Polyaxial Screws in Locked Plating of Tibial Pilon Fractures

ZACHARY C. YENNA, MD; ARUP K. BHADRA, MD; NWAKILE I. OJIKE, MD; ROBERT L. BURDEN, MEng; MICHAEL J. VOOR, PhD; CRAIG S. ROBERTS, MD, MBA

Abstract

This study examined the axial and torsional stiffness of polyaxial locked plating techniques compared with fixed-angle locked plating techniques in a distal tibia pilon fracture model. The effect of using a polyaxial screw to cross the fracture site was examined to determine its ability to control relative fracture site motion. A laboratory experiment was performed to investigate the biomechanical stiffness of distal tibia fracture models repaired with 3.5-mm anterior polyaxial distal tibial plates and locking screws. Sawbones Fourth Generation Composite Tibia models (Pacific Research Laboratories, Inc, Vashon, Washington) were used to model an Orthopaedic Trauma Association 43-A1.3 distal tibia pilon fracture. The polyaxial plates were inserted with 2 central locking screws at a position perpendicular to the cortical surface of the tibia and tested for load as a function of axial displacement and torque as a function of angular displacement. The 2 screws were withdrawn and inserted at an angle 15° from perpendicular, allowing them to span the fracture and insert into the opposing fracture surface. Each tibia was tested again for axial and torsional stiffness. In medial and posterior loading, no statistically significant difference was found between tibiae plated with the polyaxial plate and the central screws placed in the neutral position compared with the central screws placed at a 15° position. In torsional loading, a statistically significant difference was noted, showing greater stiffness in tibiae plated with the polyaxial plate and the central screws placed at a 15° position compared with tibiae plated with the central screws placed at a 0° (or perpendicular) position. This study showed that variable angle constructs show similar stiffness properties between perpendicular and 15° angle insertions in axial loading. The 15° angle construct shows greater stiffness in torsional loading. [Orthopedics. 2015; 38(8):e663-e667.]
Locked plating methods are recent developments in the treatment of distal tibia fractures\textsuperscript{1-3} and potentially accomplish many tasks, including capturing fracture fragments, stabilizing the ankle, and maintaining the articular surface.\textsuperscript{4,5}

Even more recent is the development of polyaxial locked plating devices. The biomechanical properties of locking compression plates may be well suited for many distal tibia fractures, but the nature of fixed-angle screw entry necessarily limits the type of fracture patterns and comminution that can be captured by the plate-screw construct. The introduction of locked polyaxial screw insertion may offer the mechanical advantages of fixed-angle locking plates while allowing access to previously unobtainable fracture fragment geometry.

Previous studies evaluated the biomechanics of polyaxial locked plating techniques in the lower limb.\textsuperscript{1,6-7} However, these were limited to fractures around the distal femur and proximal tibia. Gao et al\textsuperscript{8} evaluated the use of polyaxial locked plates in the distal tibia in an effort to measure clinical outcomes, including healing rates, complications, and functional outcomes.

To the authors’ knowledge, no study has attempted to evaluate the biomechanical properties of polyaxial locked plating techniques comparing fixed-angle and variable-angle constructs in pilon fractures. The goal of this study was to evaluate the axial and torsional stiffness of a polyaxial locked compression plate with screws inserted in a fixed-angle (perpendicular to the plane of the plate) configuration compared with the same plate with the screws inserted in an angled (15° from perpendicular) configuration with screws crossing the fracture gap. Unlike lag screws, these screws act as neutralization screws without necessarily compressing the fracture site. Instead they are intended to block fracture site shear.

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Material and Methods

Experimental Design

This study was a laboratory investigation conducted at a university-based Level I trauma center. It was exempt from institutional review board approval because it involved synthetic composite femurs in a biomechanics laboratory setting and did not involve human experimentation. Composite tibiae were used to evaluate the null hypothesis that there was no difference in biomechanical axial or torsional stiffness between a distal tibia fracture model plated with a 3.5-mm Distal Tibia Variable-Angle Locking Plate (Smith & Nephew, Memphis, Tennessee) with 2 central screws set at a neutral angle compared with the use of a configuration in which the 2 central screws were set into the tibia at a 15° angle and crossed the fracture gap.

Sample Preparation

The test samples for this experiment were Sawbones Fourth Generation Composite Tibia models (Pacific Research Laboratories, Inc, Vashon, Washington). Proximally, the tibia samples were attached to a custom-machined aluminum plate at the tibial plateau. A lightweight epoxy filler was sandwiched between the aluminum plate and the tibial plateau to allow transfer of compressive forces from the loading apparatus via the machined plate to the tibial plateau. Additionally, the epoxy created an anatomic mold that allowed each tibia to be aligned precisely and consistently with the machined aluminum plate. Distally, the tibial plafond was placed on a steel ball for compression testing. The plafond was potted in an epoxy mold for torsional testing.

Each tibia was plated with a 3.5-mm variable-angle locking plate (Figure 1) by an orthopedic surgery fellow (A.K.B.). Proximally, the contoured plate was affixed with 3 bicortical locking screws, again sized appropriately to allow bicortical purchase. All tibia models subsequently received a transverse cut representative of an Orthopaedic Trauma Association 43-A1.3 pilon fracture. The transverse cut was made perpendicular to the longitudinal axis of the tibia with a 0.5-mm–thick hacksaw blade and positioned approximately 5 mm below the location of the 2 variable-angle screws. This allowed 2 screws to be inserted in a neutral position, perpendicular to the longitudinal axis of the tibia, and to pass to the opposing cortical surface without bridging the fracture gap. Alternatively, these 2 screws could be angled 15° from the perpendicular position and inserted so that they were directed toward the distal fracture segment, allowing the screws to cross the fracture gap and to insert securely into the opposing distal cortical surface (Figure 2).

Testing Protocol

A servohydraulic load frame (Bionix Model 858; MTS, Minneapolis, Minnesota) was used to compress and rotate each
tibia model. Intact tibiae were initially tested for reference before instrumentation.

For axial stiffness testing, each tibia model was placed into the load frame between 2 steel balls. Proximally, the load frame generated force across a steel ball that was set into 1 of 2 depressions in the custom-machined aluminum plate. The 2 depressions were machined at locations 4 cm medial or posterior to the central longitudinal axis of the tibia model, simulating anatomic loading onto the tibial plateau from a straight-leg stance and a bent-leg stance, respectively. Distally, the tibial plafond sat atop an additional steel ball located along the central longitudinal axis of the tibia model.

For torsional testing, the machined aluminum plate on the proximal end was stabilized with a steel ball. A steel pin located 3.8 cm off-center from the central longitudinal axis was inserted into the plate, and torque was applied. Distally, the tibial plafond was potted in a lightweight epoxy filler, preventing the model from rotating.

Each tibia model was initially tested for axial compression (Figure 3) in the medial and posterior loading positions, with the variable-angle screws inserted in the neutral position. After testing, all screws atop the aluminum plate on the plateau and those of the anterior variable-angle contoured plate were checked for proper torque. To test the tibia model for torsional loading, the tibial plafond was inserted into the epoxy structure.

After completion of axial and torsional testing, each tibia model was modified so that the variable-angle screws were inserted at a 15° position. The tibia model was reinstalled into the load frame and tested for axial loading and then for torsional loading.

Axial Loading
Each tibia was placed into the servo-hydraulic load frame and preloaded to approximately 10 N. The tibia models were typically compressed to approximately 400 N as vertical displacement was applied. The samples were loaded at a rate of 0.1 mm/s, and measurements were sampled at a frequency of 100 Hz.

Torsional Loading
Each tibia model was preloaded in an axial direction at 10 N. The load frame measured torque at the tibial plafond as rotational deflection was generated at the plateau via the load frame. The tibia models were loaded at a rate of 0.5°/s, and measurements were sampled at a frequency of 100 Hz.

Main Outcome Measurements
For axial loading, the load frame applied a programmed displacement. The resulting force transmitted through the tibial plafond to the MTS Bionix actuator was sampled. For torsional stiffness, the load frame applied a programmed rotational deflection about the central longitudinal axis in both external and internal rotation and the actuator sampled the resulting torque that was transmitted to the tibial plafond.

Statistical Analysis
For both axial and torsional testing, displacement and force and torque data were obtained. A displacement-load curve was generated for each tibia model, with the y-axis representing the applied load and the x-axis representing displacement. Stiffness was obtained by selecting the linear portion of the curve and calculating the slope with Excel 2007 (Microsoft, Seattle, Washington). Tests were grouped according to loading mode (axial or torsional), loading position (for axial loading, either medial or posterior), and variable-angle screw position (neutral or 15°). For each test group, associated descriptive statistics, including mean and SD, were calculated. Mann-Whitney U test was performed with SPSS version 19.0 software (IBM Inc, Somers, New York) to determine statistically significant differences in mean axial and torsional stiffness values between comparable groups. Statistical significance was defined as $P \leq 0.05$.

RESULTS

Axial Loading
When tested in the medial loading position, no statistically significant difference was found between tibiae plated
with the central screws positioned at a 15° insertion angle compared with tibiae plated with the central screws positioned at a neutral insertion angle (Table). Similarly, when tested in the posterior loading position, there was no statistically significant difference between tibiae plated with the central screws at a 15° insertion angle compared with tibiae plated with the screws positioned at a neutral angle.

### Torsional Loading

When tested under external (clockwise) rotation, significantly greater torsional stiffness was found in tibiae with the central screws positioned at a 15° insertion angle compared with tibiae with the central screws positioned at a neutral insertion angle (Table). Similarly, when tested under internal (counterclockwise) rotation, tibiae with the central screws positioned at a 15° insertion angle showed significantly greater stiffness compared with those with the central screws positioned at a neutral insertion angle.

### Discussion

The goal of the current study was to examine the axial and torsional stiffness of composite distal tibia fracture models plated with an anterior variable-angle distal tibia plate using a 15° angled configuration vs a fixed-angle (neutral angle or perpendicular to the cortical surface) configuration.

This study is novel in that it used angled screws placed through a fracture gap in a configuration that was not previously described in the literature. This study has some similarities to fracture reduction and fixation techniques with lag screw insertion, notably that lag screws or lag screw techniques are used to bridge a fracture gap with a screw in addition to a spanning plate. In the *Manual of Internal Fixation*, Perren discussed the merits of lag screw instrumentation as well as the important biomechanical principles in using lag screws. Specifically, this method of fixation relies on the proximal aspect of the lag screw gliding through the proximal fracture fragment, with the distal screw threads engaging the distal fracture piece. This generates a large compressive force of 2000 to 4000 N across the fracture gap and contributes to the stiffness and stability of the construct.

In contrast, in the current study, fully threaded screws were inserted through the locking compression plate as well as through both the proximal and distal fracture fragments. This method engages screw threads in both the proximal and distal fracture fragments and does not specifically generate the compressive force that is seen in lag screw techniques used in diaphyseal bone. Additionally, the screws lock into the compression plate. These screws prevent the relative shearing motion across the fracture site that is common when under torsion as the plate twists slightly about a center of rotation located outside the tibial shaft. The screws accomplish this in a way that differs from the lag screw technique. Additionally, this technique is available in bone that would not otherwise sustain the compression generated by a lag screw.

The current study showed no statistically significant difference between the locked plate construct with screws inserted at a neutral angle and the configuration with the screws inserted at a 15° angle when tested in compression. This indicated a load-sharing construct, with the tibia taking most of the compressive load. However, under torsional loading, a statistically significant difference was noted in torsional stiffness, favoring the construct with the variable-angle screws inserted 15° from perpendicular and bridging the fracture gap.

The results showed that this model allowed the variable-angle screws to behave as derotational screws, limiting eccentricity of the plate fixation and transferring the center of rotation of the construct from a focus at the plate to a focus at a more axial position within the bone. This resulted in a measured increase in torsional stiffness of the construct and limited strain and shear forces across the fracture gap.

It remains to be seen how these results translate to the clinical setting. Polyaxial screw insertion is a recent advance in locked plating techniques. Biomechanical studies have been performed for different anatomic sites and different plating methods. Only Cullen et al examined a tibial fracture pattern. These authors evaluated biomechanical performance in a proximal tibia model and concluded that polyaxial locking plates showed greater stiffness and load to failure compared with conventional medial or lateral locking plates. The current study supported greater stiffness for certain force vectors, although in addition to differing anatomic sites, the study was not designed to evaluate a fracture gap model. To the authors’ knowledge, the only published study on polyaxial locked plating in the distal tibia was a clinical study evaluating outcomes in 32 patients treated with polyaxial locked plating. The endpoints studied included healing rates, complications, and functional outcomes, but not biomechanical differences.
cas properties. Although the study reported encouraging clinical results, further biomechanical evaluation is needed.

The current study used composite tibias that accurately model the geometry and mechanical stiffness of human bone while eliminating uncertainties that may occur with variable quality specimens of human cadaveric bone and allowing fundamental biomechanical properties to be evaluated. The use of composite bones in combination with the testing protocol ensured uniform, repeatable evaluation of each tibia construct, eliminating variability that may occur with cadaveric bone and joint interfaces. A strength of this study was the use of a single polyaxial locking plate affixed to 1 tibia with only the insertion of the 2 variable-angle locking screws changed throughout the testing of axial or torsional loading. This approach allowed each configuration to be tested with a minimum number of experimental discrepancies between the neutral angle configuration and the 15° angle configuration.

**Limitations**

This study was limited by the inability to evaluate all potential fracture and comminution patterns. A principal benefit of polyaxial locked plating is the ability to capture a wider array of fracture fragments than is currently offered by fixed-angle locked plating. Although this has important clinical value, biomechanical evaluation of a representative sample of comminution patterns quickly becomes unwieldy. In addition, the authors did not reproduce the range and variability of quality typically seen in human tibiae (eg, osteopenia or osteoporosis) that cannot be well modeled by composite tibia. Finally, this study did not discuss load to failure or fatigue.

The study is well suited for the evaluation of biomechanical properties of polyaxial locked plating. Many of the noted shortcomings of a study using Sawbones tibias are better evaluated in a clinical setting. Issues of variable bone quality in a given population secondary to osteoporosis, for example, are important but do not help to resolve fundamental biomechanical questions. Although load to failure and fatigue are valid concerns, they are biomechanical properties that can be evaluated in Sawbones models. However, they may manifest differently for polyaxial locked plates, depending on how locking screws are inserted into the bone. Again, this issue may be best evaluated in a clinical setting because issues of fatigue will largely be determined by the fracture pattern, degree of comminution, and subsequent load that must be carried by the locking plate and screw construct.

The current study discussed advantages of polyaxial locked plating from a biomechanical perspective; however, additional biomechanical validation is needed for load to failure and fatigue. Although Gao et al reported favorable outcomes for limb-specific assessment compared with earlier studies, further controlled clinical studies to compare outcomes may better elucidate the advantages of polyaxial locking plates. There are other concerns about locked plating techniques and the expanded indications for their use, including the physiologic concern that the locking constructs may be too stiff to promote proper fracture healing.

**Conclusion**

This study showed that polyaxial locking plates with variable-angle screws positioned to cross the fracture gap offer greater torsional stiffness than polyaxial locking plates with variable-angle screws positioned parallel to the fracture gap (neutral angle or perpendicular to the cortical surface) in the treatment of distal tibia pilon fractures. Polyaxial locking plates with 15° angled screws should be considered in clinical situations where torsional strength is required and the variable-angle screws can be positioned to capture fracture fragments that are at risk for high levels of strain and shear force.

**References**