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Tension and Motion Measurement for Extended Trochanteric Osteotomy with Different Fixation Methods

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Abstract—**The revision of total hip arthroplasty (THA) is becoming an increasingly common procedure around the world. The extended trochanteric osteotomy (ETO) has proved to be an effective way in revision of THA. Four generations of trochanteric osteotomy fixation systems have been developed, all of which has its own clinical application. However, few studies on the biomechanical stability of the above fixation methods have been reported, though many clinical follow-up studies showed some postoperative functional differences among them. Research in this field is mainly subject to constraints of measurement devices and 3D motion analysis. We designed a synchronous testing approach to acquire the tension data loaded to the greater trochanter and minimal rotation or migration of osteotomy fragment which could not be solved by strain gauge method. Active markers were designed to precisely track proximal femoral bed and the osteotomy fragment in 3D space. Six cadaver femurs constructed as vitro biomechanical models were chosen for a preliminary study. Each femur underwent the steps of prosthesis implanting, ETO and a series of five fixation methods in a random order with 2 wires, 3wires, 2 wires and a short claw plate,2 cables and a short claw plate, and a long claw plate. We also gave a preliminary result of the displacement of fragment and the stiffness of femur after ETO in this paper. Further clinical significance remains to be discussed.**

I. INTRODUCTION

With an increasing number of total hip arthroplasty (THA) patients, and improvement in life quality, more and more revisions of THA have been made [1]–[3]. The extended trochanteric osteotomy (ETO), first described by Wanger and later popularized by Younger et al [4], has proved to be an effective way in primary THA and revision THA. ETO has many advantages, such as facilitating the implant and cement removal, the correction of deformity, providing an access for new prosthesis placement, lager exposure, reducing femoral facture and large area for healing of the osteotomized segment [1], [4]–[9].

Wires and Cables were used in the early application of ETO fixation. Four generations of trochanteric osteotomy fixation systems have been developed in the past 40 years, including monofilament wires fixation, multifilament cables fixation, cable grip systems fixation and cable plate systems fixation. Each of them has its unique clinical application. Another fixation method such as using suture cords has been reported [10]. Each fixation method is still considered for patients by the judge of surgeons nowadays [4].

Though many clinical studies [3]–[6], [11]–[13] have discussed the follow-up results of patients to compare different fixation methods, few studies have explored how an osteotomy fragment tightly attached to femur bed moves in 3D space under the tension of the gluteus medius, why it is moved, and how much migration will happen under a specific given tension. Schwad et al [1] has given a study of optimal fixation of an ETO using 2 vs. 3 braided cables in nine paired cadaver femurs. Stiffness, peak force and displacement were measured. 2D imaging motion of tacking markers was used to analyze a consecutive displacement under an increasing tension until ultimate failure. Noble et al [9] examined the effects of the ETO on the torsional strength of the femur by using cadaver bones.

Based on the studies above, with the purpose of improving the accuracy of tracking, consecutive and flexible tension loading, we continued and advanced the research in this field and aimed to find a method to trace the 3D motion of osteotomy fragment under arbitrary direction of tension. With this objective, we designed a testing method and a series of experiments to validate this method. The tension applied to the fragment simulated a biomechanical model of hip joint after ETO from a seated position to a standing posture. A preliminary result will be shown in this paper.

II. METHODS

A. Materials

We used six fresh-frozen cadaveric femurs with similar geometric shape to perform the test. All specimens were anatomically normal, good in bone quality and without a history of a malignant lesion.

All specimens were disarticulated from the acetabulum and tibia. All soft tissue attachments were removed. Each was cut to remain 2/3 length of proximal femur [1]. Then, we potted the cut side to a cylindrical mold filled with denture base resin (Shanghai New Century Dental Materials CO., LTD) [1], [9]. Each potted cylinder was required the same geometric

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parameter to keep the test rigorous.

Surgical instruments were needed for the ETO. Implanted prosthesis was prepared for each femur. 18-gauge wires and cerclage cable(w/crimp, 1.8mm, dia.25 in. length 635 mm, Zimmer) were used for the fixation. Greater trochanter attachment device was applied including a short claw plate(50.8mm length, 22.1mm width, Zimmer) and a long claw plate(121.4mm length, 22.1mm width, Zimmer).

B. Experiment Preparation

Before each specimen test, there were several steps as followed. All the fixations and ETOS in revision THA were done by the same surgeon.

1) ETO: The ETO in revision THA was done in the following standard surgery steps: femoral neck cut, prothesis implant, extended greater trochanter osteotomy. The distal aspect of the osteotomy cut length was 13cm [1]–[3], [9] along the longitudinal site and the distal horizontal cut was rounded at its junction.

2) Fixation: Each femur underwent a series of five fixation methods in a random order with 2 wires, 3wires, 2 wires and a short claw plate, 2 cables and a short claw plate, and a long claw plate, shown in Fig. 1. Each plate was fixed by the additional packaged cables. In our test, the short plate needed 2 cables around the greater trochanter laterally and the femoral neck. The long plate needed 4 cables without the need of any wires. All wires were fixed by jaws of vise. All cables were fixed by a synthesis tensioner with a recommended tension of 50 kg.

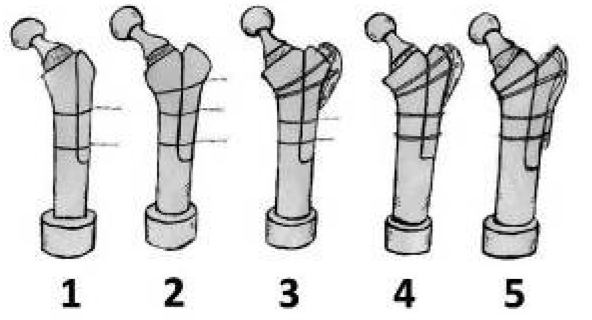

Fig. 1. The fixations from left to right are: 2 wires fixation, 3wires fixation, 2 wires and a short claw plate fixation, 2 cables and a short claw plate fixation, and a long claw plate fixation.

3) Measurement Devices: The three dimensional position and orientation of femoral bones were tracked with an Optotrak Certus^{TM} optoelectronic camera system (Northern Digital, Waterloo, Canada). The root-mean-square (RMS) accuracy of each active tracking marker connected with Optotrak Certus^{TM} was 0.1mm in the data collected plane. A servohydraulic material testing system (MTS858, Eden Prairie, MN USA) was used to offer a certain drag force from 0 N to 500 N. Sample rate of Optotrak Certus^{TM} was 10 Hz, and 2 Hz for MTS.

C. Experiment Design

Active tracking markers (infrared Emitting Diode, IR-LED) were designed specially for our experiment, shown in Fig.2. Each maker contained 2 roots with a diameter of less than 1mm and a root length of 4-5mm, so that we were able to fix it firmly to the holes drilled aforehand in the planned site. We used eight markers (Fig. 3) to track the motion of three main rigid references in 3D space. The first 3 markers were placed firmly to the femoral bed. Another three were inserted into the extended greater trochanteric osteotomy fragment. The last two makers were secured to the MTS actuator providing astatic reference points and synchronizing with the motion tracking system.

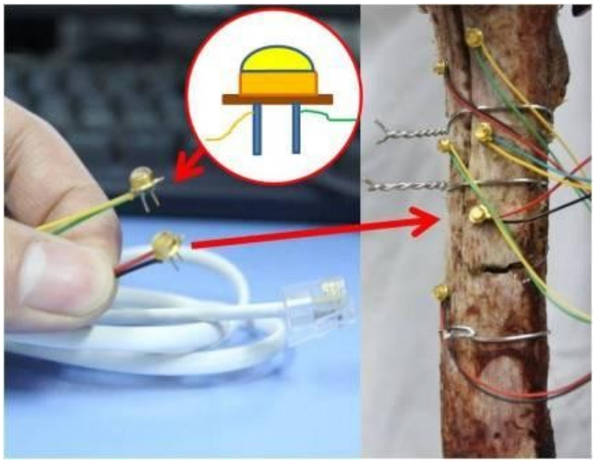

Fig. 2. Active markers were used for our experiment. Each maker contained 2 roots, each root with a diameter of less than 1mm. And they were firmly fixed to the holes drilled aforehand in the planned site.

After all the markers had been fixed firmly and checked, we designed our experiment in the following steps.

First, the biomechanical model of specimen was placed to the MTS with a zero tension but not relaxed. Auxiliary clamping connectors were designed to help us place the specimen at a particular position to simulate the tension and torsion to the greater trochanter of a healing patient. Hydraulic

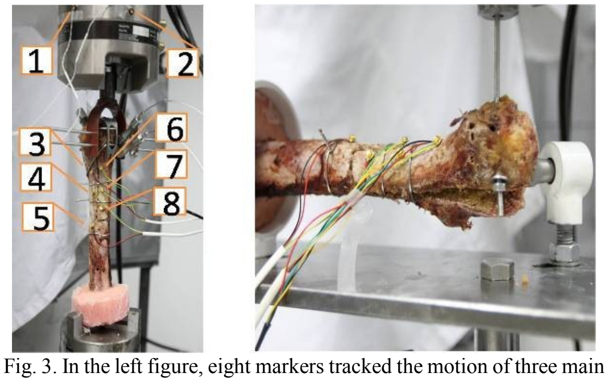

Fig. 3. In the left figure, eight markers tracked the motion of three main rigid references in 3D space: the femoral bed (3, 4, 5), the extended greater trochanteric osteotomy fragment (6, 7, 8), servohydraulic testing system (MTS) actuator reference points (1, 2).The model in the left was under a tension in vertical direction. The model in the right was under a tension in lateral direction.

clamp could tightly connect the connecters fixed to the greater trochanter. The actuator acted on the osteotomy fragment in a vertical direction which was a similar biomechanical condition to a person in a standing posture. Furthermore, the actuator acted on the osteotomy fragment in a lateral direction which was a similar biomechanical condition to a person standing from a seated position. So we placed our model in two different positions, shown in Fig. 3.

Second, after a pulling test the model stability of femur was destructed. The wires or cables fixation were required again. As a matter of fact, each test could cause a loss of bone contact surface which leaded to a friction reduction between the tight femoral bed and fragment. So the testing results of different fixation methods on the same specimen were considered to have correlation. So we designed our testing in a random order according to each model.

Third, each test was recorded and during the test all of the markers were promised to be seen excellently. The markers once attached to the bones should not be detached to avoid unnecessary installation error and for the convenience of intra-group comparison.

D. Testing

The force generated by MTS and acting on the fragment was slowly increased from 0 N to 500 N by a rate of 1N/s. At each significant rapid migration of more than 2 cm, we interrupted the test.

The 3D data of each maker in the test were collected and recorded by the software NDI First Principles associated with Optotrak Certus^{TM}. The synchronous force data from 0 N to 500 N were collected by Model 793.10 MultiPurpose TestWare associated with MTS.

E. Data processing

All data analysis was done using Matlab 2006. Theoretically, 3 markers fixed to a rig body could express 6D information if not in a line. But in our test result, each tracked object was observed of a minimal deformation. After we compared the deformation of bones with the migration between the femoral bed and fragment, the deformation was so insignificant that the femoral bed and fragment were both approximately rigid bodies.

During data processing, we synchronized the displacement data and force data. We calculated a relative migration along the direction of tension. In the lateral tension case, rotation and migration would be taken into consideration. The same site of each specimen with maximum potential migration would be discussed and compared.

Significant digit of motion tracking was 0.01mm.

III. RESULT

We assessed the 3D movement of the cut fragment with respect to the femoral bed. There were three main displacements along each axis (X, Y, Z). We chose two samples' tests respectively representing a vertical tension (F) and a lateral tension (F), as shown in Fig.4.

At the same time, we were able to calculate the angular displacement of the rotation caused by a lateral tension, as show in Fig. 5. As far as we know, this angular displacement indicates a potential lateral migration which still had not been discussed [5], [6].

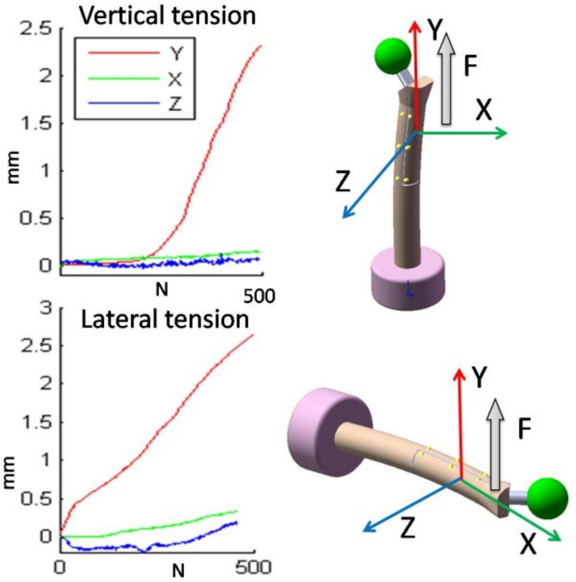

Fig. 4. The 3D displacement of fragment was caused by a vertical tension and a lateral tension. The curves indicated the displacement along each axis which was shown in the right side.

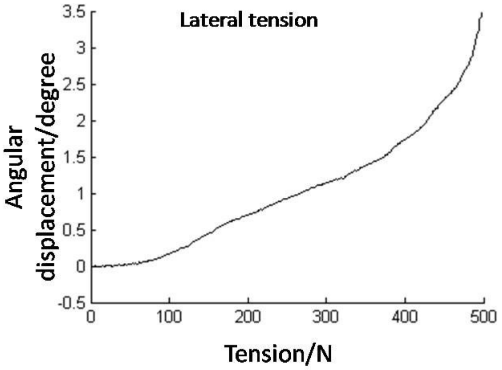

Fig. 5. The angular displacement of the rotation was caused by a lateral tension.

As the experiment designed in this paper, we have done all five fixations on a single cadaver femur which underwent ETO. So there were five curves of dynamic testing result indicating one cadaver under the tension of a defined direction, which were classified as a group. Our preliminary comparison was just a phenomenon report without a deep statistical analysis. As a matter of fact, each group showed a certain relationship among five curves in the same coordinate system diagram, as shown in Fig. 6.

As a preliminary comparison, all fixation methods showed a migration of less than 2.5 mm under a tension of 500N. In our six cadaver study we observed a similar variation trend in intragroup comparison, which was an identical result with the early studies [1].

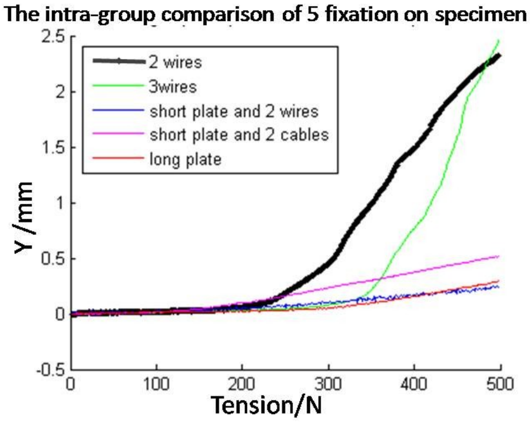

Fig. 6. Five curves of dynamic testing result indicated someone cadaver femur under the tension in vertical direction.

IV. DISCUSSION

With the method presented in this paper, we were able to clearly observe the continuous movement of a fixed femur biomechanical model after any kind of fixations. And we hope that further study of tests by our method would offer some references to the clinical choice of fixations for ETO and a better revision result.

In order to show the accuracy of our testing approach, we chose one collected data. For example, after the fixation by a long claw plate, we calculated a force and axis displacement relationship curve in six cadaver femur tests, shown in Fig. 7.

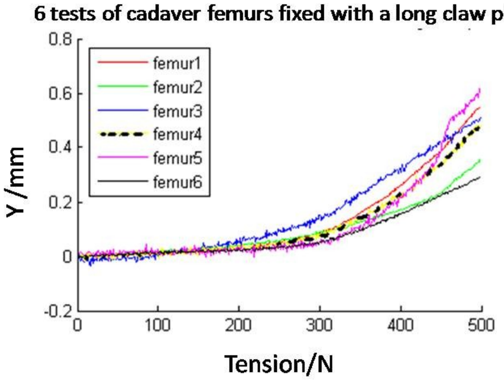

Fig. 7. A force and axis displacement relationship curve in six cadaver femur tests, The transverse axis was from 0 N to 500 N, and vertical axis was the axis displacement (MM).

There were some conformable results compared to previous studies. We also observed that most kind of fixations could stand a force of 500N, but in few ultimate elongation test of and a sudden migration of fragment happened and a peak force of failure acquired. Compared to result of Schwad et al [1], the same peak force we tested reached to 900N.

V. CONCLUSION

We introduced a testing method to observe the continuous movement of a fixed femur biomechanical model in 3D space after different fixation methods used in ETO of THA. We measured the tension and motion with high accuracy tracking technique, consecutive and flexible tension loading in the experiment of analysis. This method can test other models of cadavers and synthetic bones with fatigue and tensile test.

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