A Novel and Reproducible Reference Axis that Indicates Axial Rotation of Distal Tibia

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INTRODUCTION:
Appropriate implant alignment is essential for successful clinical outcome as well as implant longevity after total knee arthroplasty (TKA). It has been demonstrated that the implant malalignment is more frequently seen in tibia than in femur even among skillful surgeons. As for proximal tibial osteotomy with an extra-medullary guide in TKA, we usually set the instrument with reference to tibial tuberosity proximally and 1st or 2nd metatarsus distally. However, especially in case of ankle deformity, we occasionally feel dilemma how to align the instrument distally, considering the metatarsus and/or trans-malleolar axis, the latter of which is usually rotated. In the last ORS meeting, we illustrated our 3D-coordinate system of tibia, which is clinically relevant bony landmark based system. By introducing this algorithm, here we examined the reproducibility of a novel reference axis indicating axial rotation, which we defined specifically for this study, and measured the axial rotation of distal tibia.

METHODS:
Three-dimensional models of 20 tibiae were reconstructed from the less-affected side of lower-limb pre-operative CT-scan data for primary TKA by using Mimics (Materialise NV, Leuven, Belgium). The data included 20 osteoarthritic patients who underwent TKA. Their age was 73.8 ± 6.9 years.

Definition of the Mid-sagittal Plane Based Tibial Coordinate
Our coordinate system is mid-sagittal plane based algorithm defined by 3 bony landmarks including an apex of the tibial plafond, center of posterior cruciate ligament enthesis, and proximal medial edge of the tibial tubercle, which are less affected by osteoarthritic deformities. The origin of the tibial coordinate system was determined by taking projection of the midpoint of the medial/lateral eminences on the sagittal plane. Then the Z (vertical) axis was defined as the line between the origin and the apex of the tibial plafond. The normal vector of the sagittal plane was assigned as medial-lateral axis (the Y axis). The Anterior-Posterior (the X axis) was then determined as a cross product of the Z axis and the Y axis, contained within the sagittal plane. (Fig. 1)

Inter-observer Errors of Designated Points for the Reference Axes
To investigate reproducibility of the 2 axial reference axes, we investigated interobserver errors of points that were designated by 3 certified orthopaedic surgeons. Firstly differences in the coordinate system between 2 surgeons were calculated, then Interobserver Correlation Coefficient (ICC 2, 1) was examined by SPSS 18.8 (IBM, Armonk, NY, USA).

Measurements of axial rotation of distal tibia with reference to 2 reference axes
The axial alignment of distal tibia was examined by measuring the projected angle of the distal reference axes that we determined above relative to proximal ML axis in the 3D-coordinate system respectively.

RESULTS:
While defining the trans-malleolar axis, interobserver errors among the 3 surgeons were 3.14 ± 0.47 mm (medial) and 4.88 ± 0.59 mm (lateral). As for defining the plafond axis, those were 1.97 ± 0.53 mm (medial) and 2.02 ± 0.44 mm (lateral) respectively. The errors were significantly lower while designating the reference points to define the plafond axis than the points for transmalleolar axis (p<0.05). In terms of ICC (2.1), that of y-value to be point out as midial and lateral reference points for the plafond axis was higher than that for the transmalleolar axis (Table 1). The eventual axial alignment of distal tibial with reference to the plafond axes and to the trans-malleolar axis were 9.8 ± 8.4 degrees (-6.0 – 26.2 degrees), and 16.3 ± 6.3 degrees (-0.1 – 27.9 degrees) respectively. The correlation of these 2 angles was statistically significant (r = 0.78, p < 0.001).

Table 1. Inter-observer variations in identifying reference points

<table>
<thead>
<tr>
<th></th>
<th>Transmalleolar axis</th>
<th>Plafond axis</th>
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<tbody>
<tr>
<td>Medial</td>
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<td></td>
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<tr>
<td>ICC (2.1)</td>
<td>0.959</td>
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<tr>
<td>y</td>
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<td>0.907</td>
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<tr>
<td>x</td>
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</tr>
<tr>
<td>ICC (2.1)</td>
<td>0.988</td>
<td>0.955</td>
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<tr>
<td>y</td>
<td>0.899</td>
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DISCUSSION:
As for tibial geometry, the distal trans-malleolar axis externally rotates relative to the proximal medial-lateral axis in the axial plane. This discrepancy of axial alignment is one of factors for surgeons to feel dilemma to determine mid-sagittal plane of distal tibia. During TKA we normally recognize 1st or 2nd metatarsus as an indirect reference axis that indicates distal center of tibia on the coronal plane. However, in patients with ankle and/or foot deformity, these references are less reliable. In these contexts we initiated this study to discover another axial reference axis by introducing our 3D-coordinate system. As far as we know, this is the first study to demonstrate the plafond axis to be a reproducible reference axis in the 3D-algorithm.

Prior to the measurements of the tibial torsion, interobserver errors in identifying the reference points of each reference axes were investigated. In terms of coordinate value errors and interobserver correlation coefficient, the y-value were less reproducible compared to x- and z-value in designating the reference points of the plafond axis as well as the trans-malleolar axis, which implicated the difficulty of selecting these points in configuration of mid-sagittal plane while observing distal front of tibia. Our study has demonstrated that the plafond axis is expected to be a more accurate and more reproducible indicator of axial alignment compared to the trans-malleolar axis.

The plafond axis was revealed to be 6.5 degree internally rotated on average relative to trans-malleolar axis. Interestingly the standard deviation was higher in the plafond axis despite its higher reproducibility to be identified, which might indicate the plafond axis to be an axis to reflect individual patients’ alignment more specifically. The pathophysiological and clinical significance of the axis remained to be elucidated next.

SIGNIFICANCE:
We were able to propose another reference axis that indicated axial rotation of distal tibia, which would be applicable to analyses of individual 3D-geometry of tibia and to the pre-operative planning of TKA.

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