Biomechanical Stability of Bone Screws in the Proximal Humerus

Florian Kessler

Supervisors: PD Dr. Peter Varga, Prof. Dr. Philippe K. Zysset
Institutions: AO Research Institute Davos
University of Bern, ARTORG Center for Biomedical Engineering Research
Examiners: Prof. Dr. Philippe K. Zysset, PD Dr. Peter Varga

Introduction

Proximal humerus fractures (PHF) are the third most common injuries related to osteoporosis and account for 5% of all fractures. Locking plates are the most frequently applied joint-preserving treatment for complex and unstable PHF. However, up to 35% and higher complication rates for PHF treated with locking plates are reported. Secondary screw perforation into the articular cartilage of the shoulder joint is a major cause for failure and was found in up to 29% of patients. The aim of this project was to investigate the axial progression of screws in the proximal humerus under cyclic loading. It is hypothesized that progression of bone screws in trabecular bone can be described with an analytical approach based on fatigue failure.

Materials and Methods

Human bone cuboids (n=20) were extracted from cadaveric proximal humeri and embedded in polymethyl-methacrylate (PMMA). High-resolution peripheral quantitative computed tomography (HR-pQCT) scans were taken both before and after inserting a trabecular bone screw. The bone was tested in fatigue by applying a cyclic compressive load predicted with interpolation of quasi-static experiments [1] on the screw head with an electrodynamic testing system (Acumen 3, MTS Systems, Eden Prairie, MN, USA). Micro finite element (µFE) analyses of all cuboids were performed using Abaqus (Dassault Systèmes, Vélizy-Vilacoublay, France) to estimate the quasi-static force of a perforating screw. A 1D analytical approach of integrating the plastic strain due to fatigue [2] from each load level over the bone within the range of interest was developed to predict the displacement of the screw depending on the force and the bone volume fraction (BV/TV).

Fig. 1 Screws inserted in trabecular bone cuboids from the proximal humerus were cyclically compressed at 3 Hz under multiple levels until articular perforation occurred.

Results

Cyclic tests in the bone cuboids lasted between 2'746 and 93'257 cycles until the screw perforated the articular cartilage. Fig. 2 shows experimental and analytical results over the number of cycles for three load levels. Tip-joint-distance (TJD) and the loosening event (overdrill) are marked in the graph. Analytically predicted displacement of the screw as a function of the applied force and the BV/TV could qualitatively reproduce the results from the experiments. Quasi-static forces from µFE analyses show a high correlation with the local BV/TV (R^2 = 0.94, p<0.01) and with previous experiments [1] (R^2 = 0.61, p<0.01).

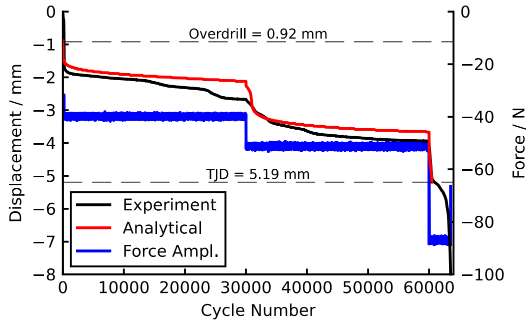

Fig. 2 The experimental displacement over the number of cycles at different load levels could be reproduced qualitatively using an analytical approach.

Discussion

Screw perforation in the experiments was dominated by the applied load and the distribution of BV/TV in front of the screw. Analytical modelling of secondary screw perforation in proximal humeral bone agrees qualitatively and may predict the number of cycles to failure in PHF fixation by superimposing the solution to the six-screw setup from a locking plate. High correlations between BV/TV and quasi-static loosening forces in µFE correspond to findings from previous studies [1].

References

[1] Vasiliki C. et al., J Mech Behav Biomed Mater, 116:104344, 2021.
[2] Rapillard et al., J Biomech 39(11):2133-2139, 2006.

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