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THE ANALYSIS OF THE GEOMETRY OF OSSEOUS TISSUE OF THE BIOLOGICAL BEARINGS INTERACTION ZONE IN THE ASPECT OF ACCURACY OF SHAPE MAPPING

Andrzej Ryniewicz [1]

[1] Cracow University of Technology, Laboratory of Coordinate Metrology, Cracow, Poland,
email: andrzej@ryniewicz.pl

Abstract – This paper presents the problem of the assessment of the shape of osseous tissue and the size of the occurring defects using the diagnosis of computer tomography. The results of assessment of shape of chosen osseous element were presented. In second part the exampled artifacts were presented and the own artifacts elaborated in Cracow University of Technology to assess the accuracy of CT were proposed.

Keywords: accuracy, shape mapping, biological bearing

1. INTRODUCTION

The present state of knowledge on the functioning of joints, displacements and tensions in the contact zone, the mechanism of lubrication and rheological characteristics of joint fluid is limited because of the lack of identification of the real shape of interacting joint surfaces. At prezent, only hip joint is known in the area of working surfaces geometry. The study of the shape of this joint and the mechanical analysis of its lubrication was included in the research project No 4083/B/T02/2008/34 entitled: Analysis of accuracy of mapping of shape of surface of working biological bearing using spatial artifacts and reverse models.

Our research project is a continuation of the above mentioned grant and will include geometrical analysis and the evaluation of tribological interaction of human joints chosen because of the risk of degenerative joint disease (DJD). Research will be done in the field of prevention and diagnosis in order to recognize early stages of joint cartilage damage for the purposes of cartilage damage treatment and construction solutions of endoprothesis.

2. AIM OF STUDY

The aim of this study is to work out methods of evaluation and identification of the working surfaces shapes of the chosen joints. This will enable a computer simulation of working articulation surfaces interaction. The simulation of the interaction will take into account laminar construction of each working compartmental element and will be used for diagnosis of DJS and for formulating theoretical basis endoprothesis construction.

In our research we plan to include the following joints: knee, ankle, foot and temporo-mandibular joints.

3. RESEARCH METHOD

Methodological theory and the range of studies include carrying out the following procedures:

- Examination of real articulation surfaces using helix computer tomography,
- Creation of laminar model of articulation surfaces applicable to bone, using finite elements method
- Visualization of the shapes and creation of virtual models of the joint,
- Simulation of the interaction comprising laminar articulation surface based on the examination of actual joint cavity shapes and cartilage thickness,
- Bases for analysis of tribological phenomena in the area of the biological knots interaction

Realization of research will give us the base for:

- Identification of the real shape and surface of working elements of the studied joints
- Diagnosis of the developing degenerative diseases and prevention on the basis of the new method of cartilage damage visualization and using the analysis of the bearing and tension distribution in the virtual joint

The issues under consideration are of the interdisciplinary character combining medical and technical science

The aim of this study was the analysis of biomechanics and biotribology of human knee. It was done on anatomic specimens of the knee in age 20-40 without symptoms of joint disease. The analysis of shape was done using computer tomography (CT).

The research of wear and lubrication were done using anatomic specimens fluid and it included the analysis of reology and biochemistry.

The outcomes gave the base for the creation of virtual model of human knee using finite elements method, especially of the joint cavity shape and cartilage thickness covered articulation surface. The precise analysis of biomechnics and biotribology is necessary to estimate the tension and shape alteration in biological knots.

4. CONTROL TESTS

Analysis of geometry of osseous elements using CT is substantiated only when the measuring uncertainty do not cross the established interval. That's why the diagnostic apparatus should be put to control tests in accordance with obligatory rules.

The aim of realization of quality control in ronthen computer tomography is to assure the constant research level. It can be achieved by making measurements regularly of the chosen physical quantities which characterize the work of apparatus and observation of their variation in time. Exceeding of measured parameters outside a certain established interval of allowed quantities testifies to incorrect work of apparatus. In this case there is a need to detect a defect and remove it or regulate it. The way of control is regulated by international standards or by rules or recommendations established in some countries. In Poland it is rather the decree of minister of Health from 24 of December 2002. [7]

In accordance with § 10 of the decree, the technical parameters of the new installed radiological devices must fulfil the requirements defined in the European Commission's document „Radiation Protection" Report No 91 [2]. Apparatuses which do not fulfill these requirements can not work from 31 of December 2006.

International standard concerning the control of tomographs was published in 1994 by IEC {International Electrotechnical Commission, the organization analogical to ISO} [7]. This standard contains the description of the measurements, recommended measuring frequencies, tolerance limits for measuring parameters and exampled formula of control protocol.

The examples of regulation can be the nationwide regulations which are in force in United States [5] approved by FDA (Food and Drug Administration, American government agency exercising control on medical devices). Thanks to these regulations, the procuders of tomographs which are installed in United States need to also provide the phantom to measure determined parameters and put into the instructions for use the tomograph the chapter containing the way how to use the phantom, recommended testing frequencies, allowable deviations of measuring parameters, recommended way of results archiving and typical pictures of phantom in photo form from the monitor and in electronic way (able to projection). FDA do not determine the methods of making tests. More accurate recommendations can be done at the state level, the example can be the document published by government of the state New Jersey [7].

British report IPEM 77 (Institute of Physics and Engineering in Medicine) [7] contains the short description of the quality control tests for diagnostic, roentgen apparatus (also for computer tomography). The range, minimal frequency and tolerance limits are given for tests. The full description of tests is in report IPEM 32 [7].

Methods of measurements of doses and parameters of rontgen beam are described in measuring protocol [9] which was used during program realization to assess the doses received from the patients examined by computer tomography in United Kingdom [7].

Exampled artifacts for the research of chosen parameters of computer tomographs are shown in figures 1-3.

Tomography picture is made on the basis of the value of linear coefficient of weakening of roentgen radiation calculated for the particular elements of the volume of studied object. These values are usually given in normalized units HU (HU - Hounsfield units, also CT values, CT numbers). Scaling of the linear coefficient of weakening of roentgen radiation μ into the HU values is made in accordance with the following formula:

$$HU = \frac{\mu_{tissue} - \mu_{water}}{\mu_{water}} \cdot 1000 \qquad (1)$$

Tomography picture is made by attribution various levels of gray to the values of HU.

The values of HU in a picture of homogeneous object always show certain random variation among the points. It is caused not only by the construction limits (finite number and capacity of detectors, imperfect algorithms of reconstruction) but also by quantum nature of emission processes and reaction with the photon nature of the roentgen radiation. The measure of this variation is the level of noise determined as a standard deviation of the value HU in chosen area of the homogeneous phantom picture.

Exampled phantom to control the picture geometry is presented in fig 4. Visible markers spaced on the square plan with known distances and markers which allow to identify the sides and directions.

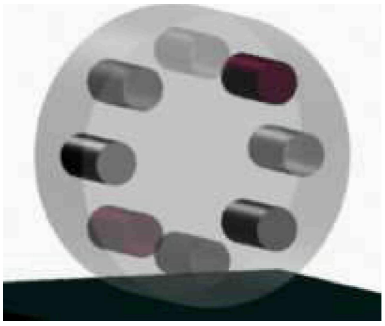

Fig. 1. Phantom to assess the value HU for various materials [7].

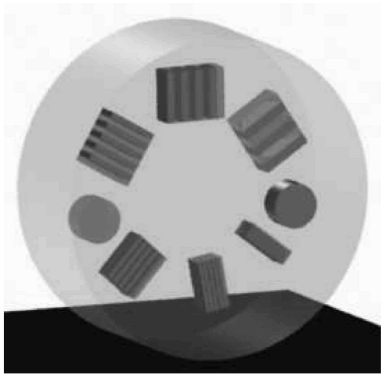

Fig. 2. Phantom to assess the resolution; visible, commutative stripes with different spatial frequencies and two homogeneous areas [7].

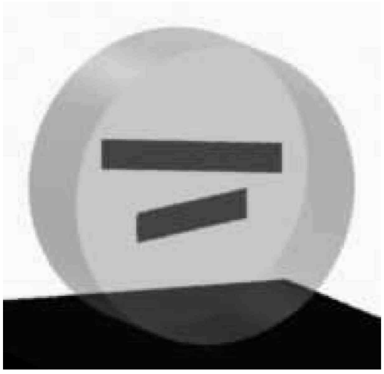

Fig. 3. Phantom to measure the thickness of the shown layer [7].

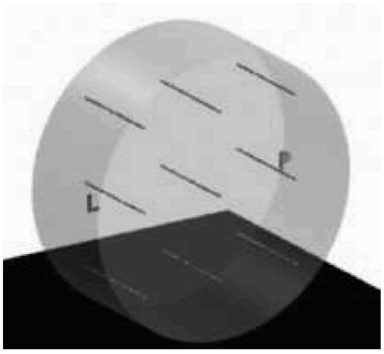

Fig. 4. Exampled phantom to control the picture geometry [7].

Simultaneously the accuracy of mapping depends on the position error of the examined object relating to gantra system axis of CT (Fig. 5).

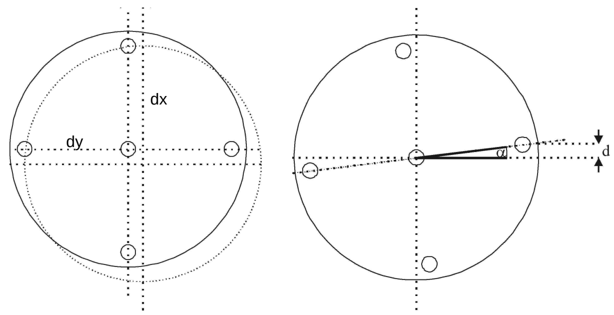

Fig. 5. Recommended accuracy of phantom position to assess the CT [9]. (d < 2,5 mm for head phantom, d < 5 mm for trunk phantom, dx < 5 mm dy < 5 mm, angle < 2°) [7].

Within a framework of research project No. 4083/B/T02/2008/34, the control method of correctness of computer tomography functionality was proposed on the basis of control model. The method was determined on the basis of cylindrical and spherical models. Within a framework of own research, various types of spatial artifacts were determined.

The assessment of accuracy of shape mapping was proposed on the basis of the analysis of replacement of the spherical areas of ceramic and Teflon artifacts. Selection of the artifact's materials was based on the characteristics of roentgen radiation absorbing (Fig. 6).

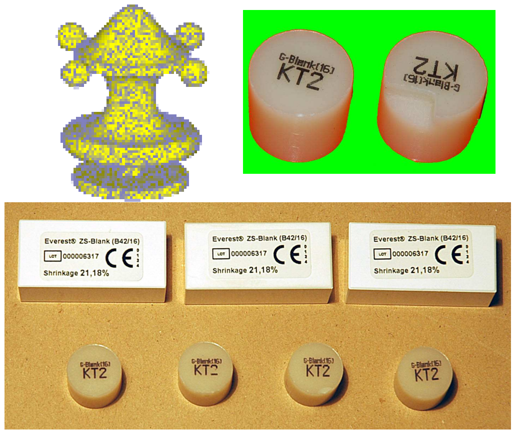

Fig. 6. Models to assess the accuracy of shape mapping [6].

5. EXAMPLED ASSESSMENT OF BONE GEOMETRY

In accordance with the procedures proposed by Cracow University of Technology the analysis of geometry of chosen bone was made on the basis of the CT research and its internal structures.

Numerical model was determined and meshing model was made for calculating program's need for example by finite elements method [5,6]. The series of measurements were made and chosen parameters of the uncertainty of measurement were determined (fig. 7).

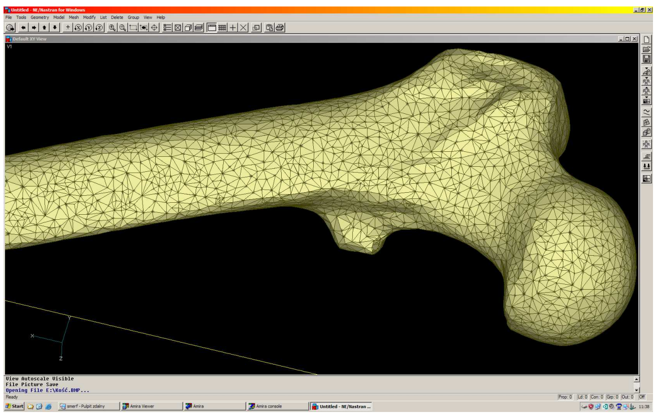

Fig. 7. The numerical picture (a) and model prepared for the MES research (b) [6].

5. CONCLUSIONS

CT is a sufficient method for imaging of bone shape.

The quality of the shape imagine and size estimation of the defects depends on the measurement strategy and selection of the best imaging sequences.

Proposed methods using special models allow actual state of CT to be assessed.

The proposed procedure of the CT control system can be used as a modern method to the quality assessment of the virtual imaging of the shapes of real bone.

In the work there is presented the new construction of the artifact to accuracy assessment of shape mapping using CT, which, together with determined research strategy and comparison method of accuracy of shape mapping obtained from 3D model with real object, is the modern system of assessment of Cts function. In comparison with actual used control models, determined system with the determined model enables:

- Measurement and assessment of a few parameters of Ct's function during one measuring run.
- Accuracy assessment of shape mapping relating to control research object.
- Assessment of influent of chosen materials in making the 3D picture of research object.
- Possibility of building models from cartilage tissue
- According to determined research strategy the assessment of function in the whole measuring space
- Determination of research protocol and function assessment of device due to accepted criteria.

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