Finite Element Analysis of Intramedullary Nail for Treatment of Femoral Shaft Fractures

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Introduction

Intramedullary nailing (IM) has been a reliable treatment for a wide variety of long bone fractures in orthopedic trauma since Küntscher’s first operation in 1940. Using the IM for treatment of long bone fracture sounds superior than the bone plate in many aspects, however, there are few key points have been discussed from time to time, such as ream or unream the medullar cavity when nail implanting, antegrade or retrograde for the distal end fracture, number of screws to obtain the stability of nail-bone complex, and others. Bucholz (1987) in evaluating 185 cases and concluded that the weakest point of the IM nail was located near the screw hole of distal end. Fatigue failure might occurred in case of fracture site being within 5cm or too close to the screw hole (Bucholz, 1987; Wei, 1989, Wu 1992). Bending moment was considered to be the failure load (Kinast, 1987). Implementation without reaming the medullar cavity was favorite by Duwelius (1995) and Hass (1995) for the reason of short operation time and less complication. But the undreamed nailing might result in delay union and screw failure (Blachut, 1997). This study was focused to find the solution of the nail failure mechanism as well as fatigue life of the nail at different fracture locations, and the loosening effect on selected fastening screws by finite element analysis.

Methods

The solid 3-D geometry of femur was constructed from the CT images of 21 years old Chinese male. Photoshop and Streamline software were used for gray level adjust and boundary detection from each CT image. Each section of femur contour was then stacked into a 3-D solid model using I-Deas CAE software. The finite element model consisted of femur, a Klemm-schellmann device (nail), and three fasten screws. Gap elements were used between nail and medullar cavity, screw and screw hole. The model had total of 4,824 nodes and 2,698 elements with two abductor muscle forces of 215N in x direction, 580N in Z direction and femoral head joint force applied. A 5mm thick comminuted fracture was created in 20mm spacing from the second screw hole of the distal end with total of 13 different locations along the femoral shaft. The simulation was performed in three different stages of bone healing, namely 0%, 33%, and 66% of original bone strength. In addition, the effect of screw loosening at distal end was studied (Fig 1).

Results and Discussion

The results of finite element analysis showed that the maximum von Mises stresses were located at the screw holes and near to the fracture side (Fig. 2). The nail might break at 0% of bone healing stage when the fracture located 50mm close to the first distal screw. This confirmed the clinic finding of Bucholtz (1985). The nail and femur had the tensile stress at lateral side and compressive stress at medial. It revealed an anteroposterior bonding moment acting on the complex. The highest stress ratio of screw hole to nail was 6.79 at 0% bone strength stage and reduced to 3.80, once the strength reached over 33%. The weakest point of nail was located near two distal screw-holes. This stress magnitude reduced from 2660 MPa to 506MPa when the bone healed over 33% of its original strength. The result also showed that the second distal screw was not necessary to be fastened. It depended on the fracture location and quality of bone(Fig. 3). The nail failed at the proximal end for the dynamic locking in the case of mid-shaft
fracture at 0 % bone healing stage, but the stress reduced tremendously once the strength of bone over 33% (Fig.4). The loosening of screw resulted in the shear fracture of the screws as well as the strength down grade of the implant-femur complex. This study concluded that too early patient’s weight bearing and screw loosening at proximal and first distal side would result in nail failure.

Figure 1: Four sets of fracture in total of 13 locations

Figure 2: Maximum von Mises stresses were near the fracture site of screw hole
**Figure 3:** Stress concentration when only one distal Screw fasten (left): second distal, less stress in first distal hole, (right) secured first distal resulted in stress in second screw hole.

**Figure 4:** Stress at different healing stage

**References**


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