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# IMPROVEMENT OF DIAGNOSTICS IN ORTHOPEDICS USING ELECTRICAL IMPEDANCE MEASUREMENT

***Abstract:*** *The bone tissue represents a complex electro-mechanical system. One of the most important parameters of this system is electrical impedance beside Young's modulus, Poison ration, speed of sound propagation, etc… Knowing bone electrical impedance can be very useful in the clinical practice related to rehabilitation of injuries, bone healing process and assessment of mineral content of bone. The bone segment can be considered an electrical circuit which consists of resistor, capacitor and inductance. Bone degradation and physiological state change directly cause change of electrical circuit parameters, especially capacitance. The progress in electrical engineering improves measurement and modelling of this parameter which can be applied in medical purpose. The methodology of bone tissue impedance measurement is shown in this study. For measurement verification the numerical model is presented too. This numerical model used Finite Element Method for capacitance determination. Geometry of the model is used by reconstructing CT scanner slices and boundary conditions are satisfied according to the experimental setup. Using this method can significantly improve diagnostic quality of bone injuries in orthopedics.*
***Keywords:*** *Electrical impedance, Bone, Capacitance measurement, Quality of diagnostic*

## 1. INTRODUCTION

It is common known that bones are a crucial component of the human body. Bones provide stability of structure so that humans may stand upright. Bones also protect internal organs, such as the brain, heart, lungs, etc. The bones play significant role in physiological process in human body due to fact of formation bone narrow cells the inside.

Intensive study on bone structure began in the last century and led to the discovery of many interesting properties which influence on the further research. Results of this research indicate that bones have dielectrical and semi-conductive properties. Some other research imply anisotropic and piezoelectric character-istics.

Knowledge of bone electrical impedance value can be very useful in the clinical practice including rehabilitation of injuries, bone healing process and assessment of mineral content of bone.

Yamada et al. [1] investigated bone electrical impedance by using fixation pins as electrodes. This study established the increase of impedance value by healing. Experimental part of study was applied on animals (sixteen immature male Japanese white rabbits). This is the reason due to this method of measuring bone impedance has clinical impact. In a similar manner, Nishida et al. [2] measured electrical impedance values of the extremities of cadavers, to determine the potential utility of measuring these properties in evaluating the bone characteristics. In addition, they evaluated the effects of sex, age, and body structure on impedance values for upper or lower extremities. Gupta et al. [3] found that the electrical properties of bones, generated by the piezoelectric effect and cellular activity, can be used as a biomarker for monitoring fracture healing. Yoshida et al. [4] measured the bone electrical impedance non-invasively by using external fixation pins as electrodes. The results of this study suggest that measurement of electrical impedance values can be used for bone healing evaluation.

There are a number of techniques for bone healing evaluation like the bending stiffness test [5,6], ultrasonic technique [7,9,10], bone density technique [7,8], quantitative computed tomography [5,7,11], acoustic emission method [12], and acoustic impedance method [13].

All of these methods, except the acoustic emission technique, have not yet been clinically established due to the complexity of method and high levels of radiation exposure dose [7]. On the other hand, the electrical impedance technique is a non-invasive and simple quantitative technique for evaluation of bone fracture healing [14,15].

In this paper procedure for bone tissue impedance measurement is considered. For computer simulation software tool COMSOL Multiphysics was used. The numerical model based on Finite element method for capacitance determination is created. The model is used for measurement results verification. The method, presented in this study can significantly improve diagnostic quality of bone injuries in orthopedics.

## 2. METHODS

In this paper, we used 3D model of the knee joint (system consisting of the femur, tibia and cartilage) obtained by CT scanner slices. The finite element method (FEM) simulations were performed using the Comsol Multiphysics software package (Comsol Inc, Burlington, USA).

The aim of this study is investigation changes of capacitance with the maturation of bone cracks. The reason for using capacitance is its high level of resistance to temperature and air humidity variation.

In terms of simplification of problem the material properties of all three components of the system have the same coefficient of permeability. This coefficient has value 80 as such as water. The voltage applied to the end of femur was 0V, and at the end of tibia was 1V.

The fracture is modelled, as spheres filled with air. By changing the diameter of the sphere, we get different fracture ratio in the range from 0 % to 100%.

In this paper the experiment wasn't considered due to fact that special equipment is needed.

The electrical impedance can be expressed as

$$Z = \frac{U}{I} \qquad (1)$$

where $U$ is the applied voltage and $I$ is measured current value. The impedance of the capacitor has the form:

$$Z = \mathrm{j}(-1/\omega C) \qquad (2)$$

where:

$$X_c = -\frac{1}{\omega C} \qquad (3)$$

is reactanse of impedance, $\omega$ is the angular frequency (the frequency of the applied voltage), and the $C$ is capacitance of capacitor.

The value of impedance is inversely proportional to the electrical capacitance which is defined by the expression:

$$C = \frac{q}{U} \qquad (4)$$

where $q$ is the charge, and $U$ is the voltage on the capacitor.

Of particular importance is the case of two close conductors which are burdened with equal quantities of electricity of the opposite sign (Figure 1).

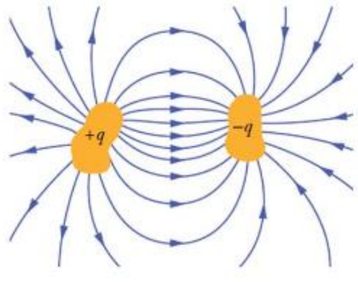


***Figure 1 - Two conductors, electrically isolated from each other and from their surroundings, form a capacitor [16]***

Such a system is called a capacitor, and the conductors which form it are called capacitor electrodes. The electric field is form in the space around the conductors. The voltage difference between the conductors is given by relation:

$$U = \varphi_1 - \varphi_2 = \int_1^2 \mathbf{E} d\mathbf{l} \qquad (5)$$

where $\varphi$ is electrostatic potential, and the **E** is vector of the electric field.

For voltage calculation, any line integral between two equipotential conductors could be considered. However, for calculation the amount of the charge and voltage for complex bodies it is necessary to apply numerical methods. In this sense, finite element method (FEM) is used for this purpose. In the analysis by finite element method, the basic idea is modelling the problem by divided whole domain of the problem on subdomains. These subdomains are known as finite elements. In the numerical simulation calculated values is obtained in a discrete form, in the points (known as nodes). The goal is to express, as good as possible, an real physical domain over the adopted finite element meshes. It should be taken into account, the fact that as the finite element mesh is denser, a difference between the approximate and exact solutions is less. The most commonly used finite elements are 3D and 2D finite elements of the continuum. The finite elements used for modelling three-dimensional body of general shape (3D continuum) are called 3D isoparametric finite elements. The typical number of nodes of these elements is from 8 to 21, and in this paper we used 3D 8-node finite elements. The FEM of electrostatics is based on reducing the system of Maxwell's equations to a system of linear equations:

$$\nabla \cdot \mathrm{D} = \varphi_{ve} \qquad (6)$$

$$\mathrm{E} = -\nabla V \qquad (7)$$

where **D** is the dielectric displacement vector, **E** is the vector of electrostatic field, $\varphi_{ve}$ is the volume distribution of free charge, $V$ is the electric potential, and constitutive relation is satisfied:

$$\mathbf{D} = \varepsilon \mathbf{E} \qquad (8)$$

where ε is relative permittivity.
Applying equations (6), (7) and (8), the final expression is obtained:

$$\nabla^2 V = -\frac{\varphi_{ve}}{\varepsilon} \qquad (9)$$

Thiis relation is known as the two-dimensional Poisson equation.
The energy function corresponding to Poisson formula (9) has the form:

$$F(V_e) = \frac{1}{2}\int_V \left[ \varepsilon \left| \nabla V_e \right|^2 - 2\varphi_{ve} V_e \right] dV \qquad (10)$$

where $F(V_e)$ represents the total energy per length within element $e$; $V_e$ and $\varphi_{ve}$ are the potentials and charge densities in nodes.

By minimizing the energy functional for the electrostatic field, the we get a system of linear equations. The potential of the nodes of elements is obtained by solving this system. The potential on the rest of domain is calculated using interpolation method.

## 3. SIMULATION RESULTS

In Figure 2, potential distribution of bone structure obtained in simulation is shown. As one can see from the figure, voltage of 0V (blue) has been applied at one end of femur, and voltage of 1V (red) at the other end of the tibia.

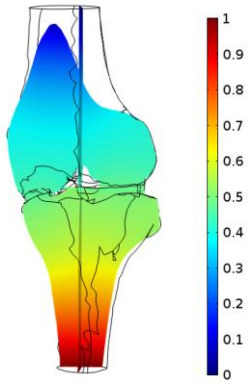


***Figure 2 - Potential distribution in bone-cartilage structure***

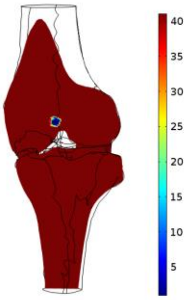


***Figure 3 - Dielectric constant distribution in bone-cartilage structure with fatigue***

In Figure 3, distribution of dielectric pemitivity constant using simulation is shown. The dielectric constant is equal for the entire system, except for the fracture where its value is equal to one.

Figure 4 shows the correlation between capacitance in pF and recuperation in percent. We can see that as the fracture heals gap reduces and capacitance increases. This agrees with results reported by Gupta [17].

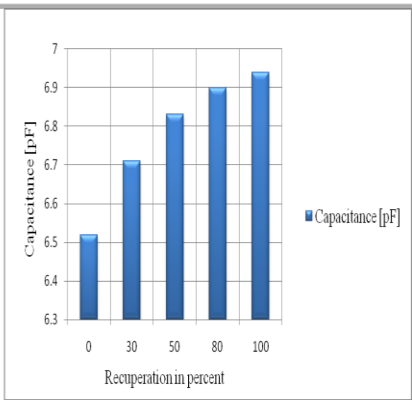


***Figure 4 - Correlation between capacitance and recuperation***

## 4. CONCLUSION

In this study the capacitance of tibia, femur and cartilage structure is simulated using finite element procedure. The result of simulation indicates correlation between capacitance and degree of recuperation after fatigue. This result can be significant in potential application of measure capacitance of bone structure in rehabilitation.

The method, presented in this study can significantly improve diagnostic quality of bone injuries in orthopaedic.

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