

## The Biomechanical Effects of Combining Rigid and Dynamic Fracture Fixation in Simple Fractures

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### Abstract

**Introduction:** Bridge plating has superseded rigid internal fixation in most situations. In simple fractures increased time to union has been reported. This biomechanical study investigates whether the combination of dynamic and rigid fixation allows for adequate interfragmentary movement.

**Methods:** Standardised fractures were created in bone surrogates and fixed with either a standard bridging plate construct using a locking compression plate or Non Contact Bridging (NCB®) plates using Far Cortical Locking screws (FCLS, MotionLoc™). The constructs were axially loaded to simulate non, touch and partial-weight bearing and interfragmentary motion measured.

**Results:** The standard bridge plating and the far cortical locking constructs fixed with a “fracture gap” showed significantly increased fracture motion ( $p < 0.005$ ) relative to other groups. No significant difference in fracture motion was demonstrated between any of the 3 groups, where the osteotomy was anatomically reduced, regardless of the presence of an inter-fragmentary screw.

**Conclusion:** The combination of a lag screw and dynamic plate osteosynthesis allows sufficient fracture motion for secondary bone healing. In simple fracture patterns the addition of a lag screw did not impair fracture motion.

**Keywords:** Osteosynthesis; Fracture fixation; Interfragmentary movement; Bone plate

### Introduction

Biologic plating of comminuted shaft fractures without anatomical reduction was introduced in the nineties [1-3]. Restoration of alignment, length and rotation was the primary goal. The importance of fracture motion [4-6] and minimal disturbance to blood supply [7] was recognized and addressed by indirect reduction methods, the application of bridging plates and by protecting the periosteal blood supply [8,9]. With the advancements of locking plates and minimally invasive surgical techniques this concept has also been applied for simple spiral fractures. However, indirect, non anatomical reduction in simple spiral fractures can leave a significant fracture gap and increased healing times have been reported [10,11], especially at the distal tibia [2].

Fracture gap and fracture motion are two fundamental parameters, which influence time to union and determine the inter-fragmentary strain (IFS) [4,11,12]. Gaps larger than 2 mm showed poor union independent of the motion and strain in transverse sheep osteotomies [12]. A reduction of the fracture gap was shown to be an important factor for union, which was further enhanced by fracture motion of up to 0.5 mm (IFS 30%). A small fracture gap in combination with fracture motion is considered optimal for rapid fracture healing [10]. Indeed, a recent clinical study found a faster healing time in simple distal tibia fractures if an inter-fragmentary lag screw was used for anatomical reduction, in combination with a dynamic bridging plate, e.g. long working length [13-15]. Despite rigid fixation and anatomical reduction with a lag screw, callus formation was seen in more than 70% of these cases. A further consideration in optimization of fracture healing is the concept of dynamically locked screws. This technology has the biomechanical benefits of providing a more flexible fixation, independent of working length, and more even load distribution along the construct with parallel interfragmentary motion [16]. This has been

shown to promote callus and fracture healing [17]. To the best of our knowledge no biomechanical studies exist to examine how anatomical reduction or inter fragmentary compression via lag screw influence fracture motion when combined with a bridging plate construct.

### Methods

#### Construct groups

Both a standard locking plate (Locking Compression Plate, Synthes) and a locking plate (Non Contact Bridging Plate, Zimmer) with dynamically locked screws (Motionlock, Zimmer) were utilized for the current study. Each plate type had 4 construct groups containing 5 samples each.

The groups compared were:

- (1) “Gap”: Bridging plate (BP) with 3 mm fracture gap,
- (2) “NoGap”: BP with anatomical reduction (no gap),
- (3) “LagL”: BP with anatomical reduction and interfragmentary lag screw loose (0.2 Nm),
- (4) “LagT”: BP with anatomical reduction and interfragmentary lag screw tight (0.5 Nm),

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## Specimens and osteotomies

For all specimens standardised cylindrical bone surrogates were used. These models have a length of 250 mm, diameter of 27 mm and wall thickness of 2 mm made of reinforced short fibre filled epoxy (Pacific Research Laboratories). 60° oblique fractures were created with a power bench saw with a measured cutting block.

## Plating systems

Two different plate systems were used. The first series underwent bridge plating with an 11 hole (206 mm) titanium narrow large fragment locking compression plate (Synthes, DePuy). Plate specific drill towers were used along with a 4.3 mm drill bit. Locking screws (5.0 mm) were inserted through the plate (Figure 1) and locked using a torque limiter of 4 Nm in accordance with the specifications of the manufacturer. Three standard locking screws were used on either side of the osteotomy. A working length of five holes (90 mm) without screws around the fracture site was used.

The second series were bridged with a 14-hole (202 mm) narrow straight Non Contact Bridge Plate (NCB®, Zimmer) (Figure 2). Two 2 mm spacers within the plate were used to hold the plate off the bone during plate application. The spacers were removed prior to loading to ensure a dynamic screw-plate construct. The working length was 60 mm which corresponds to 4 empty holes around the osteotomy. Three Far Cortical Locking Screws (5 mm, MotionLoc™, 4.3 mm drill bit with specific drill guide, 6 Nm torque, Zimmer) were used on either side of the osteotomy. The locking caps were locked with a torque of 6 Nm as specified by the manufacturer.

## Comparative groups

Group 1 had a 3 mm plastic spacer inserted at the osteotomy site to ensure a uniform fracture gap. This was removed after application of the plate and prior to load testing. Group 2 samples had the osteotomy reduced completely using 2 broad clamps (end to end and side to side) before the plate was applied. Groups 3 and 4 had the fracture reduced using the same 2 clamps as group 2. The osteotomy was then stabilised using a 4.5 mm cortical lag screw with the near cortex over drilled. The lag screw was tightened to 0.5 Nm for group 3 and was loosened a half turn to 0.2 Nm for group 4.

## Loading

Each construct was mounted between proximal and distal ball and socket joints (large 54 mm cobalt-chrome heads) in a material testing machine (MicroTester 5848, Instron®, Canton, Massachusetts; WaveMaker control software). Room temperature was controlled at 22°C. The specimens were axially loaded to 100 N and then to 200 N and 400 N, simulating non-weight bearing (NWB), touch weight bearing (TWB) and partial weight bearing (PWB), using a sinusoid loading profile at 1 Hz for 10,000 cycles.

## Outcome measurements

Construct stiffness during axial loading was calculated from force-displacement curves recorded by the material testing machine. To validate the results of the material testing machine, interfragmentary motion was also measured at the fracture site in 25 samples with a stereoscopic, contactless, full-field digital image correlation system (Vic-3D™ image correlation system, Correlated Solutions) with an accuracy of 20 microns. The Vic-3D™ sampling frequency was 10 Hz.

## Statistics

Statistical analysis was completed using MS Excel (2013), and the

R statistical environment. One-way ANOVAs and Tukey's honest significant difference (HSD) post hoc test were used to determine statistical difference. All tests were performed assuming an alpha level of 0.05 as statistically significant.

## Results

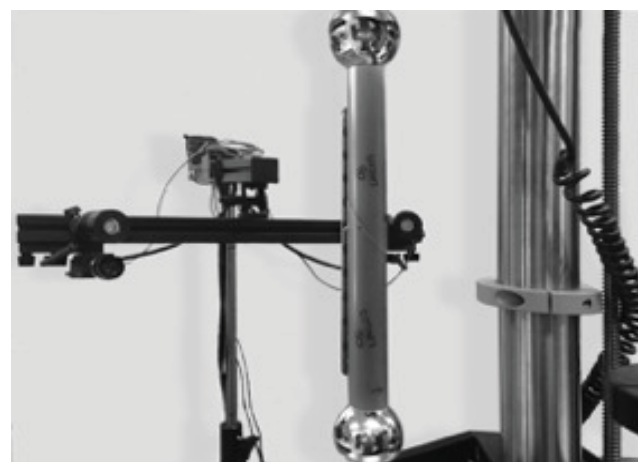
### Fracture displacement (*MicroTester*™)

Interfragmentary motion on axial loading for both constructs is shown in Figure 3 for loads of 100 N, 200 N and 400 N.

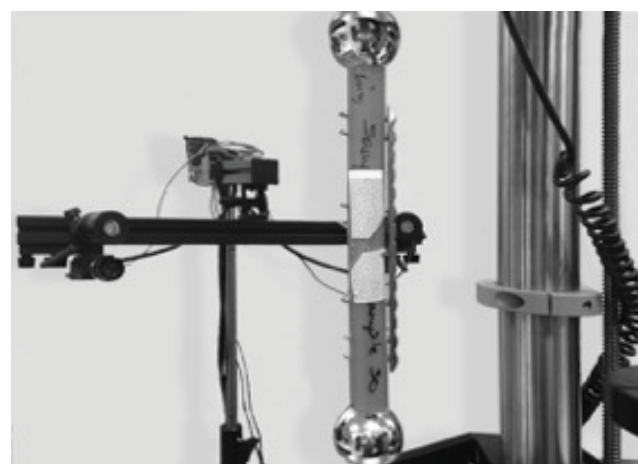
The far cortical locking construct was more than 2 times as flexible when compared to the standard locking plate for each scenario (Gap, NoGap, lagL, lagT) ( $p < 0.00001$ ) (Figure 4), irrespective of load.

In both the standard bridge plating and the far cortical locking constructs, the "Gap" groups showed significantly increased fracture motion ( $p < 0.005$ ) relative to all other groups.

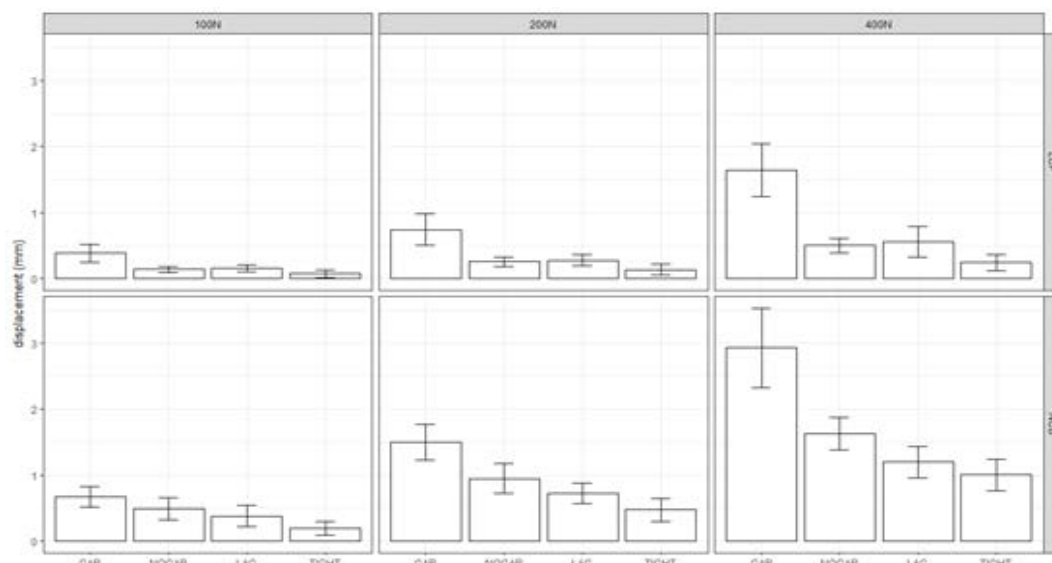
No significant difference in fracture motion was demonstrated between any of the 3 groups, where the osteotomy was anatomically reduced, regardless of the presence of an inter-fragmentary screw. This was demonstrated in both the standard locking plate construct and the plate construct utilizing dynamic locking screws.



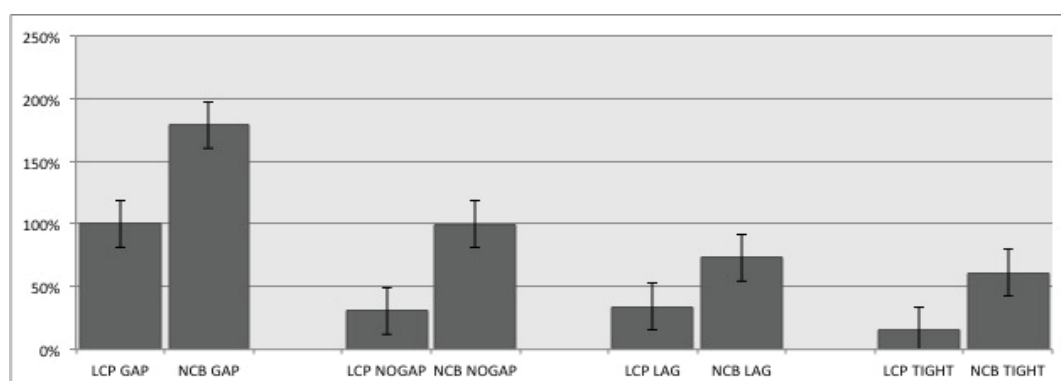
**Figure 1:** LCP plate construct on instron® testing machine.



**Figure 2:** NCB plate construct on instron® testing machine.



**Figure 3:** box and whisker plot interfragmentary motion.



**Figure 4:** Interfragmentary motion relative to LCP GAP motion.

In early operative fracture treatment rigid fixation with lag screws and compression plates ensured anatomical reduction and rigid fixation of the fracture. This ensured primary bone healing without callus formation [18]. Recent clinical studies for simple fractures, where a lag screw was combined with a bridging plate and an increased working length, callus formation was observed, indicating that some fracture motion must have occurred [14,19]. In order to optimise fracture healing of simple distal tibial fractures, both reduction of a fracture gap and provision of a bone healing environment that allows for appropriate fracture motion seem beneficial factors. It is therefore attractive to consider the use of a lag screw across the fracture site as an aid to reduction in combination with a bridging plate. Traditionally, the mixing of rigid and dynamic fixation principles has been avoided in fracture treatment. This current study is, to our knowledge, the first that provides biomechanical insight of the effect of combining these fixation principles.

Conventional fixation principles would hold that the integration of the lag screw in a bridge plate construct would make the overall construct too stiff to allow adequate fracture motion [18]. What we have

demonstrated in this study is, that the greatest increase in construct stiffness and reduction in fracture motion is actually seen when the fracture is anatomically reduced and the bone is sharing the load. Hence the “gap” group demonstrated the highest fracture motion as expected and the largest reduction in fracture motion was seen between the “gap” group and “NoGap” group, wherein the fracture was reduced anatomically but no augments to fixation were employed. Hence, once anatomical fracture reduction is achieved, the addition of a lag screw did not significantly alter the construct stiffness after 10000 Cycles for both the standard and the dynamic locking screws.

It has previously been described that ideal fracture motion should occur within the range of 0.2-1 mm [12]. It should be noted that significantly more fracture motion was noted in the far cortical locking construct than the standard bridge plate. The standard bridge plate, with a working length of approximately 90 mm, demonstrated sufficient fracture motion in the “NoGap”, “lagT” and “lagL” groups with 200 N and 400 N of axial load, simulating touch and partial weight bearing. In the far cortical locking group, optimal fracture motion was already seen at 100 N.

From this data we conclude that inter-fragmentary fixation might safely be used as a reduction aid in both standard and far cortical locked bridge plating constructs and still allow for a sound healing environment. Though there might be some benefits to the use of a dynamic locking screw technology at lower loads, both standard and far cortical locked bridge plating were able to produce adequate fracture motion.

A second benefit of augmenting bridge plate fixation with a plate independent lag screw is that this maintains the anatomical reduction during and after the application of the plate which simplifies the surgical procedure.

This study is limited to synthetic bone surrogates, which do not replicate living tissue. As such, callus formation and the impact this has on fracture motion could not be assessed. In addition, our model only assessed axial load, which is the primary loading pattern when ambulating with crutches for tibial fractures. We have not accounted for torsional forces. This model investigates an oblique fracture pattern, and has not investigated the fracture motion in spiral configurations.

The present study is a biomechanical basis to account for combining rigid and dynamic fixation principles and highlights the need for further clinically based trials to assess if this translates to earlier fracture union.

## Conclusion

This study provides a biomechanical basis to demonstrate that in the right setting both standard and far cortically locked bridge plating constructs can safely be combined with an interfragmentary screw to reduce the fracture gap and optimise fracture healing in simple fracture patterns. With an adequate working length, the remaining fracture motion should still be sufficient to allow callus formation.

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## Ethics and Consent Statement

This is a biomechanical study using synthetic bone surrogates. No human or animal tissue was utilised and as such no ethics approval or consent was required.

## Conflict of Interest

JLP: Conflict of interest: none.

SB: Conflict of interest: none.

AH: Conflict of interest: none.

RD: Conflict of interest: none.

KS: Conflict of interest: none.

MK: Receives royalties from Zimme.

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