hip joint, material properties
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MECHANICAL REASON OF FEMORAL BONE TISSUE REMODELLING -AN ATTEMPT OF PROBLEM APPROACH

The paper presents the analysis of mechanical properties of human hip joint bone behaviour basing on the finite elements methods (FEM). Models of a hip joint have been worked out. Stress patterns in these biomechanical systems have been determined. The examination covers the analysis of stress patterns in elaborated models for given examples of a femoral bone loading in respective walking phases. It has been stated that prediction of bone remodelling could be based on methods applied in mechanics of materials and data of a bone mineral content and bone mineral density determined by the densitometry method. The work is an attempt of the bone tissue assessment criterion approach useful in implantology problems in which the bone tissue density depends on the bone loading.

1. INTRODUCTION

Implants, despite of their imperfection, are widely used in medicine, as there is no effective method of recovering damaged bodily organs; what is more there are ethical, immunological and technical limitations in transplantation methods applied nowadays. Recent years have brought progress in operative technique, many new solutions of implants have been elaborated, clinical experience and general knowledge is growing. However there are still many unknown physiological effects of implantation. For many years one of the important limitations in development of that field of medicine were problems with materials. Progress in materials engineering made things much easier. Biomaterials that are available, fulfil "bioinertion" criteria and proper mechanical properties. The problem of designing implants of more perfect, which would replace bodily organs, remains. Perfect implants decide about improvement of patient's quality of life.

Proper functioning of implants is conditioned by many factors, altogether their effect is called "biofunctionality" [1]. There are many solutions for implants, and many papers describing their physiological functions. Many tests are performed in order to improve existing solutions and invent new ones which, fulfilling their tasks, would take individual features of a patient into consideration. Works on new artificial human elements enlarge our knowledge on phenomena occurring in human body, which cause illnesses. Such phenomena as for instance these that take place in the tissues of a bone system, leading to malfunctioning of motion organs like hip joint, and replacing it by

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endoprothesis. Technical and medical literature evaluates material features, shape and dimensions of implants from the point of view of mechanics of materials. Not many works are dedicated to correlation between body reaction to implantation and above mentioned implant features. There is no measurement for defining, relatively precisely, changes of biological features and body reaction after implantation. Defining such quantities would be a great help in procedures of implant designing applied nowadays.

Commonly used method of defining mechanical conditioning of bone implant functioning is the finite element method. It enables to determine stress and strain patterns in implants and surrounding tissues. This method can also be used in the analysis of human natural bone system behaviour. Interpretation of the results, however, must be very careful.

It is assumed that the condition of bone tissue of a body depends on the size of loads. The presentation of that problem is usually a descriptive one and loads are treated in a static way. There are papers describing a connection between the condition of bone tissue after implantation and stress and strain patterns in their environment.

This paper presents results of the analysis of dependence between the condition of a femoral bone tissue and quantities describing local load in particular phases of walking in a time function. It makes an attempt to present mechanical factors of movement stimulation for changes occurring in bone tissue of a natural joint.

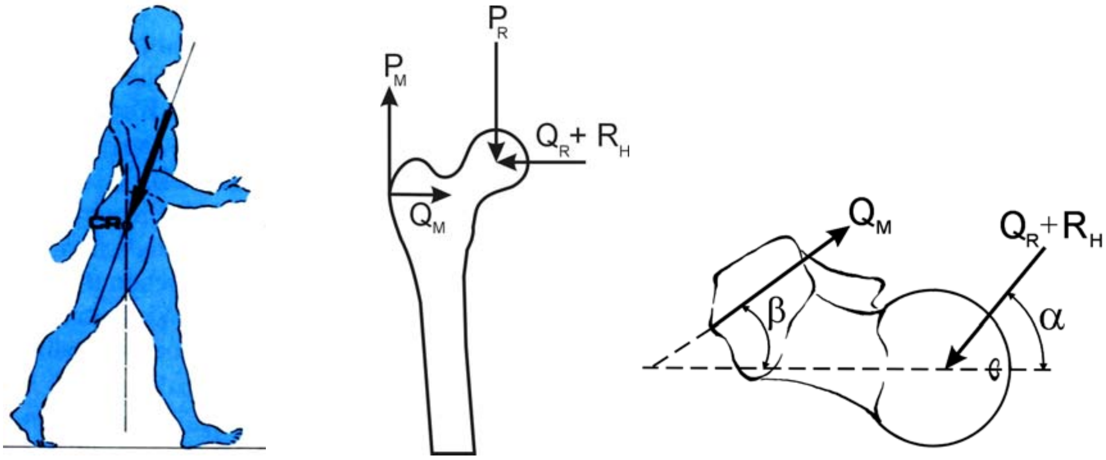
2. THE AIM AND SCOPE OF THE WORK

The aim of the paper is to analyse phenomena occurring in a hip joint, taking into account changeable properties of bone tissues. The examination covers the analysis of stress patterns in elaborated models for given examples of a femoral bone loading in respective walking phases.

3. ANALYSIS OF STRESS IN A FEMORAL BONE IN A MOTION

The paper is a continuation of carried out examinations, the aim of which was to determine changes of bone tissue density in artificial hip joint environment, and analysis of stress patterns round implants. In previous works, density of bone tissue in different parts of femoral bone in a time function was determined. The tenth day after the operation was taken as a one to be referred to [2-4].

At present models of a femoral bone with differentiated in its volume material features were elaborated. They were used to determine changeable stress patterns in a natural hip joint during the movement process. The human gate parameters have been taken from Bombelly's work [5]. It has been assumed that forces acting on the femoral bone i.e. on the greater trochanter (muscle forces) and femoral head (reaction of an acetabulum) (Fig. 1) depend the walking stage. On the Fig. 1 resultants of the distributed loads have been shown. Analysis concentrated on the influence of changeable in time and during walking process loads upon stress patterns in a femoral bone. 11 phases – from 12 to 22 of movement were examined (Fig. 2). They featured different direction and values of forces [5]. Fig. 3 presents stress patterns in a femoral bone in a natural condition, in two chosen walking stages, marked according to Bombelly's work, as number 12 and 20.



a) b) c)

Fig.1. Loading of a hip joint in human gait conditions: (a) - reaction on femoral bone head - bipodal stance phase, (b) – forces in sagittal plane, forces in horizontal plane [5]

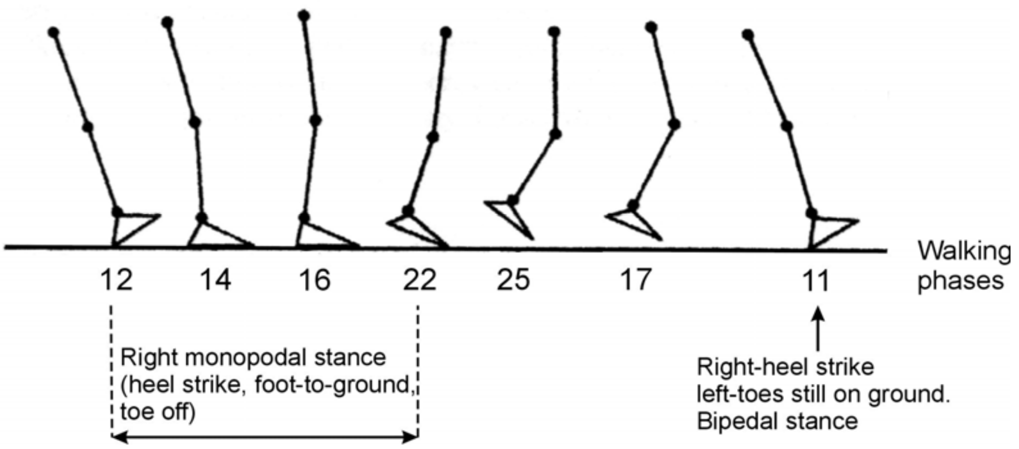


Fig.2. Walking phases of human gate [6]

a) b)

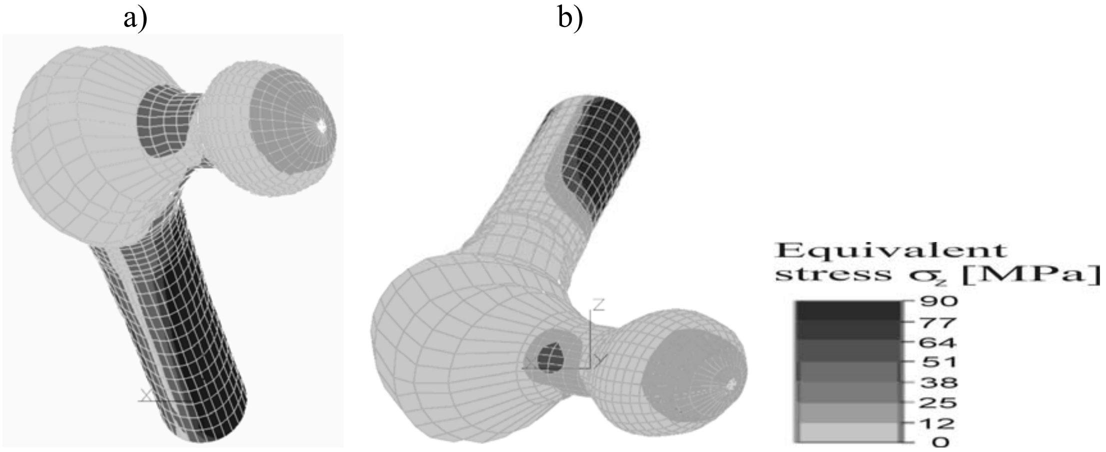


Fig.3. Equivalent stress patterns, determined according to Huber’s hypothesis in a femoral bone models in particular walking phases (view in horizontal plane): a) phase 12; b) phase 20.

Stress patterns were then used to determine changeable in time strain energy of volume change and distortion. Mean value of energy was determined in areas called Gruen's zones (Fig. 4), in which the density of bone tissue was determined earlier [2,3]. Fig. 5 and 6 present charts with changes in strain energy of volume change and distortion in different walking stages (phases). Designation 1–7 refer to consecutive Gruen's zones. Time was presented as non-dimensional, assuming t' = t /T where T is a period of monopodal stance half cycle.

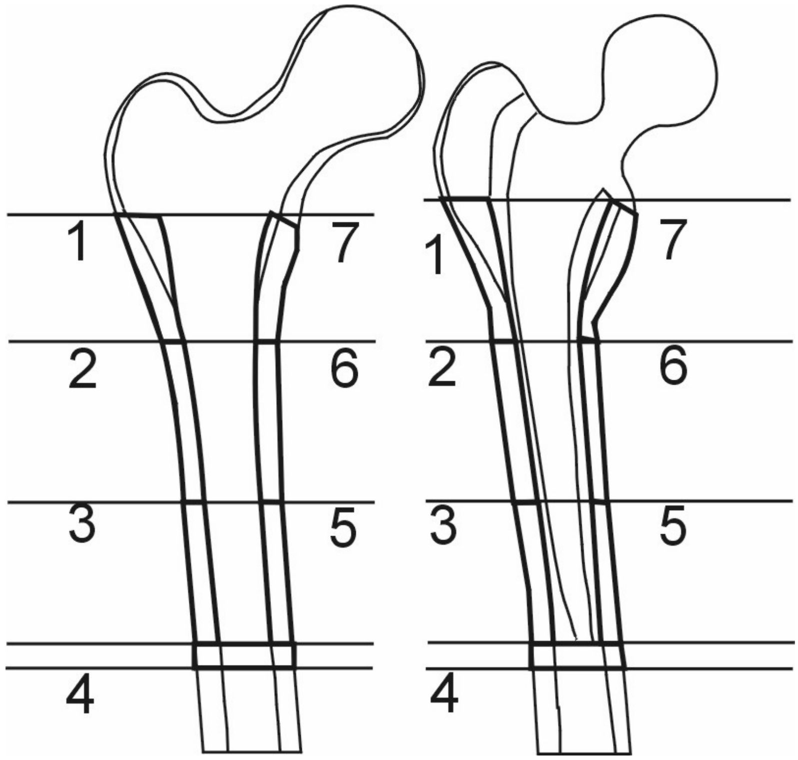


Fig.4. Natural femoral bone - (a) and with Weller endoprosthesis (b) cross-sections. The Gruen's zones have been marked on the figure as in the work [3]

For each zone, mean value of energy of deformation in a cycle was calculated on the basis of a dependence:

$$\Phi_{śr} = \int_0^1 \Phi dt' \qquad (1)$$

Results have been shown o the Fig. 7.

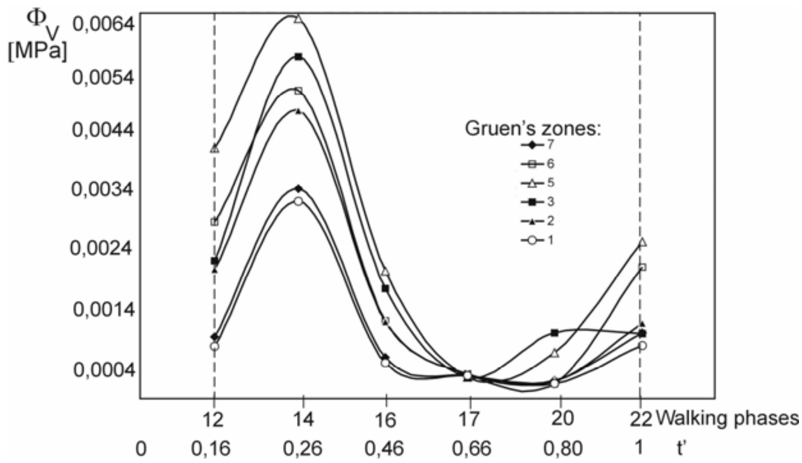


Fig.5. Profiles of strain energy of volume changes in different walking phases

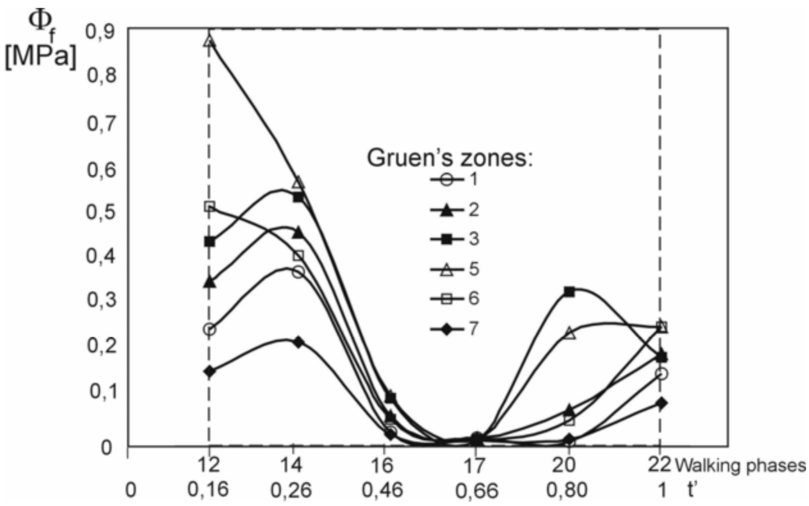


Fig.6. Profiles of changes in strain energy of distortion in different walking phases

a) b)

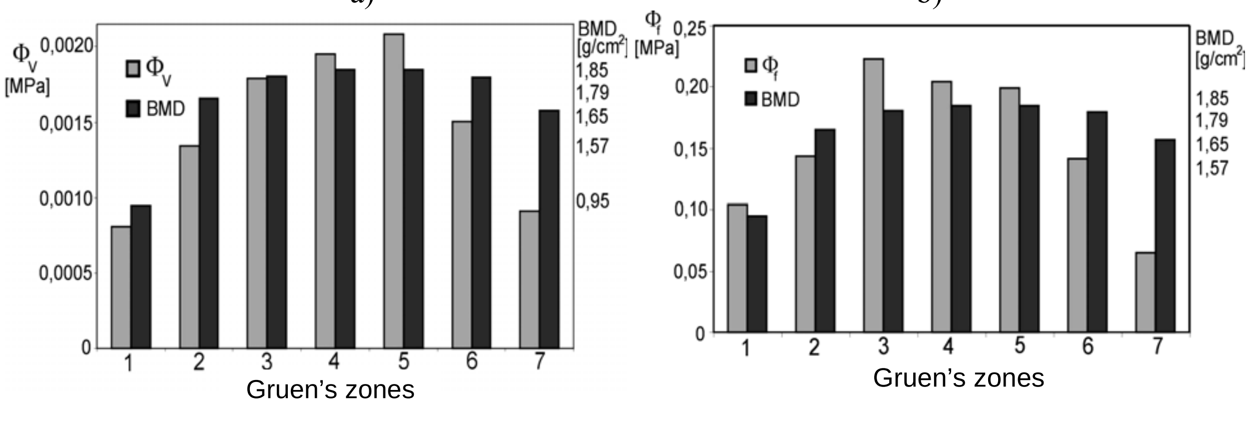


Fig.7. Setting up mean values of strain energy Φ_v and Φ_f, and bone tissue density in Gruen's zones

On the Fig 7 mean values of energy of deformation and density of bone tissue in Gruen's zones have been presented. Density of the tissue was determined, in that case, in a femoral bone in a natural joint, as on the 10th day after implantation of an artificial hip joint. Assumption like this seems to be a correct one, as significant changes in bone tissue density after the endoprothesis implantation were observed few months later. The figure shows the relation between the density of a bone tissue and the mean value of strain energy of both volume change and distortion.

4. DISCUSSION OF THE EXAMINATION RESULTS

Models available at this stage of examination enabled to find qualitative relation between mean elastic strain energy of a bone and its mineral density in natural joint. Energy $\Phi_{śr}$ determined in this paper seems to be a proper parameter defining the size of mechanical stimulation of processes connected with bone tissue reconstruction. Energy $\Phi_{śr}$ rightly takes into account dynamic character of mechanical stimulation, as for the condition of a bone tissues it is important how big the load is and how long it lasts. It cannot be assumed that the state of stress and strain in a femoral bone are the only factors determining physiological processes which decide about the condition of a tissue. Mechanical reactions should be included into all complex factors such as physical, biological and chemical ones [7-10]. They undergo scientific examinations, which might help to explain complicated processes occurring in a human body.

Presentation of a hip joint loading in a time function gives a chance to define more precisely mechanical stimulation of a bone tissue reconstruction. That would be in the future the base for elaborating new implants. Determining correlation between mechanical parameters and bone density would be a background for predicting new adaptation processes and the condition of a bone tissue round implants at different stages of medical treatment and rehabilitation.

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