Biomechanical Comparison of Bicortical Versus Unicortical Screw Placement of Proximal Tibia Locking Plates: A Cadaveric Model

Paul J. Dougherty, MD, Do-Gyoon Kim, PhD, Steve Meisterling, MD, Christopher Wybo, MS, and Yener Yeni, PhD

Objective: The purpose of this study was to compare the biomechanical properties of bicortical with unicortical screws in a proximal tibial fracture cadaveric model.

Setting: Biomechanics laboratory at a Level 1 trauma center.

Patients/Participants: Eight pairs (4 male and 4 female) of elderly (average age, 79 years; range, 63 to 104 years) cadaveric tibiae.

Intervention: Osteotomies were performed in the proximal tibia to reproduce a 41-C2 bicondylar fracture pattern. The 4.5-mm proximal tibial periarticular locking plates (Smith-Nephew, Memphis, TN) were applied to the tibiae with 4 proximal bicortical or unicortical locking screws and 3 screws distal to the fracture site. The fixed tibiae were tested by using a materials testing machine (Instron, Canton, MA) with the axial load on the medial condyle.

Outcome Measurements: The bicortical and unicortical constructs were compared for stiffness, yield load and displacement, and maximum load and displacement to failure.

Results: Bicortical screw placement significantly outperformed unicortical screw placement in stiffness (53.1 ± 6.7 N/mm versus 35.6 ± 7.2 N/mm, $P < 0.002$) and maximum load (476.5 ± 83.8 N versus 258.9 ± 62.1 N, $P < 0.001$) but the yield properties and the ultimate displacement were not significantly different.

Conclusion: Bicortical screw placement may provide a biomechanically superior construct than unicortical screw placement for the stabilization of unstable proximal tibia fractures.

Key Words: proximal tibia fractures, fracture biomechanics, locking plates

(*J Orthop Trauma* 2008;22:399–403)

Accepted for publication April 1, 2008.
From the Department of Orthopaedic Surgery, Henry Ford Hospital, Detroit, Michigan.
The authors state that they have no financial interest in the products mentioned within this article.
The devices used in this study have all been approved by the United States Food and Drug Administration.
Reprints: Paul J. Dougherty, MD, Department of Orthopaedic Surgery, K-12, Henry Ford Hospital, Detroit, MI 48202 (e-mail: pauldoug@med.umich.edu).

INTRODUCTION

Caring for patients with bicondylar proximal tibial fractures (OTA 41 C2) can be challenging.[1–17] Methods of treatment include external fixation, both with and without limited internal fixation,[5,8-10,16] and internal fixation.[1–4,6,7,10–17] Options for internal fixation include the use of bilateral buttress plates, a lateral buttress plate with a smaller posterior medial plate, or a lateral locking plate.

Application of 2 large fragment buttress plates, 1 medial and 1 lateral, has fallen into disfavor due to the high prevalence of soft tissue problems associated with this technique. Efforts to reduce the likelihood of these complications have prompted the development of locking plates, which decrease the need for a plate on the medial side of the tibia, as well as the use of smaller and lower profile plates that can be applied through smaller incisions.[1–4,6,10–17] These advances in equipment and fixation techniques require less soft tissue dissection of the fracture site for placement of the plate and allow better preservation of the biological envelope.

When locking plates were introduced, the manufacturer's recommendations specified that only unicortical screws should be used.[18] This recommendation enabled the manufacturer to reduce the number of screw sizes in inventory and allowed inclusion of a drill tip on the end of the screws to facilitate insertion. Although this initial recommendation simplified the packaging of the locking plates, the biomechanics in both the laboratory and clinical settings have not been well studied.[19–25] Specifically, neither the number of cortices requiring engagement on each fracture fragment nor superiority of bicortical or unicortical screws has been well defined.

Loss of reduction is reported with all methods of treatment. One study using strict criteria documented a 30% loss of reduction in the series and reported that patients aged 60 years and older had a failure rate of 79%.[10] Recently reported failure rates of locking plate fixation have ranged from 0 to 30%.[4,6,7,13–15,17]

To our knowledge, a biomechanical comparison of bicortical and unicortical locking screws of a proximal tibial fracture model has not been reported previously. The purpose of this study was to compare the biomechanical properties of bicortical with unicortical locking screw constructs in a proximal tibial fracture model using elderly cadaveric bone.

METHODS

Eight pairs of freshly frozen cadaveric tibiae (4 male and 4 female; average age, 79 years; range, 63 to 104 years) were obtained (International Biological, Grosse Point Farms, MI). The tibiae were stored in a freezer at −20°C. Before testing, the tibiae were thawed to room temperature over a 5-hour period, and radiographs were obtained to reveal any bone pathology. The experiments were performed at room temperature (25°C), and the specimens were kept wet during experimental procedures.

Fracture Simulation

Osteotomies were performed in the proximal tibiae to reproduce a 41-C2 bicondylar fracture pattern in the manner described by Horwitz et al.[25] Preparation of the model involved removal of a central triangle of bone from the proximal tibia to simulate an unstable fracture (Figure 1). A table band saw was used to obtain precise cuts. Beginning at the intracondylar spine, the lateral cortex was cut 4 cm from the lateral plateau. A second cut was made from the intracondylar spine to the medial proximal tibia to a point 6 cm from the medial plateau. A third cut connected the points on the medial and lateral proximal tibia. In addition, 1 cm of bone was removed from the medial side (Figure 1).

Construct

To minimize any variation between the right and left legs, each type of construct was alternated between the right and left tibiae. The 4.5-mm 6-hole proximal tibial periarticular locking plates (Smith-Nephew, Memphis, TN) were applied to the tibiae with 4 proximal locking screws (either bicortical or unicortical), and 3 bicortical screws were inserted distal to the fracture site. We varied only the proximal bicondylar screws; one group consisted of bicortical screws, and the other of unicortical screws. The unicortical screws were placed 5 mm short of the medial cortex. The placement of the screws was confirmed radiographically.

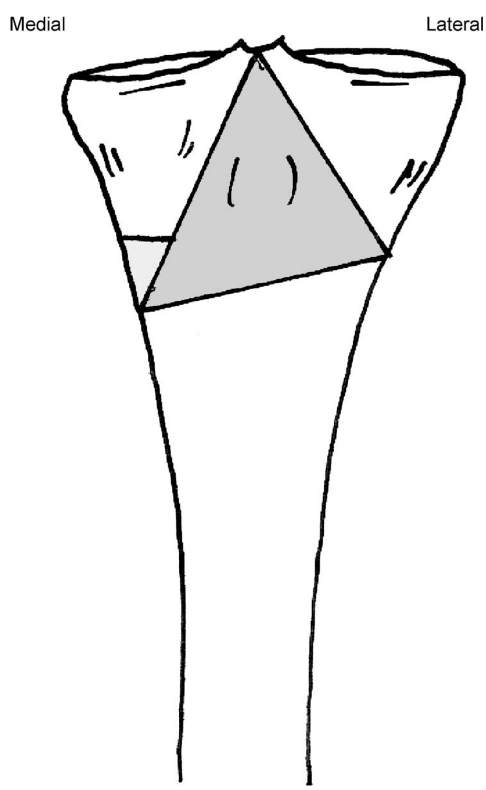

FIGURE 1. Osteotomy cuts performed on the tibia.

Testing

The tibiae were potted for use in the materials testing machine (Instron Model 8500, Canton, MA) (Figure 2). The proximal tibiae were adjusted and constrained in the pot by using 8 screws and were reinforced by filling the pot with a low melting-point Wood's metal. For each specimen, an axial load was applied to the medial tibia condyle through a femoral stem (32-mm femoral head) that was mounted on the testing machine to simulate a medial femoral condyle (Figure 2).[7,19,25] The condyle was compressed up to 20 mm at the displacement rate of 25 mm/min.[22]

Measurements

Stiffness was measured as the maximum slope of the load-displacement curve. Yield load and displacement were determined as those corresponding to the intersection of the load-displacement curve with the secant slope that is equal to 95% of the stiffness following ASTM standard (E399–83) (Figure 3).[26] Structural strength was measured as the maximum load reached before fracture. Displacement at maximum load was recorded as ultimate displacement.

In order to standardize selection of a linear region from which the maximum slope was calculated, the slope of the load-displacement curve was calculated on each point as the slope of a linear fit to the data within a selected displacement interval. The maximum of the slope versus displacement plot was recorded as the maximum slope for the size of displacement interval used in the procedure. Maximum slope was recalculated using displacement ranges varying between 0.33 mm and 2.7 mm. Maximum slopes calculated as described were plotted versus the size of the interval used. Maximum slope is initially sensitive to the size of the displacement interval used. However, the size of the interval eventually reaches a point after which further increases do not appreciably affect the calculation of the maximum slope. This interval, which corresponded to a displacement range of 2 mm in our experiment, was selected for calculation of stiffness for all constructs.

We also calculated an instantaneous stiffness for each construct at a load level of 80 N. Although stiffness values calculated by the 2 methods were different, statistical analyses of stiffness using either method reached identical conclusions for unicortical versus bicortical comparisons. Therefore, we report results from the first method only.

Statistical Analyses

Paired *t* tests were performed with one of stiffness, yield load, yield displacement, and maximum load as the outcome variable. All data passed normality test before the paired *t* test. SigmaStat 2.03 (SPSS, Chicago, IL) statistics package was used for analysis. $P \leq 0.05$ was considered statistically significant. Approval was obtained from the Institutional Review Board before the study was conducted.

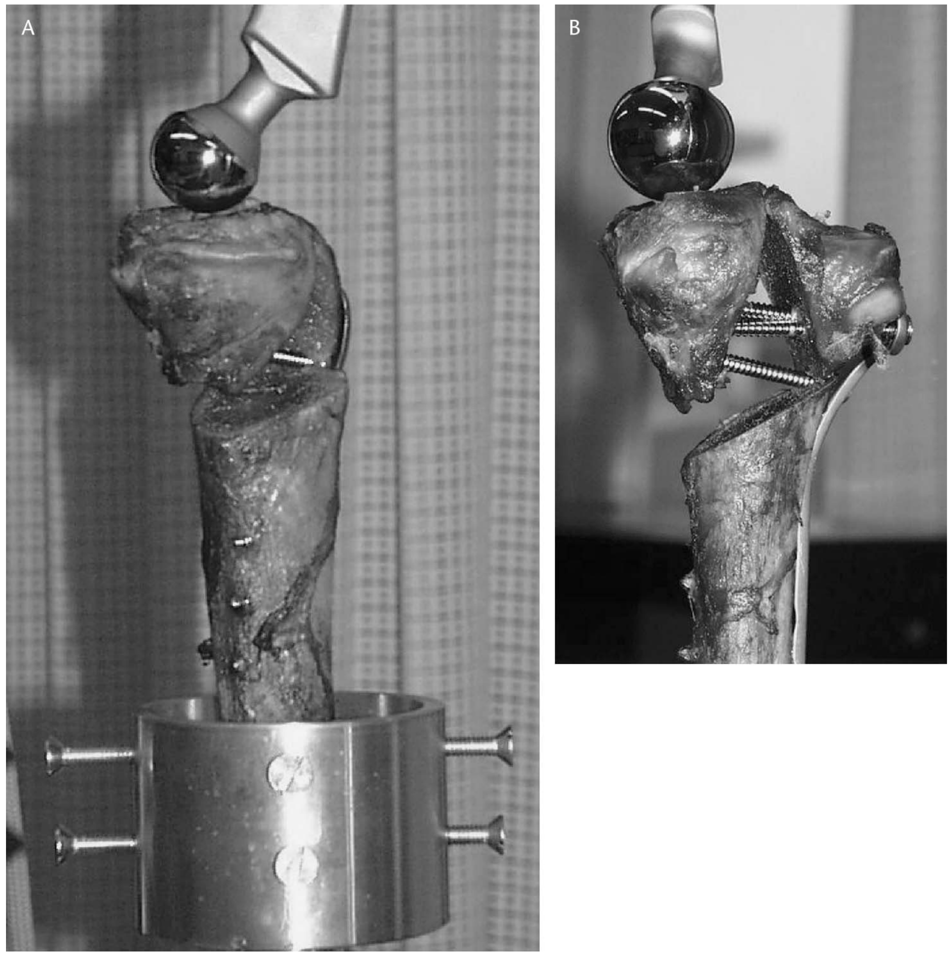

FIGURE 2. Specimen mounting on the materials testing machine: (A) front view and (B) side view.

RESULTS

All constructs failed under axial loading. Bicortical screw placement was significantly greater than unicortical in stiffness (53.1 ± 6.7 N/mm versus 35.6 ± 7.2 N/mm, $P < 0.002$), and maximum load (476.5 ± 83.8 N versus 258.9 ± 62.1 N, $P < 0.001$). Yield load, yield displacement, and ultimate displacement, however, were not significantly different between unicortical and bicortical screw placement (Table 1).

Visual inspection of failed constructs suggested that the main mechanism of failure was screw cut out through the cancellous bone. Consistent with this observation, the post-yield portion of the load-displacement curves was smoother for bicortical screw placement, whereas constructs with unicortical screw placement exhibited a larger plateau with phases of load increase and drop. Screw loosening did not occur with any of the constructs.

DISCUSSION

Loss of reduction for proximal tibia fractures continues to be a problem. Recent studies report the loss of fixation using locking plates from 0 to 30%,[4,6,7,13–15,17] although this may be underreported. In one study using careful radiographic criteria, Ali et al[10] evaluated failure of fixation for 42 patients with B and C type proximal tibial fractures. The authors used a variety of methods to treat the fractures: nonlocking plates and screws (31), cannulated screws only (6), and combined internal and

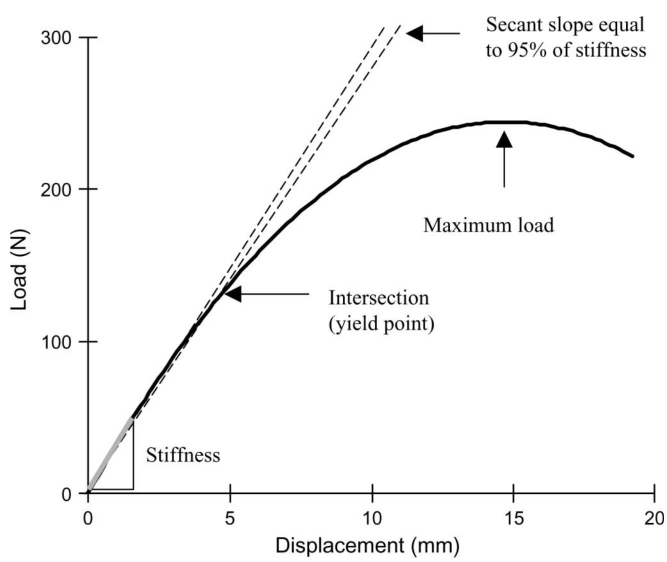

FIGURE 3. A typical load-displacement curve. The method to determine yield point and maximum load is described.

TABLE 1. Comparison of Mechanical Properties Between Unicortical and Bicortical Screw Placements

	Stiffness (N/mm)	Yield Load (N)	Yield Displacement (mm)	Maximum Load (N)	Ultimate Displacement (mm)
Unicortical	35.6 ± 7.2	171.3 ± 55.0	6.2 ± 2.4	258.9 ± 62.1	13.2 ± 4.0
Bicortical	53.1 ± 6.7	209.6 ± 51.4	4.4 ± 1.6	476.5 ± 83.8	16.8 ± 2.0
Uni/Bicortical percentage	67.0%	81.7%	140.9%	54.3%	78.6%
P value	<0.002	0.128	0.110	<0.001	0.060

external fixation (5). Of the 14 patients who were older than 60 years, 11 had failure of fixation, compared with 2 failures among patients who were younger than 60 years. The authors also found failure of fixation among all patients with marked osteoporosis. Though this study had a limited number of patients and a variety of fractures and treatments, it demonstrated that with careful observation, loss of reduction is more common than reported. Additonally, older patients with osteopenic bone are also at greater risk for loss of reduction. Loss of reduction can be for many reasons, including poor bone quality and the biomechanical limits of the implants. Because of this, it is desirable to prevent the loss of reduction by developing new techniques or implants.

We are unaware of another biomechanical study comparing periarticular bicortical to unicortical screws using a proximal tibia fracture model. This aspect may not have been previously studied because initial locking plate studies were done with the LISS plating system (Synthes, Paoli, PA) in which the manufacturer recommends unicortical screws.[18] Additionally, the LISS system screws are designed with a drill tip screw that may protrude or cause near cortex stripping if bicortical purchase with the locking screw is desired.

Comparison of the LISS sytem to more standard constructs has been previously reported. Mueller et al,[20] Egol et al,[7] and Gosling et al[19] compared the standard lateral LISS locking plate to a construct using a 4.5mm lateral plate with posteromedial plate of a 1/3 tubular plate,[19,20] a 3.5-mm reconstruction plate,[7] or a 3.5-mm dynamic compression plate.[20] All 3 studies showed comparable performance of the more conventional nonlocking plates to the LISS plating system.

More recently developed locking plate systems (Smith Nephew, Memphis, TN; Zimmer, Warsaw, IN) have a larger inventory of screw lengths than the initial LISS plating system (Synthes, Paoli, PA), which allows for more flexibility and bicortical screw placement, if necessary. At present, the literature is unclear regarding clinical recommendations for the best screw configuration for use with proximal tibial locking plates.[19–25] To our knowledge, biomechanical testing of the periarticular proximal screws using a system that is designed to use bicortical or unicortical screws has not been previously reported.

This study had several limitations. Although these results showed a difference in the biomechanical testing of the 2 constructs in cadaveric bone while using a materials testing machine, it is unclear whether this model can predict fracture site motion failure in vivo. A second limitation was that the cadaver bone was from elderly osteopenic patients (average age, 79 years), which is older than the average patient with proximal tibial fractures.[1–8,13–17] These data should be used cautiously when applied to younger patients. Given the variable properties of bone with aging, future studies should investigate younger bone as well.

Another limitation of the study was the difference in the length of the unicortical and bicortical screws. The unicortical screws were shorter and had less bone purchase, which rendered the construct less strong owing to a shorter lever arm. To minimize this potential effect, the investigators used screws measuring within 5 mm of the opposite cortex.

Finally, the number of cadaveric bone samples included in this study was small (n = 16 of 8 matched pairs in the 2 groups). However, these numbers are similar to those reported by Mueller et al (n = 24 with 3 arms), Horwitz et al (n = 9 with 3 arms), Gosling et al (n = 16 of 8 matched pairs, 2 arms), and Egol et al (n = 12 with 6 matched pairs, 2 arms). Differences in yield properties and ultimate displacement found to be nonsignificant between unicortical and bicortical screw placement may be statistically demonstrable with a larger sample size. For instance, a sample size analysis using the group means and standard deviations from this experiment indicated that a sample size of 12 per group would be necessary to demonstrate the difference in ultimate displacement at a significance level of $\alpha = 0.05$ and a power of 0.8.

The current study was designed to compare the use of bicortical or unicortical screws for the proximal fracture fragments of a bicondylar proximal tibial locking plate model. Within the limitations of the study, we conclude that for unstable proximal tibia fractures, bicortical screw placement may offer a mechanically superior construct than unicortical screw placement.

REFERENCES

1. Georgiadis GM. Combined anterior and posterior approaches for complex tibial plateau fractures. *J Bone Joint Surg Br*. 1994;76:285–289.
2. Barei DP, Nork SE, Mills WJ, et al. Functional outcomes of severe bicondylar tibial plateau fractures treated with dual incisions and medial and lateral plates. *J Bone Joint Surg Am*. 2006;88:1713–1721.
3. Barei DP, Nork SE, Mills WJ, et al. Complications associated with internal fixation of high-energy bicondylar tibial plateau fractures utilizing a two-incision technique. *J Ortho Trauma*. 2004;18:649–657.
4. Phisitkul P, McKinely TO, Nepola JV, et al. Complications of locking plate fixation in complex proximal tibia injuries. *J Orthop Trauma*. 2007;21:83–91.
5. Dendrinos GK, Kontos S, Katsenis D, et al. Treatment of high-energy tibial plateau fractures by the ilizarov circular fixator. *J Bone Joint Surg Br*. 1996;78:710–717.
6. Egol KA, Tejwani NC, Capla EL, et al. Staged management of high-energy proximal tibia fractures (OTA types 41): The results of a prospective, standardized, protocol. *J Orthop Trauma*. 2005;19:448–455.
7. Egol KA, Su E, Tejwani NC, et al. Treatment of complex tibial plateau fractures using the less invasive stabilization system plate. Clinical experience and laboratory comparison with double plates. *J Trauma* 2004; 57:340–346.
8. Marsh JL, Smith ST, Do TT. External fixation and limited internal fixation for complex fractures of the tibia plateau. *J Bone Joint Surg Am*. 1995; 775:661–673.

9. Watson JT. High-energy fractures of the tibial plateau. *Orthop Clin North Am*. 1994;25:723–752.
10. Ali AM, El-Shafie M, Willett KM. Failure of fixation of tibial plateau fractures. *J Ortho Trauma*. 2002;16:323–329.
11. Oh CW, Oh JK, Kyung HS, et al. Double plating of unstable proximal tibial fractures using minimally invasive percutaneous osteosynthesis technique. *Acta Ortho*. 2006;77:524–530.
12. Oh JK, Oh CW, Jeon IH, et al. Percutaneous plate stabilization of proximal tibial fractures. *J Trauma*. 2005;59:431–437.
13. Cole PA, Zlowodzki M, Kregor PJ. Treatment of proximal tibia fractures using the less invasive stabilization system: surgical experience and early clinical results in 77 fractures. *J Orthop Trauma*. 2004;18:528–535.
14. Ricci WM, Rudzki JR, Borrelli J Jr. Treatment of complex proximal tibia fractures with the less invasive stabilization system. *J Orthop Trauma*. 2004;18:521–527.
15. Stannard JP, Wilson TC, Volgas DA, et al. The less invasive stabilization system in the treatment of complex fractures of the tibial plateau: short term results. *J Orthop Trauma*. 2004;18:552–558.
16. Canadian Orthopaedic Trauma Society. Open reduction and internal fixation compared with circular fixator application for bicondylar tibial plateau fractures. Results of a multicenter, prospective, randomized clinical trial. *J Bone Joint Surg Am*. 2006;88:2613–2623.
17. Gosling T, Schandlemaier P, Muller M, et al. Single lateral locked screw plating of bicondylar tibial plateau fractures. *Clin Orthop Relat Res*. 2005; 439:207–214.
18. Synthes USA. Less Invasive Stabilization System (LISS) Technique Guide. Proximal Tibia. Paoli, PA: Synthes USA; 2000.
19. Gosling T, Schandelmaier P, Marti A, et al. Less invasive stabilization of complex tibial plateau fractures: a biomechanical evaluation of a unilateral locked screw plate and double plating. *J Orthop Trauma*. 2004;18: 546–551.
20. Mueller CA, Eingartner C, Schreitmueller E, et al. Primary stability of various forms of osteosynthesis in the treatment of fractures of the proximal tibia. *J Bone Joint Surg Br*. 2005;87:426–432.
21. Sommer C, Babst R, Muller K, et al. Locking compression plate loosening and plate breakage: a report of four cases. *J Ortho Trauma*. 2004;18: 571–577.
22. Peindl RD, Zura RD, Vincent A, et al. Unstable proximal extraarticular tibia fractures. *J Ortho Trauma*. 2004;18:540–545.
23. Egol KA, Kubiak EN, Fulkerson E, et al. Biomechanics of locked plates and screws. *J Ortho Trauma*. 2004;18:488–493.
24. Ali AM, Saleh M, Bolongaro S, et al. The strength of different fixation techniques for bicondylar tibial plateau fractures—a biomechanical study. *Clin Biomech (Bristol, Avon)*. 2003;18:864–870.
25. Horwitz DS, Bachus KN, Craig MA, et al. A biomechanical analysis of internal fixation of complex tibial plateau fractures. *J Ortho Trauma*. 1999;13:545–549.
26. American Society for Testing and Materials. E399–83 Standard test method for plane-strain fracture toughness of metallic materials. West Conschocken, PA: American Society for Testing and Materials; 1983.

