INTRODUCTION

Osteoporosis is a bone disease leading to an increased risk of fracture. Moreover, osteoporosis complicates fracture treatment because conventional orthopaedic implants perform less well in osteoporotic bone [1]. Yet, the exact mechanisms behind decreased implant performance are still incompletely understood. To further elucidate bone-implant failure we developed a device that combines mechanical testing of large bone-implant constructs with High-Resolution peripheral QuantitativeComputed Tomography (HR-pQCT) following the principles of image-guided failure assessment (IGFA) [2]. The goal of this study was to visualize and quantify implant failure in a clinically realistic scenario; more specifically, we investigated the failure behaviour of Dynamic Hip Screws (DHS) implanted in human cadaveric femoral heads.

METHODS

DHS screws were implanted in four cadaveric human femoral heads according to the surgical technique recommended by the manufacturer. The bone samples had been obtained from the Zurich University Hospital, and the tests were performed in accordance with pertinent laws regarding the use of human test subjects. In order to avoid metal-artefacts during CT imaging, the DHS screws were rebuilt out of the high-performance polymer Torlon. Compression experiments were carried out using a custom-made automated mechanical loading device in conjunction with an HR-pQCT system (XtremeCT, Scanco Medical AG, Brüttisellen, Switzerland). The bone-implant constructs were subjected to compression steps of 250 µm displacement, simulating a push-through test. Therefore, the screws were fully fixed at the bottom part of the system, whereas at the upper part the femoral heads made contact with a concave PMMA bed to mimic the distributed load as present in the human hip joint. Each compression step was followed by a waiting period of 10 minutes in order to avoid relaxation-induced imaging artefacts. CT scanning was performed after each relaxation period at an isotropic nominal resolution of 82 µm. Seven subsequent stacks of 110 slices each were measured leading to a field of view of 63.1 mm in length allowing for the image acquisition of the entire femoral head. Measurements were acquired at an energy of 60 kVp, an intensity of 900 µA and an integration time of 100 ms. The resulting three-dimensional (3D) images were then used to visualize bone deformation and failure of the bone-implant interface. Bone morphometric indices were calculated in a hollow cylindrical volume of interest (length: from first to last thread tip; inner diameter: inner screw thread diameter; wall thickness: 5 mm) aligned coaxially with the screw. Force-displacement data were logged during the whole IGFA experiment.

RESULTS

An image processing routine for automated segmentation and accurate registration of the bone and screw geometry based on the HR-pQCT datasets was set up. Trabecular deformations could be tracked in all specimens. Large deformations and failures were only observed in a small volume surrounding the implant, in particular close to the thread tips (Figure 2). Failure occurred at different locations along the screw. We hypothesize that this is related to local variations in trabecular bone microstructure. A good correlation was found between the failure strength and bone volume fraction (BV/TV; Figure 3), although it has to be pointed out that the sample size was very limited.

DISCUSSION

In this study we experimentally visualized for the first time bone-implant failure at the microstructural level in a clinically relevant scenario. Such experimental data are crucial to enhance our understanding on the quality of the bone-implant interface and of the trabecular bone in the process of implant failure. We hypothesize that this knowledge will be beneficial for the development of new implant designs, especially for use in osteoporotic bone.

Some limitations of this study have to be mentioned. The pure compression scenario does not exactly represent the clinical reality, since DHS are aligned at an angle to the main loading direction; this scenario was chosen to avoid excessive bending of the polymer screw during testing. The setup featuring the isolated femoral head without the trochanter counterpart can be interpreted as a worst case scenario of a DHS that has lost its sliding capability due to jamming within the barrel.

In contrast to our findings, in an in vivo rat model assessing secondary implant stability Gabet et al. [3] demonstrated trabecular failure at some distance from the implant. We hypothesize that different failure mechanisms prevail in primary versus secondary implant stability.

REFERENCES


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