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ABOUT THE DEVELOPMENT OF EXTERNAL FIXATORS APPLIED IN EMERGENCY SURGERY

O ROZVOJI ZEVNÍCH FIXÁTORŮ POUŽÍVANÝCH V ÚRAZOVÉ CHIRURGII

Abstract

At first, the doctors mentioned their own medical experience with treatment of complex pelvic injury in patients with polytrauma and give reasons for necessity of early stabilization of pelvic fractures by means of external fixation, especially with continuous hemorrhage into lesser pelvis region and the retroperitoneum. Afterwards, they used damage control surgery methods including selective embolization. However, this article is focused also on the design of external fixators applied in traumatology and orthopaedics (i.e. skills of engineers). These fixators can be used in the treatment of open and unstable (i.e. complicated) fractures of pelvis and its acetabulum. Two versions (i.e. old and new) are compared. 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.

Abstrakt

Nejprve, lékaři zmiňují své vlastní lékařské zkušenosti s léčbou komplexního poranění pánve u pacientů s polytraumaty a udávají důvody pro neodkladnou včasnou stabilizaci pánevních zlomenin pomocí zevních fixátorů, obzvláště u plynulého krvácení do nižších oblastí pánve a retroperitonea. Potom využívají metod “damage control surgery” včetně selektivní embolizace. Nicméně, tento článek je také zaměřen na design nových externích fixátorů aplikovaných v traumatologii a ortopedii (tj. zkušenosti inženýrů). Tyto fixátory mohou být využívány v léčbě otevřených a nestabilních (tj. komplikovaných) zlomenin pánve a acetabula. Dvě verze fixátorů (tj. stará a nová) jsou porovnány. Počítačové modelování (tj. metoda konečných prvků), společně CAD sw, experimenty, materiálovým inženýrstvím a nanotechnologií jsou prezentovány jako podpora vývoje nových konstrukcí zevních fixátorů.

Keywords

biomechanics, polytrauma, traumatology, fractures of pelvis, external fixators, design, numerical modelling

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1 INTRODUCTION

Increasing number of high-energy injuries brings increase in number of complex injuries of the pelvis, where apart from fractures of the pelvic girdle also arteries, nerves, soft tissues and pelvic intraperitoneal and retroperitoneal organs are injured. The most severe complication of these injuries consists in extensive haemorrhage, mainly from injured skeleton, a presacral and paravesical vascular plexes that can directly threaten life of the injured child by haemorrhagic traumatic shock.

Diagnostic methods, apart from RTG pelvic, are ultrasonography, computed tomography and computed angiotomography, see [1].

The basis for the treatment of instable pelvic fractures consists of pelvic skeleton stabilization, which in the urgent stage is ensured by application of a pelvic clamp with subsequent application of external fixator, see [1] to [4], [7] to [12] and Fig. 1.

Fig. 1 Complex pelvis fracture treated with external fixator (Trauma Centre, University Hospital in Ostrava, Ostrava, Czech Republic) and Fracture of pelvis and its acetabulum (anteroposterior radiograph - transverse with posterior wall acetabular fracture)

In case of continuous haemorrhage, we perform urgent AG with surgical treatment of injured arteries or their selective embolization, see [5]. In extensive devastating injuries we do not hesitate to perform tamponade of the pelvis with possible bilateral ligature of a. iliaca interna, see [6].

2 EXTERNAL FIXATORS FOR TREATMENT OF PELVIS AND ITS ACETABULUM

Acetabular fractures, see Fig. 1, 2 and 3, 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.).

Fig. 2 Examples of acetabular fractures

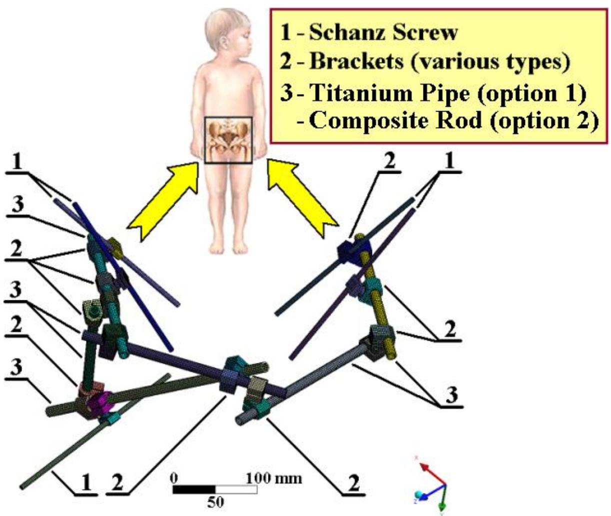

Fig. 3 Application of external fixator for treatment of pelvis and its acetabulum

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. 3 and ref. [7] and [12]. Scientific and technical developments, together with medical care and practice and engineering bring new demands for designs of external fixators. These demands are presented in Tab. 1.

Tab. 1 New ways for designing external fixators applied in treatment of open and unstable fractures

DEMANDS:	BENEFITS AND EXPLANATION:	GOALS:
Outer parts of fixators must be x-ray invisible (i.e. low x-ray absorption):	Easy to see fracture; reducing radiation exposure for patients and surgeons; shortening the operating time.	**New smart materials (mostly not metal)**
Antibacterial protection:	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 and thus prevent or reduce possible infection. 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. Antibacterial protection based on the nanotechnology was tested in the laboratory conditions.	
Material Engineering:	Material proposition and material tests; proper mechanical properties.	
Ecological perspective:	Easy to recycle.	
Weight optimalization:	To avoid the overloading of limbs fixed by external construction. This is based on the application of numerical methods and experiments too.	**New design (structure)**
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.	
Easy to assembly:		
Proper mechanical properties:	Stiffness of the whole system of fixators, fatigue testing, etc. are based on laboratory testing of new smart materials.	**Numerical modelling (FEM, SBRA Method) and experiments**
Measuring of the real loadings:	During the patient's treatment measurements of the real loadings and stiffness of the external fixators (laboratory measurement and measurement in vivo - painlessly) and data processing are needed. This is based on strain gauge measurement and applied statistics and the Simulation-Based Reliability Assessment (SBRA) Method, see [17] – [26]. This type of measuring and processing in vivo has never been applied before to the solution of problems of external fixators.	

3 FEM MODELLING

The CAD models of external fixators (i.e. “Option 1” and “Option 2”), see Fig. 3), were imported into the Finite Element (FE) software Ansys Workbench. In this software, the FE meshes were created, see Fig. 4.

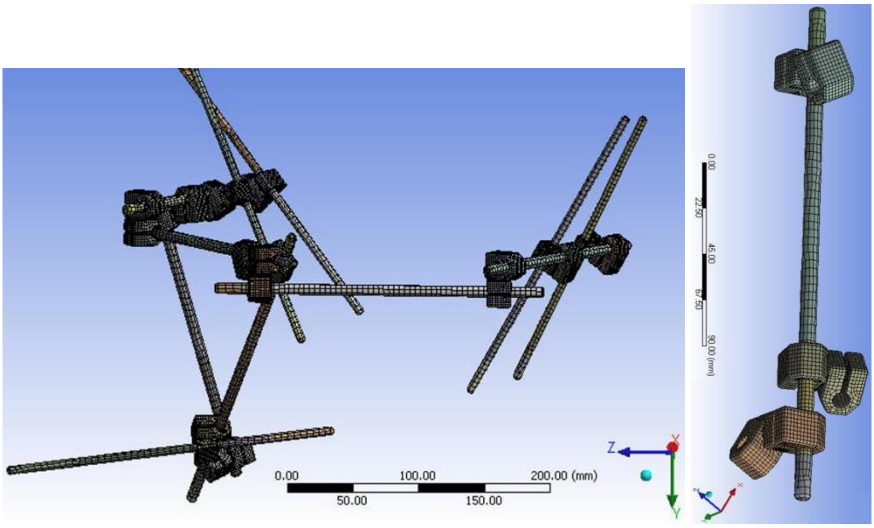

Fig. 4 FE mesh for external fixator (whole structure) and its detail

The basic information about the boundary conditions is presented in Fig. 5. 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.

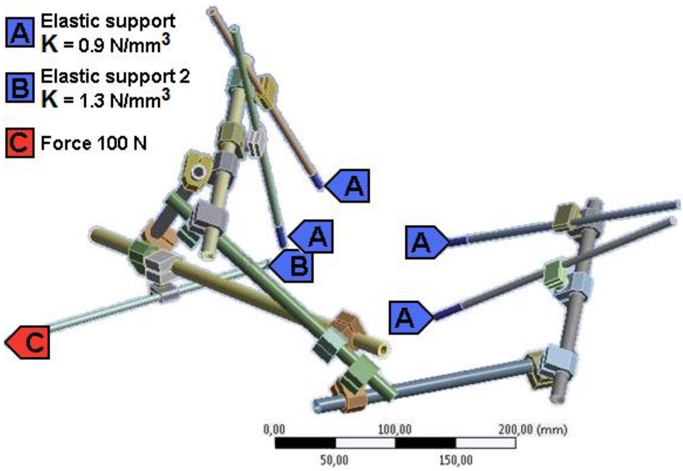

Fig. 5 FE model (boundary conditions) of external fixator for pelvis and its acetabulum

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. 5). The elastic support (defined via modulus of foundation K /Nm^{-3}/, see Fig. 5) 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 [16], [19] and [27] – [29].

Loading force 100 N (see point "C" in Fig. 5) is explained via pulling bones in their correct positions.

From the results, for example see Fig. 6, 7, Tab. 2 and reference [16], 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 Table II, the symbols "⊕" or "⊖" mean the positive or negative aspects in designing.

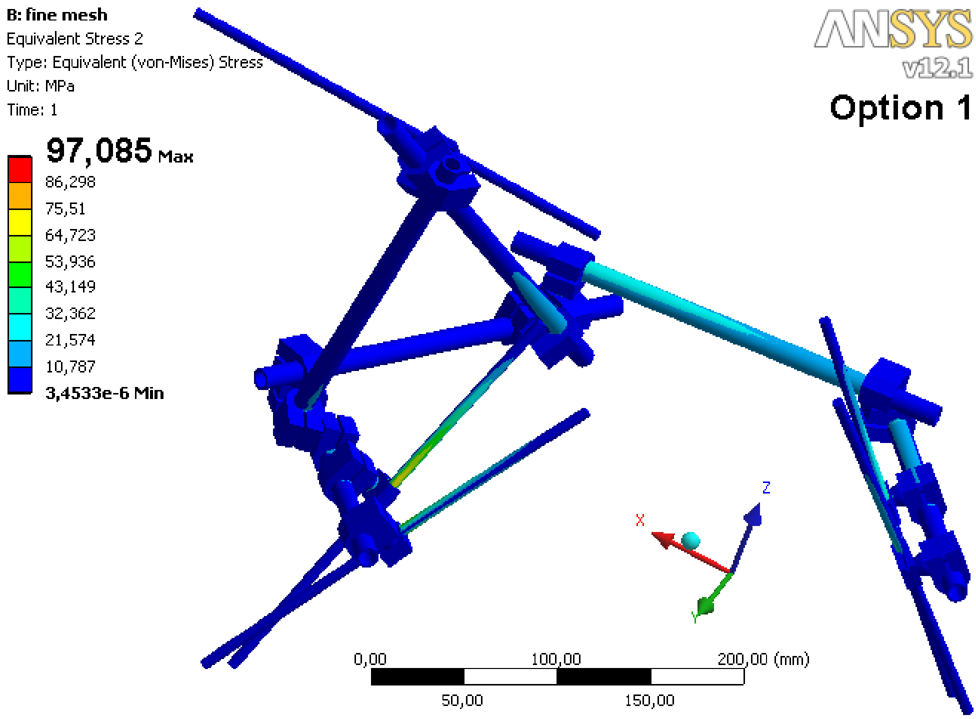

Fig. 6 "Option 1" - FE modelling of external fixator for pelvis and acetabulum (equivalent stresses for tensile loading 100 N)

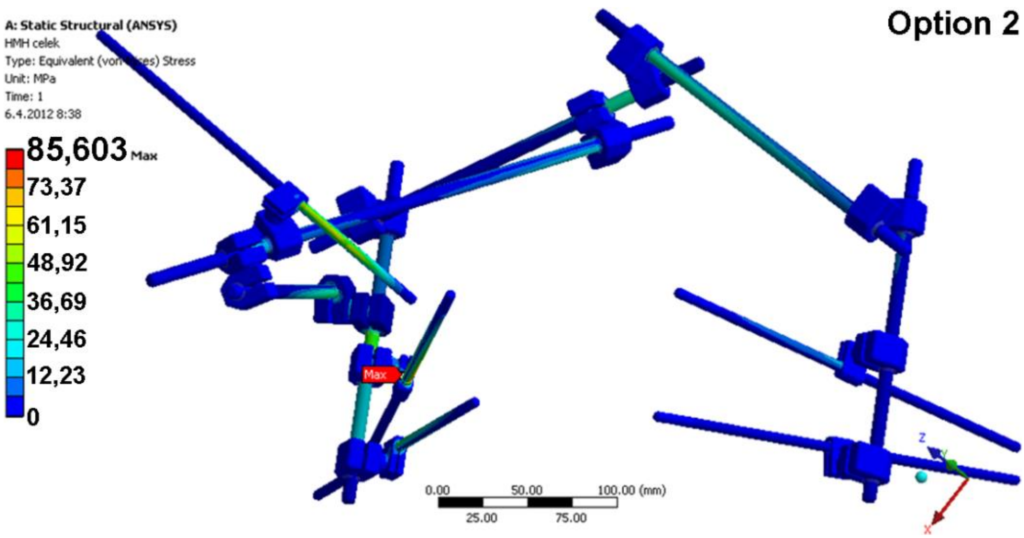

Fig. 7 "Option 2" - FE modelling of external fixator for pelvis and acetabulum (equivalent stresses for tensile loading 100 N)

Tab. 2 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. 6	⊕	85.6 – decreasing, see Fig. 7
Maximum total deformation /mm/:	⊖	5.74	⊕	4.32 - decreasing
Patient comforts:	⊖		⊕	improvement
Reliability assessment	⊖		⊕	improvement
Easy to assembly:	the same			

CONCLUSIONS

According to the results presented in Tab. 2 (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, see [15], 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). 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. Another types of fixators are presented in references [13] and [14].

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