Biomechanics of the Injured Fibula Following Plate Fixation of a Concomitant Tibia Fracture
To Fix or Not to Fix?

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Abstract

Background: The mechanical role of supplemental fibula fixation in both bone lower leg fractures is not well defined. The benefit of fibula plate fixation in this context is controversial. The purpose of this study was to ascertain the mechanical contributions of the fibula under three conditions (intact, fractured, or plated fibula) following standard tibia locked plating.

Methods: A laboratory fracture model was created with 10 cadaveric legs (5 matched pairs) with no known history of lower extremity trauma or other musculoskeletal conditions. A both bone lower leg fracture was simulated by performing distal osteotomies, 3 to 5 cm above the tibia plafond, leaving a bony defect to simulate an unstable fracture (AOTrauma OTA classification 43-A3). Coronal and sagittal gauge-pins were placed above and below the fracture sites to measure relative displacement across three planes of motion. Axial and torsional loads were applied to the leg under the following conditions: tibia intact and fibula intact (control 1), tibia fracture and fibula intact, tibia fracture and fibula fracture (control 2), and the three conditions of primary interest: tibia plated and fibula intact, tibia plated and fibula fracture (osteotomy), and tibia plated and fibula plated. The load applied for level 1 was 75 N of axial compression and 0.3 Nm of torque, and the load for level 2 was 175 N of axial compression and 1.3 Nm of torque.

Results: There were significant differences in motion across the fracture site of the injured leg when the tibia was not plated compared with an intact and plated tibia, $p < 0.05$. However, when the tibia was plated, there were no significant differences in fracture motion when the fibula was left either intact, osteotomized, or underwent supplemental plate fixation, $p > 0.05$. This was true regardless of the loads applied.

Conclusion: The mechanical stability of supplemental fibula fixation in a both bone lower leg fracture model was not significantly improved from standalone distal tibia fixation in this laboratory model. The clinical effects of these findings are yet to be demonstrated.

High energy distal tibia fractures have associated distal ipsilateral fibula fractures up to 85% of the time. In addition, low energy bending fractures of the lower extremity can also result in fractures of both bones. The presence of a concomitant fibula fracture can significantly impact fracture site mechanical behavior and overall clinical outcome.

Several surgical approaches are used to treat distal tibial-fibula fractures. Treatment is usually predicated by fracture pattern, displacement, and severity of soft tissue injury. Temporary external fixation of the lower leg followed by staged internal fixation of the tibia fracture, with or without fixation of an associated fibula fracture, is common.7,8 Traditional AO approaches have advocated external fixation of the ankle with immediate fixation of an associated fibula fracture.9 The clinical decision to perform internal fixation of the concomitant fibula fracture in this setting is not well supported with scientific evidence. As such, there is no consensus on supplementary fibula fixation following a concomitant distal tibia fracture. Lee et al.10 reported a lower rate of fibular malunions and post-traumatic ankle arthrosis following fixation of fibular fractures in conjunction with pilon fractures. Other advantages of fibula fixation that have been described include improved rotational stability as well as prevention of malalignment and fracture displacement.11
served difference in alignment and rotation when comparing a fixed versus an unfixed fibula, no significant difference in clinical outcomes were detected between the two groups.\textsuperscript{12} Furthermore, a laboratory model demonstrated that multidirectional distal locking of an intramedullary tibia nail may preclude the need for supplementary fibula fixation in both bone lower leg fractures.\textsuperscript{13}

Indeed, the plurality of distal tibia fractures are still amenable to intramedullary fixation, but for those rare instances where intramedullary nail fixation might not be so feasible (i.e., in the context of a well fixed total knee prosthesis or a comminuted proximal tibia or tibial plateau fracture) plate osteosynthesis of a distal tibia fracture might be sought. The question of what to do with the concomitant fracture fibula and understanding the behavior of the fibula in the context of extramedullary fixation comes to question.

Anecdotally, it has been the experience of the senior author (CSR) that there is minimal to no difference in outcomes when the fibula was fixed versus not fixed in both bone lower leg fractures. At our institution, locked plating osteosynthesis is used for the plurality of “very” distal tibia fractures, such as metaphyseal fractures with or without intrarticular extension, such as Pilon fractures. There is little evidence in the current literature on the biomechanical role of the fibula in distal tibia fractures treated with locked plating. The purpose of this study was to determine whether axial and torsional stiffness of a fixed distal tibia fracture are improved by supplemental internal fixation of an associated fibular fracture.

**Methods**

Ten human cadaveric legs (5 matched pairs) including the intact foot up through the distal half of the thigh were acquired from the bequeathal program of a level one academic trauma center. Cadaveric parts belonged to the deceased of 1 male and 4 females, with a mean age of 74 (range: }
68 to 84 years) with no history of lower extremity trauma or other documented musculoskeletal conditions affecting their lower extremities. For each leg, minimal soft tissue dissection was performed to expose the distal tibia and fibula, preserving all tibiofibular attachments as well as all soft tissue about the knee and ankle. Soft tissue dissection of the distal femur was also performed, and the midshaft of the femur was rigidly affixed to a polyvinyl chloride (PVC) pipe sleeve and then fastened to the material testing systems (MTS) frame (Fig. 1). Each leg was maintained in a stance position distally, with the intact foot centrally placed and plantigrade on the testing platform. The knee was kept in slight flexion (20° to 30°) during all series of testing. Using a 20° angled template, a 1.0 to 1.5 cm fracture gap was cut distally, 3 to 5 cm above the tibia plafond, simulating a comminuted varus-oriented distal tibia and metaphyseal tibia fracture (AOTrauma OTA classification 43-A3), with a corresponding same level osteotomy on the ipsilateral fibula. The fibular osteotomy was meant to signify a comminuted transverse or oblique pattern with bone loss, as commonly seen in pilon fractures. Each tibia was plated using an 11-hole (3.5 mm wide) anterolaterally placed distal tibial plate (Synthes® USA, Paoli, Pennsylvania) of the locking compression plate (LCP) design acting in a bridged manner across the fracture defect. The LCP plate was fixed to the distal tibial fragment using three fixed-angle 3.5 mm locking screws and one 3.5 mm non-locking screw. The proximal piece was fixed with a 3.5 mm self-tapping cortical screw and three fixed-angle 3.5 mm locking screws. Each fibula was plated using an 8-hole one-third tubular plate with 3.5 mm non-locking screws (Synthes® USA, Paoli, Pennsylvania).

Dissections and internal fixation of the tibia and fibula were performed by a fellowship-trained orthopedic trauma surgeon (JR). Surgical approach and application of implants were performed to simulate a “standard” clinical scenario.

Biomechanical Testing
An axial-torsional hydraulic load frame (Model 858 Bionix, MTS, Eden Prairie, Minnesota) was used to load each leg specimen. Each leg specimen was mounted on the test frame and loaded with simultaneous axial and torsional loads: first with 75 N of axial compression and 0.3 Nm of torque load followed by 175 N of axial compression and 1.3 Nm of torque. This simulated forces commonly seen with partial weightbearing and combined loads with toe-off during ambulation, respectively. The legs were serially tested in the following conditions: an intact cadaver leg (control, test condition 1), osteotomy of the tibia only with intact fibula (test condition 2), anterolateral plating of the tibia osteotomy with an intact fibula (test condition 3), anterolateral plating of the tibia osteotomy with an unplated fibula osteotomy (test condition 4), anterolateral plating of the tibia osteotomy with a plated fibula (test condition 5), and plates removed from both tibia and fibula (test condition 6), (Table 1). Test conditions 2 through 6 were carried out with a distal tibial fracture gap representing a high level of comminution at the metadiaphyseal junction (OTA 43-A3). Two pairs each

### Table 1 Testing Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>Intact specimen</td>
</tr>
<tr>
<td>2</td>
<td>Tibial osteotomy and fibula intact</td>
</tr>
<tr>
<td>3</td>
<td>Plated tibia and fibula intact</td>
</tr>
<tr>
<td>4</td>
<td>Plated tibia and fibular osteotomy</td>
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<tr>
<td>5</td>
<td>Plated tibia and plated fibula</td>
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<tr>
<td>6</td>
<td>Tibia and fibula osteotomies and all plates removed</td>
</tr>
</tbody>
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All ligamentous and native soft tissue constraints about the knee and ankle were preserved or with minimal disruption during dissection and plate fixation of all specimens.

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**Figure 2** Fixed measurements: Unloaded specimen using fixed notches on gauge pins and static distances represented by A through O. Dynamic measurements: loaded specimens using similarly fixed notches on gauge pins to measure relative displacement represented by 1 to 12.
of sagittal and coronal pins were placed above and below the fracture site to monitor the degree of displacement as torsion and axial loads were applied (Fig. 1). Displacement was manually measured using digital calipers to the nearest 0.1 mm and recorded by a single investigator at the end of each loading phase (Fig. 2). From these measurements, the complete sagittal and frontal plane relative displacements of the distal tibia fragment with respect to the proximal tibia fragment could be calculated using the method described by Kaigle et al. 16

**Data Analysis**

For each plane and axis of motion, the different fixation conditions were compared using single factor ANOVA. The motions were normalized as absolute displacements (mm) and absolute angulations in each of the six degrees of freedom measured. Statistical significance was set at an alpha value of 0.05. Load Level 1 (minimal loading) was compared (ANOVA-A) for all specimen conditions (1 through 6). Additionally, Load Level 2 (rehabilitation loading) was compared (ANOVA-B) for the three clinically relevant conditions (3 through 5) representing a plated tibia fracture with three different conditions of the fibula.

**Results**

In all measurements of load level 1 (75 N of axial compression and 0.3 Nm of torque), the most motion occurred when the osteotomized tibia was not plated, conditions 2 and 6 (Fig. 3). This was statistically significant when compared with all other conditions, p = 0.000047. Minimal motion was observed when the tibia was either intact or fixed with a plate and was not statistically significant. This was true regardless of the condition of the fibula (Table 2). In load level 1, there were no significant differences in the relative tibia displacements of the three most clinically relevant fibula scenarios (intact, plated, or fractured and osteotomized) with respect to coronal bending (p = 0.7110), sagittal bending (p = 0.3262), axial rotation (p = 0.0986), axial displacement (p = 0.5920), anterior-posterior displacement (p = 0.4050), and medial-lateral displacement (p = 0.4097). Similarly, under load level 2 (175 N of axial compression and 1.3 Nm of torque) there were no significant differences with respect to coronal bending (p = 0.7934), sagittal bending (p = 0.7938), axial rotation (p = 0.2891), axial displacement (p = 0.6441), anterior-posterior displacement (p = 0.8403), and medial-lateral displacement (p = 0.4677), (Table 2). When the above three conditions were compared, tibia plated and fibula intact, plated, or osteotomized, the most motion was seen in anterior to posterior displacement in load 1, with a mean of 1.18 ± 0.39 mm (Fig. 3). In load 2, sagittal displacement had the most motion at a mean of 1.52 ± 0.34 mm (Fig. 4). One specimen (specimen 10) had a premature fracture of the fibula during the osteotomy procedure used to simulate a grossly unstable distal tibia fracture. Load 2 of condition 6 (tibia osteotomy and fibula osteotomy) were not carried out due to the permanent deformation following the applied forces of load 1. It was assumed that load 2, which consisted of forces much greater than load 1, would produce at least similar or more deformation.

| Table 2 Data on Relative Displacement (Six Degrees of Freedom/Motion Planes) |
|-------------------------------|-----------|-----------|----------|
| Load 1                        | Mean      | Stdev     | P-values |
| Coronal                       | 0.71 ± 0.14 | 0.7109 |
| Sagittal                      | 0.93 ± 0.42 | 0.3262 |
| Axial-rotation                | 0.26 ± 0.13 | 0.0986 |
| Axial-displacement            | 0.68 ± 0.19 | 0.592 |
| AP displacement               | 1.18 ± 0.39 | 0.405 |
| ML displacement               | 0.58 ± 0.15 | 0.4097 |
| Load 1 = 75 N of axial compression and 0.3 Nm of torsional load (Torque) |
| Load 2                        | Mean      | Stdev     | P-values |
| Coronal                       | 1.19 ± 0.15 | 0.7934 |
| Sagittal                      | 1.52 ± 0.34 | 0.7938 |
| Axial-rotation                | 0.43 ± 0.14 | 0.2891 |
| Axial-displacement            | 0.51 ± 0.10 | 0.6441 |
| AP displacement               | 1.03 ± 0.13 | 0.8403 |
| ML displacement               | 1.01 ± 0.20 | 0.4677 |
| Load 2 = 175 N of axial compression and 1.3 Nm of torsional load (Torque) |

Analysis of variance for conditions 3 to 5 (tibia plated and fibula intact, tibia plated and fibula osteotomy, and tibia plated and fibula plated). Statistical significance set at p < 0.05. AP = anterior to posterior. ML= medial to lateral.
Figure 3 Comparative results of all tibia and fibula conditions for the Load 1* condition: tibia osteotomy and fibula intact (TO and FI), tibia plated and fibula intact (TP and FI), tibia plated and fibula plated (TP and FP), tibia plated and fibula osteotomy (TP and FO), and tibia osteotomy and fibula osteotomy (TO and FO). AP = anterior to posterior. ML = medial to lateral. *Note: Load 1 was 75 N axial load combined with 0.3 Nm of torque.

Figure 4 Comparative results of all tibia and fibula conditions for all the loading conditions: tibia osteotomy and fibula intact (TO and FI), tibia plated and fibula intact (TP and FI), tibia plated and fibula plated (TP and FP), tibia plated and fibula osteotomy (TP and FO), and tibia osteotomy and fibula osteotomy (TO and FO). AP = anterior to posterior. ML = medial to lateral.
Discussion

The purpose of this study was to determine the mechanical role of supplemental fibula fixation of a concomitant tibia and fibula fracture following standard distal anterolateral tibia locked plating. Our results showed that fibula fixation provided no significant mechanical advantage in terms of stability across the tibia fracture site when compared to an unfixed fibula. Lee et al.10 performed a retrospective study where three treatment modalities for concomitant distal fibula and pilon fractures were reviewed at a mean follow-up of 6 years (range: 2 to 10 years). Group A was composed of fibula fractures stabilized with plate fixation, group B employed pin fixation of the fibula, and group C included closed reduction alone. All tibia fractures were treated using plate fixation, immediate or staged following a temporal external fixator. The results showed significant improvement in fibular reduction when group A was compared to groups B and C independently. Additionally, plate fixation provided significantly better patient satisfaction scores when compared to closed reduction of the fibula alone, but no significant differences were seen between the plate and pin fixation groups. Moreover, there was no significant difference in the incidence of post-traumatic ankle arthrosis among any of the three groups.

It has been suggested that fixing the fibula contributes to better clinical outcome and reduced complication rates.11,17 Kumar et al.11 suggested that osteosynthesis of the fractured fibula restores length, improves rotational stability, and prevents future valgus deformity while maintaining continuity with the ankle mortise. This was however in the setting of intramedullary (IM) nailing of the tibia. A further study by Egol et al.18 demonstrated significantly improved maintenance of reduction when the fibula is fixed as compared to IM nailing of the tibia alone. At 12 weeks, 96% of the 72 cases with fibula fixation maintained reduction versus 87% without fibula fixation.18

Rigid fixation of the fibula in the severely comminuted distal tibia fracture may, however, contribute to varus collapse of the tibia and malunion. In theory, low energy distal tibia fractures with minimal comminution or soft tissue disruption may not require fibular fixation. A more recent study by Rouhani et al.19 compared reamed intramedullary nailing of the tibia with fibular fixation versus no fixation and found no significant difference in terms of tibial reduction, loss of reduction, infection, or malunion at an average of 6-month follow-up. These results are contrary to the above mentioned results regarding supplemental fibular fixation.

Although there are few studies specifically looking at the role of the fibula following plate fixation of the tibia, studies comparing locked plating versus IM nail fixation of the tibia have been reported. In a saw bones study by Strauss et al.,14 a significant biomechanical advantage in vertical loading in three planes was observed using tibia locked plating as well as an advantage in cantilever bending with intramedullary (IM) tibia fixation. After fibular osteotomies were made, they found significant improvement in torsional stiffness and decreased fracture displacement in concomitant fractures treated with supplemental fibular plate fixation versus tibia IM nailing alone. It was reported that torsional stiffness decreased by 22% in the intramedullary fixation group versus 11% in the locked plate group. However, one could argue that the biomechanical forces acting on the tibia following IM fixation is vastly different from that of locked plating, thus the behavior of an associated fibula fracture could also differ.

Various techniques on fibula fixation have been described in the literature and some include the use of intramedullary screws, pins, or plate fixation to stabilize the fracture. These have also been described in the context of distal tibia metaphyseal and Pilon fractures.17,18 Nevertheless, the body of evidence shows no definitive conclusion in the management of concomitant distal tibia and fibula fractures. The rationale behind not plating the fibula is to prevent varus collapse of the plated tibia and not to violate soft tissue further in the acute setting of these high energy injuries. Others argue that osteosynthesis of the fibula maintains tibial length and improves ankle joint stability. Our results suggest that fibula fixation is not critical for the stability of the plated distal tibia from a biomechanical perspective. However, these results were derived from experimental laboratory models and may not accurately reflect an in vivo clinical scenario, especially after healing and bone remodeling takes place.

Limitations to this study include the use of cadaveric models, which may have limited applicability in the clinical realm since this model may not realistically replicate an in vivo distal tibia and fibula fracture. However, compared to other models, such as sawbones, cadaveric models have the closest resemblance to the native bony and soft tissue properties of a live specimen, and as such it represents the best model outside the clinical realm to test our hypothesis. The inherent nature and condition of cadaveric specimens, including preexisting diseases of the donors, may have significant impacts on testing outcomes. As is always the case, biomechanical testing studies represent a trade-off between realistic physiologic loading and subsequent motion including controlled loading and motion measurement. In this study, we chose to maintain a realistic indirect load transfer from the femur through an intact knee and ankle joint with all soft tissue structures preserved to a ground contact condition including an intact foot. Our trade-off was precise control of the force vector and bending moments crossing the fracture site from specimen to specimen. Therefore, we present our data as a six-degree-of-freedom absolute motion (instability) analysis under each of the fixation conditions for direct comparison. This model provides insight into the clinical stability to be expected from surgical plating choices.

Conclusion

This study strives to ascertain the behavior of the fibula in the setting of a both bone lower leg fracture or distal tibia and fibula fracture, especially where the tibia may not be
readily amenable to standard intramedullary nailing. Our results conclude that fixation of an associated fibula fracture in a both bone lower leg injury does not provide additional stability to an already plated distal tibia fracture in a cadaveric laboratory model. When the ankle mortise is distorted (i.e., violation of the syndesmosis), it should be advised to restore the mortise using additional fixation techniques and supplemental fibula fixation. These findings are limited to what was observed in a cadaveric model, and any inferences from its conclusion may or may not be readily applicable to an in vivo scenario. Future prospective studies may provide definitive answers to this peculiar question. The results of the current biomechanical study suggest a stand-alone anterolateral locking tibia plate may be adequate fixation in the setting of a distal tibia and fibula fracture or pilon equivalent with an associated fibula fracture, provided an underanged ankle mortise or syndesmosis is present.

Disclosure Statement
None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

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