A Personalized Three-Dimensional Model of a Patient Using CT Images

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Abstract. In order to obtain a personalized three-dimensional model of a patient based on CT images, the InVesalius program was initially used, which performs the initial conversion of the analyzed tissues into a specific engineering file composed of the so-called "point cloud". This "point cloud" was imported into the Geomagic program, in which, using reverse engineering techniques, the "point cloud" was initially transformed into elementary triangular surfaces. These primary geometric structures have been edited, transformed, adapted so that, in the end, perfectly closed surfaces are obtained. It was done in this way, both for the bone structure of the head, but also for the dental structure. These complex geometries were loaded into SolidWorks, where they were originally transformed into virtual solids. These geometric structures were loaded and assembled into SolidWorks and interference solids were removed. Finally, a customized three-dimensional model was obtained on which different normal or pathological situations can be analyzed using kinematic simulations or using the finite element method.

Keywords: Reverse Engineering · Computer Aided Design · Personalized Human 3D Model

1 Introduction

In order to analyze the behavior of some tissues that are part of biological or human systems, it is necessary, in a first phase, to determine the geometry of the analyzed system. There are several methods to obtain these three-dimensional models. But, in order to obtain a faithful model, the tomographic images of the studied patient should be taken into account. In this way, the study becomes personalized, ie the three-dimensional model renders almost perfectly the real system analyzed. Having this model, you can analyze and study different normal, pathological, pre-surgical or post-surgical situations, having at hand programs that perform kinematic analysis, studies based on the finite element method that can be load analysis with forces, temperatures, mechanical moments, subjected to fluid leaks, but also other studies. Also, the analyzes can be combined involving several physical phenomena. For these reasons, the three-dimensional geometric pattern of the tissues of a personalized human system is very important, being the basis of these analyzes. For example, we analyzed and studied the dento-maxillary system of a real patient [1–3].

2 The Three-Dimensional Model of a Personalized Dento-Maxillary System

We analyzed and studied the dento-maxillary system of a male patient, aged 27 years. Using a Carestream CS 8200 3D CT scanner, a set of images was obtained by scanning the cranial area and the upper cervical spine. The InVesalius program dedicated to scientific research was used to obtain a primary geometry. This program uses for reconstructive transformation in 3D geometries of different tissues based on different shades of gray. Figure 1 shows the interface of this program after loading the CT images, choosing the type of tissue analyzed (in this case - Bone) and transforming it into a primary three-dimensional model, based on surfaces [4–8].

In order to carry out a study based on the finite element method, it is necessary to obtain a model consisting of virtual solids. For this reason, this primary model has undergone various computational operations. In a first stage, this model, in.stl format, contained a so-called "point cloud" similar to the models obtained by three-dimensional scanning. For this reason, the primary model was loaded into the Geomagic program, specific to reverse engineering. Figure 2 shows this model loaded in Geomagic [9–12].

By loading into Geomagic, the model was automatically transformed from a "point cloud" into elementary space triangular surfaces. The number of these surfaces was 2,014,637 in this initial phase. Because I was interested in analyzing the behavior of a
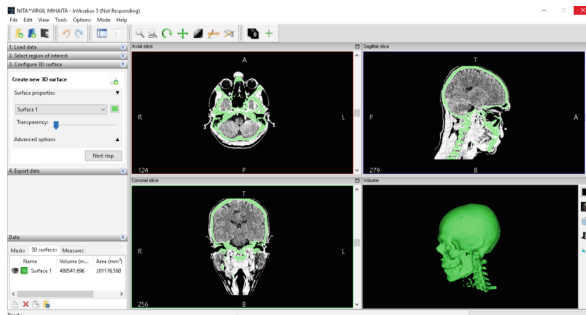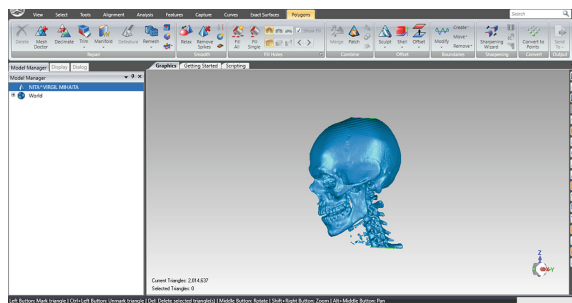

Fig. 1. CT images uploaded to InVesalius.

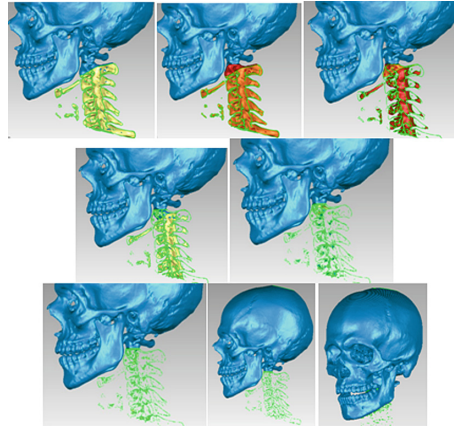**Fig. 2.** The studied model loaded in Geomagic.

Fig. 3. Stages of removal of the vertebrae of the cervical spine.
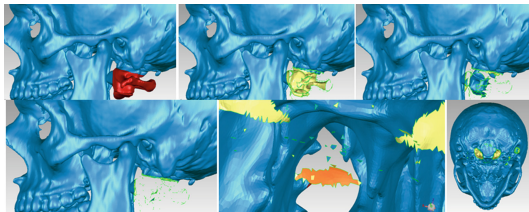

Fig. 4. Surface removal operations.

dentomaxillary system, the components of the upper cervical spine were removed in the next steps [13–16]. Elimination was done in several stages using direct lasso selection. The stages of removal of the vertebrae of the cervical spine are shown in Fig. 3. Through these operations, the number of elementary surfaces was reduced to 1,760,881.

Remember, in these initial stages, the model also contains the so-called artifacts. These elements are present in the model, but they do not belong to the real analyzed system. It is due, in particular, to the phenomena of reflexes and refraction of X-rays and which pass through tissues with different densities. Some of these artifacts were removed through the steps presented. Also, for the same reasons, the model contains a series of self-intersecting surfaces, highly creased edges, spikes, small components, small holes and small tunnels. It is more than obvious that these surface defects do not belong to the patient studied [16, 17]. These can be removed and replaced using various reverse engineering techniques. Following the application of these procedures, the number of elementary surfaces has decreased to 1,473,525. Next, the process of removing elements and surfaces that come from artifacts or that are not of interest in the study of the dento-maxillary system was resumed. Figure 4 shows these removal operations.

It is known that the tissues, the human organs are, in fact, continuous closed surfaces. For various reasons, the model also contained open surfaces. By reverse engineering
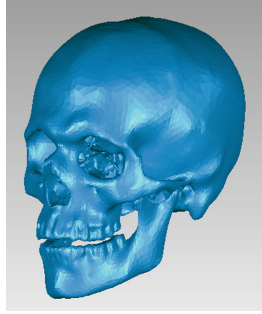
Fig. 5. The model obtained after the decimation process.
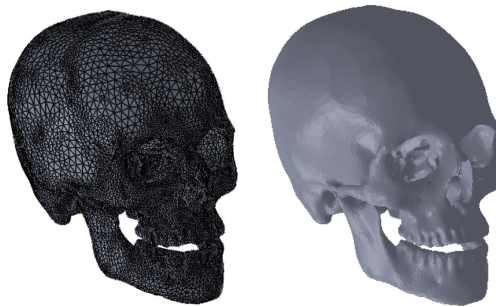

Fig. 6. The final model imported into SolidWorks (two spatial views using two visualization techniques).

filling techniques, the entire model was transformed into a closed surfaces, using the Fill All command [5–8]. The model has also undergone operations to reduce the number of elementary triangular surfaces, because if it exceeds 150,000 surfaces, a closed surface can no longer be transformed into a virtual solid. Thus, this number was decreased from 1,432,080 to 143,208, and the model became the one shown in Fig. 5.

The model has also undergone "finishing" operations, but also the removal of non-compliant surfaces. Finally, in Geomagic, the model had 109,154 elementary triangular surfaces and was exported to SolidWorks where it was automatically transformed into a virtual solid, as shown in Fig. 6.

However, this model contains, as geometry, both the bone structure (jaw and mandible) and the dentition having different material characteristics. For this reason, we had to somehow separate the dentition from the bone components. Thus, we returned to the InVesalius program and uploaded, again, the CT images of the analyzed patient. In this situation, it was intended to obtain only the patient's dentition. Thus, the Enamel option was used and the situation shown in Fig. 7 was obtained.

Obviously, the "point cloud" obtained in.stl format was exported to Geomagic. Figure 8 shows this model in the primary situation.

The model also includes structures with a density similar to Enamel geometries that need to be removed. In order for the model to be as close as possible to the reality given
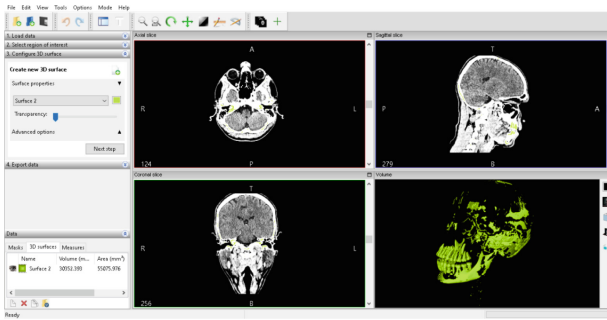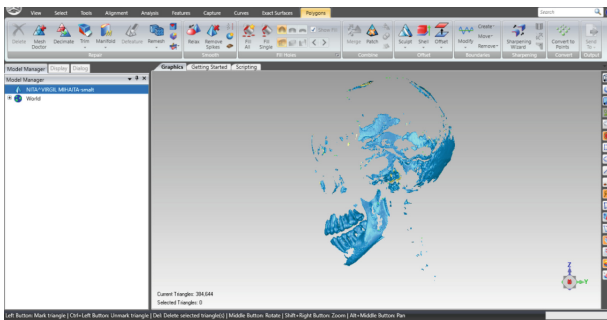
Fig. 7. InVesalius interface for Enamel filter.

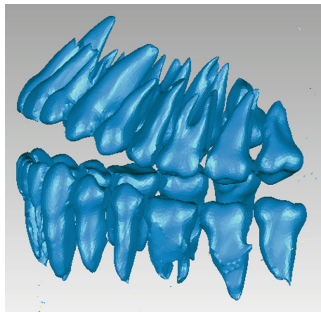**Fig. 8.** Model of Enamel type structures in Geomagic.

Fig. 9. Dental model after removal of non-conforming surfaces.

by the patient studied, the models of the teeth had to be separated. This model was corrected by removing non-compliant surfaces using the Doctor Mesh command and the model had 107,540 elementary triangular surfaces at that time, as shown in Fig. 9.

Having, at that time, a geometrically correct model, it was exported to SolidWorks where it was automatically transformed into a virtual solid. This model contains many artifacts that does not exist in reality. In the manager tree, located to the right of the screen,
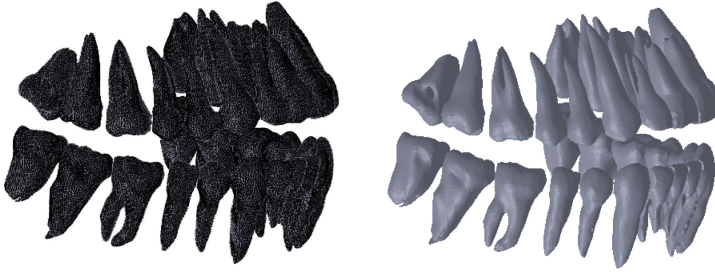
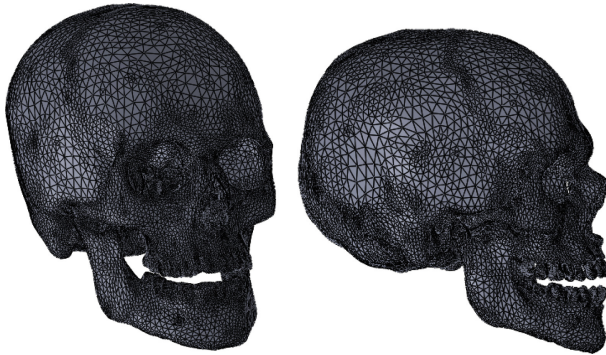**Fig. 10.** The dentition model in two visualization variants.

Fig.11. Model obtained after assembly operations.

these artifact solids can be identified. These artifacts were identified and removed one by one, so that the model became geometrically correct, as shown in Fig. 10.

Using CAD techniques, from the model obtained for the bone system, the two main bone components were detached, in turn: the jaw and the mandible. These components keep the same global coordinate system. Similarly, the two dental systems corresponding to the jaw and mandible were obtained. Also, these structures keep the same common coordinate system. In order to obtain a complete and correct model, based on the common coordinate systems, the four independent models were loaded into the Assembly module of SolidWorks. At that moment, when the three planes that are related to the common coordinate systems, were used for the correct assembly of the four models, by imposing conditions of coincidence. After these operations, the model shown in Fig. 11 was obtained. This model is not geometrically correct, because there are interference solids in the area of the dental roots.

These interference solids were removed using the Cavity jaw and mandible command. These operations led to the formation of dental alveoli, and the final model is shown in Fig. 12.
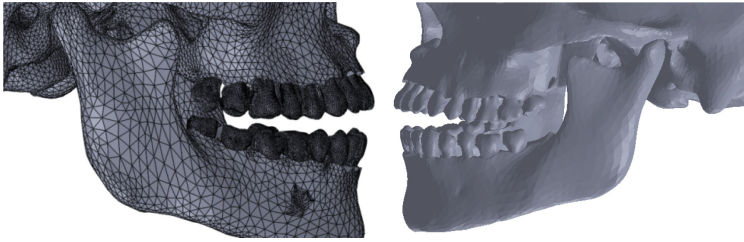
Fig. 12. The final model of the personalized dento-maxillary apparatus (two spatial views with two visual variants.

3   Conclusions

This paper presents the steps of obtaining a personalized model of an analyzed patient. This patient underwent a tomography operation, and the images obtained were used to obtain a geometrically correct dento-maxillary system.

This model can be used to develop kinematic simulations to identify the kinematic and kinetostatic parameters of the analyzed system when it is subjected to classical movements such as raising the jaw, lowering the jaw, lateral movement, but also other compound movements.

Different implantation or prosthesis components can be added to this system and the kinematic behavior can be analyzed, as well as the loading and different simulations can be made using the finite element method.

On this system you can study different normal, pathological, pre-surgical or post-surgical situations and you can simulate different cases and situations encountered in dentistry. The model can be completed with the complete structure of the teeth, taking into account that they are composed of enamel, dentin and soft tissue (dental pulp). Dental ligaments can also be shaped in the dental alveoli.

The paper demonstrates that complex analyzes can be performed on custom models that come from tomographic images and can be considered to be almost identical to reality models.

References

1. Mercut, V., Popescu, S.M., Scrieciu, M., Amărăscu, M.O., Vătu, M., Diaconu O.A., Osiac, E., Ghelase, S.M.: Optical coherence tomography applications in tooth wear diagnosis. Rom J Morphol Embryol 58(1), 99-106 (2017).
2. Petrescu, S.M.S., Țuculină, M.J., Osiac, E., Camen, A., Sălan, A.I., Mărășescu, F.I., Nicola, A.G., Bechir, E.S., Dascălu, I.T.: Use of optical coherence tomography in orthodontics. Experimental and therapeutic medicine 22(1424), 1-7 (2021).
3. Popa, D.L., Buciu, G., Calin, D.C., Popkonstantinović, B., Poenaru, F.: CAD, CAE and rapid prototyping methods applied in long bones orthopaedics. FME Transactions 47(2), 279-286 (2019).
4. Popa, D.L., Poenaru, F., Gherghina, G., Tutunea, D., Popkonstantinovic, B.: New CAD Techniques Used for Virtual Bone Models Applied in Orthopedics. Journal of Industrial Design and Engineering Graphics 12(1), 133-136 (2017).

5. Vatu, M., Vintilă, D., Popa, D.L., Mercuț, R., Popescu, S.M., Vintila, G.: Simulations Using Finite Element Method Made on a Personalized Dental System. Advanced Engineering Forum 34, 175-182 (2019).
6. Vatu, M., Vintilă, D., Popa, D.L., Mercuț, R., Popescu, S.M., Vintila, G.: Determining Mechanical Causes that Produce Dental Wear Using Finite Element Method. Applied Mechanics and Materials 896, 15-22 (2020).
7. Popa, D.L., Duță, A., Tutunea, D., Gherghina, G., Buciu, G., Calin, D.C.: Virtual Methods Applied to Human Bones and Joints Re-Construction Used for Orthopedic Systems. Applied Mechanics and Materials 822, 160-165 (2016).
8. Tarnita, D., Tarnita, D.N., Bizdoaca, N., Popa, D., Tarnita, C.E., Cismaru, F.: Modular orthopedic devices based on shape memory alloys. SYROM 2009, 709-721 (2010).
9. Tarnita, D., Tarnita, D.N., Popa, D., Grecu, D., Tarnita, R.: The Method of Finite Element applied to the study of stress distribution of tibia. Biomaterials and Biomechanics: Fundamentals and Clinical Applications, Essen, Germany (2005).
10. Vatu, M., Vintila, D., Mercut, R., Popescu, S.M., Popa, D.L., Petrovici, I.L., Vintila, G., Pitru, A.: Three-dimensional modeling of the dental-maxillary system. Journal of Industrial Design and Engineering Graphics 14(1), 207-210 (2019).
11. Tarnita, D., Boborelu, C., Popa, D., Tarnita, D.N.: Design and Finite Element Analysis of a New Spherical Prosthesis-Elbow Joint Assembly. New Advances in Mechanism and Machine Science, 127-135 (2018).
12. Calin, D., Tarniță, D., Popa, D., Calafeteanu, D., Tarnita, D.N.: Virtual model and simulation of the normal and affected human hip joint. Applied Mechanics and Materials 823, 167-172 (2016).
13. Calin, D.C., Popa, D.L., Grecu, A.F.: Virtual Experimental Analyzes of the Normal and Arthrotic Hip. Applied Mechanics and Materials 896, 3-14 (2020).
14. Tarnita, D., Popa, D., Tarnita, D.N., Bizdoaca, N.G.: Considerations on the dynamic simulation of the 3D model of the human knee joint. BIO Materialien Interdisciplinary/ournal of Functional Materials, Biomechanics and Tissue Engineering 231, (2006).
15. Petrovici, I.L., Tenovici, M.C., Vaduva, R.C., Tarnita, D.N., Vintila, G., Popa, D.L.: About Three-Dimensional Models of Osteosynthesis Systems. Journal of Industrial Design and Engineering Graphics 14(1), 159-162 (2019).
16. Tarnita, D., Popa, D., Boborelu, C., Dumitru, N., Calafeteanu, D., Tarnita, D.N.: Experimental bench used to test human elbow endoprosthesis. New Trends in Mechanism and Machine Science, 669-677 (2015).
17. Ciunel, S., Popa, D.L., Dumitru, N.: Studies about Movement Biofidelity of a Dummy Neck Used in an Impact Testing Device. Applied Mechanics and Materials 371, 539-543 (2013).