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

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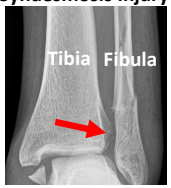
Background & Motivation

- Syndesmosis injuries catastrophically damage the ligaments between the tibia and fibula. These injuries occur in approximately 10% of all ankle fractures [1].
- Surgical treatment is achieved through syndesmosis fixation, in which the fibula and tibia are realigned and fixed.
- Some studies report malreduction rates as high as 39% and 54% [2, 3], suggesting that surgical fixation through the ideal axis is challenging to achieve.
- Two potential axes of fixation have been described:

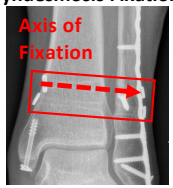
  Centroid Axis: This ideal, patient-specific fixation axis passes through the geometric centers (centroids) of the fibula and tibia [4]. This axis can be identified via intraoperative CT, a costly imaging modality that is not readily available in most operating rooms.

  Center-Center Axis: This axis is defined from a lateral ankle radiograph in which the fibula is centered with in the tibia. It has been proposed that this axis approximates the centroid axis [5], thereby providing a low-cost, readily available method to achieve patient-specific fixation.
- Haupt et al. theoretically demonstrated that the centroid axis is aligned with a simulated center-center axis on axial CT slices [6]. This study demonstrates the need for an automated method that can be scaled to validate this relationship in large sample sizes.

Syndesmosis Injury



Syndesmosis Fixation

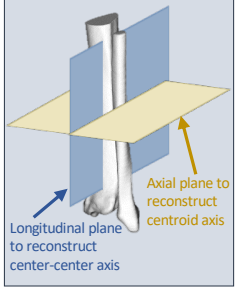


Objective: To validate that the center-center axis approximates the centroid axis as a continuous function of height relative to the ankle joint.

Methods

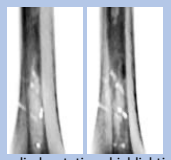
The center-center and centroid axes were derived from the same CT scans and compared by calculating the angular difference between the two axes. This calculation was performed for axes located 20 to 100 mm above the physeal scar.

CT scans of cadaveric lower limb specimens (N=3) were used to digitally reconstruct the tibia and fibula.

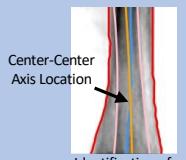


Digitally Reconstructed Radiographs (DRRs) were generated [7] to simulate fluoroscopic images:

- A range of limb rotations was simulated by rotating the longitudinal plane used to generate the DRRs.
- Edges and center lines of each bone were automatically identified via image segmentation.
- The center-center axis was defined as the axis orthogonal to where the bone centerlines overlapped.



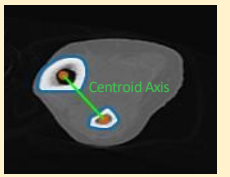
Two limb rotations highlighting change in fibula location.



Identification of center-center axis.

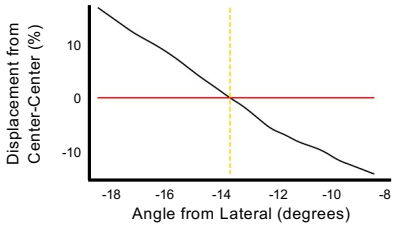
Polygon approximations of the tibia and fibula were obtained via automatic image segmentation on each axial slice.

- 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.



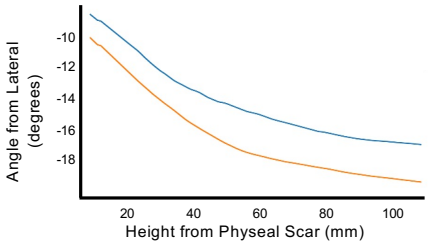
Results

Data from a Representative Limb:



At a set height, there is only one limb rotation (yellow) where the centerlines of the fibula and tibia align, which is where displacement (black) is 0 (red).

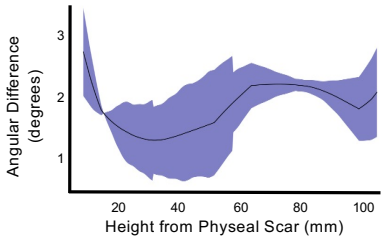
The center-center axis can be identified at only one unique limb rotation at a given level of surgical fixation.



The center-center axis (blue) deviates approximately 2 degrees from the centroid axis (orange) in this limb.

Although a 2 degree difference is small, to what extent this difference is clinically meaningful is currently unknown.

Across Limbs Mean & Standard Deviation:



The angular difference between the center-center and centroid axes is within 1-2 degrees.

The magnitude of the difference is consistent across limbs with no clear relationship to height.

Discussion and Future Work

This study computationally evaluates, without manual measurements, the difference between the center-center and centroid axes of alignment.

- **The center-center axis is a viable approach for approximating the centroid axis**
  - There is a close alignment between the center-center and centroid axes.
  - Only one unique combination of imaging projection and limb position exists to guide syndesmosis fixation when using the center-center method.
- Ongoing research is expanding on the work presented here in three key ways:
  - Increasing the sample size to establish the statistical power necessary to assess agreement between the center-center and centroid axes.
  - Using more computationally expensive, but robust segmentation methods to reduce segmentation error.
  - Evaluating how fibula displacement and bone morphology influences the relationship between the center-center and centroid axes.

References: [1] Schnetzke et al. (2016) *World J Orthop* [2] Sagi et al. (2012) *J Orthop Trauma*. [3] Gardner et al. (2006) *Foot Ankle Int*. [4] Kennedy et al. (2014) *The Foot*. [5] Cancienne & Yarboro (2015) *Tech Foot & Ankle Surg*. [6] Haupt et al. (2020) *Foot Ankle Int*. [7] Sherouse et al. (1990) *Int. J. Radiat. Oncol. Biol. Phys*.