Fibular Malalignment in Individuals With Chronic Ankle Instability

The recurrence rate of lateral ankle sprain is reportedly very high, and repeated lateral ankle sprain may lead to chronic ankle instability (CAI). Defined by recurrent lateral ankle sprain or giving-way episodes, using conventional classifications, CAI is believed to be due to either mechanical or functional ankle instability. Recently, this classification was updated, and criteria for diagnosis of CAI were proposed by the International Ankle Consortium. However, there is continuing controversy as to the contributing factors for CAI. Furthermore, osteoarthritis is thought to develop in about 80% of patients with longstanding CAI, some of whom require surgical treatment. Therefore, it is important to clarify the major causes of CAI and to prevent recurrent lateral ankle sprain.

The force across the ankle joint can reach almost 4 times body weight under weight-bearing conditions. The distal tibiofibular joint plays an important role in appropriate load distribution in the talocrural joint and load transfer more proximally by forming the mortise structure. Distal tibiofibular joint instability may be associated with lateral ankle sprain or ankle syndesmosis injury. Furthermore, some studies have indicated that instability of this joint may lead to accelerated ankle osteoarthritis and poor subjective outcomes after injury.

Although this instability is commonly assessed by radiography, the repeatability of radiographic evaluation has been uniformly reported to be poor. Thus, axial computed tomography (CT), which has been shown to be superior to radiography, is used to assess the distal tibiofibular joint. Dikos et al found individual variation in anteroposterior or mediolateral translation and rotation of the fibula by assessing axial CT images. Therefore, the fibula is considered to move 3-dimensionally relative to the tibia. However, almost all previ

*KEY WORDS: bone model, color-coded map, computed tomography, distal tibiofibular joint, lateral ankle sprain*
ous studies have assessed the fibula using 2-dimensional images limited to the region near the articular surface, and none has examined fibular alignment in ankles with pathology using 3-D techniques.

Distal tibiofibular joint malalignment has been shown to be present in individuals with CAI. Studies using axial CT imaging at the talocrural joint level have found that the fibula of ankles with CAI is displaced posteriorly compared to that of healthy ankles. In contrast, other studies using radiography have noted the presence of fibular anterior translation in the ankles with CAI. Thus, there is no consistent reported pattern of fibular malalignment in the anteroposterior direction and, to our knowledge, no previous study has considered mediolateral malalignment. Most lateral ankle sprains involve injury to the lateral ankle ligaments (eg, the anterior talofibular or calcaneofibular ligament). In patients with repeated lateral ankle sprains, talocrural anterior translation or internal rotation is increased. Considering that disruption of the lateral ankle ligaments results in abnormal talar anterior translation or internal rotation, the fibula might be displaced posteriorly because the distance between the talus and fibula is affected by the lateral ankle ligaments. In addition, it has been shown that the anterior tibiofibular ligament or interosseous membrane may be injured as a result of a lateral ankle sprain; therefore, distal tibiofibular joint instability may also occur in individuals with CAI.

The objective of this study was to determine if abnormal fibular position is present in individuals with CAI, using an analysis of CT-based bone models with 6 degrees of freedom. We hypothesized that the fibula of the ankles with CAI would demonstrate more posterior and lateral position with respect to the tibia compared to that of contralateral healthy ankles.

METHODS

Participants

The protocol of this case series, which compared the kinematics of ankles with CAI to contralateral healthy ankles, was approved by the Institutional Review Board of Yokohama Sports Medical Center. All potential participants who met specific selection criteria signed an informed-consent form prior to participation. The criteria for inclusion were as follows: healthy males; history of at least 2 episodes of unilateral lateral ankle sprain during the 1 year prior to enrollment in the study; multiple unilateral episodes of giving way; presence of unilateral ankle instability based on the foot and ankle function self-report questionnaire; current tendency of the ankle to give way during sporting activities; side-to-side difference on side hop test and figure-of-eight hop test; and contralateral healthy ankle without a history of injury or a sensation of instability. The exclusion criteria of the study were as follows: history of lateral ankle sprain in the last 3 months; ankle swelling and feeling of severe pain in the last 3 months; history of cerebrovascular disorders, neuropathy, or lower extremity injury in the last 3 months; history of rehabilitation treatment, including balance exercise, for the involved ankle; or use of any medications that could affect balance.

Seventeen males with unilateral CAI (mean ± SD age, 21.0 ± 2.4 years; side of instability: 11 right, 6 left) participated in this study. All participants reported 3 or more previous ankle sprains. Seven of the participants played basketball, 4 soccer, 3 American football, 2 lacrosse, and 1 was a runner. The average ± SD time elapsed since the most recent lateral ankle sprain was 14.9 ± 11.3 months.

Stress Radiography

All participants underwent stress radiography (anterior drawer and talar tilt) of the talocrural joint to screen for mechanical instability in both ankles. Testing was performed with a telos device (telos SE2000; telos GmbH, Marburg, Germany) using a 50-N force. The ankle with CAI was considered to have mechanical instability if there was 3 mm or greater displacement with the anterior drawer test or 3° or greater talar tilt in
that ankle compared to the contralateral healthy ankle.\textsuperscript{23}

**CT Images and Geometric Bone Models**

Participants underwent non-weight-bearing CT scan (Zomatom plus-4 VZ; Siemens, Munich, Germany) with a 1.0-mm slice pitch, spanning an area covering the distal 10 cm of the tibia/fibula to the distal end of the calcaneus. During scanning, the ankle was held in a position of neutral dorsiflexion/plantar flexion, inversion/eversion, and internal/external rotation. Geometric bone models of the tibia and fibula were created from CT images. Exterior cortical bone edges in the images were segmented using commercial software (3D-Doctor; Able Software, Lexington, MA), and these point clouds were converted into polygonal surface models.

**Anatomical Coordinate Systems**

Anatomical coordinate systems were embedded in the tibia model based on previously published methods, using a custom software program (VH KneeFitter).\textsuperscript{31,32,56}

Average interobserver difference of the anatomical coordinate systems was 0.35 mm in translation and 0.76° in rotation, and average intraobserver difference was 0.35 mm in translation and 0.85° in rotation (\textit{FIGURE 1}).\textsuperscript{56}

**Fibular Alignment Analysis**

Using a commercial software package (Geomagic Studio; Geomagic Inc, Morrisville, NC), the left tibia was flipped horizontally relative to the superoinferior anatomical axis, and the bilateral tibia was superimposed using a best-fit algorithm that moved the tibia to the position of best congruity. Then, the amount of positional difference of the tibiae based on both rotation and translation was recorded (\textit{FIGURE 2}) and adapted to the left fibula, which was reversed relative to the superoinferior anatomical axis. The software computed the positional difference of the fibulae of the ankles with CAI relative to that in healthy ankles, and displayed the separation of the bilateral fibular surfaces using a color-coded map (49 stages). The exact positional difference of the fibulae of the ankles with CAI at any location could be determined by moving the cursor to that location (\textit{FIGURE 3}). In addition, fibular rotation alignments were recorded by a best-fit algorithm. The positional difference of the anteroposterior and mediolateral tips at the lateral malleolus and of the fibula at 5 cm and 10 cm proximal to the inferior tip of the lateral malleolus
was determined. In this analysis, the anteroposterior and mediolateral tips were defined by an anatomical coordinate system.

Statistical Analysis

The 95% confidence interval (CI) was used to compare fibular alignment between healthy ankles and ankles with CAI at 3 reference points (the lateral malleolus and 5 cm and 10 cm proximal to the inferior tip of the lateral malleolus). To assess clinical significance of the data, effect sizes were calculated and interpreted according to Cohen (small, 0.20 to 0.49; medium, 0.50 to 0.79; large, greater than 0.80). All data were analyzed using a statistical software package for the social sciences (PASW Statistics 18; IBM Corporation, Armonk, NY).

RESULTS

Stress Radiography

The mean ± SD values for the anterior drawer and talar tilt tests were 0.1 ± 2.6 mm and 0.6° ± 3.7°, respectively. Four of the 17 participants had mechanical instability of the talocrural joint (anterior drawer, 1; talar tilt, 2; both, 1).

Fibular Alignment

There was no significant difference between the anteroposterior fibular position of healthy ankles and that of ankles with CAI (TABLE). But the fibula of the ankles with CAI was significantly more laterally positioned than that of the healthy ankles at all 3 reference points: the mean (95% CI) at the most prominent point of the lateral malleolus, 5 cm proximal to the lateral malleolus, and 10 cm proximal to the lateral malleolus was 0.60 (0.04, 1.16), 0.57 (0.15, 0.98), and 0.68 (0.09, 1.27), respectively. The effect size for the difference in mediolateral position was moderate (TABLE). The distribution of fibular side-to-side difference in position is illustrated in FIGURE 4. There was also a slight difference in fibular external rotation (mean ± SD, 0.07° ± 2.61°).

TABLE

<table>
<thead>
<tr>
<th>Direction/Reference Point</th>
<th>Mean ± SD*</th>
<th>Effect Size</th>
<th>95% Confidence Interval*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral malleolus</td>
<td>0.04 ± 0.92</td>
<td>0.04</td>
<td>-0.44, 0.51</td>
</tr>
<tr>
<td>5 cm</td>
<td>0.13 ± 1.03</td>
<td>0.13</td>
<td>-0.40, 0.66</td>
</tr>
<tr>
<td>10 cm</td>
<td>0.58 ± 1.73</td>
<td>0.33</td>
<td>-0.31, 1.47</td>
</tr>
<tr>
<td>Posterior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral malleolus</td>
<td>0.34 ± 1.01</td>
<td>0.34</td>
<td>-0.18, 0.86</td>
</tr>
<tr>
<td>5 cm</td>
<td>0.00 ± 1.19</td>
<td>0.00</td>
<td>-0.61, 0.61</td>
</tr>
<tr>
<td>10 cm</td>
<td>-0.14 ± 1.80</td>
<td>0.08</td>
<td>-1.06, 0.79</td>
</tr>
<tr>
<td>Medial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral malleolus</td>
<td>-0.62 ± 0.95</td>
<td>0.65</td>
<td>-1.11, -0.13†</td>
</tr>
<tr>
<td>5 cm</td>
<td>-0.57 ± 1.00</td>
<td>0.57</td>
<td>-1.08, -0.05†</td>
</tr>
<tr>
<td>10 cm</td>
<td>-0.68 ± 1.32</td>
<td>0.52</td>
<td>-1.36, 0.00†</td>
</tr>
<tr>
<td>Lateral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral malleolus</td>
<td>0.60 ± 1.09</td>
<td>0.55</td>
<td>0.04, 1.16†</td>
</tr>
<tr>
<td>5 cm</td>
<td>0.57 ± 0.81</td>
<td>0.70</td>
<td>0.15, 0.98†</td>
</tr>
<tr>
<td>10 cm</td>
<td>0.68 ± 1.15</td>
<td>0.59</td>
<td>0.09, 1.27†</td>
</tr>
</tbody>
</table>

*Values are mm.
†Significant difference between ankles with chronic ankle instability (CAI) and healthy ankles. The mediolateral position indicates the average of the positional differences of the medial and lateral surfaces of the fibula of the ankle with CAI from that of the healthy ankle. Similarly, the anteroposterior position indicates the average of the positional differences of the anterior and posterior surfaces of the fibula of the ankle with CAI from that of the healthy ankle.

DISCUSSION

The objective of this study was to determine if abnormal fibular alignment is present in individuals with CAI. On average, the fibula of the ankles with CAI was significantly more laterally positioned than that of the healthy ankles, but there was no significant difference in the anteroposterior position.

Distal tibiofibular joints with or without CAI have previously been evaluated using 2-dimensional analysis on standard axial CT or radiographic images. However, measurements obtained with these methods have been shown to be unreliable and do not allow evaluation in planes other than the selected plane. In addition, differences in measurement of fibular alignment in some studies were based on the tibia, whereas in other studies they were based on the talus, making it difficult to compare findings across studies. The present study analyzed the 3-D side-to-side difference of the position of the fibula with respect to the tibia. Although previous studies have reported fibular anteroposterior displacements in individuals with CAI, the current study did not. Because anteroposterior displacement of the fibula may be related to the severity of lateral ankle ligament injury, further study that distinguishes the severity of lateral ankle sprain or the presence of mechanical instability is required.

Many studies have demonstrated a lateral displacement of the fibula after an ankle syndesmosis injury. In addition, the alteration of the geometry of the mortise attributed to fibular malalignment is considered to contribute to the development of ankle arthritis. However, the present study demonstrated that individuals with CAI and a history of repeated lateral ankle sprain had a more lateral position of the fibula. Insidious injuries to the anterior tibiofibular ligament and/or interosseous membrane

**TABLE**

Side-to-Side Difference of the Fibula

*Values are mm.†Significant difference between ankles with chronic ankle instability (CAI) and healthy ankles. The mediolateral position indicates the average of the positional differences of the medial and lateral surfaces of the fibula of the ankle with CAI from that of the healthy ankle. Similarly, the anteroposterior position indicates the average of the positional differences of the anterior and posterior surfaces of the fibula of the ankle with CAI from that of the healthy ankle.*
may be involved in some patients with lateral ankle sprain, as suggested by several studies. Particularly, dysfunction of these ligaments may contribute to the slight external rotation of the fibula associated with fibular lateral position, as noted in the present study. Therefore, the distal tibiofibular joint instability in the ankles with CAI may be caused by damage to these tissues due to repeated lateral ankle sprains. Some in vitro studies have found that cutting of the anterior tibiofibular ligament or interosseous membrane resulted in an increase in the distance between the tibia and fibula, as well as an increase in talar rotation and tilt angle. Lateral displacement of the fibula widens the distal tibiofibular joint, affecting the mortise structure, and is associated with excessive talar rotation. Previous in vivo studies have shown an increase in talar anterior translation, inversion, and internal rotation in the ankles with CAI. Thus, complex analyses that include examination of talocrural joint alignment or kinematics, as well as investigation of the distal tibiofibular joint, will be required in the future.

Although the magnitudes of detected differences in the present study were small (0.57-0.68 mm), the effect size was moderate. Considering that weight-bearing produces forces that tend to separate the distal tibiofibular joint, greater differences may be detected in weight-bearing conditions. Although clinical tests exist to assess anterior tibiofibular ligament injury, individuals with CAI may not present with pain or discomfort when performing these tests. Future studies may investigate the association between fibular position and the likelihood of repeated giving-way events and the effects of an intervention (eg, manipulation of the tibiofibular joint) to improve distal fibular alignment.

The present study was performed in 2011 and 2012, and the selection criteria for CAI were based on the literature published before 2011. As such, the participants fit most but not all of the criteria for CAI recently published by the International Ankle Consortium. In addition, the participants of the present study were not given the recommended questionnaires.

This study had some limitations. The result may be confounded by selection bias resulting from the cross-sectional case series design. Lack of a healthy control group or a preinjury-postinjury comparison precluded determining if the positional difference of the bilateral fibulae found in this study was caused by repeated ankle sprain. Although all participants underwent stress radiography and 4 participants showed evidence of mechanical instability, the ligament condition was not investigated by magnetic resonance imaging or arthroscopy. Because this study only investigated non-weight-bearing static fibular alignment, the magnitude of difference was small. Accordingly, it will be necessary in future studies to determine the alignment of the distal tibiofibular joint during dynamic, weight-bearing activities in individuals with and without CAI.

**CONCLUSION**

**FIGURE 4.** The distribution of fibular positional difference at the fibula 5 cm proximal to the inferior tip of the lateral malleolus. The arrow indicates mean ± SD external rotation (0.07° ± 2.61°). The orange diamonds represent participants who were positive for mechanical instability, and the blue diamonds represent participants who were negative for mechanical instability. The arrow and lines represent the mean and standard deviations for lateromedial and anteroposterior differences in fibular position.
significantly more lateral position than that in healthy ankles. This study demonstrated that individuals with CAI and a history of repeated lateral ankle sprain showed lateral position of the fibula. Future studies should focus on weight-bearing conditions and an intervention to improve distal fibular alignment and prevent recurrent lateral ankle sprain and giving way.

**KEY POINTS**

**FINDINGS:** Ankles with CAI demonstrated significantly more lateral fibular position between the lateral malleolus and distal 10 cm from the inferior tip of lateral malleolus compared to healthy ankles.

**IMPLICATIONS:** In ankles with CAI, the more lateral fibular position may result in distal tibiofibular joint instability, which may cause abnormal talar kinematics and contribute to recurrent lateral ankle sprain or giving way.

**CAUTION:** Because this study only investigated non-weight-bearing static fibular alignment in ankles with CAI, dynamic fibular alignment during weight-bearing movement remains unknown.

**REFERENCES**
