An Original Study

Effect of Plate in Close Proximity to Empty External-Fixation Pin Site on Long-Bone Torsional Strength

Fred L. Speck, MD, Randal P. Morris, BS, and Ronald W. Lindsey, MD

Abstract

Complex tibia fractures are often provisionally stabilized with external fixation prior to definitive fracture fixation. Bicortical defects, such as those left after removal of a fixator pin, can decrease the torsional strength of long bone. Evaluating the effect of subsequent plate fixation in close proximity to a defect on the torsional strength of the tibia is the purpose of this study. Eight groups of 5 fourth-generation left composite tibias were tested to failure in torsion. The experimental plated groups consisted of bicortical defects at 3 cm, 2 cm, and 1 cm distal to the plate end, with 1 plated group without a defect. The control groups consisted of equivalent defects in the same distal longitudinal locations, without plates attached, as well as an unplated group without a defect. There were no statistical differences in torsional stiffness or failure torque between any of the groups. The mode of failure for all specimens with bicortical defects was a spiral fracture that bisected the axis of the defect. Based on the results of this composite tibia study, varying the proximity of a bicortical defect to a plate does not affect the torsional stiffness or torsional failure strength of the bone.

Take-Home Points

- The location of a bicortical defect in proximity to a tibia plate does not appear to affect the torsional stiffness or torsional failure strength of the bone.
- External fixator pin placement should be based on considerations other than the potential for creating a distal stress riser after definitive fracture management.

A stress riser in cortical bone may be considered any abrupt change in the contour or consistency of the hollow structure, such as a surface defect, that not only weakens the bone but concentrates stresses at that transition point.[1] A cortical defect that is 20% of the bone diameter is associated with a 34% decrease in torsional strength, thus representing a "stress riser."[2] High-energy and complex tibia fractures are often provisionally stabilized with external fixation that gives the soft tissues time to recover before definitive fracture fixation. Pin diameter for a medium-size tibia external fixator typically is 5.0 mm, resulting in a 10-mm defect in bicortical placement. Therefore, any tibia with a diameter of <50 mm is at risk for a stress riser fracture.

Although it had been established that sizable cortical defects can decrease the torsional strength of long bone,[2] the effect of a plate in close proximity to a defect secondary to an empty external-fixator pin site on torsional strength has not been determined. We conducted a study to evaluate this effect. The null hypothesis was there would be no difference in tibia torsional strength attributable to varying the proximity of a tibia midshaft plate to a 5.0-mm bicortical defect.

Methods

Forty fourth-generation, medium-size left composite tibias (Pacific Research Laboratories) were divided into 8 groups of 5 bones (**Figure 1**). To represent the stress riser created by the removal of a 5.0-mm Schantz external fixation pin, we produced distal tibia bicortical defects in 6 of the groups by creating anterior-to-posterior 5.0-mm bicortical drill holes. The longitudinal location of these drill holes was varied in relation to the distal end of a 4.5-mm × 121-mm 6-hole locking plate (PeriLoc;

Smith & Nephew) fixed in a nonlocking configuration and positioned across the tibia midline on the anterior-medial aspect. In the experimental plated groups, the bicortical defects were created 3.0, 2.0, and 1.0 cm distal to the plate end, with 1 plated group without a defect. The control groups consisted of equivalent defects in the same distal longitudinal locations, without plates attached, as well as an unplated group without a defect.

Torsion testing to failure was performed for all specimens in a manner similar to that described by Gardner and colleagues.[3] Impression molds for the composite tibia constructed from polymethylmethacrylate encased the superior and distal ends, leaving 25.5 cm of exposed midshaft. This allowed the composites to be rigidly clamped into a materials testing system (858 Mini-Bionix; MTS) equipped with a 100.0-Nm torsional load cell (**Figure 2**). The constructs were preconditioned by rotating the superior end internally up to 15.0 Nm at a rate of 0.25 Nm/s for 2 complete cycles. Next, the constructs were preloaded axially to 20.0 N and then rotated at 0.25°/s until failure. Torsional load and torsional displacement were recorded and used to determine construct stiffness and failure load. Stiffness was calculated as the slope of the linear elastic portion of the load versus displacement curves between 20.0 Nm and 40.0 Nm. Failure load was defined as the highest load achieved before fracture. One-way analysis of variance with Tukey adjustment for multiple comparisons and α set at 0.05 were used to detect differences in failure stiffness and failure load between the 8 constructs.

Results

Graphical results for torsional stiffness are presented in **Figure 3**. R^2 for all stiffness calculations was >0.99. There were no statistical differences in torsional stiffness between any of the groups. Graphical results for torsional failure load are presented in **Figure 4**. During torsion-to-failure testing, both plated and unplated specimens without distal cortical defect holes nearly exceeded the torque capacity of the load cell without failing, stopping the tests. For the specimens that failed, there were no statistical differences in failure torque. A slight trend toward higher failure loads in plated specimens with a hole in close proximity was seen in the 1.0-cm distal defect hole groups, with the plated specimen achieving a higher mean (SD) failure load, 78.14 (7.58) Nm, than the unplated group, 66.75 (1.84) Nm, but this was not significant (P = .06). Another slight trend toward lower failure
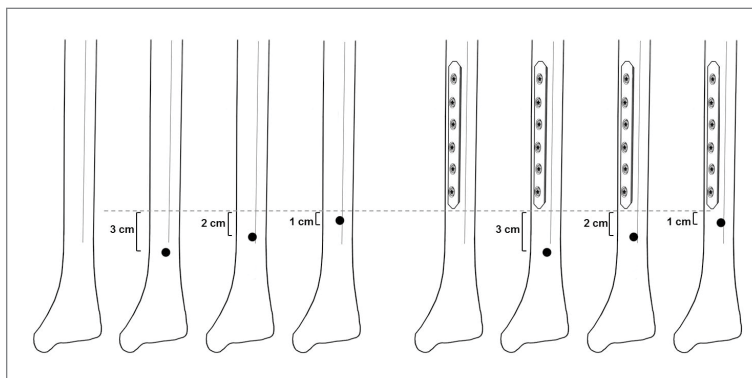

Figure 1. Study constructs (N = 8), which consist of a bicortical defect that varies in proximity to a compression plate placed on the lateral tibia. These constructs mimic the clinical situation of an external fixator pin site that remains after definitive fracture fixation by plating.
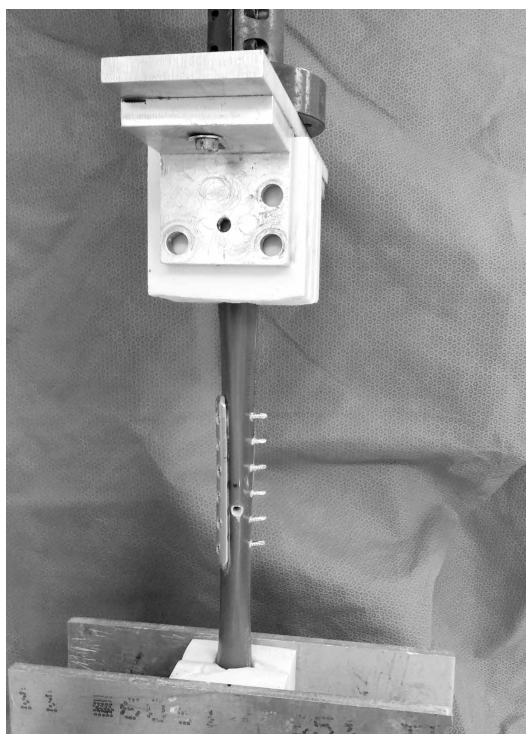

Figure 2. Biomechanical testing setup for torsional failure of composite tibia specimens.

load in unplated specimens as the defect moved proximally was seen between the unplated 3.0-cm defect group, 77.91 (6.08) Nm, and the unplated 1.0-cm defect group, 66.75 (1.84) Nm; this was also not significant (P = .07). Mode of failure for all specimens with bicortical defects, with or without a plate, was a spiral fracture that bisected the axis of the defect (**Figure 5**). Post hoc power analysis for each measure indicated statistical power of 80% for stiffness and 75% for failure torque.
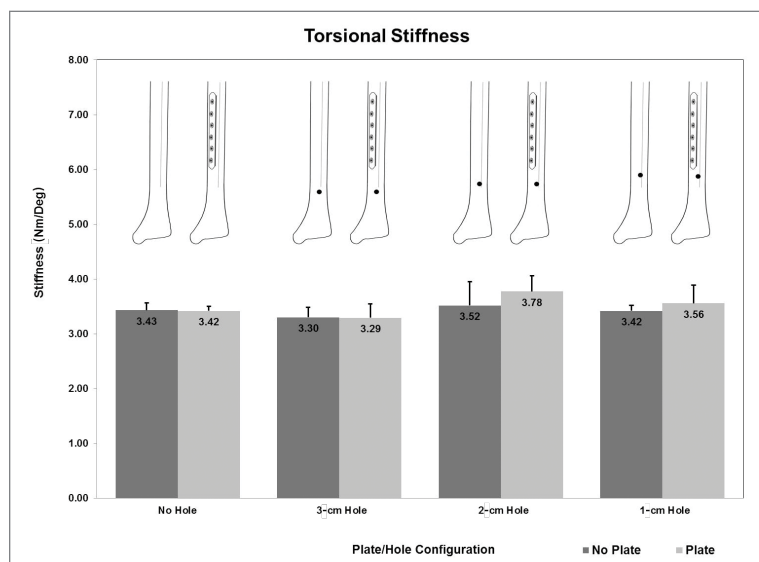
Figure 3. Mean torsional failure results for the 8 groups show no statistical difference in torsional stiffness between any of the groups, regardless of plating and defect location.
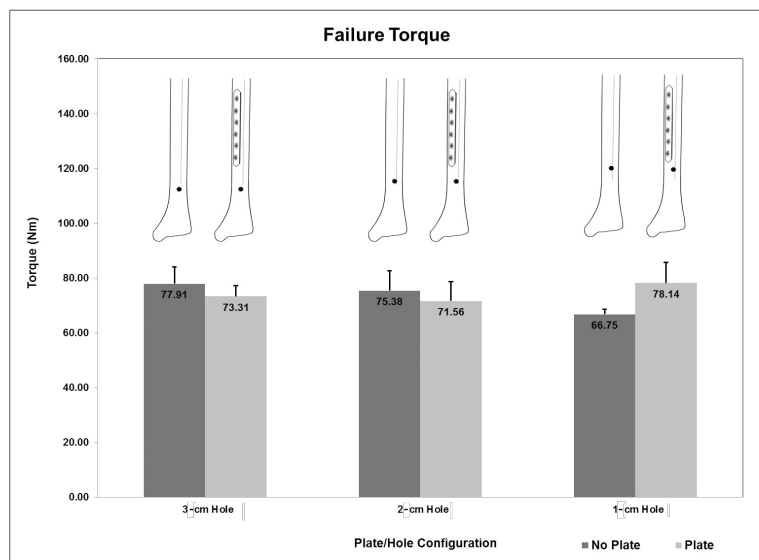

Figure 4. Mean torsional failure results for the 6 groups that failed show no difference in failure load (torque) between any of the groups, regardless of plating and defect location.

Discussion

Many tibia fractures require provisional stabilization with an external fixator that spans the knee, because of the high-energy nature of the injury or other, higher-priority polytrauma concerns. When the patient or injury is suitable for definitive fixation, the external fixator typically is removed in favor of internal fixation with a plate and screws. Depending on the nature and location of the fracture and the subsequent plate, the empty cortical pin-site defects, often lying at varying distances

from the distal end of the plate, can potentially serve as stress risers for fracture.[4]

Other studies have evaluated long-bone cortical defects biomechanically[1,2,4] and clinically,[5-7] and multiple studies have been conducted on the effects of plates on long-bone strength for fracture stabilization.[8-13] The present study evaluated the torsional strength of long bones in the presence of a bicortical defect and the proximity of the defect to a plate. There were no differences in stiffness or failure load between any of the groups of plated and unplated fourth-generation composite tibias tested to failure in torsion with varying distal bicortical defects. Hypothetically, one would expect the torsional stiffness of these specimens to increase with the mere addition of a metallic diaphyseal plate. However, this study demonstrated that the addition of a plate did not affect the torsional stiffness or strength of the tibias. Clinically, it is common practice to place external fixator pins as far as possible outside the planned incision site for definitive fracture fixation. Thus, we also hypothesized that the presence of a bicortical pin-site defect and its proximity to the plate would alter the torsional strength of the tibia specimens, and that the distal pin-site defect's location farthest from the plate would exhibit greater strength, but this did not occur. Although other studies have shown that the presence of bicortical defects decreases the strength of long bones, we were unable to quantify this decrease because the 2 intact groups of composites, plated and unplated, survived failure testing.

This study had several limitations, first being the use of composite tibias as opposed to human cadaver bone. Although fourth-generation composite bone models have been validated as a suitable and accurate biomechanical substitute for cadaver specimens,[14] anatomical variations in cadaver tibias may transfer forces differently through plates, screws, and distal pin sites. In order to test plated specimens against the unplated controls, we did not simulate a mid-shaft fracture in any of the tibias. The pin-site defects were intended to reflect the mechanical effects of bicortical defects immediately after pin removal and in the absence of any degree of bone healing. Finally, this study focused on pin-site defects that were distal to a midshaft plate and that may not represent the effects of bicortical pin-site defects proximal to the plate.

Given the results of this biomechanical study in composite tibias, varying the proximity of a bicortical defect to a plate does not affect the torsional

Figure 5. In all cases, spiral fracture mode of failure propagated through bicortical defect.

stiffness or torsional failure strength of the bone. Placement of an intended bicortical defect should be based on considerations other than the potential for creating a distal stress riser after definitive fracture management.

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This paper will be judged for the Resident Writer's Award.