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A Methodology for Biomechanical Assessment of Proximal Humerus Fractures Using an Integrated Experimental and Computational Framework

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Abstract

Fractures of proximal humerus are currently the third most common fractures in patients over the age of 65 years. An integrated experimental and computational framework is proposed for the development of novel proximal humerus plates with enhanced biomechanical and clinical performance. It involves in vitro mechanical testing of leading proximal humerus plates using 3D laser scanners as an assessment modality to allow 3D comparison of different plate-humerus constructs during tests. This paper presents the methodology and shows the preliminary work from the 3D scanning to be used for computational modelling.

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Keywords: 3D laser scanning, proximal humerus, biomechanics, locked fixation

Introduction

United Kingdom's population is living longer than ever before, with the number of centenarians increasing approximately 73% over the last decade [1]. Ageing has become one of the forefront pressures that threaten to overwhelm the National Health Service (NHS) during the current healthcare crisis. With 17% of the total UK population now over the age of 65, by 2031, the population of the 65-84 age group is predicted to increase by 50% and those aged over the age of 85 will double by 2031 and treble by 2071 [2].

Fractures of proximal humerus are currently the third most common fractures in patients over the age of 65 years [3]. With ageing population and increasing prevalence of osteoporosis, incidence of these fractures is projected to increase up to 300% over the next 30 years [4]. After the fractures, the elderly face high risk of prolonged loss of shoulder function and immobility, preventing them from performing activities of daily living.

Management of severely displaced fractures remains a challenge due to complications such as osteoporosis that are common in the elderly. Non-operative approach has been shown to be troublesome for these fractures as it could lead to shoulder deformity and stiffness. Proximal humerus plates (PHPs) are a very common operative treatment modality which have risen in popularity in the recent years since the development of locking technology. However, clinical results on the use of these plates report high incidences of complications such as varus malreduction which severely affect the patients' experience and are a major challenge to successful recovery. It is therefore crucial to develop a framework which allows development of novel plates that have enhanced biomechanical and clinical performance.

Methodology

We propose such a framework which can be divided into two phases (Fig. 1). The first phase involves in vitro tests aimed to determine the biomechanical performance of the leading proximal humerus plates in the clinical setting. Upon completion of these tests, a finite element model (FE) simulating the loading conditions of these in vitro tests will be created and validated from the obtained test results.

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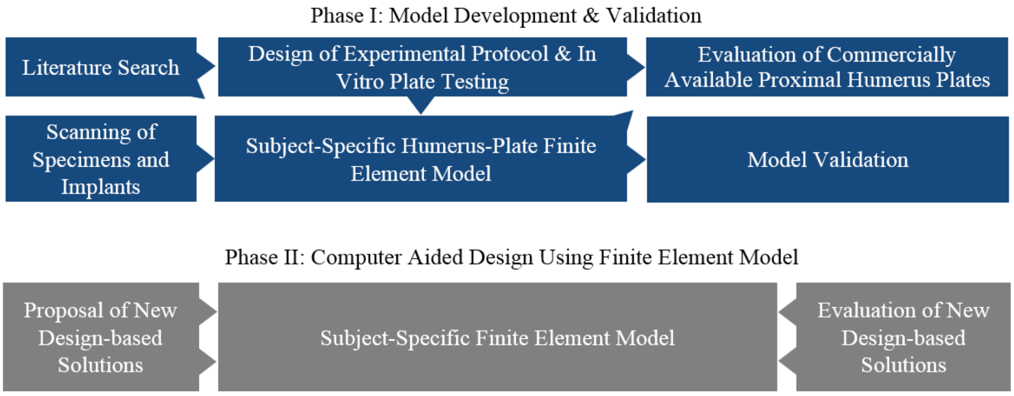

Fig. 1. Key milestones in the two phases of the combined experimental and computational framework.

In the second phase, the validated FE model will be used to test proposed plate designs. These designs are to be based on the results from the in vitro tests and the developed understanding of the mechanical and clinical aspects of the fractures in collaboration with an orthopaedic surgeon specialising in proximal humerus fractures.

Results

In vitro tests involve osteotomising of two-part transverse proximal humerus fractures on synthetic humeri (Sawbones, USA). A second cut is made 21 cm distal to the apex of the humeral head. Fractures are treated with one of the three plates: PHILOS (Synthes, USA), S^3 (Biomet, USA), Equinoxe Fx (Exactech, USA) and loading them under a selection of loads such as cantilever bending.

Three dimensional (3D) laser scanner, (EXAscan, Creaform, Canada), is used to perform 3D scans of the plate-humerus construct at regular intervals during the course of loading. Scans are both contactless and non-destructive to the specimen with duration of each being approximately 5-10 minutes. Live acquisition of the 3D data is achieved using Creaform VXelements software. The scans (.stl format) are exported to Geomagic Studio (3D Systems, USA) where they are processed (trimming, smoothing and alignment). 3D comparison of the scans is then made using Geomagic Qualify (3D Systems, USA), allowing visualisation of the 3D deformation of the test scan against the reference scan.

For example, for cantilever bending tests, 3D scans of the specimen were captured at regular intervals during the tests. Fig. 2 shows resultant (of x, y and z axes) deviation of the specimen at the end of the bending test with reference to a scan performed before any loading. While the head of the humerus is fixed and the load applied at the distal end, the 3D comparison allows the visualisation of the deviation across the specimen surface. In this case, a relatively large deviation is visible at the distal and gradually, near the plate, deviation is smaller due to implant support. 3D scans are also used to measure fracture gap at multiple points on fracture surfaces.

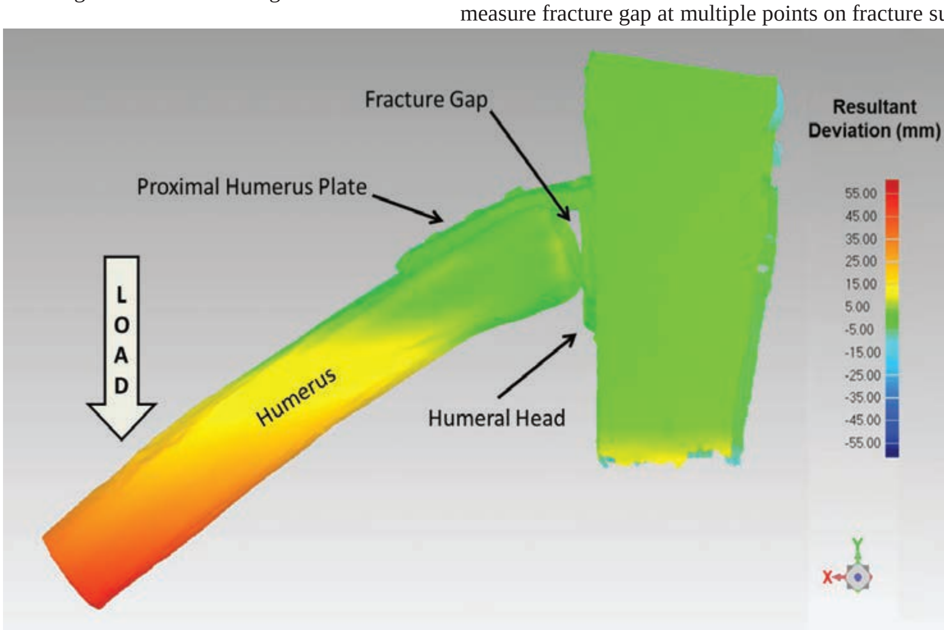

Fig. 2. Typical 3D comparison map from 3D laser scans showing resultant deviation of plate-humerus construct under cantilever bending test.