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Fracture reduction has a dominant effect over cerclage wiring in increasing stiffness of intertrochanteric OTA/AO 31-A3.1 (reverse oblique) fractures managed with cephalomedullary osteosynthesis

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Abstract

Objectives: To investigate the mechanical properties of cephalomedullary nailing of intertrochanteric OTA/AO 31-A3.1 (reverse oblique) fractures and to test the hypothesis that anatomical reduction and augmentation with cerclage wire produces a more stable construct.

Methods: A standardized fracture model in composite saw bone was created to stimulate an intertrochaneric 31-A3.1 fracture, using a 3D printed cutting guide. Simulated osteosynthesis was performed with 12 femurs divided into anatomically reduced and varus malreduced groups. Each femur was tested with and without cerclage wire augmentation. All femurs were fixed with a 215 mm, 130 degree, 11.5 mm nail. An Instron 8874 biaxial materials testing machine was used to assess the axial stiffness. Cyclic loading consisted of 5000 cycles of sinusoidal combined axial-torsion loading at 3 Hz. Axial load was 100 N to 2000 N and torsion −4.5 Nm to +4.5 Nm. Stiffness was measured before and after cyclic loading.

Results: Reduced constructs were stiffer than residual varus constructs. The mean overall fracture stiffness was 508.7 N/mm for reduced constructs and 379.2 N/mm for varus constructs. Removing the cables significantly decreased the fracture stiffness for both constructs (mean difference 60.0 N/mm, 95% CI 7.7–112.3, $P = .032$).

Conclusions: Anatomical reduction has a dominant effect on facture stiffness. Anatomically reduced fractures are stiffer than varus malreduced fractures. A cerclage wire further improves construct stiffness if anatomical reduction is achieved. Cerclage wiring is less effective if anatomical reduction is not achieved.

Keywords: femur, hip fractures, intertrochanteric femur fractures, trauma

1. Introduction

Reverse oblique fractures, or intertrochanteric OTA/AO 31-A3.1 fractures, account for 2% of all hip fractures and 5% of all intertrochanteric and subtrochanteric fractures.[1] They are a challenge to treat for anatomical and biomechanical reasons. The specific fracture line configuration compared with other types of intertrochanteric fractures produces increased fracture instability.[1] Cephalomedullary nailing is the preferred treatment option for both clinical[2–7] and biomechanical reasons.[8–10]

Poor reduction and surgical complications are common with intertrochanteric OTA/AO 31-A3.1 fractures,[11] with up to 20% of these cases not being reduced satisfactorily.[3] One-third of fractures historically fail to heal or show fixation failure.[1] More recent series have demonstrated better results.[5] The deforming muscular forces produce a characteristic varus deformity.[11] Varus deformity of the proximal femur contributes to non-union[12–15] and delayed union of fractures[16] and may increase length of inpatient stay and delay in return to preoperative mobility.[17] Bone loss and comminution can occur at the calcar, further reducing fracture stability[18] and increase the load sharing requirement of cephalomedullary nails.

The addition of a minimally invasive cerclage wire to achieve and maintain reduction before intramedullary nailing has been a

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relatively new concept to the orthopaedic literature and is most typically used in fractures in the subtrochanteric region.[14,15] There is less literature about the reverse oblique fracture pattern. The technique is typically used for oblique, spiral, or spiral wedge fractures in combination with clamp-assisted reduction when reduction cannot be achieved or maintained.[14] This decreases fracture displacement and reduces deformity,[19] facilitating bone contact and likely adds to the overall construct stability.[20]

The aims of this study were to investigate the mechanical properties of cephalomedullary nailing of intertrochanteric OTA/AO 31-A3.1 fractures in a saw bone model and test the hypothesis that anatomical reduction and augmentation with cerclage wire would increase construct stiffness, whereas non-anatomical reduction with cerclage wire would not increase stiffness.

2. Materials and methods

A standardized fracture model in composite saw bones (cancellous material only in proximal and distal ends) (left medium 3403-104 Sawbones, Vashon Island, Washington) was created to simulate an intertrochanteric OTA/AO 31-A3.1 ("reverse oblique") fracture. A 3D printed cutting jig was designed to hold the bones and allow reproducible and reliable cuts to create the intertrochanteric OTA/AO 31-A3.1 fracture pattern, using standardised cuts to remove the medial cortex with loss of the lesser trochanter and thus medial bone support in all groups. The fracture line was 55 degrees to the anatomical axis and commenced proximal to the lesser trochanter.

Simulated osteosynthesis occurred with 12 femurs divided into 2 groups of 6 (Fig. 1):

- Group 1: intertrochanteric OTA/AO 31-A3.1 fracture patterns that were anatomically reduced with cortical contact and cephalomedullary nail fixation.
- Group 2: intertrochanteric OTA/AO 31-A3.1 fracture patterns that were malreduced in varus and fixed without cortical bone support and cephalomedullary nail fixation.

Each femur in each group was tested sequentially with and without a cerclage wire around the fracture in a standardized position.

Fixation occurred using the 215 mm, 130-degree, size 11.5 mm Zimmer-Biomet Natural Cephalomedullary Nail (Warsaw, Indiana). The malreduction was designed to simulate a 10-degree varus deformity (Fig. 1). Standardized entry points and surgical technique were used for fracture fixation and a single static cross bolt applied. The entry point for the anatomically reduced group occurred at the medial tip of the greater trochanter in the posterior portion of the middle third of the trochanter and the malreduced group created with a 10-degree varus deformity on the lateral portion of the greater trochanter. This was created by using a standardized cutting guide. The proximal femur was reamed to 16.5 mm using a standardized guide to all femurs for passage of the nail. Distally canals were reamed to 15 mm over a guidewire to allow passage of the nail. 80 mm × 10.5 mm neck screws were inserted with a center–center position and a set screw inserted into the proximal portion of the nail and a 5 mm distal cross bolt placed in a static hole through the jig. Zimmer-Biomet cable-ready cable grip cerclage wire (Warsaw, Indiana) was placed proximal to the fracture line and distal to the lag screw and tensioned to 100 Newtons (Fig. 2). All specimens were prepared by the same authors (WH, SM).

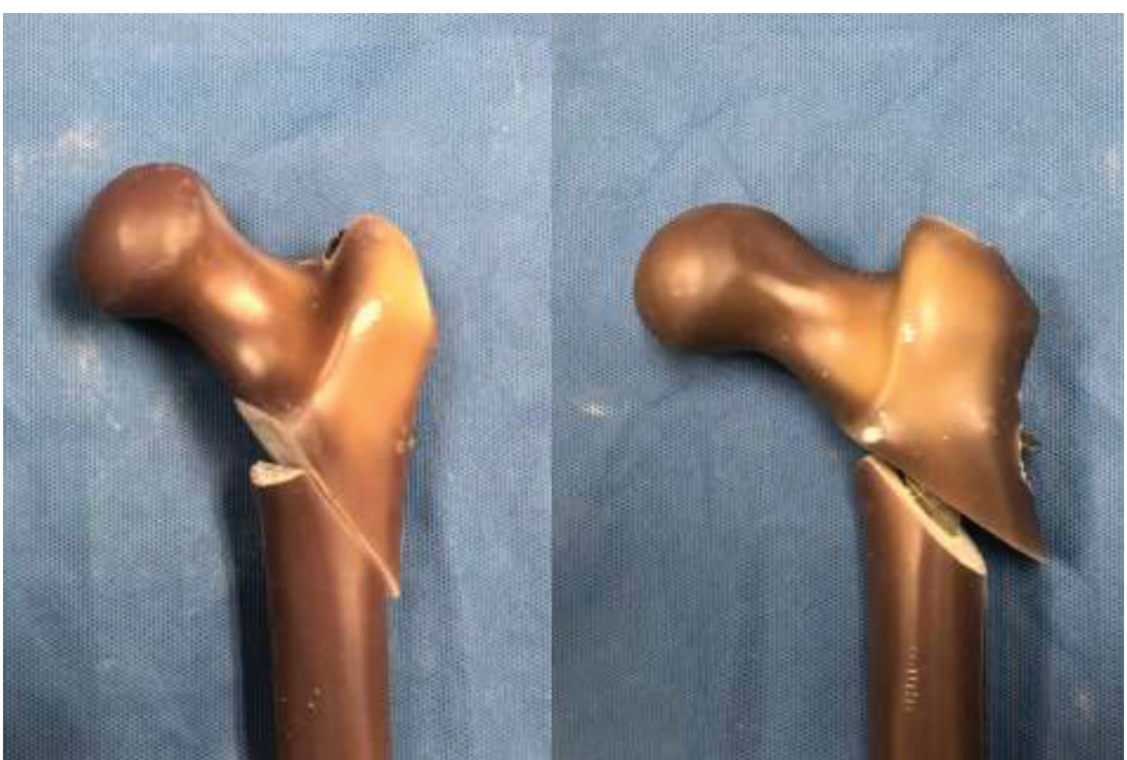

Figure 1. Clinical photograph of an anatomically reduced and a varus malreduced intertrochanteric OTA/AO 31-A3.1 ("reverse oblique") fracture prior to testing.

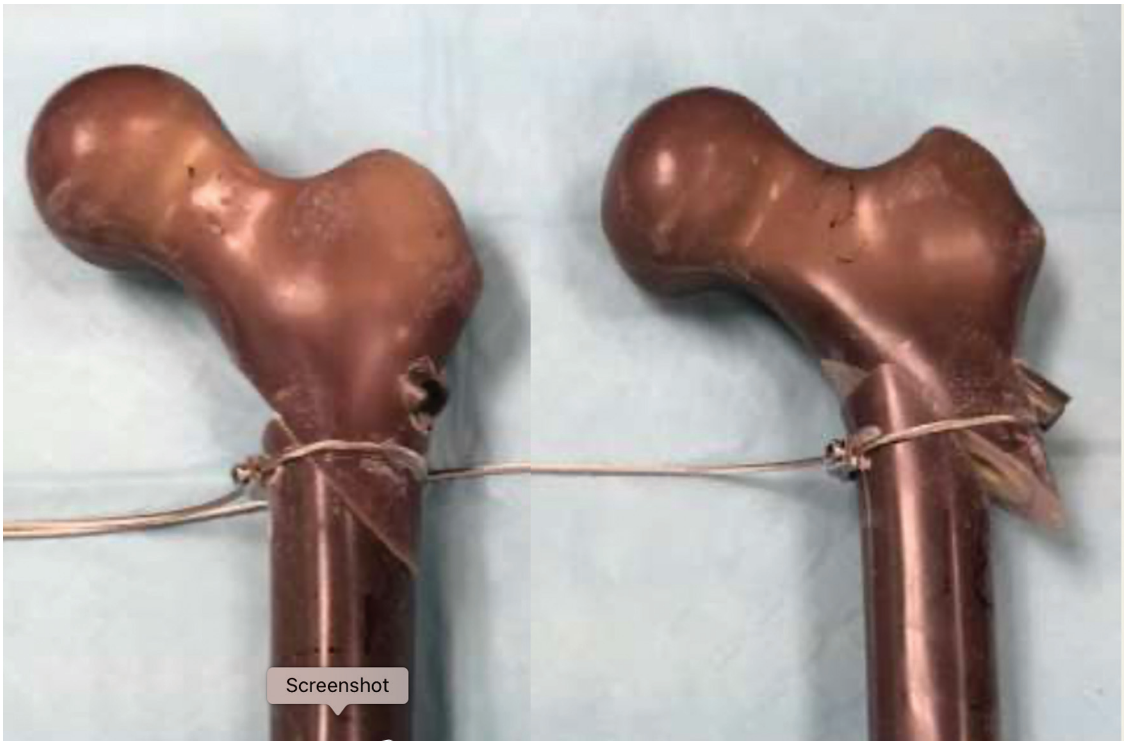

Figure 2. Clinical photograph of an anatomically reduced intertrochanteric OTA/AO 31-A3.1 fracture with cerclage wire and a varus malreduced intertrochanteric OTA/AO 31-A3.1 fracture with cerclage wire prior to testing.

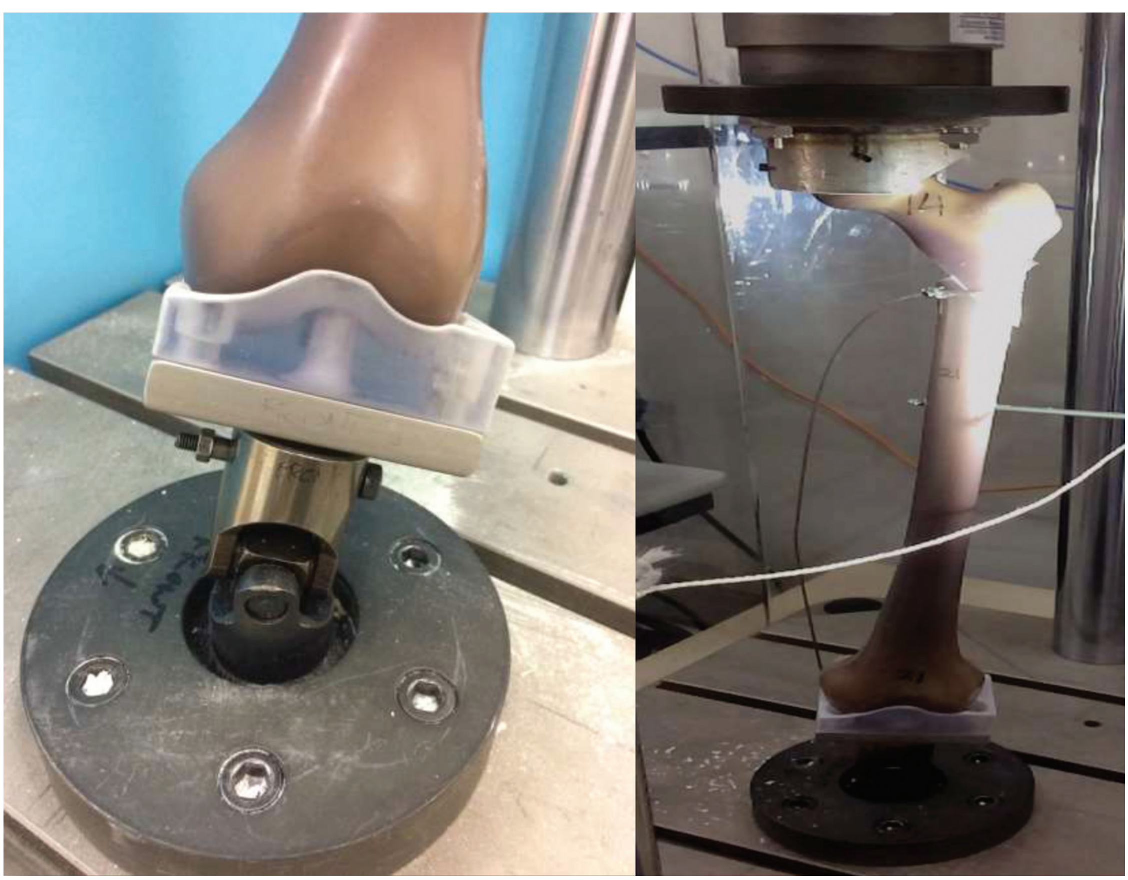

Figure 3. Clinical photograph of the custom fixtures used to secure the ends of the femur in the Instron testing machine in an unconstrained femur model.

Mechanical testing was performed at the Royal Perth Hospital Medical Engineering and Physics Department based on the work of Basci et al[21] and Henschel et al.[22] An Instron 8874 biaxial materials testing machine (Instron Pty Ltd, Melbourne, Australia) was used to load the constructs, which were loaded through ball joints at the hip and knee (Fig. 3). The mechanical axis of the femur was thus aligned with the axis of the testing machine. Both ball joints were constrained against translation and axial rotation, but free to rotate in the other axes.

A pilot study was conducted to evaluate the reliability of several test methods. Testing was planned under load control, but the samples proved too flexible so displacement control up to a load limit was used. This resulted in slightly variable maximum loads between cycles. The minimum axial load was set to 100 N to maintain contact with the hip joint throughout the test.

Cyclic loading consisted of 5000 cycles of sinusoidal combined axial-torsion loading at 3 Hz. The axial load was from 100 N to 2000 N and torsion from −4.5 Nm to +4.5 Nm. This sequence was applied to the same construct with and without the cable applied.

Axial stiffness was assessed before and after cyclic loading, then the cable was removed while the construct was still on the testing machine. Following cable removal, the stiffness and cyclic loading protocols were repeated.

The order of testing was:

1. Measure axial stiffness with cable.
2. Cyclic loading (axial and torsion).
3. Measure axial stiffness with cable.
4. Remove cable.
5. Measure axial stiffness without cable.
6. Cycling loading (axial and torsion).
7. Measure stiffness without cable.

For the stiffness tests, constructs were axially loaded to approximately 1500 N compression over 4 seconds while fracture motion was recorded. This was repeated 5 times and the stiffness calculated as the averaged slope of the load versus total displacement data (see later).

Pilot testing prior to study commencement confirmed that this protocol was a repeatable and reliable method of bone testing and that constructs should survive testing.

Statistical analysis was performed with R 3.6.2 (R Core Team, 2019) and RStudio 1.2.5001-3 (RStudio Team, 2019) running on OSX 10.12.6. Data were confirmed to fit a normal distribution (Shapiro–Wilk test and QQ plot), and intergroup comparisons were performed with the one-way ANOVA or paired *t* test, as appropriate.

3. Results

The stiffness measurements for each bone appeared repeatable and linear, with the worst fit having an r^2 of 0.992 and a standard error of residuals of 7.75%.

Anatomically reduced constructs were stiffer than varus constructs in all phases of testing and cerclage wiring was less effective if anatomical reduction was not achieved, as seen in Figure 4 and Table 1. The mean overall stiffness was 508.7 N/mm for reduced constructs and 379.2 N/mm for varus constructs (difference 129.5, 95% CI 88.5–170.5, unpaired *t* test $P < .001$). All constructs showed increased stiffness after cyclic loading (Table 1), which was greater during the first set of cyclic loading (with a cable) than the second (no cable), but in neither case was this change significant.

Removing the cables significantly decreased the fracture stiffness for both reduced and varus constructs (mean difference 60.0 N/mm, 95% CI 7.7–112.3, paired *t* test $P = .032$).

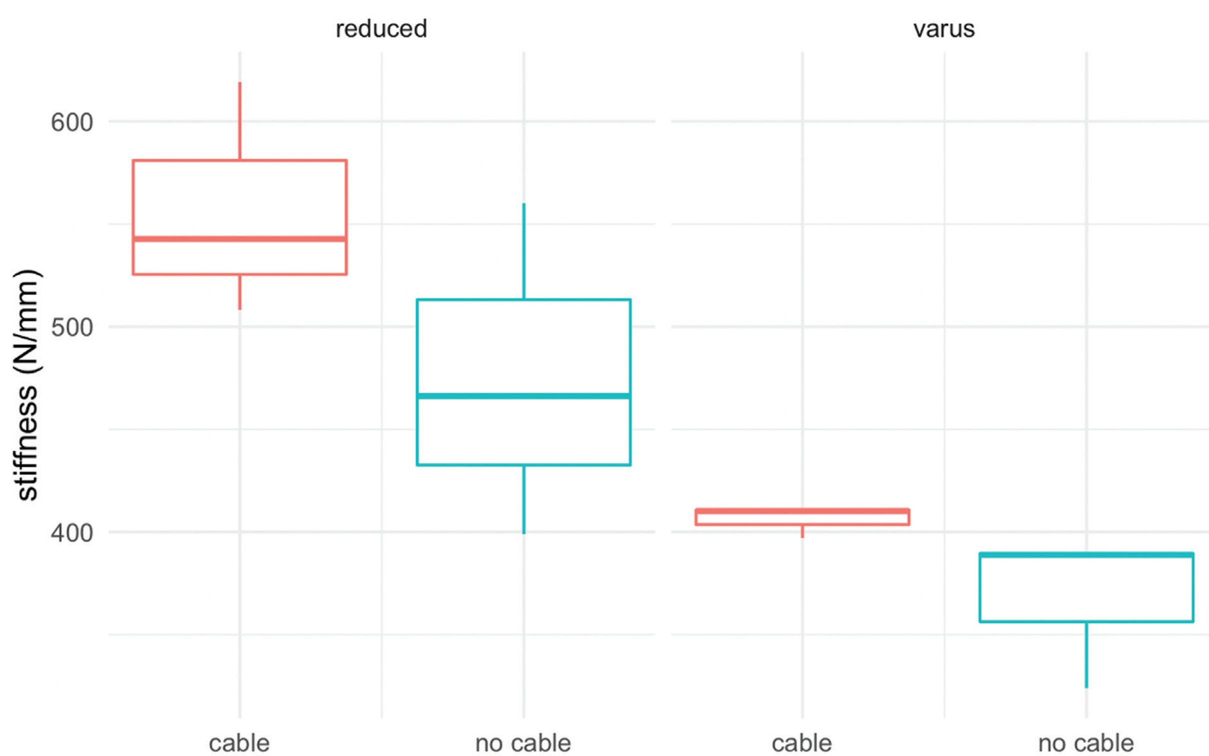

Figure 4. Boxplot of fracture stiffness for anatomically reduced and varus malreduced constructs post cycling, before and after cable removal.

Table 1

Mean (standard deviation) fracture stiffness (N/mm) for each construct (reduced and varus, with and without cable) both before and after cyclic loading

		Cable		No cable	
		Mean	**SD**	**Mean**	**SD**
Reduced	Pre cycle	507.2	48.2	475.1	81.0
Reduced	Post cycle	556.7	56.8	495.7	47.9
Varus	Pre cycle	363.7	36.6	367.7	37.9
Varus	Post cycle	406.1	7.9	379.2	21.4

4. Discussion

The main findings of this study were that anatomical reduction has a dominant effect on fracture stiffness, regardless of cerclage wire use or not. Anatomically reduced fractures were stiffer than varus malreduced fractures. Cerclage wire augmentation further improved the stiffness of the constructs. Furthermore, the effect of cerclage wiring was greater for reduced fractures. If the fracture was malreduced, cerclage wire augmentation did not affect construct stiffness as much as for reduced fractures.

This study supports clinical literature that anatomic reduction is the key to success in the management of fractures of the proximal femur.[16,19] It supports experiential knowledge that reduction is critical to stability and is often more critical than the specific implants used for fixation. A large series on reverse oblique fractures showed 46% of nonanatomically reduced fractures have treatment failure, using a variety of treatment methods.[1] Given the obliquity of the reverse oblique fracture pattern, it is a fracture that may be amenable to augmentation with a cerclage wire through minimally invasive methods,[14] or alternatively cerclage wire may be required to obtain and maintain an anatomical reduction. Our results clearly show that anatomical reduction has a dominant effect on fracture stiffness. Cerclage wire did not significantly impact construct stiffness unless an anatomical reduction was achieved. We would recommend that anatomical reduction must be achieved for reverse oblique fractures. A cerclage wire should be considered in situations where it helps obtain or maintain an anatomical reduction. If anatomical reduction can be achieved, it remains a surgeon's decision whether cerclage wire is necessary. We have shown some benefit for cerclage wire use with anatomical reduction to fracture stiffness. Although this may help prevent late varus displacement, the increased stiffness does not necessarily equate to more effective fixation. It is unclear whether cerclage wire use with anatomically reduced fractures has a clinical correlation and it is unproven whether increased stiffness influences fracture healing, ability to weight bear or other clinical parameters. Future research should target this.

There has been limited research investigating biomechanical constructs for reverse oblique fractures,[23] despite reports on the use of various implants.[1] One biomechanical study compared a 135-degree hip screw, a 95-degree hip screw, and an intramedullary hip screw.[23] This study found no difference in normalized stiffness between constructs before creation of a fracture gap. A fracture gap is likely to increase the load sharing requirement of the implant. After fracture gap creation, stiffness of all constructs was reduced. With the fracture gap, the intramedullary hip screw bone implant construct was significantly stiffer and had a greater load to failure. All models in our study were created with a loss of the lesser trochanter and medial calcar to simulate a missing medial support. The Kuzyk et al[23] study again supports the requirement for an anatomical reduction of reverse oblique fractures. The proven biomechanical support of an intramedullary nail may be why a publication from the Norwegian Hip Fracture Register has found the intramedullary nail to have less pain and greater mobility when compared with the sliding hip screw.[7]

The increase in stiffness following cycling loading was a surprising finding, we expected that cyclic loading would lead to cable loosening and reduced stiffness. This may have been due to impaction of the fractures during cycling. Wear debris from the foam core of the saw bones were observed after cyclic testing, which would support this idea. The smaller effect in varus constructs may have been due to the smaller area of bone contact or due to the locking of the proximal fragment on the screw, leading to reduced motion at the bone/implant or bone/bone interface. This effect is probably an artefact of using saw bones and is not likely to be a clinical issue. For this reason, we recommend future studies to use cadaveric models where possible as saw bone models and their limitations may not entirely be representative of clinical situations. This is a limitation of the study.

The main limitation of this study is our use of the unconstrained femur model, which meant we were not able to explore the influence of fracture reduction and cerclage augmentation on the failure mechanism. Other limitations of our study are the use of saw bones models that did not mimic osteoporotic bone. We attempted to create an unstable fracture model through loss of the medial calcar. Our fracture model cannot be extrapolated to all fracture patterns which are known to exist, notably lateral cortex comminution which may limit the use of cerclage wire.[24] These fracture patterns may be augmented by blocking screws or unicortical plates, and it is unclear whether these adjuncts would produce similar biomechanical results. Another limitation is that the saw bones are harder and smoother than bone. These factors reduce the grip of cerclage wires and increase the incidence of loosening. With fracture motion there was loosening of the cerclage wire, causing the fracture sites to impact, which affected testing. This would not have occurred with osteoporotic bone and is a feature from using hard saw bones. This study had only 6 femora in each group, although there was good reproducibility within groups. The good reproducibility may be partly attributed to using saw bones, which are all the same size, shape, and materials, but also to the use of 3D printed jigs which allowed very repeatable cuts and implant placement. The small number of samples means that the study has low statistical power. Despite this, a significant difference was detected between cable and no cable constructs. A significant limitation was that all constructs were tested with a cable for the first set of cyclic loading, then the cable was removed for the second set of cycles. Sequential testing was done for logistical reasons, and the order was chosen to minimize any effect from changing the construct. The cable could be quickly cut to remove it without affecting the construct or moving it in the testing rig, and without the need for orthopaedic instruments. Applying a cable to an already tested construct would require removal from the testing system to ensure it was done adequately. It is possible that loosening occurred during the initial testing given the loads and cycles applied, which may bias the results towards showing an effect of the cerclage. Furthermore, the clinical relevance of a cerclage wire applied after nailing a malreduced fracture, as we tested, is limited. In clinical practice, cerclage wire is used to hold a reduction prior to, and during nailing. Applying a cerclage wire across a malreduced fracture is not a typical clinical scenario. However, situations may exist where surgeons are unable to achieve a perfect anatomical reduction and a degree of malreduction is accepted. We showed that when fractures are not anatomically reduced, the application of cerclage wire does not increase fracture stiffness significantly, and any benefits of cerclage wire application without anatomical reduction must be questioned. Similarly, biologically, it remains unclear if increasing stiffness of a reverse oblique fracture fixed with an intramedullary nail and cerclage wire helps or hinders the process of secondary bone healing typically induced with intramedullary nailing. It is possible that the additional stiffness provided by the cable causes primary bone healing of anatomically reduced and compressed fracture fragments. It is also possible that the stiffness of the intramedullary nail plus the cerclage wire causes too much stiffness for secondary healing and too little for primary healing. Clinical series with radiographical follow-up are required to assess this. Lastly, we did not test to failure, although catastrophic failure of fixation is not a common complication in these fractures.

5. Conclusions

Anatomical reduction of intertrochanteric OTA/AO 31-A3.1 'reverse oblique' fractures is the dominant effect for fracture stability, regardless of cerclage wire use. Anatomically reduced fractures are stiffer than those with varus malreduction. A cerclage wire slightly increases construct stiffness if anatomical reduction is achieved. Cerclage wiring has minimal effect without anatomical reduction. Anatomical reduction of reverse oblique fractures should be the gold standard of care. Consideration should be given to augmentation with cerclage wire where it helps obtain or maintain an anatomical reduction and in situations of unstable fracture patterns such as with loss of the medial calcar.

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