Failure Risk Prediction of Fracture Fixations Using Subject-Specific Finite Element Analysis

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Introduction

Complex and unstable fractures require surgical treatment and implant fixation such as plating. Despite technical advances in osteosynthesis devices, implant failures still occur. Currently, there is no effective way to predict and therefore prevent plate failure in the early stages of bone healing, partially due to the limited understanding of the effect of rehabilitation protocols. Understanding these phenomena could help to reduce failure rates. The aim of this project was to develop a finite element (FE) simulation approach to predict plate failure in long bone fractures on a subject-specific basis.

Materials and Methods

CT scans of eight sheep that underwent a standardized osteotomy procedure and plate fixation were used to build subject-specific FE models (Fig 1). Non-linear FE simulations were performed for each animal to determine the maximum residual angle that could be achieved by loading and unloading of the construct until complete fracture gap closure. Cyclic simulations were carried out to build an analytical description aiming to predict the quantified bending angles based on the number of cycles and applied total displacement.

A CT image processing methodology was established to identify whether plastic bending occurred in the plates in vivo and quantify the bending angle. The CT-based and FE-based angle calculations were determined according to the position of landmarks placed on the bone.

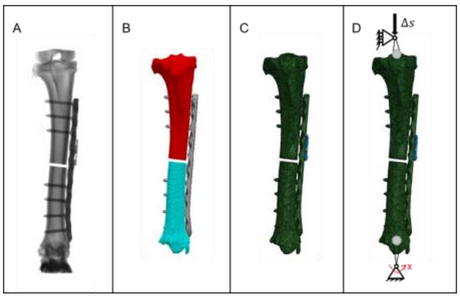

Fig. 1 CT image-based FE modeling workflow. (A) Gray value image of a postoperative CT scan. (B) Implant, proximal and distal bone masks. (C) Subject-specific FE model meshed. (D) Illustration of the boundary conditions.

Results

CT-based bending angles at 4 weeks postoperative for the 5 animals with plate deformation ranged from 1.7 to 4.5 degrees. The cyclic FE based analytical surface (Fig. 2) allowed to determine combinations of total displacements and cycle numbers that could replicate the CT-based plate bending angles for two animals.

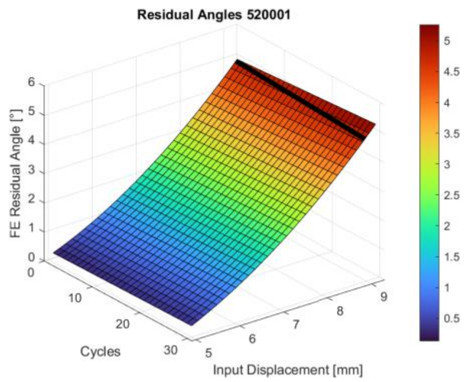

Fig. 2 3D view of the analytical surface for one specimen. The color scale represents the FE residual angle in degrees. The linear black line indicates the input displacement and loading cycles to reach the specimen's quantified CT bending angle at 4.9°.

Discussion

CT angle measurements confirmed that the bending occurred within the first 4 weeks after surgery in 5 animals. Furthermore, the analytical model was able to give the input displacement and the number of cycles needed to reach a given bending angle. However, the models still need to be validated by comparing the FE residual angles versus the residual angles obtained from the surface.

References

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