Biomechanical Comparison of Axial Load Between Cannulated Locking Screws and Noncannulated Cortical Locking Screws

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abstract

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The goal of this study was to compare the biomechanical stability of cannulated locking screws and noncannulated cortical locking screws in a periarticular locking plate. Twelve fresh-frozen porcine tibias with a 1-cm gap created distal to the tibial plateau were used to simulate an unstable proximal tibial fracture. All specimens were fixed with a periarticular proximal lateral tibial locking plate and divided into 2 groups based on whether the proximal metaphyseal screw holes of the plate were inserted with either cannulated locking screws or noncannulated cortical locking screws.

An axial compressive load was applied to cause failure in each specimen using a materials testing instrument. The axial stiffness and maximum failure strength in axial loading were recorded. Axial stiffness of the constructs using noncannulated cortical locking screw was significantly higher than that of the constructs using cannulated locking screws (P = .006). Axial failure strength of the constructs using noncannulated cortical locking screw was significantly higher than that of the constructs using cannulated locking screws (P = .002). The failure mode observed in all specimens was a permanent screw-bending deformity over the head-shaft junction of proximal metaphyseal screws, irrespective of whether they were cannulated or noncannulated cortical locking screws.

Fixation with noncannulated cortical locking screws offered more stability than cannulated locking screws with regard to axial stiffness and failure strength in a porcine model with unstable proximal tibial fractures.
Complex proximal tibial fractures commonly require operative stable fixation to achieve an acceptable functional outcome. Depending on the fracture pattern, soft tissue condition, and bone quality, different fixation methods are recommended, such as internal fixation with plates and screws or external fixators.\textsuperscript{1-4} Several articles have reported that plates with locking screws provided greater stiffness and strength than conventional standard implants.\textsuperscript{5-7} Several factors were shown to influence stability, such as working length, the number of screws, the distance of the plate to the bone, and the thread diameter of the screw.\textsuperscript{6,8} None of these studies specifically addressed the stability of different locking screws in locking plate fixation.

Periarticular plates are anatomically preshaped, which improves the fit on the bone near the articular area and decreases soft tissue problems. Following the development of the periarticular locking plate (Zimmer, Inc, Warsaw, Indiana), various commercial locking screws became available for application in different conditions. Cannulated locking screws are designed to facilitate accurate placement around the metaphyseal area to prevent the joint from being penetrated. With this design, the 3.5-mm-diameter cannulated locking screw is inserted along the 1.6-mm-diameter drill tip guidewire. Noncannulated cortical locking screws have a solid cord and the same outer thread diameter and pitch as the cannulated locking screws (Figure 1).

To determine the stability of these 2 locking screws for use in a periarticular plate system, the authors designed a simulated unstable proximal tibial fracture model in vitro to investigate the biomechanical properties under an axial load.

\textbf{Materials and Methods}

\textbf{Fracture Model}

Twelve fresh-frozen porcine tibia specimens were used. All specimens were harvested from the left hind leg of 8-month-old pigs and divided into 2 groups, with 6 specimens in each group. Prior to testing, the bone mineral density (BMD), recorded in g/cm\textsuperscript{2}, of each specimen was detected using a dual-energy X-ray absorption meter (Lunar Corp, Madison, Wisconsin). The scan was taken over proximal one-third sections of each tibia specimen. Six-hole, 3.5-mm proximal lateral tibial periarticular locking plates were applied to each specimen before osteotomy.

In the cannulated locking screw group, cannulated locking screws for metaphyseal fixation were inserted in all 4 peri-articular metaphyseal holes in the plate; in the noncannulated cortical locking screw group, noncannulated cortical locking screws were inserted in all 4 periarticular metaphyseal holes. One 3.5-mm cortical locking screw and two 3.5-mm cortical screws were inserted into diaphyseal holes of the plate for distal fixation in both groups. The plates were positioned and screws were inserted according to the manufacturer’s recommendations.\textsuperscript{9}

An osteotomy was created using a precision-cutting saw to generate a 1-cm gap, which was approximately 1-cm distal to the articular surface.
(Figure 2). An additional diagonal cut was created in the distal medial cortex to prevent bone-to-bone contact during testing. Another cut over the proximal fibular was performed to limit support from the fibula during testing. Radiographs were taken of each specimen before biomechanical testing to ensure the proper implantation and osteotomy.

**Mechanical Testing**

After preparation of the specimens, the distal end of each tibia was embedded in a polymethylmethacrylate block, which was held in a custom metal cup. Another custom-designed mold was built as a contact interface for the compression of the proximal tibia articular surface. The mold was positioned for vertical axial loading that passed through the center of the tibial plateau and the mechanical axis of the tibia (Figure 3). All constructs were stored in a freezer at −10°C and thawed to room temperature (25°C) before testing. The tests were performed in the material testing system (QTest/10; MTS Systems Corporation, Eden Prairie, Minnesota).

**Axial Loading**

After stabilizing the construct with a preload of 100 N, axial compressive loading was performed with a loading rate of 0.1 mm/s to failure, which was defined as the point of initial load reduction caused by fracture, screw breakage, screw pull-out, or substantial hardware bending. The applied axial force was automatically recorded using the computer data acquisition system of the testing instrument, and the axial failure strength and initial stiffness were calculated. The failure mode of the constructs was evaluated after testing. Scanning electron microscopy analysis was also performed to examine the failure mode on the metal constructs.

**Statistical Analysis**

Statistical comparisons were performed using SPSS version 13.0 statistical software (SPSS Inc, Chicago, Illinois). Independent Student’s *t* test was performed to evaluate the axial failure load and stiffness between the 2 groups. The level of significance was defined at a *P* value less than .05.

**RESULTS**

Mean BMD values were 1.142 g/cm² (95% confidence interval [CI], 1.029-1.257 g/cm²) in the cannulated locking screw group and 1.197 g/cm² (95% CI, 1.084-1.301 g/cm²) in the noncannulated cortical locking screw group. No statistical difference was found in BMD values between the 2 groups. This confirmed that the bone specimens were randomized appropriately. The Table provides the data on axial stiffness and failure strength for both groups. The constructs in the noncannulated cortical locking screw group were 162% stiffer than those in the cannulated locking screw group, with a statistically significant difference (*P* = .006). The constructs in the noncannulated cortical locking screw group were 105% stronger than those in the cannulated locking screw group with regard to maximal load to failure, with a statistically significant difference (*P* = .002).

Permanent bending deformations were observed in proximal metaphyseal locking screws among all constructs, regardless of whether cannulated or noncannulated screws were used. The deformity location in all screws was at the head-shaft junction of the screw (Figure 4). No screw loosening, screw pullout, bone cutout, fractures, or hardware breakage was observed during the tests. The scanning electron microscopy fractographs of the sectioned surface over the bending location of screws showed a dimpled fracture surface with microvoid coalescence in cannulated locking and noncannulated locking screws.

<table>
<thead>
<tr>
<th>Variable</th>
<th>CLS Mean (95% CI)</th>
<th>NCLS Mean (95% CI)</th>
<th><em>P</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness, N/mm</td>
<td>79.05 (58.33-99.76)</td>
<td>207.37 (157.17-257.56)</td>
<td>.006</td>
</tr>
<tr>
<td>Failure load, N</td>
<td>490.91 (421.84-559.98)</td>
<td>1004.38 (868.59-1140.17)</td>
<td>.002</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; CLS, cannulated locking screws; NCLS, noncannulated locking screws.
cortical locking screw constructs (Figure 5). It typically indicated a tensile overload failure in ductile metal. It was compatible with the bending force over the screw following the vertical axial load in the model.

**Discussion**

The authors designed an osteotomy porcine tibial model to mimic a severe unstable proximal tibial fracture without bone-to-bone support. The model was created as a worst case scenario to test the biomechanical properties of cannulated and noncannulated locking screws in a periarticular plate. The periarticular locking plate was anatomically preshaped for use in humans; however, a 6-hole plate also fitted the shape of a porcine tibia, as observed in the current test.

An important observation during testing was that all constructs eventually failed due to a bending deformation at the head-shaft junction in proximal metaphyseal screws. Apparently, the head-shaft junction of the screws was a weak point. It is possible that the area was under stress concentration in both constructs. Scanning electron microscopy fractographs over the sectioned surface of the bending area of screws in both constructs exhibited a dimpled fracture surface, which was indicative of a tensile overload. It could prove that the failure mode was metal failure over the screw-shaft junction of proximal metaphyseal screws. In addition, this was compatible with the finding of permanent deformation due to bending.

In general, the pullout strength of screws is determined by many factors, including the pitch, thread shape, and diameter of the screw. Chapman et al reported a 20% pullout strength decrease in cannulated screws compared with noncannulated screws. However, other studies that tested the strength of pullout, torsion, and 3-point bending revealed no difference between cannulated and noncannulated cancellous screws. In the current study, none of the constructs failed by screw loosening, pullout, or cutout, although they might occur in clinical settings. It is possible that the BMD of specimens in the current study was higher than that seen in clinical populations.

Bone quality in the current study had to be relatively strong to hold the screws rigidly. In clinical settings, most patients with an unstable tibial plateau fracture tend to be either middle-aged or older and have moderate or high levels of osteoporosis. In addition, gradual BMD reduction might occur after an injury that could be caused by demineralization under partial load bearing and nonweight bearing. Correspondingly, a biomechanical analysis of cadaver femurs indicated that BMD was not a predictor of success or failure in the fixation of intracapsular hip fractures with cannulated screws or sliding hip screws. However, Ramaswamy et al reported that the holding power of screws was directly correlated with bone density, thread design, and the number of threads engaging the bone. Nevertheless, the values of BMD indicated no statistical difference between groups in the current study. Consequently, the decreased variability between specimens helped the authors reflect more meaningfully on the influence of different screws in the current study.

Gausepohl et al reported that fine screws with a smaller pitch displayed a stronger holding power on polyurethane foam and bovine cancellous bone. Thompson et al reported higher pullout strength in noncannulated than cannulated screws and showed a better holding power with long-thread screws. In a foal femoral bone study, Johnson et al reported that failure of the pullout test occurred by bone shearing at the bone-screw interface and that increasing the screw diameter beyond 6.5 mm would provide increasing holding power. However, these studies all reported conventional nonlocking systems. In the current study of a locking system, cannulated locking and noncannulated cortical locking screws were the same diameter, pitch, and thread, and no screw pullout was observed.

The reasons may be not only better bone quality in the current specimens, but the locking system may have also
provided more rigid fixation. With improvements in fixation designs and materials, no screw pullout was observed in the current study, but the noncannulated cortical locking screws presented superior stiffness and strength compared with the cannulated locking screws while under axial load. The cannulated hole occupied almost half the volume of the cannulated locking screw, which tended to decrease the bending strength of the cannulated locking screws compared with the solid ones. Larger-diameter cannulated screws may improve the strength while under axial load or could result in a different failure model. However, further study is needed for evaluation.

Structural stiffness is an important issue for the treatment of bone fractures. In previous reports, sufficient stiffness provided good stability for bone healing. However, osteoporotic or comminuted fractures, which have poor bone quality, could not undergo this type of treatment. Furthermore, the blood supply was obstructed because the periosteum was compressed by the plate. Not only can the locking plate be used for the treatment of osteoporotic or comminuted fractures, but it can also enhance the blood supply for secondary bone healing. Although many types of plates have been investigated, the appropriate range of structural stiffness is still necessary to enhance the quality and speed of bone healing.

Considering the stiffness and axial failure load, noncannulated cortical locking screws were more suitable than cannulated locking screws for periarticular fracture fixation. Even noncannulated cortical locking screws had a higher stiffness and axial failure load; postoperative limited weight bearing of a diseased limb with an unstable fracture is recommended until fracture union. It is still possible for a higher load to result in screw bending. Too much weight bearing could result in failure of noncannulated cortical locking screw fixation.

A previous biomechanical study about plate fixation over the distal radius reported that failure occurred due to the plate bending at the unfilled hole at the osteotomy side, which was a potential site of weakness. In the current study, no permanent plate bending deformity occurred. This might be because the plate in the current study was made of stainless steel and designed with a thicker feature in the diaphyseal area. It was strong enough to resist deformity within the failure load of screws.

Although this biomechanical study reports higher stiffness and strength in noncannulated cortical locking screws than in cannulated locking screws, the results cannot be directly extrapolated to the clinical setting in humans. Osteoporotic human bone could cause a different failure mechanism, such as bone fracture or screw pullout. Some study limitations exist. The analysis was limited in the axial loading test. The loading of real human bone in vivo is far more complex, including cyclic and torsional loading. More biomechanical experiments are necessary to test this line of research. In addition, clinical studies are required to validate these findings in vivo.

CONCLUSION

Noncannulated cortical locking screws are superior to cannulated locking screws for metaphyseal fixation using a periarticular locking plate system for an unstable tibial fracture in a porcine model. They provide a higher stiffness and stronger axial failure load in axial strength for the prevention of fixation failure. However, the experimental data need to be tested for clinical outcomes because larger screws and osteoporotic bone could have different strength results and failure modes. More biomechanical studies in vivo are needed to confirm these experimental findings. However, the findings provided evidence for orthopedic surgeons to use noncannulated cortical locking screws with peri-articular locking plates.

REFERENCES

