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Biomechanical evaluation of the modified double-plating fixation for the distal radius fracture

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Abstract

Background. Distal radius fracture is among the most common type of skeletal injuries. To conquer the surgical and biomechanical complications of the most-frequent used double-plating operation for this fracture, modified double-plating technique was proposed in this study. The aim of this study was to investigate the biomechanical interactions of double-plating, modified double-plating and traditional single plating fixations coupled with various load conditions using nonlinear finite element analysis.

Methods. A three-dimensional finite element distal radius fracture model with three fixation methods (double-plating, modified double-plating and single) was generated based on computer tomography data. After model verification and validation, frictional (contact) elements were used to simulate the interface condition between the fixation plates and the bony surface. The rigidity, stress values and displacements at the radius end were observed under axial, bending and torsion load conditions.

Findings. The simulated results showed that the modified double-plating model demonstrated the highest rigidity and the least displacement among the three techniques in bending, but not in axial compression (similar results across the three) and torsion (modified double-plating technique possessed lowest rigidity). The maximum von Mises stress for bone was lower in modified double-plating model as well. These results indicated that modified double-plating technique demonstrated a better structural strength against bending with the least potential of fracture fragments and screw loosening.

Interpretation. Although a lower torsional rigidity, modified double-plating technique was a better choice in distal radius fracture fixation since the bending force, which has the potential to separate the fracture ends, is more detrimental in hindering fracture healing.

Keywords: Distal radius fracture; Fracture fixation; Double-plating technique; Finite element; Biomechanical analysis

1. Introduction

Fractures in the region of the distal radius are among the most common skeletal injuries. These fractures are usually caused by severe high-energy trauma, especially a fall on an outstretched arm, resulting in intra-articular involvement and/or comminution of the radius (Osada et al., 2004). In older population, particularly those with osteoporosis, the radius may fracture just above the wrist and dislocate the wrist joint. This is called a Colleś fracture. A typical displacement of this fracture is termed "dinner-fork deformity", which addresses a lateral and backward tilt of the lower bone fragment. Management of these injuries usually depends on the stability of the fracture configuration (Riis and Fruensgaard, 1989; Rogge et al., 2002; Short et al., 1987). Depending on the fracture stability, treatment

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regimes may range from simple immobilization with a splint to surgical intervention with internal fixation if cast immobilization is insufficient to repair the fracture.

Different surgical techniques can be used to fix the complicated, unstable and displaced distal radius fractures. An optimum technique should restore not only the anatomical alignment of the wrist but also it proper biomechanics, i.e. preventing re-displacement of the fragments and re-establishing the normal wrist load transmission pattern (ur Rashid et al., 2003). In order to regain normal function and decrease the risk of residual functional deficits, early mobilization of the wrist after the operation is required. Comparing with other surgical interventions, internal fixation with two metal plates, the double-plating (DP) techniques, has shown promising results regarding this aspect (Rikli et al., 2002). With DP technique, a T plate and an I (straight) plate were fixed onto the fractured radius with an angle between 50°–70°. It leads to a superior stiffness with possible early mobilization in most cases when compared with the traditional single T plate and π plate when applied to the unstable distal radius fracture model (Peine et al., 2000). Despite of these facts, problems such as loss of radial length and increase in palmar tilt could not be avoided completely, which might lead to other problems in the future (Jakob et al., 2000).

Complications for the double-plating technique can be addressed surgically and biomechanically. Surgically, a T plate placed on the dorso-ulnar side is associated with an increased risk of extensor tendon irritation or ruptures due to the interactions between the bulky screw heads and the adjacent tendons (Lugger and Pechlaner, 1984). Furthermore, because of the limited space of the distal fragment, the two fixation screws in dorsi-volar direction of the T plate might interfere with the screw in radial-ulnar direction of the straight I plate. Biomechanically, since most of these fracture occur in aged population, poor purchase in the bone might occur in the distal inserted screw due to osteoporosis. Lower bone density in the distal fragment of the radius could not provide enough strength for clenching the inserted screws, especially in dorsi-volar direction owing to the thinner cortex layer.

To conquer the surgical and biomechanical complications of the double-plating fixation, modified double-plating (MDP) technique was proposed in this study. Compare to the DP technique, MDP has an angle of 90° instead of 50°–70° in DP between the two buttressing plates to maximize the stability. The MDP technique was designed as the T and I buttressed plates placing on the dorsoulnar side (underneath the fourth extensor compartment) and the dorsoradial side (underneath the second extensor compartment), respectively. As for screw positioning, instead of four fixating screws on the T plate as in DP, only two were inserted in the bottom in dorsi-volar direction. The top holes on T plate were not screwed to avoid the risk of screw loosening and interfering with each other. The I plate had three screws inserted in radial-ulnar direction. To examine the benefits of this design, stress distribution within the bone with various loading conditions should be clarified for quantitative evidence.

Although clinical study is the ultimate method to investigate the effects of different surgical techniques, however, it is often difficult to identify and isolate important parameters because of confounding variables. Due to the limited cadaver availability, these studies are often limited by the problems originated from performing several comparative experiments on the same specimen. On the other hand, finite element (FE) method provides mechanical responses and alters parameters in a more controllable manner, driving its common use as an analytical tool in biomechanical studies (Adam et al., 2003; Chen et al., 2004; Lin et al., 2006; Rogge et al., 2002). Accordingly, the aim of this study was to investigate the biomechanical performance of DP, MDP and single plate fixations under axial, bending and torsion load conditions using nonlinear FE stress analysis.

2. Methods

2.1. Finite element modeling

An intact healthy male right radius was scanned in the neutral position using computed tomography (CT). A series of 80 scans at 1 mm intervals with a resolution close to 0.24 mm/pixel were taken in the transverse plane direction. The contours of the cortical and cancellous bone were extracted from the set of CT images and converted into mathematical entities on a personal PC using a commercial software (Mimics, 6.1-Materialise Software, Leuven, Belgium, UK). These data were then imported into a finite element package (ANSYS, v 8.0, Swanson Analysis Inc., Houston, PA., USA) to generate the solid bone models.

To simulate the distal radius fracture, a 1-mm extra-articular fracture gap, 25-mm from the distal end of the radius was created using an idealized planar cut. Three models were built for the comparison of different surgical techniques, including a MDP model (Fig. 1a), a DP model, and a single T plate model. In the MDP model, a 2.0-mm titanium T and an I plates (Synthes, Solothurn, Switzerland) were selected as the two buttressed plates and designed for placement on the dorsoulnar side and the dorsoradial side, respectively. The I plate positioned on the dorsoradial side formed an angle of approximately 90° to the T plate. Two screws were positioned in the proximal side for both buttressed plates but only one screw was fixed on the I plate in the distal fragment. In the DP model, the T and the I plate form an angle of 70° with four screws in volar-dorsal direction (two screws in distal fragment and the other two in proximal segment) of the T plate and three screws on the I plate. For the single T plate model, a standard 3.5 mm titanium T plate was placed on the dorsoulnar side (the same position with the MDP model) with two screws in the distal fragment and two screws in the proximal fragment. Thread details of the locking screws were