New External Fixators for Treatment of Complicated Periprosthetic Fractures

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***Abstract*—** In this article, doctors want to draw attention to the possibilities of treatment of periprosthetic fractures of femur. They present their own experiences with the treatment of these fractures by using various types of internal and external fixation. In this article, Engineers report about the new design of external fixators invented at the VŠB - Technical University of Ostrava and at the Trauma Centre of The University Hospital in Ostrava together with MEDIN a.s. companiy. These fixators are intended for the treatment of open, unstable and complicated fractures in traumatology and orthopaedics for humans or animals limbs. The new design is based on the development of Ilizarov and other techniques (i.e. shape and weight optimalization based on composite materials, application of smart materials, nanotechnology, low x-ray absorption, antibacterial protection, patient's comfort, reduction in the duration of the surgical treatment, and cost).

***Keywords* —** biomechanics, traumatology, orthopaedics, design, experiments, numerical modelling, external fixators, fractures, periprosthetic fractures, limbs

I. Introduction

CHANGES in lifestyle, increased age and development of endoprosthetics are connected with increased occurrence of periprosthetic and other types of fractures in recent years, see [9]. There are descriptions of several possibilities of treatment of these fractures including their complications.

For example, incidence of periprosthetic fractures after the application of the total arthroplasty varies. The incidence between 0.6–2.5 % was described in cases of supracondylar fractures above the femoral component of knee arthroplasty, see [10]. The creation of these fractures is preceded by accident (as in case of other fractures) or there is a slow process of bone corruption for various reasons. The fracture then is caused by minimal trauma. In many cases, patients do not even mention the accident. The fracture turns up during a common activity.

Fig. 1 X-ray Rorabeck type II fracture – lateral view (source internet [12])

Hence, treatment of periprosthetic fractures is a challenge for the surgeon because of decreased bone quality and complicating systemic diseases The most prevalent type of periprosthetic fracture is the Rorabeck type II, see Fig. 1 and [11] – [13]. Recommended treatment options are plating, external fixation and retrograde intramedullary nailing (RIMN), see Fig. 2.

There is still continuing debate which treatment option is optimal for these patients. There is no consensus on the technique to be used but logically it must be minimally invasive to decrease mortality and morbidity, see [5] and [13] – [15]. Stable osteosynthesis obtained by minimal

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invasive techniques assures more rapid fracture union.

Fig. 2 Periprosthetic fracture above the total knee arthroplasty treated by intramedullary nailing, see [5]

The treatment of periprosthetic fractures depends on the type of fracture (comminutives etc.), location – distance from arthroplasty and other factors (osteoporosis, general condition of patient). Generally we can divide methods of treatment to conservative and surgical – 70 % success in both methods if correctly implemented.

The plaster of Paris, see Fig. 3, skeletal traction or a combination of both can be used as a conservative method. Individual or fabricated orthesis can be used during after-treatment.

Fig. 3 Periprosthetic fracture of femur above the total knee arthroplasty treated by closed method (plaster of Paris), see [5]

Concerning surgical method, the descriptions of practically all types of internal and external fixation or their combinations appear in specialized literature, see Fig. 4, 5 and 6.

Fig. 4 Treatment of periprosthetic fracture of femur above the total knee arthroplasty by external frame fixation, see [5]

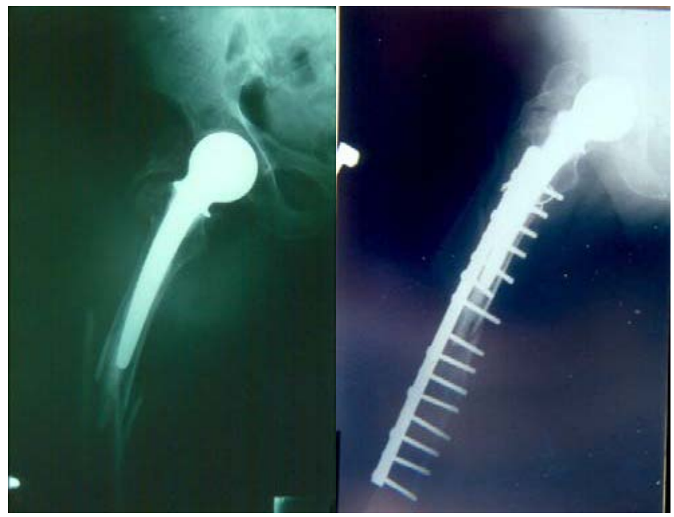

Fig. 5 Plate osteosynthesis of periprosthetic fracture under hemiarthroplasty of the hipp, see [5]

Fig. 6 Model of internal fixation by clamp plate on the bone model and X-ray after the internal fixation, see [5]

II. External Fixation

External fixators can be applied in traumatology, surgery and orthopaedics for treatments such as: open and unstable (complicated) fractures, limb lengthening, deformity correction, consequences of poliomyelitis, foot deformities, hip reconstructions, etc. Hence, external fixators can be used for treatment of humans and animals, for example see Fig. 4 and 7 and example (i.e. one story) of patient treatment Fig. 8, 9 and 10.

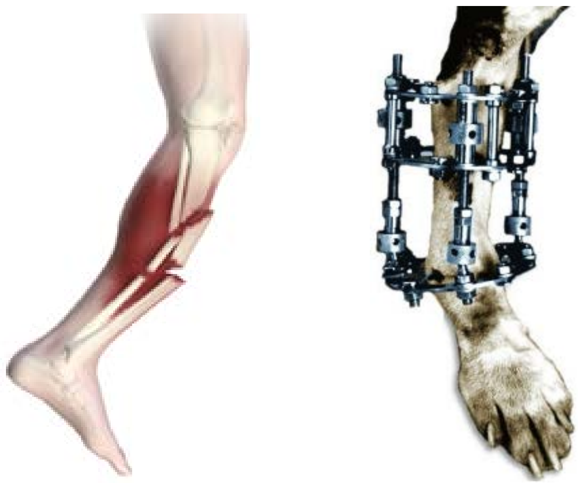

Fig. 7 a) Example of open and complicated fracture (human), b) Application of external fixator (treatment of dog) – source internet

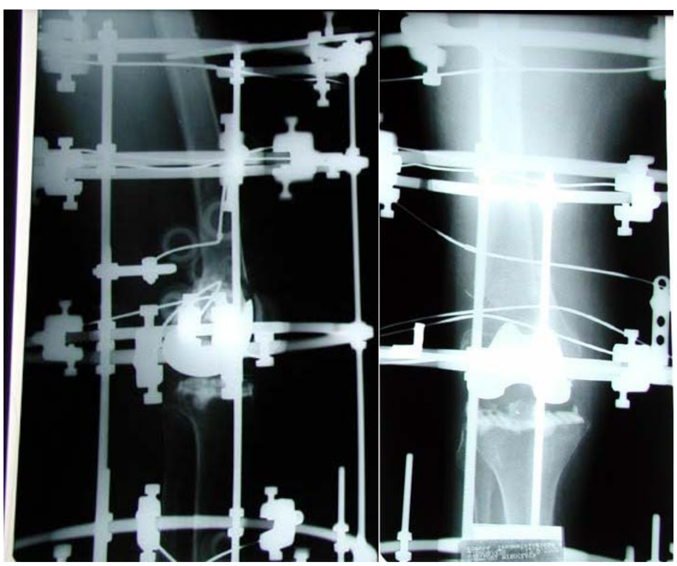

Fig. 8 Post-operativ X-ray snapshot after the external fixation of periprosthetic fracture above the knee arthroplasty - see [5]

Fig. 9 Before removal of external fixator - see [5]

Fig. 10 Three months after the operation - see [5]

III. Engineering point of view

According to current studies and research, performed at VŠB – Technical University of Ostrava, Trauma Centre of the University Hospital of Ostrava (Ostrava, Czech Republic) and Trauma Hospital of Brno (Brno, Czech Republic), together with MEDIN a.s., for examples see [2], [4], [5], [6], [8] and [16] – [18], the current design of external fixators can be modified.

Since the bolts pierce the skin, proper cleaning to prevent infection at the site of surgery must be performed. External fixation is usually used when internal fixation is contraindicated, or as a temporary solution. During its use, it is also possible to use and exercise the broken limbs and even walk. However, a modern design of these fixators is needed to satisfy new trends in medicine. Hence, this paper reports about the designing of external fixators intended for treatment of open or complicated fractures of limbs (such as mentioned periprosthetic fractures).

IV. New Demands for Designing External Fixators

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, see chapter IV.1.
2. New design, see chapter IV.2.
3. Measuring of the real loadings, see chapter IV.3.
4. Numerical modelling and experiments, see chapter IV.4.

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

IV.1 Applications of new smart materials

a) Low X-ray absorption (i.e. rtg. invisible) for the outer parts of fixators, see Fig. 11. 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.

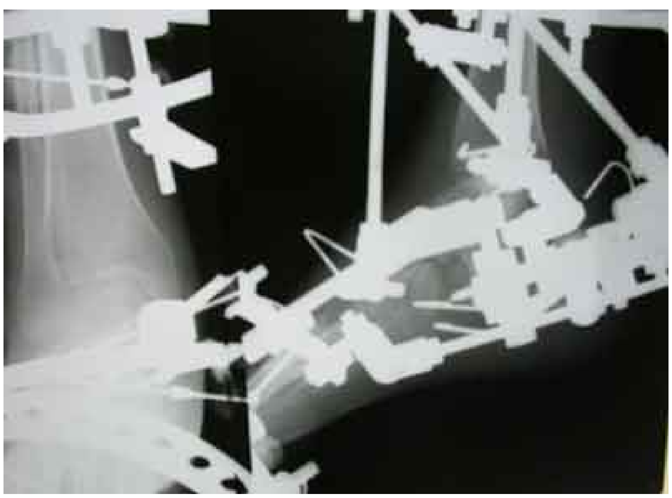

Fig. 11 Problems with high X-ray absorption (it is difficult to see broken limbs because there is so much metal parts)

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 references [2] and [7].

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

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 which uses proper plastics (polymers), because some current solutions based on light metals (aluminium, titanium etc.) are visible in X-ray diagnostic, see Fig. 12.

Fig. 12 Design of external fixators a) Based on metals (current design, heavier, expensive, etc.), b) Based on reinforced polymers (new design, lighter, cheap, more friendly etc.)

IV.2 New design

A new design should be made according to shape, ecological perspective, a 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. 12. In addition, polymers are easy recycled.

IV.3 Measurements of the real loadings and stiffness 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 [1], [3] and [19] – [25] and Fig. 13. This type of measuring and processing in vivo has never been applied before to the solution of problems of external fixators.

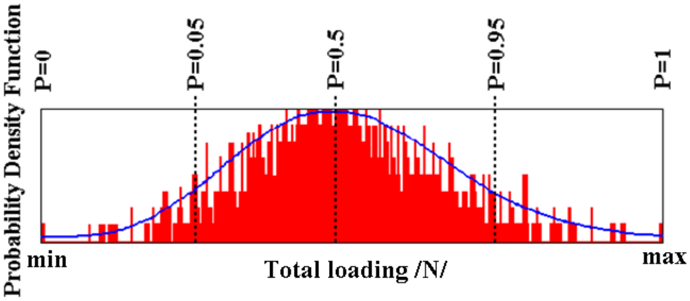

Fig. 13 Typical loading spectrum of an external fixator (histogram, overloading is included)

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.

IV.4 Numerical modelling and experiments

Numerical modelling and experiments (based on the previous skills, see [2], [4], [5], [6], [8] and [16] – [18], as support for research and design, are a very important part of the solution, see Fig. 14 to 18 (i.e. applications of FEM and experiments – fixator for fractures of limbs).

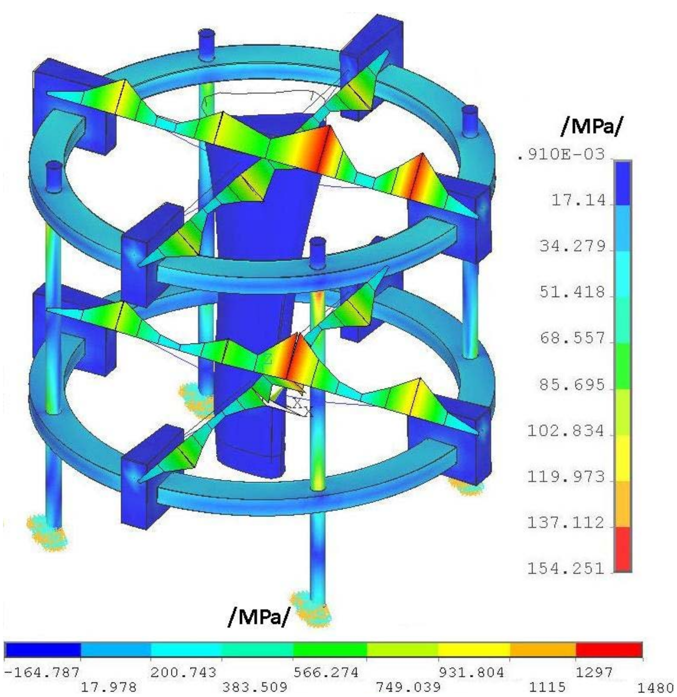

Fig. 14 Numerical modelling (FEM – equivalent von Mises stresses in the structures)

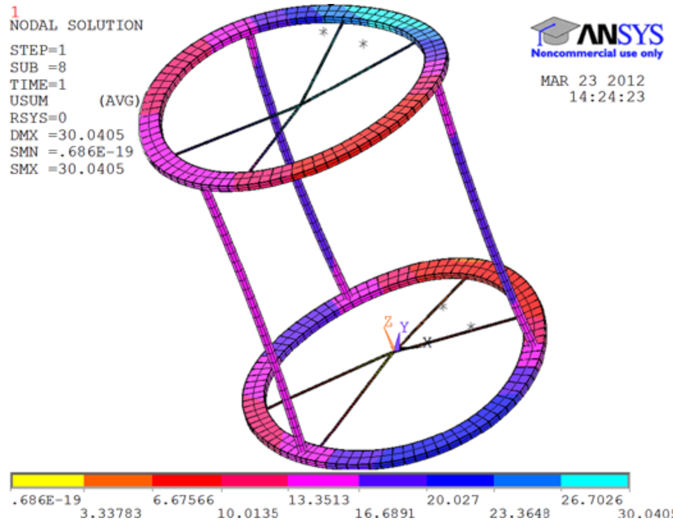

Fig. 15 Numerical modelling (FEM – total displacements in the structure)

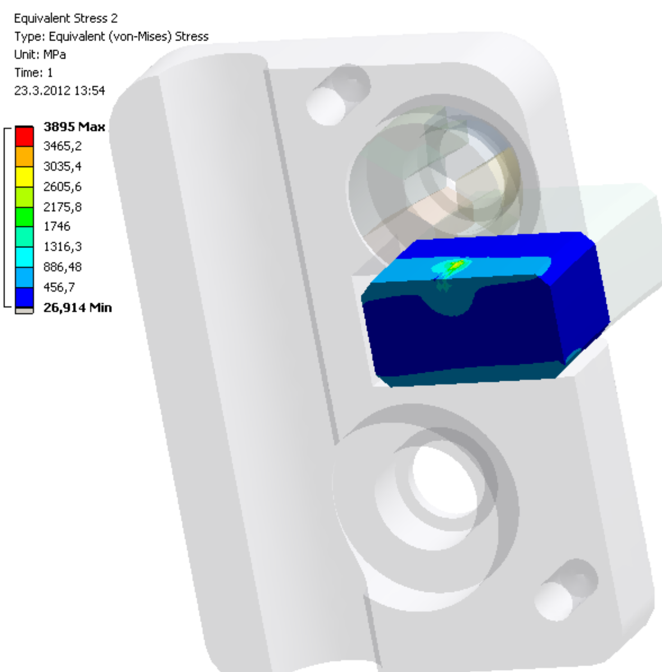

Fig. 16 Numerical modelling (FEM - equivalent von Mises stresses at the ring attachment)

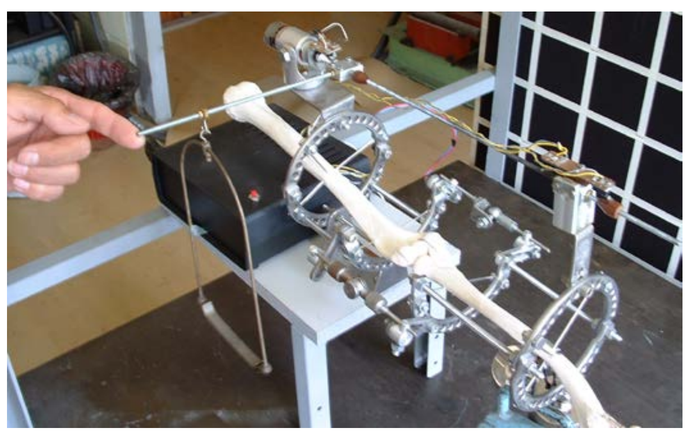
Fig. 17 Experimental measurements

Fig. 18 Numerical modelling (FEM - Kirschner wire and detail of its attachment).

V. CONCLUSION

Medical point of view: Periprosthetic fractures make an important therapeutical problem for their individual and specific character. Their diversity from other types of fractures consists in thefact that they are fractures of bone with the implants of total arthroplasty and therefore the method of treatment must often be different from therapeutical as in case of other types of fractures. Among the general risk factors we can include osteoporosis, rheumatoid arthritis, treatment with corticosteroids and naturally other diseases which may affect healing processes of patients. Emergence of these fractures can be additionally caused by technical problems e.g. anterior notching of the femoral cortex of total knee arthroplasty, damage of proximal femur at application of the total hip arthroplasty and other. Among other possible complications there can be postoperative treatment and patient's personality – early weight bearing. The complications may occur at conservative treatment as well as after the surgical treatment and they are affected by right evaluation of fracture and right choice of the treatment method and also by the patient preparation and leading of the treatment including rehabilitation and weight bearing.

Engineering point of view: Report about the new ways to design of external fixator, 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.The results of experiments fit quite well with numerical modelling. According to the results, the improvements in the designing of external fixators for treatment of limb fractures are evident. 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 a.s (Nové Město na Moravě, Czech Republic). Therefore, all results could not be published in this paper due to confidentiality reasons.

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Under the leadership of Assoc. prof. Leopold Pleva, the Trauma Centre currently draws on significant traditions by introducing new operating methods in polytrauma, which are concentrated in the Trauma Center from the whole North-Moravian region. The scientific research activity focuses on solution of state research tasks, where the physicians of the Trauma Center are successful solvers of new therapeutic methods.

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