Effects of Lag Screw Design and Lubrication on Sliding in Trochanteric Nails

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Abstract
This study compared the sliding characteristics of three lag screw designs used with trochanteric nails and determined the effects of lubrication on sliding. They were tested by an established method to measure initiation and ease of lag screw sliding. These tests were then repeated with calf serum lubrication. There were significant differences ($p < 0.05$) between the loads required to initiate lag screw sliding that appeared to be related to design. Screw sliding was similar for all three designs; however, the presence of lag screw locking slots affected sliding in that region. Lubrication did not affect either parameter. Lag screw design aspects, such as diameter and, particularly, surface finish, affect sliding. Due to the small contact area between the lag screw and nail creating high interface stresses, lubrication had no effect on lag screw sliding.

Sliding of the lag screw in hip fracture fixation devices enables fracture consolidation and transmission of forces through the fracture site that are thought to be advantageous to healing. Lack of sliding (or jamming) may lead to nonunion or device failure. Previous studies of lag screw sliding have shown that for sliding hip screws\textsuperscript{1} the material of the device and lag screw angle were the most important determinant factors; whereas, for intramedullary nails,\textsuperscript{2} nail design was the most important factor.

In this experiment, nails of similar material, design, and lag screw angle were used in an attempt to focus on the effects of lag screw design, as it affects sliding. As the previous studies discussed frictional effects on sliding and mentioned but did not study lubrication, the current study also examined this factor.

Materials and Methods
This study is based on an elementary analysis,\textsuperscript{1,2} in which the hip joint reaction force (JRF) acting on the lag screw can be resolved into two forces, one acting perpendicular to the lag screw and causing bending ($F_b$), and a second acting parallel to the lag screw, causing compression and sliding ($F_c$), as illustrated in Figure 1. The previous studies\textsuperscript{1,2} assumed a stable fracture, where 75% of the JRF was borne by the bone, resulting in a calculated $220N$ $F_b$ on the lag screw.

Three short (11 mm x $\sim 170$ mm) titanium trochanteric nails and associated 100 mm standard lag screws were obtained for each of three design types: Gamma\textsuperscript{3} (Stryker, Mahwah, New Jersey), PTN (peritrochanteric nail; Biomet, Parsippany, New Jersey) and TFN (trochanteric fixation nail; Synthes, West Chester, Pennsylvania). These nails and lag screws have different surface finishes, possibly anodization treatments, resulting in differently colored appearances. The distal ends of the lag screws differ in design to achieve rotational locking (if desired) by the setscrew internal to the nail (Fig. 2).

These locking aspects start approximately 1 cm from the lateral end and extend approximately 3 cm. The Gamma\textsuperscript{3} lag screw has four slots, each with an arcuate bottom; the PTN has four small flat areas, each divided by ridges into four regions, and an end collar to prevent component disassociation. The TFN nail has a single, large flat region to engage a wedge driven by the setscrew. The end of the TFN lag screw is beveled, which lines up when the locking mechanism is engaged to be flush with the lateral aspect of the nail.

The dimensions of the nails and screw were measured with calipers ($\pm 0.0025$ cm). The nail and nail-screw angles ($\pm 0.5^\circ$) were measured with a protractor from digital images. The testing set-up was similar to that of two previous studies.$^{1,2}$ A servohydraulic testing machine (MTS; Eden,
Prairie, Minnesota) was used. The nail was held within a vise (using two side blocks for support) that was attached to a base platform (Fig. 3).

The position of the nail was adjusted so that the lag screw was perpendicular to the base, using an angle square, and the vise tightened. A moveable LVDT (linear variable differential transformer, Omega, Sanford, Connecticut) was used to check if nail bending or movement occurred during testing and to determine if the MTS displacement output for lag screw translation was correct. The head of the lag screw was held within the central aspect of an aluminum carrier, whose upper Teflon® coating rode against a Teflon®-coated platen attached to the MTS load cell.

Using a pulley and cord attached to the carrier, a load normal to the lag screw ($F_b$) could be applied; 220N was chosen to compare to previous testing. Compression was applied to the platen by the head of the lag screw at 1 cm per minute. Tests began when the lag screw was extended 8 cm (tip of screw to nail) and concluded after a distance of 4 cm was transversed. Three tests were run for each nail, with the lag screw rotated 5° within the nail, and the base platform holding the nail rotated 5° the other way to ensure new surfaces for each test. The testing was repeated after the lag screw was immersed in fetal calf serum as a lubricant before assembly; additional serum was applied at lag screw-nail junction immediately before testing.

A total of nine tests were run for each lag screw type in both the lubricated and non-lubricated conditions; load to initiate sliding and load to continue sliding as a function of distance were measured from load-displacement curves. The data were analyzed by a one-way ANOVA, with a Tukey post hoc test; $p < 0.05$ was considered significant.

**Results**

The measurements of the various nails are given in Table 1. The Gamma3 nail had a slightly smaller diameter lag screw compared to the TFN and PTN nails. The holes in the nail for the lag screws were larger for the TFN and PTN nails and did not have the same lateral and medial diameters. The TFN nail had a 5° lower lag screw-nail shaft angle than the other two nails.

The loads to initiate sliding are given in Table 2. The TFN lag screw had the highest load (44% greater than the PTN), followed by the Gamma3 and PNT. These differences between lag screws were significant. Lubrication had no apparent effect on these loads. A typical result of the applied compressive load-displacement response is shown in...
Figure 4. Once initiated, the loads for sliding decreased in a linear fashion. This decrease of 80N/cm was similar for all lag screws and was not affected by lubrication. The initial 2 to 3 centimeters of sliding was sometimes erratic for the Gamma3 and PTN lag screws, as shown in Figure 4.

Examination of the lag screws after testing showed some fine, longitudinal scratches on the Gamma3 and PTN screws; the TFN screws had much more damage, with the colored coating disrupted so that bare titanium was visible.

Discussion and Conclusion

This experiment found significant differences in the forces to initiate sliding between the three lag screws that were as high as 40%. Once sliding was initiated, the screws behaved similarly. Lubrication with serum had no effect on the initiation or continuation of sliding. Previous studies\(^1\,^2\) have shown nail type, material, and screw angle were the important parameters that affect sliding; however, in this case, these were relatively constant. It appears that for trochanteric nails, the diameter of the lag screw and, particularly, its surface finish were the important factors that affected sliding.

The nail-lag screw angle was 5° lower for the TFN nail than the other two nails, but the angle that affects sliding is the angle between the lag screw and the proximal portions of these nails, which are bent laterally. This angle ranged from 137° (TFN) to 142° (PTN). Calculation of the effect of these angle variations on the sliding force \(F_c\) shows approximately a 6% difference between the nails, with the PTN lag screw having the greatest \(F_c\) (easiest sliding). All these trochanteric nails would theoretically show greater ease of lag screw sliding, compared to standard 135° nails.

Lag screw geometry and its extension affect the elastic bending of the lag screw that has to be overcome for sliding to occur. In this case, the smaller diameter Gamma3 lag screw would be approximately 14% more resistant to sliding, because bending is proportional to the diameter cubed. Although a previous study\(^2\) showed a higher value of sliding resistance for the Gamma nail than standard nails with larger nail diameters, the Gamma3 is a later version, and in this experiment, nail diameters were similar. Because bending is also proportional to the distance, the lag screw is extended, all lag screws that were tested demonstrated a similar linear behavior, in that the sliding force decreased approximately 80 N/cm for each type. The locking slots did have a minor effect on the ease of initial sliding if they directly contacted the nail hole, particularly for the Gamma3 and PTN lag screws with four slots.

Theoretically, the contact between the lag screw and the internal hole in the nail would be a straight line, as the lag screw has a smaller diameter than the nail hole; however,

<table>
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<tr>
<th>Table 1</th>
<th>Measured Dimensions and Angles of the Nails and Lag Screws</th>
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<tbody>
<tr>
<td>Nail</td>
<td>Length of Screw Tip from Nail (cm)</td>
</tr>
<tr>
<td>Gamma3</td>
<td>8.6</td>
</tr>
<tr>
<td>TFN</td>
<td>8.2</td>
</tr>
<tr>
<td>PTN</td>
<td>8.3</td>
</tr>
</tbody>
</table>

\(^a\) angle of screw with longitudinal shaft of nail. \(^b\) angle of proximal portion of nail with longitudinal shaft of nail.
when the lag screw is loaded, it contacts this hole at its lateral and medial aspects at two points (Fig. 5).

In actuality, deformation of both the screw and nail at these contacts result in two small areas. The contact stresses on these areas are very high and explain the observation that lubrication has little effect on sliding, as it is squeezed out. These stresses also explain the observed coating disruptions, particularly with the TFN lag screw and its resulting higher sliding load.

There are several factors that limit the direct comparison of these findings to expected clinical behavior. The initial loading assumptions\textsuperscript{1,2} were based on a two-dimensional, static case of one-legged stance; whereas, actual loads are three-dimensional and dynamic. One study\textsuperscript{3} demonstrated greater sliding with the Gamma nail when it was cyclically loaded. Another factor was the assumption\textsuperscript{1,2} that the lag screw was bearing only 25% of the joint reaction force, which would not be the case in comminution or where the position of the head shifts due to poor quality bone. In this case, increased bending forces on the lag screw would increase resistance to sliding or possibly lead to jamming. This could also occur with a weighty patient or one whose femur requires a longer length lag screw.

In conclusion, lag screw design aspects, such as diameter and, in particular, surface finish, affect sliding. Due to the small contact area between the lag screw and nail, lubrication has no effect.

**Disclosure Statement**

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**References**


<table>
<thead>
<tr>
<th>Nail</th>
<th>Load to Initiate Sliding-N (SD)</th>
<th>Load to Initiate Sliding-Lubricated-N (SD)</th>
</tr>
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<tbody>
<tr>
<td>Gamma\textsuperscript{3}</td>
<td>379 (48)</td>
<td>388 (62)</td>
</tr>
<tr>
<td>TFN</td>
<td>458 (43)</td>
<td>451 (39)</td>
</tr>
<tr>
<td>PTN</td>
<td>319 (36)</td>
<td>327 (29)</td>
</tr>
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