The Effect of Concurrent Fibular Fracture on the Fixation of Distal Tibia Fractures: A Laboratory Comparison of Intramedullary Nails With Locked Plates

Eric J. Strauss, MD, Daniel Alfonso, MD, Frederick J. Kummer, PhD, Kenneth A. Egol, MD, and Nirmal C. Tejwani, MD

Objective: To compare the fixation stability of intramedullary nails to that of locked plates for the treatment of distal metaphyseal tibia and fibula fractures.

Methods: A simulated, distal metaphyseal tibia fracture was created in 8 pairs of cadaveric tibia-fibula specimens. One of each pair was treated using an intramedullary nail (Trigen IM Nail System; SN Richards, Memphis, TN) and the other with a locked plate (Peri-Loc Periarticular Locked Plating System; SN Richards). Each specimen was vertically loaded to 250 N in central, anterior, posterior, medial, and lateral locations; loaded to 250 N in cantilever bending in anterior to posterior and posterior to anterior directions; and loaded to 250 N mm in torsion. Load-displacement curves were generated to determine the construct stiffness for each loading scenario, with comparisons made between the 2 treatment groups. Each specimen was then cyclically loaded with 750 N vertical loads applied for 10, 100, 1000, and 10,000 cycles. Measurements of fracture displacements were made and compared between treatment groups. A fibular osteotomy was then created in each specimen at the same level as the tibia fracture to simulate a same-level tibia-fibular fracture. Torsional stiffness assessment and cyclic vertical loading for 10, 100, 1000, and 10,000 cycles were repeated and fracture displacement measurements were again obtained.

Results: The locked plate construct was stiffer than the intramedullary nail construct for central, anterior, and posterior loading scenarios ($P < 0.005$, $P < 0.03$, and $P < 0.02$, respectively). The intramedullary nail construct was stiffer than the locked plate construct for both anterior to posterior and posterior to anterior cantilever bending ($P < 0.03$ and $P < 0.02$, respectively). No statistically significant difference in stiffness was noted between treatment groups for medial and lateral vertical loading or for torsional loading ($P = 0.09$, $P = 0.32$, and $P = 0.84$, respectively). There was no significant difference between treatment groups with respect to fracture displacement after cyclic vertical loading. After creation of the fibular osteotomy fracture, construct displacements after 1000 and 10,000 cycles significantly increased and torsional stiffness significantly decreased for both treatment groups. The locked plate constructs had significantly less displacement after cyclic loading of 1000 and 10,000 than the locked nail constructs ($P < 0.001$ and $P < 0.0001$, respectively). Locked plate constructs were stiffer in torsion after osteotomy than the intramedullary nail constructs ($P < 0.05$).

Conclusion: This study demonstrated that, in the treatment of distal metaphyseal tibia fractures, locked plates provided more stable fixation than intramedullary nails in vertical loading but were less effective in cantilever bending. An intact fibula in the presence of a distal tibia fracture improved the fracture fixation stability for both treatment methods. In fracture patterns in which the fibula cannot be effectively stabilized, locked plates offer improved mechanical stability when compared with locked intramedullary nails.

Key Words: distal metaphyseal tibia fracture, locked plate, intramedullary nail, biomechanics

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INTRODUCTION

Fractures of the distal tibia metaphysis typically occur as a result of axial and rotational forces on the lower extremity and represent approximately 10% of fractures of the distal end of the tibia[1,2] The management of these distal injuries is often more complex than the treatment of tibia diaphyseal fractures, leading to the potential for postoperative complications and poor outcome.[3–5] Although different treatment methods have been developed for distal tibia fractures, there is currently no consensus on the optimal mode of management.[1]

Traditional management of distal tibia metaphyseal fractures with open reduction and plate fixation often requires an extensive surgical approach, which can lead to devitalization of the surrounding soft tissue, wound complications, infection, and postoperative ankle stiffness.[6–9] Fracture fixation with intramedullary nails was developed in an effort to limit these potential operative complications. The use of intramedullary nails obviates the need for extensive surgical dissection, spares the extraosseous blood supply, and allows the device to function in a load-sharing manner.[1,6] However, intramedullary management of distal tibia metaphyseal fractures is accompanied by its own complications, including malalignment, hardware failure, and the risk of fracture propagation into the ankle joint.[4–6,10]

Locked plate designs act as fixed-angle devices whose stability is provided by the axial and angular stability at the screw-plate interface instead of relying on the frictional force between the plate and bone,[11] which is thought to preserve the periosteal blood supply around the fracture site. Locked plates are indicated for fracture management in osteoporotic bone and in periarticular fracture patterns, making them a feasible treatment option for distal tibia metaphyseal fractures.[12]

The role of fibular fracture fixation in cases of distal metaphyseal tibia-fibula fractures has been examined in both clinical and laboratory settings. Studies have demonstrated that effective plating of the fibula fracture improves alignment and the ability of the tibial fracture fixation to resist motion across the defect and prevents loss of reduction.[13–15] To date, there are no reports on the impact of fibular fixation on construct stiffness and fixation stability of intramedullary nails compared to locked plates.

This study was performed to compare the mechanical properties and fixation stability of intramedullary nails versus locked plates used in the management of distal metaphyseal tibia fractures in a cadaveric model. Additionally, the impact of a concomitant, same-level fibula fracture on the fixation stability of each treatment option was evaluated. We hypothesized that there would be no significant difference between the 2 implant designs with respect to mechanical stiffness and fracture fragment displacements after cyclic loading.

MATERIALS AND METHODS

Eight matched pairs of embalmed cadaver tibiae-fibulae (from donors 45–63 years of age) were selected according to plain radiographs and bone mineral density evaluation with a Hologic DEXA Scanner (Boston, MA) to include specimens of similar lengths (range, 29.0–33.5 cm) and canal diameter (range, 10.5–12.0 mm) and exclude specimens with pathologic lesions or extreme osteopenia from the study. The specimens were stripped of their soft-tissue attachments, leaving the proximal and distal tibiofibular ligaments intact. Throughout the experiment, each specimen was kept tightly wrapped in airtight double bags to avoid desiccation and by the use of saline-soaked gauze during testing.

Specimen Preparation

First, each specimen was marked with ink in 2 planes, above and below the planned osteotomy site, to facilitate maintenance of rotational alignment during subsequent fracture fixation with each implant. Next, an experimental distal metaphyseal tibia fracture was simulated in each potted cadaveric tibia-fibula, using an oscillating saw to create a transverse osteotomy 2 metaphyseal diameters (approximately 5 cm) proximal to the articular surface, analogous to an OTA type 43A1 distal tibia fracture. Next, a 1 cm fracture gap, simulating the complete lack of cortical contact observed in severely comminuted fractures, was created by removing bone. One specimen from each matched pair was randomly selected to undergo fracture fixation with an intramedullary nail (Trigen; Smith and Nephew, Memphis, TN), whereas the other was fixed with a medial locked plate (Peri-Loc Plating System; Smith and Nephew). Each fracture was instrumented

according to the manufacturer's suggested protocol for each device. A 1 cm spacer was inserted into the fracture gap to facilitate fixation. The intramedullary nails (10-mm-diameter Trigen IM nails of specimen specific length) were inserted with an unreamed technique, under fluoroscopic guidance to a depth of 3 mm from the distal articular surface, to ensure the ability to place all 3 distal locking screws (2 medial to lateral and 1 anterior to posterior) distal to the fracture site. The nails were locked proximally, and the guidance jig was used to insert all 3 of the available proximal locking bolts (transverse, medial oblique, and lateral oblique). In the locked plate group (Peri-Loc Plate), the plate was placed along the medial aspect of the tibia with 4 locking screws distal to the fracture site, and the plate was secured to the diaphysis with 4 3.5-mm locking screws proximally. Once the specimens were instrumented, the 1.0 cm spacer was removed. Next, clay was placed over the anterior and posterior surface of the proximal and distal tibiofibular joints, over the surface of the plate and screws in the locked plate specimens, and over the exposed heads of the locking screws of the specimens treated with intramedullary nails to prevent engagement with the potting material. The proximal and distal aspects of each specimen were then potted with acrylic cement in 10 cm diameter polyvinyl chloride pipe that was 4 cm long[16] (Fig. 1).

FIGURE 1. Cadaveric distal metaphyseal tibia fracture model with fibula intact. Fractures were treated with either the Peri-Loc periarticular locking plate system (left) or the Trigen locked intramedullary nail system (right).

Mechanical Evaluation: Assessment of Construct Stiffness

Mechanical evaluation was performed with an Instron 2000 Universal Material Testing Machine (Instron, Canton, MA) for axial compressive loading at central, anterior, posterior, medial, and lateral locations, cantilever bending in anterior to posterior and posterior to anterior directions, and in torsion. Each specimen was loaded at a rate of 2.5 N/second to a maximum load of 250 N for each test.[17] Displacements were determined by the position of the loading actuator during testing.

Axial Compressive Loading

For axial compression loading, the loading positions were marked on the top of the flat, proximal, circular potting fixture, with central loading defined as the center of the circle. The tibial tubercle served as the reference point for the rest of the loading positions, with the anterior loading position defined as loading in line with the tibial tubercle. The posterior loading point was 180 degrees from the anterior loading point (as measured with a goniometer), and the medial and lateral loading points were 90 degrees from the anterior loading point in either direction, each 2 cm from the central loading position (Fig. 2).

Independent point loading at each designated loading point was accomplished with a 5-mm-diameter loading bolt with a hemispherical head attached to the load cell of the Materials Testing Machine (MTS) machine. The relatively small size of the loading bolt relative to the total surface area of the superior aspect of the potted specimen allowed us to evaluate distinctively different loading scenarios.
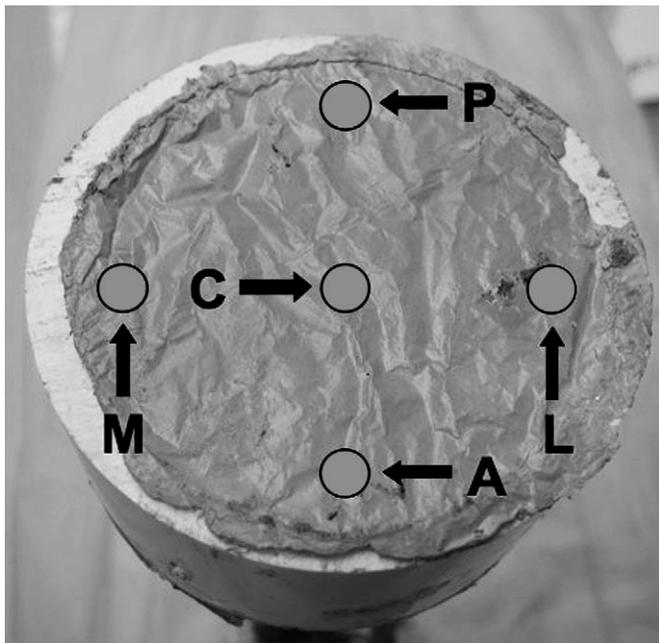

FIGURE 2. Axial compressive loading test setup. Loading positions were determined using the tibial tubercle as a reference point. C, central loading point; P, posterior loading point; M, medial loading point; L, lateral loading point.

Cantilever Bending

Anterior to posterior and posterior to anterior cantilever bending was accomplished by mounting the specimen horizontally in a vise 90 degrees to the load cell of the MTS machine, with the tibial tubercle facing either directly anterior or directly posterior and the load cell bolt centered over the distal potting fixture. The cantilever point (metal support structure) was positioned 1 cm proximal to the osteotomy site (6 cm from the applied load). Loading the central aspect of the distal pot with 250 N provided a bending moment of 15 Nm.[17–19]

Torsional Loading

To facilitate torsional loading, the specimens were mounted horizontally with the proximal potting fixture secured in a vise and the distal potting fixture supported by rollers. A 6 mm coupling rod for the 5-mm-diameter loading bolt was inserted in a radial direction on the lateral aspect of the distal potting fixture, centered over the lateral malleolus. The coupling allowed the conversion of a vertical load applied by the MTS machine into a torsional load experienced across the fracture site.[17–19] The displacement of the loading bolt was converted to an angular displacement by trigonometric analysis (as well as a correction for torque caused by the position of the loading bolt on the coupling rod). A maximum load of 250 N resulted in a torsion of 12.5 Nm.

Five minutes between testing phases allowed the specimens to reach equilibrium. Load-displacement curves were generated for each specimen for each mode of loading, and the slope of the curve was determined. Construct stiffness was calculated in newtons/millimeter for axial loading, newton-meters/millimeter for cantilever bending and newton-millimeters/degree for torsional loading.

Mechanical Evaluation: Fracture Displacement With Cyclic Loading

Two 0.062 inch Kirschner wire segments were inserted on each side of the fracture line, projecting 5 mm from the bone to act as reference pins for measurement of displacements. Mechanical evaluation of each specimen was then performed by securing the potted bone/implant construct in a vise, oriented to allow each specimen to be loaded in line with the mechanical axis of the tibia. Each specimen was initially loaded in the central loading position with 750 N (to simulate body weight) and allowed to come to equilibrium (5 minutes) before displacement measurements were recorded. Measurement of the gap distance between the reference pins with the specimen in the loaded state (elastic displacement) was made using a digital caliper with a resolution of 0.05 mm and an accuracy of 0.1 mm (Avenger 6" Digital Caliper; Boulder City, NV). The specimen was then unloaded and allowed to reach equilibrium before the gap-distance measurements were repeated to determine whether permanent displacement of the fracture fragments had occurred. Next, each specimen was cyclically loaded, with 750-N vertical loads applied at 3 Hz for 10, 100, 1000, and 10,000 cycles. Each specimen was allowed to reach equilibrium after each cyclic interval, and displacement measurements in both the loaded

(elastic displacement) and unloaded (permanent displacement) states were taken.

Impact of Concurrent Fibular Fracture

To determine the effect of concomitant fibular fracture on fixation stability, a simulated fibular fracture was created at the same level as the distal tibia fracture with an oscillating saw. A 1 cm fracture gap was created in the fibula by removing bone. Torsional stiffness was reassessed for each specimen after creation of the fibular fracture by generating load-displacement curves using an applied 250-N load. Cyclic loading with 750-N vertical loads was then repeated for 10, 100, 1000, and 10,000 cycles, with displacement measurements taken with the constructs in both the loaded and unloaded states.

Statistical Analysis

Paired Student t tests were used for statistical comparisons. A $P < 0.05$ was considered to be statistically significant.

RESULTS

Bone mineral density of the specimens used was similar between groups, with a mean density of 0.34 g/cm^2 for the locked plate group (range, 0.27–0.40 g/cm^2) and 0.36 g/cm^2 (range, 0.28–0.41 g/cm^2) for the intramedullary nail group ($P = 0.91$).

Construct Stiffness With an Intact Fibula

Under central vertical loading, the locked plate group demonstrated a mean stiffness that was significantly greater than that seen in the IM nail group ($P < 0.005$). For both anterior and posterior vertical loading, the locked plate group was significantly stiffer than the IM nail group ($P < 0.02$ and $P < 0.03$) (Fig. 3).

In an anterior to posterior cantilever bending scenario, the intramedullary nail group was significantly stiffer than the locked plate group ($P < 0.03$). Similarly, for posterior to anterior cantilever bending, the mean stiffness of specimens treated with an intramedullary nail was significantly greater than the mean stiffness of specimens treated with locked plates ($P < 0.02$) (Fig. 4).

No statistically significant difference in construct stiffness was noted between treatment groups for medial and lateral vertical loading or for torsional loading ($P = 0.09$, $P = 0.32$, and $P = 0.84$, respectively). A post hoc power analysis demonstrated that 16, 44, and 14,000 specimens per group respectively would be required to detect a difference between the treatments with 90% power.

Fracture Displacement With Fibula Intact

After 1000 and 10,000 cycles, in both the loaded and unloaded state, there was no significant difference in elastic or permanent fracture fragment displacement between the locked plate and IM nail groups when the fibula was intact ($P = 0.81$ [loaded] and $P = 0.93$ [unloaded] for 1000 cycles and $P = 0.98$ [loaded] and $P = 0.87$ [unloaded] for 10,000 cycles) (Fig. 5).

Effect of Fibular Osteotomy

After fibular osteotomy, the torsional stiffness of both the IM nail group and locked plate group decreased compared to that seen with the fibula intact (22% decrease [$P < 0.01$] and 11% decrease [$P < 0.04$], respectively). In this distal tibia-fibula fracture pattern, the mean torsional stiffness of specimens treated with locked plates was significantly greater (mean of 20%) than that seen for specimens treated with intramedullary nails ($P < 0.05$) (Table 1).

Fibular osteotomy had a impact on fracture fragment displacement, with significantly more displacement during cyclic loading in both treatment groups compared to that seen with the fibula intact ($P < 0.006$ and $P < 0.004$ for the locked plate group after 1000 and 10,000 cycles and $P < 0.0001$ after 1000 and 10,000 cycles for the IM nail group, respectively). However, the specimens treated with the locked plate demonstrated significantly less elastic and permanent fracture
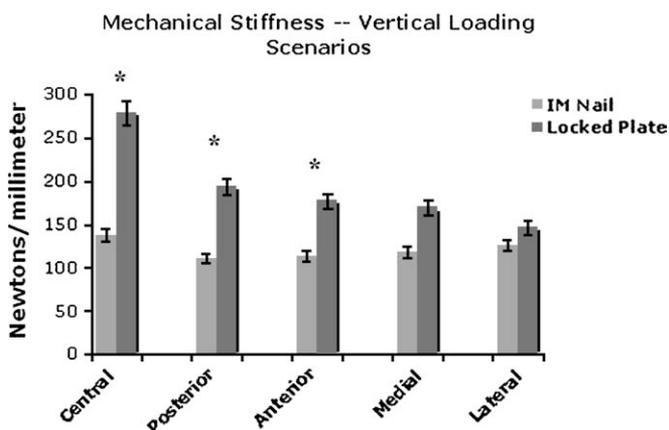
FIGURE 3. Evaluation of construct stiffness with an intact fibula: Vertical loading scenarios. The locked plate construct was significantly stiffer than the intramedullary nail, with central, anterior, and posterior vertical loading (*denotes statistically significant difference in stiffness between treatment groups).
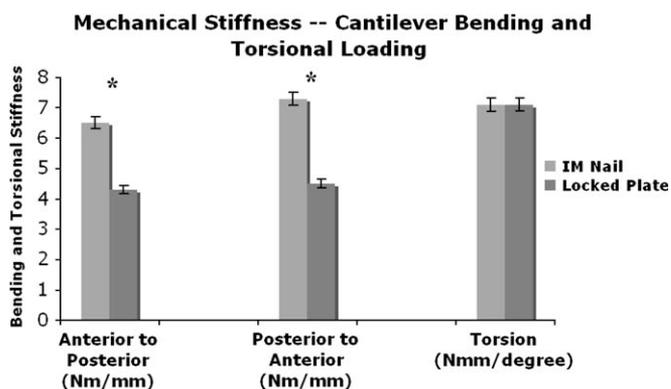
FIGURE 4. Evaluation of construct stiffness with an intact fibula: Cantilever bending and torsional loading scenarios. The intramedullary nail construct was significantly stiffer than the locked plate for both anterior to posterior and posterior to anterior cantilever bending. There was no difference detected between groups with respect to torsional stiffness (*denotes statistically significant difference in stiffness between treatment groups).
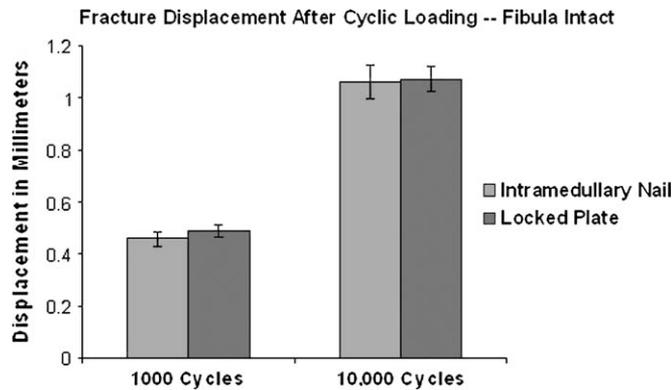
FIGURE 5. Elastic fracture displacement after cyclic vertical loading: Intact fibula. After 1000 and 10,000 cycles, there was no significant difference in elastic fracture fragment displacement between the locked plate and the intramedullary nail treatment groups.
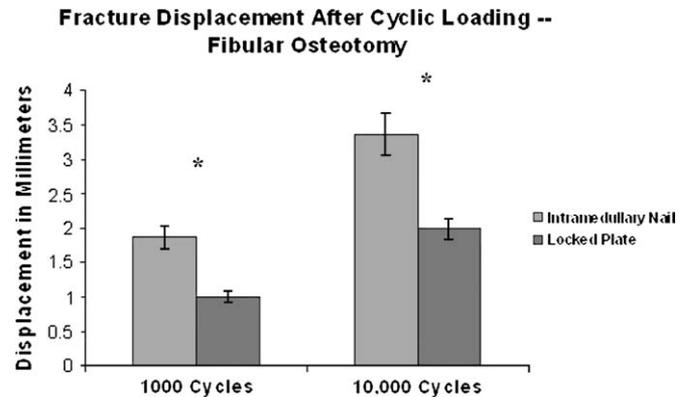

FIGURE 6. Elastic fracture displacement after cyclic vertical loading: Fibular osteotomy. Specimens treated with locked plates demonstrated significantly less elastic fracture fragment displacement than those specimens treated with intramedullary nails (*denotes statistically significant difference between treatment groups).

displacement than those specimens treated with IM nails ($P <$ 0.0006 [loaded], $P <$ 0.0004 [unloaded] for 1000 cycles and $P <$ 0.0001 [loaded] and $P <$ 0.0002 [unloaded] for 10,000 cycles) (Fig. 6).

DISCUSSION

In this study, we found that for axial loading situations, locked plate constructs were twice as stable as intramedullary nails in a cadaveric distal tibia metaphyseal fracture model. We believe that this improved stiffness occurred as a result of the relative proximity of the proximal fixation of the locked plate to the fracture site. The proximal locking screws being closer to the fracture site than the proximal locking bolts of the nail appears to provide better stability in response to compressive loads. For cantilever bending scenarios, the intramedullary nail was approximately 50% stiffer than the medially placed locked plate, likely as a result of its intramedullary position across the fracture site, closer to the ventral axis. With an intact fibula, there was no significant difference in torsional stiffness or fracture displacement after cyclic vertical loading. Creation of a fibula osteotomy simulating a concomitant same-level fibula fracture had a significant impact on both the torsional stiffness of the implants and the amount of fracture displacement that occurred with cyclic loading. In the concomitant tibia-fibula fracture model, the locked plate provided a stiffer construct to torsional loading and allowed fewer fracture displacements than the intramedullary nail.

Our data support the use of a locked plate construct for fracture patterns with significant distal tibia and fibula comminution or bone loss. The mechanical advantage provided by the locked plate likely occurs as a result of the fixed-angle stability afforded by the locking screws and the position of the proximal fixation of the plate closer to the fracture site than the proximal locking screws of the intramedullary nail. Additionally, our data demonstrated that the presence of a concomitant, same-level fibula fracture significantly worsened fracture fixation stability for both treatment methods.

The impact of fibular fracture fixation in cases of distal metaphyseal tibia-fibula fractures has been examined in the orthopedic literature. Egol et al[13] reported on 72 distal metaphyseal tibia-fibula fractures and demonstrated that plating of the fibula fracture resulted in a significantly higher percentage of cases maintaining reduction after 12 weeks (96%) compared to cases managed with an intramedullary nail alone (87%). The authors concluded that fibula fracture stabilization offers protection against loss of fracture reduction when distal metaphyseal tibia-fibula fractures with intramedullary fixation are being managed. Our mechanical data support these clinical findings, suggesting that IM nail fixation of a comminuted unstable distal tibia-fibula fracture without fibular stabilization may be unable to maintain fracture reduction under physiologic loading.

A mechanical investigation by Kumar et al,[14] using a cadaveric distal tibia-fibula fracture model treated with intramedullary nail fixation of the tibia fracture, demonstrated significantly less fracture fragment displacement in specimens with fibular plate fixation than in those without fibular plate fixation. The addition of fibula fracture stabilization to intramedullary nailing increased the initial rotational stability of the fracture fixation compared to intramedullary nailing alone; however, as applied torque increased, this added stiffness was no longer evident between treatment groups. The authors concluded that the addition of supplemental fibular fracture fixation to intramedullary nail fixation of distal tibia

TABLE 1. Effect of Fibular Osteotomy on Torsional Stiffness

	Mean Torsional Stiffness After Fibular Osteotomy	*P* Value
Locked plate treatment group	5.8 N-mm/degree	<0.05
Intramedullary nail treatment group	6.5 N-mm/degree	

fractures increases construct stability and may decrease the risk of valgus malunion.[14]

In addition to increasing construct stiffness and providing protection against the potential for loss of reduction, plating the fibula may also serve as a primary reduction aid during the management of distal tibia-fibula fractures to obtain appropriate length, alignment, and rotation of the distal tibia segment. In a recent clinical review of 36 distal tibia fractures managed with intramedullary nail fixation, Nork et al[6] used fibular plating to assist in distal tibial segment reduction in 19 patients, helping them achieve acceptable radiographic alignment in 92% of their study patients. Similarly, Megas et al,[20] in their series of 14 distal tibia-fibula fractures managed with intramedullary nailing, used plate fixation of the concurrent fibula fracture in all 14 cases to facilitate nail placement with appropriate length and alignment.

Limitations of our investigation include the use of cadaveric specimens, with their inherent variability. We attempted to standardize our treatment groups through radiographic evaluation to use specimens of similar length and intramedullary canal size and to rule out any occult pathology or extreme osteopenia that would alter the results. Another limitation to the study is the creation of artificial fractures to simulate distal metaphyseal tibia and fibula fractures. Although these artificial fractures do not truly represent the manner in which an unstable distal tibia-fibula fracture occurs, the ability to examine a construct with no interdigitating fracture fragments allowed us to assess the fracture fixation by the implant in its purest form. Our model did not take into account the impact the surrounding soft-tissue envelope has on fixation stiffness. Additionally, there is the potential of an ordering effect, in which one loading test influences the outcome (stiffness or displacement) of the next. We attempted to limit this potential bias by varying the order of loading scenarios between specimens while keeping the sequence the same between treatment groups. Our evaluation of construct stiffness with torsional loading subsequent to the creation of the fibular osteotomy required that this testing to be performed after the fibula intact specimen had undergone cyclic vertical loading, which may have affected the stiffness results observed and is a limitation inherent to our testing method. Additionally, we did not include an assessment of construct stiffness with medial to lateral or lateral to medial bending, nor did we repeat stiffness calculations for axial loading and cantilever bending scenarios after the fibular osteotomy was created. We assumed that differences in displacements between paired specimens occurred at the osteotomy site; a more precise technique would incorporate displacement transducers across the osteotomy. It is possible that, as a result of the relatively small sample size and the resultant low power of the tests, differences between the 2 treatment groups for certain loading scenarios may not have been detected.

CONCLUSION

This laboratory study demonstrated that in the treatment of distal metaphyseal tibia fractures, locked plates had an increased fixation stability compared to intramedullary nails for vertical loading but were less stiff in cantilever bending scenarios. Locked plates appear to provide better fixation than intramedullary nails for fracture patterns in which the fibula cannot be effectively stabilized.

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