Computational Comparison of Center-Center and Centroid Axes in Syndesmosis Fixation

Nicholas J. Jackson, Christopher W. Reb, Joel B. Harley, Jennifer A. Nichols
University of Florida, Gainesville, FL
nicholas.jackson@ufl.edu

Disclosures: Nicholas J. Jackson (N), Christopher W. Reb (N), Joel B. Harley (N), Jennifer A. Nichols (N)

INTRODUCTION: Syndesmosis injuries, which catastrophically damage the ligaments between the tibia and fibula, occur in approximately 10% of all ankle fractures [1]. These injuries are surgically treated through syndesmosis fixation, in which the fibula and tibia are realigned and fixed. However, syndesmotic malreduction occurs at a very high rate with some studies reporting rates as high as 39% and 54% [2, 3]. The axis of syndesmosis fixation, which defines the drill path used during surgery, has been shown to influence syndesmosis malreduction and clinical outcomes. To reduce the incidence of malreduction, Kennedy et al. proposed an ideal patient-specific fixation axis passing through the geometric centers (centroids) of the fibula and tibia [4]. Cancienne and Yarboro proposed the centroid axis can be visualized on a lateral radiographic view of the ankle in which the fibula is centered within the tibia (i.e. “center-center” method) [5]. Haupt et al. validated this correlation by manually plotting centroid and center-center axes on axial computed tomography (CT) scans at three discrete locations [6]. The objective of this study was to utilize digitally reconstructed radiographs (DRRs) and automated image segmentation to validate that the center-center axis approximates the centroid axis as a continuous function of height relative to the ankle joint.

METHODS: CT scans (0.5 - 0.976 mm slice thickness, 512 x 512 resolution, 100-135 kVp, and 30 - 80mA) of three through-knee cadaveric lower limb specimens were used to digitally reconstruct the tibia and fibula. For each limb, an anatomic coordinate system was defined based on the tibia; this enabled consistent definition of the anatomical planes across limbs. Centroids were defined as the geometric center of polygon approximations of the tibia and fibula in the axial plane (Fig. 1, gold). The polygon approximations were obtained via automatic image segmentation, and the centroids were computed continuously along the length of the tibia and fibula. The centroid axis was defined as the line connecting the bone centroids. DRRs were then generated [7] to simulate clinically obtained fluoroscopic images at specified limb rotations (Fig 1, blue). The edges of the tibia and fibula were automatically identified in DRRs for each limb rotation, and each bone’s center was defined as the point equidistant from the respective edges (Fig. 2A). The center-center axis was defined as the location where the centers of the tibia and fibula overlapped. The centroid and center-center axes were quantitatively compared by calculating the angle between them. Average differences were examined across limbs and heights relative to the ankle joint.

RESULTS: The center-center axis is achieved at exactly one simulated limb position for a given height above the ankle joint (Fig. 2B). The center-center axis aligns with the centroid axis within 1-2 degrees across the length of each limb (Fig. 2C) with an average standard deviation of 0.21 degrees (Fig 2D). This trend is consistent for all limbs.

DISCUSSION: To our knowledge, this study is the first to computationally evaluate, without the use of manual measurements, the difference between the center-center and centroid axes of alignment. As such, the computational methods established here provide the foundation needed to evaluate how these axes vary across the population due to differences in bone morphology and other patient-specific factors. Validation that the center-center alignment is achieved at exactly one simulated limb position for a given height above the ankle joint is an important finding, as it indicates there is only one unique combination of imaging projection and limb position that can be used intraoperatively to guide syndesmosis fixation when using the center-center method. Additionally, the close alignment of the center-center and centroid axes indicate that the center-center method is a viable approach for achieving patient-specific fixation. Future work will expand this analysis to a larger sample size to establish the statistical power necessary to assess agreement between the calculated axes.

SIGNIFICANCE/CLINICAL RELEVANCE: Confirmation that the center-center axis and centroid axes are closely aligned provides objective evidence supporting the use of the center-center method, which is a syndesmosis fixation technique that has not yet garnered widespread adoption.

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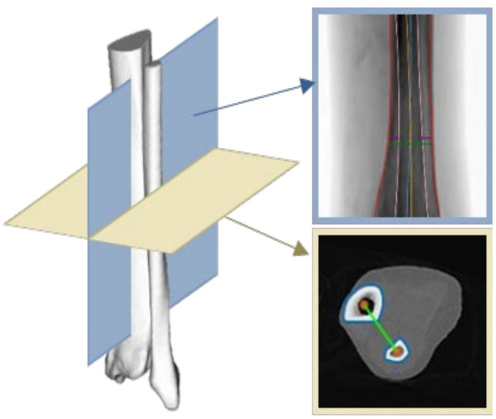

Figure 1: The centroid axis is defined as the vector drawn through the axial centroids of both bones projected through the sagittal plane (gold). The center-center alignment is defined as the continuum of angles and heights that constitute the fibula being centered within the tibia (blue).

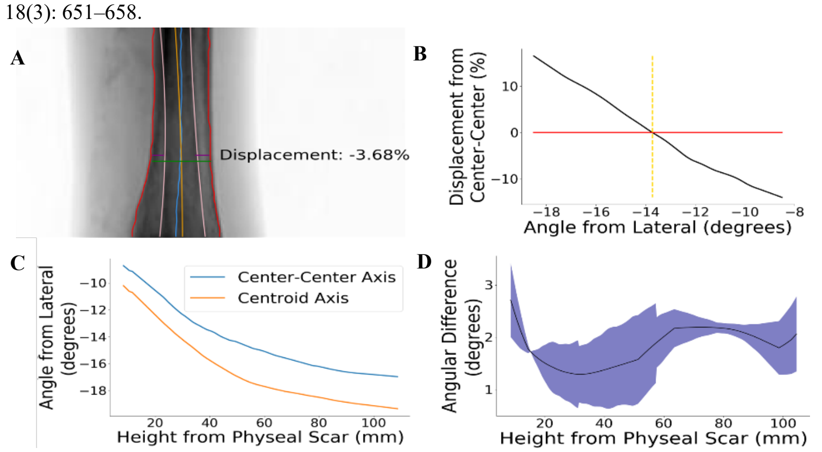

Figure 2: (a) A sample DRR of one cadaver limb with the tibia (red) and fibula (pink) edges identified. The blue and orange lines represent the centers of the tibia and fibula, respectively. **(b)** The difference between tibia and fibula centers at one axial location and varying limb rotations. **(c)** The comparison of center-center axis (blue) to centroid axis (orange) in one limb. **(d)** The average angular difference between the center-center and centroid axes across all limbs. Blue shading represents one standard deviation.