Mechanical considerations for the syndesmosis screw. A cadaver study
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ABSTRACT: The purpose of this study was to examine the mechanical necessity of using a syndesmosis screw to supplement rigid internal fixation of the fibula and medial malleolus in the treatment of pronation-external rotation fractures. The legs of thirty embalmed and five fresh cadavera were dissected and mounted through the tibia to a frame so that multiple radiographs could be made with a constant relationship between the specimen and the x-ray apparatus. A standardized pronation-external rotation load was applied to the foot, and widening of the syndesmosis was studied on mortise radiographs that were made after each experimental step.

On the basis of previous investigations, we developed a model for pronation-external rotation injuries that included disruption of the syndesmosis and interosseous membrane up to the level of the fibular fracture. Accordingly, multiple repaired fibular fractures could be simulated at several levels in the same specimen by incremental proximal division of the interosseous membrane. Specimens were separated into two groups. Group I consisted of thirteen specimens in which the deltoid ligament, syndesmosis, and interosseous membrane were serially sectioned in 1.5-centimeter increments. Group II (ten sections) was subjected to the same protocol, except that the deltoid ligament was kept intact until the final step. The five fresh specimens were sectioned in the same way as those in Group I.

In Group I, since the simulated pronation-external rotation injury included a deltoid tear, rigid medial fixation was not possible; accordingly, there was rigid fibular fixation only. In this group, the mean widening of the syndesmosis increased only gradually from 0.5 to 4.5 millimeters as the level of fibular fracture rose from 1.5 to fifteen centimeters proximal to the ankle. Measurements for the five fresh specimens were consistent with those for the embalmed legs. In Group II, the pronation-external rotation injury was simulated with a medial malleolar fracture rather than a deltoid tear. After simulated rigid fixation of both the medial malleolus and the fibula, only minimum widening of the syndesmosis (1.4 ± 0.3 millimeters) occurred, even when the fibular fracture was fifteen centimeters proximal to the ankle. The mean maximum widening of the syndesmosis in Group II, in which division of the deltoid ligament was the last step, was equivalent to that in Group I, validating comparison of the two groups.

CLINICAL RELEVANCE: Considering the range of clinically acceptable widening of the syndesmosis, the critical transition zone for the level of a fibular fracture that is fixed with a plate is three to 4.5 centimeters proximal to the ankle. When the fibular fracture is proximal to this level and rigid medial fixation is not possible, the syndesmosis may have to be stabilized to supplement the fixation with the plate. However, rigid medial and lateral fixation should acceptably stabilize the syndesmosis without further additional supplementation. This study provides mechanical evidence that internal fixation of pronation-external rotation injuries that include disruption of the syndesmosis often does not need to be supplemented with trans-syndesmotic fixation.
The need for trans-syndesmotic stabilization of the distal tibiofibular joint after pronation-external rotation injuries is controversial. Although the syndesmosis screw is used after distal tibiofibular disruption, there are few guidelines for use of the screw to treat specific fracture configurations. Many authors have reported using the syndesmosis screw for repair of most pronation-external rotation injuries. Others have claimed that such additional fixation is rarely indicated. Some authors have relied on intraoperative assessment of instability of the syndesmosis.

The syndesmosis screw is effective in stabilizing the tibiofibular joint to allow ligamentous healing, but a separate procedure may be necessary to remove the screw, weight-bearing is often delayed postoperatively, and the procedure is not without complications. Criteria for more efficient use of the syndesmosis screw would be beneficial.

The purpose of this study was to determine the mechanical necessity of use of a syndesmosis screw to supplement rigid internal fixation of the fibula and medial malleolus in the treatment of fractures that were produced by pronation and external rotation. This task was undertaken with the hypothesis that the syndesmosis screw may currently be overused.

We hypothesized that the anatomical configuration of the uninjured soft tissues at the site of any pronation-external rotation injury provides acceptable stability for the syndesmosis after rigid fixation of the fibula and the medial malleolus without trans-syndesmotic fixation. Disruption of soft tissue often plays a vital role in decreasing the stability of a fracture. Few anatomical studies have dealt with the contribution of soft-tissue stabilization in pronation-external rotation injuries of the ankle. In this type of injury, the deltoid ligament or medial malleolus and the syndesmosis are usually disrupted. However, the level of disruption of the interosseous membrane is variable and is related to the level of the fibular fracture. Although the physiological role of the interosseous membrane is controversial, it has been shown to be an important stabilizer of the ankle in the absence of the deltoid ligament and the syndesmosis.

As far as we know, in the anatomical studies in which the role of the interosseous membrane has been investigated, the authors have treated it as a single structure and sectioned it in its entirety. We know of no study in which the effect of sequentially sectioning the interosseous membrane after disruption of the deltoid ligament and syndesmosis has been examined. Such an experiment would help to determine the contribution of the intact soft tissues in pronation-external rotation injuries that result in fibular fracture at various levels. Accordingly, the experimental protocol was designed to determine the maximum diastasis of the syndesmosis possible for various configurations of pronation-external rotation fractures that were treated without supplementing the fibular and medial malleolar fixation with a syndesmosis screw.

**Materials and Methods**

The legs of thirty embalmed and five fresh cadavera were dissected to expose the deltoid ligament, the anteromedial part of the joint capsule, the syndesmosis, and the distal fifteen centimeters of the interosseous membrane. Each specimen was mounted by bolting the tibia to a wooden frame in 15 to 20 degrees of internal rotation. Multiple
radiographs were made, with a constant relationship between the specimen and the x-ray apparatus (Fig. 1-A). A foot-plate was bolted to the foot and was loaded through a rope-and-pulley system. A uniform pronation-external rotation load of 440 newtons was applied at the distal lateral corner of the foot-plate. When the frame and the pulley system were designed, the direction of the pronation-external rotation force was empirically chosen to produce maximum widening of the syndesmosis during preliminary testing of specimens in which the interosseous membrane had been sectioned to six centimeters proximal to the ankle.

The direction of the loading force was constant for all specimens. In addition, the moments that were imposed on the ankle were equal for all specimens, due to constant placement of the center of rotation of the ankle relative to the foot-plate and to the point of origin of the load (Fig. 1-B). Mortise radiographs were made, and the width of the syndesmosis was measured one centimeter proximal to the joint line, from the incisura to the medial part of the fibular cortex (Fig. 2). The reproducibility of the measurements of the syndesmosis was assessed by a paired t-test comparison of determinations of baseline width as measured by two observers on the thirty specimens.

**Fracture Model**

We developed a model for pronation-external rotation injuries on the basis of the observations of Lauge-Hansen and others that the syndesmosis and interosseous membrane are disrupted proximally up to the level of the fibular fracture. For a series of pronation-external rotation soft-tissue injuries of different patterns, we studied the widening of the syndesmosis, in response to loading of the ankle, before and after osteotomy and rigid fixation of the bone (Fig. 3). If widening of the syndesmosis under load were equal in both situations, the model would allow simulation of rigidly fixed fibular fractures at multiple levels in the same specimen, simply by creating the corresponding soft-tissue injury. By obviating the necessity of breaking the bone and fixing it with a plate, the model enabled simulation of multiple repaired fractures at intervals along the fibula in each specimen, which also could serve as its own control for baseline width of the syndesmosis. Accordingly, by calculating incremental widening of the syndesmosis over the baseline width in each ankle, data from multiple specimens could be pooled without being affected by the natural variations in baseline width.

Since 30 to 60 per cent of pronation-external rotation injuries involve a deltoid tear rather than a medial malleolar fracture, two experimental groups were designed to study residual instability of the syndesmosis after internal fixation of both types of medial injury. In Group I, pronation-external rotation injury with a deltoid tear as the medial component was simulated by sectioning the deltoid ligament first. In Group II, pronation-external rotation injury with a repaired fracture of the medial malleolus was simulated and the deltoid complex was left intact.

For each of the first seven embalmed specimens, a baseline mortise radiograph was made with the specimen under load. The medial malleolus was osteotomized at the level of the joint and was fixed with two 4.5-millimeter malleolar screws. Then another mortise radiograph was made, with the specimen under load, and widening of the syndesmosis compared with the baseline was calculated. Next the deltoid ligament, the anteromedial aspect of the joint capsule, and the syndesmosis were cut. The interosseous membrane of each specimen was cut at 1.5, 3.5, 5.5, 7.5, 10.0, 12.5, or 15.0 centimeters proximal to the ankle. Again, radiographs were made of the loaded specimen.

Next, the fibula was osteotomized at the most proximal level of the section of the interosseous membrane and was repaired with a six-hole compression plate and cortical screws. Another mortise radiograph was made, with the
The width of the syndesmosis (horizontal black line) was measured from the incisura (vertical black line) to the medial part of the fibular cortex on mortise radiographs, as demonstrated on a baseline specimen (left) and a specimen after the sectioning protocol was completed (right).

In a series of pronation-external rotation soft-tissue injuries of different patterns, the width of the syndesmosis was compared before and after osteotomy and rigid fixation of the bone. The width of the syndesmosis was equal before medial malleolar osteotomy and fixation (A) and afterward (B). After section of the deltoid ligament, the anteromedial part of the joint capsule, the syndesmosis, and the interosseous membrane, the width of the syndesmosis was equal before fibular osteotomy and rigid fixation (C) and afterward (D). These observations helped to generate a model that simulated rigid fixation of fibular fractures at multiple levels in the same specimen, simply by creating the corresponding soft-tissue injury. By obviating the necessity of breaking and fixing the same bone with a plate at 1.5-centimeter intervals, the model enabled each specimen to serve as its own control for the baseline width of the syndesmosis. Accordingly, data from multiple specimens could be pooled and compared with regard to incremental widening of the syndesmosis compared with the baseline of that particular leg, thereby minimizing the effect of interspecimen variability.
The thirteen specimens in Group I were sequentially sectioned and the width of the syndesmosis was measured under load after each step. A, intact specimen; B, division of the deltoid ligament, the anteromedial part of the capsule, and the syndesmosis; and C, D, and E, incremental division of the interosseous membrane from 1.5 to fifteen centimeters proximal to the ankle.

specimen under load, and the widening of the syndesmosis was compared with that before osteotomy and fixation.

In addition, the five fresh specimens were used to determine the sensitivity of widening of the syndesmosis to variations in load by making measurements with loads of 110, 220, 330, and 440 newtons.

The remaining embalmed specimens were separated into two groups to study instability of the syndesmosis as a function of disruption of the syndesmosis and the interosseous membrane.

Group I: In the thirteen specimens in Group I, the deltoid ligament and anteromedial part of the capsule, the

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**Fig. 5**

Widening of the syndesmosis after fixation of simulated pronation-external rotation fractures. The shaded band represents the clinically acceptable range of widening of the syndesmosis. In Group I (open triangles), the range is no longer acceptable for a fibular fracture that is more than 3.0 to 4.5 centimeters proximal to the joint. In Group II (solid triangles), the range remains clinically acceptable for fibular fractures that are fifteen centimeters proximal to the joint. However, after the deltoid ligament is sectioned, the maximum widening is equivalent to that in Group I.
syndesmosis, and the interosseous membrane were sequentially sectioned in 1.5-centimeter increments (Fig. 4). The width of the syndesmosis was measured on mortise radiographs, with the specimen under load, that were made before sectioning and after each experimental step, as was already described. Widening of the syndesmosis was calculated as the increase in the width of the syndesmosis compared with the baseline measurement for the individual specimen. Five fresh specimens were sectioned in the same way to assess the effects of embalming on the experimental results.

**Group II:** The ten specimens in Group II were sectioned according to the same protocol as was used for the specimens in Group I, except that the deltoid ligament and anteromedial part of the capsule were left intact. As a final step, however, the medial structures were divided to measure the maximum widening of the syndesmosis for comparison with Group I.

**Results**

In the thirty embalmed specimens, one observer determined the baseline width of the syndesmosis to be 3.2 ± 0.2 millimeters (mean and standard deviation). A second observer determined the mean baseline width to be 3.1 ± 0.2 millimeters, and the interobserver variation was not significant (p = 0.4). Measurement of the first seven embalmed specimens demonstrated that, in this pronation-external rotation injury model, widening of the syndesmosis under load was equal for intact bone and for that treated with an osteotomy and fixation with a compression plate. Therefore, fibular fractures that had been fixed with a plate at multiple levels in the same specimen were simulated by incremental proximal division of the interosseous membrane. Similarly, fixation of medial malleolar fractures was accurately simulated by the unbroken malleolus. In the five fresh specimens, widening of the syndesmosis was not affected by varying the loading force from 110 to 440 newtons.

For the Group-I specimens, in which the deltoid ligament and anteromedial part of the capsule had been divided, the mean widening of the syndesmosis with application of load increased gradually from 0.5 to 4.5 millimeters as the level of disruption of the interosseous membrane increased from 1.5 to fifteen centimeters proximal to the ankle (Fig. 5). The largest increase was from 1.0 to 1.7 millimeters of widening, which occurred when the level of the simulated fracture was moved from 3.0 to 4.5 centimeters proximal to the ankle. The mean amount of widening of the syndesmosis for the fresh specimens was not significantly different from that for the embalmed specimens (p = 0.66).

In Group II, the simulated pronation-external rotation injury included a medial malleolar fracture rather than a deltoid tear. When the medial malleolus and fibula were intact, only minimum widening of the syndesmosis (1.4 ± 0.3 millimeters) was possible under load, even when the interosseous membrane was disrupted to fifteen centimeters proximal to the ankle (Fig. 5). However, when the last step, division of the deltoid ligament, was carried out, the mean maximum widening of the syndesmosis in Group II was not significantly different from that in Group I (p = 0.5).

**Discussion**

Pronation-external rotation injuries of the ankle comprise 13 to 45 per cent of malleolar fractures. According to Lauge-Hansen’s classification, these injuries occur in four sequential stages: medial malleolar fracture or deltoid tear (Stage 1), anterior disruption of the syndesmosis and interosseous membrane (Stage 2), fibular fracture (Stage 3), and posterior disruption of the syndesmosis (Stage 4). Pronation-external rotation fractures correspond to Type-C fractures in the Danis-Weber classification, in which the injury is labeled according to the relationship of the level of the fibular fracture with respect to the syndesmosis.

The recent literature has emphasized the importance of anatomical repair of the lateral malleolus in fractures of the ankle. Ramsey and Hamilton demonstrated that a one-millimeter lateral displacement of the talus results in a 42 per cent reduction in tibiotalar contact. Since most pronation-external rotation injuries are associated with rupture of the syndesmosis and interosseous membrane, many surgeons supplement rigid fixation of the fibula and medial malleolus with some type of trans-syndesmotic fixation. Although the syndesmosis screw is often employed, the few published guidelines for its use have been vague and conflicting.

To avoid unnecessary use of the syndesmosis screw, it must be demonstrated that acceptable stability of the syndesmosis can be achieved without trans-syndesmotic fixation in certain situations. In our study in cadaveria, disruption of the syndesmosis and interosseous membrane resulted in minimum widening of the syndesmosis, provided the deltoid complex was intact. Accordingly, in this situation, rigid fixation of the fibula and medial malleolus should restore adequate stability to the syndesmosis without trans-syndesmotic fixation. In contrast, when the deltoid complex was disrupted, widening of the syndesmosis was greater and was directly related to the amount of disruption of the interosseous membrane and, therefore, to the level of the pronation-external rotation fracture of the fibula.

Discussion of these results in any clinical context must include consideration of the potential inaccuracies of the experimental design and the fracture model. Although fractures of the ankle are generally protected in a cast after internal fixation, this model tested the stability of an unprotected syndesmosis. In addition, the simulated pronation-external rotation injuries involved disruption of all ligaments in the syndesmosis, corresponding to a Stage-4 Lauge-Hansen injury. Actually, after a pronation-external rotation injury in which the posterior syndesmosis remains intact (Stage 3), the syndesmosis may be more stable than is indicated by this model.

Although most of the experimental data were generated from embalmed specimens, the measurements were consistent with those generated from fresh tissue. The results from Group II (in which the deltoid ligament was intact)
were consistent with reported observations from studies on fresh cadavera. The results from the embalmed specimens in Group I (in which the deltoid ligament was divided) were consistent with published observations and, more importantly, were not significantly different from our own measurements in five fresh specimens.

In addition to the potential inaccuracies of our model resulting from the variable severity of the pronation-external rotation injuries and the use of embalmed specimens, the fact that we studied experimental rather than physiological loading of the structures in the ankle deserves consideration. Preliminary testing, confirmed in the five fresh specimens, demonstrated that widening of the syndesmosis was relatively insensitive to loading. Accordingly, the loading force was selected to produce the maximum widening of the syndesmosis that was possible for a given fracture configuration without resulting in permanent deformation or failure of the remaining intact interosseous membrane. The force was also comparable with the force that the fibula and interosseous membrane might sustain during walking.

With repeated loading of the interosseous membrane in the twelve-step sectioning protocol, it is possible that the intact interosseous membrane may have undergone progressive deformation and weakening; however, the equivalent end-point in both Group I and Group II suggests that this was not a major factor. In this model, the intact portion of the interosseous membrane was not appreciably loaded until the deltoid ligament had been divided. Accordingly, although the interosseous membrane was loaded through eleven cycles in Group-I specimens and only once in Group II, the end-points of widening of the syndesmosis were the same in both groups.

To facilitate clinical application of these results, we measured the width of the syndesmosis by means of a common clinical modality — mortise radiographs — rather than in a direct in vivo manner. Our mean baseline measurement of the width of the syndesmosis was comparable with that reported in the literature, when the same standard radiographic technique was used.

Recent studies have demonstrated that the reduction of the distal tibiofibular syndesmosis correlates with the functional outcome of the ankle and the development of arthritis. In addition, one to two millimeters of widening of the syndesmosis, compared with the normal side, has yielded acceptable clinical results in the treatment of pronation-external rotation fractures.

For fibular fractures that are fixed with a plate, we determined the critical transition zone between a level of fracture that results in clinically acceptable and one that results in unacceptable widening of the syndesmosis to be three to 4.5 centimeters proximal to the ankle (Fig. 5). Therefore, we postulate that, when rigid medial fixation is not possible, supplemental trans-syndesmotic stabilization may be needed for fractures proximal to the transition zone, but that such supplementation is not necessary for fractures distal to this zone. If the deltoid complex is intact and rigid medial fixation can be achieved, widening of the syndesmosis should remain in the clinically acceptable range without trans-syndesmotic fixation, regardless of the level of fibular fracture.

Conclusions

We explored the relationship between specific mechanical configurations and the need for trans-syndesmotic fixation in an effort to aid decision-making in the operative treatment of pronation-external rotation fractures of the ankle. The need for trans-syndesmotic fixation to supplement rigid fixation of the fibula and medial malleolus can be determined by the height of the fibular fracture and the competence of the deltoid ligament. Concern about extrapolation of data from cadavera to patients is justified; however, two points should be emphasized. First, even if the precise level of the transition zone between the levels of a fracture that will and will not result in unacceptable widening is slightly different in vivo, the observation that stability of the syndesmosis is a function of the length of the intact interosseous membrane when the deltoid ligament is disrupted should still be valid. Second, since the experimental design was chosen to favor overestimation of widening of the syndesmosis, instability in vivo should be the same or less.

In some injuries that result in the loss of the ability to achieve rigid medial fixation operatively (that is, injuries that include a deltoid tear), direct clinical application of these results may foster more emphasis on fixation of the syndesmosis than might be necessary. However, in all pronation-external rotation fractures that had rigid medial and lateral fixation, the stability of the syndesmosis was clinically acceptable and overestimation would not affect operative decisions.

Finally, these results suggest that acceptable stability of the syndesmosis can be achieved after rigid internal fixation without trans-syndesmotic fixation in many pronation-external rotation fractures.

References


