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Prevention of femur neck fractures through femoroplasty

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Abstract – Femur neck fractures continue to be a threat to patients with advanced osteoporosis [1]. Due to the reduction of bone material even low energy situations like low height falls can lead to fractures. To prevent long immobilization the usual choice of treatment is an implantation of a hip prosthesis. Due to the limited lifespan of endoprostheses a re-operation will be necessary eventually. To delay or even prevent fractures, bone cement (PMMA) could be placed in the femur neck to increase the mechanical strength of the bone in a femoroplasty procedure. The cement is injected with patented surgical tools so that a hollow tube like PMMA body (Fig. 2 (a)) is achieved which reduces the volume and therefore the heat generated during polymerization.
10 human femur pairs, age ranging from 66 to 88 years, were tested in a Hayes-fall configuration to represent a common fall scenario. The left of each pair was modified with a femoroplasty while the other side acted as control [2]. Beforehand the femur pairs were scanned in a computer tomography and the CT data was used to create finite element models using Amira (FEI, Visualization Sciences Group, Bordeaux, France) for image segmentation and geometry reconstruction. The models consist of 10-node tetrahedrons which had their Young's modulus assigned by an in-house Python code using the grey values of the CT cross sections. The open-source program Salome was used as a preprocessor and postprocessor with *Code Aster* as finite element solver.

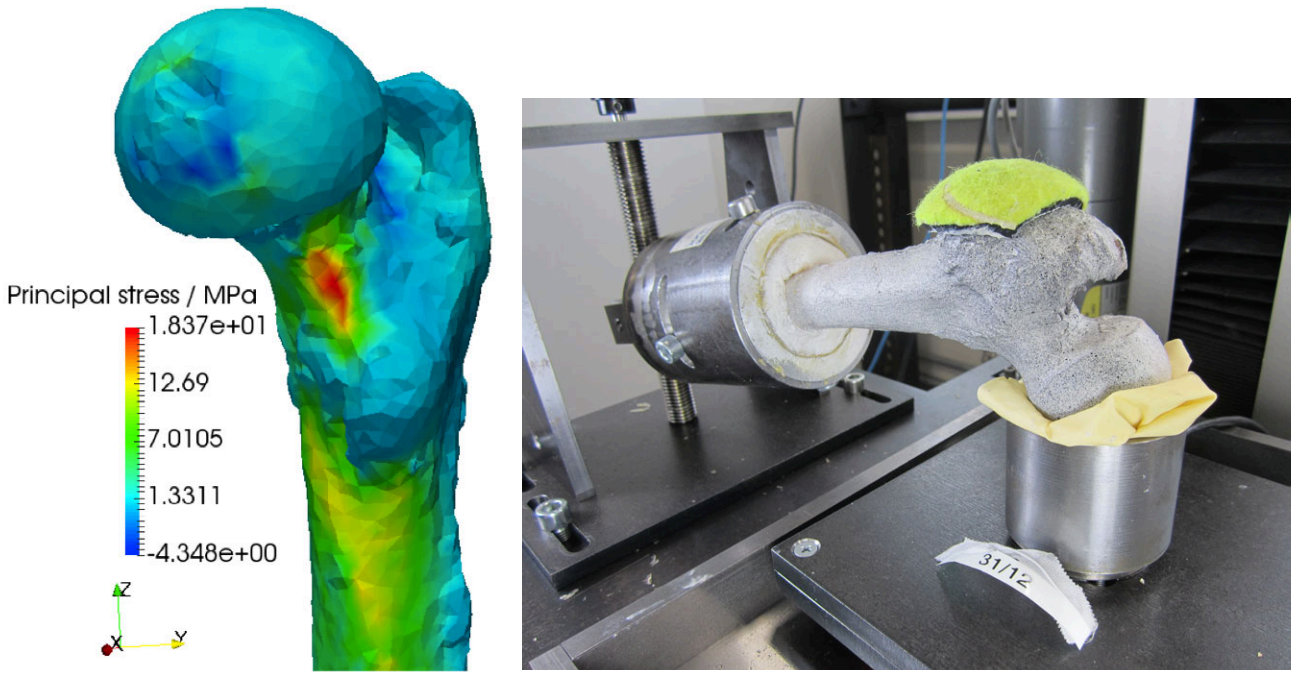

Fig.1: (a) Major principle stress in the finite element simulation and (b) Experimental setup

The experimental setup in Fig. 1 (b) fixed the distal femur against translations but allowed for rotations about one axis. The femur head was allowed to translate in the horizontal plane. Compressive forces were applied through the trochanter major while a part of a tennis ball was used to prevent point forces. The boundary conditions of the finite element models were chosen to represent the experimental configuration. The distal fixation is realized by an axis which is fixed for translation but allows rotation around itself. Proximal forces are applied on the trochanter major surface in x direction, while the opposing surface on the femur head prevents displacements in the same.

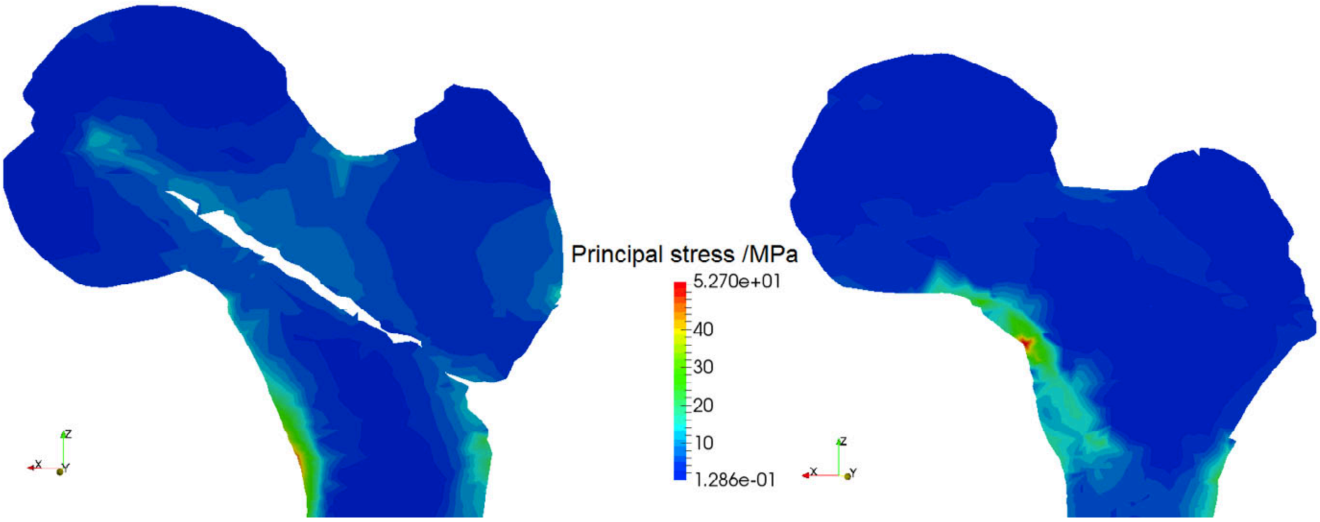

Fig.2: Finite element cross section of one femur pair (a) with and (b) without femoroplasty

The results of the experiments show a varying increase of peak fracture forces in the augmented femur in Fig. 2 (a) compared to the natural femur in Fig. 2 (b), while the simulation visualizes the shift in location and magnitude of peak major principal stresses when comparing the augmented and control femur. The femoroplasty causes a reduction and a shift of peak stress to a more distal location as well as a distribution of stress across the femur neck which doesn't show in the non-augmented control. The simulation show the effective load transfer from the PMMA injection to the spongiosa. Besides giving insight into the stress distribution through cross sections, the finite element model can show the impact of the rubber between the bone and test setup. Reduced stiffness and increased displacements are seen with an added hyperelastic rubber component to the trochanter major. Taken together, conclusions about the effectiveness of the femoroplasty and possible improvements to the procedure itself can be drawn.

The mechanical tests showed that five of the femora in the the seven valid tests underwent a strengthening. On average the maximum force carried by the untreated bones was 2439.6 N ranging from 1200 N to 4700 N. The average maximum force carried by the femora with femoroplasty was 3379.7 N ranging from 2200 N to 6200 N. In 2 cases no strengthening has been observed [3]. The locations of fractures could be related to the locations of higher major principal stress.

References

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