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Biomechanical analysis of polyaxial locking vs. non-locking plate fixation of unstable fractures of the distal fibula: A cadaver study with a bone only model☆

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ABSTRACT

Background: Open reduction and internal fixation is the current standard of treatment of displaced distal fibula fractures, whereupon using a lag screw often is impossible because of a multifragmantary fracturezone. This study investigates in what extend polyaxial-locking plating is superior to non-locking constructs in unstable distal fibula fractures.

Methods: Seven pairs of human cadaver fibulae were double osteotomized in standardized fashion with a 5 mm gap. This gap simulated an area of comminution, where both main fragments were no longer in direct contact. One fibula of the pair was managed using a 3.5-mm screw in a polyaxial-locking construct and the other fibula in a non-locking construct.

In a biomechanical test bending and torsional stiffnesses and the number of cycles to failure under cyclic bending loading of the constructs were measured and subjected to a paired comparison.

1. Introduction

Ankle fracture is one of the most common injuries encountered in daily clinical practice. The current standard of operative treatment of displaced fractures of the distal fibula is open reduction and internal fixation using a lag screw and plate osteosynthesis [1].

Particular difficulties arise in the management of unstable fractures with a multifragmented fracture area or an area of comminution. In such fractures, using an interfragmentary lag screw as an essential component of lateral osteosynthesis is often not possible [1]. This in turn leads to markedly reduced biomechanical stability of the entire internal fixation construct.

The current literature contains numerous biomechanical studies on various types of fixation of the distal fibula using different types of plate osteosynthesis with both conventional non-locking and locking screw-plate constructs [2–7].

Up to now specific investigations of comminuted distal fibula fractures are rare.

Bariteau et al. investigated locking and non-locking plating systems for the management of unstable fractures of the distal fibula in an osteoporotic saw bone model [8]. The study revealed that locking plating was superior to the non-locking constructs. Using a bone model with fresh frozen cadavers White et al. revealed no significant difference between locked and standard one-third tubular plating techniques [9]. Until now ther is no evidence in the literature about plating techniques for surgical management of unstable distal fibula fractures.

In the present study, we hypothesized that polyaxial-locking plating is superior to non-locking plating for stabilizing an unstable fracture with regard to the biomechanical properties. To examine this, we evaluated the biomechanical properties of a plate osteosynthesis of an artificial created unstable facture of the

☆ Clinical relevance: Information on the behavior of polyaxial locking plates is relevant to surgeons performing internal fixation of distal fibula fractures.

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distal end of fibular bone using an anatomical plate with different types of screws.

2. Materials and methods

2.1. Specimes

We used seven pairs of fresh frozen human cadaveric fibulae (4 female and 3 male). First, bone mineral density (BMD) was determined in the associated calcanei of all specimens (DXA standard machine, model QDR 4500W, S/N 48892, Hologic, Bedford, MA, USA).

The fibulae were separated from the surrounding soft tissue and supplied deep-frozen in sealed plastic bags. After thawing at room temperature, the remaining adhering soft tissue was removed with a scalpel, scissors and brush. Next, the surfaces were cleaned and degreased. The bone was stripped of all articular cartilage. The fibulae were then cut to a length of 13 cm using a commercially available miter saw.

2.2. Fracture model

Fibula specimens were subjected to a double osteotomy extending perpendicular to the long axis, 3 cm proximal to the fibular tip, thus creating a 5-mm gap. This gap simulated an area of comminution, where both main fragments were no longer in direct contact.

2.3. Osteosynthesis

Next, fibula pairs were stabilized using a VariAx fibula lateral plate (Stryker Leibinger GmbH & Co. KG, Freiburg, Germany).

One fibula of each pair was managed using a 3.5-mm screw in a polyaxial-locking construct and the other fibula in a non-locking construct. The 5-mm osteotomy gap was maintained in each case. Two bicortical screws were placed proximal to the osteotomy gap. Four screws were placed distal to the osteotomy gap, with the screw tips touching but not penetrating through the juxta-articular corticalis. No lag screw was used (Fig. 1).

The stabilized fibula with an osteotomy gap was embedded at its tip and shaft in liquid methylmethacrylate bone cement (Technovit 3040, Heraeus Kulzer GmbH, Wehrheim, Germany) in a cylindrical form, approximately matching the size of the mounting device of the test machine. Prior to embedding into the bone cement, all segments of the osteosynthesis material that could come in contact with the embedded specimens were covered with plasticine.

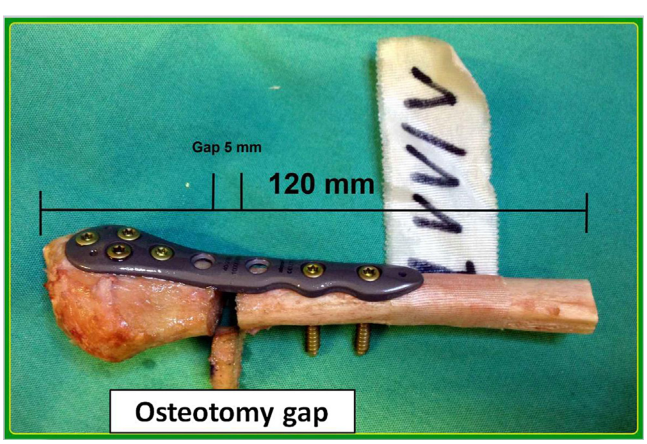

Fig. 1. Specimen managed with a plate osteosynthesis, displaying a 5-mm osteotomy gap.

2.4. Test design and procedure

The testing machine (table top testing machine Type TCFR1.0TH.D09, Zwick Z1.0; Zwick/Roell, Ulm, Germany) was used for torsional and bending testing. First torsional stiffness was determined, followed by bending stiffnes. Finally bending loading with 5000 cycles of loading and unloading, each with a similar force of 30 Newton, was performed.

For the torsional test the distal cylinder of the specimes could slide freely along the longitudinal axis in case of a change of length during the test. A maximum force of 30 Newton was applied by the machine on the proximal cylinder over a 60-mm long lever arm with a speed of 1 mm/s. After two riveting cycles, torsional stiffness was determined in the mean average of the subsequent five measurement cycles. Additionally, the corresponding range of motion (ROM) was recorded by registering the movement of the distal end of the lever arm.

For the bending test, the specimens were mounted onto a two-dimensional freely suspended cross table. The articular surfaces of the distal fibula were maintained in the same vertical position at all times. The force of 30 Newton was applied directly to the proximal cylinder with a speed of 1 mm/s. As before, bending stiffness was determined with the mean average of five measuring cycles following two riveting cycles. In addition, ROM was determined by registering the movement of the proximal cast cylinder.

The initial torsional and bending testing was followed by cyclic testing with a total of 10,000 constant bending cycles to determine the number of cycles to failure. The number of cycles to failure of a specimen was determined with the failure criterion defined as a 120% overshoot of ROM measured in the cyclic bending loading over the ROM determined in the initial bending test.

2.5. Statistical analysis

The measured stiffness, ROM, and cycles to failure were subjected to statistical tests. The small number of samples in the study groups did not allow for unequivocal conclusions regarding the distribution forms of the metric data. Therefore, the nonparametric Wilcoxon signed-rank test was used for statistical comparison. In addition, a Monte Carlo simulation served as an accurate approximation method. Kaplan–Meier survival analysis was performed to evaluate the cycles to failure. A $p < 0.05$ (95%) was considered statistically significant for all tests. The IBM SPSS Statistics software (version 20, IBM Corp., Armonk, NY, USA) was used for all calculations.

3. Results

3.1. Bone mineral density measurement

The measured median values for bone density did not differ significantly between the two groups (BMD polyaxial-locking 0.467 g/cm^3 (0,241–0,776 g/cm^3); BMD non-locking 0.480 g/cm^3 (0,325–0,640 g/cm^3); $p = 0.687$).

3.2. Torsion and bending results

One pair of fibulae was not evaluated in the initial testing due to failure. Pull-out failure of a proximal screw in a specimen treated with variable-angle plating occurred already during the initial bending loading.

The median values (interquartile ranges) of the initial torsional and bending stiffness and the numbers of cycles to failure are shown in Table 1.

There was no statistically significant difference between the two test groups in the torsional test (polyaxial-locking plate: T