Quantification of Ankle and Subtalar Joint Instability: A New Technique

S.I. Ringleb*, S. Siegler*, J.K. Udupa^, B.E. Hirsch#^, H.J. Hillstrom+

*Department of Mechanical Engineering and Mechanics, College of Engineering, Drexel University
^Medical Imaging Processing Group, Department of Radiology, University of Pennsylvania
#Department of Anatomy and Cellular Biology, Temple University School of Medicine
+Gait Study Center, Temple University School of Podiatric Medicine

Introduction

Difficulty in the clinical diagnosis of injuries to collateral ankle ligaments occurs because the diagnosis is based on a subjective examination and/or a stress radiograph. Neither method reveals the exact location of the ligament damage.

An arthrometer, the ankle flexibility tester (AFT), was developed to quantify six degree-of-freedom measurement of ankle flexibility. It measured the relative motion between the calcaneus and the tibia/fibula produced in response to manually applied forces and moments (1). The AFT has been used to measure the flexibility characteristics of the ankle complex in vitro by incrementally sectioning the lateral collateral ligaments (2), and in patients with unilateral ligament injuries (3). These studies have shown statistically significant changes in ankle flexibility in the presence of a damaged collateral ligament. The AFT cannot detect subtalar joint (STJ) instability and it is limited by soft-tissue interference.

A technique quantifying and displaying the motion of an individual’s hindfoot using a quantitative analysis of 3D reconstruction of bones from magnetic resonance imaging (MRI) has also been developed (4). This technique describes the shape, size, and proportion of each bone in the hindfoot; the relative positions and orientations between the bones; and the kinematics between the bones (4). Stindel et al. used this information to propose a technique used to classify foot type in the open kinetic chain, which allowed an accurate reproducible 3D characterization of the in vivo relationship between bones (5).

Based on the aforementioned studied, the combination of the AFT and the quantitative MRI is hypothesized to create a reliable and quantitative diagnostic modality for ankle joint instability, which would improve the management of ankle injuries. This method would be capable of detecting talo-crural and subtalar joint injury and indicate the location of the ligament injury.

Methods

The AFT was redesigned as a non-metallic, which fit into a commercial 1.5 tesla MR machine (Figure 1). This AFT is capable of stressing the ankle in inversion/eversion, internal and external rotation, and anterior draw (4). The AFT was locked in the stressed configuration while the ankle is scanned in the MR imager. The software system 3DVIEWNIX was used to segment the bones, reconstruct 3D representations (Figure 2), and determine their relationships (5,6).

A complete set of data was obtained from one patient with a unilateral chronic lateral ankle ligament injury. Information was collected from each ankle in a neutral position and stressed in an inverted configuration. The ankles were stressed to their maximum tolerable range, as specified by the patient, 20° and 36° for the healthy and injured ankles, respectively.
The centroid, location of the principle axes, axis of rotation, and angle of rotation were calculated in 3DVIEWNIX (5) with respect to the global coordinate frame. The motion of the talus relative to the calcaneus was calculated using the direction cosines and the location of the centroid, provided by 3DVIEWNIX (equation 1). A final rotation matrix was then calculated to represent the motion of the talus from position one to position two (equation 2). This information was used to calculate the angle of rotation for that coordinate system (equation 3), when the ankle moved from neutral to inverted with the healthy and injured ankles.

\[
\begin{align*}
C_T &= C^{-1} T \quad (1) \\
T_T &= C^{-1} T \quad (2) \\
\phi &= \sin^{-1} \frac{d}{2} \quad (3)
\end{align*}
\]

where, 
\[
d = (T_T(2,3) - T_T(3,2))^2 + (T_T(3,1) - T_T(1,3))^2 + (T_T(1,2) - T_T((2,1))^2
\]

Results

The reconstruction of the calcaneus and the talus in the frontal plane clearly showed a greater separation between the talus and the calcaneus in the stressed configuration of the injured ankle (Fig 3). The angles of rotation of the talus in the global and talar reference frames are shown in Table 1.
Table 1. Angle of Rotation in Global and Talar Reference Frames

<table>
<thead>
<tr>
<th>Reference Frame</th>
<th>Healthy</th>
<th>Injured</th>
<th>Difference</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>13.39</td>
<td>6.29</td>
<td>7.1</td>
<td>53.02</td>
</tr>
<tr>
<td>Talar</td>
<td>0.0539</td>
<td>0.0749</td>
<td>0.021</td>
<td>38.96</td>
</tr>
</tbody>
</table>

**Discussion**

Figure 3 qualitatively demonstrates a change in the frontal plane subtalar joint motion when a lateral ligament injury is present. Table 1 shows that there is a difference in the angle of rotation of the talus varies from the healthy to the injured side. It is difficult to interpret the change in subtalar joint motion in reference to the global frame because the global reference frame is not aligned with the inversion/eversion axis. When examining the angle of rotation of the talus in the talar reference, it is suggested that there is more talar motion with the injured ankle, as seen by the increased inversion angle measured with the AFT. The qualitative measure of subtalar joint separation and the change in angle of the talus measured in its own reference frame suggest that this new technique may improve the clinical diagnosis and management of unstable ankles.

**References**

4. Hirch BE, et al. 3D Imaging in Medicine, 2000

**Acknowledgements**

This research is funded by NIH.