Intraoperative Syndesmotic Reduction: Three-Dimensional Versus Standard Fluoroscopic Imaging

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Background: The quality of reduction of the syndesmosis is an important factor in the outcome of ankle fractures associated with a syndesmotic injury. The purpose of this study was to directly compare the accuracy of syndesmotic reductions obtained using intraoperative standard fluoroscopic techniques against reductions obtained using three-dimensional imaging of the Iso-C3D fluoroscope.

Methods: We prospectively reviewed imaging studies of patients who were diagnosed as having preoperative or intraoperative evidence of syndesmotic diastasis (on the basis of the fluoroscopic Cotton test and/or a manual external rotation stress test) who underwent syndesmotic fixation at one of two level-I trauma centers. Center A used intraoperative computed tomography (CT) imaging to assess reduction (≤2 mm), while Center B assessed reduction under standard fluoroscopic imaging. Postoperative alignment was assessed in a standardized manner, measuring anterior fibular distance, posterior fibular distance, and the anterior translation distance. Measurements were taken on the injured side and the uninjured side and compared between the groups on postoperative axial CT scans.

Results: A total of thirty-six patients in both centers met our inclusion criteria and were included in the data analysis. Despite utilization of the Iso-C3D, a high rate of malreductions was noted in both groups. Anterior translation distance malreductions occurred in 31% of the sixteen patients in Center A and 25% of the twenty patients in Center B (p = 0.72). The number of anterior fibular distance malreductions was similar, with a rate of 38% in Center A and 30% in Center B (p = 0.73). A significant difference among the centers (p = 0.03) was noted, however, when the posterior fibular distance data was analyzed, with 6% being malreduced by >2 mm in Center A and 40% in Center B.

Conclusions: The results of our study support previous investigations that have cited high rates of syndesmotic malreductions and demonstrate that the addition of advanced intraoperative imaging techniques does not help to reduce the rate of malreductions in this cohort.

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

Ankle fractures with an associated disruption of the syndesmotic complex are common. Due to their inherent instability, it is well established that syndesmotic fixation should be performed as part of standard care in these patients. Although functional outcomes in patients with these fracture patterns have generally been shown to be acceptable, there is evidence that this pattern of injury is associated with more pain and poorer function at one year than are fractures without an associated syndesmotic injury, which are treated operatively. Recent studies have cited a rate of syndesmosis malreduction of up to 16%, and the quality of the reduction, in addition to the primary damage caused by the injury, may affect the outcomes. Furthermore, a variety of authors have demonstrated that current fluoroscopic and

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radiographic techniques are inadequate for detecting syndesmotic malreduction.\textsuperscript{1,9,13}

Currently, intraoperative assessment of the syndesmosis is performed utilizing two-dimensional fluoroscopy. Established radiographic measurements are then made in order to specifically assess the quality of the syndesmotic reduction. These are the tibiofibular clear space and tibiofibular overlap on the anteroposterior and mortise ankle radiographs. In many cases, the presence of syndesmotic disruption is identified preoperatively and may be planned for. In other cases, syndesmotic stabilization is performed when instability is identified on intraoperative fluoroscopic stress radiographs, following malleolar fracture stabilization. Despite advances in the identification of syndesmosis instability and the knowledge that these injuries need to be addressed, problems attaining syndesmotic reduction continue.

The SIREMOBIL Iso-C\textsuperscript{3D} C-arm fluoroscope (Siemens Medical Solutions, Malvern, Pennsylvania) enables intraoperative three-dimensional imaging similar to that obtained by a computed tomography (CT) scan. The Iso-C\textsuperscript{3D} device has been validated for use in articular fracture reductions as well as against a CT scan in previous studies.\textsuperscript{1,4,13} It has been hypothesized that this type of technology may help surgeons to improve the accuracy of intraoperative syndesmotic reduction. The purpose of this study was to directly compare the accuracy of intraoperative syndesmotic reductions evaluated using standard fluoroscopic techniques against reductions evaluated using three-dimensional imaging with the Iso-C\textsuperscript{3D} fluoroscope. Our null hypothesis was that the use of intraoperative three-dimensional imaging for syndesmotic reductions would not improve reduction accuracy over the standard fluoroscopic techniques in our study population. A secondary aim of this study was to define a reproducible measurement scheme by which fibular malrotation and translation could be quantified using an axial image of the syndesmosis.

\textbf{Materials and Methods}

We conducted a prospective institutional review board-approved study that utilized two university-based level-I trauma centers. The trial was registered at ClinicalTrials.gov (NCT00556010). Eligible patients included all skeletally mature patients with closed, unilateral, unstable ankle fractures (AO/OTA [Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association] 43B and 44C and Lauge-Hansen PER4 [pronation–external rotation type-IV] or SER4 [supination–external rotation type-IV] fractures or Maissonneuve variants\textsuperscript{16,17}) amenable to open reduction and internal fixation. All patients who were diagnosed as having preoperative or intraoperative evidence of syndesmotic diastasis, on the basis of a Cotton test or a manual external rotation test is performed by internally rotating the tibia while applying an lateral force to the fibula with a bone hook, bone clamp, or a Key elevator.\textsuperscript{18,19} Lateral displacement causing tibiofibular widening is considered pathologic and an indication for syndesmotic fixation. A manual external rotation test is performed by internally rotating the tibia while applying an external rotatory moment to the foot and looking for tibiofibular widening on fluoroscopy.\textsuperscript{20}

All patients who underwent syndesmotic fixation were asked to provide study consent postoperatively at which point the study protocol was initiated. We excluded pediatric patients, open fractures, fractures with an associated compartment syndrome, patients who sustained a tibial plafond fracture (i.e., AO/OTA type 43B and C), even when it was associated with a fibular fracture, and syndesmosis disruption. Women of childbearing age were excluded if, preoperatively, they had a positive \textit{β}-human chorionic gonadotropin (HCG) pregnancy test or if they refused a \textit{β}-HCG test.

All patients underwent surgery to treat an unstable mortise following a rotational ankle fracture. All fractures underwent a similar operative protocol, which included open reduction of the fibula, medial malleolus, and posterior malleolus using standard open direct reduction and small-fragment plate-and-screw fixation. Following fracture stabilization, all ankles were evaluated for syndesmotic instability with either a Cotton test or a manual external rotation stress test.\textsuperscript{18,19} All distal tibiofibular joints were reduced indirectly and stabilized with one or two transsyndesmotic screws. The selection of the size and number of screws and the purchase of three or four cortices were done by the operating surgeon. At Center A (Hadassah Hebrew University Hospital, Jerusalem, Israel), the SIREMOBIL Iso-C\textsuperscript{3D} C-arm device (Siemens Medical Solutions) was used intraoperatively for verification of the reduction of the syndesmosis (52 mm) following fixation of the fibula, medial malleolus, and posterior malleolus using standard open direct reduction and small-fragment plate-and-screw fixation. Following fracture stabilization, all ankles were evaluated for syndesmotic instability with either a Cotton test or a manual external rotation stress test.\textsuperscript{18,19} All distal tibiofibular joints were reduced indirectly and stabilized with one or two transsyndesmotic screws. The selection of the size and number of screws and the purchase of three or four cortices were done by the operating surgeon. At Center B (Jamaica Hospital Medical Center, Jamaica, New York), closed reduction of the syndesmosis and insertion of the syndesmotic screw(s) under standard fluoroscopy (anteroposterior, lateral, and mortise views) was used in each patient. The reduction was performed with a pointed reduction clamp while the ankle was maintained in a neutral position. The location of the clamp was adjusted on the basis of the fluoroscopic images obtained intraoperatively.

The interpretation of the intraoperative fluoroscopic images was performed by the operating surgeon. Fluoroscopic measurements indicative of syndesmotic diastasis included a tibiofibular clear space of $>5$ mm, tibiofibular overlap of $<10$ mm on the anteroposterior view, or tibiofibular overlap of $<1$ mm on the mortise view. The surgeons adjusted the reductions until they were satisfied that the fluoroscopic images did not show diastasis. The images from the SIREMOBIL Iso-C\textsuperscript{3D} were interpreted by the operating surgeon subjectively with regard to the seating of the fibula within the tibial incusia. All surgeons
left the operating room confident that the criteria for syndesmotic reduction had been met or were within the acceptable limits.

During the immediate postoperative period and prior to hospital discharge, all patients underwent bilateral axial CT scans, which were utilized as the reference standard imaging study in this paper. These scans utilized a specific limited radiation protocol to assess axial images of both ankles at the level of the syndesmosis. Both ankles were scanned simultaneously in the majority of patients to limit the total radiation exposure to the patient.

Since, to our knowledge, no standardized scheme exists to measure syndesmotic reduction on a CT scan, we created a standardized measurement method (Fig. 2). We used postoperative CT scans to compare the injured side and the uninjured side. (Note that this measurement technique was not utilized for the intraoperative Iso-C3D images since only the affected side was imaged intraoperatively.) The measurements for each ankle were made at a level 1 cm proximal to the tibial plafond, at which point a line connecting the widest portion of the fibula from anterior to posterior was established. At each end of this line, perpendicular lines were drawn to the tibial incisura. The anterior line was defined as the anterior fibular distance, and the posterior line was defined as the posterior fibular distance. The distance between a line parallel to an extension of the anterior fibular distance at the anterior border of the tibial incisura, called the anterior translation line, and the anterior fibular distance line provided the anterior translation distance. This measurement scheme allows for an assessment of fibular rotation by comparing the lengths of the anterior fibular distance and posterior fibular distance in the injured and uninjured ankles. Fibular translation is assessed by using the anterior translation distance, which relies only on the anterior aspect of the tibia, avoiding inaccuracies associated with possible posterior malleolar fracture displacement. The measurements were performed using the Centricity Enterprise Web PACS (picture archiving and communication system; GE Healthcare). A single, unblinded research assistant trained in the measurement technique performed all of these measurements.

**Statistical Analysis**

The anterior fibular distance, posterior fibular distance, and anterior translation distance measurements were performed on all uninjured ankles, and a normative value for each of these measurements was established using the measurement technique described above. We then conducted an analysis of each individual patient and assessed whether the reduction of the syndesmosis deviated from the contralateral side by \( \pm 1 \) mm or \( \pm 2 \) mm. Absolute values were used when calculating these differences. The Fisher exact test was used to compare the two groups for each of the measurements. Sample size was calculated to detect a large effect size of 0.8 between the two groups in the proportion of patients in whom the syndesmosis deviated from that on the contralateral side. It was determined that sixteen patients were required to achieve 80% power, with \( \alpha = 0.05 \). For all statistical tests, the alpha level of significance was set at 0.05.

**Source of Funding**

No external source of funding was used in this study.

**Results**

A total of thirty-eight patients were enrolled between the two centers. Of the thirty-eight patients, two patients from...
Center A (N = 16) | Center B (N = 20)
---|---
No. of patients | 16 | 20
Mean age (yrs) | 33.94 (0.04) | 35.20 (12.65)
Sex (no.) | | |
M | 11 (69%) | 13 (65%)
F | 5 (31%) | 7 (35%)

To further characterize the type of malreductions, we performed an analysis based on the actual translation, rotation, compression, and distraction at the syndesmosis. For example, when anterior translation distance was noted to be smaller on the injured side than on the uninjured side, this was interpreted as anterior translation. In patients in whom the anterior translation distance was larger on the injured side than on the uninjured side, this was interpreted as posterior translation. Similarly, anterior fibular distance and posterior fibular distance were measured, and the measurements were characterized as distracted, compressed, or normal. The assumption is that asymmetric compression of the syndesmosis posteriorly or anteriorly would potentially cause rotational change, while symmetric compression or distraction would signify another form of malreduction.

With regard to the anterior translation distance involving ≥2 mm of displacement, the fibula was posteriorly translated in one patient (6%) and anteriorly translated in four patients (25%) in Center A. In Center B, three patients (15%) showed posterior translation and two patients (10%) had anterior translation. With the numbers studied, the difference in proportions between Centers A and B in this regard was insignificant (p = 0.50). An analysis of the anterior fibular distance showed that four patients (25%) in Center A had widening of ≥2 mm and two patients (13%) had compression. In Center B, the anterior fibular distance was widened by ≥2 mm in one patient (5%) and was compressed in five patients (25%). Again, with the numbers studied, these differences did not achieve significance (p = 0.23). A significant difference between the centers was noted, however, in the analysis of the posterior fibular distance data (p = 0.03). In Center A, the posterior fibular distance was widened by ≥2 mm in one patient (6%) and was not compressed in any patient. In Center B, the posterior fibular distance was widened by ≥2 mm in one patient (5%) but was compressed in seven patients (35%).
TABLE IV Dichotomous Groups of Absolute Change (2-mm Change)

<table>
<thead>
<tr>
<th>Change of ≥2 mm</th>
<th>Center A (N = 16)</th>
<th>Center B (N = 20)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior translation distance (no.)</td>
<td>5 (31%)</td>
<td>5 (25%)</td>
<td>0.72</td>
</tr>
<tr>
<td>Anterior fibular distance (no.)</td>
<td>6 (38%)</td>
<td>6 (30%)</td>
<td>0.73</td>
</tr>
<tr>
<td>Posterior fibular distance (no.)</td>
<td>1 (6%)</td>
<td>8 (40%)</td>
<td>0.03*</td>
</tr>
</tbody>
</table>

*The difference was significant (alpha = 0.05).

Discussion

In this study, we found that in the operative treatment of unstable ankle fractures, despite the use of intraoperative three-dimensional imaging, malreduction of the syndesmosis frequently remained a problem. Our data showed that the use of intraoperative three-dimensional imaging was not effective in reducing translational malreductions, although the rate of posterior syndesmosis compression was lower with use of three-dimensional imaging. We were therefore only able to partially disprove our null hypothesis. Furthermore, we established a novel measurement technique that assesses translational and rotational malreductions on axial CT scan images.

With a difference of >1 mm between the injured and uninjured side in any measured parameter as an indication of malreduction, we found that the rate of malreduction ranged from a minimum of 38% to a maximum of 70%, and the rates were similar in both groups. A difference of ≥2 mm occurred at a rate ranging from 6% to 40%, also without a difference between the centers with regard to the anterior fibular distance and the anterior translational distance; however, a significant difference in the posterior fibular distance was detected. These rates of malreduction are in line with those reported previously.

Approximately 20% of unstable ankle fractures are associated with a syndesmotic injury requiring stabilization. The recent literature has shown that functional outcomes after fractures associated with syndesmotic injury are poor. Furthermore, many authors have reported that the radiographic assessment currently used to determine the accuracy of syndesmotic reduction is inadequate, and it is therefore possible that malreduction of the syndesmosis occurs because of deficiencies in radiographic technique.

A number of CT-based measurement methods at the level of the syndesmosis have been proposed to evaluate the articulation and possible malreduction. Gardner et al. described a method for evaluating the syndesmosis using axial CT scans, but this measurement technique accounts only for malreduction in rotation and diastasis and does not address translational malreduction. In addition, the landmarks for the measurement of the anterior tibiofibular space and posterior tibiofibular space are poorly defined and difficult to reproduce. Marmor et al. described a more precise mechanism in which they measured fibular rotation within the incisura on axial scans of the syndesmosis. Similar to the method described in the present study, their method requires the establishment of a line connecting the widest portion of the fibula from anterior to posterior as well as an anterior-to-posterior line drawn parallel to the border of the posterior facet. This tibiofibular angle allowed those authors to obtain rotational measurements. This system, however, relies on an intact or anatomically reduced posterior tibial facet, which is frequently not the case in these fracture patterns, in which the posterior malleolar fracture extends into the posterior facet. Furthermore, the tibiofibular angle does not provide for measurement of translational malreduction, which we believe is a more important type of malreduction with regard to clinical outcomes since it can be associated with translation of the talus within the plafond.

Another technique proposed to measure the syndesmosis on a CT scan was described by Elgafy et al., who measured scans of the normal (uninjured) syndesmosis for the purpose of establishing normal ranges of syndesmosis shape. They concluded that the normal tibiofibular distance at the syndesmosis is 2 mm anteriorly and 4 to 5 mm posteriorly. In our study, the average anterior tibiofibular distance was 4.5 mm, and the average posterior tibiofibular distance was 8.2 mm. It is important to note that the measurement techniques described by Gardner et al., Marmor et al., and Elgafy et al. rely on a postoperative CT scan and are therefore of limited practical use. This limitation contrasts with the theoretical benefit of an intraoperative three-dimensional imaging modality.

We sought to establish a reproducible, CT-based measurement technique of syndesmotic reduction, which accounted for rotation, translation, syndesmosis compression, and distraction. This measurement scheme was applied to postoperative CT scans of the injured as well as uninjured syndesmosis. The previously proposed CT-based measurement techniques discussed above failed to account for translational as well as compression and distraction types of malreductions. Although our measurement system is not validated by cadaver studies, we did employ it consistently throughout the study and used the contralateral, uninjured side as a control.

Our analysis set differences of 1 mm and 2 mm in any of the measured planes to assess the possibility of a malreduction. These stringent criteria for syndesmotic malreduction were based on the past literature and allowed us to calculate even the smallest side-to-side differences. Using these criteria, when the two surgical imaging techniques were compared, only the 2-mm analysis showed a significant difference in one of the reduction parameters, the posterior fibular distance. We detected no difference in the rate of malreduction in the other two parameters that were measured, and the use of intraoperative...
advanced three-dimensional imaging did not appear to decrease the rate of malreductions overall. We ascribe the difference found in posterior fibular distance between the centers to a systematically different method of reducing the syndesmosis, wherein surgeons in Center A likely placed the reduction clamp on a more anterior aspect of the fibula, therefore creating a gap in the posterior syndesmosis in the process. Although we do not know that these malreductions will lead to a functional deficit, we do not think that the use of advanced imaging techniques that provided axial imaging of the ankle contributed to a clinically important improvement in syndesmotic reductions. That being said, it is possible that if both ankles had been imaged intraoperatively using the Iso-C3D and compared using our objective criteria described in the present study, the surgeons would have noted these malreductions and attempted to correct them.

Limitations of our study include the subjective interpretation by the operating surgeon of the intraoperative imaging and the use of individual reduction techniques, although none of the surgeons performed a direct open reduction of the syndesmosis. Our measurement technique of axial images of the syndesmosis relies on identifying a 1-cm distance from the tibial plafond articular surface; however, this technique was not utilized intraoperatively nor was the contralateral side imaged intraoperatively in Center A in order to judge articular malreduction. It is also conceivable that, since the extent of functional deficits caused by 1 or 2 mm of malreduction is unknown, intraoperative correction may not have been performed by the surgeon even when it was detected. An additional limitation of our study is the sample size.

Our findings support previous work that has cited high rates of syndesmotic malreduction and demonstrate that the addition of advanced intraoperative imaging techniques probably does not help to reduce these rates.21 However, utilizing the new measurement criteria presented in this study may assist in determining the degree of malreduction in future cases using three-dimensional imaging. The measurement technique proposed in the present study for evaluation of the syndesmosis allows for reproducible and consistent measurement of the syndesmosis with regard to translation, rotation, compression, and distraction. More information is required to understand whether the type of malreductions noted have any importance with regard to functional outcomes.

References


