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Dual Nonlocked Plating as an Alternative to Locked Plating for Comminuted Distal Fibula Fractures: A Biomechanical Comparison Study

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ABSTRACT

The purpose of this cadaveric study was to compare the biomechanical properties of dual nonlocked plating and single-locked plating using matched pairs of isolated fibula specimens. Fractures were simulated in 10 matched pairs of isolated cadaveric fibulae and plated with a single lateral locking plate for right-sided specimens, or with a one-third tubular plate and a 7-hole 2.4-mm minifragment adaption plate for left-sided specimens. An external rotation torque was applied at a rate of 1°/second, and torque at 10° was measured. Each fibula specimen was evaluated using a micro computed tomography scanner, and bone mineral density was calculated as milligrams of bone per cubic centimeter of volume. Dual nonlocked plating and locked plating specimens demonstrated torque measurements that were not significantly different at 10° of external rotation (1.48 N·m and 1.92 N·m, respectively; $p = .093$). The stiffness of the dual nonlocked plated and locked plating constructs were not significantly different ($p = .228$ and $p = .543$, respectively). The effect of bone mineral density on maximum torque at failure was not a reliable predictor of maximum torque in either the dual nonlocked plating or locked plating specimens ($R^2 = 0.548$ and $R^2 = 0.096$, respectively). We found no differences in torque at 10° of external rotation or stiffness between locking plate and dual nonlocking plate fixation constructs. This study provides evidence that dual nonlocked plating likely constitutes adequate fixation in situations in which a locking plate is being considered for comminuted distal fibula fractures.

Rotational ankle fractures are extremely common injuries, and if the fracture is unstable, open reduction-internal fixation is necessary to restore normal ankle joint stability and to prevent accelerated joint degeneration (1). Lateral malleolus fractures are associated with pronation-abduction and supination-external rotation type injuries, and are frequently comminuted (2). Although the injury patterns with rotation ankle injuries are predictable, the optimal treatment strategy remains controversial (3). There is still debate regarding whether locked plating is biomechanically superior to nonlocked plating in these fractures, and whether this proposed biomechanical superiority confers any clinical advantage (4–7). Posterior buttress plating has been shown to be superior to lateral neutralization plating in multiple biomechanical studies, although peroneal tendon irritation can occur with posterior plating (3,8,9). Alternatively, dual nonlocked plating with 1 plate posterolaterally as a buttress and 1 plate laterally to augment the fixation in poor-quality bone has been evaluated in a single case series, with 100% union at 14 weeks (10); however, the use of dual nonlocked plating has not been compared with single-locked plating, biomechanically or clinically. The purpose of this cadaveric study was to determine whether dual nonlocked plating has significantly different biomechanical properties to single-locked plating, using matched pairs of isolated fibula specimens. We hypothesized that there would be no clinically significant difference between the 2 constructs.

Materials and Methods

Inclusion and Exclusion Criteria for Cadaver Specimens

Matched pairs of distal fibulae were used for comparison of fixation methods to minimize potential differences between bone quality and anatomy. Distal fibulae were obtained from 10 fresh-frozen cadavers in which bilateral distal fibulae were present (see Table 1 for demographic data). Age range was 55 to 83 years (median 65.5), and all were Caucasian or African American. Specimens were obtained from the Anatomic Gifts

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Table 1
Demographic data for cadaver fibulae matched pairs

Specimen no.	Age (y)	Sex
1	71	Female
2	73	Male
3	60	Female
4	55	Male
5	58	Female
6	83	Female
7	59	Male
8	57	Female
9	73	Female
10	72	Male

Registry (Hanover, MD). Specimens with ankle hardware in place from previous surgery were excluded from this study. The use of isolated distal fibula bone for biomechanical testing was not unprecedented, and simplifies the model by allowing all force to be transmitted directly through the construct to test the area of interest (11).

Harvesting Distal Fibulae Specimens

The distal 15 cm of each fibula was isolated by removing all soft-tissue attachments using a standard oscillating saw for the bony cut. The specimens were labeled and stored in a freezer at −20°C. Twelve hours before fracture simulating and plating, the distal fibula specimens were thawed to room temperature to best approximate physiologic biomechanical properties of the bone.

Simulation of Fracture

Comminuted fractures were simulated in the 10 matched pairs of isolated cadaveric fibulae using a standard oscillating saw at a 30° inclination from anteroinferior to posterosuperior, as is seen with supination-external rotation type ankle fractures, located 4.0 cm proximal to distal tip of each fibula. A 2-mm gap remained after fixation of each specimen to ensure that the fixation across the osteotomy, and not the native bone, was being tested in the biomechanical study.

Plate Fixation of Osteotomized Specimens

All plates and screws were stainless steel (Depuy-Synthes, West Chester, PA) to prevent comparison of dissimilar metals. Within each pair, the right fibula was plated with a 4-hole 2.7-mm distal fibula lateral locking plate, using three 3.5-mm cortical screws proximally and four 2.7-mm locking screws distally (Fig. 1*A*). The left fibula of each pair was plated with the combination of a 7-hole one third tubular plate with three 3.5-mm cortical screws proximally and two 4.0-mm cancellous screws distally, and a 7-hole 2.4-mm minifragment adaption plate with two 2.4-mm cortical screws proximally and three 2.4-mm cortical screws distally (Fig. 1*B*). In both constructs, all screws proximal to the osteotomy had bicortical purchase, whereas the screws distal to the osteotomy had unicortical purchase to simulate prevention of talofibular joint penetration. All screws were inserted by hand. No lag screws or screws outside of the plates were used, because the purpose of the study was to compare the properties of the 2 different plating constructs in a model simulating fracture comminution.

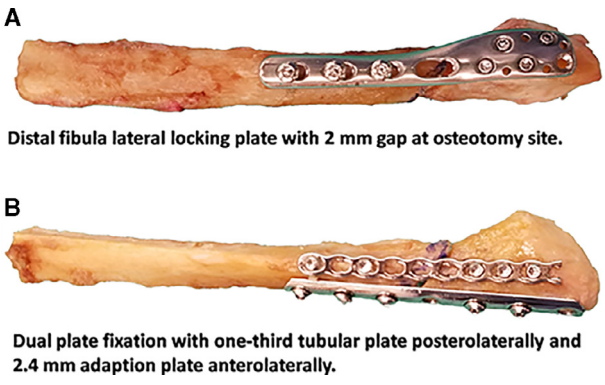

Fig. 1. (*A*) Osteotomy and locked plating (*B*) and dual nonlocked plating of fibula specimens.

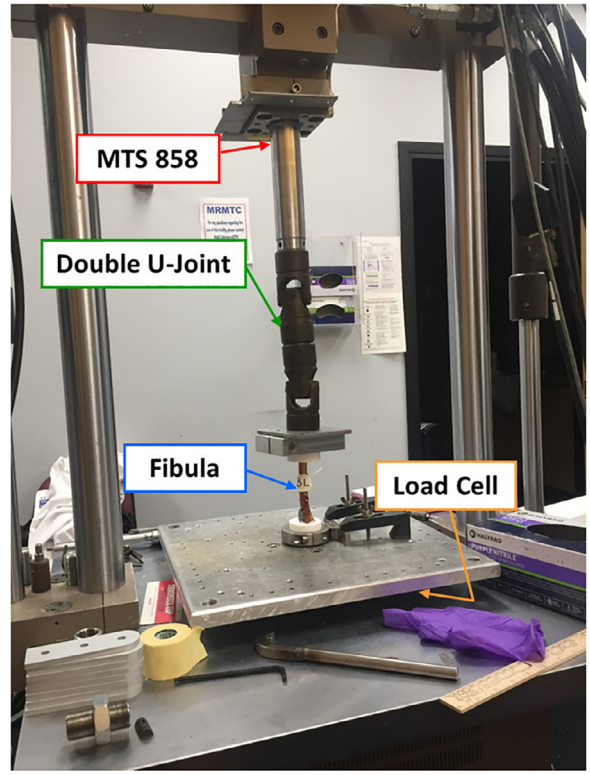

Fig. 2. MTS 858 machine testing setup.

Potting of Specimens

Plated distal fibula specimens were each potted in Smooth-Cast® 300 (Smooth-On Inc., Macungie, PA) liquid plastic ultra-low viscosity resin in preparation for rotational testing. Screws were secured to the ends of each fibula to allow for purchase of the potting material. Clay was used to completely cover the plates to prevent the potting material to add additional fixation between the plate and bone. The release agent, Universal Mold Release (Smooth-on Inc.), was sprayed into custom potting molds with a 2-in. diameter and a 1.5-in. height. The fibulae were suspended above custom molds, and the liquid plastic was mixed and poured into the molds. The potted specimens were removed from the molds after 10 minutes to allow the material to cure fully. Each fibula was then flipped and the process was repeated on the other end.

Torsional Testing Methods

After pilot testing to optimize potting conditions, all biomechanical testing was carried out in a single session on the MTS 858 biaxial testing machine (MTS Systems Corporation, Eden Prairie, MN) to minimize variations in testing conditions between samples. The distal end of the potted fibula was secured to the base of the testing machine using custom clamps and fixtures (Fig. 2). Once secured, the loads were zeroed to compensate for gravity. The proximal end was then secured to the machine with a double U-joint in line to allow for misalignments in potting and to ensure all torques applied were about the axis normal to the base (i.e., about the long axis of the fibula). Loads were measured using the load cell mounted on the base. Once secured to the machine, the machine was programmed to maintain 0 axial load. Depending on whether the sample was a right or left fibula specimen, the machine would rotate in the positive or negative direction at a rate of 1°/second to generate an external rotation torque using a rotary actuator attached to the proximal fracture fragment. Angular displacement and torque were measured and collected at 100 Hz. Throughout the testing, 0 axial loads were maintained.

Analysis

Data were low-pass filtered at 3.5 Hz. For each sample, the external rotation torque at 10° was measured (N•m). Initial torsional stiffness was calculated as the change in torque over the change in rotational displacement between 0.25 and 0.5 N•m of torque. Failure of the construct was defined as additional bone fracture or screw pull-out, whichever occurred first.

Micro Computed Tomography Testing for Bone Mineral Density Determination

Each fibula specimen was evaluated using a micro computed tomography scanner for determination of bone mineral density (BMD) according to standard protocols. BMD was calculated as milligrams of bone per cubic centimeter of volume (mg/cc).

Statistics

Ten matched pairs were required for a power of 1− ß = 0.8 at a significance level of $\alpha = 0.05$. Paired *t* tests were used to compare dual- versus single-plating constructs, and the outcome variables included torsional stiffness and instantaneous torque measured at 10° of external rotation. The effect of BMD on torsional load at failure was determined using linear regression analysis.

Results

The biomechanical outcomes of interest are summarized in Table 2. Dual nonlocked plated and locked plating specimens demonstrated no significant difference in torque measurements at 10° of external rotation (1.48 N·m and 1.92 N·m, respectively; $p = .093$). The stiffness of the dual nonlocked plating and locked plating constructs were calculated from 0.25 tp 0.5 N·m and from 0.5 to 1.0 N·m, and were not significantly different in either region of the curve ($p = .228$ and $p = .543$, respectively; Fig. 3). BMD was not significantly correlated with on maximum torque in either the dual nonlocked plating or locked plating specimens by linear regression analysis ($R^2 = 0.548$ and $R^2 = 0.096$, respectively; Fig. 4 and Table 2).

Of note, most specimens failed by fracturing through a proximal screw hole, which indicates that the weakest part of the constructs in both types of plate fixation is not the osteotomy site but rather the proximal screw holes. In only 3 specimens (2 dual nonlocked plating specimens and 1 locked plating specimen), the failure occurred through distal screw pull-out.

Table 2
Summary of biomechanical outcome variables with significance levels (N = 10 matched pairs)

Parameter	Dual Plating	Locked Plating	*p* Value
Stiffness (N•m/°) at 0.25–0.5 Nm	0.16	0.20	.228
Stiffness (N•m/°) at 0.5–1 Nm	0.18	0.20	.543
Torque (N•m) at 10°	1.48	1.92	.093

Discussion

Dual plating of distal fibula fractures has been proposed as an alternative fixation method to locked plating when bone quality is poor, especially in situations when soft-tissue closure over a bulky locking plate is difficult, or in a thin patient in which a bulky subcutaneous plate is undesirable (12); however, no biomechanical study comparing locking plates to dual nonlocked plating has been published. We compared the torsional stiffness of matched pairs of fibulae that were osteotomized to simulate a comminuted fracture and plated with either a locking plate construct or dual nonlocking plates, and found no differences in stiffness or torque at 10° of

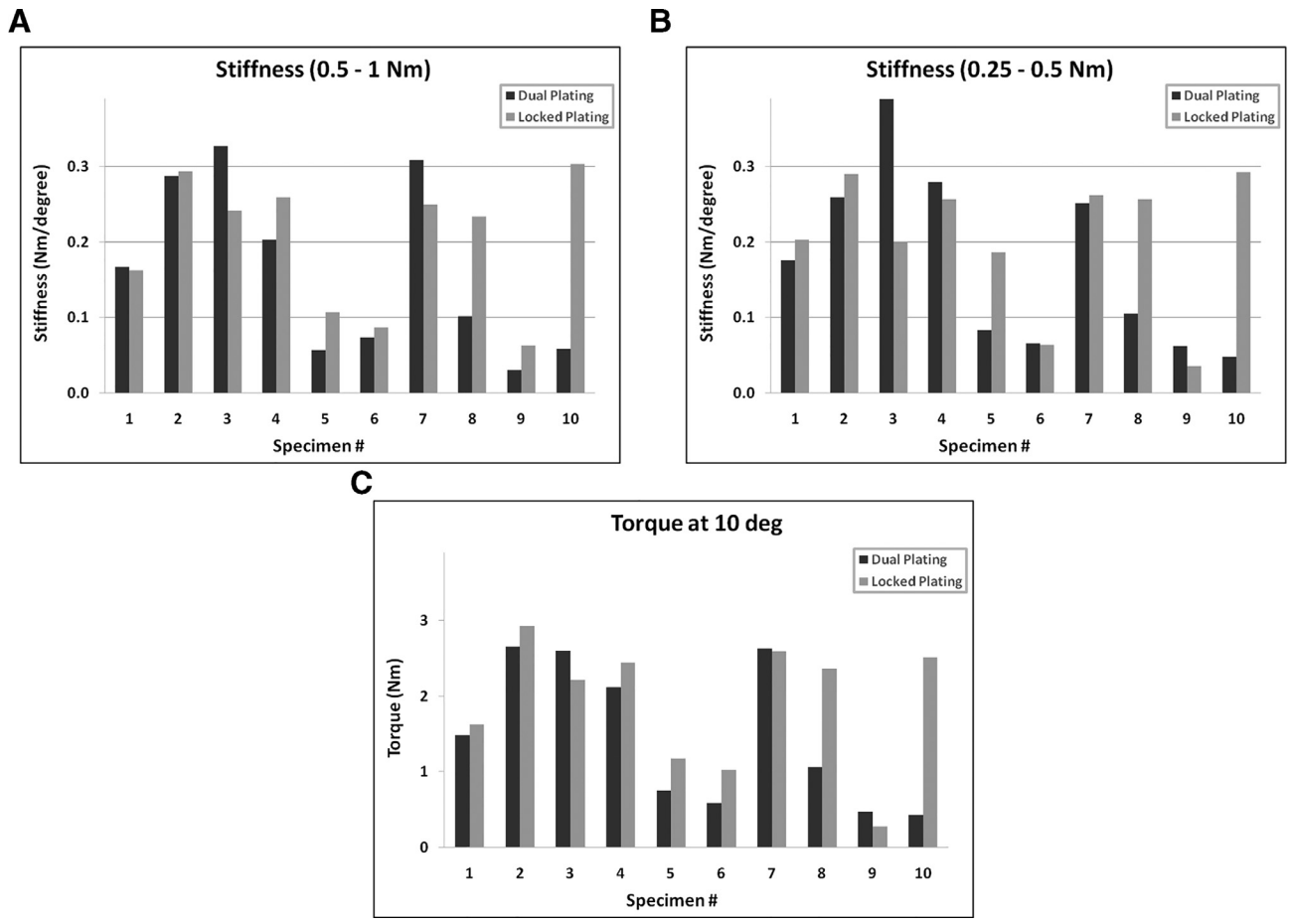

Fig. 3. Results of biomechanical testing, (*A*, *B*) including stiffness and (*C*) torque at 10° of external rotation.

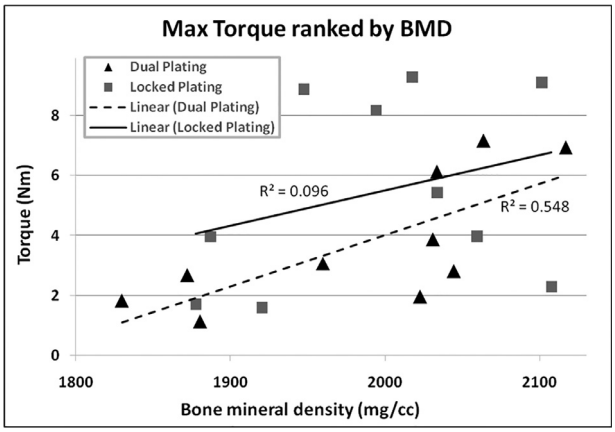

Fig. 4. Maximum torque plotted against bone mineral density demonstrating coefficients of determination.

external rotation. Clinically, external rotation in excess of 10° is unlikely to occur in a postoperative splint or cast, which are used routinely after fixation of comminuted fractures, and was considered the threshold for failure in a previous study (3). Additionally, the stiffnesses and maximum torques seen in our study are comparable to those seen in other biomechanical studies comparing distal fibula fracture fixation (13–16). A recent meta-analysis comparing locked plating to conventional nonlocked lateral plating in the bone of elderly patients found no significant differences among a myriad of biomechanical parameters, but suggested that locked plating may be preferred in cases of poor bone quality as the properties of the locking plate are independent of bone quality (13). Our study shows that bone quality is not a reliable predictor for maximum torque at failure in locked plating or in dual nonlocked plating specimens. Additionally, because failure occurred most frequently with fracture through the proximal cortical screw holes in both types of constructs in our study, it may be worthwhile to consider testing a construct with locking screws in the proximal holes. The bone quality in the proximal fragment rarely requires locking screw fixation in clinical practice, however.

Limitations

This study was limited by the use of isolated fibula specimens, because this model does not consider all of the forces transmitted through soft-tissue attachments that contribute to clinical distal fibula fracture fixation failures. Using isolated fibulae allowed for simplification of testing, and is not unprecedented in the literature for biomechanical testing of fibula fracture fixation constructs (11).

In addition, we did not establish a distinct relationship between BMD and maximum torque. If there is a relationship, it is possible that it may be nonlinear, and a larger sample size may be necessary to characterize it.

Strengths

The use of matched pairs of fibulae allowed testing for the desired biomechanical properties of interest without the interference of confounding variables. This study also raises the possibility of other applications for dual nonlocked plating, especially for surgeries that traditionally rely on locking plate fixation. Examples of these applications include fixation of supramalleolar osteotomies or pilon fractures. The use of dual plating in upper extremity fractures is well documented (17). Further biomechanical studies are needed before recommendation of the use of dual nonlocked plating for these other lower extremity applications. Furthermore, our fracture simulation methods and biomechanical testing protocol could be applied easily to test these additional applications of dual nonlocked plating.

In conclusion, this study provides evidence that dual nonlocked plating likely constitutes adequate fixation in situations in which a locking plate is being considered for comminuted distal fibula fractures, because the 2 constructs are biomechanically equivalent up to 10° of external rotation. The rotational displacements experienced by a postoperative ankle fracture with protected weightbearing and a splint or cast in place are unlikely to exceed the threshold of 10° of external rotation, and the loads required to cause fracture through a proximal screw hole clearly exceed the limitations of any reasonable postoperative fracture fixation protocols.

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