MINIMALLY INVASIVE INTERNAL FIXATION TECHNIQUES FOR MANAGEMENT OF SACRAL BONE INJURIES

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1. Introduction

The presented research focuses on bone injuries in the region of human pelvic ring. A special attention is paid to fractures that usually occur during high-energy impact events such as car accidents or sports injuries.

Herein, minimally invasive internal fixation techniques that support the fractured bone structures are investigated. A unilateral transforaminal sacral bone fracture (Denis type II) [1] is selected as the reference case for this study. The mechanical response of the pelvic ring treated using a number of sacral bone fixation techniques is quantified.

Both experimental and computational analysis are conducted.

2. Studied fixation techniques

The studied sacral bone fixation techniques are based on application and/or a combination of the following orthopaedic fixators: transiliac internal fixator (TIFI) [2], iliosacral screw (ISS) [3], sacral bar (SB) [4] or transiliac plate (TP) [5]. Overall 9 fixation techniques were examined.

3. Methods

The experimental analysis is performed using orthopaedic models of male pelvis made of solid foam [6]. This enables to maintain consistency of the measured data, which would be hard to achieve if cadaveric pelves were applied.

The models are positioned in the rigid stand and the intact and treated pelvic structures are subjected to external quasi-static loading up to 300 N, 500 N respectivelly. The load is applied in a perpendicular direction to the base of the sacral bone. In general, the stability of each fixation technique is assessed according to the measured displacement of the sacral base, the ratio between the stiffness of the treated and intact pelvic structure respectively. This is supported by quantification of relative displacements of the fractured bone parts.

In order to quantify the motion of the bone structures, both an extensometer and a multi-camera digital image correlation (DIC) system are applied. The relative motion of the fractured sacral bone parts is captured from the dorsal view. In order to analyse the stability of each technique, dislocations of selected points at sacrum’s dorsal surface are quantified.

The computational part of the study is based on the finite element (FE) analysis. The model geometry, the computational mesh of the FE model respectively, is based on CT scans of the experimentally studied pelves with fixators. Thus an exact orientation of the applied fixators within the bone structures is provided. The input data for validation of the numerical simulations are based on the results of the above described experimental campaing. An extra set of tensile and compression tests are performed in order to determine the material properties of the orthopaedic plastic models.

Within the FE analysis of elastostatics of the loaded pelvis, the interaction of the fractured bone parts is modelled by a standard surface-to-surface contact algorithm with a finite sliding formulation and a non-zero friction.

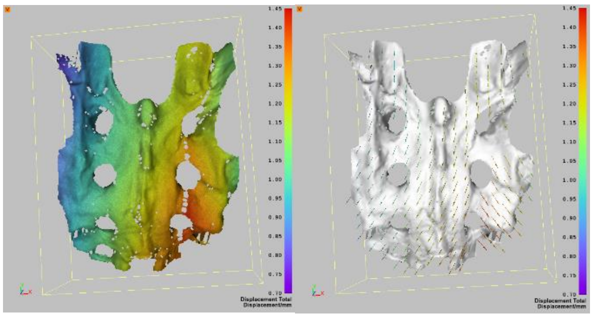

Fig. 1. Experimental analysis of pelvic ring ISS fixation: contour plot of displacement magnitudes (left) and displacement vectors (right) at dorsal surface of the sacral bone under load of 500 N.

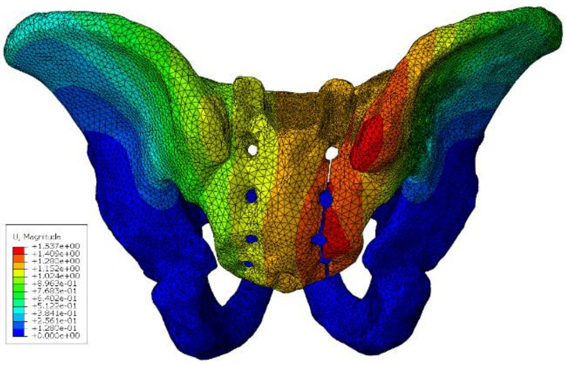

Fig. 2. Finite element analysis of pelvic ring ISS fixation: contour plot of displacement magnitudes under load of 500 N.

4. Results and discussion

The presented figures show results for pelvic ring ISS fixation technique. In Fig. 1, results of the DIC analysis of bone deformations during the experiments at maximal load of 500 N are displayed. Both contour plot of displacement magnitudes along the dorsal surface of the sacral bone and displacement vectors at selected locations are presented. The magnitude of displacements is symmetric along the fracture line which goes through foramina on the right side of sacrum. Similar results are also obtained from the computational analysis, as shown in Fig. 2.

5. Conclusion

The computational model is developed and validated based on the in-house experimental data. Both experimental and computational studies provide a direct comparison of the stability of selected pelvic ring fixation techniques, while the computational model is designed so that it enables an analysis of more complex pelvic ring injuries (which would be hard to assess experimentally) and an assessment of their optimal treatment in future.

Acknowledgements

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References

[1] Fakler, J.K.M., Stahel, P.F., Lundy, D.W., Classification of Pelvic Ring Injuries. In: Fractures of the pelvis and acetabulum, W.R. Smith, B.H. Ziran, S.J. Morgan (eds.), CRC Press, Boca Raton, 2007, pp.~11-26.

[2] Dienstknecht, T., Berner, A., Lenich, A., Zellner, J., Mueller, M., Nerlich, M., Fuechtmeier, B., Biomechanical analysis of a transiliac internal fixator, International Orthopaedics 35 (12) (2011) 1863-1868.

[3] Giráldez-Sánchez M.A., Lázaro-Gonzálvez, Á., Martínez-Reina, J., Serrano-Toledano, D., Navarro-Robles, A., Cano-Luis, P., Fragkakis, E.M., Giannoudis, P.V., Percutaneous iliosacral fixation in external rotational pelvic fractures. A biomechanical analysis, Injury 46 (2) (2015) 327-332.

[4] Gorczyca, J.T., Varga, E., Woodside, T., Hearn, T., Powell, J., Tile, M., The strength of iliosacral lag screws and transiliac bars in the fixation of vertically unstable pelvic injuries with sacral fractures, Injury 27 (8) (1996) 561-564.

[5] Suzuki, T., Hak, D.J., Ziran, B.H., Adams, S.A., Stahel, P.F., Morgan, S.J., Smith, W.R., Outcome and complications of posterior transiliac plating for vertically unstable sacral fractures, Injury 40 (4) (2009) 405-409.

[6] http://www.sawbones.com/products/product.aspx?231