TECHNICAL NOTE

Does Screw Order Matter? A Technique Tip to Prevent Loss of Fracture Reduction during Surgical Fixation of Lateral Malleolus Fractures

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Abstract

When obtaining surgical fixation of lateral malleolus fractures, a cortical lag screw is commonly used to obtain anatomic reduction. Subsequently, a neutralization plate is applied. Slight loss of fracture reduction after plate placement occasionally occurs. Although this is frequently attributed to poor bone quality or suboptimal initial lag screw fixation, a frequently overlooked factor is screw order when applying the neutralization plate. The purpose of this technique tip is to highlight the biomechanical rationale behind this loss of reduction and advocate a specific screw order for lateral malleolus fixation.

Level of evidence: V

Keywords: Ankle fracture, Biomechanics, Lateral malleolus fracture, Screw order

Introduction

Ankle fractures are one of the most common injuries treated surgically and have an increasing rate of incidence in the elderly.[1] After anatomic fracture alignment is obtained, a common fixation construct advocated by the Arbeitsgemeinschaft für Osteosynthesefragen (AO) is placement of a cortical lag screw perpendicular to the fracture, which affords interfragmentary compression and initial stabilization. A tubular plate and screw construct is then applied which neutralizes rotational forces.[2]

Slight loss of fracture reduction after plate placement occasionally occurs and is often attributed to poor bone quality or suboptimal initial lag screw fixation. While loss of initial reduction may be multifactorial, screw order when applying the neutralization plate is often overlooked. Previous biomechanical studies describe how the plate working distance in a final construct affects its rigidity across a fracture site, thus supporting the AO principle of minimizing the distance between the two screws closest to the fracture site.[3, 4] However, these studies describe the biomechanics after the construct is completed, but not how screw order during implantation of the plate construct can influence stability. To the best of our knowledge, there is no work in the current literature that has examined screw order and its potential effects on final fracture alignment. The purpose of this work is to illustrate the biomechanical importance of screw placement order when applying a neutralization plate to prevent or minimize loss of initial fracture reduction.

Technical note

Biomechanical rationale

The importance of screw order is directly related to appropriate plate contouring, ie. how well the plate contour matches the fibular cortical surface. When perfectly contoured, there is near uniform contact between the underside of the plate and the fibular cortical contour, and negligible bending forces are created by screw insertion. However, when a mismatch exists between plate contour and the fibular cortical surface, torque and bending forces are created upon screw application, making screw order an important consideration. It is especially important when the surgeon does not pre-contour the neutralization plate at all, instead asking for each screw to sequentially pull the plate down onto the bony surface without disrupting the fracture reduction. Depending on multiple factors, torque

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dissipation can either predominantly contour the plate or shift the fracture.

Precise plate contouring can be technically challenging and may be an overlooked aspect of fibular fixation. Appropriate medial/lateral as well as axial bending is required to maximize contact at the implant/bone interface. Significant variations in fibular morphology exist which may make even prefabricated anatomically contoured fibular plates ill-fitting.

Mathematically, the end goal is to minimize the torque applied on the fracture in the coronal, sagittal, and axial planes to minimize displacement. The force required to bend an imperfectly contoured plate by screw application must be countered by an equal or greater force in the bone to prevent fracture displacement. In the coronal, sagittal, and axial planes, the torque applied on the fracture with each screw insertion is minimized when the distance between the two screws (L) is maximized. Please see the appendix for the full mathematical proof of this. Therefore, the order of screw placement should be the farthest holes on the plate first in order to maximize L and minimize$Torque_{Fracture}$. Subsequent screws should then alternate proximally and distally towards the fracture, marching inwards.

It is important to separate this concept of maximizing the distance between the first two screws in order to decrease torque across the fracture site from the AO concept of minimizing plate working distance for fracture care.[5] The concept of minimizing plate working distance between the two screws closest to either side of the fracture strives to minimize motion at the fracture site, and only applies after the final construct is completed.[4,6] In contrast, the order of screw application strives to minimize fracture displacement during creation of the final construct.

Technique

Application of screws on a fibula neutralization plate often consists of a “drill-and-fill” mentality after initial reduction is obtained. However, this may inadvertently result in loss of reduction if the plate is not perfectly contoured to the fibula surface. While the seemingly intuitive solution is to contour the plate perfectly prior to application, this can be challenging due to need for bending in multiple planes. Furthermore, while intraoperatively a plate may appear well-seated to the cortical bone, visualizing all points of contact is difficult.

Thus, given the biomechanical rationales described above, the recommendation could be made to alternate screw placement both above and below the fracture site starting at the distal most screw hole and progressing inwards to minimize fracture site torque. However, practical considerations exist in-vivo that may alter the screw order from the theoretically optimal biomechanical sequence. For example, surgeons often limit initial incision exposure, therefore making the most proximal and distal screws more challenging options for initial fixation. Furthermore, initial screw placement in a central hole may allow for easier “seating” of the plate against the fibular cortex and assessment of proper rotational/translational placement in regards to the fibular long-axis.

We consider these biomechanical principles in the setting of technical and practical surgical considerations to recommend a specific screw order to minimize fracture torque and loss of reduction. Our preferred technique is as follows:

- After fracture, reduction is obtained and an interfragmentary screw is placed, the plate is precontoured and applied to the fibula for radiographic assessment [Figure 1].

Figure 1. Screw order for fibular plate. Fracture is reduced and lag screw is placed. Plate is provisionally placed onto the fibula

- First, a screw is placed proximal to the fracture site utilizing one of the more proximal screw holes. This allows for provisional positioning of the plate while still allowing slight rotational correction distally if required [Figure 2]. We recommend gently seating this initial screw given plate malleability and the potential for altering plate contour secondary to deformation if the initial screw is applied too rigorously.

Figure 2. Screw order for fibular plate. A screw is placed proximal to the fracture

- Next, a screw is placed distally, using either a cortical or a cancellous-type screw [Figure 3]. While the most distal screw hole can be utilized, it is our preference to use the second most distal screw hole to better seat the plate against the cortical bone. The most distal hole frequently covers the distal curve of the fibula contour and frequently sits slightly off the bone. Again, we recommend gentle seating of this second screw and confirmation that fracture reduction has not been lost.

Figure 3. Screw order for fibular plate. The second most distal screw is placed

- Additional screws are then placed in standard fashion working towards the fracture site with the most proximal screw placed last. The need for possible syndesmotic stabilization should be considered prior to filling all screw holes [Figure 4]. The initially placed first and second screws are then tightened in standard fashion.

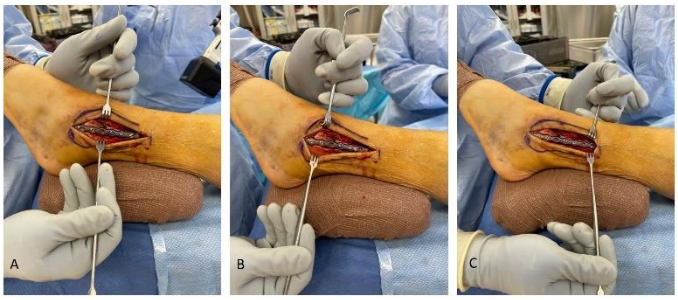

Figure 4. Screw order for fibular plate. Additional screws are placed working towards the fracture. The most distal and most proximal screws are placed last

Discussion

While loss of initial reduction in oblique lateral malleolus fractures may be multifactorial, improper screw order is a poorly recognized cause. This work considers biomechanical principles in the setting of practical surgical considerations to recommend a specific screw order when applying plate fixation to minimize fracture torque and loss of reduction attributable to suboptimal plate contour.

This work has some limitations to consider. First, while offering a practical approach to screw order based on simplified engineering principles, additional variables may affect maintenance of reduction in-vivo such as poor bone quality and presence of cortical defects. Furthermore, specific clinical situations such as the use of a push-screw technique (for fibular shortening) necessitates different screw order placement. Second, implant material properties such as metal type (stainless steel v. titanium), plate thickness, and design influence bending stiffness. Plate features including transitional thicknesses, edge contour, radius of curvature, and screw spacing vary widely amongst manufacturers and all influence the implant's mechanical properties. As such, specific implants may be differentially affected by screw order. For example, a rigid, thick stainless steel plate will be more likely to lead to fracture displacement with suboptimal screw order than a thinner, malleable titanium-alloy plate. Third, although we offer a biomechanical rationale for screw order to minimize fracture displacement, further research is required to demonstrate the clinical applicability of this concept.

Considering that "perfect" plate contouring may not be clinically feasible, we believe that minimizing torque across the fracture during plate application is important to prevent loss of reduction. We suggest the aforementioned screw order as a technique guide and highlight the importance of avoiding a "drill-and-fill" mentality when applying a neutralization plate for the fixation of distal fibula fractures.

Appendix mathematical proof

In the coronal plane, an imperfectly contoured plate can be simplified into a cantilever beam model.[7] The first screw fixes the plate at one end, and as the second screw is inserted, the second screw exerts a force (F) along the inter-screw distance (L) that creates a set amount of deflection (d). In a cantilever beam model, the mathematical relationship is:

$$F = K * d$$

Where K is the cantilever beam stiffness. The cantilever beam stiffness can be further refined as:

$$F = \left[\frac{3 * E * I}{L^3}\right] * d$$

Where E is the elastic modulus of the material (a fixed constant) and I is the moment of inertia of the beam. The moment of inertia in a plate is defined by the width (w) and thickness of the plate (t), such that the final equation is:

$$F = \left[\frac{3 * E}{L^3} * \frac{w * t^3}{12}\right] * d$$

Finally, we calculate the torque at the fracture site as:

$$\text{Torque}_{\text{Fracture}} = F' * L'$$

Where L' is the distance from the fracture site to the position of the second screw. As the second screw applies force F to the plate, there is an equal counterforce F' preventing the bone from translating towards the plate. Because F'=F, the torque at the fracture site is:

$$\text{Torque}_{\text{Fracture}} = \left[\frac{3 * E}{L^3} * \frac{w * t^3}{12}\right] * d * L'$$

We can see from this equation that as the screw moves more distal, both L and L' increase proportionally. However, because torque at the fracture site is inversely proportional to L to the third power and directly proportional to L' to only the first power, the greater the inter-screw distance L, the less torque is applied at the fracture site. This is summarized in [Figure 5].

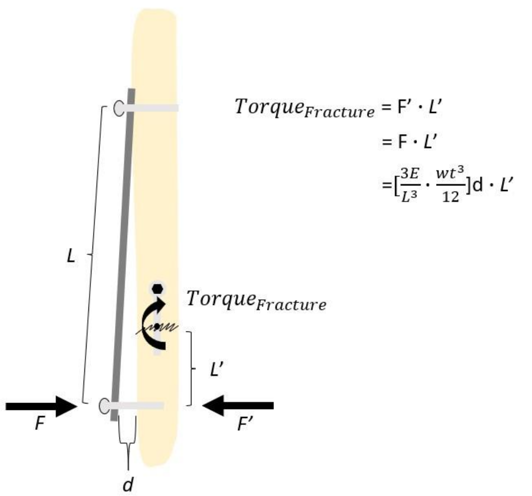

Figure 5. Torque in the coronal plane, modeled by the cantilever beam model. F= force imparted by screw insertion. F'=counterforce preventing bone from shifting towards the plate. L= distance between first and second screws. L'= distance from second screw and the fracture site. d=deflection distance. E=elastic modulus of plate material. w=width of the plate. t=thickness of the plate

In the sagittal plane, the torque required to insert the screw must be resisted by an equal/greater counter torque at the fracture site to prevent rotation in the sagittal plane. The torque required to insert a screw can be represented by:

$$\text{Torque}_{\text{Screw}} = K * D * F$$

Where K is a constant determined by inherent screw characteristics such as screw geometry and thread friction, D is the screw diameter, and F is the screw insertion force. From the model above, we know that:

$$F = \left[\frac{3 * E}{L^3} * \frac{w * t^3}{12}\right] * d$$

And therefore:

$$\text{Torque}_{\text{Screw}} = K * D * \left[\frac{3 * E}{L^3} * \frac{w * t^3}{12}\right] * d$$

Because the screw insertion torque must be resisted by an equal counter torque at the fracture site to prevent rotational displacement, we know that $\boldsymbol{Torque_{Fracture}} = \boldsymbol{Torque_{Screw}}$. Therefore:

$$\text{Torque}_{\text{Fracture}} = K * D * \left[\frac{3 * E}{L^3} * \frac{w * t^3}{12}\right] * d$$

Once again, torque at the fracture site is decreased by increasing the inter-screw distance L [Figure 6].

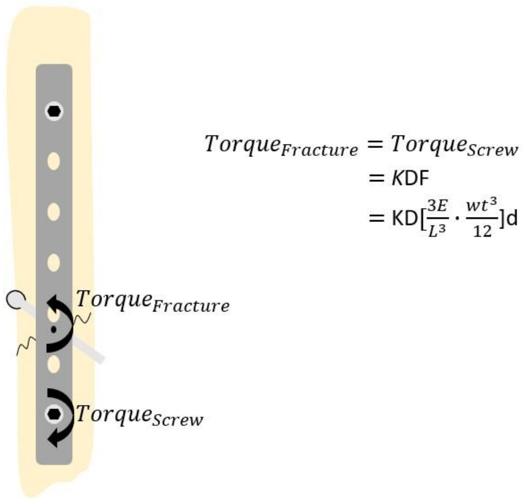

Figure 6. Torque in the sagittal plane. K=constant determined by inherent screw characteristics (screw geometry, thread friction). D=screw diameter. F=screw insertion force

Finally, torque in the axial plane can be represented by a model for beam torsion.[8] The torque required to twist a plate must be resisted by an equal/greater counter torque at the fracture site to prevent axial rotation. Thus, axial torque on a beam can be expressed as:

$$\text{Torque}_{\text{Fracture}} = \text{Torque}_{\text{Plate}} = \frac{\theta * G * I_t}{L}$$

Where $\boldsymbol{\theta}$ is angle of twist of the beam, G is the shear modulus of elasticity (inherent to the material), $\boldsymbol{I_t}$ is the St Venant torsional constant, and L is the length of the beam. For a thin rectangular beam, such as a fibular plate, where the width w >> t thickness (w/t ≥ 8), $\boldsymbol{I_t}$ can be simplified to:

$$T = \frac{\theta * G * w * t^3}{3 * L}$$

Similar to the coronal and sagittal planes, axial plane torque is minimized when L is maximized.

If instead screws are filled unilaterally on one side of the fracture first, as in a distal fibula fracture with all proximal screws placed prior to securing distal fixation, the plate's cantilever beam stiffness increases. In the formula:

$$\mathrm{Torque}_{\mathrm{Fracture}} = \left[\frac{3 * E}{L^3} * \frac{w * t^3}{12}\right] * d * L'$$

L has effectively shortened to the distance between the screws closest to the fracture proximally and the distal screw to be applied. $\boldsymbol{Torque_{Fracture}}$ is subsequently increased, thus risking displacement across the fracture site should the bone not be able to withstand that high of torque [Figure 7].

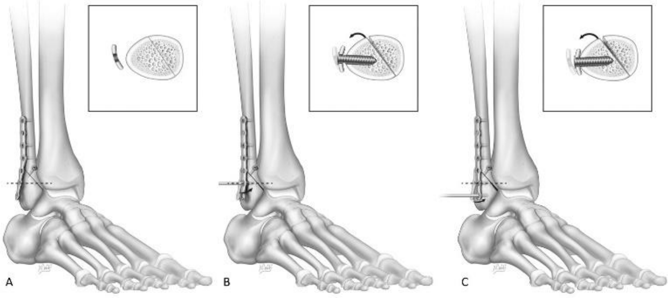

Figure 7.Diagram demonstrating fracture displacement with improper screw order. A. All of the screws proximal to the fracture are filled. The plate is imperfectly contoured. B. As the first screw is placed distal to the fracture, the fracture displaces towards the plate, as the plate is too stiff. C. Final distal screw is placed. Fracture is displaced

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