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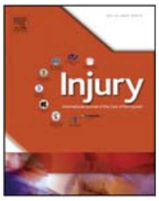

Influence of the number and position of stripped screws on plate–screw construct biomechanical properties

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KEYWORDS

screw stripping
stiffness
plate–screw construct

ABSTRACT

Introduction: Screw stripping is a common situation in fracture fixation, particularly in osteopenic bone treatment. Surgeons' perception of screw stripping is relatively poor and the real number of loose screws in every plate–screw construct is unknown. The biomechanical and clinical implications of the different possible screw-stripping situations are also unidentified. In this study, construct stiffness in different scenarios of stripped screws is investigated.
Method: A bone surrogate comminuted osteoporotic fracture was fixed with four screws in both sides of the fracture gap in 75 specimens. In four groups, one or two screws closest or distal to the gap were over-tightened and left in place in one part of the construct and the remaining screws were tightened with 0.3 N m torque (four groups). In the fifth group (control), all the screws were tightened with 0.3 N m torque. Construct stiffness was tested in terms of compression, bending, and torsion for 1000 cycles.
Results: When one or two screws closest to the gap were stripped, stiffness only decreased by, respectively, 5.7% or 7.6% under compression and 4.7% or 6.7% under bending; however, stiffness in torsion was 15.1% or 32%, respectively, lower than the initial stiffness. When a screw distal to the gap was stripped, the stiffness decreased by 28% under bending and 10% under compression; no change was noted under torsion. When two screws distal to the gap were stripped, the stiffness decreased by 11% in compression, collapsed under bending, and decreased by 8% under torsion.
Conclusions: Position and number of stripped screws affect the biomechanical properties of a construct in different ways, depending on the acting forces.

Introduction

Screw and plate osteosynthesis is one of the most common methods of fracture and osteotomy fixation, providing reliable fracture stability and union. Unlocked screw fixation is dependent on the force generated between screw threads and the bone. Thus, the use of this method is reliant on thread engagement in bone tissue and dependent on bone mineral density. Although fracture healing potential is not impaired in osteoporotic and osteopenic bone, fixation failure increases the risk of reduction loss, malunion, and non-union [1].

Furthermore, unlocked plate–screw construct fixation is highly dependent on compression between the plate and bone; the so-generated friction is necessary to maintain stability. The estimated minimum screw insertion torque required for construct stability is at least 3 N m [2]. However, with poor bone quality, screw stripping can occur before achieving the sufficient torque, leaving the construct unstable. Moreover, stripping torque has been suggested as an extremely important predictor of successful internal fracture fixation [3]. An adequate insertion torque is essential for primary stability of the fixation, whereas over-tightening can result in micro-failure of the bone around the threads, which could result in screw loosening or, particularly in osteoporotic bone, outright failure of the material around the threads and immediate loss of fixation [4].

In the clinical setting, most surgeons rely on their experience in tightening screws to plates, the "2-fingers tight" being the most used method. Experienced orthopedic surgeons typically tighten screws to 86% of the maximum insertion torque [5]. However, surgeons' perception is relatively poor considering the challenges on the extent of tightening and identifying whether or not screw stripping occurred. Stoetsz *et al.* found that surgeons detected stripping <10% of the times that it occurred, when testing with synthetic bones, and only after they had substantially bypassed the stripping torque [6]. Poor improvement after repeating the procedure eight times suggests that surgeons failed to recognise stripped screws [6]. One study found that at least one stripped

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screw occurs routinely during the internal fixation of displaced lateral malleolar fractures in up to 88% of patients >50 years [7]. Another study with elderly ankle cadaver found that 9% of screws were inadvertently stripped and 12% over-tightened during plating. However, no significant predictors of impending screw stripping were identified [8].

Once a screw is stripped, its purchase (pullout strength) is reduced by 80% and it no longer contributes substantially to plate fixation [9]. An 82% reduction in pullout strength was observed when 3.5 mm cortical screws were inserted into a bone model using correct Association for Osteosynthesis/Association for the Study of Internal Fixation techniques and subsequently over-tightened to screw stripping [9]. Wall *et al.* observed similar results (87% pullout reduction) when over-tightened screws were tested in cadaver radii [10]. Although the clinical consequences of over-tightening and inadvertently stripping screws are unknown, over-tightening may result in diminished pullout strength, which infers some damage sustained by the cortex and might lead to screw loosening and eventual loss of fixation [11].

Inadvertent screw stripping appears to be a real problem, albeit not sufficiently considered. Thus, this study aimed to investigate how the number and position of stripped screws, left in place, contribute to decreased construct stiffness and to compare the stiffness between the construct with stripped screws and that with perfectly engaged screws.

Materials and methods

Test preparation

Currently, a pronounced trend toward surrogate bone use when assessing fixation device performance exists [12]. Here, cylindrical polyurethane bars (length, 380 mm; diameter, 25 mm; Synbone, Malans, Switzerland), specially designed for the testing of devices used on bones with a high degree of osteoporosis [13,14] were used to simulate low bone density behavior and compare different screw loosening scenarios. A cross-section of the bar reveals an outer area (width, 1.6 mm), which simulates the cortical bone, and an inner area of lower density, which simulates the trabecular bone area. Initially, the bars were cut to obtain sections (length, 126 mm). An aluminum cylinder (length, 126 mm; diameter, 25 mm) was also manufactured. A 5-mm gap was chosen to simulate a comminuted osteoporotic fracture [15]. Thereafter, the corresponding plate was assembled, centered over the surrogate bone and aluminum cylinder bars with a 5-mm gap between them. A narrow 4.5/5.0 locking compression plate (LCP) (length, 188 and 13 mm wide; Synthes, Soleura, Switzerland) was used. This plate, which was made of stainless steel, has ten holes that can be used with both locking screws and normal screws (NS). In this study, NS with a diameter of 4.5 and length of 40 mm were used. Four NS were placed on both sides of the fracture gap and in the holes furthest from it (Figure 1).

Five different stripping scenarios were studied. To identify them clearly, the four screws placed on the bone side were labelled with numbers from 1 to 4 (Figure 1), starting from the screw in the hole furthest from the fracture. Table 1 shows the code of each of these five different groups and the torque applied to each of the labelled screws. The “X” in Table 1 means that the screw was stripped on purpose.

Table 1
Torque applied to each screw in the five different configurations (e.g. SS#12 means that screws 1 and 2 were stripped).

	Torque (N m)			
	Screw #1	Screw #2	Screw #3	Screw #4
RIG	0.3	0.3	0.3	0.3
SS#1	X	0.3	0.3	0.3
SS#4	0.3	0.3	0.3	X
SS#12	X	X	0.3	0.3
SS#34	0.3	0.3	X	X

The “X” means that the screw was stripped on purpose.

To strip the screws, a progressive torque was applied until stripping torque is reached. Thereafter, screwing continued; the final torque measured for these screws was close to 0 N m. The torque applied to the rest of the screws was 0.3 N m to avoid damaging the surrogate bone [16–18]. All torques were applied at <10 rpm, using a dynamic measuring gauge (Lorenz Messtecnik GMBH, Alfdorf, Germany).

Cyclic tests

A total of 75 cyclic tests (25 compression tests, 25 torsion tests, and 25 cantilever bending tests; $n = 5$ for each group) were performed up to 1000 cycles; load and displacement data (in compression and bending tests) and load and degree data (in torsion tests) every 100 cycles were recorded [19].

In the cyclic compression tests, stiffness (N/mm) was determined from the slope of the load–displacement curve. The constructs were subjected to a sinusoidal cyclic load at a frequency of 2 Hz, between 0 and 400 N. This test was characterized by a reference load of 200 N, with an alternating load amplitude of 200 N. The displacement and load values obtained by the machine’s sensor system were used to determine the stiffness. System stiffness or the maximum load–total displacement relationship was determined by the ratio F/δ (where F is the force applied by the machine in N and δ is the total displacement, from 0 to the current value, expressed in mm).

In the cyclic torsion test, the aluminum cylinder was fixed to the clamp of the testing machine, which applied the torque. On the opposite clamp of the testing machine, the surrogate bone cylinder had free axial movement to avoid axial load appearance during the test. A fully reversed sinusoidal load was applied to the constructs with a torque amplitude of 2 N m. Torsional stiffness (N m/deg) was calculated from the slope of the torque–rotation angle curve. System stiffness was expressed by the value of the relationship between the total applied torque and total rotation.

In the cyclic cantilever bending tests, the constructs were placed in the moveable lower system of the machine, with the load applied by a roller located in the upper fixed part of the machine. During the test, the lower moveable shaft was aligned with the upper fixed point of load application and the test specimen was moved upwards, causing the bending load. Total displacement δ (from 0 to the current value) and applied load data were recorded. Subsequently, with the geometric and boundary condition values known, the apparent bending stiffness

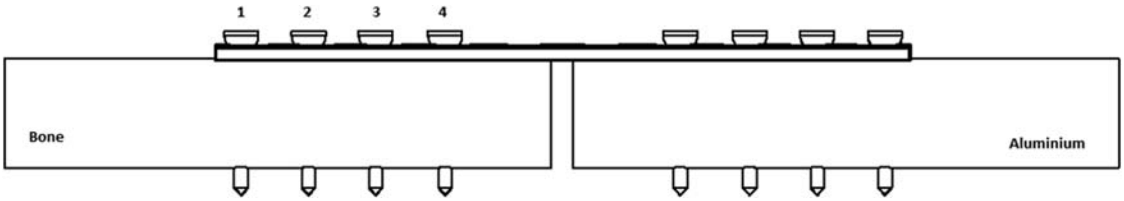

Fig. 1. Layout of the construct, with the labelled screws on the bone side.