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Original research

Comparison of three fixations for tibial plateau fractures by biomechanical study and radiographic observation

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HIGHLIGHTS

- Effects of three fixation devices for tibial plateau fracture were compared.
- Axial controlled intramedullary nail had better biomechanical properties.
- Intramedullary nail resulted in shorter healing time than plate and external fixator.

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ABSTRACT

Aim: The aim of this study was to compare the fixation effects of three fixation devices for tibial plateau fracture (AO/OTA classification 41 A1). **Methods**: Sixteen human cadaver tibial specimens were randomly divided into four groups. An A1 fracture model was established. The fractures were subsequently fixed by axial controlled intramedullary nail, external fixation and steel plate fixation. Each specimen was subjected to axial compression, torsion test and three-point bending test. Then a rat model was used to evaluate the therapeutic effect of these three fixations by evaluation of callus formation time and healing time. **Results**: It was found that the axial controlled intramedullary nail group obtained superior biomechanical properties of resistance ability of bending, torsional and axial compressive, compared with external fixation and steel plate group. In animal experiments, the axial controlled intramedullary nail group had a significant shorter callus occurrence and healing time than steel plate and external fixator group. **Conclusion**: The axial controlled intramedullary nail fixation has a superior biomechanical characteristic and fixation effect for tibial plateau fractures than steel plate and external fixator.

1. Introduction

A tibial plateau fracture (TPF) involves the articular surface of the proximal tibia that supports the opposing femoral condyle [1]. TPF is often occurred in an elderly population for osteoporosis, and also in a young population increasingly for practicing high-risk sports and using two-wheeled vehicles [2]. TPF can lead to knee instability and knee degeneration in advanced stage if not managed properly [3]. Proper reduction and mechanical properties of fixation techniques are essential for the tibia functional rehabilitation. The objective of TPF treatment is precise reconstruction of the articular surfaces, stable fragment fixation for early motion, and repair of all concomitant lesions [4,5].

Treatment of TPF includes nonsurgical treatment, and surgical approaches, open reduction and internal fixation, arthroscopy and percutaneous fixation, external fixation, bone grafting [1]. Among which, axial controlled intramedullary nail, external fixator and steel plate fixation are popular recently. Steel plate has attracted sufficient attention due to its fewer trauma and fewer complications [6]. Internal and external fixation devices fixed tibial fractures

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have achieved a clinically proven good therapeutic effect. However, in clinical practice, phenomenons of plate broken, intramedullary nail breakage and nails drop happen occasionally which result in inadequate fixation and produces complications such as malunion or nonunion [7], wound infection, skin incision, flap necrosis, and bone compartment syndrome [8,9]. In recent years, aplenty of biomechanical comparative analysis of various fixation methods have been reported for TPF treatment [9–18]. However, controversial opinions still exist concerning the ideal method for TPF and the comparison of healing effect among these fixation devices is lack.

The process of fracture healing is a complex sequence of inflammatory reaction, callus formation, tissue differentiation within the callus, and callus resorption and finally bone modeling [19]. Callus formation occurred in the secondary phase (reparative phase) of fracture healing within one or two weeks after injury [20], and it is sensitive to mechanical conditions and influences the course of healing [21].

Therefore, in our experiment we compared the biomechanical behaviors of three different techniques of axial controlled intramedullary nail, external fixator and steel plate fixation on an adult cadavers simulated A1 tibial plateau fracture pattern according to AO/OAT classification [1,22]. Additionally, we evaluated the fixation effects of these methods in a rat tibial fractures model by X-ray radiography to compare the bone callus formation and fracture healing time.

2. Materials and methods

All protocols have been approved by Central Hospital of Yiwu City Ethics Committee and performed in accordance with the ethical standards.

2.1. Materials

Axial controlled intramedullary nailing of tibia (GK nail, 8 mm/240 mm, Shanghai Puwei Medical Instrument Co., Ltd., China); steel tibial fracture plates (YJBL03,length: 123 mm/155 mm/187 mm, Changzhou Huasen medical appliance Co., Ltd., China); tibia external fixator (Ø11 mm, Shimadzu, Japan); electronic universal testing machine (AG-10TA, Shimadzu, Japan); polymethylmethacrylate (denture powder, Shanghai dental materials Factory, China); fixture (Shanghai mechanical experiment Center, China).

2.2. Biomechanical experiments

2.2.1. Specimens preparation

A total of 16 pairs of fresh frozen human cadaveric tibias (Department of Anatomy, Shanghai Medical University, China) were randomly divided into four groups, intramedullary nail group, steel plate group, external fixator group, and control group. Excepting control group, the tibia specimens of the rest three groups were sawed off by a wire saw to make a tibial plateau fracture model (AO/OTA classification 41 A1). The fractures were fixed by axial controlled intramedullary nail, steel plate and external fixator, respectively. Then the two ends of specimen were embedded with dentures powder for biomechanical test. The remaining four complete tibias were performed as control group.

2.2.2. Measurement of the bone mineral density

A Dual-energy X-ray absorptiometry (DXA, Hologic Inc., Bedford, MA, USA) was used to determine the bone mineral density of the cadaveric specimens in each group. The values of bone mineral density is represented by T-score which is the most significant index reflecting the severity of osteoporosis. The T-score is the SD of which comparing the measured bone mineral density value with that of healthy people aged 30–35 years old. $T > -1.0$ means normal bone; $-2.5 \leq T \leq -1.0$ indicates osteopenia; $T < -2.5$ suggests osteoporosis.

2.2.3. Biomechanical testing

Stress–Strain indicators of the tibias in control group were tested to determine the instrument parameters. The parameters were set as: the vertical compressive stress 0–1000 N, torsion angle 0–3°, three-point bending stress 0–400 N. The day before biomechanical testing, the specimens were rewarmed in saline at 37 °C, and square fixing pads were made by denture powder in both ends of the specimens. An electronic universal testing machine (Hegewald–Peschke, Nossen, Germany) was used to perform the biomechanical testing. Axial compression, torsion and three-point bending tests were conducted on each specimen.

2.2.3.1. Axial compression test. Tibia fracture model was embedded on the biomechanical testing machine. The probe (transferring the strain value to a computer) was installed in the both ends of fracture line. The applied vertical load was gradually increased from 0 N to a maximum load of 1000 N with a loading rate of 1 mm/s. The vertical strain and lateral strain values were outputted automatically by a computer data acquisition system. A set of data was recorded in each 100 N (totally 10 sets) for statistical analysis.

2.2.3.2. Torsion test. The specimens of the model groups were clamped on both ends at the middle of biomechanical testing machine axle. A left and right direction torsional stiffness test was conducted with a torsion rate of 2°/s, and the torsion angle was 3°. The torsion value was recorded with a computer data acquisition system. The data at intervals of 0.3° (totally 10 sets) was collected for statistical analysis.

2.2.3.3. Three-point bending test. The three-point bending test was conducted with a similar procedure as the axial compression. A continuous tibial front loading stress of 0–400 N was applied with a loading rate of 1 mm/s. A vertical direction stress value of every 50 N (totally 8 sets) was selected for statistical analysis.

2.3. Animal experiments

2.3.1. Animal and modeling

A total of 30 Wistar rats (body weight 280 ± 30 g, 15 males and 15 females) were used for modeling of tibia plateau fractures in this study. The protocol was in accordance with the principles of the Guide for the Care and Use of Laboratory Animals [23]. Sodium pentobarbital (1%) were administrated to rats by intraperitoneal injection at the dose of 3 mg/100 g for anesthesia. The rat limbs were fixed on the operating table. After preoperative hair removal with barium sulfide, a 1 cm straight incision was made on the skin of front side of hind limb into deep fascia. The tibia was exposed after separating the abductor hallucis longus and the musculus extensor carpi radialis longus. A hand surgery saw was used to make a tibial plateau fracture model by sawing in the bilateral tibia, resulting in a 1-mm wide single fracture. Postoperative wound suture was performed without dressing or fixation. The rats were marked with picric acid in back. After waking up, the rates were fed *ad libitum* in the cage. In the first 3 days after modeling, each rat received an intramuscular injection of penicillin 40,000 U/d to prevent infection. During the process of modeling, 3 rats died because of inflammation. The fixation was performed after the soft tissue swelling subsided, if any (about 3–5 days).