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PHOTOELASTICIMETRY APPLICATIONS IN BIOMECHANICS

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Abstract: The connecting elements of strength, in terms of mechanical resistance, included in the skeleton, that are loaded with exterior forces are being deformed and, as a consequence, inside those elements is implied a state of stresses, witch is determined by the forces that hold together the particles of a solid. The study is conducted on a plane model made of epoxy resin, that represents a longitudinal strip of the upper extremity if the human hip. The study of the light fringes distribution that occur after the application of compressive and bending loads in a vertical plane was made using the photoelasticimetry method for the experimental analysis and the finite element method for the numerical analysis.

1. INTRODUCTION

The femoral head accounts as the articular surface where through the femur (Figure 1) articulates with the ace tabular cavity of the pelvic bone. It represents two thirds (2/3) of a sphere that has a diameter between 40 and 50 mm and it is coated with a thick layer of cartilage. Through its geometrical center point passes through the three axes of the pelvic-hip joint. The head is sustained by the neck witch assures the connection with the shaft (body of the femur). The femorals neck axes is oriented diagonal up, inside and forward forming with the shafts axes an angle –angle of dip- that for an adult has a average value of 126 degrees – fig.1. The femoral necks axes plane with the femural condyles frontal plane makes an angle opened forward and inside of 10 – 15 degrees (12 aprox.) – angle of dip. The femoral neck (Figure 2) consists of a strong bone column, with a lenght of 35-40 mm, flattened in front and back. At the joining point of the femoral neck and shaft we come across a tubercle orientated up and outside – the greater trochanter. It represents the insertion site of the hip and pelvic muscles. In the bottom-inner and rear part of the femoral neck there is a smaller tubercle – lesser trochanter – wherethe psao major and iliacus muscles are inserted.

During the loadings it is subject for, normally, the femur is compressed between the ace tabular (socket) of the pelvis and the tibiae platous.

The action line of this compression is called the mechanical axes and it is defined as the linier that joins the center of the femoral head with the center of the knee. The mechanical axes together with the shafts axes make a 6-9 degrees angle [1].

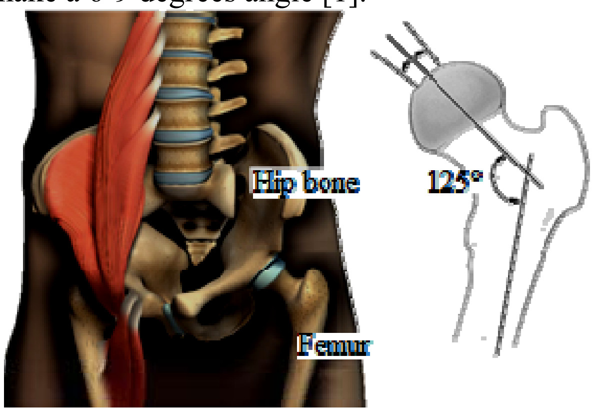

Fig.1. Femoral bone anatomy

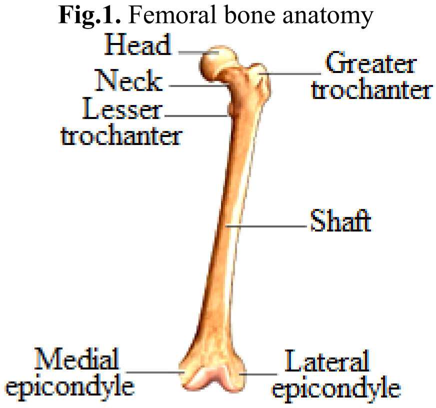

Fig.2. Anatomical elements of femur [5]

The geometry and position of the femoral bone make so that, in one leg stand, the vertical line droped from the weight center of the body is excentric with the shaft.

The pelvic bone is sustained horizontally by the force of the adductor muscles, that cross over the hip of the supporting leg (form the pelvic bone to the greater trochanter). The pelvis and the femur can be compared with the loading case of a crane. The femur will be subject of a composed loading of compression and bending, similiare to the column. The neutral axes divides the femoral shaft in two unequal proportion areas, one loaded with a compression force and the other one with a bending force. The two areas have a helical configuration, as a result the position of the neutral axes varies. In the upper segment, the compressed area, inner positioned, and the streched area, outside positioned, share, almost equally the surface of a section. In the lower sector, the streched area este significantly smaller, the compressed area representing almost all the section [1].

2. EXPERIMENTAL ANALYSIS

Among the most commonly used means of experimetal analysis of stresses we can include the photoelasticimetry method. This is one of the investigation methods based on the interpretation on measurement data form accidental birefringence (Figure 3) – [1].

Based on the optical principels and the mathematical theory of elasticity, photoelasticimetry noted from the beginning to be a simple experimental technic, yet haveing ample oppotunities in the the state of stresses and strains analysis.

Unlike other methods of tensometry (mechanical, optical or electrical) witch provides information in discrete points, photoelasticimetry provides a complete picture of the field of stresses, thereby enabling the determination of the state of stresses (in magnitude and direction) in any point of the model tried.

Using photoelasticimetry for the study of the principal stresses distribution on a plane model and their trajetories in the proximal femur is a simplification of the real phenomena. The results obtained lead to important qualitative indications of the most loaded areas, that can be constitute the basis for a proper numerical analysis (finite element method) or can give worthy information in choosing optimum femoral neck osteosynthesis of fractures process (Figure 4).

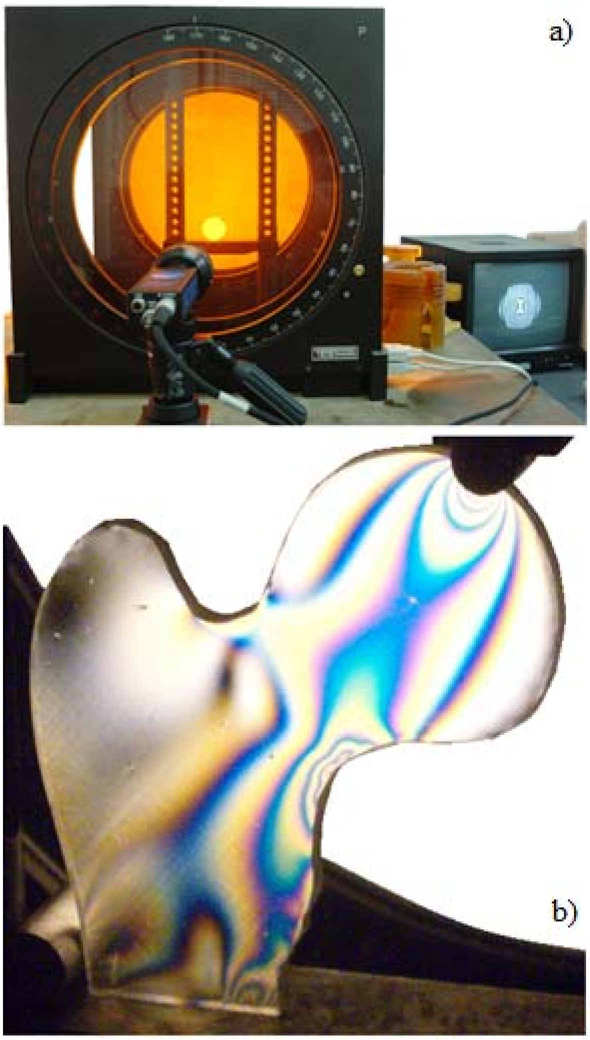

Fig.3. Experimental setup: a) polariscop, b)isocromates grid for a loaded plane model

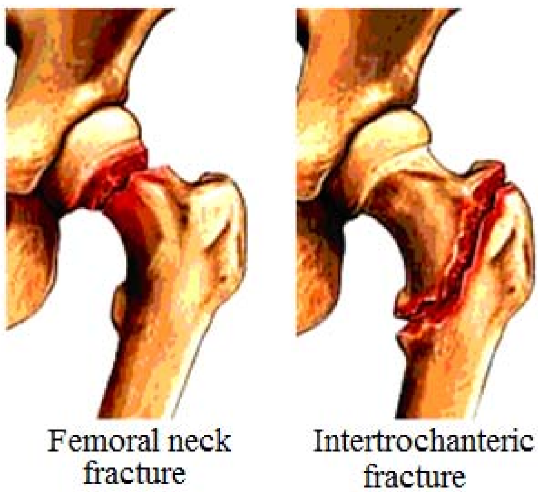

Fig.4. Proximal femur fractures [4]

The complexity of the problem of femoral neck fracture osteosynthesis and the range of building solutions are highlighted by the many biomechanical factors which must be taken into account in the choice of optimal solutions to various cases: psychological and biological status of the patient (age, sex, height, weight, etc.), physical-mechanical properties of bone fracture (hardness, elasticity, porosity, etc.), geometric configuration of bone and fracture path, the state of stresses in the fracture zone and adjacent regions, dislocations caused by bone fractures, etc. Each of the factors listed depends, in turn, by others so that the phenomenon of osteosynthesis should be considerede in all its complexity, taking into account the interdependence of the various causes that have big effects on reinforced fractures - [2].

In the paper it is studied the state of stresses for a plane model made of epoxy resin.The study using the photoelasticimetry method gets through the following steps: photoelastic calibration of the material, setting the model in a suitable device, determinating the number of isocromate refering to the state of stresses in the plane model loaded to compression and bending.

Photoelastic calibration: The calibration aims to determine the photoelastic constant σ_o for a model with the thickness d made from an optical active material (epoxy resin). The calibrations shall be performed on a axial compressed disc (Figure 5).

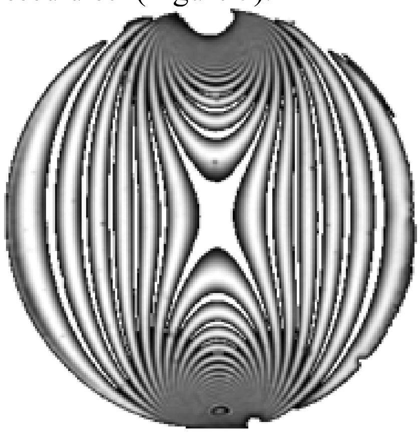

Fig.5. 6th degree isocromates shown in the calibration disc axally compressed

The calibrations is carried out using sodium yellow light circular polarized. This is achieved if between the cross ploarizing lenses two quarter plates are sited, rotated bt 45 degrees to the polarizing lenses. In the circularly polarized light only the isocromate appear, the isocline being removed – [3].

The loading scheme of the disc is shown in Figure 6.

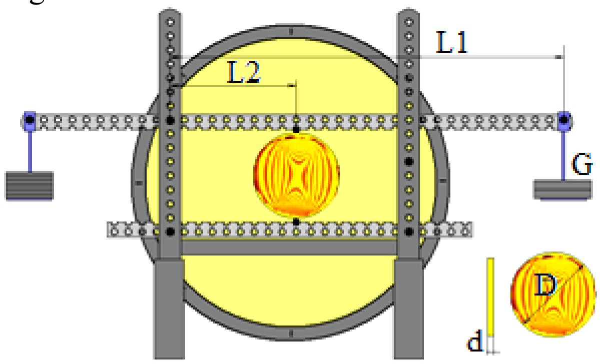

Fig.6. Photoelastic calibration setup for the optical activ material (epoxy resin)

The lever is balanced and loaded gradually following the isocromates evolution in the model until in center appears the degree 4th or 5th isocromate. The weights are marked G and the applied force F of the model is calculated.

$$F = \frac{L_1}{L_2} G \qquad (1)$$

In the theory of elasticity is shown that the inequality of the main stresses in the center of the disc can be calculated with the equation:

$$\sigma_1 - \sigma_2 = \frac{8F}{\pi D d} \qquad (2)$$

We also know that:

$$\sigma_1 - \sigma_2 = K\sigma_o \qquad (3)$$

so:

$$\sigma_o = \frac{8F}{\pi D d K} \qquad (4)$$

where K is the degree of the isocromate in the center of the disc.

The results are presented in tabel 1.

Table 1

Geometrical elements of the experimental setup, the degrees of the isocormates and the photoelastic constant

L_1 mm	L_2 mm	G N	F N	D mm	d mm	K	σ_o MPa
524	67	122,6	958,7	34,4	4	5,34	3,323
524	67	136,65	1068	34,4	4	6	3,295

The average value of the photoelastic constant is calculated with the equation:

$$\sigma_{om} = \frac{\sum_{i=1}^{n} \sigma_{oi}}{n} \qquad (5)$$

The average value of the photoelastic constant is $\sigma_o = 3{,}309$ [MPa].

Plane model study. A wide plane model is used, made of epoxy resin. In the early phase the aim is to determine the most loaded areas in the femoral neck [2]. The model is loaded with a concentrated force (resultant) that is driven at an angle of 36.53 degrees from the vertical one (see Figure 3). In Figure 7 there are presented three cases of the plane model loading that coresponde with three forces that have the magnitude of 360, 460 and 625 N.

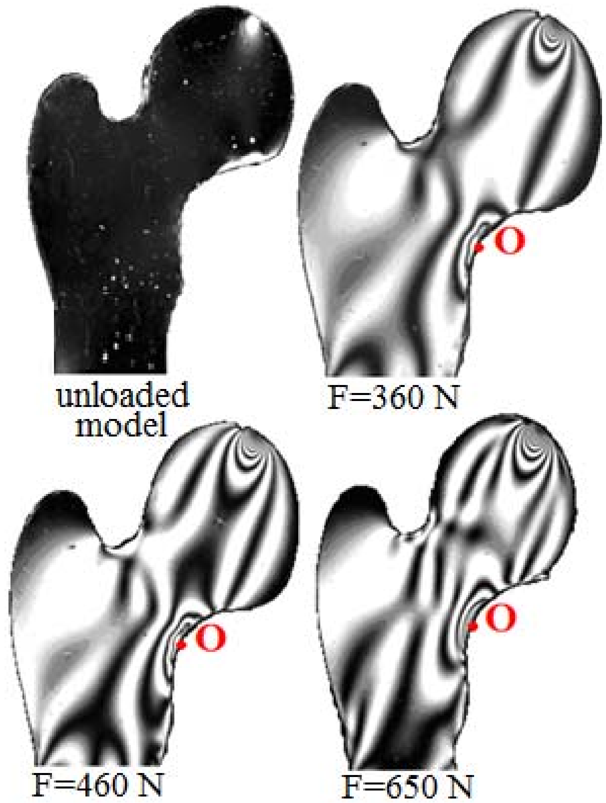

Fig.7. Isocromates distribution in the plane model

As you can see the most loaded area is the one of the femoral neck. The isochromatic order reffred to the distribution of sreeses in this area are representes in Tabel 2. The force F=625 N also represents the maximum amount that can be loaded on the model, during the loading the model broke at that value (Figure 8).

Using a plan model for a bone with a space geometric shape, eliminating the complex pattern of muscle forces, not taking into account the heterogeneous structure of the bone, etc., allow, however, qualitative evidence of stresses distribution in the head, neck of the femoral bone and of the areas with their concentration. The photoelastic determination prior to the main trajectories of the stresses in the models to be studied with the numerical analysis (finite element method) allows an effective meshing, using elements whose sides overlap, as possible, over the isostatics (main stresses winder).

Table 2

Main stresses 1 (O – Figure 7) vs force F

F N	**K**	σ_1 MPa
360	3,576	11,83
460	4,507	14,91
625	5	16,54

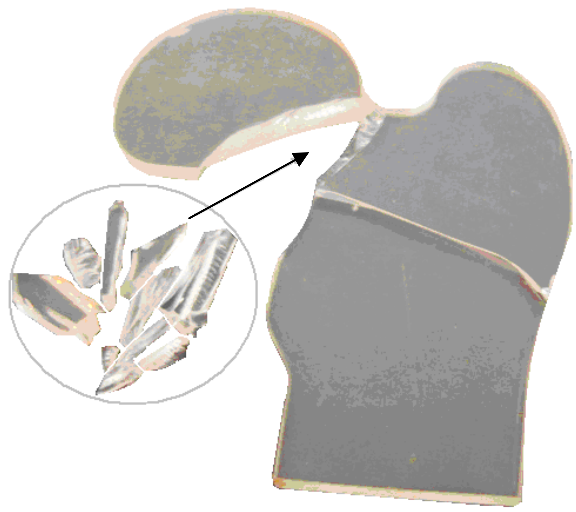

Fig.8. Breaking sections of the plane model

3. NUMERICAL ANALYSIS

In principle, it must be ensured that the idealized structure to be an optimal solution of several conflicting requirements regarding the numbers of nodes and elements, types of elements, load cases, the number of forces and supports, etc.

In addition to there general requirements it should be considere specific features of the osteoarticular system biomechanics (biomechanic system of the bones and joints). It must also be taken into account that the finite element method is a numerical calculation method, which uses as input the effective numerical values of elastic constants and of the loads, in determinating which high difficulties arise.

The bone is highly anisotropic and inhomogeneous and it is desirable that the idealized structure to be developed as such. If in which regards the development of the structure no unsolved problems remain, the most difficult problems arrise in determinating the variable elastic characteristics of the bone tissue [1].

Difficulties also arise in determinating the values of the loads and their points of application. In general, to a bone are transmited forces through the articular surfaces, witch are three-dimensional, with a rather complicated geometric configuration. In these circumstances, the consideration of concentrated loads is a rough shaping of reality, and the consideration of a distribute load requires knowledge of its distribution law.

The method has proved effective in objectively and effectively analysing complex structures, such as those of osteoarticular system.

Figure 9 shows the meshing (RDM 6.15) with triunghiular finite elements reffered to the state of stresses (Tresca) on the thickness of femoral neck for the case when the model is loaded with a force F=625 N.

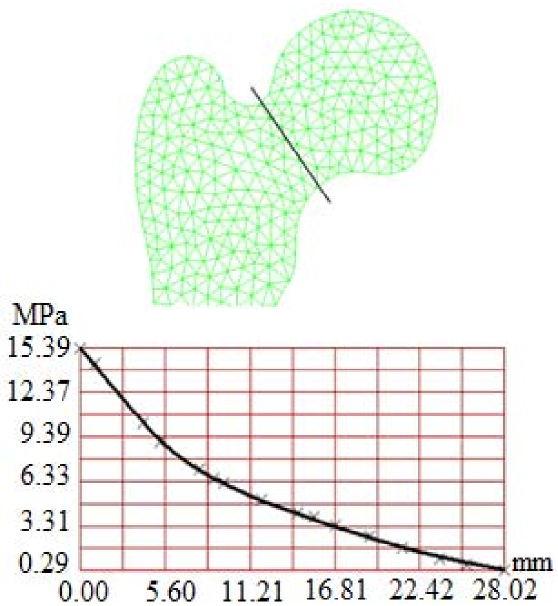

Fig.9. Meshing mode of the plane model and the equivalent stresses Tresca variation on the femorals neck thickness

4. CONCLUSIONS

There is a satisfactory agreement between the experimental and results using FEM, for the plane model studied. The realtive error between the two methods is 6.9 percent. There can be highlighted the main research directions:

- the study of various typers of femoral neck fracture remodeling using screws – Figure 10.
- realization of a spatial model using epoxy resin and its study with the photoelasticimetry method and finite element modeling.
- study on a real femoral bone of the different type of fracture remodeling (Figure 11).

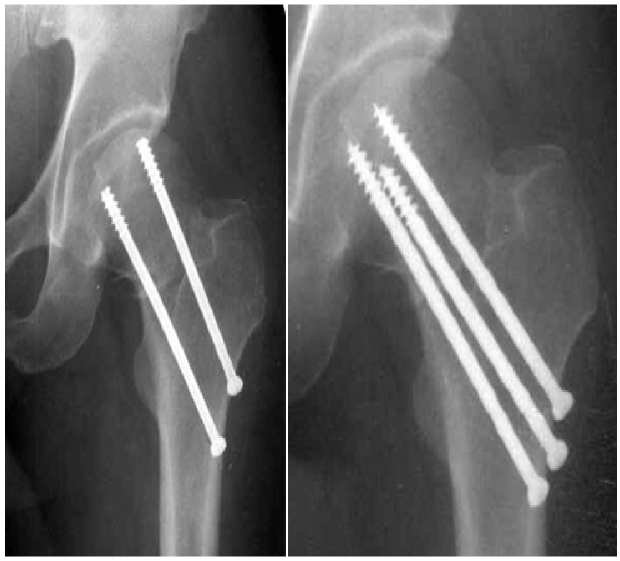

Fig.10. Types of fracture remodeling

Fig.11. Real model study

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APLICAȚII ALE FOTOELASTICIMETRIEI ÎN BIOMECANICĂ

Rezumat: Elementele de legătură, în termeni de rezistență mecanică, incluse în scheletul osos, care sunt solicitate de forțe exterioare sunt deformate şi, ca o consecință, în interiorul acelor elemente apare o stare de tensiuni, care este determinată de forțele care țin legate particulele unui solid. Studiul este realizat pe un model plan care reprezintă o fâşie longitudinală a extremității superioare a osului femural uman realizat din răşină epoxidică. Studiul analizează distributia frajelor de lumina care apar in urma solicitarii la compresiune si incovoiere in plan vertical a modelului folosind metoda fotoelasticimetriei în analiza experimentală şi metoda elementlui finit pentru analiza numerică.

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