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Micro-finite element analysis for the prediction of the stiffness of fractured bone

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Introduction

In recent studies, High-Resolution peripheral QCT imaging and micro-finite element (micro-FE) analysis were used to analyze the fractured region of patients with a distal radius fracture. Interestingly, it was found that this stiffness first drops during healing, and only increases after 3 weeks of healing. We hypothesize this initial drop is because the micro-FE approach overpredicts the immediate post-fracture bone stiffness because 1) it may fail to detect the loss of connectivity: fractured trabeculae from opposing fragments may move relative to each other whereas in the HR-pQCT images, they appear to be directly connected and 2) the bone tissue material properties itself will be affected due to formation of microcracks, but these are not visible and not accounted for in the model. The goal of the present study therefore was to investigate to what extent micro-FE analyses can predict the compressive stiffness of fractured bone.

Materials and methods

A total of 60 7.5 mm cylindrical porcine tibia bone samples, were scanned using microCT and mechanically tested using a compression test before and after a fracture was induced to the sample. Four different types of fracture morphologies were created, varying from very smooth (precision saw) to very irregular (wire-cut, and compression and bending impact fractures). The micro-CT scans were downscaled to clinically feasible resolutions (80 microns) after which micro-FE models were made and the stiffness before and after fracture was calculated. The loss in stiffness due to the fracture was quantified from the micro-FE results and compared to that measured in the compression tests.

Results

The loss of stiffness measured in the experiment ranged from 40% (smooth cut) to 86% (irregular fractures) (Fig. 1). The micro-FE analyses can well represent this drop in stiffness in the case of the smooth fracture, but less well in case of irregular fractures. In case of compressive impact fractures, large variations in results were found and on average even an increase in stiffness was predicted due to densification of the fracture region.
Discussion and Conclusion

The micro-FE results indeed tend to overestimate the stiffness of the fractured bone. However, good predictions can be obtained for smooth fractures where little damage to the tissue is expected. This suggests that the resolution of the images is adequate to detect the loss of connectivity. For the fractures created by more destructive methods, the results were less favorable, likely because in these cases damage to the tissue will play an important role as well. In case of severe densification, the micro-FE analyses will be unreliable.

In conclusion: the micro-FE analyses partly captured the loss in stiffness. In the absence of densification it can provide reasonable estimates.

FIGURE 1. Loss in stiffness measured in the experiment (blue) and micro-FE (red).