# Limb Rotation Alters Apparent Fibular length and Talocrural Angle on Ankle Radiographs 

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INTRODUCTION: The anatomical relationships within the foot and ankle are essential to stability and force transmission. For example, altered fibular length and rotational alignment can lead to altered mechanics, ankle osteoarthritis, pain, and poor functional outcomes [1]-[6]. Despite the known clinical importance of restored anatomical alignment, the difficulty of assuring proper reduction without residual shortening, improper rotation, or fibular translation in the transverse plane has been well documented during fibula fracture repair [2]. Of the several radiographic parameters available to assess fibular length, the talocrural angle has demonstrated particular promise in a previous study, which found limited variability of measurements between a 2-D x-ray and 3-D computed tomography (CT) compared to other parameters of fibular length. It is also predictive of clinical outcomes following ankle fracture [7], [8]. Yet, it is currently unknown how changes in limb positioning in 3-D space influence the ability to assess fibular length on 2-D imaging using the talocrural angle. Thus, the objective of this study was to investigate the effect of limb rotation on the talocrural angle. By gauging its validity in measuring fibular length in the context of limb rotation, surgeons can more confidently use the parameter in clinical applications and research.

METHODS: CT scans ( $0.5-2 \mathrm{~mm}$ slice thickness, $512 \times 512$ FOV, $120-135 \mathrm{kVp}, 30-450 \mathrm{~mA}$ ) of 21 lower limbs ( $13 \mathrm{males}, 8$ females, age range $36-89$ years) with no bone injury were identified retrospectively from the medical record (IRB \#202100043). Each scan included at least 30 mm superior to the tibiotalar joint space. Limb orientation was standardized across limbs using an anatomic coordinate system aligned to a true mortise view of the ankle. The 21 uninjured limbs were used as a baseline measurement with 0 mm of fibular length translation. Then, each limb was synthetically altered by moving the fibula through 4 increments of fibular translation ( $-4,-2,2,4 \mathrm{~mm}$ ) to simulate shortening (positive) and lengthening (negative). This generated a total of 105 limbs ( 21 CTs x 5 fibular translations). Use of synthetic image manipulation enabled control of confounding variables, such as lateral plane rotation. For each limb, the talocrural angle was calculated as the angle between the line intersecting the medial and lateral malleoli and the line parallel to the distal articular surface of the tibia. To evaluate the effect of limb orientation, talocrural angle was computed as a function of sagittal plane rotation (i.e., altered location of x-ray equipment relative to limb). Sagittal plane rotation was simulated by rotating the bone models within a range of $+/-25$ degrees in increments of 1 degree. The talocrural angle was then quantitatively evaluated as a function of sagittal rotation by calculating the average and variation across limbs relative to fibular translation.

RESULTS: The mean talocrural angle is 74.3 degrees (SD 4.7 degrees) for a true mortise projection angle with anatomical alignment (i.e., 0 mm change in fibular length). Both the position of the x-ray equipment relative to the limb and the magnitude of fibular length translation affect the measurement of the talocrural angle. Notably, in both the healthy and synthetically altered limbs, the talocrural angle varied as a function of sagittal plane rotation (Fig. 1) with a 1.0 degree change in sagittal plane rotation corresponding to about a 0.1 degree change in talocrural angle at 0 mm of fibular length translation. However, the interdependency between talocrural angle, sagittal plane rotation, and fibular length can result in a false perspective (i.e., a talocrural angle in the healthy range for a limb with a shortened or lengthened fibula). For example, a limb with a fibula that has been shortened by 2 mm and is rotated, on average, 14.1 degrees (CI:13.2, 15.1 degrees) in the sagittal plane will achieve the same talocrural angle as the same limb with the fibula anatomically reduced (Fig. 2).

DISCUSSION: Our results confirm the talocrural angle is a sensitive measure of fibular length, and similar to prior literature [9] found that 2 mm of fibular shortening resulted in a 1.8 degree ( $95 \%$ CI:1.75, 1.81) change in talocrural angle. Furthermore, our results demonstrate that rotation in the sagittal plane can lead to a false assessment of fibular length, potentially contributing to current rates of malreduction. Thus, efforts should be taken to standardize the limb position or control the confounding effect of sagittal rotation when attempting to assess fibula length on radiograph or measuring the talocrural angle. In the long term, studies demonstrating how other metrics to evaluate fibular length such as Shenton's Line and the Dime Sign are needed in addition to studies demonstrating how to best control for these effects.

SIGNIFICANCE/CLINICAL RELEVANCE: Our results confirmed that the talocrural angle is a valid measure of fibular length. They also demonstrate that variation in the sagittal plane rotation can lead to inaccurate assessment of fibular length where a shortened fibula, which is clinically detrimental, could go undetected due to an x-ray projection angle that falsely corrects the talocrural angle.

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Figure 1. Talocrural angle as a function of sagittal plane rotation. Colors represent fibular length translations. Black dots illustrate a false positive reduction, wherein the talocrural angle incorrectly indicates 0 mm fibular translation at 2 mm short (purple) and -2 mm long (orange).


Figure 2. The magnitude of rotation to produce a false positive in a 2 mm shortened limb. False positive is defined as the same talocrural angle in the shortened limb and an anatomically reduced limb (i.e., 0 mm translation). Mean (solid) and standard deviation (shaded) across limbs is displayed.

