# A SIMPLE, ANATOMICALLY BASED CORRECTION TO THE CONVENTIONAL ANKLE JOINT CENTER

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## INTRODUCTION

The conventional gait model defines the ankle joint center as the midpoint of the most medial and lateral aspects of the malleoli (Kadaba et al., 1990; Davis et al., 1991), yet *in vivo* studies suggest a more distal location would be more accurate. Lundberg et al. (1989) placed tantalum beads in bones of the foot and shank, and obtained radiographs as sagittal, coronal, and transverse plane rotations occurred about the ankle complex (i.e., the aggregate of joints between the foot and shank). Helical axes for these rotations all passed near a point at the center of the talus, approximated by the midpoint of the tips of the malleoli. In a study of six degree-of-freedom (6DoF) joint powers, Buczek et al. (1994) reported translational joint velocities when the conventional ankle center was used, and hypothesized that these were due to an incorrect center of rotation. When an ankle center consistent with Lundberg et al. (1989) was used, these velocities were nearly eliminated for much of stance phase.

The purpose of this study was to develop and evaluate an anatomically based offset that would move the conventional ankle joint center to a more accurate location, without requiring medical imaging or markers at the tips of the malleoli. We hypothesized that common anthropometric measurements could be used to define the offset, and that its use would reduce calculated joint translations at the ankle complex during gait.

## METHODS AND PROCEDURES

Existing coronal plane lower extremity radiographs from 30 pediatric subjects (ages 7-16 yr.) were chosen at random in this Human Subjects Exempt study; patients with pathologies likely to adversely affect normal bony geometry were excluded. Locations for conventional motion capture markers were estimated at the skin surface, and from these, virtual points were derived (Figure 1). A line was drawn between KC and AC, and extended inferiorly to intersect a line drawn between LT and MT. This intersection point did not always fall on the midpoint between LT and MT, but the difference was considered negligible (< 0.5 mm), and the intersection point was considered the true ankle center (AC'). Distance measurements were then made to the nearest half millimeter,

**Figure 1. Radiograph.** Physical marker locations were estimated at the skin surface, permitting derivation of virtual points at the knee and ankle joint centers.

ME: medial epicondyle
LE: lateral epicondyle
MM: medial malleolus
LM: lateral malleolus
MT: medial malleolus tip
LT: lateral malleolus tip
KC: knee center
AC: ankle center (conv)
AC': ankle center (true)

and linear regression analyses were used to relate these to the desired Offset:

KW: distance between ME and LE
AW: distance between MM and LM
SL: distance between KC and AC
Offset: distance between AC and AC'

To evaluate the performance of the regression equation providing the best correlation, a 6DoF foot model (Walker et al., 2008) was applied to gait data from eight normal subjects, using both AC and AC'. Joint translations were calculated in Visual3D (C-Motion, Inc., Rockville MD, USA) and averaged over one gait cycle for each subject. A two-tailed, paired t-test was used to detect differences in joint translations obtained using AC and AC'.

## RESULTS

Offsets measured on the 30 radiographs ranged from 6.0 to 13.0 mm (mean 9.7 mm, SD 1.7). Of the three radiographic measurements, SL showed the best bivariate linear correlation with Offset, with a Pearson coefficient, r, of 0.89 (0.76 for KW and 0.71 for AW). The line of best fit passed very close to the origin (y-intercept = 0.2 mm), suggesting that a simple percentage of SL would provide sufficient accuracy:

Offset (predicted) = 0.027 SL

Using this equation, the mean error in predicting Offset for these 30 radiographs was 0.6 mm (6% mean Offset), and the maximum error was 1.7 mm (18% mean Offset). Mean joint translations during a gait cycle obtained using AC' (1.8 mm, SD 0.5) were significantly smaller (p = 0.0001) than those obtained using AC (2.4 mm, SD 0.6). These joint translations were reduced for each of the eight subjects (Figure 2).

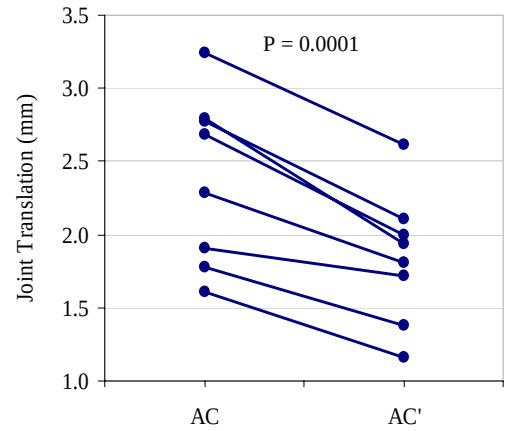


**Figure 2. Joint Translations.** Using a predicted ankle center between the tips of the malleoli (AC'), rather than between their prominences (AC), mean joint translations during a gait cycle were reduced for all eight subjects.

## DISCUSSION

Using measurements easily derived from markers associated with the conventional gait model, we developed a simple correction for AC that results in AC', an ankle joint center consistent with *in vivo* studies free from skin movement artifact. Reductions in joint translations associated with AC' suggest that a greater level of accuracy was achieved for normal gait. Effects on gait kinetics were not studied, but are likely to be small due to the magnitude of the required Offset (< 13 mm).

## REFERENCES


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