Clinical data and numerical simulations in aided of diagnosis risky states in human bone system

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Abstract

In this article the issue of aid of diagnosis dangerous state in human bone system is raised. This topic on the example of pelvic bone was presented. In the paper two methods of obtaining information about bones are described. The best source of data about bones are radiological examinations (in this case it is Quantitative Computed Tomography). But with regard to difficulties with tomography data the second method was applied – the computer program to obtaining distribution of material parameters in numerical model of pelvic bone on the base decreasing of bone mass was developed. In a consequence the numerical models of pelvic bone, in which the material properties are different in different places was done – changeability of material parameters representing non-homogenous structure of bone. On the base relationship between CT images or decreasing of bone mass and results from strength analysis the procedure to aid of detection risky state in pelvic bone was developed.

Keywords: bone system, material properties, numerical model, Quantitative CT, pelvic bone

1.   Introduction

Human bone system is subject to frequent affections. In generally one of them like fractures, sprains are the results of external conditions e.g. incorrect loading, others are connected with internal structure of bones – one of them is osteoporosis. This is a systemic disease of skeleton which causes progressive decreasing of bone mass and changes in bone structure. In the course of time these changes are so serious that bones become weaker and weaker and can undergo accidental fractures [1, 5].

From mechanical point of view the fracture of bone occurs in two cases:

- the correct structure of bone but the loads are so big that cause the stresses larger than stress limit,
- the disorders of bone structure caused decrease of strength properties of bone when normal activity of organism can result stresses larger than stress limit.

The paper concerns the second situation, which take place e.g. in osteoporosis.

Very important factor is early detection of osteoporosis. It is a serious problem because disease progresses without symptoms – first symptoms appear when the loss of bone mass is a big (about 30%) and the large risk of fractures s high. The treatment of osteoporosis usually depends on providing analgesic and stabilization of places of fractures. It would be better to prevent that disease because lack of movement is causes of weakness of bones. Knowledge of physical properties of bone tissue is helpful in diagnosing of the diseases of the bone system (especially that properties change during progress of disease) [3], [4]. There is many methods to detect osteoporosis. In this paper the Quantitative Computed Tomography was used. In chapter 2 more information about this method was presented.

2.   Quantitative Computed Tomography

In this method the images from CT are used to analyze the mineral density of bone. Through using the composition of projection images from different directions one can to get cross-sectional and solid images in all researched structures. Tomograms consist of individual voxels. Each voxel is characterized by coordinates x, y, z and color in gray scale. On the base of an experimental research the formulas between amount of radiation and bone density is possible determining a value of density for each voxels. By dint of applied procedure one may to estimate bone density (in g/cm^3) in all analyzed object, with exact to one voxel.

After radiological examination we obtain images of researched structure. The next step is to converse these data to receive information about analyzed bones.

Quantitative Computed Tomography differs than standard tomography occurrence of density phantom which is X-rayed together with patient. Our phantom composed on six specimens. For each specimen the value of density is known. On the base these standard density the calibration curve is drown. Formula of this curve enables to determinate the density for every voxel of researched bone. Exemplary calibration curve was shown in Figure 1.
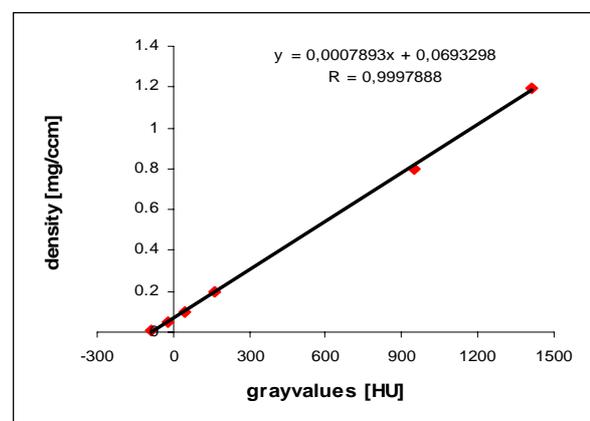

y = 0,0007893x + 0,0693298
R = 0,9997888

Figure 1: The calibration curve

3. Numerical model

3.1. Applying of radiological data

Data from QCT was used to create the numerical model of human pelvic bone. First we have to get geometry of researched bone. We can use geometry from tomography or from measuring coordinate machine. The bigger problem is to determinate the distributions of material properties in prepared model. This procedure one can describe following. For every CT image the matrix of values of elastic modulus is determined. When we combine all matrix for one series of CT images in one big matrix we will collect values of elastic modulus in one file. The next step is subordinating values of Young modulus from this matrix to numerical model . Finally we get numerical model of pelvic bone where in every finite element the individual material parameters are assigned.

3.2. Applying of numerical simulations

Second approach consist of division of whole model into subregions. In each of these subregions values of elastic modulus in individual finite element was determined on the base of decreasing of bone mass and the range of changeability of Young modulus. In both of presented methods the final results were obtained the numerical model of human pelvic bone which in every finite element were individual material parameters. After completing model on boundary conditions one can go to the next step – performing strength calculations.

4. Program to aid of diagnosis risky state

The human tissues have different physical properties therefore coefficient of absorption has to also be different (hue of gray in CT images). After QCT examinations the tomorgams of researches structure are obtained. At the first, it is necessary to determine the radiological density. To transformation of that quantity one should rescale it to HU. The next step it is delimitation the density of bone tissue (on the base of density in HU). By using relationship between density of bone tissue and material properties it is possible to calculate material properties of bone tissue in each voxel. From the other hand, on the base of QCT data it is possible to create the geometry of numerical model. When the model is prepared the material properties are inserted and the strength calculation (according to FEM) are performed. On the ground of obtained results (distributions of stresses, strains and displacements) one can get to know about effort in researched bone [6]. When the large amount of QCT examinations will be realized (the set of data will be converted and strength calculations will be performed) it will be possible to create the base of data. This base will be aid detection of dangerous changes in human pelvic bone.

The general principle working of the program one can show following: after radiology examination it takes place searching to finding the most similar images (searching CT photo from data base). When these images are found the whole model with strength parameters is assigned. Next the results (from strength calculations) are analyzed. As a consequence, particular images from QCT are subordinated effort of bone. In case of need it is possible to return to searching of base and analyzing the larger number of data. The simplified block diagram of the program is presented in Figure 2.
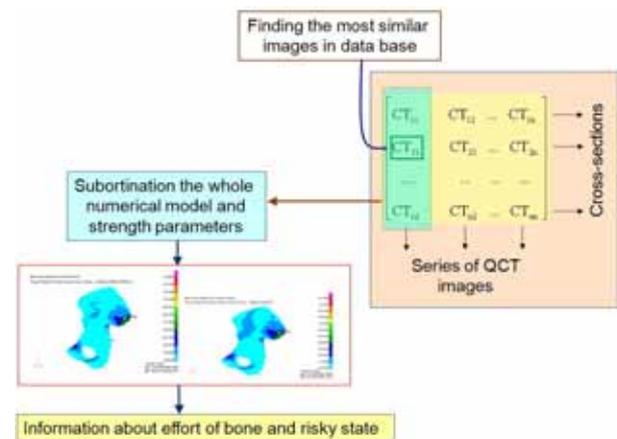

Figure 2: Procedure to aid of diagnosis dangerous state in pelvic bone

5. Summary

- Using QCT it makes possible to diagnosis risky states of bones system (when physiological loading can cause the fracture of bones).
- Information from QCT can be helpful for researching progress of osteoporosis in individual clinical cases.
- The maximum values of the stresses and strains occur local (in region of displacements boundary condition) and even though they have small influence on whole structure, the local values can conduce to microfractures, decohesion and in consequence they can initiate fractures.
- Creation of numerical model on the base of radiological data (especially material properties) to make that they are close to real conditions.
- Presented procedure enables noticing changes in bones more precisely than standard methods (this is important when the difficulties with clear diagnosis appear).

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