Drilling the near cortex with elongated figure-of-8 holes to reduce the stiffness of a locking compression plate construct

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ABSTRACT

Purpose. To compare the stiffness of locking compression plate (LCP) constructs with or without drilling the near cortex with elongated figure-of-8 holes.

Methods. 24 synthetic bones were sawn to create a 10-mm gap and were fixed with a 9-hole 4.5-mm narrow LCP. In 12 bones, the near cortex of the adjacent holes to the LCP holes was drilled to create elongated figure-of-8 holes before screw insertion. The stiffness of LCP constructs under axial loading or 4-point bending was assessed by (1) dynamic quasi-physiological testing for fatigue strength, (2) quasi-static testing for stiffness, and (3) testing for absolute strength to failure.

Results. None of the 24 constructs had subcatastrophic or catastrophic failure after 10 000 cycles of fatigue loading (p=1.000). The axial stiffness reduced by 16% from 613±62 to 517±44 N/mm (p=0.012) in the case group, whereas the bending stiffness was 16±1 Nm² in both groups (p=1.000). The maximum axial load to catastrophic failure was 1596±84 N for the control group and 1627±48 N for the case group (p=0.486), whereas the maximum bending moment to catastrophic failure was 79±12 and 80±10 Nm, respectively (p=0.919).

Conclusion. Drilling the near cortex with elongated figure-of-8 holes reduces the axial stiffness of the LCP construct, without compromising its bending stiffness or strength.

Key words: bone plates; compressive strength; fracture fixation

INTRODUCTION

The locking compression plate (LCP) enables bridge plating in severely comminuted fractures or osteoporotic bones, while preserving blood supply to the bone by maintaining the space between the bone and plate.1–4 It promotes fracture union through secondary bone healing by callus formation.5,6 Nonetheless, the high stiffness of the LCP construct may suppress interfragmentary motion and result...
in suboptimal callus formation,\textsuperscript{7,8} and even atrophic non-union.\textsuperscript{9}

The need to reduce stiffness of the LCP construct to improve fracture healing has been recognised.\textsuperscript{10} Modification of the configuration of the plates or screws is unreliable, as it is not standardised. This study compares the stiffness of LCP constructs with or without drilling the near cortex with elongated figure-of-8 holes.

**MATERIALS AND METHODS**

24 synthetic bones (Synbone, Malans, Switzerland) simulating an adult osteoporotic femoral diaphysis (25 mm in tube diameter and 9 mm in canal diameter) were used. The stainless steel 9-hole 4.5-mm narrow LCP (Synthes, Zuchwil, Solothurn, Switzerland), 170 mm in length, was used. A 10-mm gap simulating a comminuted diaphyseal fracture was sawn in the middle of the bone.\textsuperscript{11,12} Fixation was made using the standard LCP construct, with a 10-mm block placed between the 2 fragments to ensure a uniform gap. The 9-hole LCP was placed on the bone, with the fracture gap lying on hole 5. Holes 1 to 3 and 7 to 9 were drilled with a 4.3-mm drill-bit (Fig. 1). The LCP screws were inserted and tightened with a power drill with the torque limited to 4.0 Nm. In 12 bones, the near cortex of the adjacent holes to the LCP holes was drilled to create elongated figure-of-8 holes (Fig. 2) before screw insertion. The far cortex was only tapped once by the LCP screws to preserve its strength.

Weight-bearing bones are subjected to both axial and bending forces during ambulation.\textsuperscript{13} The stiffness of LCP constructs under axial loading or 4-point bending was assessed by (1) dynamic quasi-physiological testing for fatigue strength, (2) quasi-static testing for stiffness, and (3) testing for absolute strength to failure.

Six controls and 6 cases were tested for axial loading. For the dynamic quasi-physiological testing, interfragmentary motion at the fracture site was recorded using a contact extensometer with 0.01 mm resolution (Fig. 3). Stiffness measured by the displacement of the loading actuator alone is considered less accurate.\textsuperscript{14} Estimated loading force at the start of weightbearing could be as high as 150%
of bodyweight. For an average adult weighing 70 kg, 150% of the bodyweight would be 1050 N and thus a loading force of up to 1100 N was used. After a static preload of 100 N, sinusoidal loading with load amplitude of 100 N was applied at 2 Hz. Every 1000 loading cycles, the load amplitude was increased stepwise by 100 N until 10 000 cycles or construct failure. Stiffness was recorded for 30-cycle bouts at the initiation of testing and at each 1000-cycle interval. Subcatastrophic construct failure was determined by comparing the stiffness of the construct at each 1000 cycles. Subcatastrophic construct failure was defined as a decrease in stiffness by &gt;25%, whereas catastrophic failure was defined as gross implant cut-out or fracture.

After testing for fatigue strength, the waist between the 2 adjacent holes forming the figure-of-8 was crushed to form an elongated hole at the near cortex (Fig. 4). The axial stiffness of the constructs was then evaluated non-destructively. For the quasi-static testing, axial loading force was gradually increased to 1100 N at 20 N/s for 6 cycles. To account for system settling, minor pre-loading of 50 N was maintained during testing and data from the first 3 cycles were discarded. The slopes of the load-displacement curves of the final 3 cycles were analysed over the entire loading range, and the mean axial stiffness for each LCP construct was calculated.

For testing for absolute strength to failure, axial loading force was gradually increased at 20 N/s until construct failure.

Six controls and 6 cases were tested for 4-point bending in a gap-closing direction over the whole plate length (Fig. 5). Similarly, the dynamic quasi-physiological testing was performed first. After a static preload of 1 Nm, sinusoidal loading with load amplitude of 1 Nm was applied at 2 Hz. Every 1000 loading cycles, the load amplitude was increased stepwise by 1 Nm until 10 000 cycles or construct failure.

The bending stiffness was then evaluated non-destructively. Bending force was gradually increased till a maximum of 11 Nm at 0.1 Nm/s for 6 cycles and minor pre-loading of 0.5 Nm was maintained during testing. The slopes of the load-displacement curves of the final three cycles were analysed over the entire loading range, and the mean bending stiffness for each LCP construct was calculated.

The absolute strength to failure was then evaluated. Four-point bending force was gradually increased at 0.1 Nm/s until construct failure.

Axial stiffness was calculated by dividing the axial loading force by the displacement amplitude. Bending stiffness was determined using the following formula: flexural rigidity = Fa^2 (3L-4a)/12y, where F was the total force applied (N), a was the distance between the upper and lower supports (55 mm), L was the distance between the lower supports (400 mm), and y was the displacement of the upper supports (mm).

One-way ANOVA with repeated measures test was used to compare the 2 groups for difference in axial and bending stiffness during fatigue loading. The unpaired t-test was used for other quantitative variables. A p value of &lt;0.05 was considered statistically significant.

Figure 4  The waist between the 2 adjacent holes forming the figure-of-8 is crushed to form an elongated hole at the near cortex.

Figure 5  Testing for 4-point bending of the locking compression plate construct.
For fatigue testing of axial stiffness, the 2 groups were comparable for the first 2000 cycles \((p=0.776)\), but the case group was significantly lower from the 3000 to 10 000 cycles \((p=0.037, \text{Fig. 6a})\). None of the 24 constructs had subcatastrophic or catastrophic failure after progressive, cyclical axial loading up to 10 000 cycles \((p=1.000)\).

For fatigue testing of 4-point bending stiffness, the 2 groups were comparable over 10 000 cycles \((p=0.366, \text{Fig. 6b})\). None of the 24 constructs had subcatastrophic or catastrophic failure \((p=1.000)\).

For quasi-static testing of axial stiffness, the axial stiffness reduced by 16\% from 613±62 to 517±44 N/mm \((p=0.012)\) in the case group, whereas the bending stiffness was 16±1 Nm² in both groups \((p=1.000)\).

For testing of absolute strength, the maximum axial load to catastrophic failure was 1596±84 N for the control group and 1627±48 N for the case group \((p=0.486)\), whereas the maximum bending moment to catastrophic failure was 79±12 and 80±10 Nm, respectively \((p=0.919)\). All 24 constructs failed due to bending of the plate and fracture of the diaphysis through the screw hole at the plate end.

### Discussion

The success of plate fixation is due to its moderate bending stiffness to provide adequate fixation to achieve callus union; its low axial stiffness enables the underlying bone to share the physiological stresses needed for bone remodelling.\(^{13}\) In our study, when the near cortex was drilled with elongated figure-of-8 holes, the axial stiffness of the LCP construct decreased by 16\%, but the bending stiffness of the construct did not decrease. This may be because the elongated figure-of-8 holes enable wider containment boundaries of the screw shaft in the near cortex in a unidirectional manner (in the axial plane only), thus allowing increased micromotion with loading only in the axial plane.

An optimal mechanical environment at the fracture site is important to the healing process.\(^{17-19}\) Reducing the axial stiffness of fixator-bone constructs from 700 to 500 N/mm significantly increases the rate of fracture healing.\(^{17}\) Substituting slots for holes at the near cortex is also able to reduce the stiffness of the LCP construct; axial stiffness and torsional stiffness are significantly reduced with the creation of at least 3 slots.\(^{20}\) Conversion of holes to near cortical slots would not cause loss of fixation stability or purchase, but it requires the use of a pre-manufactured jig.\(^{20}\)

Comparing far-cortical locking with conventional LCP constructs, the initial stiffness of the former averages 88\% lower in axial compression, 58\% lower in torsion, and 29\% lower in bending.\(^{11,21}\) The far-cortical locking screw is manufactured by Zimmer (Warsaw [IN], United States) as the MotionLoc screw, but it is not available or approved yet in many parts of the world. Our technique of drilling the near cortex

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**Figure 6** Testing for (a) axial stiffness and (b) 4-point bending stiffness of standard locking compression plate constructs and figure-of-8 constructs under progressive, cyclical loading until 10 000 cycles.

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**RESULTS**

For fatigue testing of axial stiffness, the 2 groups were comparable for the first 2000 cycles \((p=0.776)\), but the case group was significantly lower from the 3000 to 10 000 cycles \((p=0.037, \text{Fig. 6a})\). None of the 24 constructs had subcatastrophic or catastrophic failure after progressive, cyclical axial loading up to 10 000 cycles \((p=1.000)\). For fatigue testing of 4-point bending stiffness, the 2 groups were comparable over 10 000 cycles \((p=0.366, \text{Fig. 6b})\). None of the 24 constructs had subcatastrophic or catastrophic failure \((p=1.000)\). For quasi-static testing of axial stiffness, the axial stiffness reduced by 16\% from 613±62 to 517±44 N/mm \((p=0.012)\) in the case group, whereas the bending stiffness was 16±1 Nm² in both groups \((p=1.000)\). For testing of absolute strength, the maximum axial load to catastrophic failure was 1596±84 N for the control group and 1627±48 N for the case group \((p=0.486)\), whereas the maximum bending moment to catastrophic failure was 79±12 and 80±10 Nm, respectively \((p=0.919)\). All 24 constructs failed due to bending of the plate and fracture of the diaphysis through the screw hole at the plate end.
with elongated figure-of-8 holes provides a cheaper alternative. There were limitations to our study. The results were not fully validated against cadaveric bone. Torsional stiffness and strength were not evaluated owing to equipment and funding constraints. Further studies to test the effectiveness of this technique in different bone densities, and clinical studies are needed.

CONCLUSION

Drilling the near cortex with figure-of-8 holes reduces the stiffness of the LCP construct in a unidirectional manner (in the axial plane only) without compromising its bending stiffness or strength. This technique is simple and cost-effective, without the need for additional hardware.

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DISCLOSURE

No conflicts of interest were declared by the authors.

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