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Syndesmotic Injury Assessment With Lateral Imaging During Stress Testing in a Cadaveric Model

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Abstract

Background: External rotation, lateral, and sagittal stress tests are commonly used to diagnose syndesmotic injuries, but their efficacy remains unclear. The purpose of this study was to characterize applied stresses with fibular motion throughout the syndesmotic injury spectrum. We hypothesized that sagittal fibular motion would have greater fidelity in detecting changes in syndesmotic status compared to mortise imaging.
Methods: Syndesmotic instability was characterized using motion analysis during external rotation, lateral, and sagittal stress tests on cadaveric specimens (n = 9). A progressive syndesmotic injury was created by sectioning the tibiofibular and deltoid ligaments. Applied loads and fibular motion were synchronously measured using a force transducer and motion capture, respectively, while mortise and lateral radiographs were acquired to quantify clinical measurements. Fibular motion in response to these 3 stress tests was compared between the intact, complete lateral syndesmotic injury and lateral injury plus a completely sectioned deltoid condition.
Results: Stress tests performed under lateral imaging detected syndesmotic injuries with greater sensitivity than the clinical-standard mortise view. Lateral imaging was twice as sensitive to applied loads as mortise view imaging. Specifically, half as much linear force generated 2 mm of detectable syndesmotic motion. In addition, fibular motion increased linearly in response to sagittal stresses (Pearson's r [ρ] = 0.91 ± 0.1) but not lateral stresses (ρ = 0.29 ± 0.66).
Conclusion: Stress tests using lateral imaging detected syndesmotic injuries with greater sensitivity than a typical mortise view. In addition to greater diagnostic sensitivity, reduced loads were required to detect injuries.
Clinical Relevance: Syndesmotic injuries may be better diagnosed using stress tests that are assessed using lateral imaging than standard mortise view imaging.

Keywords: biomechanics, diagnostic imaging, syndesmosis, syndesmotic injury

Syndesmotic injuries are largely rotational in nature and may present as isolated ligamentous injuries or in combination with bony injuries.[20] Radiographic criteria have been developed to diagnose these injuries on a mortise radiograph and include an assessment of medial gutter widening, as well as distal tibiofibular clear space and overlap.[7,16,22] Although some syndesmotic injuries are readily apparent on injury radiographs, others may not be as obvious.[1,13] Furthermore, assessing rotational instability can be difficult to assess with 2-dimensional radiographs. Historically, fibular fracture level has been linked with the probability of a syndesmotic injury.[5] For example, syndesmotic fixation is not needed in pronation-external rotation ankle fractures if rigid bimalleolar fixation is achieved or the fibula fracture is within 4.5 cm from the tibiotalar joint.[3] However, recent data suggest that using fibular fracture level to predict syndesmotic injury has unacceptably low sensitivity.[8,13,22]

External rotation, lateral, and sagittal stress tests are commonly used clinical tests to detect syndesmotic instability.[4,6,19,21] The external rotation stress test is advantageous in that it can be performed preoperatively, whereas lateral or sagittal stress tests apply a force to the fibula intraoperatively. Stress tests

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rely on the principle of there being sufficient syndesmotic injury to allow the fibula more unconstrained motion relative to the tibia compared to the uninjured state. If medial clear space or distal tibiofibular alignment surpasses a threshold, instability is determined to be present and fixation is recommended. However, the dependency of fibular motion on the magnitude of applied stress is poorly understood and may explain suboptimal exam efficacy.[12]

Therefore, the purpose of this study was 2-fold: (1) to establish the specificity and sensitivity of several stress tests for diagnosing syndesmotic injuries and (2) to characterize fibular motion in response to varying amounts of applied stresses. We tested our working hypothesis that fibular motion measured in the sagittal plane would provide greater sensitivity and specificity for syndesmotic injury severity than mortise imaging. To test our hypothesis, we used a controlled-cadaveric experiment where stress tests were performed while fibular motions were measured using motion analysis in addition to fluoroscopic imaging.

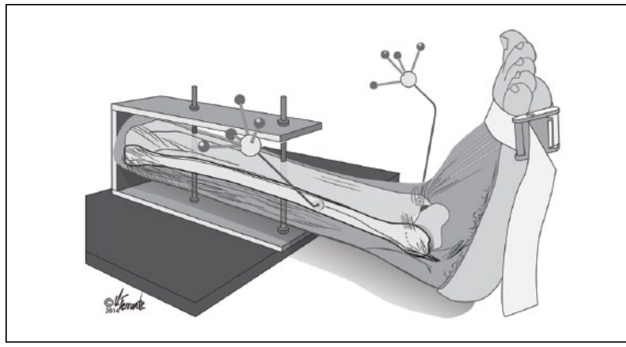

Figure 1. Specimens were secured in a custom-made frame that restricted tibial motion and allowed unconstrained fibular motion. Tibiofibular motions were quantified using motion capture while clinical stress tests were applied to the specimens. Stress tests were performed by a fellowship-trained foot and ankle surgeon using equipment instrumented with force measuring transducers.

Methods

Clinical exams to detect syndesmotic injuries were tested in 9 fresh-frozen lower leg cadaveric specimens (mean age, 71 years; range, 50-84 years). Specimens were free of gross lower extremity deformity or overt pathology based on medical history and a screening physical examination. Skin and subcutaneous tissue were removed from the knee to the midfoot, and care was taken to preserve the proximal tibiofibular joint and surrounding soft tissues. Two anterior to posterior directed threaded rods were placed through the tibia: one at the proximal one-third and one at the distal one-third junction of the tibia. Rods were secured to a custom frame that prevented tibial motion while allowing unconstrained fibular motion during stress testing (Figure 1).

Syndesmotic injuries were created by sequentially sectioning the anteroinferior tibiofibular ligament (AITFL), the distal 10 cm of the interosseous membrane (IOM), the posteroinferior tibiofibular (PITFL), and the deltoid ligament (all superficial and deep components sectioned).[10,11] This sequential sectioning approach created partial syndesmotic injuries (AITFL and AITFL + IOM), a full syndesmotic injury (AITFL + IOM + PITFL), and complete ankle injury (AITFL + IOM + PITFL + deltoid).

Fibular motion resulting from 3 stress tests was measured in each injury condition.[11] External rotation and linear—lateral and sagittal—stress tests were performed by a fellowship-trained foot and ankle surgeon in a randomized order for each sequential sectioning condition. (1) An *external rotation stress test* was performed by applying an external rotation moment to the forefoot with the ankle in neutral dorsiflexion (the tibia was rigidly secured to the loading frame, which was fixed to the testing table). The load was applied with a canvas strap secured to the forefoot, and a digital load cell was secured in series to the canvas strap so the tester could monitor the load applied. The distance from the forefoot to the center of the lateral malleolus (center of rotation of the ankle for an external rotation stress test) was measured and used to calculate the external rotation moment. Two fellowship-trained foot and ankle surgeons were asked to apply a "strong external rotation stress test" as they would do clinically to a pilot specimen secured to a materials testing system calibrated to record loads. The surgeons were blinded to the values during testing and performed 5 external rotation stresses. The average applied external rotation stress was 6.5 Nm, which was used as the maximum applied moment during subsequent testing. (2) A *lateral stress test* was performed by applying an 80-N laterally directed force to the fibula at the level of the syndesmosis with a small bone reduction clamp; 80 N was chosen because pilot testing revealed that in some specimens, a 100-N force caused the bone clamp to damage the fibula. A load cell was attached in series to the reduction clamp and force was displayed to the examiner. (3) A *sagittal stress test* was performed by applying a posteriorly directed force of 80 N to the fibula with a sharp Senn retractor placed on the anterior aspect of the fibula at the tubercle of Wagstaffe. A load cell was attached in series to the retractor, and loads were displayed to the examiner.

Syndesmotic instability was assessed using radiographs and fibular motion analysis during clinical stress tests.[11] True mortise and lateral radiographs were acquired during the unloaded and maximally loaded instances for all stress tests and syndesmotic conditions. To ensure true mortise and lateral radiographs were obtained for the stress test conditions, the fluoroscope was locked in place once a true mortise or lateral image was obtained in the unloaded condition. A true mortise image was defined as symmetrical medial and lateral gutter spaces and approximated 15 degrees of internal rotation. A true lateral image was observed when the talar dome projection was a single clean line. Because the tibia was rigidly fixed to the testing table and the fluoroscopic imaging machine was locked in place, fibular motion was likely representative of true fibular motion, rather than imaging artifact. Tibial and fibular motions were also tracked with a 4-camera motion capture system with a resolution of 0.5 mm and 0.5 degrees (Eagle 4; Motion Analysis Corporation, Santa Rosa, CA). Reflective markers were rigidly secured to the tibia and fibula 3 cm proximal to the syndesmosis. Fibular motion was characterized by lateral motion (ie, coronal plane motion parallel with the transmalleolar axis) and posterior motion (ie, sagittal plane motion of the fibula perpendicular to the transmalleolar axis).

Sensitivity and specificity of the lateral and external rotation stress tests under mortise radiograph and the sagittal and external rotation stress tests under lateral radiography were assessed for the ability to correctly detect injuries that resulted in 2 mm of syndesmotic instability. Fibular overlap with the plafond less than 50% (as measured on lateral radiographs) was considered a positive test for lateral radiographs (Figure 2). Radiographic measures were compared across injury conditions using repeated-measures analysis of variance to detect differences in syndesmotic stability as a function of injury. Tukey post hoc tests were performed to control for multiple comparisons, and statistical significance was set to $\alpha = .05$. Load-displacement plots were created for lateral and posterior fibular motion under lateral and external rotation stress tests. These 4 load-displacement curves were assessed for linearity by calculating the Pearson correlation coefficient for each of the curves. From the curves, the amount of force required to produce 2 mm of displacement of the fibula was identified.

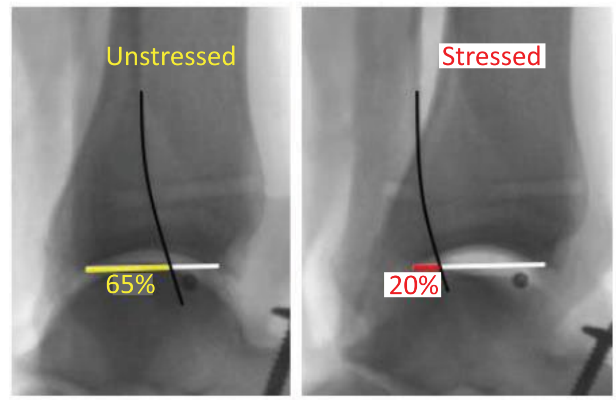

Figure 2. A true lateral radiograph is made by referencing the tibial plafond and the talar dome with the foot held in neutral dorsiflexion. The anterior fibular cortex is identified, and the percentage of the tibial plafond that is covered by the fibular shadow is estimated. If <50% of the tibial plafond was covered by the fibular shadow, it was defined as radiographic criteria for an injury.

Results

Partial and complete ankle injuries analyzed with lateral imaging were identified with greater sensitivity than analyzed under mortise radiographs (Table 1). All stress tests had high specificity (≥0.89) when assessing a complete ankle injury, but sensitivity was lower and more variable among the different imaging planes and stress tests (0.23-0.67).

Full syndesmotic and complete ankle injuries were detected following sagittal and external rotation stresses (Figure 3). Both applied stresses generated 1 and 1.5 cm of sagittal fibular motion in the full syndesmotic and complete ankle injury conditions, respectively ($P < 0.05$). Increased incisural and medial clear space (0.5-1.0 cm, $P < 0.05$) was detected following a complete ankle injury but was mostly not observed following a full syndesmotic injury (Figure 3).

Sagittal displacement of the fibula was twice as sensitive to applied loads as coronal motions. To generate a clinically detectable amount of syndesmotic instability, 34 N and 16 N were required to generate coronal and sagittal displacements of 2 mm. Lateral and sagittal stress tests caused fibular motion that increased linearly with applied load in full syndesmotic and complete ankle injury conditions (Pearson's r (ρ) > 0.91 ± 0.2) (Figure 4). External rotation stress testing with a full syndesmotic injury produced linear fibular motion in the sagittal plane (ρ = 0.92 ± 0.09). However, fibular motion in the coronal plane was nonlinear under external rotation stresses (ρ = 0.29 ± 0.66) and persisted even with an additional complete deltoid injury (ρ = 0.48 ± 0.61).

Discussion

This study quantified the amount of fibular motion following lateral, sagittal, and external rotation stress testing to answer several questions: (1) how is fibular motion altered by the state of the syndesmotic and deltoid ligaments, (2) is fibular motion linear or nonlinear in response to stress tests, and (3) how much force should be applied to elicit 2 mm of fibular motion in the presence of a syndesmotic injury? This study begins to address the lack of consensus in existing force values and suggests that due to the linearity of different stress tests, it is important for a surgeon to proactively choose an appropriate amount of force when assessing syndesmotic injuries using stress tests.

Our results showing fibular motion in different stages of syndesmotic injury were similar to previous studies. For example, we found that fibular instability was greater in the sagittal plane compared to the coronal plane, which was reported previously.[4] In addition, others have found that measurements of the medial clear space did not correlate with whether or not the deltoid ligament was intact, which was consistent with our linearity findings.[9] Ogilvie-Harris et al[14] concluded that the AITFL, PITFL, and IOM provided over 90% of the contribution of ligaments to stabilize the syndesmosis without the deltoid sectioned. While

Table 1. Sensitivity and Specificity of Stress Tests Under Mortise and Lateral Imaging.

	Mortise Imaging				Lateral Imaging	
	>2 mm Incisural Widening		>2 mm Medial Gutter		50% Anterior Fibula	
Characteristic	Lateral Stress	ER Stress	Lateral Stress	ER Stress	Sagittal Stress	ER Stress
Sensitivity	0.63	0.23	0.37	0.48	0.63	0.67
Specificity	1.00	1.00	1.00	1.00	0.95	0.89
PPV	1.00	1.00	1.00	1.00	0.95	0.91
NPV	0.63	0.45	0.50	0.56	0.62	0.63

Abbreviations: ER, external rotation; NPV, negative predictive values; PPV, positive predictive values.

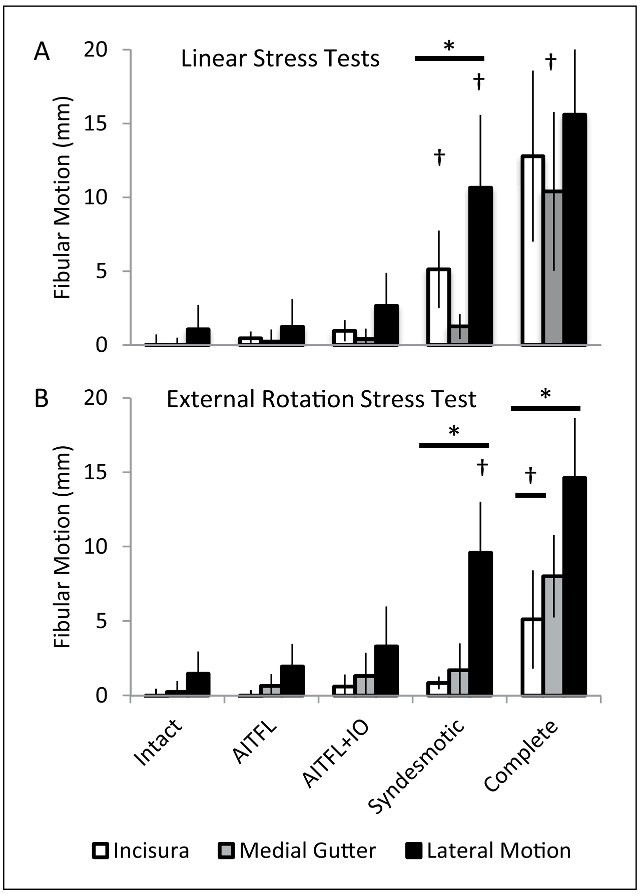

Figure 3. Fibular motion caused by linear (A) and rotational (B) stress tests performed under mortise and lateral radiography. Fibular motion measured under lateral radiography (black bars) detected greater amounts of motion (*, $P < .05$) than mortise radiography (white and gray bars). Increases in fibular motion compared to intact (†, $P < .05$) were detected sooner with lateral radiography than mortise radiography.

we did not specifically investigate this question, our results showed that sectioning of the deltoid led to significantly ($P < .05$) more motion in the coronal plane compared to the intact condition in external rotation stress testing, which suggests the important role the deltoid plays when assessing coronal plane fibular motion using external rotation stress testing. Despite the routine use of syndesmotic stress tests in the literature and clinic, there is little consensus regarding how large a load is required to achieve clinically relevant fibular displacement. Multiple authors have failed to report the amount of torque used when assessing stress tests and others report using varied amounts, including 7.2 Nm and 7.5 Nm torque (which is recommended by the Telos stress device users' manual).[2,8,9,15,18,21] Therefore, we performed pilot testing to determine a realistic force to make our results most clinically applicable and repeatable. We used the average external rotation stress of 6.5 Nm that was measured when 2 foot and ankle fellowship-trained surgeons were asked to apply a strong stress that they perform clinically. This allowed us to use a lower value than many of the previous reports that was determined in a less arbitrary way and is consistent with treatment provided by providers at our institution. Due to the majority of past reports citing a 2-mm displacement indicated a positive test, we also used this value in our study. Furthermore, prior work suggests a displacement of 2 mm increases ankle contact stress by decreasing the amount of contact area during joint loading.[17]

Our findings highlight that lateral radiographs are more sensitive than mortise radiographs. Using 2 mm as a positive stress test, the specificity of both anteroposterior (AP) and lateral radiographs for lateral, sagittal, and external rotation stress tests was very high, indicating that these tests rarely found a syndesmotic injury when none was present. However, sensitivity was low, particularly for the external rotation stress test in the mortise AP view (0.23), meaning that this test frequently failed to accurately diagnose syndesmotic injuries. Of note, sensitivity was highest on lateral radiographs from an external rotation stress test (0.67), implying that this may be the most accurate way to diagnose a syndesmotic injury when using stress tests. This value was still far from perfect, meaning that stress tests may not diagnose all syndesmotic injuries, demonstrating the need for other diagnostic measures.

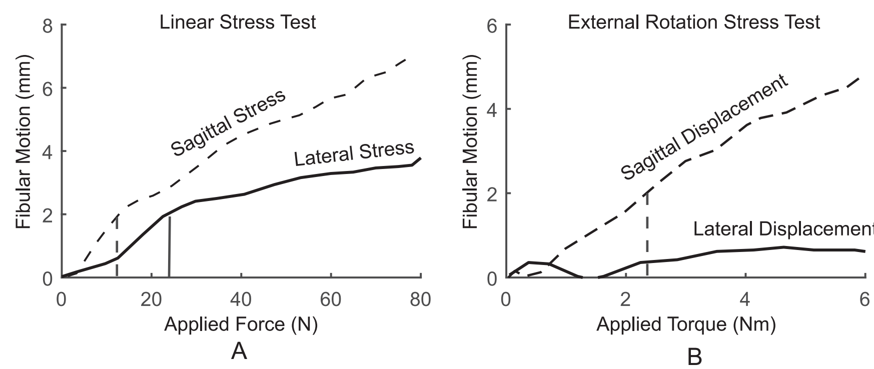

Figure 4. (A) Linear and (B) external rotation stress tests generated fibular motions that increased with applied loads (representative figure of a single cadaveric specimen shown). Sagittal and external rotation stresses imaged under lateral radiography produced larger and more linear displacements than mortise radiography assessments.

Stress tests imaged under lateral radiography demonstrate linear displacements in response to applied loads. This result provides clinicians with confidence that syndesmotic instability can be assessed with consistent increases in nondamaging loads. Conversely, stress tests imaged under mortise radiography were nonlinear, which reduces the predictability of how syndesmotic instability will manifest without knowing the exact applied load. However, neither imaging modality had perfect sensitivity, which may suggest that bony geometries play another key factor in syndesmotic instability under clinically applied stresses.

This study was affected by several limitations. First, the cadaveric model did not allow for any biologic response that normally would occur with injuries. In addition, ankle ligaments were sectioned rather than mid-substance ruptures that occur during severe ankle injuries. However, our cadaveric model allowed us to characterize the effects of progressive ankle injury on stress test measurements. We decided against imposing a fibula fracture to isolate the effects of ligamentous injuries on stress test sensitivity and specificity. Therefore, we assumed that proper fibular reduction needs to be achieved for our findings to be translated to clinical practice. Clinically relevant external rotation stresses were determined based on the results of 2 fellowship-trained foot and ankle surgeons who performed the stress test on an instrumented cadaveric specimen. It is possible that this load of 6.5 Nm is not representative of other orthopaedic surgeons. However, this load is similar to prior reports[8,21] and generated clinically relevant amounts of fibular motion. We constrained tibial motion in this controlled-cadaveric study with steel rods while clinicians resisted tibial motion with their hands clinically. However, the effect sizes of applied stresses and imaging views were far greater than these possible measurement artifacts during clinical implementation of these stress tests.

In conclusion, our results have important clinical implications for the use of stress tests as a diagnostic tool. When applying our findings to the clinical setting, we suggest that external rotation stress tests under lateral radiography are the most accurate way to diagnose a syndesmotic injury. Furthermore, our study showed that the external rotation stress test required drastically less force than other tests to achieve enough displacement to indicate a positive test, meaning that this test places the least stress and risk on the patient. However, there are instances where stress tests are unable to detect syndesmotic injuries, highlighting the need for other techniques to be used when stress tests do not agree with other clinical presentations.

Authors' Note

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Declaration of Conflicting Interests

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