Optimal Screw Configuration in Locked Plates: A Biomechanical Study

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Summary

Introduction: The majority of new generation locking plates accept locked or conventional screws in the plate shaft. Biomechanical studies investigating an optimal screw configuration are rare. Within this study the bio-mechanical strength of different screw configurations were systematically investigated. **Material & Method**: Conventional, locked with and without bone / plate offset and hybrid screw configurations were tested. A bi-cortical osteoporotic diaphyseal model was simulated. **Results:** The position, number and type of the screw as well as the offset between plate and bone influenced the primary bending strength. A screw configuration with only locked screws reached the highest primary strength followed by a hybrid screw configuration of locked and conventional screws. When leaving an offset between plate and bone, the primary strength was reduced. **Conclusion:** The results of the study shows how the primary strength of the construct can be affected by the use of locking screws and reduced plate offset. The strongest construct was a fully locked plate with no offset; however a hybrid screw configuration using one conventional screw to place the plate on the bone, and locked screws to increase the strength, had similar properties. The larger the number of locked screws placed around the conventional one, the higher the primary strength.

1. Introduction

Most of today's available locking plates accept locked or conventional screws in the diaphysis. A few biomechanical studies have investigated different screw configurations regarding biomechanical strength [1][2][3]. Many reasonable screw configurations using only conventional screws, only locked screws or a combination of both screw types - hybrid screw configurations - are theoretically possible. The optimal screw configuration remains unclear.

From a biomechanical perspective, the primary strength of the bone/ implant construct is thought to be influenced by the screw configuration. Clinically, hybrid screw configurations might be the most commonly used construct. A study was set out, which aimed to systematically investigate the optimal screw configuration(s) for new generation locking plates in a diaphyseal fracture model.

2. Material & Method

Diaphyseal locking plates (AxSOS™, Basic Fragment Waisted Compression Plates, narrow, Ø5.0mm, Stryker®) were used for testing (Figure 1). These plates allow the choice between locked or conventional screws. To create a fixed angle construct a Locking Insert needs to be plugged into the standard hole followed by a locking screw.

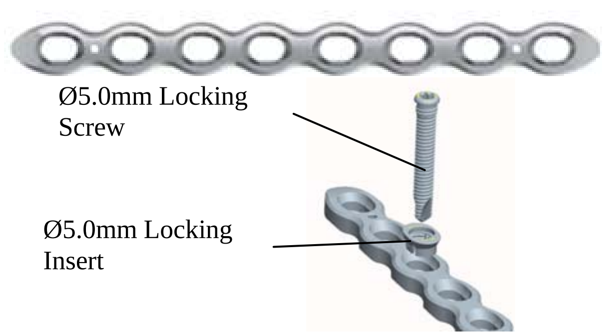


Figure 1: AxSOS™ Locking Plate System

A bicortical osteoporotic diaphyseal fracture model was created (Figure 2). On the right hand side the plate was rigidly fixed to a solid aluminium cylinder. On the left side the bicortical osteoporotic model was simulated using a solid slotted aluminium cylinder, equipped with 3mm thick PU-foam sheets placed medially and laterally (Solid Rigid Polyurethane Foam, grade 20, ASTM F1839, Sawbones® [4]).

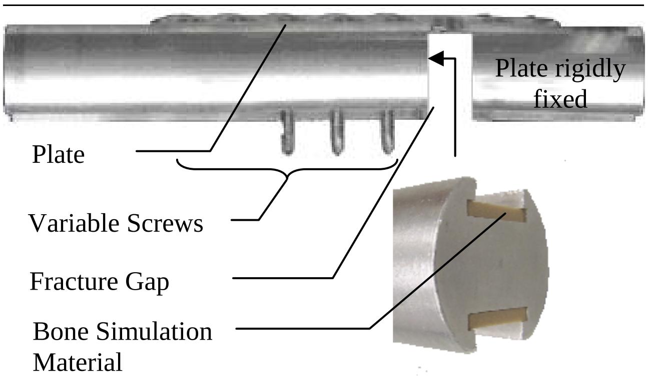


Figure 2: Fracture Model

Preliminary investigations at Bath University with Polyurethane foam grade 30 were made. Based on these results, the lower density model (PU grade 20) was selected for this enhanced study. A constant fracture gap of 10mm was simulated. The plate was placed on the tension side. For 3-hole and 5-hole screw configurations with various screw arrangements the following 4 scenarios were tested:

- Conventional screws with plate on bone
- Locked screws with plate on bone
- Locked screws with 2mm offset between plate and bone
- Hybrid

The screw configurations are shown in Table 1.

Table 1: Screw Configurations

8 hole plate							
variable					gap	rigid fixed	
Max. 3 holes occupied (3 hole configuration)		⊕	⊕	⊕		•	•
		O	⊕	⊕		•	•
		O	O	⊕		•	•
		O	⊕	O		•	•
		⊕	O	O		•	•
		⊕	⊕	O		•	•
		⊕	O	⊕		•	•
⊕	O	⊕	O	⊕		•	•
⊕	⊕	⊕	⊕	⊕		•	•

⊕ = locked or conventional screw; O = no screw, • = fixed

Additionally 4 hybrid screw configurations were tested (Table 2).

Table 2**:** Hybrid Screw Configurations

8 hole plate							
variable					gap	rigid fixed	
O	O	⊗	⊗	©		•	•
O	O	⊗	©	⊗		•	•
⊗	O	⊗	O	©		•	•
⊗	O	©	O	⊗		•	•

⊗ = locked screw, © = cortical screw, • = rigid fixed,
O = no screw

For the hybrid screw configurations, the conventional screws were inserted first, in order to place the plate on the bone. Afterwards, the locked screws were inserted. Each screw configuration was tested with five specimens. All specimens were constructed following recommendations of the manufacturer and assembled by an experienced surgeon. The locked screws were tightened to 4 Nm, the conventional screws to 0.2 Nm using a torque limiter. The 0.2 Nm corresponds to 50% of the screw stripping torque in this bicortical model. The screw stripping torque was derived by over tightening conventional screws while measuring the maximum applicable torque before failure (screw stripping).

A quasi static 4-point-bending test, similar to ASTM F382 – 99, with a constant crosshead speed of 5mm / minute, was performed (Figure 3).

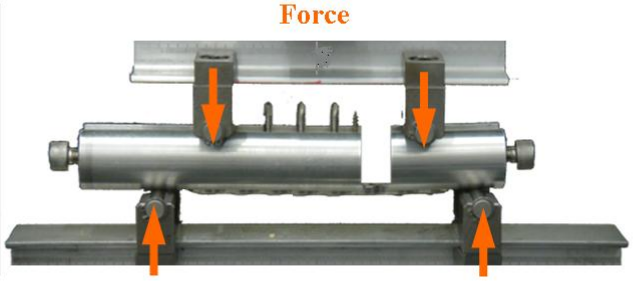


Figure 3: Test Set-Up

The test was stopped when failure (such as plastic deformation of an implant or construct collapse due to screw pull out failure) occurred. The force and the vertical displacement were recorded. The maximum failure force was then derived from the force displacement chart and defined as the primary strength. Finally the results were compared with a 1-tailed, non-parametric Mann-Whitney-Test ($p=<0.05$, SPSS).

3. Results [5]

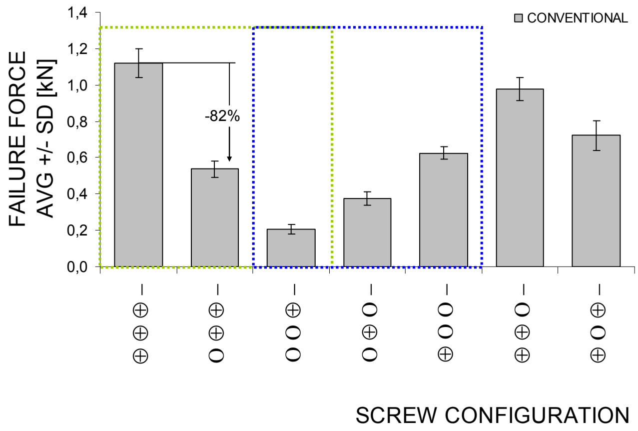
For all tested specimens screw pull out occurred. Only one screw configuration showed plastic deformation (irrecoverable bending) of the plate plus screw pull-out (Figure 4).

Figure 4: Failed Specimen

Preliminary investigation at Bath University with Polyurethane foam grade 30 showed higher primary strength values for all screw configurations. With this higher density foam model screw pull out and plate bending occurred for the more stable screw configurations. In particular, the 5-hole screw configurations failed mainly by plate bending, so that no differences between the various screw configurations could be observed.

3.1 3-hole screw configurations

Conventional



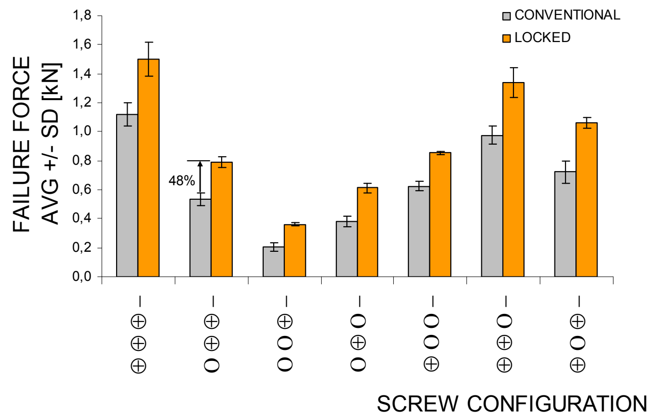
⊕ = screw, O = no screw

Figure 5: Conventional Screw Configurations

For the conventional screw configurations, variations of up to 82% between the different screw configurations were found (Figure 5). A correlation between the number of screws used (green) and the primary strength, as well as the screw position (blue) and the primary strength was determined. In summary, the results showed the following:

- The more screws used, the higher the primary strength.
- The bigger the distance between the fracture gap and the first screw, the higher the primary strength.

Conventional & Locked (without Offset)

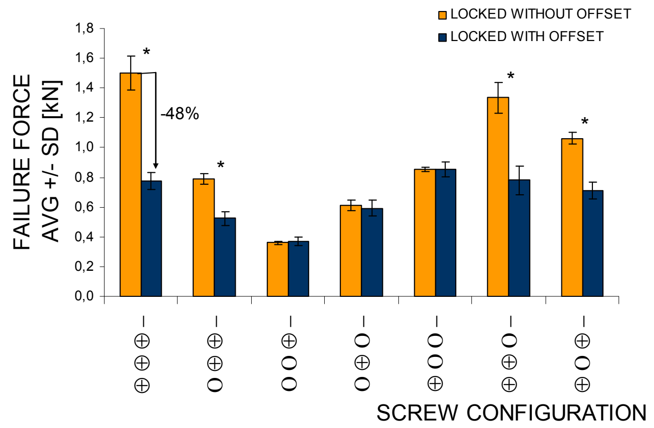


⊕ = screw, O = no screw

Figure 6: Conventional versus Locked Screw Configurations

Figure 6 shows a comparison between conventional and locked screw configurations without offset. Compared to the conventional screw configurations all locked screw configurations showed a statistically significant increase of the primary strength (p=0.008). This increase was biggest for the O⊕⊕- screw configuration (+48 %).

Locked with & without Offset

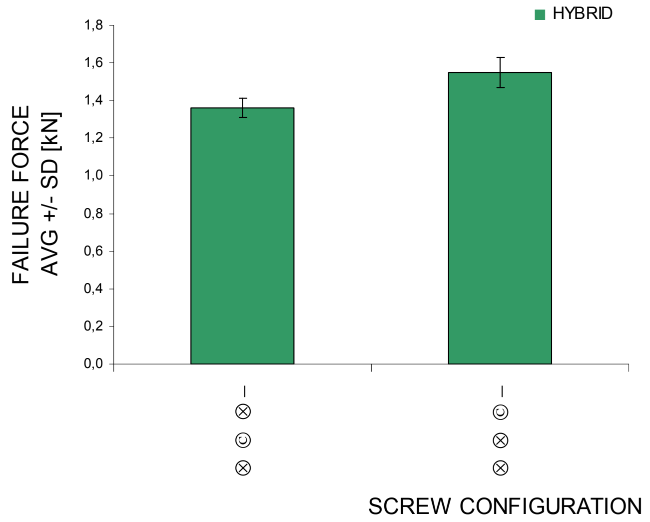


⊕ = screw, O = no screw, * = sig. difference

Figure 7: Locked Screw Configurations with and without Offset

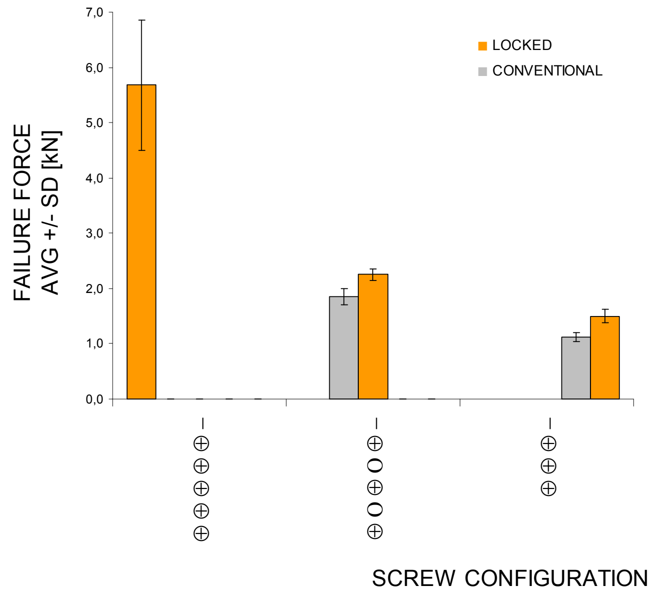
As shown in Figure 7, in more than 50% of the tested screw configurations a statistically significant decrease of the primary strength due to a 2mm offset between plate and bone was observed. This effect was biggest for the ⊕⊕⊕- screw configuration (-48%).

Hybrid



⊗ = locked, © = conventional

Figure 8: 3-hole Screw Hybrid Configurations



⊕ = screw, O = no screw,

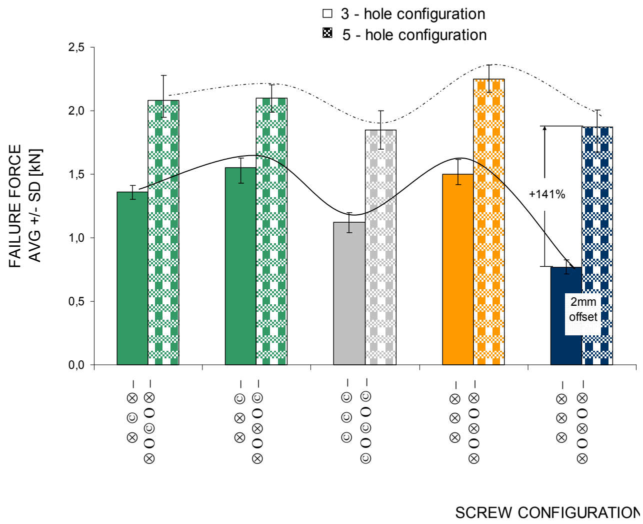
Figure 9: 5-hole and 3-hole Screw Configuration

The hybrid screw configuration, using one conventional screw near the fracture gap and two locked screws beside this screw (⊗⊗©-), provided the highest primary strength (Figure 8). However, in clinical loading conditions, bending may occur in 2 directions (i.e. the plate would be loaded in tension or compression). Considering this, the hybrid screw configuration with one conventional screw in the middle (⊗©⊗-) is advantageous. In addition, this hybrid screw configuration shows only a slightly lower primary strength of -9% compared to the fully locked screw configuration (⊗⊗⊗-).

3.2 5-hole vs. 3-hole screw configurations

The second part of the study consisted of testing 5-hole screw configurations. The primary strength results of 5-hole and 3-hole screw configurations are shown in Figure 9.

Comparing the primary strength of locked screw configurations without offset, the ⊗O⊗O⊗- showed 50% higher strength then the ⊗⊗⊗- screw configuration. For conventional screw configurations the ©O©O©-screw configuration showed a similar increase of primary strength (+65%) compared to the ©©©-screw configuration. The fully locked screw configuration with 5 screws (⊗⊗⊗⊗⊗-) showed an enormous gain of primary strength (+153%) compared to the ⊗O⊗O⊗- screw configuration. The reason for this is the increased number of screws, especially in the area far from the fracture gap. Furthermore, the fully locked screw configuration with 5 screws (⊗⊗⊗⊗⊗-) was the only screw configuration where plate bending plus screw pull out occurred as the failure mechanism. Generally, all 5-hole screw configurations provide a statistically significant higher stability than the 3-hole screw configurations, respectively (max. 141%, $p=0.008$). The trends between the different combinations of screws are similar for 3-hole and 5-hole screw configurations (see trend lines in Figure 10). Relative strength differences between screw configurations are larger in the 3-hole group than in the 5-hole group.



⊗ = locked, © = conventional

Figure 10: Comparison of 5-hole and 3-hole Configurations; hybrid, conventional, locked and locked with offset

In addition, the hybrid screw configurations did provide a higher primary strength than the conventional screw configurations and the fully locked screw configuration with 2mm offset. Furthermore the primary strength of the hybrid screw configurations was close to the level of fully locked screw configuration without offset. The primary strength of ⊗©⊗- screw configuration is reduced by 9%, (p=0,034) compared to the ⊗⊗⊗- screw configuration.

4. Discussion & Conclusion

The results suggest that the primary strength of the locking plate construct depends on the following variables:

- The number of screws used and the position of the screws
- The screw type (locked / conventional)
- The offset between plate and bone
- The locked length of the plate

The study only looks at the primary strength of the construct using a comparable model. Longer plates, reduced offset and increased number of locked screws all increased the strength. Hybrid screw configurations, using one conventional screw to reduce offset and locked screws, together with fully locked screw configurations provided the highest primary strength. By design, most locked screws do not control the offset between the plate and the bone. This might be a disadvantage regarding the strength as shown with this biomechanical investigation - the offset reduced the strength by up to 48% and clinically surgeons use the plate to aid fracture reduction (Figure 7). To benefit from the advantages of both screw techniques - locked and conventional - hybrid screw configurations are necessary. To optimize the primary strength, the following steps have to be considered: insert the conventional screws first to minimize the offset between plate and bone and therefore increase the strength, then insert the locked screws to provide additional strength to the construct. Because of the bending in both vertical directions a hybrid screw configuration with the conventional screw in the middle seems to be the most reasonable one for clinical use.

It could be considered that disrupting the cortical blood supply below the plate could make a difference to the fracture healing but this is a controversial topic and has never been demonstrated clinically. Also by compressing the plate on the bone, the soft tissue bulk of the implant is reduced, which was a reported problem with the first generation of locking plates [7]. Even if the fully locked screw configuration reached a slightly higher primary strength when compared to the hybrid screw configurations, this is difficult to control since an offset could drastically reduce the strength (see Figure 10). This investigation suggests that both hybrid screw configurations ⊗©⊗- or ⊗O©O⊗- might be the biomechanically optimal combinations for clinical use.

Since this is an in vitro investigation, these results may not reflect exactly the same relative clinical differences. However, in plate osteosynthesis screw pull out is a clinically common failure mode (see Figure 11) [6].

Figure 11: Clinical Failure, Reprinted from Publication Title, Vol 35, P. Hamilton et al. , Technical difficulty of metal removal after LISS plating, 626-628, Copyright 2003, with permission from Elsevier.

Since this was the only failure seen in this investigation, it might be concluded that the utilized test model generates clinically relevant results and therefore can be suggested as a valid set-up to compare different screw configurations.

To further improve the clinical relevance of this study, it would be advantageous to repeat specific plate/screw configurations using cadaveric bone to verify the results described above. Finally, such influences as bone quality, dynamic loading etc. were neglected and should be analyzed in further studies. The study is also limited as only primary strength is tested, while in clinical practice there may be a degree of local bone remodeling or osteoporosis around the screws and the implant which could influence the results.

The results of this study could help guide surgeons with regard to the optimal placement of plates and screws with the modern locking plating systems in treating diaphyseal fractures.

5. References

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