In-vivo Kinematics of the Tibiotalar and Subtalar Joints in Asymptomatic Subjects with Application to Chronic Ankle Instability

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Disclosure

The authors have no conflicts to disclose.
Introduction

Clinical Motivation:
- ~30% of individuals who suffer ankle trauma experience chronic ankle instability (CAI) afterwards\(^1\).
- Instability in the ankle may alter natural biomechanics.
- Trauma and altered biomechanics likely cause ankle OA\(^2\).

Measurements of Joint Kinematics
- Determine the importance of deleterious motions in promoting ankle disorders such as ankle osteoarthritis (OA)
- Prognosticate on the success/failure of surgery

Problem:
- Kinematic roles of the tibiotalar and subtalar joints are often assumed, but in-vivo measurements to confirm mechanisms of action are severely lacking
- Traditional skin marker methods do not measure motion of tibiotalar and subtalar joints independently

Solution: Dual Fluoroscopy (schematic, right)
- Submillimeter and sub-degree accuracy\(^3\)
- Display motion relative to 3D reconstructions of bony anatomy (i.e. ‘arthrokineamtics’)
Objectives & Experimental Setup

Objectives:

1. Measure *in vivo* arthrokinematics in asymptomatic tibiotalar and subtalar joints using dual fluoroscopy to determine the kinematic roles of each joint.

2. Quantify and compare in vivo tibiotalar and subtalar arthrokinematics of CAI patients to those of asymptomatic controls.

Subjects:

- 10 asymptomatic volunteers: 30.5±6.9 years, BMI: 23.5±3.5
- 4 CAI patients w/ lateral ligament injuries (ATFL, CFL, PTFL): 30.8±4.1 years, BMI: 25.7±3.4

Dual fluoroscopy (system setup: above, right) and Vicon data acquired simultaneously while subjects completed 2 trials of various activities:

- Single-leg, balanced heel-rise
- Ambulated on instrumented treadmill at 2 speeds: 0.5 m/s and 1.0 m/s
Data Analysis

- CT scan of each subject segmented to create 3D bone models of the tibia, talus and calcaneus.
- Digitally reconstructed radiographs (DRRs) generated by projecting a plane through the CT data.
- DRRs were input to model-based tracking, a semi-automatic technique that aligns dual fluoroscopy images with the DRRs (below, left) to derive bone arthrokinematics throughout heel-rise or the captured phase of stance (below, right).
- Quantified 3D bone motion was used to calculate tibiotalar and subtalar joint angles and translations.

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Translational ROM was not significantly different between the two joints, except in the AP direction during 0.5 m/s gait (above, left).

Joint translations were non-zero, indicating that each joint undergoes 6 degree-of-freedom (DOF) motion rather than rotational motion alone (above).

- Translational ROM was not significantly different between the two joints, except in the AP direction during 0.5 m/s gait (above, left).

- Joint translations were non-zero, indicating that each joint undergoes 6 degree-of-freedom (DOF) motion rather than rotational motion alone (above).
- Tibiotalar joint was primarily responsible for dorsi/plantarflexion (above).
- Subtalar joint was primarily responsible for inversion/eversion (above).
- Subtalar joint was primarily responsible for IR/ER during gait (above, left and middle), but both joints exhibited similar IR/ER ROM during heel-rise (above, right), indicating that the joint responsible for IR/ER may be activity-dependent.
- The D/P rotational profile of most CAI patients was similar to the control subjects (above).
- CAI-02 exhibited much more tibiotalar plantarflexion than CAI patients or controls:
  - More plantarflexed neutral position
  - More flexible in the plantarflexion direction
  - Stronger fibularis longus, soleus, or gastrocnemius muscles
CAI patients may activate fibularis longus and/or extensor digitorum, producing more eversion, to compensate for lateral instability and lack of inversion restraint provided by ATFL and CFL.

CAI-01 also had evidence of chronic deltoid injuries, possibly limiting eversion restraint and causing increased eversion in the subtalar joint.

CAI-03 had torn deltoid ligaments in addition to ATFL and CFL injuries, causing both medial and lateral instability and rotational profiles similar to controls.
Injured PTFL and CFL of CAI patients may have attributed to increased eversion at maximum plantarflexion, since both ligaments provide external rotation restraint.

Torn deltoid ligaments of CAI-03, which provide restraint of internal rotation, may have caused a slight decrease in subtalar eversion, opposite of the other CAI patients.

- Injured PTFL and CFL of CAI patients may have attributed to increased eversion at maximum plantarflexion, since both ligaments provide external rotation restraint.
- Torn deltoid ligaments of CAI-03, which provide restraint of internal rotation, may have caused a slight decrease in subtalar eversion, opposite of the other CAI patients.
Key Findings:

- Both joints undergo full 6 DOF, not just rotational motion\textsuperscript{7-14}.
- The mode of action of each joint and the synergy between the two joints may be activity-dependent.
- Few significant differences in ROM between controls and CAI patients.
- Balanced heel-rise In/Ev and IR/ER rotational profiles varied between the two groups.
- Results indicate that arthrokinematics are altered once ligamentous damage is experienced –
  - Are these changes patient/injury-specific?
  - Do these changes in mechanics cause degradation of cartilage leading to OA?
  - Are original ankle mechanics restored following surgery?

Future Work:

- Evaluate whether patient treatment restores original biomechanical function.
- Explore additional loading scenarios and patient groups.
- Investigate the belief that tibiotalar fusion causes hypermobility in adjacent joints.
- Use arthrokinematics for computational models or to improve the design and articulating motion of total ankle replacement devices.
References


