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Biomechanical Comparison of Cannulated Locking Screws and Non-cannulated Cortical Locking Screws in Periarticular Locking Plate- Porcine Proximal Tibial Fracture Model

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***Abstract*—The aim of this study was to compare the biomechanical stability of cannulated locking screws (CLS) and non-cannulated cortical locking screws (NCLS) in periarticular locking plate. Six fresh-frozen porcine tibias with 1-cm gap created distal to tibial plateau were used to simulate an unstable proximal tibial fracture. All specimens were fixed with periarticular proximal lateral tibial locking plate and divided into two groups: The proximal metaphyseal screw holes of plate were inserted with CLSs in the CLS group and NCLSs in the NCLS group. The preliminary results show that the axial stiffness of NCLS constructs was significantly 162% higher than that of CLS constructs (p=0.006). The axial failure load of NCLS constructs was significantly 105% higher than that of CLS constructs (p=0.002). The failure mode observed in all specimens was permanent screws bending deformity over head-shaft junction of proximal metaphyseal screws, irrespective of whether they were in the CLS or NCLS groups. In conclusion, periarticular locking plate with metaphyseal NCLS fixation provided more stability than that with CLS in axial stiffness and failure strength in the porcine model of unstable proximal tibial fracture.**

Key words: Biomechanical, Cannulated locking screws, Tibial unstable fracture

I. INTRODUCTION

Complex proximal tibial fractures are commonly required operative stable fixation to achieve an acceptable functional outcome. Depending on the fracture pattern, soft tissue condition and bone quality, different fixation methods can be recommended such as internal fixation with plates and screws or external fixators [1,2]. Many reports have demonstrated plates with locking screws could provide greater stiffness and strength than conventional standard implant [3,4]. Several factors were shown to influence stability, such as working length, number of screws, distance of plate to the bone, and thread diameter of screw. However, none of these studies specifically addressed the stability of different locking screws in locking plate fixation.

The periarticular plates are anatomically pre-shaped, which improves the fit on the bone near the articular area and reduces soft tissue problems. Following the development of the periarticular locking plate (Zimmer Inc., Warsaw, IN, USA), various commercial locking screws are available for applications in different conditions. Cannulated locking screw (CLS) is designed to facilitate accurate placement around the metaphyseal area in order to prevent the joint from being penetrated. With this design, the CLS in a diameter of 3.5 mm is readily inserted along the drill tip guide wire in a diameter of 1.6 mm. Non-cannulated cortical locking screw (NCLS) was with a solid cord and same outer thread diameter and pitch with CLS (Fig.1). To determine the stability between these two locking screws, a simulated unstable proximal tibial fracture model was used to investigate their biomechanical properties of cannulated and non-cannulated cortical in periarticular plate system.

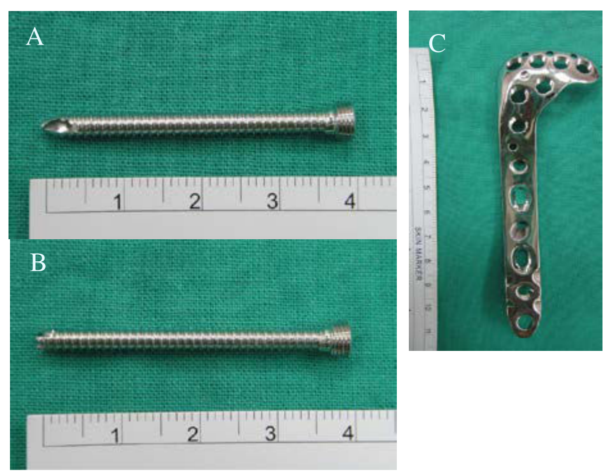

Figure 1. Feature of screws. A: Non-cannulated screw. B: Cannulated screw. C: periarticular locking plate.

II. MATERIALS AND METHODS

A. Fracture Model

Six fresh-frozen porcine tibia specimens were used in this study. All specimens were harvested from left hind leg of 8

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months-old pigs, and divided into two groups with three specimens each group. Six-hole 3.5-mm proximal lateral tibial periarticular locking plates were applied to each specimen before osteotomy. In CLS group, cannulated locking screws for metaphyseal fixation were inserted in all four periarticular metaphyseal holes in the plate; and in NCLS group, non-cannulated cortical locking screws were inserted. 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. Osteotomy was created using a precision-cutting saw to create a 1-cm gap distal to the articular surface about 1 cm of proximal tibia in each specimen mimicking an unstable AO/OTA 41-A3 fracture pattern (Fig.2). An additional diagonal cut was created in distal medial cortex to prevent the bone-to-bone contact during testing.

B. Mechanical Testing

The distal end of each tibia was embedded in to a polymethylmethacrylate block which was held in a metal cup. The mold was positioned to vertical axial loading that passed through the center of tibial plateau and mechanical axis of tibia (Fig. 3). The tests were performed on the material testing system (QTest/10, MTS testing Corp. MN. USA). All constructs were stored in a freezer at - 10°C and thawed to room temperature of 25°C before test.

Figure 2. Porcine model, unstable proximal tibial fracture porcine model: 1-cm gap created over proximal metaphysis distal to the articular surface about 1 cm.

Figure 3. Testing model, providing vertical axial load pass through the center of tibial plateau and mechanical axis of tibia in the specimen

C. 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/sec to failure. Failure was defined as the point of initial load reduction caused by fracture, screw broken, screw pullout, or substantial hardware bending. The applied axial force was automatically recorded by a computer data acquisition system of the testing instrument, and the axial failure strength and initial stiffness were calculated. Scanning electron microscopy (SEM) analysis was performed for the examination of failure mode on the metal constructs.

D. Statistical Analysis

Statistical analyses were carried out using Statistical Package for Social Sciences (SPSS) version 13.0. The data were presented as mean (95% confidence interval). The level of significance was defined at $p < 0.05$.

III. RESULTS AND DISCUSSION

The BMD values were 1.242 (1.129 to 1.357) g/cm^2 in the CLS group and 1.297 (1.184 to 1.401) g/cm^2 in the NCLS group. There was no statistical difference between two groups. This confirmed that the bone specimens were randomized appropriately. Table 1 demonstrates the data of axial stiffness and axial failure strength for both constructs. The constructs of NCLS group tended to be 162% stiffer than the CLS group with a statistically significant difference (p=0.006). The NCLS constructs were 105% stronger than the CLS constructs in maximal load to failure that carried with a statistically significant difference (p=0.002).

Table 1. Stiffness and Failure load in groups

	Cannulated locking screws	Non-cannulated locking screws	P
Stiffness (N/mm)	79.05 (58.33 to 99.76)	207.37 (157.17 to 257.56)	0.006
Failure load (N)	490.91 (421.84 to 559.98)	1004.38 (868.59 to 1140.17)	0.002

Values are the mean (95% confidence interval [CI])

Permanent bending deformations were observed in proximal metaphyseal locking screws among all constructs in cases of either cannulated or non-cannulated. The location of deformity in all bending screws was near the head-shaft junction of the screw (Fig. 4). However, less deformation was found in NCLS group than CLS one. No screw loosening, screw pullout, cut–out of the bone, fractures, or hardware broken was observed during the tests. The SEM fractographs of sectioned surface over the bending location of screws showed dimpled fracture surface with micro-void coalescence in both CLS and NCLS construct (Fig. 5). Typically, it indicated a tensile overload failure in ductile metal.

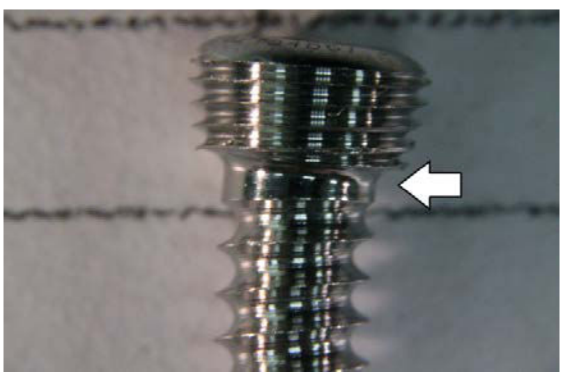
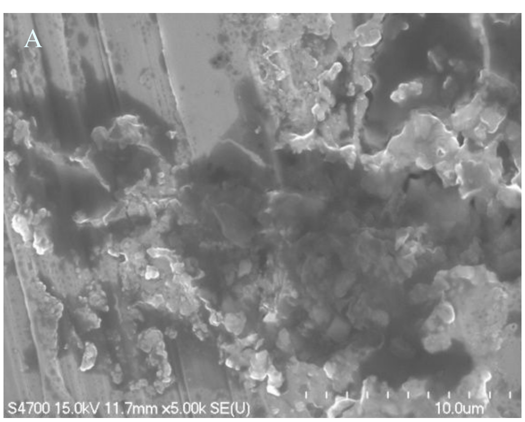


Figure 4. Mode of failure: permanent bending deformation over head-shaft junction of screw (see arrow)



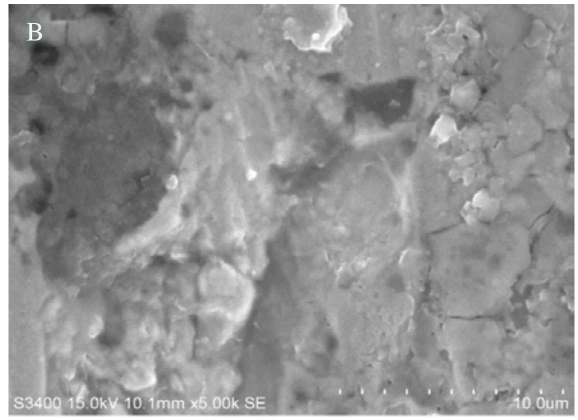


Figure 5. SEM fractographs of sectioned surface in bending deformity location presented microvoid coalescence. A: CLS group. B: NCLS group

We designed an osteotomy porcine tibial model to mimic severe unstable proximal tibial fracture without bone to bone support. An important observation during testing was that all constructs eventually failed by proximal metaphyseal screw bending deformation on head-shaft junction of screw grossly. Apparently, the head-shaft junction of screw was potentially a site of weak point. SEM observation on the sectioned surface of bending area of screws in both constructs exhibited dimpled fracture surface which was indicative of a tensile overload. It could prove the failure mode was metal failure over the screw-shaft junction of proximal metaphyseal screws. And, this was compatible to the finding of gross observation.

The structural stiffness is an important issue of the treatment of bone fractures. In previous concept, sufficient stiffness provided good stability for bone healing, e.g. conventional compression plate which led to primary bone healing. However, osteoporotic or comminuted fracture which has poor bone quality could not use this kind of treatment. Furthermore, the blood supply was obstructed due to the periosteum was compressed by the plate. Locking plate not only can be applied to the treatment of the osteoporotic or comminuted fractures but enhance the blood supply for secondary bone healing. Although many kinds of plate were investigated, the appropriate range of structural stiffness was still necessary to enhance the quality and speed of bone healing. Considering of the stiffness and axial failure load, NCLS was more suitable in periarticular fracture fixation than CLS. Even NCLS provided higher stiffness and axial failure load, postoperative limited weight bearing of diseased limbs with unstable fracture was suggested until fracture union. Too higher load was still possible to result in screw bending.

Though this biomechanical study presented higher stiffness and stronger strength in NCLS than CLS, the results cannot be directly extrapolated to the clinical setting in human. There are some limitations in our study. 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 in this line of research. Besides, the clinical studies are required to validate these findings in vivo.

IV. Conclusion

In summary, NCLS are superior for metaphyseal fixation than CLS in a periarticular locking plate system in porcine unstable tibial fracture model. It provides higher stiffness and stronger axial failure load in axial strength for the prevention of fixation failure. However, the experimental data may not be relevant in clinical outcome. More biomechanical studies in vivo are needed to confirm these experimental findings.

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