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Experimental Determination of Computed Tomography Settings for Jaw Scanning

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Introduction

The dental implantation has become a very popular and fastest growing area of odontology. One of implant constructions is subperiosteal implant which has served as satisfactory prosthetic device for long time. The subperiosteal implants are currently fabricated by using the classic two-stage direct bone impression technique [1]. At present, the application of new diagnostic possibilities of computer tomography scanning may provide the three-dimensional (3D) image of the jaw fragment [2]. This new technique allows use one - stage procedure using computer tomography/computer-assisted design – computer-assisted manufacture (CT/CAD-CAM) for generation of model on which the implant is fabricated [3]. In this way, the patient's treatment time is shortened and the number of interventions is reduced, thus preventing the patient from the additional risk of infection.

3D physical reproduction of desired tissues allows making surgical guides and use model for treatment planning, teaching and more additional activities in odontology. However, it is very important that computer tomography (CT) scan is correctly taken. CT with right parameters is fundamental for accurate 3D reproduction.

We aimed to assess the impact of computer tomography scanning operation modes on the accuracy of the generated jaws model, used for implant manufacture.

Description of the method

The conventional geometric calibration algorithms generally require particular calibration phantoms, such as a small pin or wire, which may not be practical for large size objects or all CT equipment. We present an alternative method to calibrate system parameters from scans of human jaw, without prior knowledge of the its form.

For assessment of the impact of computer tomography scanning operation modes on the accuracy of the generated jaws model the spatial distribution between matched points in jaw model obtained from CT data and the three dimensional model obtained using optical scanner will be evaluated.

For creation of 3D computer models, first, the test object was scanned with a spiral computer tomograph Siemens Somatom Emotion 6 by changing its operation mode defining parameters, e.g. thickness of the layer, scanning step, the anode current and the reconstruction algorithm. Multisectional spiral computed tomography was performed of the area from alveolar region of maxilla to the base of mandible. In order to fix the occlusion between both jaws, the special plastic roller was used. To avoid the movement artefacts, during the examination, the test object was fixed in supine position so that the central facial line would coincide with sagital plane. The Gantry Tilt was set to zero.

The spatial resolution of the CT is affected by the pixel size of the image and by the thickness of the slice. The resolution of image in one slice is determined by pixel size, which can be calculated as

$$Pixelsize = \frac{Field\ of\ view}{Matrix\ Size}. \qquad (1)$$

In our case, the field of view of CT was 25 cm and the matrix size 512 X 512. So, one pixel survey scans in 2D described area of 0.5×0.5 mm^2. The pixel size and the thickness of slice are used for describing the voxel size. A voxel is the volume element, defined in 3D space. The reconstruction of 3D model of jaw is done using the geometrical parameters defining voxel size.

The data was stored in DICOM format files and uploaded to the software package Osirix 3.6.2., which

carries out X-ray images segmentation and creation of 3D computed model of the desired bone fragment. The obtained computer model (Fig. 1) was further processed i.e. filtered, removed the noise, which was induced by the patients movement and impact of the metal artefacts.
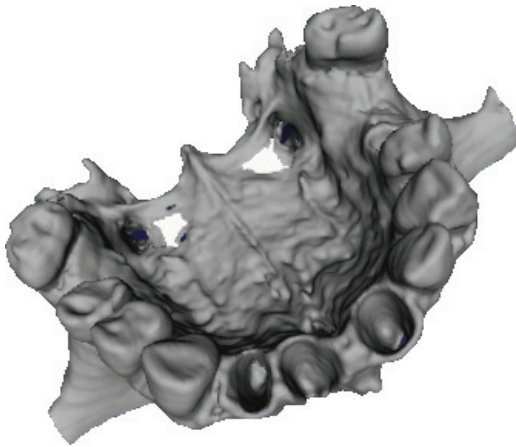

Fig. 1. 3D computer model of maxila, obtained from computer tomography data

At second step, the same test object was scanned using the 3D laser scanner based on the laser triangulation method [4]. 3D computer model, required for this study, was formed using the ScanStudio HD 1.01 software. Each of computer models had own position in space and own rotation (Fig. 2).

The main step of algorithm was used for evaluation the mismatch between two 3D models obtained using different technologies consists of the alignment step and calculation of mean square distance between the given surfaces. For the first task, approximating the transformations between the models, a coarse alignment was applied, and then a fine alignment by iterative closest points (ICP) algorithm was performed.
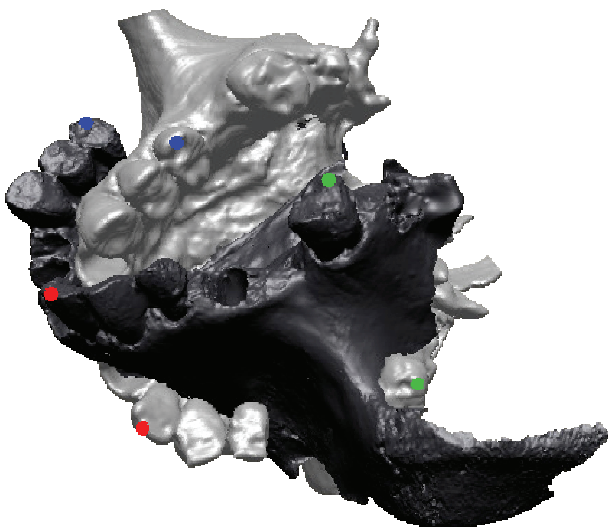

Fig. 2. 3D computer models of maxila, obtained using different scanning technique: black model obtained using 3D laser scanner, grey - using computer tomography and segmentation software. The models are not aligned. For coarse alignment 3 corresponded points on the surface of each model are marked

The coarse alignment approximates the rigid transformation between models. This is a manual step in which the user must select three corresponding 3D points on the model obtained from CT data and on the 3D model obtained using laser scanner (Fig 2). Rigid transformation (R, t, S) including rotation R, translation t and scale S is computed using the selected points.

The fine alignment algorithm is an iterative procedure minimizing the mean square error (*MSE*) between points of the first model surface and the closest points, respectively, on the other surface. At each iteration of the algorithm, the geometric transformation that best aligns the 3D model, obtained using laser scanner and the model, obtained from CT data, is calculated. Having two sets of points $L = \{l_i\}$, as a laser scanner data, and $C = \{c_i\}$, as a data of computer model obtained from computer tomography, the goal is to find the transformation (R,t) of L points which minimizes the distance between these two sets of points

$$l_i(R,t) = R \cdot l_i + t. \qquad (2)$$

So, the principle of ICP consists of determining for each point l_i of set L the nearest point in the second set C (minimal Euclidean distance between two points) and L point set transformation that minimizes the mean square error (*MSE*) of these pair [5]

$$MSE = \frac{1}{N_l}\sum_{i=1}^{N_l}\left\|c_i - R(l_i) - t\right\|^2, \qquad (3)$$

where N_l – the size of L set.

Transformation of L according to (R, t) must be done until the *MSE* is above a predefined threshold ε, and if the maximum number of iterations is not reached.

The Euclidean distance is measured for each pair of corresponding points obtained by ICP algorithm and histogram of distribution of distances and a colour map (the distances are presented by colors) are calculated (Fig. 3).
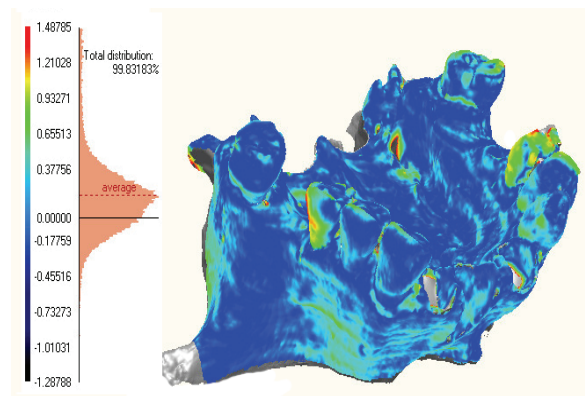

Fig. 3. Spatial deviation and colormap between the 3D model obtained from CT data and the 3D model obtained using laser scanner

From histogram the mean square value of distances between two surfaces and standard deviation of point-to-

point distances were estimated. Those two parameters were used for assessment the impact of computer tomography scanning operation modes (thickness of the layer, scanning step, the anode current and the reconstruction algorithm) on the accuracy of the generated jaws model.

Results

To obtain maximum accuracy and to prevent human from the exposure to X-rays, as a continuous object was chosen a body cranium, covered with a layer of paraffin, simulating a soft tissue (Phantom 1). The Phantom 1 was fixed with material belt in supine position, so that the central facial line would coincide with sagital plane during the examination. By using the above described method, the jawbone of Phantom 1 was scanned with a spiral computed tomograph working in the different operation modes, and then - with the 3D laser scanner. The obtained data were processed and mean square value of distance between surfaces and standard deviation of distance values were estimated. The comparison of these values revealed, that the least deviation was obtained by using spiral computer tomography within slice thickness of 1 mm, scanning step of 0.5 mm, and reconstruction algorithm of H70s (in case that computer tomograph Siemens Somatom Emotion 6 is used). After the comparison of obtained data of Phantom 1 upper jaw by using the optical scanner and a spiral computer tomograph with the scanning step from 0.6 mm to 1.7 mm, the negative influence of the big step was determined. In case of large scanning step mean square value of distance between two surfaces for the whole surface of the upper jaw comes close to 0.3 mm. The discrepancy of some surface points was 1 mm and more. Therefore these computer models are not suitable for accurate subperiosteal implants design and manufacture.

For the examination of the accuracy of the models depending on the exposure parameters, the head of the dead roe, which was covered with a natural soft tissue, (Phantom 2) was used. During the examination the roes head was fixed with the material belt so that the central facial line would coincide with sagital plane. The occlusion between both jaws was fixed with the special plastic roller. In these examinations the anode current, witch leads to the main exposure of the patient, was varied from 30 to 110 mA, while keeping stable the scanning step of 0.5 mm and layer thickness of 1 mm. In second step, the roes head without soft tissue was scanned using the optical 3-D scanner. The computer models of roe's skull, obtained using different scanning technique, were formed and compared. The mean square value between two surfaces was estimated. We determined that the best congruence between two surfaces was estimated by using the anode current of 41 mA (Fig. 4). However, it can be seen, that exposure rates by changing the anode current, had no noticeable effect on the accuracy (the change of average value of distance between two surfaces is only 0,0032 mm).

Similar experiment was made for examination of

accuracy depending on the selected CT reconstruction algorithm. The minimal mean square error was obtained by using H70s reconstruction algorithm (Siemens CT software).
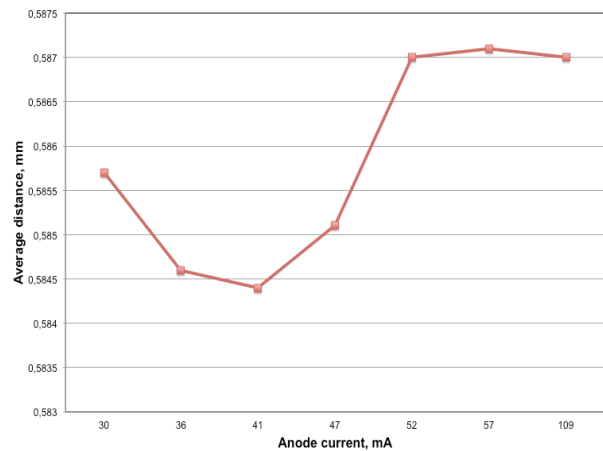

Fig. 4. Determination of optimal anode current for head scanning. The average value of distance between two surfaces, obtained using different scanning technologies

For final examination of the accuracy the human skull without the lower jaw, not covered with paraffin wax (Phantom 3) was used. Optimal value of anode current (41 mA), layer thickness of 1 mm, scanning step of 0,5 mm and H70s reconstruction algorithm were set for scanning. Phantom 3 was scanned using 3D laser scanner also. The mean square difference between surfaces of models, obtained using different technologies is 0,063 mm. The discrepancy of some surface points was 1,9 mm and more (Fig. 5). It was caused by selection of one optimal threshold value of all possible thresholds within the entire grey-value range (Hounsfield units). However, the attenuation of X-ray in tooth and bone are different, so we have errors in the area of teeth, because optimal threshold value is selected for segmentation only of bone structures. The dynamic methods must be used (not Osirix software) for more precise segmentation of CT images. Presented method can be used for evaluation of segmentation algorithms and selection of methods for enhancement of CT images [6]. Therefore, this computer model is suitable for accurate design and manufacture of subperiosteal implants, because we have accurate reconstruction of bone structures in the field of possible implantation.

Similarly, the computer tomography data base, which consist of 14 patients jaws fragments and 3D models, obtained using 3D scans of direct bone impressions [7] was investigated in vivo. The different computer tomography equipment was used for scanning of different patients. It was found, that decreasing the scanning step, when the thickness of the layer is double, values of the mean square value of distance between two surfaces were negligible. We have chosen two patients with the same thickness of the layer and scanning step, but different anode currents. We determined that exposure rates by changing the anode current had no noticeable effect on the accuracy.
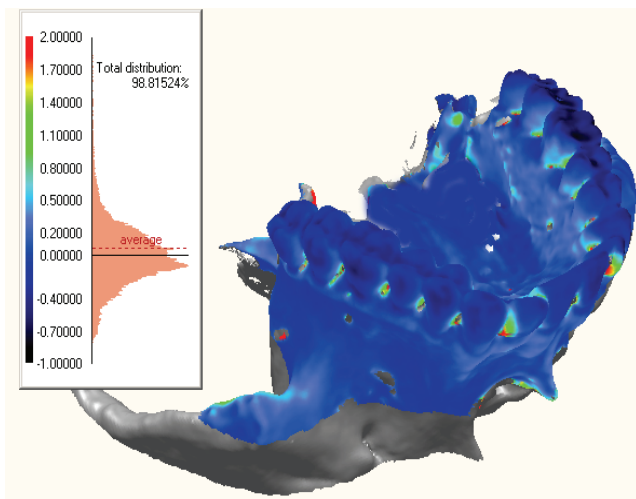
Fig. 5. Spatial deviation and colormap between the 3D model obtained from CT data (optimal settings) and the 3D model obtained using laser scanner

Conclusions

1. Large scanning step and commensurate a large layer thickness significantly increase the spatial distortions of the 3D computer model, obtained from a computer tomography images. In addition, the obtained model is not smooth and the stratification defects are visible.

2. Changes of the anode current exposure settings, even within the large range, had no noticeable effect on the accuracy of the final model.

3. Increasing the thickness of the layer at the same pitch value increases the resolution of images brightness information, which allows obtain more accurate models.

4. Presented method can be used for evaluation of segmentation based image processing software and for determination of parameters of CT image processing algorithms.

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R. Adaskevicius, D. Macianskytė, E. Monastyreckiene. Experimental Determination of Computed Tomography Settings for Jaw Scanning // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 5(111). – P. 129–132.

Aim of our study is to develop a method for the experimental identification of the settings of a computed tomography (CT) scanner used for scanning of human jaw. I this case, CT can be used for rapid prototyping of human jaw, design and manufacture of implants. The experimental identification of settings of a computed tomography scanner is done by comparing 3D computer models built using different data acquisition technologies: CT scanner and 3D laser scanner. The modified Iterative Closest Points algorithm is used for alignment of 3D computer models, obtained using different scanning methods. The different test objects were scanned using a spiral CT scanner and 3D laser scanner for testing the method. 3D computer models were compared uding the mean square value of distance between two surfaces. The test results indicate hardware and software parameters impacting on the accuracy and surface quality of 3D computer model reconstructed from CT data. Ill. 5, bibl. 7 (in English; abstracts in English and Lithuanian).

R. Adaškevičius, D. Mačianskytė, E. Monastyreckienė. Kompiuterinio tomografo, skirto žmogaus žandikauliui skenuoti, darbo režimų eksperimentinis nustatymas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 5(111). – P. 129–132.

Darbo tikslas – sukurti eksperimentinį metodą kompiuterinio tomografo, naudojamo žmogaus žandikauliui skenuoti, darbo režimams nustatyti. Taigi kompiuterinė tomografija gali būti taikoma formuoti erdvinių kompiuterinių modelių prototipams, skirtiems implantams projektuoti ir gaminti. Tomografo darbo režimai parenkami lyginant kompiuterinius modelius, gautus skirtingais skenavimo metodais: skenuojant kompiuteriniu tomografu ir erdviniu lazeriniu skeneriu. Iteratyvus gretutinių taškų algoritmas naudojamas modeliams sutapdinti. Metodui patikrinti įvairūs testiniai objektai buvo skenuojami tomografu ir erdviniu lazeriniu skeneriu. Gauti erdviniai modeliai buvo sutapdinti ir apskaičiuota vidutinė kvadratinė jų paviršių tarpusavio nesutapimo vertė. Tyrimo rezultatai rodo įrangos ir programų parametrus, turinčius įtakos į formuojamo erdvinio modelio tikslumui ir paviršiaus kokybei. Il. 5, bibl. 7 (anglų kalba; santraukos anglų ir lietuvių k.).