiotalar joint line (Figure 2) was used to calculate the gutter angles. Lines were drawn along the medial and lateral gutters, and a line

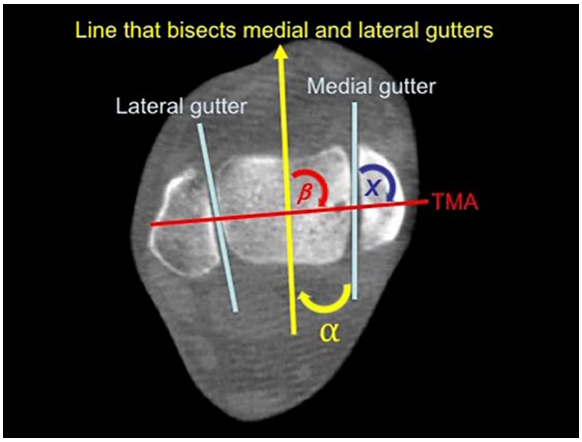

Figure 2. Axial slice of a computed tomography scan taken 4 mm below the tibiotalar joint line. Lines were drawn along the medial and lateral gutters. The gutter lines were then bisected. These lines were then referenced against the transmalleolar axis (TMA). Angle α represents the difference between the medial gutter line and the line bisecting both gutters. Angle β represents the angle between the line bisecting both gutters and the TMA. Angle X represents the angle between the medial gutter line and the TMA.

bisecting both gutters was drawn. The angle between the gutter lines and the TMA was measured, and then a line that bisected both gutters equally was drawn and referenced to the TMA (β) (Figure 2).

Foot position relative to the TMA was calculated by measuring the angle between the TMA and a line bisecting the second metatarsal shaft, where the foot was in a plantigrade position as measured by the sagittal CT scanogram with the foot in the specialized foot holder. The foot was determined to be plantigrade if the tibial shaft and the fifth metatarsal of the foot were between 88 and 92 degrees. The angle was calculated using the PROPHECY software (Figure 3).[18]

Statistics

Post hoc power analysis demonstrated that the study was sufficiently powered ($\alpha = 0.05$; $\beta = 0.2$). Differences between groups were evaluated using paired *t* tests and repeated-measures analysis of variance (SPSS v22.0, IBM Corp, Armonk, NY). Kolmogorov-Smirnov tests were performed to look for normal distribution. Significance was set at $P < .05$. Relationships between variables were analyzed using Pearson correlation (all data were normally distributed). All measurements were performed by A.N. and Y.G. Both authors were blinded to each other's measurements. To determine intraobserver (same tester) reliability, 50 measurements were repeated 1 week apart by A.N. To determine interobserver (different tester) reliability, 50 measurements were repeated by A.N. and Y.G. Reliability was assessed using intraclass correlation coefficient and Pearson correlation.

Results

The mean external tibial torsion was 34.5 ± 10.3 degrees. The range was between 11.8 and 62 degrees. The data were normally distributed. There was no significant difference between the mean tibial torsion between the right and left ankles (34.4 and 34.6 degrees, respectively; $P = .89$). Males had a higher mean tibial torsion compared with females, although the difference was not significant (35.0 and 33.8 degrees, respectively; $P = .5$). The relationship between the external tibial torsion and the internal rotation of the foot relative to the TMA had a Pearson correlation of 0.62 ($P < .001$). As the tibial torsion increased, the foot internal rotation increased (Figure 4).

The mean angle between the medial third of the tibial tuberosity and the TMA was 16.4 ± 9.3 degrees. This ranged from 1.0 to 44.6 degrees. The medial third of the tibial tuberosity was always internally rotated relative to the TMA.

The foot position was always internally rotated relative to the TMA (mean, 21.0 ± 10.6 degrees). This ranged from 0.7 to 38.4 degrees. Twenty-five patients were excluded from this measurement due to fixed equinus of more than 2 degrees, and hence this measurement was based on 125 patients. The foot position was more internally rotated relative to the TMA in female patients compared with male patients, although this difference was not significant (22.8 and 18.4 degrees, respectively; $P = .2$).

The mean angle between the medial gutter line and a line perpendicular to the TMA (Figure 2, angle X) was 7.5 ± 2.6 degrees. This angle ranged from 2.8 to 13.7 degrees. In 96% of patients, the medial gutter line was greater than 3 degrees internally rotated relative to the TMA. The mean angle between the line bisecting both gutters and a line perpendicular to the TMA (Figure 2, angle β) was 1.3 ± 2.6 degrees. This angle ranged from 0.1 to 4.7 degrees. The mean difference between the medial gutter line and the line bisecting both gutters (Figure 2, angle α) was 4.9 ± 2.8 degrees (range, 1.7-9.4 degrees). In 120 patients (80%), the medial gutter line in relation to the line bisecting both gutters was greater than 3 degrees. In 76 patients (51%), the difference was greater than 5 degrees.

The relationship between the tibiotalar angle and foot position was assessed (Figure 5). The tibiotalar angle varied from 19 degrees varus to 16 degrees valgus (mean tibiotalar angle, 0.8 ± 6.2 degrees varus). As the ankle arthritis became more valgus, the foot became less internally rotated (ie, more externally rotated) relative to the TMA. The Pearson correlation was −0.40 ($P = .01$) (Figure 5). There was no relationship demonstrated between the tibiotalar angle and

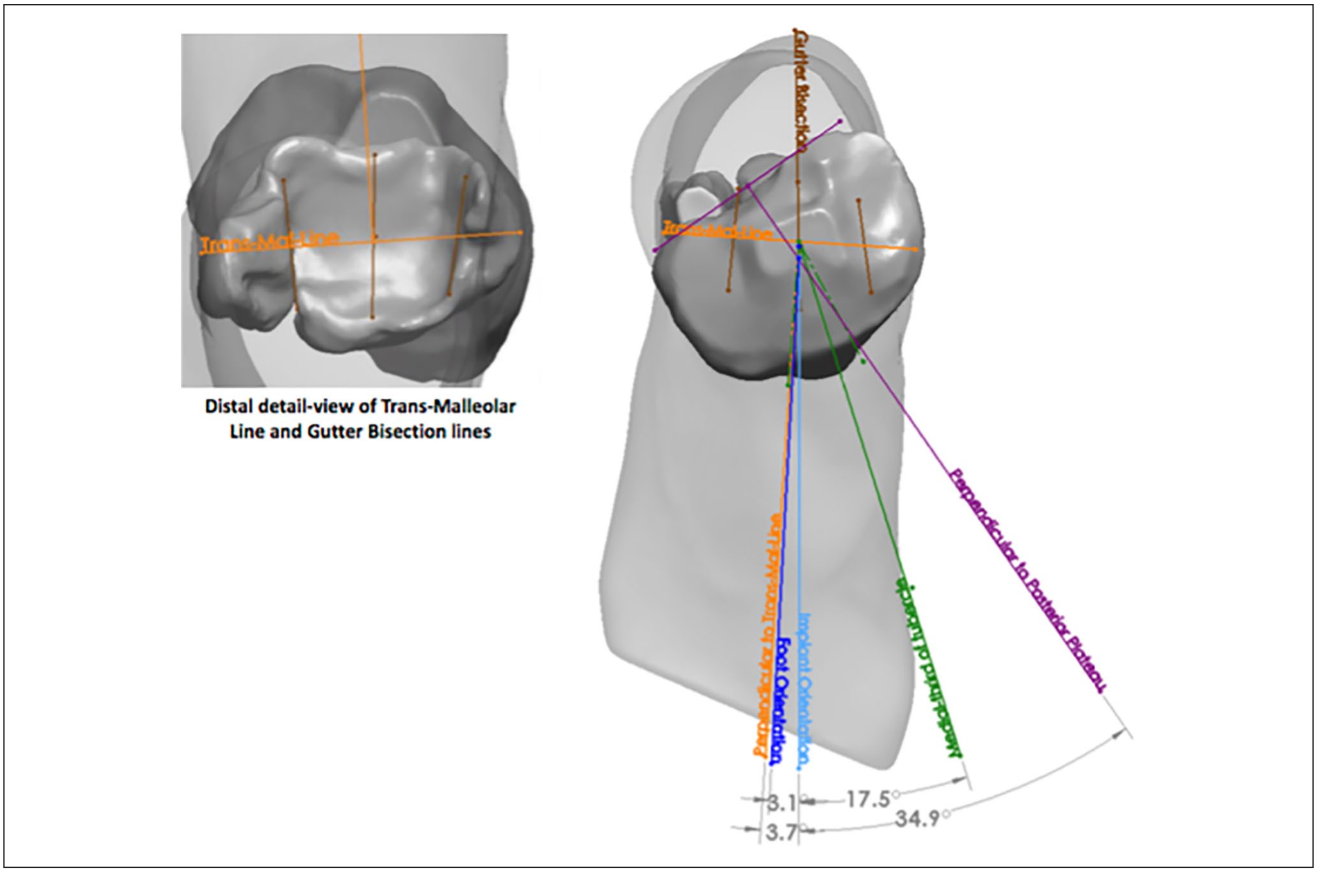

Figure 3. 3D representation of the computed tomography scans demonstrating (left) the ankle mortise as viewed from underneath and (right) the knee overlying the ankle from above showing the line perpendicular to the posterior tibial plateau, the medial third of the tibial tuberosity, and the transmalleolar axis. These images were also used to demonstrate the foot position (second metatarsal shaft) and proposed implant orientation. Images taken from PROPHECY templates, courtesy of Wright Medical Technology, Memphis, TN.

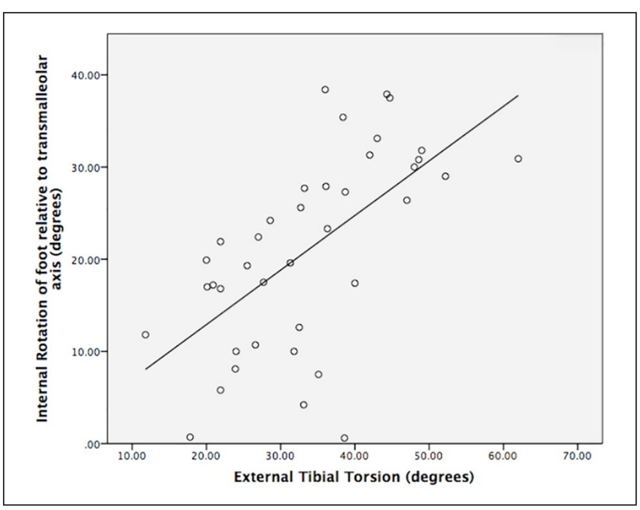

Figure 4. Scatterplot representing the relationship of external tibial torsion (degrees) and internally rotated foot position relative to the transmalleolar axis (degrees). The line marks the correlation (Pearson correlation, 0.62; $P < .001$).

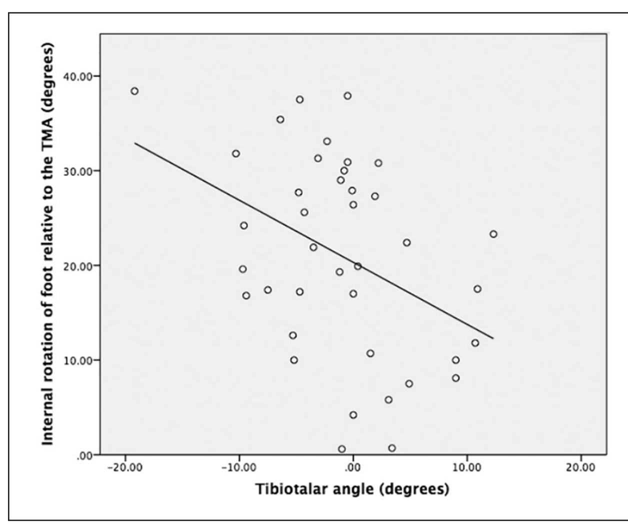

Figure 5. Scatterplot representing the relationship of the tibiotalar angle (degrees) and internally rotated foot position relative to the transmalleolar axis (degrees). The line marks the correlation (Pearson correlation, −0.4; $P = .01$). TMA, transmalleolar axis.

Table 3. Subgroup Analysis and Results of External Tibial Torsion and Foot Position Relative to the TMA in Patients With Inflammatory Arthritis and Those With Previous Tibial Fractures.

		No. of Patients	External Tibial Torsion, Mean ± SD (deg)	Foot Position Relative to TMA (Internal Rotation), Mean ± SD (deg)
Type of arthritis	Inflammatory arthritis	33	36.2 ± 9.1	20.3 ± 9.0
	Noninflammatory arthritis	117	36.0 ± 12.9	21.2 ± 10.5
	P value		.35	.39
Tibial fracture or deformity	Present	25	30.0 ± 11.5	16.4 ± 8.9
	Absent	125	35.1 ± 10.0	21.4 ± 10.2
	P value		.1	.34

Abbreviations: SD, standard deviation; TMA, transmalleolar axis.

external tibial torsion (Pearson correlation, 0.01; $P = .96$). There was no relationship between the tibiotalar angle and tibial tuberosity (Pearson correlation, −0.09; $P = .48$).

Subgroup analysis revealed no significant differences between inflammatory and noninflammatory arthritis (Table 3). There was a difference in the patient's foot position relative to the TMA and the tibial torsion in patients who had a previous tibial fracture, although this difference was not significant. The patients with tibial fractures tended to have less external tibial torsion and less internal rotation (ie, more external rotation) of the foot relative to the TMA.

Measurements were performed twice in separate sessions, indicating excellent intra- and interobserver reliability (intraclass correlation coefficients, 0.86 and 0.80, respectively; Pearson correlations, 0.95 and 0.89, respectively; $P < .001$). The manually measured CT results and PROPHECY results were well correlated (intraclass correlation coefficient, 0.81; Pearson correlation, 0.91; $P < .001$).

Discussion

Axial orientation of total ankle implants is poorly defined. There is little consensus between surgical guides of the various implants on the market in relation to rotation in the axial plane (Table 1). We have shown that there is a wide range of tibial torsion in patients with ankle osteoarthritis (11.8-62.0 degrees) without any appreciable difference in torsion between the right and left sides (34.4 and 34.6 degrees, respectively; $P = .89$). We believe this to be the first study to report on adult tibial torsion in the context of ankle arthritis.

The literature on tibial torsion mainly pertains to the pediatric population and describes normal external tibial torsion to be around 30 degrees[1,7,13,20]; however, it has been described to be as high as 82 degrees in normal patients.[13] Excessive external tibial torsion may contribute to an external foot progression angle and has been associated with progressive equinoplanovalgus foot segmental malalignment, hallux valgus, and midfoot degenerative arthritis in adults,[4,6] and following tibial malunion, an increased risk of ankle arthritis has been shown.[14] This study shows that the tibial tuberosity is not a reliable measure to assess tibial torsion, with a range of 1.0 to 44.6 degrees relative to the TMA. In addition, if the tibial tuberosity is used as a reference point for the external alignment rod, then significant external tibial torsion could lead to errors in coronal plane alignment as the rod goes into an artificial valgus position, increasing with increasing torsion.

We have shown that the foot is always internally rotated relative to the TMA, but the range can vary from 0.7 to 38.4 degrees. This finding was also related to the tibiotalar angle and the amount of external tibial torsion. Patients with an externally rotated tibia are likely to have more internal rotation of the foot relative to the TMA. Patients with valgus ankle arthritis are more likely to have less internal rotation (ie, more external rotation) of the foot relative to the TMA. This is an important consideration during preoperative and intraoperative assessment of rotation. Twenty-five of our patients (17%) had fixed equinus. Since the foot internally rotates as the ankle moves from dorsiflexion to plantar flexion,[5] coupled with the difficulties in standardizing clinical assessment to always be at 90 degrees, overall we consider the second metatarsal to be a very unreliable guide of rotational alignment of the implants.

Some implants reference the medial gutter lines; others reference the line bisecting both gutters. We have shown that there is a large variation between the medial gutter line and line bisecting both gutters. The range was between 1.7 and 9.4 degrees. These measures differ by more than 3 degrees in 81% of patients and more than 5 degrees in more than half of patients. This is particularly pertinent to implants that use both PSI techniques as well as non-PSI or instrumented techniques to implant the same prosthesis, such as the INFINITY implant. In our experience of the PSI technique, the coronal plane alignment is set as the line bisecting both gutters in comparison with the non-PSI

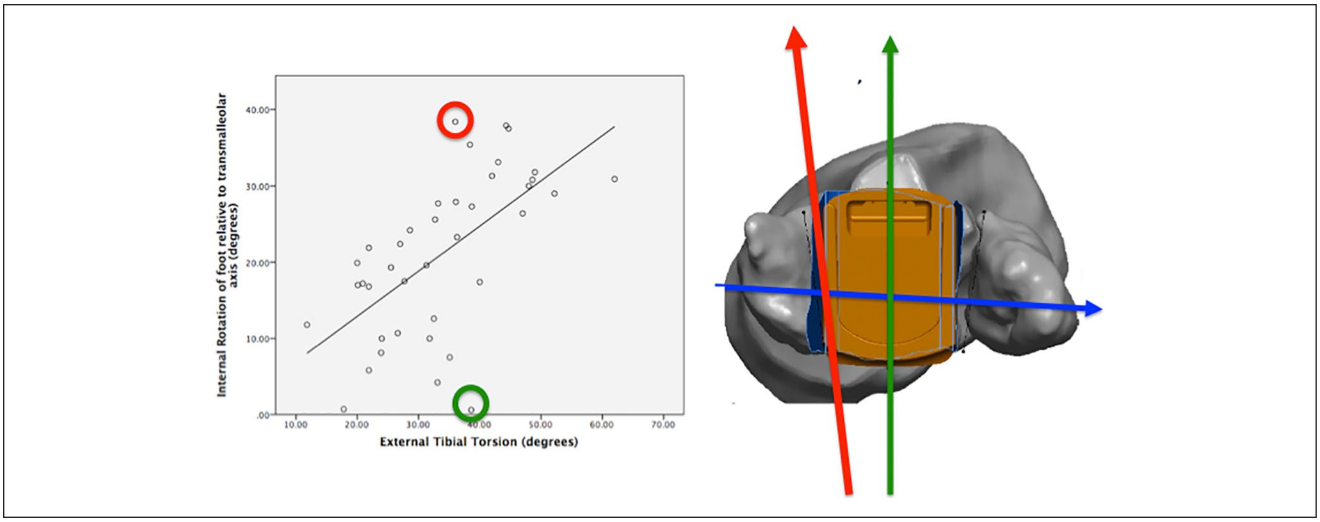

Figure 6. Scatterplot from Figure 5 with 2 outliers demonstrated. The horizontal line represents the transmalleolar axis (TMA). The patient in the upper circle has a tibial torsion of 36 degrees but an internally rotated foot of 38 degrees relative to the TMA. The patient in the lower circle has a similar tibial torsion but an internally rotated foot of only 2 degrees. The arrows show how the patient in the upper circle would benefit from a more internally rotated implant (left verticle arrow) (in line with the medial gutter pin), and the patient in the lower circle would benefit from a more externally rotated implant bisecting the gutters (right verticle arrow). The orientation is set using the PROPHECY PSI technique.

technique, which uses the medial gutter fork to set rotation for the same implant. In our study, we found that had a non-PSI technique been employed for our cohort, the result would have been greater than 5 degrees internal rotation of the implants in more than 50% of patients, compared with the PSI technique that we used. This study was not designed to determine whether these differences are clinically relevant, but further research into this area is clearly necessary.

Clinical Relevance

Our study revealed a large variation in axial anatomy between patients. In Figure 4 we have plotted external tibial torsion against foot position, which appears to be a linear line (noting that our data only include patients who could achieve plantigrade foot positions during the planning scans). However, we use 2 outliers in Figure 6 to illustrate how these data have influenced our practice.

The patient in the red circle has tibial torsion of 36 degrees but an internally rotated foot of 38 degrees relative to the TMA. The patient in the green circle has a similar tibial torsion but an internally rotated foot of only 2 degrees. We now routinely use our PSI reconstructed images (as shown in Figure 6) to set axial rotation of the tibial implant. The talar implant rotation is set to match. In the patient in the red circle, we would tend to use more internal rotation (we usually bisect the line that would be set by the medial gutter pin with the line bisecting both gutters). In the patient in the green circle, we would tend to position the tibial implant more externally rotated, namely dividing the line bisecting both gutters. In some circumstances where the TMA is externally rotated in comparison with the line bisecting both gutters, we choose the TMA.

In these 2 patients, the position of the foot relative to the TMA would be different. Figure 6 highlights how the patient in the red circle would benefit from a more internally rotated implant (in line with the medial gutter pin), and the patient in green would benefit from a more externally rotated implant (more in line with the TMA).

Gutter Debridement

Causes of gutter impingement include component design and sizing issues, subsidence and avascular necrosis, hypertrophic bone, and uncontrolled varus or valgus thrust.[26] Gutter impingement requiring a secondary procedure to clear the gutters after TAR occurs in up to 7% of patients.[23,25] Malalignment of TAR has been associated with heterotopic ossification in the gutters, leading to a reoperation for gutter debridement after the initial surgery.[21] Prophylactic gutter debridement at the time of TAR is performed by many surgeons in order to excavate the medial and lateral gutters to allow for proper frontal plane orientation of the talus.[26] It also removes a potential source of pain from impingement. Schuberth et al[26] referred to the TMA as being key to rotational placement of TAR.

Our interest in gutter debridement was sparked by serial observations that incorrect orientation in the axial plane of the tibial component appeared to lead to gutter impingement,

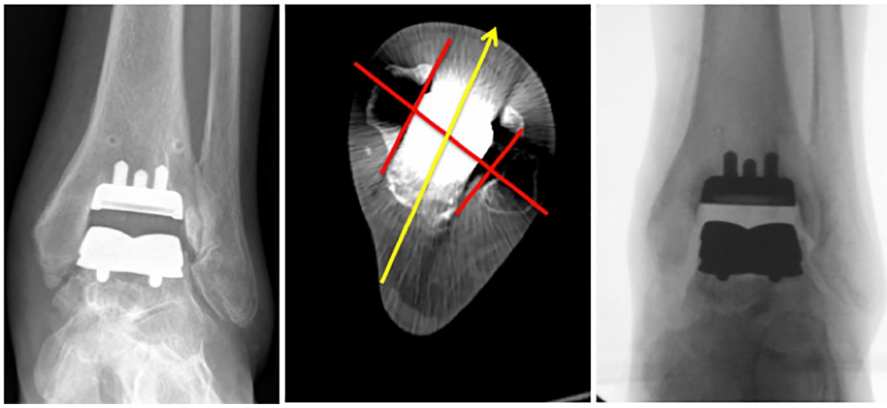

Figure 7. Case example of a 68-year-old female patient with medial gutter impingent postoperatively after placement of PROPHECY INFINITY total ankle replacement (left image). The middle image (axial computed tomography scan postoperatively) demonstrates the axial positioning of the talar implant (arrow), which is 15 degrees internally rotated relative to the transmalleolar axis (line bisecting both malleoli). The right image shows the postoperative result after medial gutter debridement, interposition arthroplasty, and transosseous sutures.

and responded to gutter clearance. It is our hypothesis that component malrotation will always lead to gutter impingement, but that this will be more symptomatic where bony contact occurs (such as in the presence of gutter arthritis and bony osteophytes). In our practice, we no longer routinely clear gutters unless there are impinging bony osteophytes or bone and bone contact. In our series, 3 cases of medial impingement occurred in the first 10 cases, demonstrating part of our learning curve, and all cases required reoperation. In each case, an axial weightbearing CT scan confirmed internal rotation of the tibial component (and hence the talar component) and medial impingement (Figure 7). All 3 patients were found intraoperatively to have medial impingement due to the talus abutting against the medial malleolus on load bearing. They underwent a medial gutter debridement and all patients' symptoms resolved.

We believe that prophylactic gutter debridement may be a proxy method to deal with malrotation issues since it creates additional space for the incorrectly placed implants to move into. However, it must be appreciated that the downsides to prophylactic gutter debridement include:

1. Instability of TAR within the tibiotalar mortise, especially in the presence of an unbalanced foot
2. Weakened malleoli, increasing the risk of malleolar fractures
3. Unnecessary bone resection, which may have an impact on future revision surgery

Clearly, this topic is controversial, but it may also explain why 3-component mobile-bearing implants placed in axial malalignment function well, because the mobile bearing to some extent can deal with different rotations of the tibial and talar implants.

Despite the 3 cases of gutter impingement in our early cases, after the 10th case we changed our practice on axial rotation and, indeed, in our total series only had 1.9% of medial impingement despite routinely electing to leave the gutters untouched. This is lower than the quoted literature of 7%[23,26] and, in our opinion, supports the notion that correct axial rotation can remove the need for gutter debridement, especially in cases where the gutter cartilage is preserved.

Individualized Assessment

We recommend careful clinical assessment preoperatively and intraoperatively, to include a full hip, knee, and dynamic ankle assessment. A useful method of examination that we have found effective is to have the patient positioned with a leg hanging off the end of an examination couch. The surgeon places 1 finger on the tibial tuberosity, and the index finger and thumb from the other hand on the medial and lateral malleoli. The patient then moves their ankle through a range of dorsiflexion and plantar flexion. This allows the surgeon to clinically assess:

1. Tibial torsion (relationship of tibial tuberosity to TMA)
2. Foot position relative to the TMA (especially when the foot is plantigrade)
3. Relationship of the tibial tuberosity to the center of the ankle (to guide implant placement in the coronal plane)

We believe that we are the first group to independently validate a commercially available digital technique for image analysis (Solidworks software, Dassault Systèmes). By comparing the digital measurements with a manual process previously described, we have shown that there is good correlation between the 2 methods.[2,3,9,10,13,18,22]

There are limitations to our work. Our sample size is small; yet to our knowledge, this is still the largest series of patients undergoing PSI TAR. Comparisons with normal (nonarthritic) patients would have been useful to see if the rotational alignment varied, and most importantly, we have not attempted to correlate rotation with clinical outcomes, which is of course an essential next step. It is important, however, to appreciate that clinical outcomes are complex and would be confounded by a magnitude of patient, technique, and implant variables.

One of the main strengths of our study is the standardization of CT scans. Those with fixed equinus have been excluded from the foot position results, therefore ensuring that all measurements were taken with the foot plantigrade. In addition, the CT methodology is a reproducible method to assess variation in anatomical measurements. The role of weightbearing CT scanners to capture data in a weightbearing situation is being explored and in the future may have clinical utility; however, these data would need careful interpretation. For example, an internally rotated or medialized talus due to chronic cavovarus deformity with a deficient medial malleolus would need to be restored toward normal and not the position obtained during the scan. We believe our current data based on bony anatomy in a nonloaded situation are an important starting point for such research.

Conclusion

Standardization of rotation of TAR during surgery is very challenging given the large variability of tibial torsion and foot position. There was wide variance between the medial gutter line and the TMA, and surgeon designers and implant manufacturers should develop consistent methods to guide surgeons as to the appropriate axial rotation of their implant. Planning of TAR surgery needs to be on an individual basis, and we recommend 3-dimensional imaging preoperatively on all patients, and careful clinical assessment to enable determination of the correct rotation and bone preservation surgery of the gutters. Future research needs to focus on the correlation between alignment and the impact on clinical outcomes, in particular symptoms, reoperation, and revision rates.

Declaration of Conflicting Interests

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