Improvement of the geometrical accuracy of the human mandible body parametric model

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***Abstract*— The mandible is one of the frequently fractured bones in skeletal system of man. Reconstruction of the damaged mandible bone requires detailed and precise preoperative planning, which enable maxillofacial surgeons to improve execution of surgical interventions. For that purpose, 3D geometrical model of human mandible of specific patient is necessary in preoperative planning. In previous research, 3D parametric model of human mandible body was developed using Methods of Anatomical Features (MAF). The 3D parametric model is defined as point cloud, where coordinates of points are described by parametric functions, whose components are morphometric parameters (dimensions which are read on medical images). Ten central and bilateral morphometric parameters were used to create the parametric model of human mandible. The main benefit of this model is ability to adapt model to the specific patient, by applying patient specific values of morphometric parameters. The main focus of this study was to reduce number of parameters, while at the same time preserve geometrical accuracy of the personalized model. With this aim, statistical analysis (multiple regression) was applied in order to create "best fit" model with reduced number of morphometric parameters. Geometrical accuracy of the obtained parametric model was tested by the application of the deviations analysis in CATIA software. Deviations analysis was performed between input and resulting model. The results of analysis satisfied necessary accuracy of the models.**

I. Introduction

The human mandible can be significantly damaged because of its location and anatomy and due to various traumas (congenital and acquired deformities, injuries, tumor, fractures). Reconstruction of the missing, damaged or deformed mandible bone requires detailed and precise preoperative planning. Preoperative planning is an essential prerequisite for the success of surgical procedures [1]. In order to improve preoperative planning, personalized 3D geometrical model of the complete mandible or its part have become indispensable. Personalized 3D geometrical model is model that has close resemblance to the actual part in terms of specific bone geometry and topology.

Numerous studies that are based on personalized 3D geometrical model are performed until today [2-4]. In general, personalized geometrical model of human bone are based on predictive models created by using volumetric scanning methods (Computer Tomography, Magnetic Resonance Imaging). The construction of this model provides that by the application of specific parameters, model adapts into 3D personalized geometrical model of the specific human bone.

In order to create such model, 3D parametric model of the mandible, previously developed by the use of Method of Anatomical Features was used in this research [5]. 3D parametric model is defined as a set of parameter equations, developed by application of multiple regressions. However, in any statistical modeling based on regression analysis the goal is to develop the "best" model (equation) that best fits the data [6]. It is well known that the regression model that includes all of the independent variables has the highest coefficient of determination, however, as a rule, all variables do not contribute significantly to explaining the variability. In the previous research, ten central and bilateral morphometric parameters were determined and used to create the parametric model of human mandible. Parametric models were defined as a set of parametric equations (functions), whose independent variables are morphometric parameters, measured on medical images. The main focus of this study was to examine whether the reduced number of morphometric parameters in the already defined parametric equations attains an appropriate geometrical accuracy of resulting models. The optimization number of morphometric parameters was performed by preliminary statistical analysis.

II. Optimization of Number of Parameters

The procedure for the optimization of number of parameters consists of following steps:

1) Selection of morphometric parameters;
2) Loading the set of anatomical points;
3) Statistical analysis;
4) Examination of the interconnectedness of parameters;
5) Creation of parametric model with optimal selection of parameters;

For geometric analysis of human mandible twenty (20) mandible samples were used, scanned by 64-slice CT MSCT (Toshiba, Aquilion 64, Clinical Center Nis), according to standard parameters: resolution 512 x 512 pixels, thickness 0.5 mm, radiation 120 kVp, 150 mA current, rotation time of 0.5 s. The mandible sample came from Serbian adult male from 22 to 72 years.

Selection of morphometric parameters

Identification and definition of morphometric parameters have important role in the process of creation parametric surface model of human mandible. In accordance with the geometric and morphometric analysis of the bone the 10 basic central and bilateral mandibular morphometric parameters are defined and presented in the Fig. 1. According to the scientific literature [7], they are sufficient for a complete definition of the geometry of the mandible. On each specimens mandibular morphometric parameters are defined and measured.

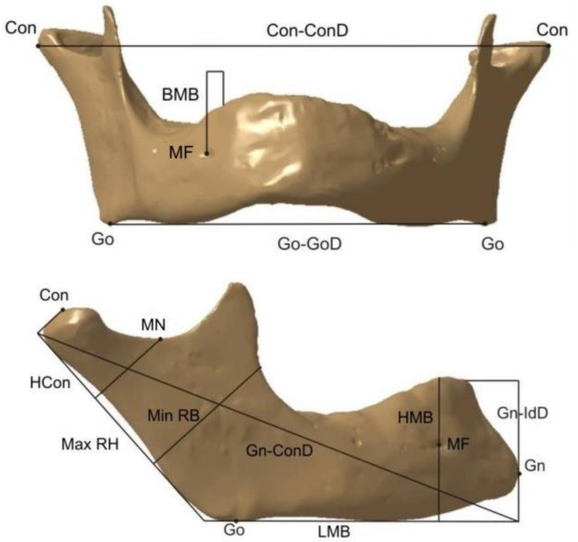

Figure 1. Morphometric parameters

Loading the set of anatomical points

The process of creation the human mandible body parametric model is based on the Method of Anatomical Features (MAF) [8]. MAF has been already applied for the creation of the geometrical models of various human bones. Parametric model of the human mandible is a geometrical model defined as a point cloud. Each point in point cloud is defined by parametric equation (function), whose arguments are morphometric parameters [9].

On the mandible body 56 anatomical points were selected. Anatomical points are used to create spline curves in accordance to the bone geometry and morphology. In the absence of a sufficient number of anatomical points for the fully characterize shape of mandible body, support points (semilandmarks) were added on spline curves. A collection of anatomical points, semilandmarks and constructed spline curves are presented in Fig. 2. Spline curves can be used to create a volumetric model of human mandible.

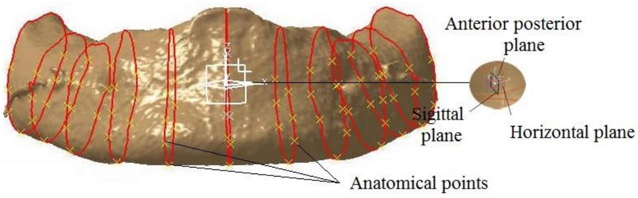

Figure 2. Definition of the anatomical points on polygonal model of the body of the human mandible

The coordinates of points have been measured in relation to a predefined coordinate system in all three directions X, Y and Z. The same procedure is performed for each specimen in input set for statistical analysis. The teeth region is not considered in the statistical analysis because, in general, teeth differ in their number and the topology of the reconstructed geometry from patient to patient.

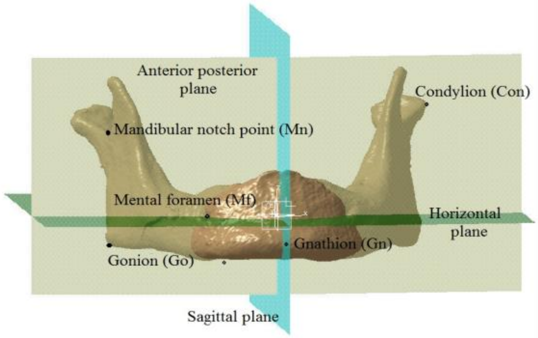

Figure 3. Definition of coordinate system and the characteristic anatomical points on polygonal model of the human mandible

Statistical analysis

The measured values of the coordinates of points and morphometric parameters represent the input data in the statistical analysis (multiple linear regression). Basic multiple regression model looks like:

$$C = \beta_0 + \beta_1 C_1 + \beta_2 C_2 + \beta_3 C_3 + \ldots + \beta_p C_p + \varepsilon \qquad (1)$$

where: C-dependent variable (variable response), C_1-C_P - is an independent variable (explanatory variable), β-parameters to be assessed, ε-error measurement. In our case, C_1, C_2, ... , Cp represent the values of morphometric parameters measured in all samples of the mandibles. The calculation was performed for all anatomical and support points on the human mandible body. For each X, Y and Z coordinate of 56 point there is parametric equation that defines it.

Examination of the interconnectedness of parameters

Testing of multicollinearity is an integral part of the selection of regression model [6]. The elimination of one or more independent variables that have high collinearity with another is one way of solving the problem. The bases of identification of the independent variables that are to be excluded are correlation coefficient between them. Using the statistics software Minitab the values of the Pearson's correlation coefficient are determined. The analysis involved estimating the strength of all independently variable. The high values of the correlation coefficients between the independent variable C1 and C4 indicate a strong correlation between them. When there is a strong correlation between independent variable (variables have a similar meaning), it is not necessary that both be included in the regression model.

By elimination an independent variable C4 from a regression model, an analysis of the results was performed. Based on the value of the coefficient of determination (R) and p values of predictors, it can be concluded that the new regression model with a smaller number of independent variable is just as good as the regression model that contains all the independent variables.

In order to elimination of variables that overlap with others and therefore have little or no contribution to accuracy in forecasting model, stepwise regression is used. The results of the method gave optimal number of independent variables for all three coordinates of all anatomical points, which significantly affect the accuracy in predicting model. On the coronoid process of human mandible it was easiest to group the optimal number of variables for all three coordinates [10]. However, on the body of the human mandible, the grouping of a subset of variables for all three coordinates was impossible.

Creation of parametric model with optimal selection of parameters

The main objective of this analysis was to develop “best” regression model, with the least number of variables, which still explains sufficient variability in the dependent variable. As a result of the analysis new set of parametric equations (functions) are obtained. The created 3D human mandible body parametric model (Fig. 4. and 5.) consists of the new set of the parametric equations.

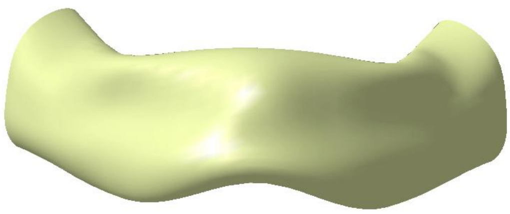

Figure 4. 3D human mandible body parametric model

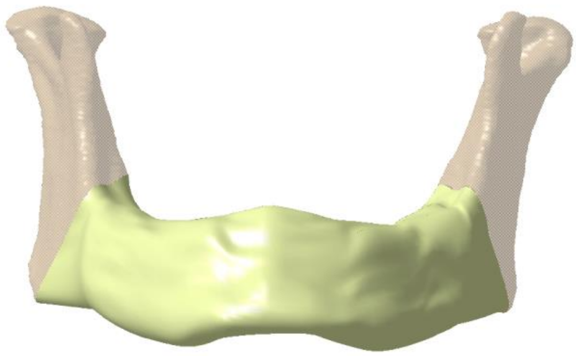

Figure 5. 3D human mandible body parametric model

III. Results

The calculation was performed for all anatomical points on the body of human mandible. In Table 1. coefficients of the multiple linear regression functions are presented for chosen anatomical point.

For example, statistical function for X coordinate of anatomical point is presented in:

$$X = b_0 + b_1 \cdot C1 + b_2 \cdot C2 + \ldots + b_7 \cdot C7 + b_8 \cdot C8 + b_9 \cdot C9$$

$$= -27.025 - 0.101 \cdot C1 - 0.083 \cdot C2 + \ldots + 0.098 \cdot C7 - 0.298 \cdot C8 - 0.04 \cdot C9$$

Anatomical part		b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9
Body of mandibule	x	-27.025	-0.101	-0.083	0.173	0.007	0.055	0.216	0.098	-0.298	-0.04
	y	-12.989	0.509	-0.341	0.095	0.136	-0.663	1.225	-0.211	-0.150	).286
	z	-33.744	-0.646	0.392	0.169	-0.317	0.285	-0.864	0.302	-0.188	-0.23

Table 1. Coefficients of the multiple linear regression functions

Number of samples	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	IXX	XX
1.Max.Deviation [mm]	1.83	1.57	2.89	1.82	1.88	1.77	1.79	1.64	1.96	1.92	1.95	1.21	1.78	1.88	2.25	1.56	1.48	2.12	2.90	1.65
2.Max.Deviation [mm]	1.53	1.03	2.38	2.06	1.97	1.74	2.05	1.64	1.82	1.62	1.74	1.06	2.11	1.67	2.57	1.45	1.56	1.97	1.82	1.78

Table 2. Comparing the obtained value of deviation resulting surface model created based on the all MP and the resulting model created on the basis of reduced number of MP

IV. Discussion

Based on correlation coefficient, we were able to reduce the selection of morphological parameters. As a result of this approach a new regression model is obtained with a smaller number of independent variables, where *p* values for regression coefficients in equations are less than 0.0339 and value of variance R^2 is up to 86.3%.

Geometrical accuracy of the obtained surface models was tested by the application of the deviations analysis in CATIA software. Deviations analysis was performed between input and resulting model. Comparing the obtained value of deviation resulting surface model created based on all morphometric parameters (row 1 in table 2) and the resulting model created on the basis of optimal selection of morphometric parameters (row 2 in table 2), one can draw the conclusion that the geometrical accuracy of the model is about the same.

IV. Further work

Further work by the authors of this study will be based on creation of complete parametric model of human mandible with reduced number of morphometric parameters in the already defined parametric equations. This task will be performed in order to examine whether the reduced number of morphometric parameters attains an appropriate geometrical accuracy of complete resulting model.

V. Conclusion

This preliminary study indicated that by reducing the central and bilateral mandibular morphometric parameters, it is possible to create geometrically accurate and anatomically correct parametric model of the body of the human mandible. Above all, the importance of this analysis is that resulting models based on a smaller number of morphometric parameters have appropriate geometric accuracy.

The resulting models have an accuracy level that is clinically acceptable. The application of these models is broad in: training of medical staff, preoperative planning, creation of implants and virtual simulations of treatment.

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