

EVALUATION OF BIOMECHANICAL PERFORMANCES OF SOME OSTEOSYNTHESIS TECHNIQUES APPLIED IN THE TREATMENT OF FEMORAL FRACTURES

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Abstract: In order to evaluate the biomechanical behaviour of some types of osteosynthesis techniques (elastic or rigid) frequently used in the femoral fractures treatment, a comparative study undertaken by Finite Element Method (FEM), is presented in this paper. FEM results are used to emphasize the biomechanical particularities that can appear in the case of some elastic osteosyntheses with: Kuntscher nail (OEK), Ender nails in secant arch (OES), Ender nails and external lock (OEF), and also in the case of rigid osteosynthesis with locked intra-medullar nail (ORZ). Evaluation criteria of the biomechanical behaviour of these osteosyntheses refer to the level of compression stresses and displacements in the fracture focus. The stress state and resultant displacements, in different zones of the bone and implants were also analysed. For comparison, the stress state and displacements were also determined for the unfractured (normal) bone. Simulations were performed for monopodal position, corresponding to the walking sequences when one leg or the other successively realizes the ground support.

Keywords: osteosynthesis, stresses, nail, femur, tibia, finite element method

1. ELEMENTS OF BIOMECHANICS AND PHYSIOPATHOLOGY

The long bones of the human skeleton have an important role in sustaining the weight of the trunk and transmission of loads to the floor. In the same time, these bones accomplish important functions of locomotor apparatus, through their movements.

From anatomical point of view, the bones of the lower limb (femur and tibia) are the longest and the most powerful bones of the human body. Surrounded by a mass of heavy muscle inserted on a large part of their surface, these bones are connected through a mutual joint (knee joint). At the end of each of them, important joints of the lower member (coxo-femoral joint and ankle joint) are formed.

Due to their orientation mode and anatomic and functional architecture, these bone segments are subjected to complex loading under the action of the transmitted loads. Bending and compression are the most important loadings, giving rise to bending and compression normal stresses σ . The distribution of these stresses in different sections changes along the bone. So, in the case of femoral diaphysis (Fig. 1), the load transmitted through the femoral head is applied eccentrically and produces traction or compression stresses in different cross-sections. At the proximal part, the traction stresses are situated in the outer part of the section, while the compression stresses are on the inner side. At the distal part, the traction stresses develop at the inner part of cross-section and the compression ones – at the exterior. Thus, along the femoral shaft, the neutral axis follows a helicoidal line,

dividing the cross-sections in unequal zones loaded in traction or compression. Therefore, the place where fracture occurs and the stress distribution should be taken into account in the treatment of the femoral fractures, as to achieve through the adopted osteosynthesis a large zone loaded in compression, with a moderate level of stresses.

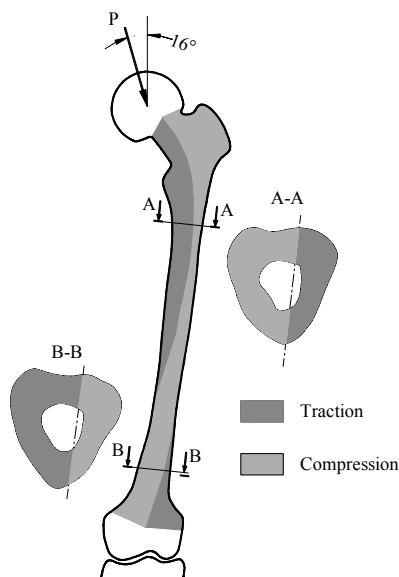


Fig. 1

The lower limb bones can be fractured at different levels, due to the high values of the loads that appear in case of accidents (industrial, in traffic or when practising sport). Different types of osteosynthesis techniques (elastic or rigid) can be adopted for the fracture treatment, depending on the place and type of fracture

2. SIMULATIONS ON FEM MODELS

The biomechanical comparative study undertaken by FEM was done for the bone-implant ensemble, in the case of a femur with a closed diaphysis fracture. For the fracture treatment, the osteosynthesis techniques presented in Fig. 2. (OEK, OES, OEF and ORZ), were considered.

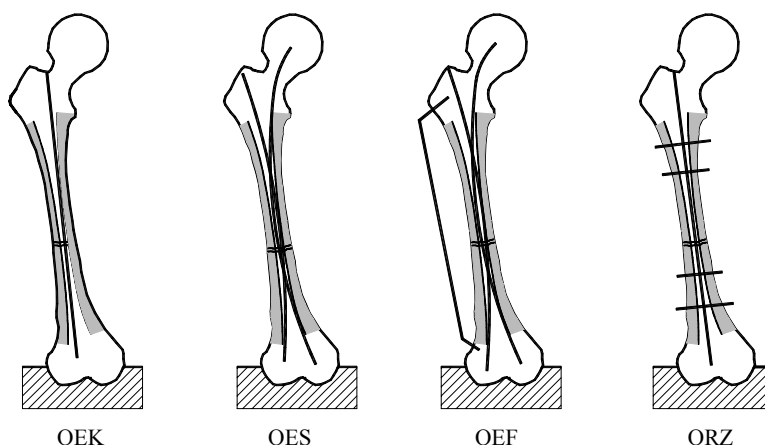


Fig. 2

The mesh for the bone tissue and implants was built using triangular and quadrilateral isoparametric elements with three degrees of freedom. Due to the small dimensions of the cross sections of the implants ($\phi = 5$ mm), with respect to those of the medullar canal, they were represented by their longitudinal axis.

The simulations were performed for the case of one leg standing (monopodal) position. The femur was considered free at the upper part and constrained in the condyl zone. A load $P = 500\text{ N}$ was applied in the centre of the femoral head, inclined at an angle of 16° with respect to a vertical line (Fig. 3). The bone tissue was considered isotropic, having a Young's modulus $E = 1,65 \cdot 10^4\text{ MPa}$, and a Poisson's ratio $\nu = 0,24$. For the implants (manufactured from steel), the following values were adopted: $E = 2,1 \cdot 10^5\text{ MPa}$ and $\nu = 0,3$.

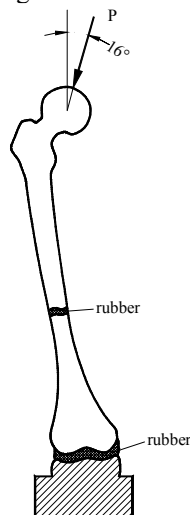


Fig. 3

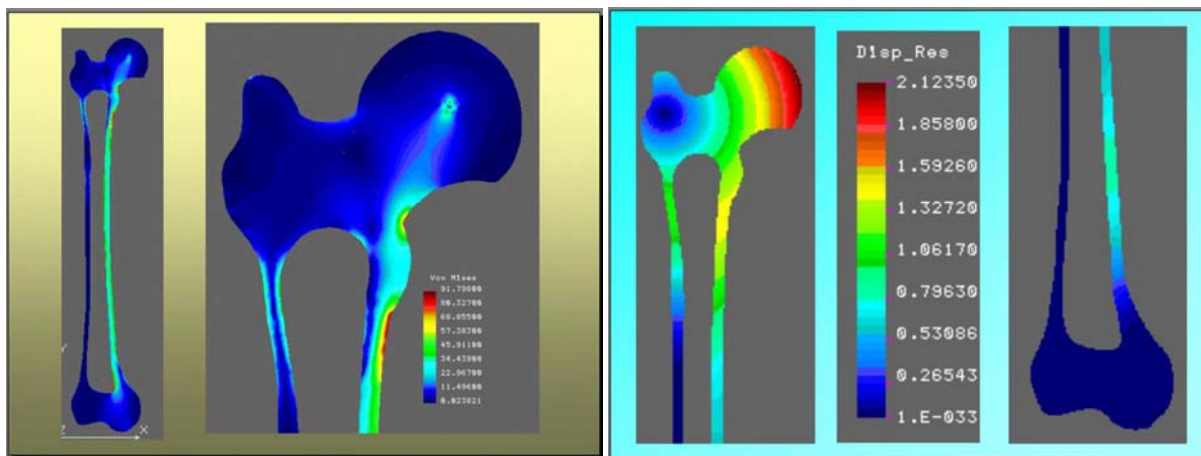
For comparison, the stress and strain state were analysed on the model of a femur without fracture, for the same supporting and loading conditions.

3. RESULTS

As it is known, the osteosynthesis techniques used in fracture treatment must provide stability to the bone fragments from the fracture focus, as much as possible. That is why the implants must constrain the relative displacements of the bone fragments, avoiding thus the appearance of pseudoarthroses. In the same time, the implants must provide a certain level of compression stresses in the fracture focus, suitable for forming the primary callus. Therefore, in order to compare the biomechanical performances of the studied osteosynthesis systems, the stresses and displacements in the focus of the fracture were firstly analysed. For this, the fields of equivalent von Mises stresses and resultant displacements were obtained by processing the results. These results, corresponding to each of the considered assemblages, are presented in Figs. 4.a ... 8.a (equivalent von Mises stresses) and in Figs. 4.b ... 8.b (resultant displacements). Detailed views of the areas with higher stresses and displacements are also shown in these figures.

4. DISCUSSIONS

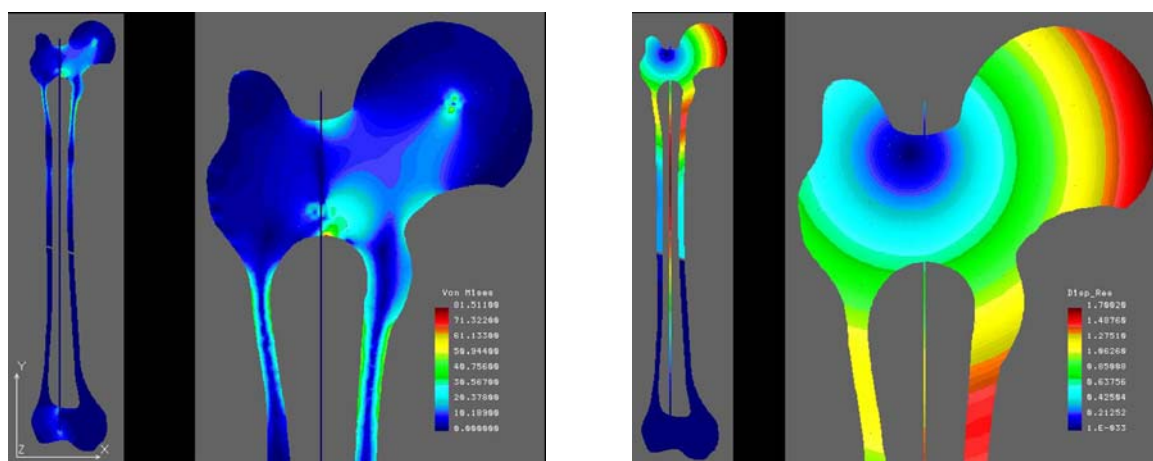
The results of the finite element simulations show that the highest level of stresses is in the cortical zones and along the femoral diaphysis (internal), especially in the metaphysis zone, where bending is predominant. The analysis of the results shows that the stress level is smaller ($20 \dots 40\text{ MPa}$) for the fractured bone with different types of osteosynthesis, in comparison with the unfractured bone ($80 \dots 95\text{ MPa}$). Consequently, one can state that a part of the load is taken over by the implants, providing a reasonable level of stress in the fracture focus.



a.

b.

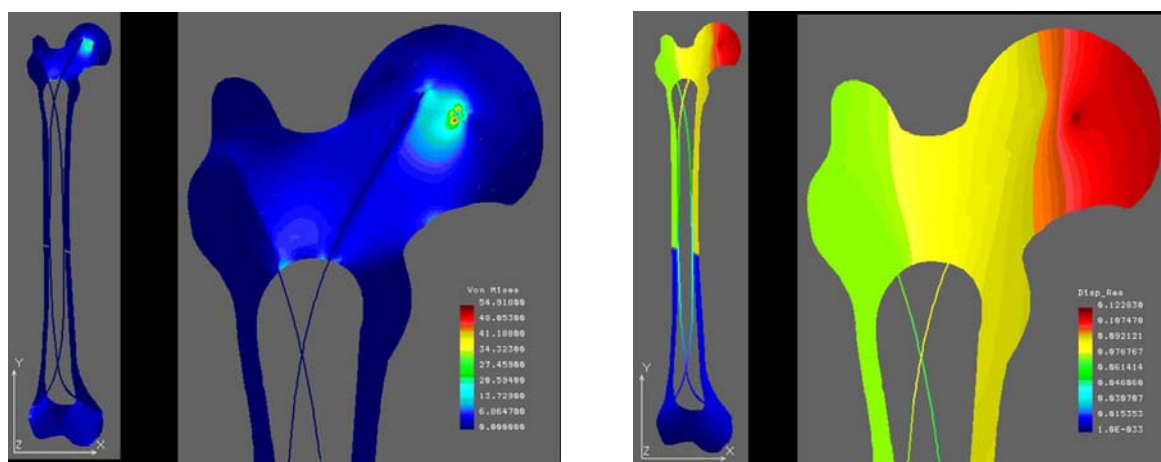
Fig. 4 (unfractured bone)



a.

b.

Fig. 5 (OEK)



a.

b.

Fig. 6 (OES)

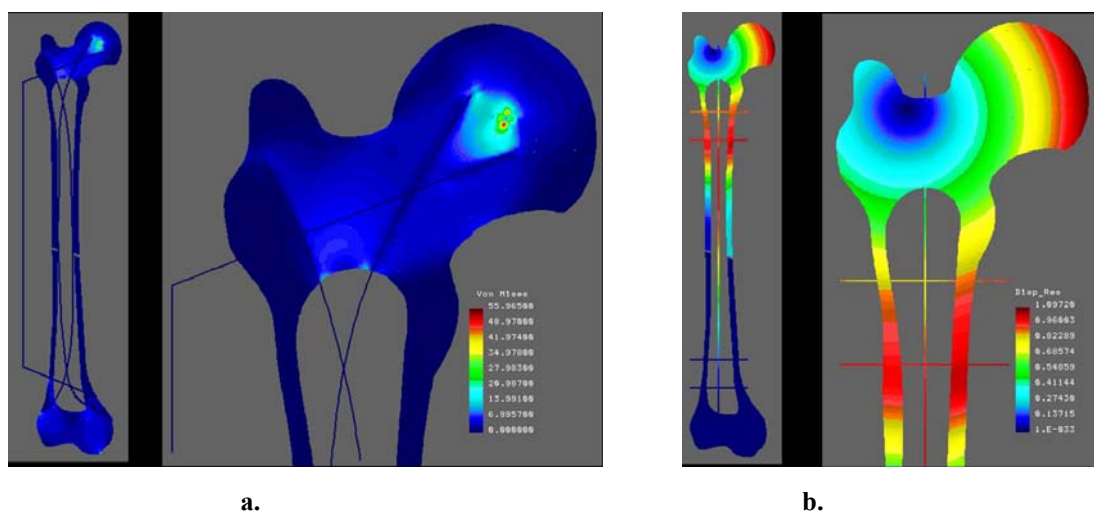


Fig. 7 (OEF)

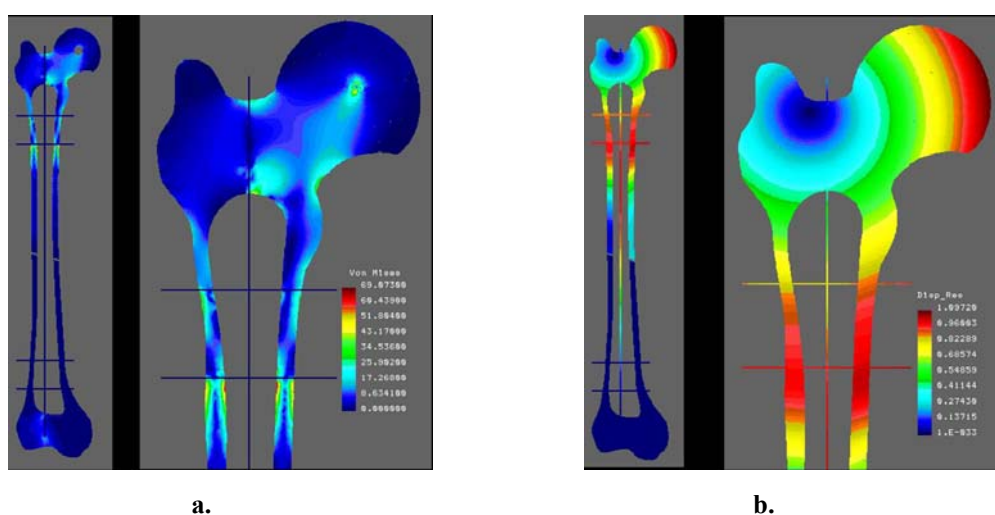


Fig. 8 (ORZ)

By analysing the stresses in the bone tissue, for OEE and OEF, it can be seen that they have values between 10 ... 14 MPa, while for ORZ they are greater (35 ... 45 MPa). The greater values of these stresses may appear due to the fact that bone is cut through at the upper part by the nail. In this case, the bone takes over a great part of the load. The stresses in the fracture focus are less than 8 MPa in all cases, confirming thus the data from the scientific literature [2].

In the case of osteosynthesis with locked intra-medullar nail, one can observe that greater values of the stresses (40...45 MPa), appear at the upper part of the femoral shaft, in the locking area. Stresses of the same level can be seen both in the nail and in the upper crochets. Also, it must be underlined that in all cases one can observe high stress concentrations in the contact zones of the nails with the bone tissue.

The displacements in the focus of the fracture are between 0.08 and 0.1 mm, for OEK, OES and OEF fittings. These displacements usually appear at the upper fragment of the fractured bone and have the greatest values in the femur shaft, in the areas loaded in traction. Greater values of the displacements (0.1 ... 0.2 mm) can be noticed in the focus fracture for the ORZ fitting.

Under the action of the loads, implants deform. In the case of OES, the greatest displacements (0.08 ... 0.09 mm), occur in the external nail, which takes the traction stresses produced by the bending moment. Great values of the displacements (0.6 ... 0.8 mm) can be observed also at ORZ fitting, both in the nail and in the crochets.

5. CONCLUSIONS

The results of finite element simulations for the four types of osteosynthesis put in evidence superiority of the elastic osteosynthesis. These assemblages take a part of the loads transmitted from the femoral head, providing an optimum level of compression stresses in the fracture focus. During walking, when the leg is up, the load vanishes, the deformed nail revolves at its initial undeformed position, pushing through their ends in the bone tissue where they are fixed. In this way, the collagen fibres which form in the fracture focus are subjected to traction. So, one can say that during walking, the collagen fibres formed in the fracture focus are subjected to cycles of variable loading of compression-traction which provide the necessary environment to stimulate the process of bone regeneration. These cycles of traction-compression act on the osteogenic cells, producing in the bone structure, by piezoelectric effect, bio-currents, that change periodically their polarity. Under the action of these currents, the mineral salts deposit on the collagen fibres along the principal directions of stresses.

The biomechanical stimulating effect produced by the elastic osteosynthesis techniques is determined by the correct embedding of nails and, in the same time, by the capacity of the tissue to take the local stresses developed in the contact zones.

The results of this study show that the use of elastic osteosynthesis in the femoral fracture treatment provides an optimization of the mechanical factors effect in the process of structural regeneration of the bone tissue. In this way, the process of forming of primary callus is accelerated and the healing time of patients is shortened.

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