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Biomechanics of pelvic ring fixation techniques

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The study focuses on development of computational tools for prediction and analysis of osteosynthesis of pelvic ring injuries. Fractures of pelvic bones may occur after high-energy impact events such as car accidents or sports injuries. For surgical treatment of unstable fractures either internal or external fixators can be applied in order to support the healing bone structures. In the following, a special attention is paid to minimally invasive internal fixation techniques for management of sacral bone injuries.

During osteosynthesis, the fractured bone parts are repositioned and the applied orthopaedic fixators prevent their relative motion. A set of ten fixation techniques is examined and a unilateral transforaminal sacral bone fracture (Denis type II [2]) is selected as the reference case for the study. The studied fixation techniques utilise a single or a combination of the four following orthopaedic fixators: iliosacral screw (ISS) [3], transiliac internal fixator (TIFI) [1], transiliac plate (TP) [5] or sacral bar (SB) [4].

The geometry of the computational model is developed based on CT scans of orthopaedic models of male pelvis. These solid foam models are also used in the experimental campaing that provides input data for validation of the numerical simulations. The experiments study a mechanical response of the model pelvic bones without fracture and a response of fractured bones with a selected fixation technique under physiological loading. The computational model itself is based on the finite element method. An example of the pelvic model geometry and the related computational mesh is provided in Fig. 1.

Due to the fact that each fixation technique is tested using orthopaedic plastic models, variations in cadaveric samples of pelves are avoided. Thus both experimental and computational studies provide a direct comparison of the stability of selected pelvic ring fixations. All pelvic models are tested in an intact condition as well as after creation of artificial unilateral transforaminal fracture and application of the selected fixation technique by an orthopaedic surgeon. In addition, the mechanical properties of the material, the orthopaedic models are made of, are determined experimentally during an extra set of tensile and compression tests.

Absolute and relative motion of the bone structures is examined, a symmetry of bone deformations along the median sacral crest is assessed, an evolution of the fracture line is tracked and a relative displacement of the fractured bone parts is quantified. The ratio between the stiffness of the treated pelvic structure and the stiffness of the intact model (each fixation technique is tested using an extra pelvic model) is determined. The gathered data are used to evaluate the stability of each applied fixation technique.

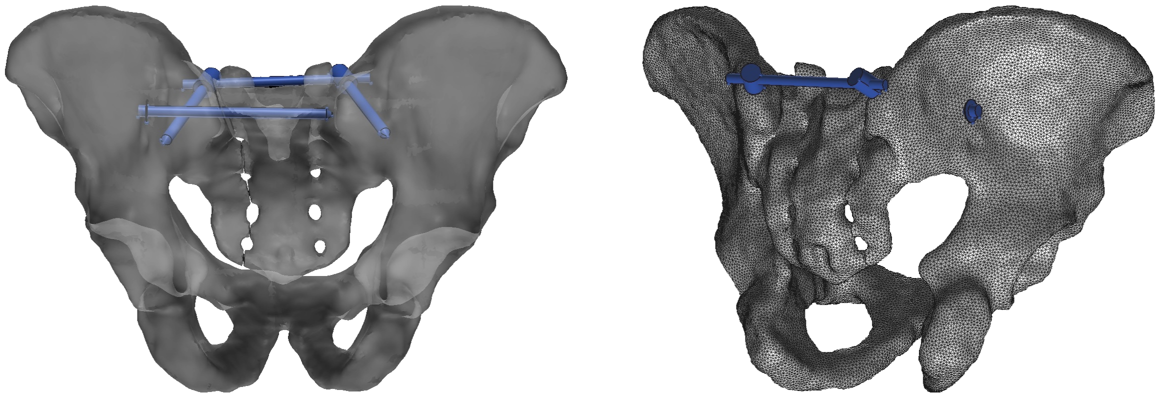

Fig. 1. The three-dimensional geometry reconstruction based on CT scans (*left*) and the computational mesh for the finite element analysis (*right*) of the fractured pelvis model with the TIFI+ISS fixation technique applied

In the experiments, a quasi-static loading is applied. The computational model reflects the experimental setup and material properties and the problem of elastostatics is solved using a finite element solver. The interaction of bone parts along the fracture line is modelled by a standard surface-to-surface contact algorithm with a finite sliding formulation and a non-zero friction. Results of the numerical simulations are compared to the experimental data and an analysis of the stability of the applied fixation techniques is provided.

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