Preoperative Radiographic and CT Findings Predicting Syndesmotic Injuries in Supination-External Rotation-Type Ankle Fractures

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Background: The Lauge-Hansen classification system does not provide sufficient data related to syndesmotic injuries in supination-external rotation (SER)-type ankle fractures. The aim of the present study was to investigate factors helpful for the preoperative detection of syndesmotic injuries in SER-type ankle fractures using radiographs and computed tomography (CT).

Methods: A cohort of 191 consecutive patients (104 male and eighty-seven female patients with a mean age [and standard deviation] of 50.7 ± 16.4 years) with SER-type ankle fractures who had undergone operative treatment were included. Preoperative ankle radiographs and CT imaging scans were made for all patients, and clinical data, including age, sex, and mechanism of injury (high or low-energy trauma), were collected. Patients were divided into two groups: the stable syndesmotic group and the unstable syndesmotic group, with a positive intraoperative lateral stress test leading to syndesmotic screw fixation. Fracture height, fracture length, medial joint space, extent of fracture, and bone attenuation were measured on radiographs and CT images and were compared between the groups. Binary logistic regression analysis was performed to identify the factors that significantly contributed to unstable syndesmotic injuries. Receiver operating characteristic curves were calculated, and cutoff values were suggested to predict unstable syndesmotic injuries on preoperative imaging measurements.

Results: Of the 191 patients with a SER-type ankle fracture, thirty-eight (19.9%) had a concurrent unstable syndesmotic injury. Age, sex, mechanism of injury, fracture height, medial joint space, and bone attenuation were significantly different between the two groups. In the binary logistic analysis, fracture height, medial joint space, and bone attenuation were found to be significant factors contributing to unstable syndesmotic injuries. The cutoff values for predicting unstable syndesmotic injuries were a fracture height of >3 mm and a medial joint space of >4.9 mm on CT scans, and a fracture height of >7 mm and medial joint space of >4.5 mm on radiographs.

Conclusions: Fracture height, medial joint space, and bone attenuation were useful factors for the preoperative detection of unstable syndesmotic injuries in SER-type ankle fractures.

Level of Evidence: Diagnostic Level II. See Instructions for Authors for a complete description of levels of evidence.

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Syndesmotic injuries are often concurrent with ankle fractures, increasing the instability of the fractures and making fracture reduction and stabilization more difficult. Chronic untreated syndesmotic instability could result in pain on walking, giving way, and early degenerative arthritis.

Although recent advances in diagnostic tools have been introduced for evaluating syndesmotic injuries, the standard of care in evaluating syndesmotic injuries concurrent with ankle fractures is the intraoperative lateral stress test, which may be somewhat subjective. Preoperative recognition on imaging studies is an important issue for orthopaedic surgeons performing surgical procedures for ankle fractures.

Stage-3 and 4 pronation-external rotation injuries and stage-3 pronation-abduction injuries in the Laue-Hansen classification system frequently coincide with syndesmotic injuries, which correspond to Danis-Weber type-C fractures. Supination-adduction injuries in the Laue-Hansen classification system rarely occur concurrently with syndesmotic injuries, which correspond to Danis-Weber type-A fractures. However, supination-external rotation (SER) injuries in the Laue-Hansen classification system, corresponding to Danis-Weber type-B fractures, require further clarification related to concurrent syndesmotic injuries.

The aim of this study was to investigate and identify the factors associated with syndesmotic injuries requiring operative fixation in SER-type ankle fractures. It was hypothesized that fibular bone mineral density, determined by attenuation seen on computed tomography (CT), fibular fracture height from ankle joint line, and concurrent deltoid ligament injuries, would contribute to syndesmotic injuries.

### Materials and Methods

This study was approved by the institutional review board at our institution. Informed consent was waived because of the retrospective nature of the study. Consecutive patients who had undergone operative reduction and internal fixation for unstable ankle fractures from May 2009 to December 2012 were enrolled. Preoperative ankle radiographs, including a mortise view, and a three-dimensional CT reconstruction were made for all patients. Demographic data, including age and sex as well as injury mechanism (low or high-energy trauma) were recorded. The inclusion criterion was an ankle fracture classified as an SER-type injury with a lateral malleolar fracture. Exclusion criteria were (1) patients with a CT scan done at an outside hospital; (2) an ankle fracture resulting from a direct blow; and (3) abnormal ankle anatomy due to congenital anomaly, previous surgeries, trauma, infection, or tumors.

High-energy trauma was defined as a traffic accident or a fall from a height of ≥2 m, and low-energy trauma was defined as a slip down or a fall from a height of <1 m. Selection of SER-type fractures was by two experienced orthopaedic surgeons.

The patients underwent operative reduction and internal fixation using a plate and screws for the lateral malleolus and two 5.0-mm cannulated screws or tension band wiring for the medial malleolus. The posterior malleolus was fixed using a 5.0-mm cannulated screw. An unstable syndesmotic injury was evaluated on a fluoroscopic lateral stress test (the Cotton test) intraoperatively after all fractures were internally fixed and was defined as a tibiofibular clear space of >5 mm. The measurement was made by comparing the relative distance (the ratio of the tibiofibular clear space to the fibular width) measured on the fluoroscopic image and the absolute value of the fibular width measured on the radiographic image using picture archiving and communication system (PACS) software. This test has been reported to be reliable and is frequently used in clinical practice.

Syndesmotic screw fixation was performed using a 5.0-mm cannulated screw when unstable syndesmotic injuries were diagnosed. The patients were assigned to two groups: the unstable syndesmotic group or the stable syndesmotic group, according to the presence (unstable) or absence (stable) of syndesmotic screw fixation.

### Ankle Radiographs and CT Scans

Anteroposterior, mortise, and lateral radiographs of the ankle were made using a UT 2000 x-ray machine (Philips Research, Eindhoven, The Netherlands) at a source-to-image distance of approximately 100 cm with the patient in the supine position. The radiograph settings were 46 to 50 kVp and 4.5 to 5 mAs, depending on the body size of the patient.

Ankle CT scans were performed using a Brilliance iCT scanner (Philips Healthcare, Cleveland, Ohio) with 120 kVp, 150-mm field of view, and 0.5-mm slice thickness. The scanner was calibrated daily. CT scans were made with the patient in the supine position. Multidetector CT and three-dimensional reconstructions were performed. Radiographic images were retrieved using the PACS, and measurements were subsequently carried out using PACS software (IMPAX; Agfa Healthcare, Mortsel, Belgium).

### Table I: Intraobserver and Interobserver Reliabilities of Measurements

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Intraobserver Reliability*</th>
<th>Interobserver Reliability*</th>
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<tbody>
<tr>
<td></td>
<td>ICC</td>
<td>95% CI</td>
</tr>
<tr>
<td>Radiograph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture height</td>
<td>0.957</td>
<td>0.933 to 0.975</td>
</tr>
<tr>
<td>Medial joint space</td>
<td>0.924</td>
<td>0.857 to 0.961</td>
</tr>
<tr>
<td>CT scan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture height</td>
<td>0.985</td>
<td>0.971 to 0.992</td>
</tr>
<tr>
<td>Fracture length</td>
<td>0.945</td>
<td>0.885 to 0.973</td>
</tr>
<tr>
<td>Medial joint space</td>
<td>0.921</td>
<td>0.867 to 0.956</td>
</tr>
<tr>
<td>Mean bone attenuation of lateral malleolus</td>
<td>0.831</td>
<td>0.729 to 0.903</td>
</tr>
<tr>
<td>Mean bone attenuation of medial malleolus</td>
<td>0.820</td>
<td>0.672 to 0.904</td>
</tr>
</tbody>
</table>

*ICC = intraclass correlation coefficient, and CI = confidence interval.
Consensus Building and Measurements

Prior to the CT and radiographic measurements, a formal consensus-building session to select and define the measurements was held by four experienced orthopaedic surgeons. The orthopaedic surgeon participants in the study were (1) surveyed for current practices, (2) presented with a detailed systematic review of the relevant literature, (3) given the opportunity to voice and discuss opinions collectively, and (4) asked to vote regarding preferences privately.

Previous studies were reviewed, and five relevant CT indices and two radiographic indices were identified. These five CT indices were fracture height, fracture length, medial joint space, extent of fractures, and osseous attenuation. On preoperative ankle mortise radiographs, two items were measured: fracture height and medial joint space.

Fracture height was defined as the vertical height between the distal tibial articular surface and the lowest point of the fracture line of the lateral malleolus. Fracture length was defined as the vertical height between the highest and the lowest points of the fracture line of the lateral malleolus. Medial joint space was defined as the perpendicular distance between the medial malleolar articular surface and the medial talar articular surface.

Reliability Testing

Interobserver reliability for the three orthopaedic surgeons, who measured CT and radiographic indices independently without knowledge of the patients’ clinical information or the other surgeons’ measurements, was determined using intraclass correlation coefficients (ICCs). One of the surgeons repeated the CT and radiographic measurement to assess intraobserver reliability with an interval of three weeks after interobserver reliability testing. Intraobserver and interobserver reliability testing was performed on thirty-six patients; the sample size was calculated with a target ICC value of 0.8 and a 95% confidence interval of 0.2 at the setting of a single measurement and absolute agreement. Following the reliability test, all radiographic measurements were made by one of the authors who performed intraobserver reliability testing.

Data Analysis

The demographic data, mechanism of injury, as well as the CT and radiographic measurements between the unstable and stable syndesmotic groups were compared. Binary logistic regression analysis was performed to determine the factors that significantly contributed to unstable syndesmotic injuries in SER-type ankle fractures. Sensitivity and specificity of the receiver operating characteristic curve were calculated for the significant factors.
Statistics
Descriptive statistics including the mean, standard deviation, and proportions were determined. A Kolmogorov-Smirnov test verified the normality of the distribution of continuous variables.

Comparison between the unstable and stable syndesmotic groups was conducted using a t test or Mann-Whitney U test and a chi-square test according to the data characteristics. To combine the factors that significantly contributed to unstable syndesmotic injuries, binary logistic regression with the stepwise selection method using CT measurements (fracture height, medial joint space, and bone attenuation) was used.

The estimated area, sensitivity, and specificity of the receiver operating characteristic curve were calculated for each radiographic and CT measurement. The DeLong test was used to detect the significance of the area under the curve at each measurement.

All statistics were two-tailed, and a p value of <0.05 was considered significant.

Source of Funding
There was no external funding source.

Results
A total of 660 patients with an ankle fracture underwent operative treatment from May 2009 to December 2012. Of those, 191 patients with SER-type ankles fracture were included. The mean age (and standard deviation) of the patients at the time of surgery was 50.7 ± 16.4 years (range, eighteen to eighty-five years). There were 104 male and eighty-seven female patients. Of those, thirty-eight patients (19.9%) had a syndesmotic injury and underwent syndesmotic fixation along with fracture reduction and internal fixation.

CT and radiographic measurements showed satisfactory interobserver and intraobserver reliabilities (Table I). In the comparison between the unstable and stable syndesmotic groups, age, sex, the proportion of high-energy trauma, fracture height on CT, medial joint space on CT, and bone attenuation of the medial malleolus and lateral malleolus were significantly different (p < 0.05 for all). The fracture height (p < 0.05) and medial joint space (p < 0.05) on radiographs were also significantly different between the groups (Table II).

The binary logistic regression model, including age, sex, mechanism of injury, fracture height on CT, fracture length on CT, medial joint space on CT, and bone attenuation of the lateral malleolus, showed that fracture height, medial joint space, and bone attenuation of the lateral malleolus were significant factors in predicting unstable syndesmotic injuries.

| TABLE II Comparison of the Unstable Syndesmotic Injury and Stable Syndesmotic Injury Groups |
|-----------------------------------------------|-----------------------------------------------|
| Unstable Syndesmotic Group | Stable Syndesmotic Group | P Value |
| No. of patients | 38 | 153 | – |
| Age* (yr) | 40.6 ± 17.0 | 53.2 ± 15.2 | <0.05 |
| Sex (M:F) | 31:7 | 73:80 | <0.05 |
| Low-energy:high-energy trauma (no. of patients) | 20:18 | 128:25 | <0.05 |
| Fracture type (I/II/III/IV) | 16/7/6/9 | 63/17/51/22 | |
| Radiograph* | | | |
| Fracture height (mm) | 15.1 ± 18.8 | −1.28 ± 7.2 | <0.05 |
| Medial joint space (mm) | 5.8 ± 3.4 | 3.3 ± 1.5 | <0.05 |
| CT scan* | | | |
| Fracture height (mm) | 13.9 ± 17.4 | −0.9 ± 6.9 | <0.05 |
| Fracture length (mm) | 37.5 ± 13.6 | 34.5 ± 11.6 | 0.181 |
| Medial joint space (mm) | 5.6 ± 3.5 | 3.4 ± 1.6 | <0.05 |
| Bone attenuation of lateral malleolus (HU) | 333.6 ± 91.0 | 244.7 ± 94.7 | <0.05 |
| Bone attenuation of medial malleolus (HU) | 311.6 ± 88.1 | 254.8 ± 85.1 | <0.05 |

*The values are given as the mean and the standard deviation.

<table>
<thead>
<tr>
<th>TABLE III Logistic Regression Analysis (Stepwise Selection Method)</th>
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<tbody>
<tr>
<td>Variable</td>
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<tr>
<td>Fracture height (mm)</td>
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<tr>
<td>Medial joint space (mm)</td>
</tr>
<tr>
<td>Bone attenuation of lateral malleolus (HU)</td>
</tr>
</tbody>
</table>
space, and bone attenuation of the lateral malleolus were significant contributing factors to unstable syndesmotic injury in SER-type ankle fractures (Table III).

The receiver operating characteristic curve showed that fracture height, medial joint space, and osseous attenuation of the lateral malleolus were useful to determine cutoff values for unstable syndesmotic injuries. The area under the curve for fracture height on CT was 0.765, and the appropriate cutoff value was 3 mm. When a fracture height of >3 mm on a CT scan was used as a threshold, a sensitivity of 63.2% and a specificity of 92.8% were achieved in determining the unstable syndesmotic injuries in SER-type ankle fractures. The area under the curve for the medial joint space on CT was 0.731, and the cutoff value was 4.9 mm, with a sensitivity of 47.4% and a specificity of 90.8%. The area under the curve for bone attenuation of the lateral malleolus was 0.753, and the cutoff value was 263 HU, with a sensitivity of 81.6% and a specificity of 62.1%.

The receiver operating characteristic curves for fracture height and medial joint space on radiographs of unstable syndesmotic injuries were also calculated. The area under the curve for fracture height was 0.779, and the cutoff value was 7 mm, with a sensitivity of 60.5% and a specificity of 95.4% (Fig. 3). The area under the curve for the medial joint space was 0.731, and the cutoff value was 4.9 mm, with a sensitivity of 47.4% and a specificity of 90.8%. The area under the curve for bone attenuation of the lateral malleolus was 0.753, and the cutoff value was 263 HU, with a sensitivity of 81.6% and a specificity of 62.1%.

The receiver operating characteristic curves for fracture height and medial joint space on radiographs of unstable syndesmotic injuries were also calculated. The area under the curve for fracture height was 0.779, and the cutoff value was 7 mm, with a sensitivity of 60.5% and a specificity of 95.4% (Fig. 3). The area under the curve for the medial joint space was 0.731, and the cutoff value was 4.9 mm, with a sensitivity of 47.4% and a specificity of 90.8%. The area under the curve for bone attenuation of the lateral malleolus was 0.753, and the cutoff value was 263 HU, with a sensitivity of 81.6% and a specificity of 62.1%.

The area under the curve for the logistic regression model with the stepwise selection method using CT measurements (fracture height, medial joint space, and bone attenuation) was 0.870. A sensitivity of 68.4% and a specificity of 86.7% were achieved.

Discussion

The present study investigated the factors that could be used to detect unstable syndesmotic injuries concurrent with SER-type ankle fractures preoperatively and to provide cutoff values based on preoperative CT and radiographic measurements. Fracture height, medial joint space, and bone attenuation were the significant preoperative factors that were associated with unstable syndesmotic injuries requiring transsyndesmotic screw fixation. When the fracture height is >7 mm or the medial joint space is >4.5 mm wide on radiographs, unstable syndesmotic injuries should be suspected, appropriately evaluated, and managed at the time of ankle fracture surgery.

This study has some limitations. First, the data were collected retrospectively, which introduces the possibility that a strictly uniform protocol might not have been maintained. Second, bone attenuation on conventional CT images, not quantitative CT, were used as a surrogate marker for bone mineral density, which correlates with bone strength. However, a previous study noted that conventional CT was comparable with quantitative CT for measuring bone mineral density or bone attenuation. We made a CT scan because it is clinically useful for detecting occult injuries, planning surgical treatments, and predicting prognoses of ankle fractures. Although CT examination did not have better results than radiographs in predicting syndesmotic injuries within SER-type ankle fractures, it has many other clinical benefits. Third, as the intraoperative stress examination was performed by two surgeons and a noncalibrated fluoroscopy machine was used, these factors could lead to biased results. Fourth, the levels of sensitivity of both the radiographs and CT measurements were low, while the degrees of specificity were
high in both cases. Of the total of 191 SER-type ankle fractures, thirty-eight (19.9%) had concurrent syndesmotic injuries. A higher number of cases could produce more accurate results pertaining to the levels of sensitivity and specificity.

Compared with the stable syndesmotic group, the unstable syndesmotic group had clinical features of young male patients injured by high-energy trauma. However, when these clinical features were adjusted by CT and radiographic measurements, fracture height, medial joint space, and bone attenuation representing bone mineral density were significant factors that predicted the unstable syndesmotic injuries in patients with SER-type ankle fractures.

There has been a consensus that the height of lateral malleolar fractures could predict the stability of ankle fractures, especially syndesmotic injuries. This is the basic concept of the Danis-Weber classification system14. A Danis-Weber type-A fracture is a stable syndesmotic injury, and type C is an unstable syndesmotic injury. For a Danis-Weber type-B fracture to be comparable with a SER-type fracture, there was a need to define the fracture height at which orthopaedic surgeons should seriously consider syndesmotic injury at the time of ankle fracture surgery.

A widened medial joint space was another significant factor associated with unstable syndesmotic injuries in SER-type ankle fractures. A wide medial joint space implies concurrent deltoid ligament injury, inferring that deltoid ligament injuries aggravate the effect of syndesmotic injuries on the ankle mortise, as suggested by previous cadaveric studies21–24,37. Therefore, unstable syndesmotic injuries need to be evaluated and appropriately managed when concurrent deltoid ligament injuries with SER-type ankle fractures are suspected38.

Although bone mineral density and osteoporosis around the ankle joint have not been clearly defined, we believe that bone strength of the lateral malleolus measured by bone attenuation on CT39 could play a role in syndesmotic injuries of SER-type ankle fractures. The initiation of an SER-type injury begins at the anterior portion of the syndesmosis or lateral malleolus around the syndesmotic ligament. If the lateral malleolus is stronger (high bone attenuation on CT) than the syndesmotic ligament, then disruption of the relatively weak syndesmotic ligament occurs first, and osseous injuries occur later at a level proximal to the ankle joint. On the contrary, if the lateral malleolus is weaker (low bone attenuation on CT) than the syndesmotic ligament, then the stress from trauma concentrates on and breaks the relatively weak lateral malleolus distal to the level of the ankle joint, leaving the syndesmosis intact (see Appendix). This explanation is supported by our study results, but needs to be further investigated.

CT and radiographs showed comparable sensitivity and specificity for diagnosing unstable syndesmotic injuries in terms of fracture length and medial joint space. However, the cutoff value of fracture height was somewhat different between the CT and radiographic measurement. Fracture height was measured between the anterior margin of the distal tibial articular surface and the lowest point of the fracture line on the radiographs, while the fracture height was measured between the nearest distal tibial articular surface (selected from the anteroposterior arc of the distal tibial articular surface) and the lowest point of the fracture line on the CT images. Therefore, fracture height on the CT scan was the shortest distance between the distal articular surface and the lowest point of the fracture line. This could explain the difference between the cutoff values of the fracture height of the CT and the radiographic measurements.

In conclusion, concurrent syndesmotic injuries need to be evaluated and appropriately managed in SER-type ankle fractures caused by high-energy trauma in young patients without osteoporosis, especially when the lateral malleolar fracture line begins >7 mm proximal to the ankle joint line or the medial joint space is >4.5 mm wide on radiographs. We suggest that SER-type ankle fractures be further classified into SER with syndesmotic injury and SER without syndesmotic injury to raise orthopaedic surgeons’ awareness of syndesmotic injury preoperatively and to ensure appropriate management of the injury.

Appendix

A figure showing that one of the determinants of syndesmotic injury is the relative strength between the syndesmotic ligament and the lateral malleolus is available with the online version of this article as a data supplement at jbjs.org.

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References


