EXPERIMENTAL AND COMPUTATIONAL STUDY ON MECHANICAL STABILISATION OF SACRAL BONE INJURIES

Libor LOBOVSKÝ[1], Michaela MAREŠOVÁ[2], Tomáš MANDYS[1], Jana HLUCHÁ[2], Martin SALÁŠEK[1,3], Drahomíra WEISOVÁ[3], Tomáš PAVELKA[3], Jiří KŘEN[1,2]

[1] NTIS – New Technologies for Information Society, Faculty of Applied Sciences, University of West Bohemia, Univerzitní 2732/8, 30100 Plzeň, Czech Republic, E-mail: lobo@kme.zcu.cz

[2] Department of Mechanics, Faculty of Applied Sciences, University of West Bohemia, Univerzitní 2732/8, 30100 Plzeň, Czech Republic

[3] Clinic for Orthopaedics and Traumatology of Locomotive Organs, University Hospital, alej Svobody 80, 30460 Plzeň, Czech Republic

1. Introduction

Selection of an appropriate osteosynthesis technique for pelvic ring injury depends on the type of fracture and the level of its instability. In general, the selected technique should stabilise the bone structures and minimise morbidity of the injury, including necrosis of surrounding soft tissues and potential iatrogenic complications.

In the following, selected minimally invasive fixation techniques are investigated. Series of experiments on fixation of sacral bone fractures are carried out. The examined fixation techniques utilise transiliac internal fixator (TIFI) [1], iliosacral screw (ISS) [2], transiliac plate (TP) [3] or sacral bar (SB) [4].

Based on the experimental data a computational model of the pelvic bone structures and their fixations is developed. The model is further used for analysis of unstable pelvic ring injuries with spinopelvic dissociation and their treatment with lumbo-sacral fixation techniques [5]. Influence of a cross-link transverse connector and of an additional ISS fixation on the stability of lumbo-sacral fixation is assessed.

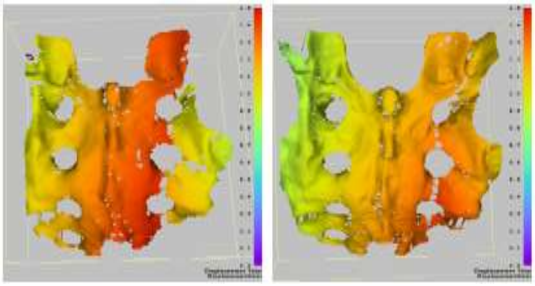

Fig. 1. Contour plot of displacement magnitude at dorsal surface of sacrum as recorded by DIC during the experiments for TP (left) and SB (right) fixations.

2. Materials and methodology

The experimental study is performed using physical models of male pelvis made of solid foam. Using models instead of cadaveric pelves assures a high repeatability of experimental data and enables a straightforward setup and control of the tests. The models are made of homogeneous isotropic material with elastic properties similar to trabecular bone, i.e. the stiffness of the tested model structure is significantly lower than the stiffness of real pelvic bones. Nevertheless, its homogenity and isotropic properties simplify development of the computational model.

The pelvic model is mounted on a stand which provides a rigid support in both acetabula such that the position of pelvis is fixed in space and its rotations are prevented. A quasi-static mechanical loading is applied in order to examine the structural stiffness of the model in an intact state and of the same model with a treated unilateral transforaminal fracture. The three-dimensional motion of sacrum is analysed using a four camera digital image correlation (DIC) system and an extensometer, Fig. 1. In order to analyse stability of the fixators, dislocations of selected points at the dorsal surface of sacrum are quantified.

The experimental data are used for verification of the computational model which is based on the finite element method. The computed tomography (CT) scans of the tested physical models (with selected fixation techniques) are used for preparation of geometry of the tetrahedral computational mesh. Between the fractured bone parts, a dedicated contact problem is solved. The computational model is verified for a wide range of fixations of unilateral transforaminal fracture.

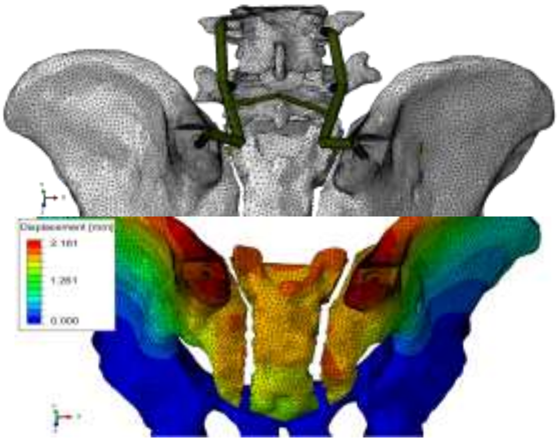

Fig. 2. Computational model geometry of pelvis with bilateral fracture treated with lumbo-sacral and ISS fixation: full model geometry (top), contour plot of displacement magnitude at pelvic bones (bottom).

In order to analyse osteosynthesis of unstable sacral fractures with comminuted zone (either unilateral or bilateral), the computational model is extended by the 4th and the 5th lumbar vertebrae and intervertebral discs [6] based on CT scans of a selected clinical case of a male patient with the lumbo-sacral fixation applied, Fig. 2 (top).

3. Results

Both experiments and computations focus on absolute motion of the bone structures, a symmetry of bone deformations, an evolution of the fracture line and a relative displacement of the fractured bone parts. The stability of each fixation technique is assessed based on the sacral base displacements which are used to determine the ratio between the stiffness of the treated pelvic structure and the stiffness of the intact model.

Results for the examined fixation techniques of fractures without comminuted zone indicate that the computational model fully reflects the trends observed during the experiments. The deviation of the computationally predicted stiffness ratio from its experimental value is in a range of percents.

The fixation of unstable pelvic ring fractures is significantly enhanced by application of the lumbo-sacral fixation combined with the ISS fixator. This is pronounced especially for the cases with spinopelvic dissociation, such as bilateral fracture with comminuted zone Fig. 2. In the case of lumbo-sacral fixation with cross-link connector, application of ISS reduces displacement of sacral base by 59 %. If the cross-link transverse connector is omitted but the ISS is applied, this difference drops to about 50 %.

4. Conclusions

Based on the experimental data, the computational model of human pelvic ring is developed and used for prediction of stability of selected mini-invasive fixation techniques.

When the lumbo-sacral fixation is combined with ISS, the cross-link transverse connector may be omitted as its application brings minor enhancement in the stability of the entire structure. This reduces the size of incision necessary for application of the fixation and allows a real minimally invasive approach to fracture treatment.

The effect of soft tissue structures in lumbo-sacral region, such as muscles and ligaments, on stability of the pelvic structure is not reflected.

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