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Biomechanical evaluation of various fixation methods for proximal extra-articular tibial fractures

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ABSTRACT

Objective: Proximal tibial fractures are a challenging clinical problem. The treatment protocols for these fractures include a dynamic compression plate (DCP), a locking compression plate (LCP), interlocking intramedullary nailing (IMN), and external fixation (Ex-Fix). However, the optimal fixation method for proximal tibial fractures remains controversial. The purpose of this study was to investigate the biomechanical properties of these four fixation instruments in the treatment of tibial proximal fractures.

Methods: Thirty-two tibial specimens were retrieved and randomly divided into four groups. Extra-articular proximal tibial fractures (AO classification 41-A2) were created in each specimen. The fractures were subsequently fixed by DCP, LCP, IMN, and Ex-Fix. The bone density of the proximal tibiae was examined by quantitative computed tomography. Each specimen was subjected to axial compression and three-point bending tests.

Results: Bone mineral density did not significantly differ among the groups. In compression testing of the four fixation instruments, the highest degree of axial stiffness was found in the IMN group; there was no significant difference between DCP and LCP groups ($P > 0.05$). The results of the three-point bending test revealed that DCP demonstrated the highest bending stiffness, which differed significantly from the other groups ($P < 0.05$). The Ex-Fix had the lowest level of stiffness during the compression and three-point bending tests.

Conclusions: IMN has good mechanical properties, but its clinical application for proximal tibial fractures often leads to malalignment deformities. Compared with DCP, LCP is strong enough to fix the proximal tibial fractures and has the additional benefit of minimally invasive surgery.

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1. Introduction

Nonarticular proximal third fractures account for approximately 5%–11% of all tibial shaft injuries and result from a variety of mechanisms. Proximal tibial fractures present unique treatment challenges [1]. Fracture reduction and stability are dependent on proximal control. Optimal functioning of the proximal tibia requires coronal and sagittal plane

This study was performed at Research Institute of Testing Machine, Changchun, China.

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alignment and angulation, in addition to correct rotational alignment. Treatment protocols for these fractures include dynamic compression plates (DCPs), locking compression plates (LCPs), interlocking intramedullary nailing (IMN), and external fixation (Ex-Fix). IMN is an effective method for the treatment of tibial fractures and is especially effective in the fixation of diaphyseal tibial fractures. However, the treatment of proximal tibial fractures by IMN remains controversial [2]. The LCP has been widely used in recent years for the treatment of tibial fractures [3]. The optimal fixation method of these fractures remains controversial, and improper fixation usually leads to an unsatisfactory prognosis. To our knowledge, a biomechanical comparison among DCP, LCP, IMN, and Ex-Fix has not been reported previously. The purpose of this study was to compare the biomechanical properties of these four fixation constructions in a proximal fracture model using cadaveric bone.

2. Materials and methods

2.1. Specimen preparation

Thirty-two fresh and unembalmed tibial specimens were obtained from 16 voluntarily donated adult cadavers. Fluorescent screening of the tibiae was performed to eliminate any gross pathology. The average tibial length was 360 mm (range 310–405 mm). The tibiae were cleaned of any soft tissues, vacuum packaged, and subjected to cryopreservation at -20° within 1 h of harvesting. The average storage duration before examination was 7 d. The 32 fresh tibia specimens were randomly classified into four treatment groups: the IMN fixation group, the DCP fixation group, the LCP fixation group, and the unilateral Ex-Fix group. On the day of testing, each specimen was thawed at room temperature. Radiographs of all specimens were taken in the anterioposterior direction under standardized conditions.

2.2. Measurement of bone mineral density

The bone mineral density (BMD) of each tibia was measured at 20 mm, 45 mm, and 80 mm intervals distal to the tibial plateau using quantitative computed tomography (Somatom DR-H scanner; Siemens AG, Erlangen, Germany). BMD of the bones in each group was recorded to determine their quality and density.

2.3. Fracture imitation and construction

Extra-articular proximal tibial fractures (AO classification 41-A2) were created using a thin blade saw described by Jiang *et al.* [4]. The cut was directed from lateral cortex 5 cm to the plateau, thereby making the angle equal to 45° (Fig. 1).

The fractures were then anatomically reduced under direct vision. Thirty-two tibial specimens were randomly stabilized with one of the following four fixation methods: (A) IMN (φ8 mm diameter, 260 mm length, Wujin Medical Limited, Changzhou City, China PR) was performed with a reamed technique, and the nail was then fixed with two 3.9-mm locking blots proximally and distally, respectively; (B) a DCP (5 holes, Jianda Medical Limited, Changchun City, China PR) was placed laterally, and the plate was fixed with two 4.5-mm cancellous screws proximally and three 4.5-mm cortical screws distally; (C) an LCP (9 holes, Wujin Medical Limited, Changzhou City, China PR) was fixed with five 3.2-mm cancellous screws and four 4.5-mm cortical screws; and (D) a unilateral external fixator (Wujin Medical Limited, Changzhou City, China PR) was placed medially, and the external fixator was fixed with two 5.0-mm Schanz screws proximally and distally, respectively. There were eight specimens in each fixation group. The proximal and distal articular surfaces of all the specimens were fixed by polymethylmethacrylate for mechanical testing.

2.4. Mechanical testing

An electronic universal testing machine (CSS-4401, Changchun Research Institute for Testing Machines, Changchun, China) was used to perform the biomechanical examinations. Axial compression and anterior-lateral three-point bending tests were conducted on each specimen (Fig. 2). The application of a 10 N preload at a rate of 3 mm/s resulted in tibial compression. The applied load was gradually increased from 10 N to a maximum load of 400 N to simulate normal adult weight. Each experiment was repeated three times. Load–distance curves were automatically recorded by a computer. Finally, each specimen was subjected to destructive axial compression and three-point bending tests.

2.5. Statistical analysis

The results were statistically evaluated using SPSS 11.0 software (SPSS, Chicago, IL). One-way analysis of variance with *post hoc* testing was performed to determine between-group significant difference. P values of <0.05 were considered significant.

3. Results

3.1. Bone mineral density

No significant difference in BMD was observed between the individual test groups (Table 1). Whereas the BMD values varied significantly within each group, the BMD at the distal tibia level (80 mm) was significantly higher than that at the proximal tibia level ($P < 0.01$).

3.2. Axial compression test

The biomechanical parameters of each individual group are displayed in Table 2. Fracture fixation stiffness was the highest in the IMN group and the lowest was recorded in the Ex-Fix group. The axial loads that caused failure of the bone-implant interface were observed to be the highest in IMN group (F_{max} [failure loads], 3406 N) and the lowest was in Ex-Fix group (F_{max}, 729 N). Statistical analysis of axial stiffness found that there was no significant difference between DCP and LCP groups ($P > 0.05$). The failure loads of DCP (F_{max}, 5010) and LCP groups (F_{max}, 4850 N) were similar. The deformation distances

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