

Locked plate fixation of the comminuted distal fibula: a biomechanical study

Neil J. White, MD*
David T. Corr, PhD†
James P. Wagg, MD‡
Caeley Lorincz, MD, PhD§
Richard E. Buckley, MD¶

From *Orthopaedic Trauma, the Royal Infirmary of Edinburgh, Scotland, †Biomedical Engineering, the Rensselaer Polytechnic Institute, Troy, New York, ‡Orthopedic Surgery, the Saint John Regional Hospital, Saint John, NB, the §Kinesiology Research Centre, the University of Calgary, and the ¶Department of Surgery, Foothills Medical Centre, Calgary, Alta.

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Correspondence to:

N.J. White
Department of Orthopaedic Surgery
Foothills Medical Centre
1403-29 St. NW
Calgary AB T2N 2T9
neiljwhite@gmail.com

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Background: The purpose of this study was to compare the biomechanical properties of locked versus nonlocked lateral fibular bridge plating of comminuted, unstable ankle fractures in a mode of catastrophic failure.

Methods: We created comminuted Weber C fractures in 8 paired limbs from fresh cadavers. Fractures were plated with either standard or locked one-third tubular bridge plating techniques. Specimens were biomechanically evaluated by external rotation to failure while subjected to a compressive load approximating body weight. We measured the angle to failure, torque to failure, energy to failure and construct stiffness.

Results: There was no significant difference in construct stiffness or other biomechanical properties between locked and standard one-third tubular plating techniques.

Conclusion: We found no difference in biomechanical properties between locked and standard bridge plating of a comminuted Weber C fibular fracture in a model of catastrophic failure. It is likely that augmentation of fixation with K-wires or trans-tibial screws provides a construct superior to locked bridge plating alone. Further biomechanical and clinical analysis is required to improve understanding of the role of locked plating in ankle fractures and in osteoporotic bone.

Contexte : Cette étude avait pour but de comparer les propriétés biomécaniques d'une plaque péronière latérale verrouillée ou non verrouillée dans des fractures de chevilles comminutives instables, en présence d'une défaillance catastrophique.

Méthodes : Nous avons infligé des fractures comminutives de Weber de type C à 8 paires de membres de cadavres frais. Les fractures ont été corrigées au moyen de plaques tubulaires d'un tiers standard ou fixes. Les spécimens ont été évalués au plan biomécanique par rotation externe jusqu'à défaillance, tout en étant soumis à une charge compressive correspondant environ au poids corporel. Nous avons mesuré l'angle, le moment de torsion et l'énergie au point de défaillance et la rigidité de la structure.

Résultats : Nous n'avons noté aucune différence significative sur le plan de la rigidité de la structure ou des autres propriétés biomécaniques entre les plaques tubulaires d'un tiers fixes et standard.

Conclusion : Nous n'avons trouvé aucune différence sur le plan des propriétés biomécaniques entre les plaques standard et fixes sur des fractures péronières comminutives de Weber de type C dans un modèle de défaillance catastrophique. Il est probable qu'une fixation accrue au moyen de broches en K ou de vis trans-tibiales procure une meilleure structure que les plaques fixes seulement. Il faudra effectuer d'autres analyses biomécaniques et cliniques pour mieux comprendre le rôle des plaques fixes dans les fractures de la cheville et dans l'os ostéoporotique.

Ankle fractures are among the most common injuries treated by orthopedic surgeons.^{1,2} It has been established that anatomic reduction, including length and alignment of the fibula, in displaced ankle fractures is essential for best possible outcomes.³⁻¹² One-third tubular plates, dynamic compression plates (LCDCP) and locking plates have been used. Absolute stability with interfragmentary screw fixation is the gold standard when technically possible.^{3,4,13} When fractures are comminuted or associated with high-energy tibia fractures, many authors advocate the use of LCDCP to gain added construct stiffness.¹⁴⁻¹⁶

To our knowledge, there is no evidence in the literature to direct plate selection when using bridge plate fixation in comminuted fibular fractures. When fibular fractures occur in osteoporotic bone, augmentation with intramedullary K-wires or screws through the tibia have been advocated.^{17,18} More recently, locking plates have been used in many areas of the body, often for comminuted fractures, short metaphyseal segments and osteoporotic fractures.¹⁹⁻²³

The LCDCP has been shown to add stiffness to a fracture construct compared with one-third tubular plating.^{16,24} The disadvantage is a bulkier plate in a directly subcutaneous location that causes more frequent hardware irritation and results in subsequent removal.^{11,25} One-third tubular locked bridge plating offers a low profile construct while potentially providing greater stiffness than standard one-third tubular plating.

The present study was designed to compare 2 types of bridge plate fixation of a comminuted fibular fracture. Paired laboratory-recreated comminuted fibular fractures (Weber C, Lauge-Hansen pronation-external rotation, AO/ASIF 44C2.1) were plated using either locked or standard one-third tubular bridge plating techniques. They were loaded to catastrophic failure to assess biomechanical properties, with the primary outcome being construct stiffness.

METHODS

The protocol for biomechanical testing was drawn from several previous studies,^{7,16,17,26} as well as our own extensive pilot studies in cadaveric limbs ($n = 12$). Sixteen paired fresh cadaver limbs were harvested at the tibial tubercle for this study. We obtained radiographs to rule out any gross bony abnormalities. Dual-energy radiograph absorptiometry (Discovery A S/N 81289; Hologic) scanning of 12 of the 16 specimens was performed. (All 16 specimens were scanned; however, for 4 of the specimens the data became corrupted and thus irretrievable.) The entire specimen was scanned, and we documented bone mineral density (BMD) for 3 regions of interest: the entire specimen, the calcaneus and the distal tibia.

The proximal 10 cm of the tibia and fibula were skeletonized, preserving the interosseous membrane. A lateral approach to the fibula was performed. We used an oscillating saw to create a transverse fracture 3 cm above the ankle joint, and we removed 2 mm of bone (plus 2 saw widths) to recreate comminution at the fracture. The anterior-inferior syndesmotic ligaments were transected. We made a medial transverse incision inferior to the medial malleolus. Through this incision, we completely transected deep and superficial deltoid ligaments. This model was chosen to recreate the situation in which bridge plating would normally occur. The 2 mm gap to recreate comminution was chosen based on previous models.^{16,17}

We randomly assigned the paired limbs to standard or locked one-third tubular plating by coin toss (heads = left,

locked). Five-hole locked or nonlocked plates were used with 2 bicortical cortex screw points of fixation above and below the fracture. We threaded all locked screws exactly perpendicular to the plate to ensure that a true locked technique was used. Locked screws used self-tapping threads. For standard screws, a standard 3.5 mm tap was used (Fig. 1). The medial skin incision was closed with heavy stitch, leaving the superficial and deep deltoid completely transected to represent a closed injury.

We then potted the limbs in custom-designed aluminum pots, maintaining proximal syndesmotic distance. The proximal end of each specimen was secured within the pot using 2 transcortical cross-pins to provide rotational stability. The pot was then packed with polymethylmethacrylate (PMMA) bone cement to secure the bones within in the pot and provide axial and torsional fixation.

Once the PMMA was fully cured, the proximal end of each specimen was directly mounted vertically to the actuator of a servohydraulic materials testing machine (MTS MiniBionix, MTS Corp.) for biomechanical evaluation (Fig. 2). We tested each specimen using a custom-designed protocol simulating pronation and external rotation of the ankle to failure while under a compressive load approximating body weight. Briefly, the specimen was lowered until the plantar aspect of the foot contacted the load plate of the testing machine and rested in a plantigrade position with 5° of pronation. Under a 50-N compressive preload, the foot position was secured medially and laterally on to the load plate with rectangular positioning bars. A 700-N axial compressive force was developed over 5 seconds and maintained for the duration of the test in force control. Dorsal stabilization of the foot was not required owing to this compressive load. With the limb under axial compression (similar to body weight), we internally rotated the proximal tibia at a constant rate (20°/s), thereby creating an external rotation of the ankle. Axial force, axial displacement, angular displacement (rotation), torque and time data were simultaneously recorded at 100 Hz and stored in a personal computer. We defined failure as the first point at which the specimen exhibited a reduction in torque with an increase in rotation angle.

Biomechanical quantities of interest were the failure properties (torque to failure, rotation to failure and energy to failure) and construct stiffness. The area under the torque-angle curve was determined using trapezoidal integration of the torque-angle curve from initial rotation to failure. This represents the amount of energy that must be delivered to the specimen to cause failure. Construct stiffness was determined as the slope of the torque-angle curve in the linear portion of the response before failure. Construct stiffness was the primary outcome measure. All specimens were inspected and photographed at completion of testing. Detailed notes were recorded on method of failure.

Statistical analyses of the biomechanical properties were performed using Student paired t tests.

RESULTS

Sixteen paired limbs from 4 female and 4 male cadavers were tested. The average age at time of death was 82 (range 61–94) years. All specimens were from cadavers of white race.

No significant differences ($p > 0.05$) were observed between the 2 constructs. Biomechanical parameters were remarkably similar. Mean construct stiffness was 649 Nm/° for the locked group and 611 Nm/° in the standard group, with nearly complete overlap of 95% confidence intervals (locked 426–873 Nm/°, unlocked 398–825 Nm/°). There were no significant differences between the groups in torque to failure, rotation to failure or energy to failure (Table 1). A post hoc power analysis revealed the power of this study to be 0.53. Using these data, 112 paired specimens (56 matched pairs) would be required to create a power of 0.80.

All constructs failed with fracture or screw loosening distal to the osteotomy (fracture gap). No plates actually failed; this finding is consistent with those of other similar studies.^{17,27} One pair of specimens in each group failed bilaterally with transverse fractures distal to the plate. All of the remaining 7 pairs ($n = 14$) failed with a coronal oriented fracture propagating from the fracture gap distally through the screw holes and then out the anterior cortex of the fibula. Within each

pair, both locked and unlocked specimens consistently failed in the same mode (Fig. 3). All plates had a characteristic convex and external rotation deformity.

A significant difference was seen between male and female specimens in construct stiffness ($p < 0.001$). Bone mineral density positively correlated with stiffness ($n = 12$), independent of construct (Pearson coefficient = 0.48). This suggests that increasing BMD is a predictor of greater construct stiffness, independent of the fixation method used. We observed a significant difference in between male and female specimens in bone density ($p = 0.024$). The variables of sex and bone density were not independent predictors of construct stiffness.

DISCUSSION

Locked plates have become a standard implant for osteoporotic or short end segment fractures of the proximal humerus, distal radius, distal femur and proximal and distal tibia.^{19–23} Their benefit and specific indications throughout the body have not yet been well established. Our hypothesis was that lateral locked plates could provide better mechanical stability than standard lateral plating of the fibula. If this were the case, then locked plates could be used in

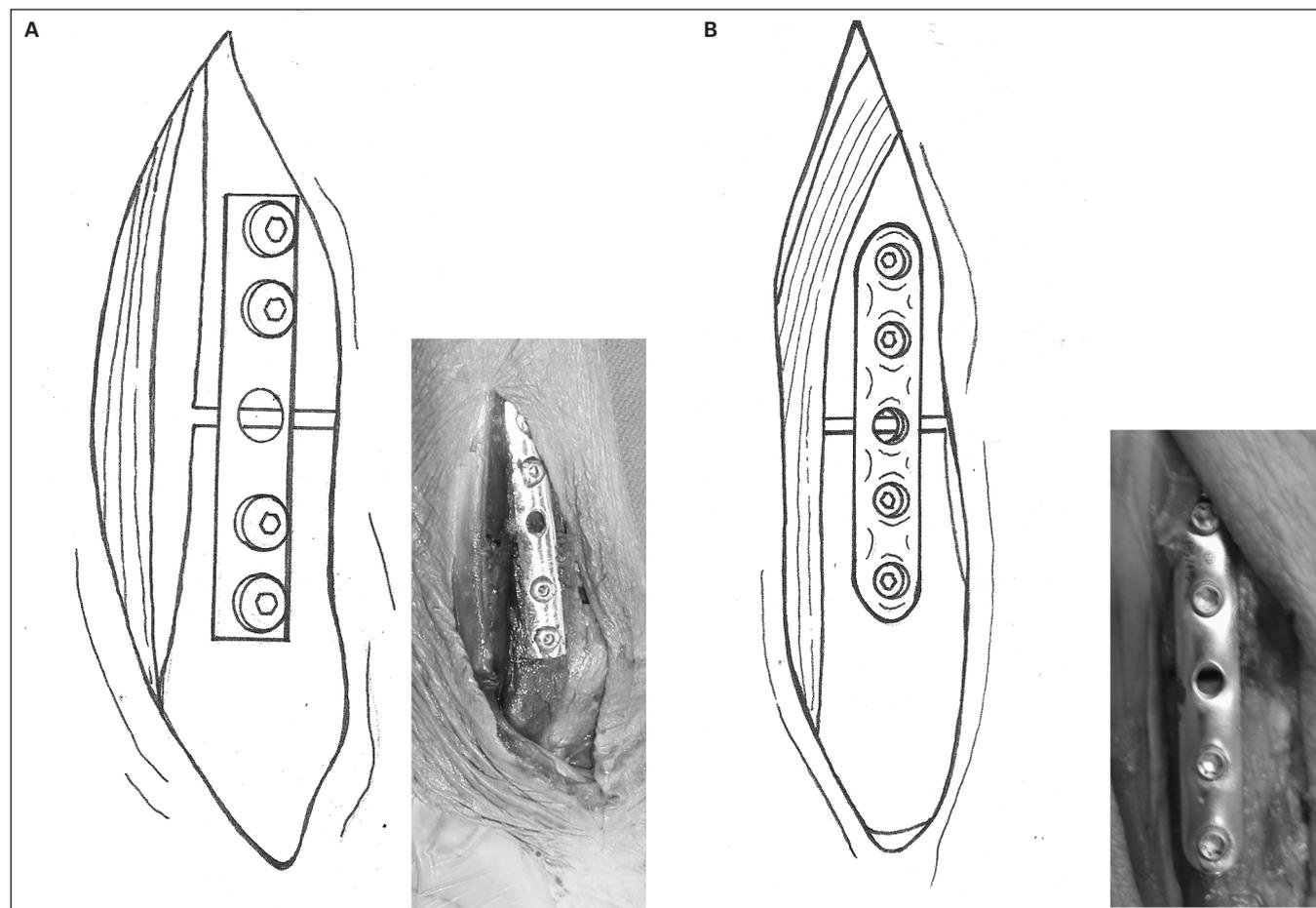


Fig. 1. (A) Standard plate specimen displaying construct and fracture gap. (B) Locked plate specimen displaying construct and fracture gap.

osteoporotic bone and in comminuted short end segment fractures to improve construct stability while remaining low-profile. We did not observe any difference in construct stiffness, torque to failure, energy to failure or angle to failure between these 2 constructs. The biomechanical properties were remarkably similar between the 2 groups.

Evidence to date does not support the use of locked plating in the distal fibula. Minihane and colleagues,²⁷ using a biomechanical model similar to ours, reported that posterolateral antiglide plating provides a stiffer construct than lateral locked plating. Kim and colleagues²⁸ have shown lateral locked plating with 2 distal unicortical screws to be equivalent to standard plating with 3 distal unicortical screws. In the present study, we compared 2 types of fixation. The only side-to-side difference was the use of locked screws, and no differences were observed in any of the biomechanical properties measured.

Locked plating has many potential benefits, including increased stiffness of the construct, while remaining low-profile, especially in the osteoporotic bone where “added” stiffness is felt to be necessary. The difficulty lies in achieving adequate distal fixation in the short end segment of the distal fibula. In the humerus and distal radius, the local anatomy allows for multiple multidirectional metaphyseal locked screws, as the bones flare at their articulations. This does not occur in the relatively narrow distal fibula, and at

the time of this study, protocol plating systems allowed for only a single screw at each axial level. Subsequently, newer precontoured anatomic plates (standard and locking) have become available for the distal fibula. These plates allow for multiple smaller screws at each axial level distally. Conceptually, this makes sense, but to our knowledge, there is no published literature to support the use of these plates.

Koval and colleagues,¹⁷ and others have reported on supplementary fixation with K-wires in osteoporotic bone and have actually shown significant biomechanical differences. Dunn and colleagues¹⁸ recently described the use of screws through the tibia to augment fibular fixation. It is our opinion that when faced with a difficult, comminuted fibular fracture (especially in osteoporotic bone), the surgeon

Table 1. Biomechanical properties of locked versus unlocked construct

Biomechanical parameter	Construct, mean (SD)		p value
	Locked	Unlocked	
Stiffness, Nm/°	649.4	267.4	0.32
Energy to failure, J	7 945.3	7 619.2	0.76
Torque to failure, Mm	20 471.3	14 141.8	0.83
Angle to failure, °	43.9	15.2	0.81

SD = standard deviation.

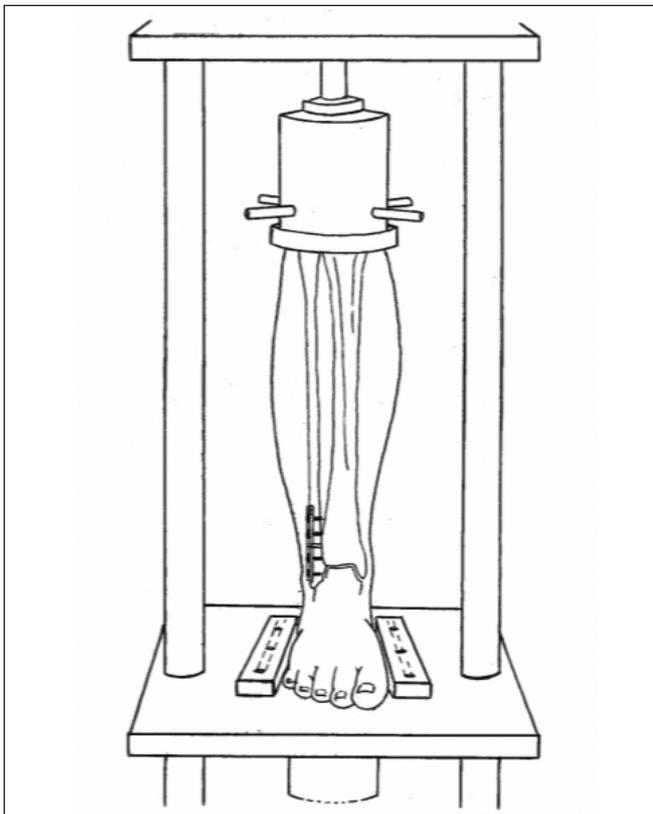


Fig. 2. Potted specimen mounted on servohydraulic materials testing machine with foot blocked in 5° of pronation to allow for controlled external rotation.

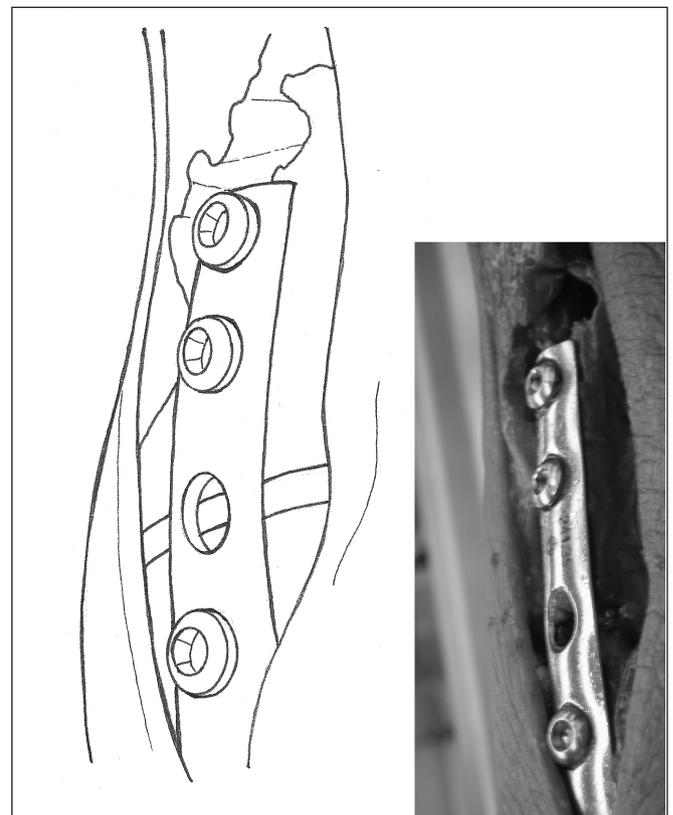


Fig. 3. Standard plate specimen displaying characteristic failure pattern through distal screw holes at bone screw interface (right = distal fibula). This pattern failure was observed in 14 of the 16 specimens.

should not be overconfident in the use of a locked plate technique. The use of locked plates should not supplant the use of more traditional techniques of increasing construct stiffness, such as K-wires, intramedullary Steinman pins or trans-tibial screws.

Theoretically, the locked construct should have a greater benefit as bone becomes more osteoporotic. We observed an opposite trend: as bone became “stronger,” we noted a widening difference in construct stiffness. This correlation was weak and does not make sense. As such, it was not reported in this study. Note the large difference in absolute bone density of the specimens ranging from less than 0.4 g/cm² to more than 1 g/cm². This observation is likely to explain the wide confidence intervals seen in biomechanical properties (Table 1). In the context of wide confidence intervals and a small sample size, this trend is not significant. It is, however, an important observation and a potential direction for future research. Moving forward, it will be key to understand the benefit of locked plating in bones with different densities.

Several different biomechanical models have been used to study ankle fracture fixation. The present design relied heavily on previous literature. A 2 mm fracture gap was used to generate the “worst case scenario” where bridge plating (with or without augmentation) would be the only reasonable technique to provide stability.^{17,18} A four cortices construct on either side of the fracture was chosen to ensure matched fixation and to simplify the model. The four cortices construct was the most common in other similar models.^{27,28} We chose a model of catastrophic failure to create reproducible results. Pronation–external rotation was used to cause failure based on the presumption that the construct would be weakest by recreating the fracture mechanism.

Limitations

The present study has some limitations. Catastrophic failure from pronation and external rotation was tested, yet in vitro plates most often fail from unpredictable catastrophic loading or from micromotion. As such, further investigation is required to better understand fatigue properties and alternate modes of failure. A comment on the overall strength of the construct cannot be inferred from this study alone. Our study is also limited by a relatively small sample size and by our inability to acquire BMD for all 16 limbs tested. However, the consistency in failure modes and marked similarity between biomechanical properties of the 2 constructs in combination with no conflicting literature published to date suggests minimal added benefit from locked lateral bridge plating of the distal fibula.

CONCLUSION

We were unable to show a difference in biomechanical properties between locked and standard bridge plating of a

comminuted Weber C fibular fracture when testing was done using a model of catastrophic failure in pronation–external rotation. Based on this study and others, it is likely that augmentation of fixation with K-wires, pins or trans-tibial screws provides a superior construct to locked bridge plating alone. Further biomechanical and clinical analysis is required to better understand the role of locked plating in ankle fractures and in osteoporotic bone.

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Competing interests: None declared.

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