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The biomechanical effect of bone quality and fracture topography on locking plate fixation in periprosthetic femoral fractures

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ABSTRACT

Optimal management of periprosthetic femoral fractures (PFF) around a well fixed prosthesis (Vancouver B1) remains controversial as adequate fixation needs to be achieved without compromising the stability of the prosthesis. The aim of this study was to highlight the effect of bone quality i.e. canal thickness ratio (CTR), and fracture topography i.e. fracture angle and its position in relation to the stem, on the biomechanics of a locking plate for a Vancouver B1 fracture. A previously corroborated simplified finite element model of a femur with a cemented total hip replacement stem was used in this study. Canal thickness ratio (CTR) and fracture topography were altered in several models and the effect of these variations on the von Mises stress on the locking plate as well as the fracture displacement was studied. Increasing the CTR led to reduction of the von Mises stress on the locking plate as well as the fracture movement. In respect to the fracture angle with the medial cortex, it was shown that acute angles resulted in lower von Mises stress on the plate as opposed to obtuse angles. Furthermore, acute fracture angles resulted in lower fracture displacement compared to the other fractures considered here. Fractures around the tip of the stem had the same biomechanical effect on the locking plate. However, fractures more distal to the stem led to subsequent increase of stress, strain, and fracture displacement. Results highlight that in good bone quality and acute fracture angles, single locking plate fixation is perhaps an appropriate management method. On the contrary, for poor bone quality and obtuse fracture angles alternative management methods might be required as the fixation might be under higher risk of failure. Clinical studies for the management of PFF are required to further support our findings.

Introduction

Total hip arthroplasty (THA) is complicated by periprosthetic femoral fractures (PFFs), with incidence varying from about 1% for cemented and 5.4% for uncemented primary prostheses [1,2]. The majority of the PFFs are located around the tip of the stem and are subdivided as B1 with the stem stable, B2 with the stem unstable and B3, with significant bone loss, according to the Vancouver classification [3]. Optimal management of Vancouver B1 periprosthetic femoral fractures around a well fixed prosthesis remains controversial as adequate fixation needs to be achieved without compromising the stability of the prosthesis [2].

Locking plates have been frequently used in the management of B1 PFFs with variable published results [2,4,5]. Over recent years there has been an increase in number of PFF fixation failure reports including locking plates [2,4,5]. While various studies are investigating development of new fixation methods for these fractures, patient bone quality, stem stability and fracture level are also considered as contributing factors to the success or failure of PFF fixations [1,2].

A recent clinical study by Leonidou et al. highlighted that fracture angle may also need to be considered as an independent parameter when contemplating a treatment method for Vancouver type B1 fractures [1]. Regardless, the definition of bone quality and fracture level in B1 fractures is also not clear [1].

Therefore the underlying hypothesis of this study was that, bone quality, fracture angle and level (fracture topography) can change the biomechanics of PFF fixation in B1 fractures where

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some cases might be at higher risk of failure. The specific aim of this study was to illustrate the effect of bone quality, fracture angle and level in a simplified finite element (FE) model replicating a Vancouver B1 fracture. It must be mentioned that the simplified model has been widely used in literature to understand the biomechanics of fracture fixation and was validated against a clinical case study in one of our recent studies [6]. Nevertheless, due to its simplified nature our results here have intended as a preliminary investigation where the emphasis has been put on the pattern of FE results rather than their exact predictions.

Materials and methods

Model description

A simplified parametric finite element model of a cemented total hip replacement (Fig. 1) was developed previously by Moazen et al., and was adopted in this study [7]. The model was validated against a clinical case study [6]. The bone, stem and the cement were modelled as concentric cylinders. A transverse fracture below the tip of the stem was created and fixed laterally with a ten holes plate. In order to achieve an appropriate bridging length, two holes in the centre of the plate (i.e. across the fracture line) were left empty [8]. The fracture was held in place with four unicortical screws proximally and four bicortical screws distally [9,10]. The screws were modelled as cylinders with a diameter of 4.5 mm corresponding to common diameter of locking cortical screws used in the femur [11]. The plate was placed directly on bone, as it has been shown that direct contact of the locking plate with the bone in combination with two holes of working length resulted in decreased stresses on the construct [8]. All parts of the model were assigned isotropic materials properties with a Young modulus of 2 GPa for cement, 20 GPa for bone and 200 GPa for the metal plate and screws [12]. A Poisson's ratio of 0.3 was used for all materials.

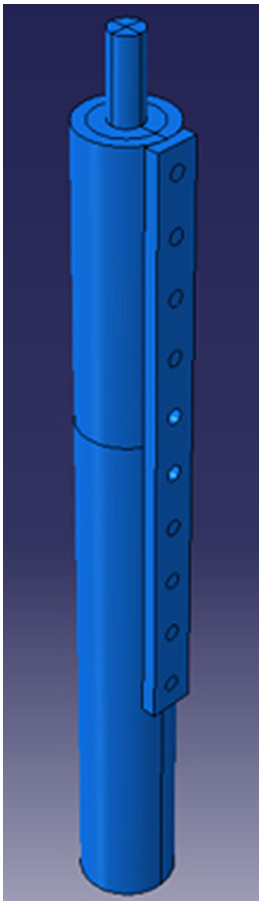

Fig. 1. Simplified model as created in Abaqus CAE Software.

Boundary conditions and loads

The stem–cement, cement–bone, and screw head–plate interfaces were tied together. Interaction at the plate–bone interfaced was modelled with contact elements with coefficient of friction of 0.3 [13]. Interfaces at the fracture site were also modelled with contact elements with coefficient of friction of 0.04, corresponding to early stages of fracture healing, where no callus has formed between the two fragments [7]. The distal part of the model was rigidly fixed and the proximal part of the stem was loaded with a transverse force equal to $P = 5W \times \sin\theta$, where W was the body weight and θ was the loading angle between the line of action of gravity and the long axis of femur. Body weight of 600 N and loading angle of 11° were used in this study [12].

Mesh sensitivity

The model was meshed with Tetrahedral (C3D4) elements. Convergence was tested by increasing the number of elements from 42,000 to 1,600,000 in five steps. The solution converged on the parameters of the interest ($\leq$5%-for von Mises stress across the two empty screw holes where the plate is at high risk of failure [7,12,13]) with approximately 300,000 elements. Models with this number of elements or more were used for each of the cases presented.

Bone quality and fracture topography

Three models with different canal thickness ratio (CTR) were developed representing poor, average and best bone quality with respective CTRs of 0.44, 0.88 and 1.46 (Fig. 2). This was done based on our previous study, which indicated that bone quality can vary within Vancouver B1 fractures [1]. Further three models were developed with angle fractures varying from the unstable transverse (0°) and short oblique (146°) to the stable long oblique configuration (76°) (Fig. 3). Finally, three models were developed with the fracture at the tip of the stem, 4 mm and 14 mm below the tip of the stem (Fig. 4).

Simulations and measurements

The models were solved and analysed using a finite element simulation package (ABAQUS v. 6.9, Simulia Inc., Providence, RI, USA). The pattern of von Mises stress on the plate and fracture movement was compared across the cases. Fracture movement was quantified as the relative displacement of the most distal point of the proximal fragment and the most proximal point of the distal fragment on the medial side of the bone.

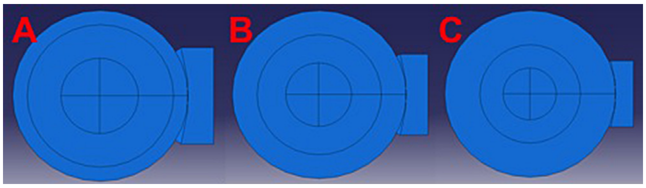

Fig. 2. Sagittal view of the model showing different bone quality configurations. (A) Worst bone quality (CTR = 0.44), (B) average bone quality (CTR = 0.88), (C) best bone quality (CTR = 1.46).