

New Ways for Designing External Fixators Applied in Treatment of Open and Unstable Fractures

Karel Frydryšek, Pavel Košťál, Karla Barabaszová and Jana Kukutschová

Abstract—This paper deals with a new way for designing external fixators applied in traumatology and orthopaedics. These fixators can be applied in the treatment of open and unstable fractures or for lengthening human or animal bones etc. The new design is based on the development of Ilizarov and other techniques (i.e. shape and weight optimization 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, design, external fixators, new materials, traumatology

I. INTRODUCTION

ACCORDING to current studies and research, performed at VŠB – Technical University of Ostrava and Traumatology Centre of the University Hospital of Ostrava (Ostrava, Czech Republic), for examples see references [1] to [5], the current design of external fixators can be modified, see Fig. 1 and 2. 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 in humans and animals.

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 reduction, 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 connect the bolts to make a stiff support. The complicated fracture can be set in the proper anatomical configuration.

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Fig. 1 Current design of external fixators



Fig. 2 Current design of external fixators

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, see the following text.

II. NEW WAYS 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 III
2. new design, see chapter IV
3. measuring of the real loadings, see chapter V
4. numerical modelling and experiments, see chapter VI

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

III. APPLICATIONS OF NEW SMART MATERIALS

Applications of new smart materials should satisfy the following requirements:

a) Low x-ray absorption (i.e. x-ray invisible) for the outer parts of fixators, see Fig. 3. The outer parts of fixators are usually made of metal, 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.

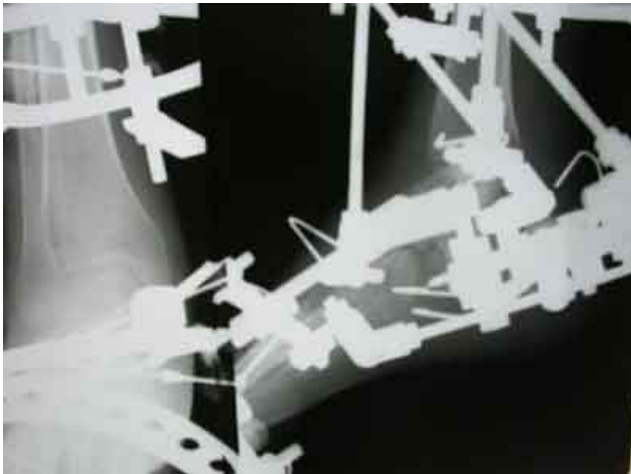


Fig. 3 Problems with high x-ray absorption (it is difficult to see broken limbs because there is so much metal parts).

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.

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

d) Weight optimization - 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. 3.

The prospective polymer could be polyurethane. Its chosen physical properties are in the Tab. I.

TABLE I

THE CHOSEN PHYSICAL PROPERTIES OF THE POLYURETHANE

MECHAN. PROPERTIES AT 23 °C AFTER HARDENING (1)			
Flexural modulus	ISO 178 : 2001	MPa	2.100
Flexural strength	ISO 178 : 2001	MPa	105
Tensile modulus	ISO 527 : 1993	MPa	2.700
Tensile strength	ISO 527 : 1993	MPa	75
Elongation at break in tension	ISO 527: 1993	%	9
Charpy impact strength	ISO 179/1 eU : 1994	kJ/m ²	27
Final hardness	ISO 868 : 2003	Shore D1	87

THERMAL AND SPECIFIC PROPERTIES (1)			
Glass temperature transition (Tg)	ISO 11359 : 2002	°C	110
Heat deflection temperature (HDT 1.8 MPa)	ISO 75 Ae :1993	°C	100
Maximal casting thickness		mm	10
Demoulding time at 70 °C (thickness 3 mm)		min.	45

(1) Average values obtained on standard specimens/Hardening
4 hrs at 80 °C + 16 hrs at 100 °C

However, the most useful applications are composites based on the mentioned polymer and reinforced by carbon nanotubes (CNT), see reference [15]. CNT are allotropes of carbon with a cylindrical nanostructure (i.e. members of the fullerene structural family). These cylindrical carbon molecules have novel properties, making them potentially useful in many applications in nanotechnology, electronics, optics, and other fields of materials science, as well as being potentially useful in architectural fields. They may also have applications in the construction of body armour etc. They exhibit extraordinary strength and unique electrical properties, and are efficient thermal conductors. Their name is derived from their size, since the diameter of a nanotube is on the order of a few nanometres (approximately 1/50000th of the width of a human hair), while they can be up to 18 centimetres in length (as of 2010), see reference [16] and Fig. 4. Moreover, nanotubes naturally align themselves into "ropes" held together by van der Waals forces.

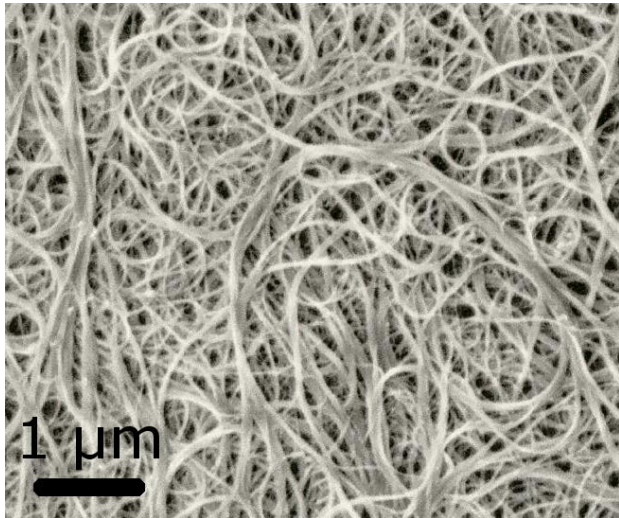


Fig. 4 Scanning electron microscope image of CNT bundles

CNT are categorized as single-walled nanotubes (SWNT) and multi-walled nanotubes (MWNT), see Fig. 5.

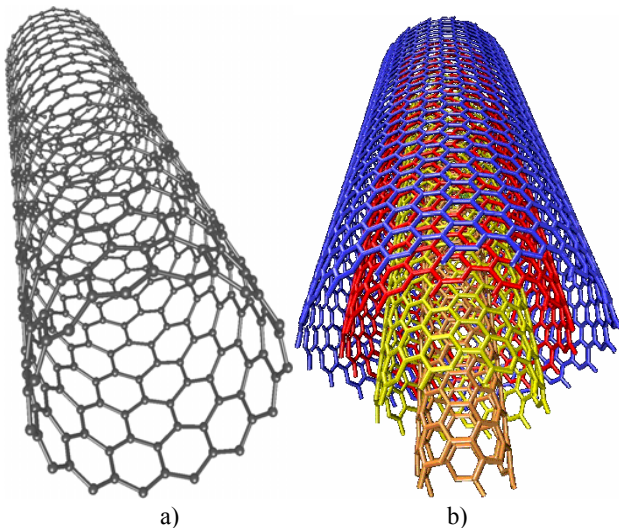


Fig. 5 CNT a) single-wall carbon nanotubes (SWCNT)
b) multi-wall carbon nanotubes (MWCNT)

A large variety of physical properties of polyurethanes filled by carbon nanotubes were described in [17] to [19]. An advantage of this type of material is also in its x-ray invisibility.

Bionano-composite, a new generation of composite materials, signifies an emerging field in the frontier of materials science, life science, and nanotechnology. Bionano-composites are composed of a natural polymer matrix and organic/inorganic filler with at least one dimension on the nanometre scale. These bionano-composites show the remarkable advantages of biodegradability and biocompatibility in various medical, agricultural, drug release and packaging applications. Biodegradability and biocompatibility of polymers can form various chemical

bonds with transition metals and heavy metals components of composite materials and, thus, can enhance the stability of the nanoparticles. The applications of biodegradable polymers are generally limited by their poor physical and mechanical characteristics and by difficulty of processing, see [20].

Hence, the chosen properties of CNT and other materials are collected in Table II. From Tab. II, it is possible to clearly see the excellent mechanical properties of both SWCNT as well as MWCNT. For more information about material properties see references [11] to [19]. A review of CNT-polymer composites is given in the work [14]. Prospective materials with the needed qualities are polyurethanes filled by MWCNT and SWCNT. They have good mechanical (static and dynamic) properties and low x-ray absorption (i.e. high invisibility), see Fig. 6.

TABLE I
THE MATERIAL PROPERTIES OF NANOTUBES AND ITS COMPARING

Material:	Young's modulus /GPa/:	Tensile strength /GPa/:	Density /g×cm ⁻³ /:
SWCNT	1054	150	1.4
MWCNT	1200	150	2.6
Steel	208	0.4	7.8
Epoxy	3.5	0.005	1.25
Wood	16	0.008	0.6

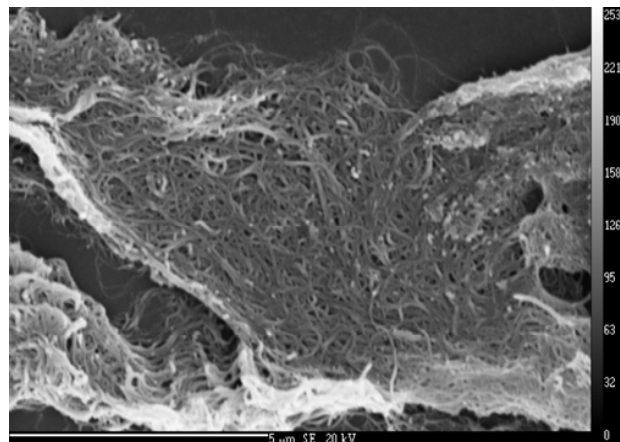


Fig. 6 Mechanical activated CNT for polymer composites preparation

IV. 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. 7. In addition, polymers are easy recycled.

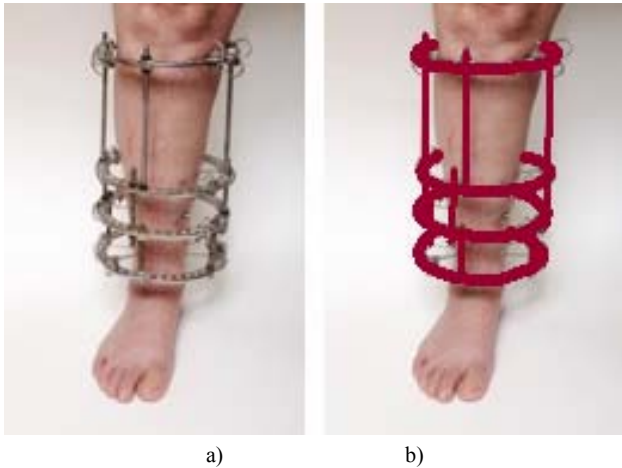


Fig. 7 Design of external fixators

- a) Based on metals (current design, heavier, expensive, etc.)
- b) Based on reinforced polymers (new design, lighter, cheap, more friendly etc.)

A new proposed design cannot be more specifically described here for confidentiality reasons.

V. MEASURING OF THE REAL LOADINGS

During the patient’s treatment measurements of the real loadings and stiffness of the external fixtators (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 [6]. This type of measuring and processing in vivo has never been applied before to the solution of problems of external fixators.

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 references [6] to [10]).

Let us consider the SBRA Method, a probabilistic direct Monte Carlo approach, in which all inputs are given by bounded histograms. Bounded histograms include the real variability of the inputs. Application of the SBRA method is a modern and innovative trend in mechanics, for example see references [6], [7], [9] and [10].

Using the SBRA method, the probability of failure (i.e. the probability of an undesirable situation) is obtained mainly by analyzing the reliability function $RF = RV - S$, see Fig. 8, 9 and 10, where RV is the reference (allowable) value and S is a

variable representing the load effect combination. The probability of failure is the probability that S exceeds RV (i.e. $P(RF \leq 0)$). The probability of failure is a relative value depending on the definition of RV and it usually does not reflect an absolute value of the risk of failure (for example, it usually does not correspond to a “total” collapse).

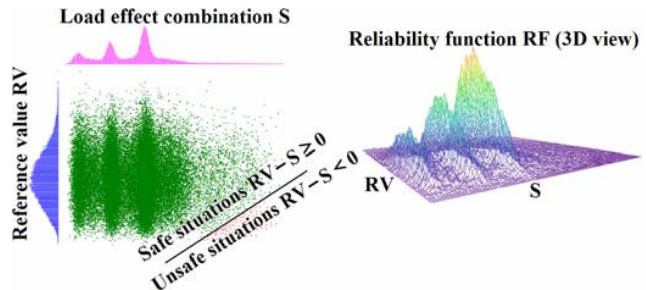


Fig. 8 Definition of the reliability function RF (SBRA method)

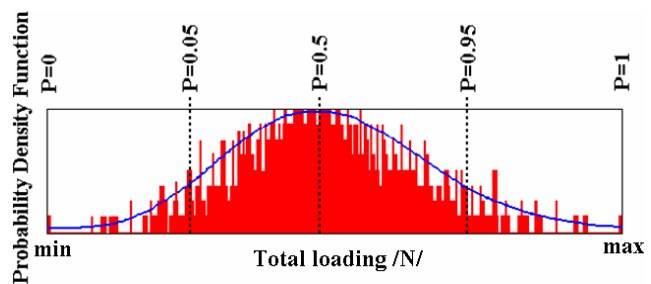


Fig. 9 Typical loading spectrum of an external fixator

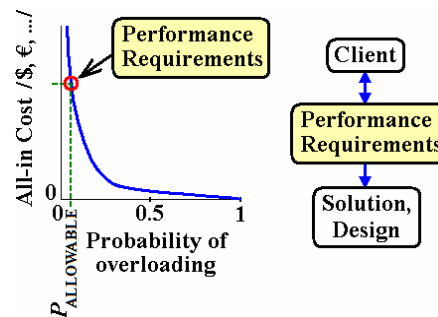


Fig. 10 Definition of the acceptable probability of overloading

VI. 4. NUMERICAL MODELLING AND EXPERIMENTS

Numerical modelling and experiments (based on the previous skills, see [2] to [5]), as support for research and design, are a very important part of the solution, see Fig. 11 and 12 (i.e. application of the Finite Elements Method - FEM).

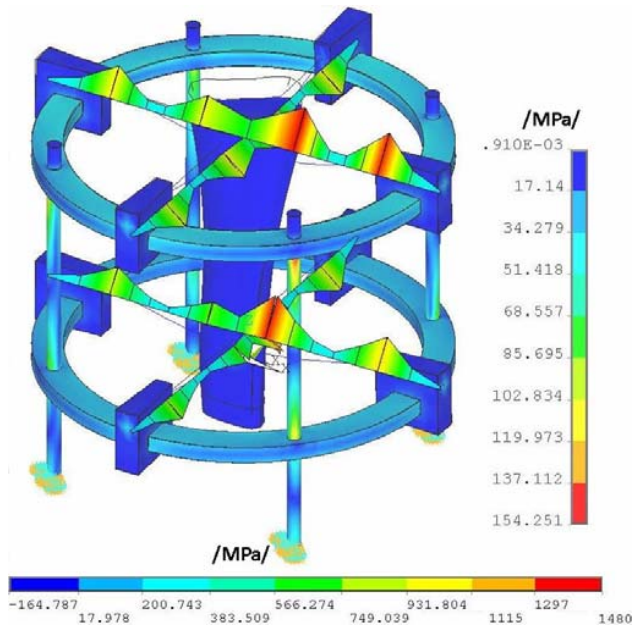


Fig. 11 External fixator (numerical modelling, FEM, treatment of leg, ANSYS software)

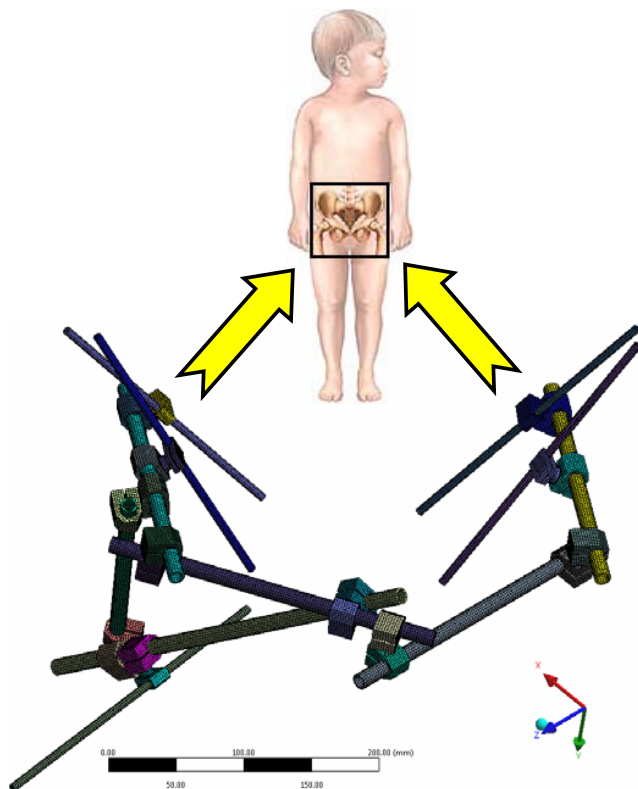


Fig. 12 External fixator (numerical modelling, FEM, treatment of pelvis and acetabulum, MSC.PATRAN software)

VII. CONCLUSION

Report about the new ways to design of external fixators, based on the results of previous research, were presented.

Hence, the new designs and materials of fixators will satisfy the ambitious demands of modern traumatology, surgery and economics.

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 a new design for external fixators. Hence, they are in cooperation with the Czech producer MEDIN Nové Město na Moravě (Czech Republic).

Therefore, all results could not be published in this paper due to confidentiality reasons.

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