Application of Artificial Neural Networks in Prediction of Human Mandible Geometry

Jelena Mitić*, Nikola Vitković*, Miodrag Manić*, Miroslav Trajanović*

* Faculty of Mechanical Engineering, University of Niš, Serbia

jelena.mitic153@gmail.com

nvitko@gmail.com

miodrag.manic@masfak.ni.ac.rs

miroslav.trajanovic@masfak.ni.ac.rs

***Abstract*—Accurate predictive models of human mandible are the most important component in maxillofacial reconstruction surgery when medical images of the whole bone are not available (due to the bone illness, fracture or an extreme traumatic bone damage, osteoporosis). Existing predictive models are based on predicting the intermediate form of the model including all of its variations based on the input data set, but the shortcomings are inaccurate prediction of shape variations and geometry of the bone outside of the input set. In this paper, the method for building predictive 3D model of the human mandible, which geometry can be changed according to the specific patient's bone, is presented. The method is based on the Method of Anatomical Features, with the implementation of the important improvement, with the application of artificial neural networks in the prediction of human mandible geometry. This approach enables easy personalization of the model's shape and geometry and can serve as a template for individual treatment planning.**

I. Introduction

Complications following surgical interventions are often associated with inadequate reconstruction of the skeleton of the face. To correct functional and aesthetic requirements, the precise surgical intervention is required. A set of techniques that use computer technology for surgical planning and performing surgical interventions is called a Computer-Assisted Surgery (CAS)[1]. The most important component for the CAS is the development of an accurate geometrical model of the human bone, tissue and muscle.

An extreme traumatic bone damage, osteoporosis or cancer can be possible reasons for the lack of complete geometrical model of the human bones. In such situations, it is essential to apply a method for the reconstruction of the complete geometric model of a human bone structure based on the geometry prediction. The division of methods that allow the reconstruction of the complete 3D bone model can be performed according to the method of creation: method based on statistical, parametric bone models and methods based on other techniques [2].

As a prerequisite for the development of the method, techniques that can be applied for the creation of predictive 3D models of human bones are analyzed. In the literature review, it is noted that there is a very small number of papers that are based on the development of parametric models of human bones. Proper reconstruction of complete 3D geometrical models of human bones or their missing part is a very complex process. In most cases, the reconstruction of the geometric model of a human bone is based on the application of Statistical Shape Models – SSM [3, 4]. Statistical models of human bones are models formed over a set of bone input models. They are created based on statistical methods and allow the prediction of the geometry and shape of the bones of a specific sample. Statistical models are based on a prediction form of a model; however, shape variations and geometry outside the input data cannot be accurately predicted [5].

The main motivation of the research was to develop a predictive (parametric) model of the human mandible which will improve the preoperative procedure. They are based on the input set of bone samples, obtained from the medical scanning device. The benefit of predictive model application can be creation of complete bone models or bone segments even in cases when we have incomplete information about the patient's bone.

The predictive model is constructed by defining the referential geometric entities (points, axes, lines, planes) that correspond to anatomical features. It is defined as a point cloud model, where each point is defined by an individual parametric function. In the previous research, multiple regressions were applied for creation of the parametric function [6]. The focus of this analysis was to examine whether the application of other statistical and Artificial Intelligence (AI) methods for the creation of parametric function attain the appropriate geometrical accuracy of the resulting models.

II. Materials and Methods

For the geometrical analysis of the human mandible eighteen samples were used. Clinical CT scans of the adult's male human mandible were obtained from the Clinical Center of Nis, Institute of Radiology, scanned by 64-slice CT (MSCT) (Aquillion 64, Toshiba, Japan). The CT scans were collected using the resolution of 512 x 512 px and slice thickness of 0.5 mm.

The method developed by the authors of this research introduces a new approach for the prediction of a human mandible geometry. The method is based on the MAF method [6,7], which has so far has been successfully applied for the creation of the complete geometrical models of various human bones in the skeletal system of a man, even in cases when the information about the patient's bone are incomplete. MAF method served as the initial basis for further research analyses aimed at solving the problem of the prediction of the human bone geometry. It is important to note that MAF method is based on a prediction algorithm which involves the application of the multiple regression. In this research, a new approach in geometric modelling of a human mandible is based on the prediction of human bone geometry using artificial neural network techniques.

The procedure for the creation predictive (parametric) 3D model of human mandible consists of following steps:

- Preparatory process;
- Definition of referential geometrical entities;
- Definition of anatomical points and morphometric parameters;
- Development parametric functions;
- Creation parametric 3D model.

A. Preparatory process

In order to demonstrate the new approach in the geometrical modeling of the human mandible, eighteen (18) mandible samples were used. The mandible samples came from Serbian adults' males aged from 50-70 years.

The preparatory process consists of: CT scanning of the patients, segmentation of medical data in medical software, transformation geometrical data into the STL format, importing geometrical data into CAD software and creation of polygonal model.

B. Definition of referential geometrical entities

One of the most important steps in creating of a predictive geometrical model of the human mandible is definition of Referential Geometrical Entities (RGEs). They are representing a plane, line, axis, points that will serve as the basis for the creation constituent geometric entities [8]. The procedure for defining RGEs starts with a position of characteristic anatomic points on a polygonal model. On the polygonal model of the human mandible in accordance with the anatomical and morphological characteristics of the bone, five anatomical characteristic points are defined (represented in Fig. 1) [9]. They were used as the basis to creation characteristic planes, axes and views. The correct identification of RGEs is of great importance for the successful geometric modeling of human bones, because constituent geometric entities (spline, surfaces and solids) are spatially referenced in relation to them.

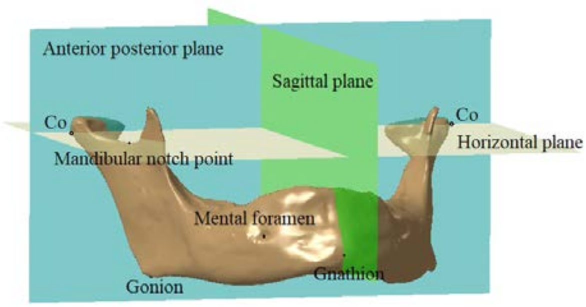

Figure 1. Referential geometrical entities on human mandible

C. Definition anatomical points and morphometric parameters

Parametric model of human bones is defined as point cloud models, which represent an approximation of human bone boundary [10]. In this research, point cloud contains of 156 anatomical points positioned on the right side of human mandible. They are used to describing specific anatomical locations (Fig. 2). Each anatomical point coordinate (X, Y and Z) in the point cloud model is defined by parametric function.

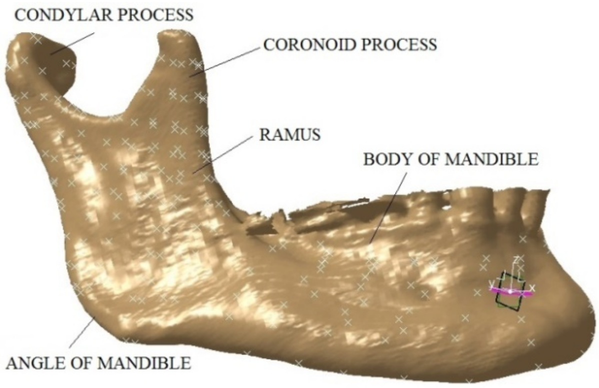

Figure 2. Location of anatomical points on the anatomical parts of the human mandible

Morphometric parameters represent arguments in parametric function. They are dimensions which can fully describe the configuration of the human mandible [11]. These dimensions can be acquired from medical images by using adequate software. In our case, morphometric parameters are defined and measured from polygonal model in CATIA software (Fig. 3).

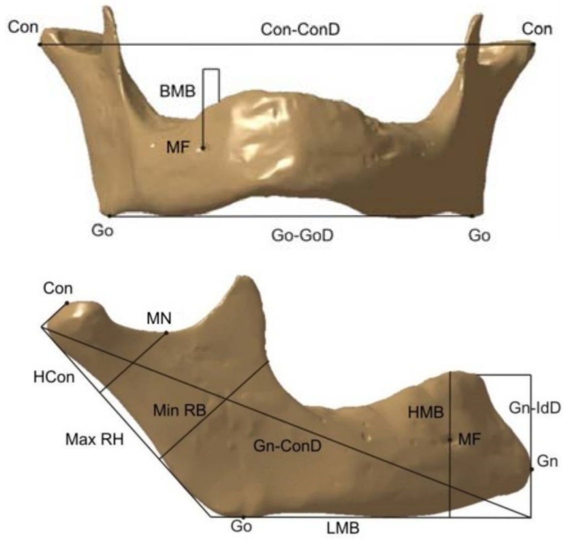

Figure 3. Morphometric parameters defined on the polygonal model of the human mandible

D. Development of parametric functions

Artificial Neural Networks (ANN) is applied for the creation of parametric functions. The ANN model with input data (measured values of morphometric parameters) and output data (values of X, Y and Z coordinates) is shown in Fig. 4.

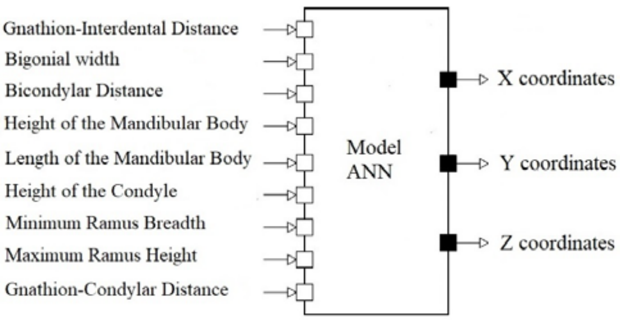

Figure 4. The ANN model with input and output data

MATLAB software was used for mathematical modeling. By using MATLAB Neural Net Toolbox, the precise connections between the variables have been established.

The first phase of the analysis defines: the set of rules using to the training of the ANN and the set of input - output data. To create a mathematical model, 75% of randomly selected data was used, while the remaining 25% was used for validation. To avoid the instability of the neural network, the pre-processing (scaling) of input-output data was performed before the training process. Usually the data preparation is done in the form of data normalization (scaling) to some standard ranges such as 0 to 1 or -1 to 1. The most elementary method for selection of architectural and training parameters settings is the use of a trial and error method. In order to determine the optimal values of ANN parameters, several neural networks of different structures were developed and tested. The best-performing model was presented in Table I. ANN model was trained by Levenberg-Marquardt algorithm [12], and sigmoid transfer functions were selected in a hidden and output layer.

The training of the ANN was interrupted when there was no further reduction in the error between the expected and the resulting output values. Mean sum of Squared Error (MSE) was used to evaluate the predictive accuracy of the ANN model.

TABLE I. ANN training parameters

Number of input neurons	9
Number of hidden neurons	50
Number of output neurons	3
Algorithm	BP
Momentum	0.625
MSE	0.038
Number of training epochs	1464
Trans. fun. in hidden layer	logsig*
Trans. fun. in output layer	logsig

*log - sigmoid transfer function

E. Parametric 3D surface model

The construction of a 3D surface model of the human mandible is based on the predictive values of the coordinates of the anatomical points. The surface model is created in CAD software CATIA by the application of adequate software modules and features.

III. Results and Discussion

The geometrical accuracy of the obtained surface models was tested by the application of the deviations analysis in CATIA software. Deviations analysis was performed between an input and resulting model. The maximum value of deviations was presented in Table II.

TABLE II. Maximum value of deviations [mm]

Body of the mandible	-0.10 to 0.38
Ramus	-0.36 to 0.21
Coronoid process	-0.29 to 0.20
Condylar process	-0.40 to 0.21
Angle of human mandible	-0.23 to 0.58

IV. Conclusion

The approach presented in this research enables creation of complete 3D geometrical models of human mandibles and bone fragments [13], even in the cases where the input data of patient’s bone are not complete.

By comparing the geometric accuracy of resulting models created by MAF method [14] and new approach in geometric modelling of human mandible, it can be concluded that the models created using the ANN are geometrically more accurate. A study suggests that the improved approach for the geometric modelling of the human mandible represents a significant contribution towards improving the geometric and anatomical accuracy of the resulting models.

The resulting models based on the artificial neural network technique have a precision level that is clinically acceptable and can be applied in: preoperative planning, surgical simulation, post-operative recovery of the patient, design of osteofixation material, etc.

Acknowledgment

The paper presents results of the project III 41017 Virtual Human Osteoarticular System and its Application in Preclinical and Clinical Practice sponsored by the Ministry of Education, Science and Technological Development of the Republic of Serbia for the period of 2011 - 2019.

References

[1] G.J.C. Baar, N.P.T. Liberton, H.A. Winters, T. Forouzanfar, F.K. J. Leusink,“Accuracy of computer-assisted surgery in mandibular reconstruction: A systematic review,” *Oral Oncology*, DOI: 10.1016/j.oraloncology.2018.07.004, pp. 52-60, 2018.

[2] S. Filippi, B. Motyl, C. Bandera, “Analysis of existing methods for 3D modelling of femurs starting from two orthogonal images and development of a script for a commercial software package,” *Computer Methods and Programs in Biomedicine*, vol. 89, iss.1, pp. 76-82, 2008.

[3] M.A. Fuessinger, S. Schwarz, C.P. Cornelius, M.C. Metzger, et al, “Planning of skull reconstruction based on a statistical shape model combined with geometric morphometrics,” *International Journal of Computer Assisted Radiology and Surgery*, vol. 13, iss. 4, pp. 519-529, 2018.

[4] R. Vallabh, J. Zhang, J. Fernadez, G. Dimitroulis, D.C. Ackland, “The morphology of the human mandible: A computational modelling study,” Biomechanics and Modeling in Mechanobiology, doi.org/10.1007/s10237-019-01133-5, pp. 1-16, 2019.

[5] S.G. Kim, W.J. Yi, S.J. Hwang, S.C. Chio, S.S Lee, M.S. Heo, “Development of 3D statistical mandible models for

cephalometric measurements," *Imaging Science in Dentistry*, vol. 42, iss. 3, pp. 175-182, 2012.

[6] V. Majstorović, M. Trajanović, N. Vitković, M. Stojković, "Reverse engineering of human bones by using method of anatomical features," *Cirp Annals*, vol. 62, iss.1, pp. 167-170, 2013.

[7] M. Manić, N. Vitković, M. Stojković, D. Mišić, M. Trajanović, "Design of customized anatomically adjusted implants," 13th International Scientific Conference MMA 2018 Flexible Technologies, pp.1-6, 28-29. September 2018, Novi Sad, Serbia.

[8] M. Stojković, M. Trajanović, N. Vitković, J. Milovanović, S. Arsić, M. Mitković, "Referential geometrical entities for reverse modeling of geometry of femur," *Procedings of the Second Thematic Conference on Computational Vision and Medical Image Processing*, pp. 189-194, 2009.

[9] S. Arsić, P. Perić, M. Stojković, D. Ilić, M. Stojanović, Z. Ajduković, "Komparativna analiza linearnih morfometrijskih parametara humane mandibule dobijenih direktnim i indirektnim merenjem," *Vojnosanitetski Pregled*, vol. 67, iss. 10, pp. 839-846, 2010.

[10] N. Vitković, S. Mladenović, M. Trifunović, M. Zdravković, M. Manić, M. Trajanović, D. Mišić, J. Mitić, "Software Framework for the Creation and Application of Personalized Bone and Plate Implant Geometrical Models," *Journal of Healthcare Engineering*, vol. 2018, Article ID 6025935, 11 pages, 2018.

[11] J. Mitić, N. Vitković, M. Manić, M. Trajanović, S. Petrović, S. Arsić, "Reverse modeling of the human mandible 3D geometric model," *Vojnosanitetski Pregled*, OnLine-First April (00): 63-63. DOI 10.2298/VSP170727063M, 2018.

[12] H. Demuth, M. Beale, "Neural Network Toolbox User's guide", The Mathworks Inc., 2004.

[13] J. Mitić, M. Manić, S. Petrović, S. Krasić, N. Vitković, M. Trajanović, "Rekonstrukcija geometrijskog modela nedostajućeg dela na telu donje vilice čoveka," *ETIKUM 2018, Proceedings*, pp: 93-96, 06-08.12.2018. Novi Sad, Serbia, 2018.

[14] N. Vitković, J. Mitić, M. Manić, M. Trajanović, K. Husain, S. Petrović, S. Arsić, "The Parametric Model of the Human Mandible Coronoid Process Created by Method of Anatomical Features,"*Computational and Mathematical Methods in Medicine*, vol. 2015, Article ID 574132, 2015.