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Interfragmentary lag screw fixation in locking plate constructs increases stiffness in simple fracture patterns

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ABSTRACT

Background: The aim of the current biomechanical cadaver study was to quantify the influence of an additional lag screw on construct stiffness in simple fracture models at the distal femur stabilised with a locking plate.

Methods: For biomechanical testing paired fresh frozen human femora of 5 donors (mean age: 71 (SD 9) years) were chosen. Different locking plate configurations either with or without interfragmentary lag screw were tested under torsional load (2/4 Nm/deg) or axial compression forces (500/1000 N).

Findings: Data show that plate constructs with interfragmentary lag screw reveal similar axial and torsional stiffness values compared to intact bone as opposed to bridging plate constructs that showed significantly lower stiffness for both loading conditions.

Interpretation: The current biomechanical testing unveils that the insertion of a lag screw combined with a locking plate dominates over a bridging plate construct at the distal femur in terms of axial and torsional stiffness.

1. Introduction

The major goal in modern fracture care is to restore limb function by enabling undisturbed fracture healing with minimal invasive stabilisation of fragments, preserving soft tissues and thus allowing fast rehabilitation of patients (Tan and Balogh, 2009). So far, anatomic reduction and conventional plate osteosyntheses represented the gold standard for many years (Egol et al., 2004). The combination of lag screws and conventional plating, however, required additional exposure and extension of surgical approaches resulting in further damage to the surrounding soft tissue with eventual devascularisation of fragments, high complication rates and fracture healing disturbances (Augat et al., 2005; Marti et al., 2001; Plecko et al., 2012; Tan and Balogh, 2009). More recently, the introduction of minimal invasive techniques with limited exposure and percutaneous insertion of locking plates led to the concept of “biological osteosyntheses” (Claes, 2011; Dobele et al., 2010, 2014; Frigg et al., 2001; Krettek et al., 2001; Link et al., 2012). In consequence, anatomic reduction and absolute stable fixation leading to direct bone healing were no longer considered to be necessary. Restoration of length, axis and rotation combined with bridging plate osteosynthesis was regularly associated with progressive callus formation and accelerated regain of function (Claes, 2011; Dobele et al., 2010; Ehlinger et al., 2013; Plecko et al., 2012). The introduction of locking plates providing angular stable screw fixation and increased stability exactly addressed this philosophy and revolutionised plate fixation techniques. Locking plate fixations have widely proven their advantages over conventional plates, especially in comminuted fractures and poor (osteoporotic) bone stock (Baumgaertel et al., 1998; Tan and Balogh, 2009). Despite these advantages, angular stable screw fixations have also proven asymmetric healing responses frequently with imbalances of callus formations (Dobele et al., 2010, 2014; Lujan et al., 2010). Due to the fact that micro-motion is known to stimulate healing response (Schell et al., 2005), the decreased callus formation at the near cortex was linked to the increased stiffness under the plate when compared to the far cortex (Adams et al., 2015). To allow a more symmetric callus formation, even under the plate, dynamic fixation concepts were introduced (Adams et al., 2015; Dobele et al., 2010; Gardner et al., 2009, 2010; Richter et al., 2015). Although the trend in modern fracture care is towards less rigid fixation options, some authors have questioned the strict separation of the philosophy of absolute (lag screw and compression plate) and relative (locking plate) stability for simple fracture patterns (Horn et al., 2011; Plecko et al., 2012). Horn et al. demonstrated significantly faster fracture healing when using lag screws in a locking plate construct at the distal tibia (Horn et al., 2011). Modern locking plates and surgical techniques allow for closed reduction and percutaneous plate insertion thus respecting the key steps of biological osteosyntheses. When closed anatomic reduction can be achieved with these techniques, an additional lag screw can be inserted percutaneously prior to plate fixation without significantly

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damaging soft tissue. Although, mixing of fixation philosophies is clinically in use or even recommended in clinical teaching courses, these recommendations are not based on quantitative data (Plecko et al., 2012). Mixing fixation philosophies is controversially discussed among biomechanical and reconstructive trauma experts (Horn et al., 2011).

Therefore, the aim of the current biomechanical cadaver study was to quantify the influence of an additional lag screw on construct stiffness in simple fracture models at the distal femur stabilised with a locking plate.

2. Methods

For biomechanical testing paired fresh frozen human femora of 5 donors (1 male, 4 female, five each side, average age at death: 71 (SD 9) years) were chosen. Left and right femora were assigned equally to the tested groups to avoid any bias. Specimens were derived from the local anatomy department and all donors gave informed consent prior to death. After explantation, the femora were mechanically cleaned from surrounding soft tissues and stored at −30 °C. To exclude bone pathologies and to determine bone mineral density specimens were subjected to quantitative computed tomography (qCT) scans (LightSpeed VCT 16, GE Healthcare, Milwaukee, USA). Prior to testing they were thawed overnight at 6 °C and prepared at room temperature just before testing started. First the locking plate (LCP-DF, Synthes, Oberdorf, Switzerland) was placed relative to the bone according to the manufacturer's recommended surgical technique. This was also performed for testing the intact bone in order to ensure that all tested bones have equal preconditions. Angular stable drill guides were used for each screw to ensure the correct predetermined direction. All screws were placed bicortically. At the distal part of the plate all possible screws ($n = 7$) were set identical for all groups (Fig. 1a). Distal femur condyles

Table 1
Detailed group definitions of the biomechanical investigation (see Fig. 1d for illustration). The intact bone served as control group. Every group was tested at axial and torsional load according to the test protocol. To avoid a bias resulting from an unequal distribution of the anatomical side of the bone, the specimen was assigned to the groups with an equal right–left distribution.

Group	Short Title	*N*	Definition
A	Intact	10	Intact bone
B	4LS-lag	5	Anatomic reduction with interfragmentary lag screw and four locking head screws at the shaft
C	3LS-lag	5	Anatomic reduction with interfragmentary lag screw and three locking head screws at the shaft
D	3LS-lag-rem	5	Same as group 3LS-lag except lag screw was removed after shaft fixation in order to simulate temporary lag screw fixation intraoperatively
E	4LS	5	Anatomic reduction without lag screw fixation and four locking head screws at the shaft
F	3LS	5	Anatomic reduction without lag screw fixation and three locking head screws at the shaft

were embedded in poly-methyl-methacrylate cement (PMMA, Technovit 3040, Heraeus Kulzer, Wehrheim, Germany) in conically shaped molds with the epicondyles orientated parallel to the bottom of these molds. Modelling clay (Carl Weible, Schorndorf, Germany) was wrapped around the distal and proximal tip of the plate and the surrounding bone to allow plate movements and prevent fixation of the plate by the PMMA

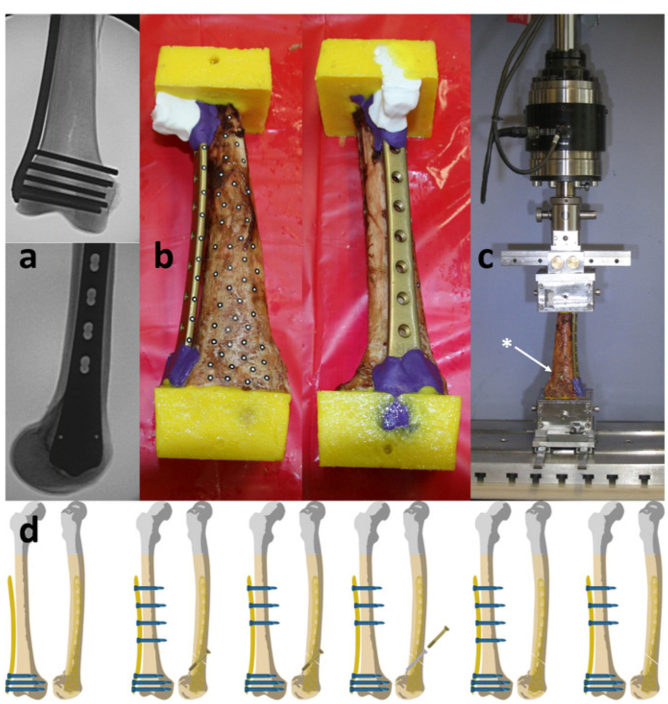

Fig. 1. Throughout all tests all distal screw options of the plate were used (a). In order to avoid embedding of the plate at the distal and proximal end modelling clay was used as shown (b). The prepared specimen was then tested according to the described test protocol. The picture (c) shows the setup of the biomechanical testing (*: insertion point of the lag screw at the anterior cortex). A schematic illustration of the different test configurations (please see also Table 1 for description) is additionally shown (d). First the intact bone (left) was tested, second the configurations with lag screw (second and third form the left) as well as the configurations without lag screw (first and second from the right) were tested. In addition the lag screw of group C was removed and the bone tested again (middle).

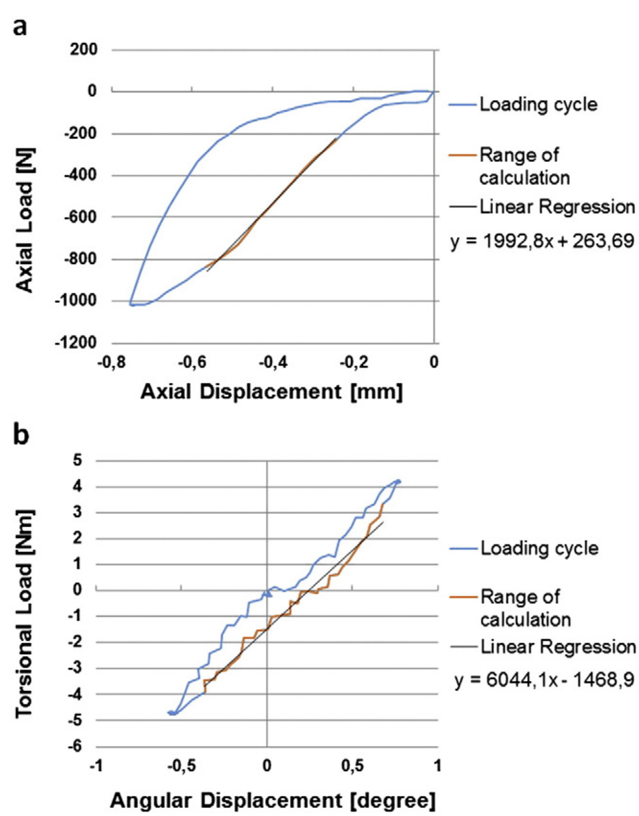

Fig. 2. In order to calculate the construct stiffness the resulting graphs were analysed by using the regression formula of the best fitting linear line for both axial (a) and torsional (b) loads. To standardise the calculation axial values between 20 and 80% and torsional values from 80% external to 80% internal of the load–displacement graphs were included. The shown graphs are examples of a 1000 N axial and 4 Nm torsional loading test.