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Biomechanical comparison of a lateral polyaxial locking plate with a posterolateral polyaxial locking plate applied to the distal fibula

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ABSTRACT

Background: Polyaxial locking plates are becoming popular for the fixation of distal fibula fractures. This study establishes how construct stiffness and plate loosening, measured as range of motion, differs between lateral and posterolateral plate location.
Methods: Seven matched pairs of cadaver fibulae were osteotomized in standardized fashion to produce a Weber type B distal fibula fracture. The fragments were fixated with an interfragmentary lag screw and polyaxial locking plates, with one fibula in each pair receiving a posterolateral anti-glide-plate, and the other a lateral neutralization-plate. In a biomechanical test, the bending and torsional stiffnesses of the constructs and the ranges of motion (ROM) were measured and subjected to a paired comparison.
Results: The laterally plated group had a higher median (interquartile range) bending stiffness (29.2 (19.7) N/mm) and a smaller range of motion (2.06 (1.99) mm) than the posterolaterally plated group (14.6 (20.6) N/mm, and 4.11 (3.28) mm, respectively); however, the results were not statistically significant ($p_{bending} = 0.314$; $p_{ROM} = 0.325$). Similarly, the torsional stiffness did not differ significantly between the two groups (laterally plated: 426 (259) N mm/°; posterolaterally plated: 248 (399) N mm/°; $p_{torsion} = 0.900$). The range of motion measurements between the two groups under torsional loading were also statistically insignificant (laterally plated: 8.88 (6.30) mm; posterolaterally plated: 15.34 (12.64) mm; $p_{ROM} = 0.900$).
Conclusion: In biomechanical cadaver-model tests of Weber type B fracture fixation with polyaxial locking plates, laterally plated constructs and posterolaterally plated constructs performed without significantly difference. Therefore, other considerations, such as access morbidity, associated injuries, patient anatomy, or surgeon's preference, may guide the choice of plating pattern. Further clinical studies will be needed for the establishment of definitive recommendations. *Clinical relevance*: Information on the behavior of polyaxial locking plates is relevant to surgeons performing internal fixation of distal fibula fractures.

1. Introduction

Ankle fractures are among the most frequently encountered fractures in orthopedic practice [1]. The fractures are common also in elderly subjects [2] and their incidence may be expected to rise as the general population ages [3]. Undisplaced fractures below the level of the syndesmosis tend to respond well to conservative management, whereas displaced fractures at or above the level of the syndesmosis will require surgery [1,4]. As people live longer, risk factors for ankle fractures, and the prevalence of comorbidities such as diabetes and peripheral artery disease, will rise [5–9]. However, the expectations and the activity levels of today's geriatric patients are higher than in the past [10–13] and there is now a demand for operative treatment.

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For the operative management of uncomplicated fibula fractures at the level of the syndesmosis, many different techniques have been published [14–19]. Fixation with an interfragmentary lag screw plus a lateral neutralization plate, and fixation with an interfragmentary lag screw plus a posterolateral anti-glide plate have become established techniques [1]. The anti-glide plate has been shown to be biomechanically superior to the neutralization plate [19,20] without providing greater clinical benefit [20,21]. Usually surgery is followed from 6 to 8 weeks non-weight bearing of the injured leg. For treating geriatric patients primary full-weight bearing is claimed to prevent immobilization [22]. Referring to this biomechanical properties have to be improved, whereupon modern locking plates seems to be advantageous and should be investigated systematically.

Over the past years, modern polyaxial locking devices have proved clinically useful [22]. Several studies have been published regarding the biomechanical behavior of contemporary locking plates applied to the distal fibula. However, to the authors' knowledge, there has been no comparison between a lateral locking plate and a locking anti-glide plate. The present study was performed to establish whether the proven biomechanical superiority of the anti-glide plate over the lateral neutralization plate would also apply where the anti-glide plate used was of the locking design. We hypothesized that the known biomechanical advantages of the anti-glide plate would be even more pronounced with a locking, rather than a conventional, plate.

2. Materials and methods

The approval of the Ethics Committee was obtained prior to the initiation of the study.

2.1. Specimens

The present study performed using a matched – pairs design on the basis of 7 pairs of fresh-frozen human fibulae. The bones had been harvested from five female and two male donors; the median donor age was 79 years (range, 64–87 years). The specimens were thawed at room temperature, and stripped of their soft tissues. Next, they were cut to a length of 13 cm, and osteotomized in standardized fashion to produce a simple oblique Weber type B fracture starting anteriorly at a point 30 mm proximal to the tip of the fibula and extending in a posterior direction, at an angle of 55° (see Fig. 1).

2.2. Implants

The plates and screws used in this study were part of the VariAx Fibula Locking Plate System (Stryker Leibinger GmbH & Co. KG, Freiburg, Germany). In this system, both the (posterolateral) straight plates and the lateral plates are made of commercially pure (CP) titanium, while the locking screws and the non-locking screws are made of titanium alloy (Ti–6Al–4V), which is slightly

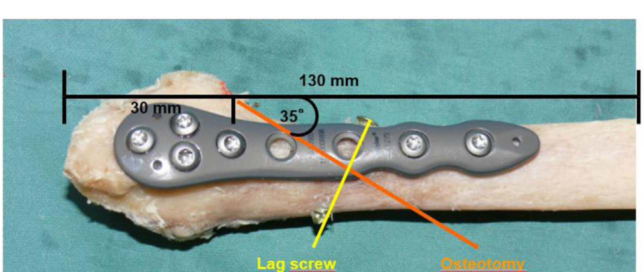

Fig. 1. Fracture model (showing lateral plate, with independent lag screw fixation).

Fig. 2. Posterolateral plate (straight plate). This plate has one elongated oblong hole for through-the-plate insertion of an interfragmentary lag screw.

harder than the plates. All (locking as well as non-locking) screws have an outer shaft diameter of 3.5 mm. The titanium alloy locking screws feature a threaded head which, upon insertion, deforms the softer CP titanium plate to achieve secure locking over a polyaxial angulation range of ±15° respect to the plate. The posterolaterally applied straight plates (Fig. 2) have an elongated oblong hole third from the distal end, which permits through-the-plate lag screw insertion. The lateral plates (Fig. 3) feature a spoon-shaped distal expansion with a cluster of holes. The lateral plate do not provide for through-the-plate placement of a lag screw.

2.3. Constructs

Within each pair of fibulae, the two plate designs were randomly allocated to either the right or the left fibula, with one fibula receiving a lateral plate (neutralization plate), while the contralateral fibula was fixated with a straight plate. In the present study, all the straight plates had overall 6 holes, while all the lateral plates had 4 holes along the plate shaft.

For the fixation of the laterally applied neutralization plate, an independent lag screw was inserted perpendicularly to the osteotomy plane, then a plate was applied over the osteotomy as shown in Fig. 3. For the posterolaterally applied straight plate, an interfragmentary lag screw was placed through the elongated oblong hole as shown in Fig. 2. In this study, all screws were placed at right angles to the plate. In the case of the lateral (neutralization) plates, a custom-made targeting device was used for the placement of the distal locking screws. All the screws used for the attachment of the plates, both to the distal and to the proximal fragment, were 3.5-mm-diameter locking screws. In all cases, screw length was selected to ensure perforation of the opposite cortex of the fibular shaft (proximal fragment). The same applied to the lag screw. Screw length for the distal fragment was selected to ensure attachment of the screw in the opposite cortex without perforating the articular surface.

2.4. Potting and testing

Prior to the potting of the specimens, the osteotomy gap and the parts of the hardware that would subsequently be within the potting cup were covered with an elastic rubber compound. The distal and the proximal ends of the specimens were then placed in cylindrical steel cups matching the jigs of the testing machine, and

Fig. 3. Lateral plate. The construct includes an independent interfragmentary lag screw.

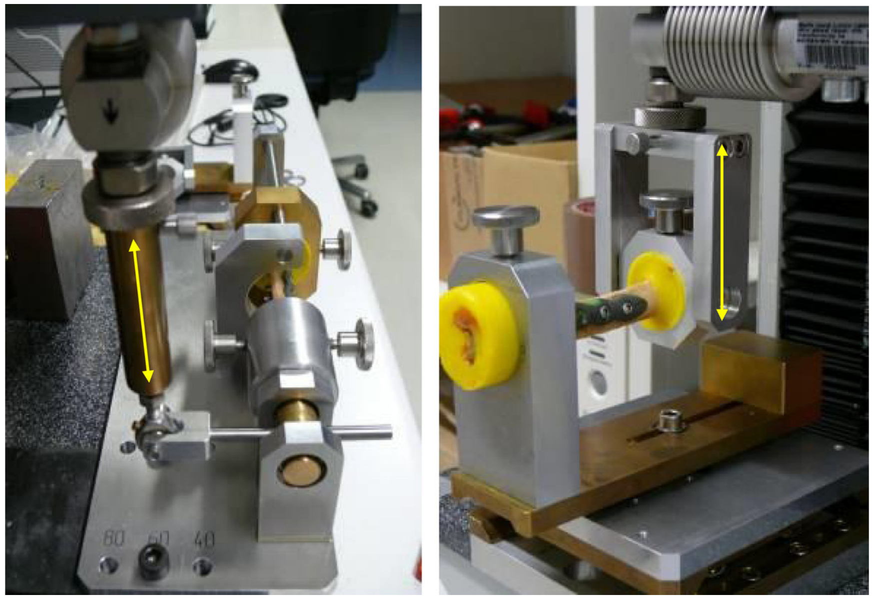

Fig. 4. (A and B) Test set-up. (A) The set-up used for torsional loading; (B) the set-up used for bending loading.

potted in methyl methacrylate (MMA) (Technovit 3040, Heraeus Kulzer GmbH, Wehrheim, Germany).

Biomechanical testing was performed on a universal testing machine with a 100 N load cell (table top testing machine Type TC-FR1.0TH.D09, Zwick Z1.0; Zwick/Roell, Ulm, Germany) (Fig. 4). The specimens were tested for initial torsional and afterward for bending stiffnesses. In both loading modes, the load applied was 30 N. While changing the testing configuration from torsional to bending load the specimens were analyzed macroscopic by the tester to ensure that the fixation was not degraded while testing in torsion.

Torsional stiffness was measured in internal rotation/external rotation around the longitudinal axis of the fibula. A special rig was used, with the two potting cups firmly attached, but with provision for the distal cup to travel freely along the specimen's longitudinal axis in the event of a change in length. A 60-mm-long lever at the proximal cup was used to apply/remove a load of $\pm$30 N, with two conditioning cycles and five measuring cycles. The ranges of motion were recorded. The test set-up is shown in Fig. 4 (left).

In order to investigate the bending stiffness the distal potting cup was mounted on an *XY* table with 2° of freedom, care being taken to ensure that the fibular joint surface was aligned vertically, so as to obtain load transmission in the plane of the joint surface. At the proximal potting cup, a load of $\pm$30 N was applied with two conditioning cycles followed by five measuring cycles. In this setting the length of lever arm is equal to the total length of the specimen (13 cm). The ranges of motion were recorded. The test set-up is shown in Fig. 4 (right).

2.5. Statistical evaluation

The Mann–Whitney *U* test was used for the comparison of the median values and the rank sums of the two groups. As an additional, more exact approximation, a Monte Carlo simulation with 10,000 samples was performed. The software used was IBM SPSS Statistics for Windows, Version 20.0 software (IBM Corp.; Armonk, NY, USA). Significance was set at $p < 0.05$.

3. Results

The results are presented in Fig. 5 and Table 1. The comparison of the torsional stiffness and the range of motion (ROM) in the torsional loading mode did not show any significant intergroup differences (torsional stiffness: $p = 0.900$; ROM: $p = 0.900$).

In the laterally plated group, there was a higher median bending stiffness associated with a lesser median ROM, as compared with the results in the posterolaterally plated group. However, the differences were not significant (bending stiffness: $p = 0.314$; ROM: $p = 0.325$).

4. Discussion

Ankle fractures are among the most common fractures, and are frequently encountered in elderly subjects [2]. In today's aging population, the rate of ankle fractures is likely to rise substantially [3]. However, there is no agreement on how simple fractures of the distal fibula should be surgically managed [4]. Among the many concepts that have been proposed, two have become established in surgical practice. One of these techniques uses an independent interfragmentary lag screw and a laterally applied neutralization plate, while the other uses a posterolaterally applied anti-glide plate and a through-the-plate lag screw [1]. The lateral plate has the advantage of a very straightforward surgical approach that spares the peroneal tendons, however, it is associated with a higher incidence of soft-tissue irritation. Biomechanically, the non-locking anti-glide plate is more stable than the non-locking lateral plate [20]; however, it has been found to be associated with peroneal tendon irritation [23].

In a cadaver model, Schaffer and Manoli found that an anti-glide plate achieved superior biomechanical stability as compared with a laterally applied plate [20]. All the plates used in this study were of the non-locking type. One caveat: Schaffer and Manoli did not use an interfragmentary lag screw in the lateral neutralization plate constructs.

In view of the rising incidence of geriatric [7,10] and of diabetic [5] patients, sound implant fixation is becoming an increasingly important topic. The use of modern locking-plate systems could be advantageous [22]. The biomechanical properties of angle-stable implants for the fixation of distal fibula fractures have been studied by several authors [19,24–27]. The published results vary, and, to some extent, contradict each other. Kim et al. using eight pairs of ankles, compared a conventional (non-locking) lateral plate with a fixed-angle (locking) lateral plate [24]. However, the authors were

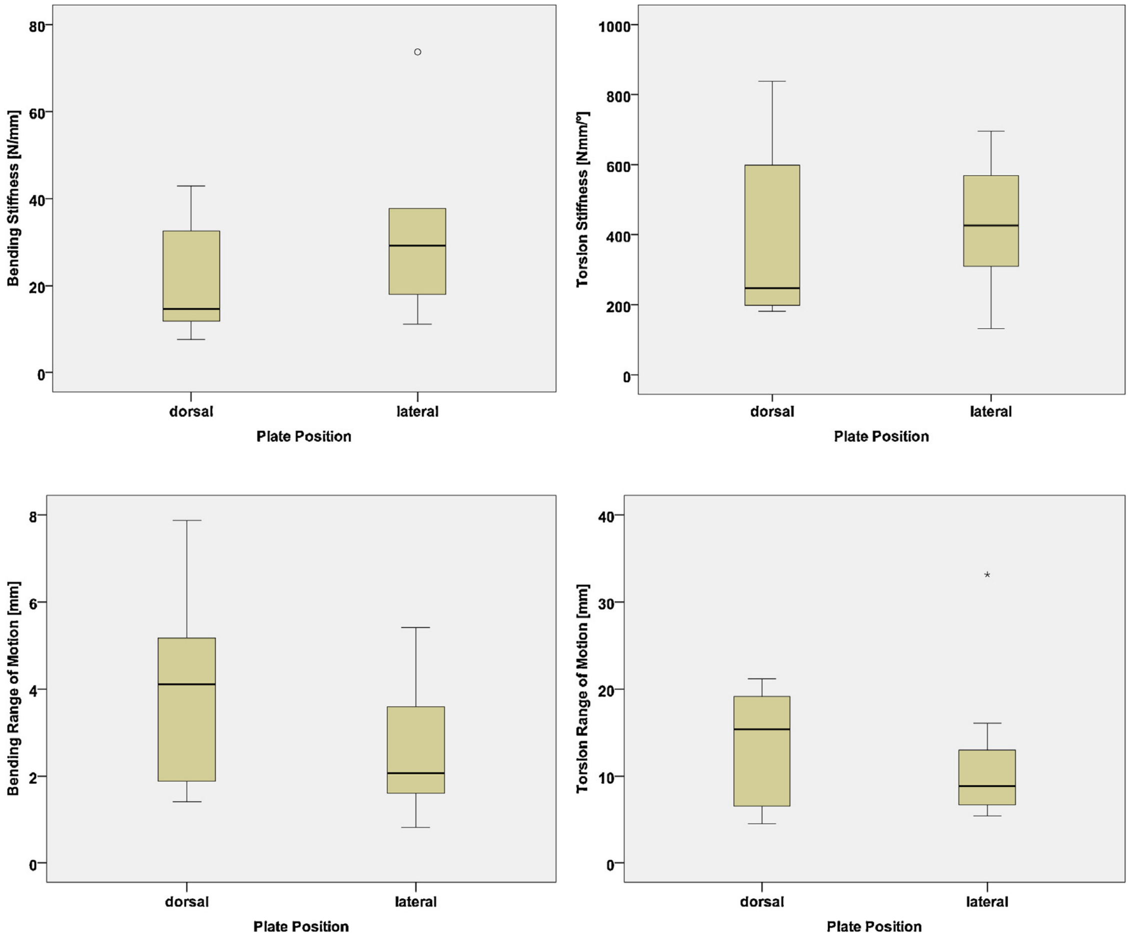

Fig. 5. Stiffness and range of motion (ROM) results presented as box-and-whisker plots. The height of the box represents the interquartile range (IQR); the black bar within the box represents the median. The whiskers extend to the smallest and the largest values within 1.5 (IQR). Outliers between 1.5 (IQR) and 3 (IQR) are marked with a circle (°); extreme outliers beyond 3 (IQR) are marked with an asterisk (*). All the data points were used for statistical analysis.

unable to demonstrate superiority of the locking plate over the conventional plate. Zahn et al., in 10 cadaver specimens, also compared the biomechanical properties of a lateral locking plate with those of a lateral conventional plate, and found the constructs fixated with the lateral locking plate to have superior stability [25].

Minihane et al. in a cadaver model, compared lateral locked plating with posterolateral antiglide plating for the fixation of a distal fibula fracture and showed that the antiglide plate had improved stability as compared to the lateral locking plate [19].

We hypothesized that the biomechanical advantages of the antiglide plate over the lateral plate demonstrated by Minihane et al. [19] and Schaffer and Manoli [20] would be even more pronounced if a locked, rather than a non-locking, antiglide plate was used. However, this hypothesis was not confirmed in the present study. The differences between the constructs using a locked lateral plate (neutralization plate) and those using a locked posterolateral straight plate were not statistically significant either with bending or with torsional loading.

When comparing the current results with those obtained by Minihane et al. [19] and by Schaffer and Manoli [20], it is important to highlight that the test set-ups and the hardware designs used by these authors were not identical with the set-up and the hardware in the present study. Both Minihane et al. and Schaffer and Manoli used intact ankles and legs, respectively, thereby retaining the ankle-joint-forming bones (tibia, fibula, talus) and at least some of the ankle-stabilizing ligaments. These set-ups differed from the one used by the present study, in which the fibula was the only structure retained. This set-up had been used before [16,17,26] and, in our view, is more appropriate for an evaluation of plate properties, since it looks at the "pure" fibula, without being influenced by the (non-measurable) effects of "non-fibula" stabilizers (ligaments, medial malleolus, joint capsule). Our study also differed from the investigations by Minihane et al. [19] and Schaffer and Manoli [20] in that these studies only measured torsional stiffness and load to failure. The present study measured torsional stiffness as well as bending stiffness without testing the

Table 1
Median (interquartile range) bending and torsional stiffness, and ranges of motion, with bending and with torsional loading ($n = 7$).

	Bending		Torsion	
	Stiffness	ROM	Stiffness	ROM
Laterally plated constructs	29.2 (19.7) N/mm	2.06 (1.99) mm	426 (259) N mm/°	8.88 (6.30) mm
Posterolaterally plated constructs	14.6 (20.6) N/mm	4.11 (3.28) mm	248 (399) N mm/°	15.34 (12.64) mm
p-Value	0.314	0.325	0.900	0.900

ROM = range of motion.

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specimens to destruction. Also, all the implants used in our study were polyaxial locking plates, whereas in Minihane et al.'s [19] study only the lateral plate was of that type. Schaffer and Manoli [20] exclusively used conventional (non-locking) one-third tubular plates, and did not use an interfragmentary lag screw for lateral plating. Another difference between the present study and the prior investigation using a lateral locking plate [19] was the pattern of the distal end of that plate: our plate had a spoon-shaped expansion (see Fig. 3), whereas Minihane et al. [19] used a one-third tubular plate with a standard-pattern distal end. The number of screws inserted into the distal fragment was greater with both plate types (lateral: four screws; posterolateral: two screws) than was the case in the studies by Minihane et al. [19] and Schaffer and Manoli [20], who both used two distal screws for the lateral plates, and one distal screw for the posterolateral plates.

The larger plate-bone contact area provided by the distal spoon-shaped expansion of the plate, and the possibility of inserting four unicortical screws into the distal fragment may have contributed substantially to the identical performance of the two plating options in our study. Unlike Schaffer and Manoli [20], the use of a lag screw is important in lateral (neutralization) plating.

As with all biomechanical investigations, the current study has certain limitations. The test protocol and test set-up provided for the sequential testing of torsional and of bending stiffness. This meant that in both modes the loading was in two planes only so that the complex movement pattern of the ankle joint was grossly oversimplified. The effect of bone healing could not be taken into account. Cyclic testing was not part of the protocol. This would have made the results more meaningful, since, in routine clinical practice, construct failure will more commonly be the result of repetitive stress.

In the present study, the bone mineral density of the specimens was not determined. However, since this was a comparison of matched pairs of fibulae, with one fibula of each pair receiving one plate pattern and the other fibula being fixed with the other pattern, bone mineral density was assumed equal in the two construct groups. An earlier study [16] has shown that major bone density differences between the two sides of a matched fibula are unlikely.

The 30 N load (in both loading modes) was chosen based on previous experience to reduce the likelihood that specimens would fail at the first application of the load. The physiological ankle stabilizers, such as an intact medial malleolus and the ankle ligaments, had been removed, which allowed a fairly low force to be used, and eliminated effects of non-fibula stabilizers. Since the implants were applied with identical screws made of the same titanium alloy and inserted through screw holes of identical geometry, the only factors affecting the behavior of the constructs were the plate site and the (site-specific) plate pattern of both plate types with different plate designs and different numbers of screws placed in the distal fragment. The lateral plate feature a spoon-shaped distal expansion what provides the possibility for fixation with 4 screws, in contrast to the posterolateral plate with only 2 screws. Due to the anatomy the screws of lateral plating has to be placed monocortical to obviate perforating the articular surface, posterolateral plates can be fixed bicortical even in the distal fragment. So both plates are fixed via four layers of cortical bone similarly. This fact probably tends to result in biomechanical equality of both plate designs and positions in the present study.

In the present study of polyaxial locking-plate fixation of a simple Weber type B fracture of the distal fibula, lateral plating in combination with an independent lag screw was biomechanically not different to posterolateral plating. As a result, the fixation pattern choice and the surgical approach may be guided by other considerations, such as the prevention of wound healing problems [9,28] in patients with various comorbidities (e.g. diabetes or peripheral artery disease) [5–7] and of peroneal tendon irritation [23].

Further biomechanical studies, including cyclic loading, as well as clinical studies are required in order to establish whether and to what extent the fixation of a distal fibula fracture optimized under laboratory conditions can be reproduced in routine clinical practice.

Conflict of interest

There is no conflict of interest.

Acknowledgement

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