When Evaluating Ankle Joint Motion, Consider The Activity

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Introduction

Background

- Ankle ligamentous injuries are common in the general population and athletes, constituting up to 23% of all athletic injuries[1-3] (Figure 1).
- Repeated ankle injuries can lead to chronic ankle instability and increased risk post-traumatic arthritis accounting for more than 70% of cases[1,2].
- Understanding of ankle joint complex (AJC) kinematics during high-demand activities can serve as a benchmark for evaluating treatments to restore ankle stability.
- Previous *in vivo* studies focused on AJC kinematics during straight-ahead walking and running, but failed to include the fibula in their analysis[5-9].

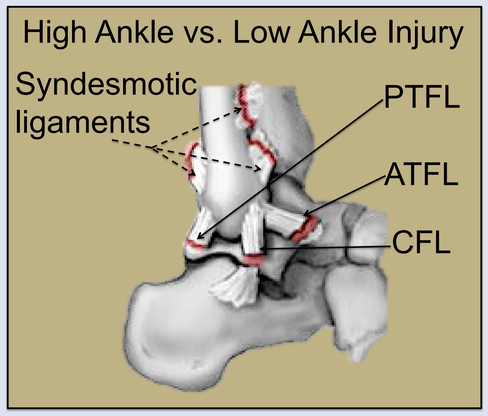

Figure 1: *Depiction of common ligamentous injuries. Note: all ligaments either originate or insert on the fibula.*

Aims

- Determine the accuracy of a radiographic model-based tracking (MBT) technique[10] for reporting *in vivo* ankle kinematics.
- Determine six degrees-of-freedom tibiotalar (TT), subtalar (ST) and distal tibiofibular (TF) joint ranges of motion (ROM) during seven dynamic weight-bearing movements.

Methods

Data Collection

- Following Institutional Review Board (IRB) approval, two female subjects ages 25 and 27 years old provided informed consent and completed the study.
- Three to five 1.0 mm diameter tantalum beads were surgically implanted into the tibia, fibula, talus, and calcaneus during lateral ankle ligament repair.
- Following a six month rehab, seven dynamic weight bearing movements were tested:
  - Two single leg hops (straight and lateral)
  - Two alternating single-leg push-offs (front-back and side-side)
  - Vertical jumping
  - Running
  - Walking

Data Collection

- Bone motion was tracked using radiostereophotogrammetric analysis (RSA) utilizing bead positions as the “gold standard” and a volumetric model-based tracking (MBT) process that matched subject-specific bone models to biplane radiographs (Figure 2).
- The primary kinematic outcome variables were the six degree-of-freedom kinematics of, TT, ST and TF[9].

Data Analysis

- Kinematic differences between MBT and RSA tracking results were calculated for each pair of biplane radiographs and averaged over the support phase of each movement (RMS error) to assess the accuracy of the MBT system.

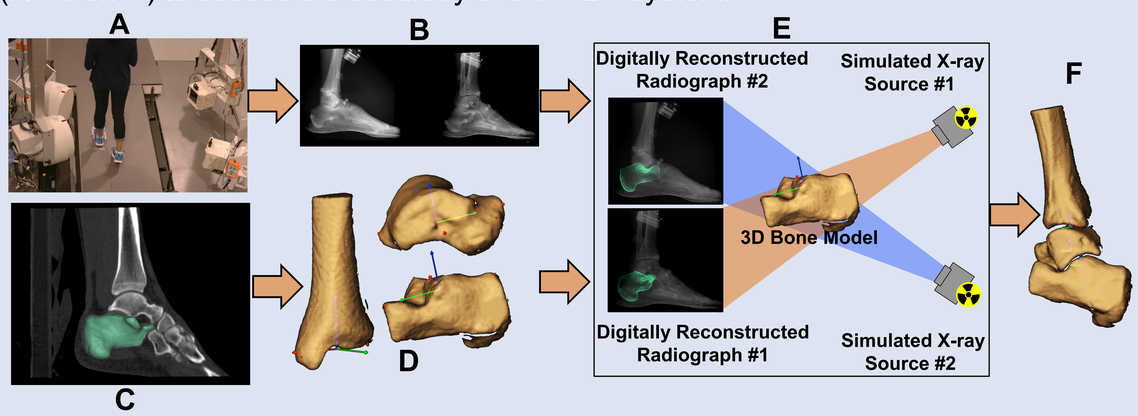

Figure 2: ***(A)*** *Participants performed movement trials within the biplane radiography system.* ***(B)*** *Synchronized radiographs were collected at 100 and 150 images per second, with 1 ms exposure.* ***(C)*** *A CT scan (0.5 x 0.5 x 1.25 mm) of the ankle was segmented.* ***(D)*** *Anatomic coordinate systems were created[9].* ***(E)*** *3D knee kinematics were measured using CT MBT tracking process.* ***(F)*** *Calculated six degree-of-freedom kinematics of TT, ST and TF joints.*

Results

- The RMS error of the MBT was 0.6 mm, 1.1 mm and 1.0 mm or better in translation, and 2.2°, 2.0° and 2.7° or better in rotation for the TT, ST and TF joints respectively.
- Average AJC ROM was dependent upon activity (Tables 1 and 2), with TT joint ROM greatest during jumping, side-to-side push-off and walking, and ST joint ROM greatest during lateral hopping and straight hopping (Table 1).

Table 1: Tibiotalar (TT) / Subtalar (ST) Range of Motion

		Front back	Jump	Lateral Hop	Run	Side-side	Straight Hop	Walk
ML Translation (mm)	TT	2.8 ± 0.6	1.3 ± 0.7	2.5 ± 1.6	1.9 ± 0.5	**2.9 ± 1.4**	2.6 ± 1.3	2.0 ± 0.1
	ST	2.6 ± 0.8	1.3 ± 0.8	**2.8 ± 0.4**	1.4 ± 0.6	1.5 ± 0.8	2.4 ± 1.7	1.6 ± 0.1
AP Translation (mm)	TT	2.8 ± 0.5	**5.0 ± 4.6**	2.4 ± 1.5	2.3 ± 1.2	2.5 ± 2.1	3.2 ± 1.3	2.0 ± 0.8
	ST	1.8 ± 0.5	1.8 ± 1.1	**2.9 ± 0.7**	1.4 ± 0.5	1.1 ± 0.4	2.7 ± 1.5	1.5 ± 0.3
SI Translation (mm)	TT	2.9 ± 1.9	3.9 ± 4.4	4.3 ± 2.2	1.5 ± 1.2	**4.8 ± 2.7**	3.6 ± 1.7	1.7 ± 0.6
	ST	2.5 ± 0.6	2.0 ± 1.4	2.7 ± 0.7	1.7 ± 1.2	2.4 ± 0.7	**3.3 ± 1.9**	1.6 ± 0.7
Dorsiflexion (deg)	TT	20.5 ± 6.0	**34.4 ± 10.8**	22.1 ± 10.2	18.4 ± 2.2	24.0 ± 8.6	17.9 ± 6.1	22.2 ± 0.1
	ST	3.5 ± 1.3	3.6 ± 0.8	3.3 ± 0.7	4.0 ± 0.5	3.7 ± 1.6	**4.2 ± 2.1**	4.0 ± 0.3
Internal Rotation (deg)	TT	8.8 ± 0.3	8.1 ± 3.0	7.8 ± 2.0	6.8 ± 2.9	6.1 ± 2.2	7.5 ± 4.2	**12.3 ± 3.3**
	ST	4.7 ± 1.4	5.0 ± 0.9	4.5 ± 1.0	3.8 ± 1.5	5.2 ± 1.8	**8.4 ± 5.3**	4.7 ± 0.2
Inversion (deg)	TT	6.1 ± 2.1	6.9 ± 2.1	4.8 ± 0.6	4.6 ± 1.9	4.6 ± 1.4	5.8 ± 1.3	**7.3 ± 0.6**
	ST	7.5 ± 1.5	6.0 ± 2.0	6.6 ± 2.5	7.3 ± 0.9	6.1 ± 2.5	**8.4 ± 5.6**	8.3 ± 0.9

Average tibiotalar (TT), subtalar (ST) range of motion during 7 dynamic weight bearing activities (mean ± SD). The largest ROM for each DOF is highlighted in ***bold****.*

- TF joint ROM was generally largest during walking (Table 2). No components of the average joint ROM were largest during front-back push-offs or running.

Table 2: Distal Tibiofibular (TF) Range of Motion

	Front Back	Jump	Lateral Hope	Run	Side-side	Straight Hop	Walk
ML translation (mm)	2.3 ± 0.8	1.9 ± 1.0	1.6 ± 0.6	2.1 ± 0.5	1.5 ± 0.3	1.7 ± 1.0	**2.6 ± 0.4**
AP translation (mm)	3.5 ± 1.6	2.8 ± 1.7	2.8 ± 2.1	4.1 ± 2.7	1.9 ± 0.5	3.6 ± 2.1	**5.2 ± 2.7**
SI translation (mm)	3.0 ± 0.9	2.3 ± 1.0	2.8 ± 0.4	3.0 ± 2.0	2.3 ± 0.3	2.5 ± 0.9	**4.0 ± 1.7**
Coronal rotation (deg)	5.8 ± 2.4	7.6 ± 5.2	**8.0 ± 5.7**	4.8 ± 0.7	4.8 ± 1.5	6.0 ± 4.5	6.7 ± 3.0
Sagittal rotation (deg)	5.1 ± 4.2	6.3 ± 6.8	4.1 ± 3.0	5.6 ± 5.1	3.0 ± 1.9	5.4 ± 4.9	**10.0 ± 3.3**
Internal rotation (deg)	2.1 ± 0.5	2.7 ± 1.3	1.9 ± 0.7	2.8 ± 0.7	2.8 ± 1.8	3.5 ± 1.1	**3.7 ± 0.7**

Average tibiofibular range of motion during 7 weight bearing activities (mean ± SD). The largest ROM for each DOF is highlighted in ***bold****.*

Discussion

- This is the first study to report AJC ROM for high-demand loading activities.
- The results indicate that jumping, hopping and side-to-side motions may be more appropriate tests to evaluate the stability of the AJC compared to walking and running.
- This is the first study to assess the ability of a markerless matching technique to measure distal TF motion during weight- bearing activity.
- Establishing the accuracy of the model-based tracking technique provides a foundation for future studies to assess AJC kinematics performing demanding athletic movements.
- The ability to track fibular motion makes it possible to assess outcomes of surgical techniques to restore ankle stability after syndesmotic injury.

Clinical Significance

- **AJC motion during high-demand activities is dependent upon the movement performed, with hopping, jumping and side-to-side motions eliciting the largest ROM in the TT and ST joints, and walking eliciting the largest ROM between the tibia and fibula.**

References and Acknowledgements

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