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Biomechanical effect of the configuration of screw hole style on locking plate fixation in proximal humerus fracture with a simulated gap: A finite element analysis

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ABSTRACT

Background: Locking plate fixation for proximal humeral fractures is a commonly used device. Recently, plate breakages were continuously reported that the implants all have a mixture of holes allowing placement of both locking and non-locking screws (so-called combi plates). In commercialized proximal humeral plates, there still are two screw hole styles included "locking and dynamic holes separated" and "locking hole only" configurations. It is important to understand the biomechanical effect of different screw hole style on the stress distribution in bone plate.
Methods: Finite element method was employed to conduct a computational investigation. Three proximal humeral plate models with different screw hole configurations were reconstructed depended upon an identical commercialized implant. A three-dimensional model of a humerus was created using process of thresholding based on the grayscale values of the CT scanning of an intact humerus. A "virtual" subcapital osteotomy was performed. Simulations were performed under an increasing axial load. The von Mises stresses around the screw holes of the plate shaft, the construct stiffness and the directional displacement within the fracture gap were calculated for comparison.
Results: The mean value of the peak von Mises stresses around the screw holes in the plate shaft was the highest for combi hole design while it was smallest for the locking and dynamic holes separated design. The stiffness of the plate-bone construct was 15% higher in the locking screw only design (132.6 N/mm) compared with the combi design (115.0 N/mm), and it was 4% higher than the combi design for the locking and dynamic holes separated design (119.5 N/mm). The displacement within the fracture gap was greatest in the combi hole design, whereas it was smallest for the locking hole only design.
Conclusions: The computed results provide a possible explanation for the breakages of combi plates revealed in clinical reports. The locking and dynamic holes separated design may be a better configuration to reduce the risk of plate fracture.

Introduction

Fractures of the proximal humerus are among the most common injuries. Due to cancellous bone depletes with age, it has become a typical injury of elderly individuals with osteoporosis [1]. Besides, a high energy impact or falling can also lead to proximal humerus fractures. Various fixation methods are available, including percutaneous Kirschner wires, T-plates, angled plates, cloverleaf plates, intramedullary nails, tension band wires, and primary prosthesis [2]. Nowadays, locking plates are increasingly used to surgically treat these injuries. Each of these implants offers threaded screw holes, which allow screws to thread to the plate and function as a fixed-angle construct. Although good clinical results were reported [3–5], the plate

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breakages were continuously revealed [6–13]. Interestingly, these failure series all were the recently introduced plate systems with specially designed combination holes (so-called combi hole) in which one side of the hole can be used with a traditional non-locking screw and the other side can be used with a locking head screw.

Locking plates were developed based on the biomechanical principle of external fixators which can provide good stability and do not require compression of the plate to the bone that may inhibit periosteal blood supply and compromise the vascularity of the fracture site. With these benefits, many manufacturers now supply bone plates that have locking options. In contemporary anatomical plates, the screw hole styles can typically be categorized into "combi hole" design (like the PHILOS plate, Synthes, Switzerland), "locking hole only" design (like the NCB Proximal Humerus Plate, Zimmer, United States), and "locking and dynamic holes separated" design (like the Proximal Lateral Humerus Locking Plate, A Plus Biotechnology, Taiwan). A number of clinical literatures had found breakage of the plate in the dynamic compression part of the combi hole. From the biomechanical viewpoint, this dynamic unite is the weakest part of this screw hole design because it should be used for bending if required. However, the biomechanical difference between these three screw hole styles is still unknown. The objective of this computational study was to investigate the effect of screw hole style design on plate stress distribution with use of a finite element analysis (FEA). We hypothesized that more stress concentration would exist in the plate with combi holes. Also, the stiffness of the plate-bone construct and the directional displacement within the fracture gap were evaluated to compare the fixation stability between the implants with different screw hole styles.

Materials and methods

A three-dimensional (3D) geometry of an intact humerus was generated from the CT scan of a 58-year-old Chinese male. The CT scanning (Light Speed VCT, GE Medical System, General Electric Company, USA) was collected with slice thickness of 1.25 mm and 512×512 pixels per image, which was approved by the Institutional Review Board of Show Chwan Memorial Hospital (No. 1021004). The CT scan data were then imported into a self-development image processing software to outline cortical and cancellous contours via the grayscale difference of the CT images. A CAD software, PTC Creo 2.0 (Parametric Technologies Corp., Needham, MA, USA) was utilized to reconstruct the 3D humerus model via the cortical shell and cancellous core. A fracture gap at the subcapital site was simulated by resecting a segment of 10 mm length [14].

Three CAD models of proximal humeral plate with different screw hole style were constructed using PTC Creo 2.0. Among the three models, the Proximal Lateral Humerus Locking Plate (A Plus Biotechnology Co., Ltd., New Taipei City, Taiwan) with locking and dynamic holes separated design was designated as a baseline model. Other two implants with combi holes and locking holes, respectively, were modified from the Proximal Lateral Humerus Locking Plate model, in order to directly compare different screw hole styled implants of the same shape without the intervention of other influencing factors. Similarly, the locking screws were kept identical in the three designs. All plate models were featured nine holes anchored in the proximal humeral head and four holes in line distally (Fig. 1).

The three plate-bone constructs were imported into a commercial FEA solver of ANSYS Workbench 11.0 (ANSYS Inc., Canonsburg, PA, USA) for computational analysis. To evaluate the accuracy of our finite element models, a convergence test of total strain energy was performed. For the convergence test, a new FE model with more element numbers was calculated and the results of the presented FE model was compared with that of the new FE model. After the completion of the convergence test, the mesh generated for each designs contained 511,899 elements on average. Due to the complex geometry of the bone plates and the threaded screw holes the mesh consists tetrahedral elements only.

Fig. 2 illustrates the loading and boundary conditions established on the model for each design. The base of the humerus was fixed in all degrees of freedom. A vertical compression point load was applied to the humeral head until 200 N (loading increment: 50 N; four loading steps) based upon the experimental data reported by Seide et al. [14] and Brianza et al. [15]. Isotropic and linearly elastic behaviour is assumed for all components in the current study. The material properties assigned in the FE models are summarized in Table 1 [16]. For the interfacial surface between the different components of the models, frictional contact was defined between the bone–plate interactions with a frictional

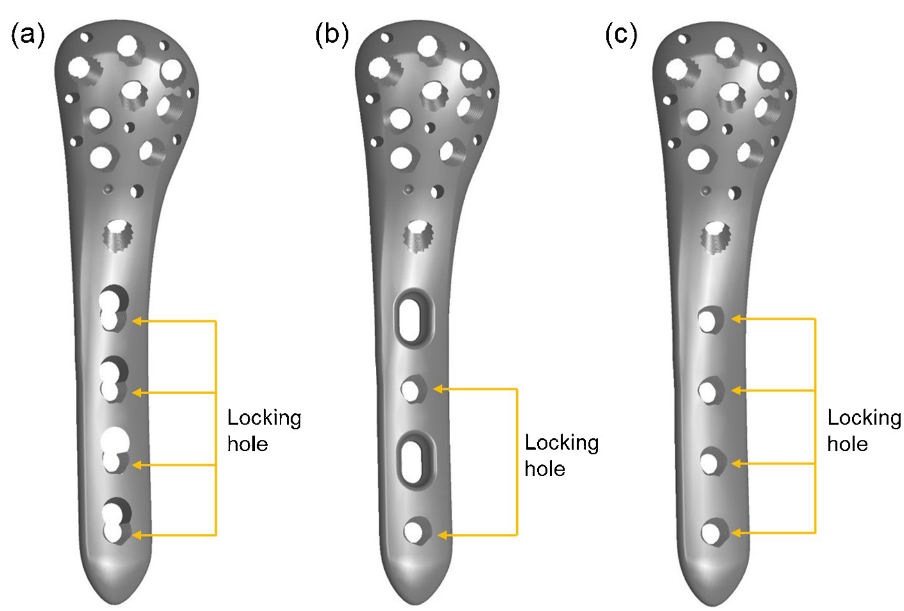

Fig. 1. CAD models of three humerus plates involved in the study. (a) Combi design; (b) locking and standard holes separated; and (c) locking hole only.