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Conceptual finite element study for comparison among superior, anterior, and spiral clavicle plate fixations for midshaft clavicle fracture

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Open reduction internal fixation technique has been generally accepted for treatment of midshaft clavicle fractures. Both superior and anterior clavicle plates have been reported in clinical or biomechanical researches, while presently the spiral clavicle plate design has been introduced improved biomechanical behavior over conventional designs. In order to objectively realize the multi-directional biomechanical performances among the three geometries for clavicle plate designs, a current conceptual finite element study has been conducted with identical cross-sectional features for clavicle plates. The conceptual superior, anterior, and spiral clavicle plate models were constructed for virtual reduction and fixation to an OTA 15-B1.3 midshaft transverse fracture of clavicle. Mechanical load cases including cantilever bending, axial compression, inferior bending, and axial torsion have been applied for confirming the multi-directional structural stability and implant safety in biomechanical perspective. Results revealed that the anterior clavicle plate model represented lowest plate stress under all loading cases. The superior clavicle plate model showed greater axial compressive stiffness, while the anterior clavicle plate model performed greater rigidity under cantilever bending load. Three model represented similar structural stiffness under axial torsion. Played as a transition structure between superior and anterior clavicle plate, the spiral clavicle plate model revealed comparable results with acceptable multi-directional biomechanical behavior. The concept of spiral clavicle plate design is worth considering in practical application in clinics. Implant safety should be further investigated by evidences in future mechanical tests and clinical observations.

1. Introduction

Clavicle fractures are especially common at the mid-shaft, with around 80% of all clavicle fractures reported to occur at this location [1–5]. Open reduction internal fixation for treatment of clavicle fracture is accepted for reducing the postoperative complications such as instability, malunion, or non-union of fracture site due to conservative treatment [6–9]. Conventionally, a bent reconstruction plate is generally utilized for fracture fixation due to the complexity of clavicle curvatures both in frontal and coronal views. While stronger plates having improved anatomical features have been designed to match the curvature of the superior surface of the clavicle, these designs are reported to be subject to complications such as screw loosening, screw breakage, plate breakage or severe deformation [10]. Anterior clavicle plates were subsequently introduced having advantages such as a lower prominent feature and better bony purchase. Apart from their ability to be introduced via an anterior approach, however, anterior clavicle plates do not appear to offer any distinct advantages over plates applied in the superior position [11]. The improved biomechanical stability afforded by the superior clavicle plate has been demonstrated both experimentally and in finite element analysis [12,13].

The concept the "spiral clavicle plate" is embodied in current commercial products such as the LCP superior anterior clavicle plate (SYNTHES GmbH, Switzerland) and the C.A.S. locking plate system (Aplus Biotechnology, Taiwan). The structure of the spiral clavicle plates was extended from anterior-proximal surface to superior-distal clavicle. The techniques for surgical implantation or these spiral plate designs is similar to conventional clavicle plates,

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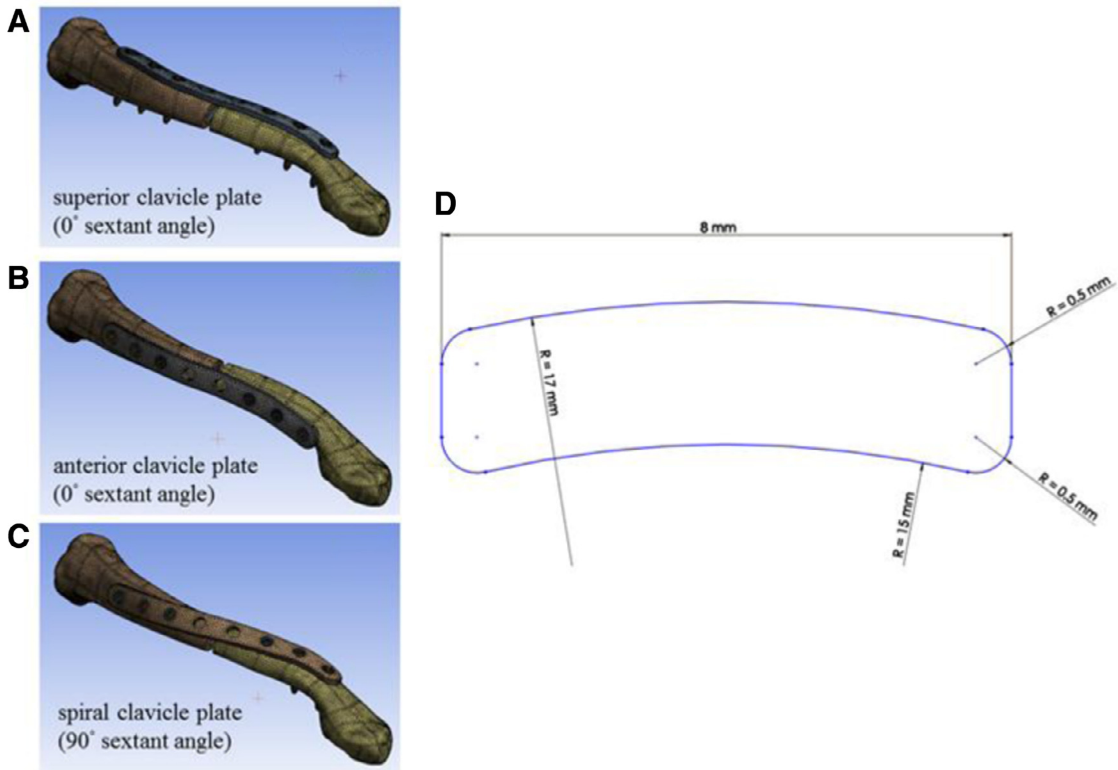

Fig. 1. Finite element models applied in current study: (A) superior clavicle plate model; (B) anterior clavicle plate model; (C) spiral clavicle plate model. All plates were constructed with identical cross-sectional feature (D).

while the spiral feature may enable the bone screw to achieve a radial fixation to the clavicular axis. In a previous finite element study, Mari showed that a pre-contoured superior-anterior clavicle plate enhances the structural stability and reduces the stress on the plate in a specifically simulated upper limb activity [14].

Differences such as type and size of screw holes, cross-sectional geometry of the plates, reconstruction or decompression features of commercial products, are all likely to influence the biomechanical responses. The aim of the current study, therefore, was to undertake an objective comparison of the conceptual spiral clavicle plate design with the conventional superior and anterior clavicle plate designs.

2. Materials and methods

A series of computed tomography images (Light Speed VCT, GE Medical System, General Electric Company, USA) of a healthy subject (male, 69 y/o, left clavicle, slice thickness: 1.25 mm, 512 × 512 pixels per image) was utilized for three-dimensional clavicle model reconstruction with IRB approval by Show Chwan Memorial Hospital (No.1021004). A simulated midshaft transverse fracture with a fracture gap of 2.5 mm left between the fractured segments was made referring to the assignment in a previous finite element study by Farve et al. [13]. Three conceptual clavicle plate models – the superior plate (Fig. 1A), the anterior plate (Fig. 1B), and the spiral plate (Fig. 1C) were constructed with identical cross-sectional feature (Fig. 1D). Measured lengths of the plates in direction parallel to the clavicle axis were identically 80 mm, while the curvatures of the plates were drawn along the path of clavicle bone. Thickness of the bone plate was identically 2 mm. The spiral increment of the spiral plate model was 1.125 deg/mm from 0 degrees to 90 degrees that completes the spiral feature extended from the distal superior surface to the proximal anterior surface. Eight screw holes with 4.0 mm in diameter and 10 mm in screw hole distance were assigned on each clavicle plate model. Axial directions of screw holes were perpendicular to the surface of clavicle plates. Six 2.4 mm (in diameter) locking screws were inserted into the screw holes and left the 2 center screw holes empty in each model. All screws were assigned as bi-cortex fixation to eliminate possible error from different simulated conditions. Order of the screw 1–6 was defined from distal to proximal ones. Screws in the superior and anterior clavicle plate models were all assigned in parallel, while the sextant angle between the most proximal and distal screw in the spiral clavicle plate model was 78.75 degrees.

Table 1
Material properties utilized in finite element models [14].

Materials	Young's modulus (MPa)	Poisson's ratio
Cortical bone	11,000	0.3
Cancellous bone	500	0.1
Titanium alloy	110,000	0.3

For simplifying the locking mechanism between both of the bone/screw and screw/plate interfaces, all screw threads were removed and the boundary conditions between the bone/screw and screw/plate interfaces were assigned as bonded. To avoid bone plate penetration into the clavicle, a frictionless contact behavior was defined for the contact pair. A coefficient of friction of 0.2 was assigned between the fractured segments for possible contact after loading. The material properties for each solid component in the finite element models are listed in Table 1 [15]. By fully constraining the proximal end of the clavicle, three loading modes were respectively applied at the distal end of the clavicle for determining the multi-directional biomechanical behavior of the three conceptual clavicle plate models: (1) an 100 N cantilever bending load (downward); (2) an 100 N axial compressive load; (3) an 1 Nm axial torque, as shown in Fig. 2. The tetrahedral elements contained were respectively 157,841 for the superior plate model, 157,396 for