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Design of External Fixators Used in Traumatology and Orthopaedics – Treatment of Fractures of Pelvis and its Acetabulum

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Abstract

This article is focused on the design of external fixators applied in traumatology and orthopaedics. These fixators have been designed in the Czech Republic and they can be used in the treatment of open and unstable (i.e. complicated) fractures of limbs, pelvis and its acetabulum. Two versions (i.e. old and new) are compared and evaluated. Numerical modelling (i.e. Finite Element Method), together with CAD modelling, experiments, material engineering and nanotechnology are presented as a support for developing of a new design of external fixators.

Keywords: biomechanics, traumatology, external fixator, fractures, design

1. Introduction

This paper reports about the designing of external fixators applied in traumatology and orthopaedics. This work was performed by VŠB – Technical University of Ostrava together with University Hospital in Ostrava and companies MEDIN a.s. and ProSpon s.r.o. (Czech Republic), see web page [22] (i.e. work of the project "External Fixation", see Fig. 1).

External fixation, see Fig. 1 and 2, is a surgical treatment usually used to set bone fractures in which a cast (plaster) would not allow proper alignment of the fracture. In this kind of treatment, holes are drilled into uninjured areas of bones around the fracture and special bolts or wires are screwed into the holes. Outside the body, rods and curved pieces of metal with special joints (bracket) connect the bolts to make a stiff support. The complicated fracture, see Fig. 1b, can be set in the proper anatomical configuration, see ref. [3], [10], [17] to [23].

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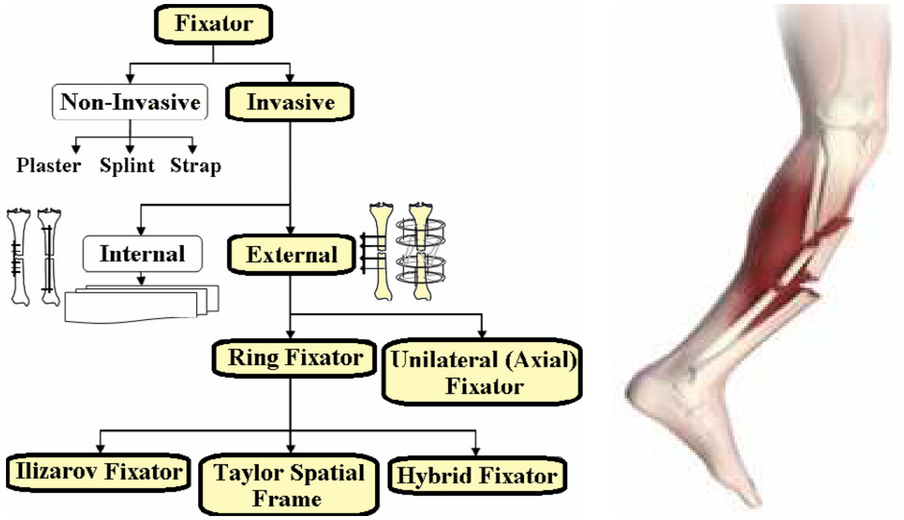

Fig. 1. Focus of our project "External Fixation".

Fig. 2. Application of external fixator (treatment of a dog, treatment of a human, experiments in our laboratory).

However, this paper is focused on the external fixators intended for pelvis. These fixators can be applied in the treatment of unstable (i.e. complicated) fractures of pelvis and its acetabulum, for example see Fig. 3, 4 and 5.

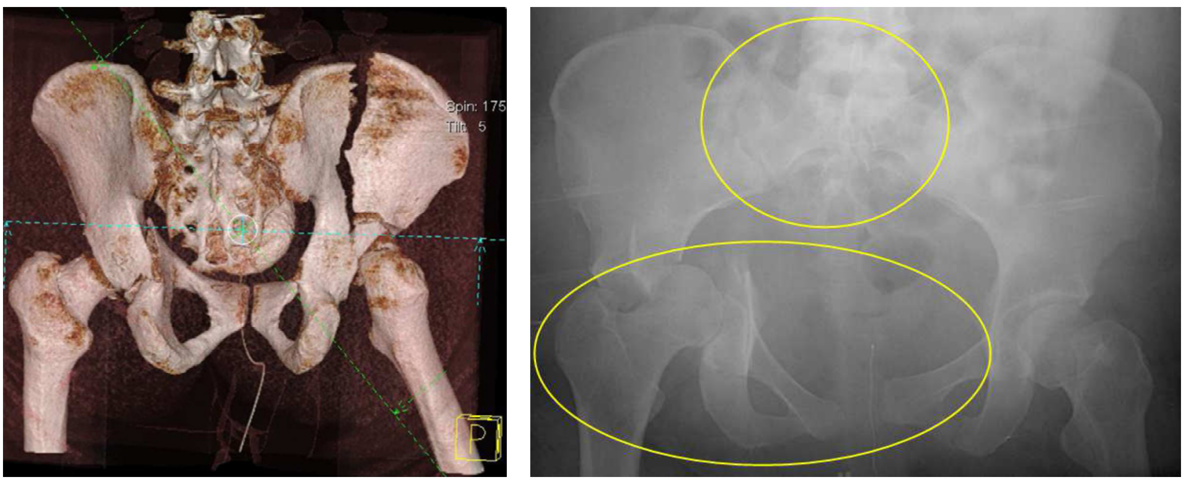

Fig. 3. Examples of complicated pelvis fracture and fracture of pelvis and its acetabulum (anteroposterior radiograph - transverse with posterior wall acetabular fracture).

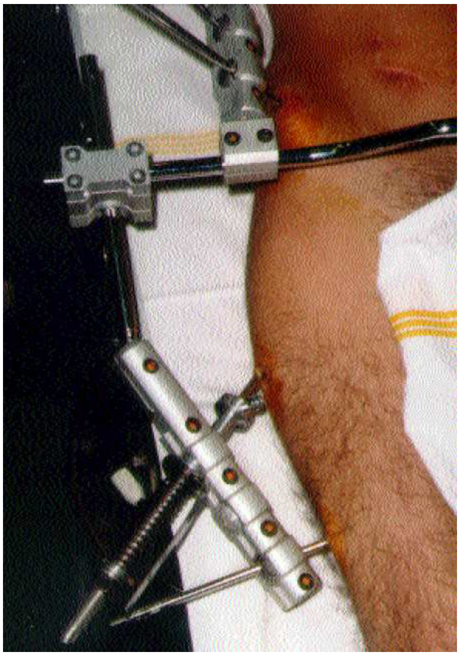

Fig. 4. Application of external fixator for treatment of pelvis and acetabulum.

Fig. 5. Examples of acetabular fractures.

Acetabular fractures, see Fig. 3b, 4 and 5, either occur with high-energy trauma (e.g. automobile collisions, falls, etc.) or as an insufficiency fracture. In younger patients, there is almost always significant trauma, and commonly associated injuries, when an acetabular fracture occurs. In elderly patients, acetabular fractures can occur due to bone weakened (i.e. consequences of osteoporosis, periprosthetic fractures etc.).

At the VŠB – Technical University, two designs of external fixators intended for treatment of pelvis and acetabulum fractures was designed and tested (i.e. an old version noted as "Option 1" and a new and modern version noted as "Option 2"), see Fig. 6 and ref. [10], [17], [18] and [20].

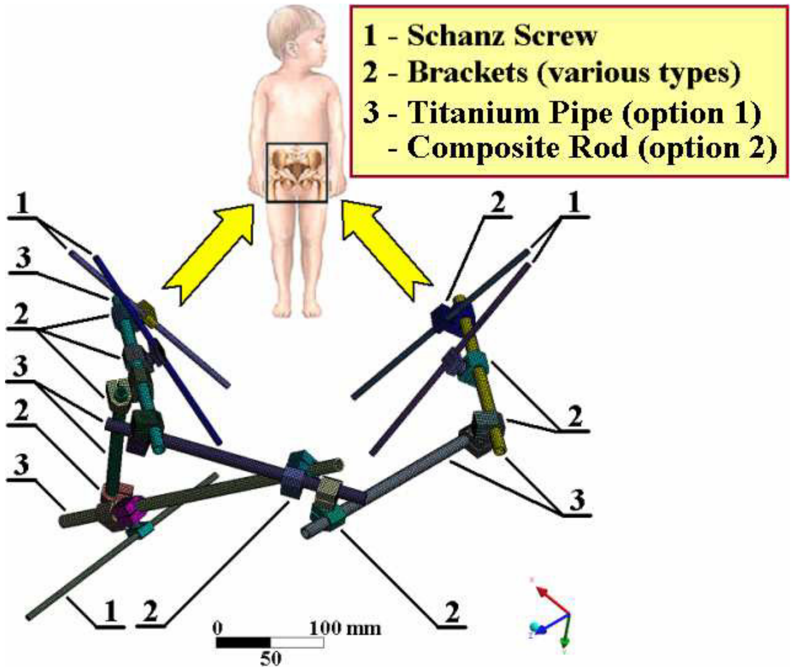

Fig. 6. Application of external fixator for treatment of pelvis and its acetabulum (two designs “Option 1” and “Option 2”).

The “Option 1” is fully metallic (i.e. the old design which does not satisfy the new demands presented in Chapters 2). On the contrary, the “Option 2” is partly metallic (i.e. the new design which satisfies the new demands presented in Chapters 2). There are composite rods made of carbon fibres which are X-ray invisible, see Fig. 6.

2. Design Requirements

Scientific and technical developments, together with medical care and medical practice, bring new demands for designs of external fixators. These demands should be solved by:

1. Applications of new smart materials.
2. New design.
3. Measuring of the real loadings.
4. Experiments.
5. Numerical modelling.

These points which are mutually connected are discussed in the following text.

Desired requrements of new design:

a) *Low X-ray absorption (i.e. rtg. invisible) - for the outer parts of fixators*, see Fig. 7. The outer parts of fixators are usually made of metal (titanium, duralumin, stainless steel), which are visible in X-ray diagnostic. Sometimes, the surgeons must repeat X-ray diagnostics (from different points of view) during the operation, because it is difficult to see the broken limbs. Therefore, it is important to make the outer parts X-ray invisible, which leads to shortening the operating time and reducing radiation exposure for patients and surgeons.

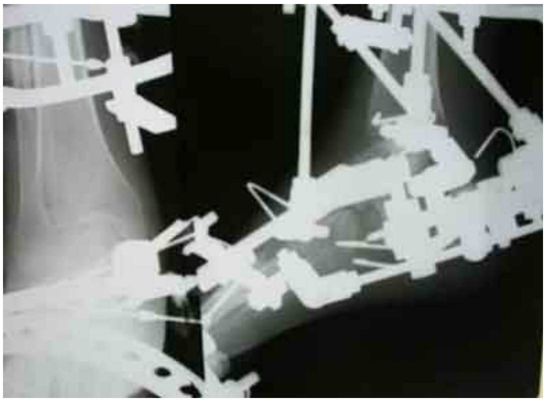

Fig. 7. Problems with high X-ray absorption (it is difficult to see broken limbs because there is so much metal parts).

b) *Application of nanoadditives* - containing selected metal-based nanoparticles on the surface of the outer parts of the fixators may allow for growth inhibition of several pathogens present on human skin and thus prevent or reduce possible infection. Nanotechnology allows a built-in antibacterial protection for solid products, coatings and fibres. Antibacterial protection gives products an added level of protection against damaging microbes such as, bacteria, mould and mildew that can cause cross-contamination and product deterioration. Antibacterial nanotechnology, combined with regular cleaning practices, helps to improve hygiene standards and provides extra protection wherever it is used. For more information see ref. [3], [11] and [13].

c) *Proper mechanical properties* - (stiffness of the whole system of fixators, fatigue testing, etc.) are based on laboratory testing of new smart materials (composites, see Fig. 8).

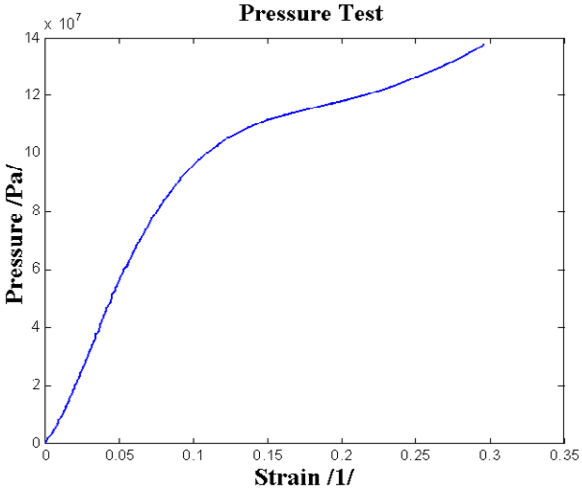

Fig. 8. Pressure tests of a new composite.

d) *Weight optimalization* - to avoid the overloading of limbs fixed by external construction. This is based on the application of numerical methods and experiments.

It is possible to satisfy all these demands with a new material (i.e. design “Option 2”) which uses proper composites, because some current solutions based on light metals (aluminium, titanium etc.) are visible in X-ray diagnostic, see Fig. 6 and 7.

A new design should be made according to shape, ecological perspective, patient's comfort, reducing the time of the surgical operation and reducing the overall cost. Technical aesthetics of fixators also have impacts on the psyche of the patients (i.e. "friendly-looking design of fixators"). For example, patients usually have better feelings, easier motion and physiotherapy with fixators made up from lighter composites (reinforced plastics) than heavier metals, see Fig. 6 and 9. In addition, polymers are easy recycled.

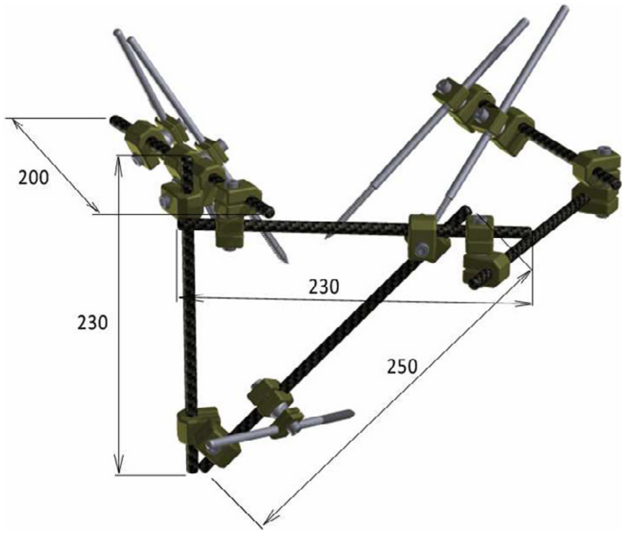

Fig. 9. CAD model of external fixator for pelvis and its acetabulum ("Option 2" design).

3. Measurements of the Real Loadings and Stiffnesses of the External Fixators

During the patient's treatment, it is important to do measurements of the real loadings and stiffness of the external fixators (laboratory measurement and measurement in vivo - painlessly) and data processing are needed.

The original type of measuring is very important for future possible enhancements. This is based on strain gauge measurement and applied statistics and the Simulation-Based Reliability Assessment (SBRA) Method, see ref. [1], [2], [4], [6], [8], [9], [15], [16] and Fig. 10. This type of measuring and processing in vivo has never been applied before to the solution of problems of external fixators.

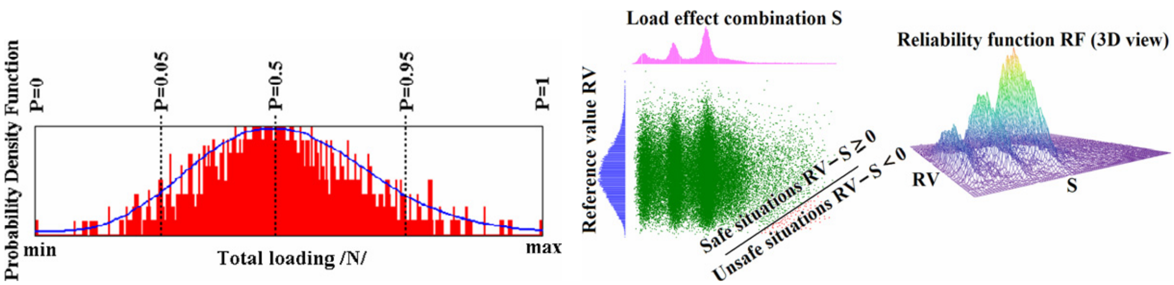

Fig. 10. Typical loading spectrum of an external fixator (histogram, overloading is included) and the Reliability function RF (SBRA Method).

This new solution promises new (so far not investigated) information about real loadings of external fixators during the treatments of patients. In a structural reliability assessment the concept of a limit state separating a multidimensional domain of random (stochastic) variables into "safe" and "unsafe" domains has been generally accepted and is increasingly used in structural reliability theory and in design applications, see Fig. 10.

4. Experiments

The new types of external fixators for treatment of fractures of pelvis and its acetabulum were tested in the laboratory at the VŠB – Technical University of Ostrava (Ostrava, Czech Republic), see ref. [17] and Fig. 11.

The experiments were focused mainly on the stiffness and reliability for the whole system of the fixator and pelvis interaction (i.e. measuring at the place "A" and "B" – pulling the hip bone outwards from acetabulum after the reposition of pelvis fragments), see Fig. 11. The maximum value of force 100 N denotes the overloading (i.e. the tests were performed for excessive loading which is not usual during the treatment of patients).

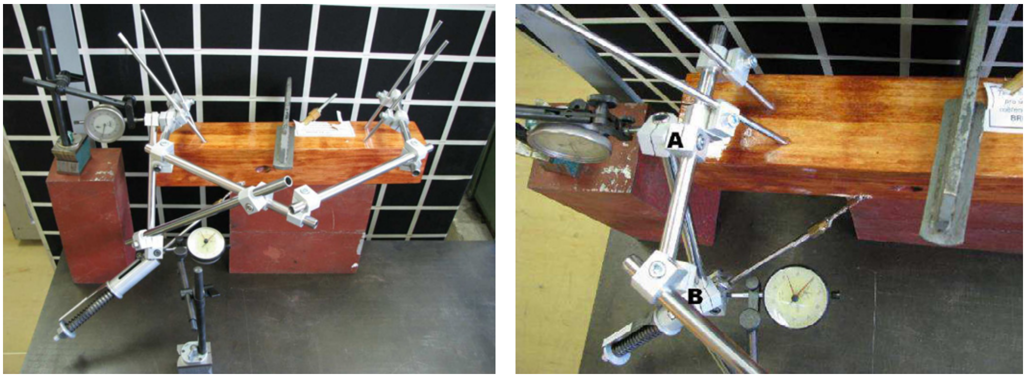

Fig. 11. Measuring - prototype of the external fixator for pelvis and acetabulum and its measurement (“Option 1” design) and detail of measuring - Prototype of the external fixator for pelvis and acetabulum and its measurement (“Option 1” design).

5. Numerical Modelling – FEM

The CAD models of external fixators (i.e. “Option 1” and “Option 2”), see Fig. 6 and 9 – i.e. a general configuration), were imported into the Finite Element (FE) software Ansys Workbench. In this software, the FE meshes were created, see Fig. 12.

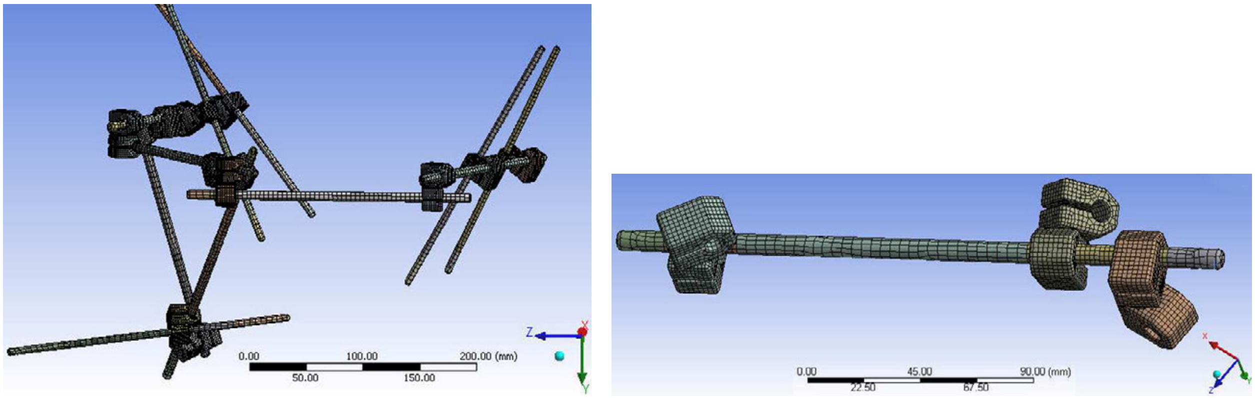

Fig. 12. FE mesh for external fixator (whole structure and its detail).

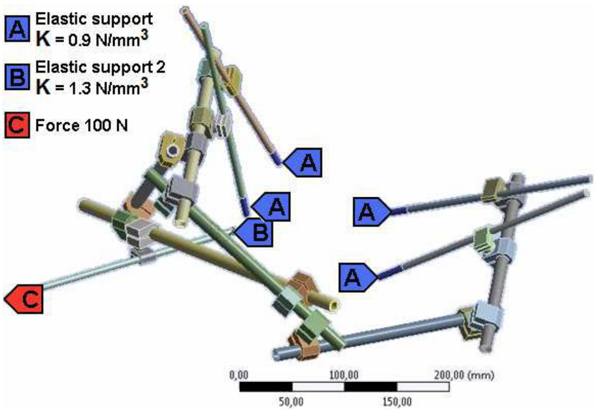

Fig. 13. FE model (boundary conditions) of external fixator for pelvis and its acetabulum.

The basic information about the boundary conditions is presented in Fig. 13. There are defined mechanical contacts with friction between the brackets and titanium pipes (“Option 1”) or between the brackets and composite rods (“Option 2”) and between brackets and Schanz screws.

Schanz screws are embedded in pelvis and its acetabulum in drilled holes. Their attachments are modelled by elastic supports (i.e. by Winkler's foundation, see point “A” and “B” in Fig. 13). The elastic support (defined via modulus of foundation K /Nm^{-3}/, see Fig. 13) is applied in the radial and axial direction on the surface parts of Schanz screws. This is quite good and popular simplification of the real complicated interaction between screw and bone, see ref. [4], [5], [7], [12], [14], [15] and [16].

Loading force 100 N (see point “C” in Fig. 13) is explained in the Chapter 4.

From the results, for example see Fig. 14, Tab. 1 and ref. [10] and [18], is evident very important improvement of the new design (i.e. the new design “Option 2” is better than the design “Option 1”). In the Tab. 1, the symbols “⊕” or “⊖” mean the positive or negative aspects in designing.

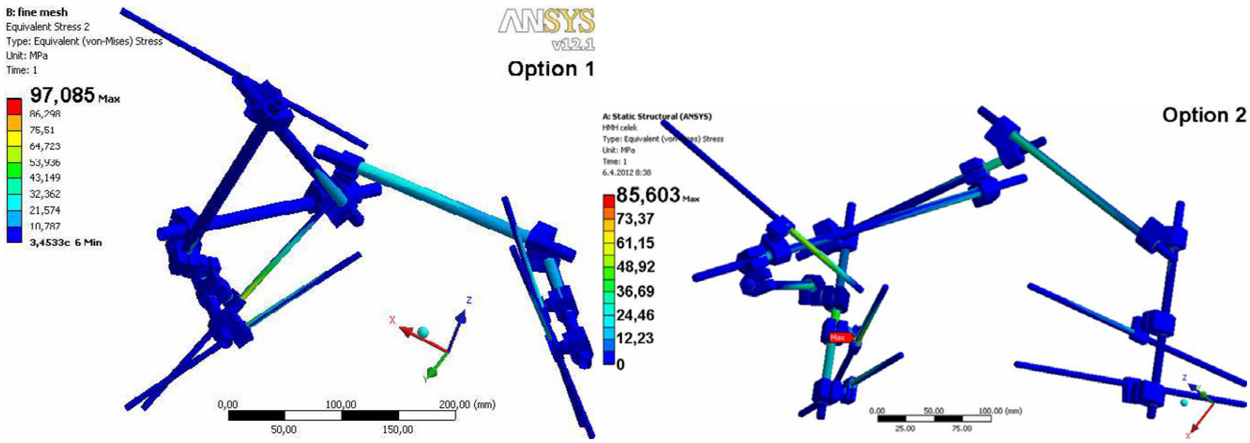

Fig. 14. “Option 1” and “Option 2”- FE modelling of external fixator for pelvis and its acetabulum (equivalent stresses /MPa/ for tensile loading 100 N).

Table 1. Results comparing – external fixator for pelvis and its acetabulum (designs “Option 1” and “Option 2”)

ATTRIBUTES:	OPTION 1:		OPTION 2:	
Design:	⊖	old	⊕	new
Material:	⊖	titanium, stainless steel	⊕	carbon fibre, titanium, stainless steel
Added antibacterial protection:	⊖	no	⊕	yes
X-ray invisible:	⊖	no	⊕	partly yes
Weight of external fixator	⊖		⊕	decreasing
Stiffness of external fixator:	⊖		⊕	increasing
Maximum von Mises stresses /MPa/:	⊖	97.1, see Fig. 14	⊕	85.6 – decreasing, see Fig. 14
Maximum total deformation /mm/:	⊖	5.74	⊕	4.32 - decreasing
Patient comforts:	⊖		⊕	improvement
Reliability assessment	⊖		⊕	improvement
Easy to assembly:	the same			

6. Conclusion

According to the results presented in Tab. 1 (i.e. comparing of the new design with the old one), the improvements in the designing of external fixators for treatment of pelvis and acetabulum fractures are evident.

The results of experiments fit well with numerical modelling.

VŠB - Technical University of Ostrava together with University Hospital of Ostrava and Trauma Hospital of Brno are now in the middle of a process creating new designs for external fixators. Hence, they are in cooperation with the Czech producers MEDIN Nové Město na Moravě (Czech Republic) and ProSpon Kladno (Czech Republic). Therefore, all results could not be published in this paper due to confidentiality reasons.

Report about the new ways to design of external fixator for the treatment of fractures of pelvis and its acetabulum, based on the results of previous research, was presented. Hence, the new designs and materials of fixators will satisfy the ambitious demands of modern traumatology, surgery and economics.

Our team is focused on the solution of external fixator for treatment of open and complicated fractures of limbs too, for example see Fig. 15.

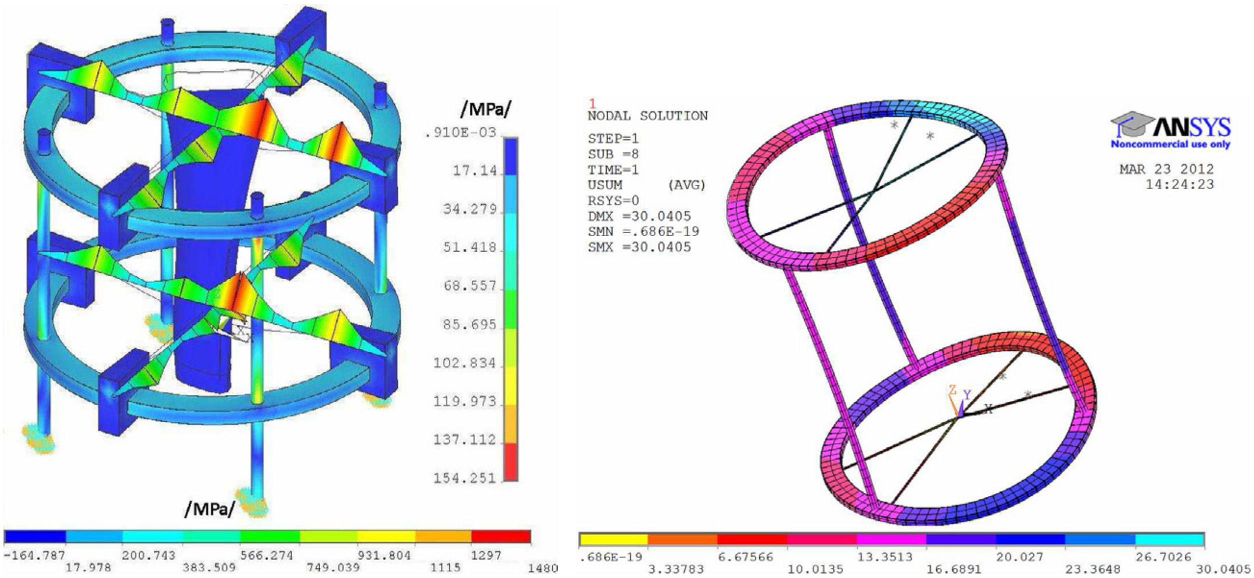

Fig. 15. Examples of FE solutions of external fixator for treatment of lims.

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