

# Three-Dimensional Model of the Human Eye Development based on Computer Tomograph Images

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**ABSTRACT:** Introduction. The objective of this study was to obtain a virtual biomechanical three dimensional model of the human eye through a multidisciplinary collaboration between researchers in various medical and informational fields in order to reach a better understanding of the optical performance of the healthy and diseased eye. Material and Method. In order to obtain the virtual model, we analyzed the CT and MRI images of six patients, aged between 21 and 80 years old, dating from February 2013 until January 2019. These scans totaled 4226 images. We selected to use for the construction of the model the CT images of a male patient of 54 years old. In Vesalius and Geomagic for SolidWorks programs were used. Results. Based on the CT images analysis and using the above mentioned programs, we created a virtual model of the human skull in which the orbit is located, including the eye globe and the extraocular muscles. The SolidWorks virtual model allows the attachment of materials with real properties of the eye tissues. This model can be used in various simulations for the healthy and diseased eye. Conclusions. The biomechanical eye model of the eye was created based on a "in vivo" eye model. As the SolidWorks format enables using materials with identical properties to those of the human eyeball, this virtual model can provide very realistic eye simulations.

**KEYWORDS:** Virtual Eye Model, InVesalius, SolidWorks, Geomagic.

## Introduction

Developing a virtual 3D eye model was made possible through interdisciplinary collaboration between researchers in various medical and informational fields in order to reach a better understanding of the optical performance of the healthy and diseased eye.

Using the same model, pathological, surgical or post-surgical conditions may be analyzed or it may be used to simulate parameters of eyes with different types of implants, in order to characterize the refractive elements used (IOL, contact lenses).

Three dimensional virtual models similar to the one proposed in this study have been applied in other fields of medicine, computer reconstructions of the dento-maxillary system [1], elbow [2] and knee joint [3] being reported. In the medical literature there are described 3D virtual eye models used for educational and training purposes [4], for the analysis of the eye performance in various disorders [5,6].

In order to properly understand the eye function under normal and pathological

condition, it is important to know the optical and anatomical properties of all the structures that form the human eye, as well as the morphology and physiology [7,8,9].

To obtain an accurate simulation model of the human eye function under normal and pathological conditions, we began by modeling the main components of this biomechanical system, designing their 3D geometry.

For this purpose, we divided the visual system in two main sections: intraocular structures, which included the eyeball composed of the cornea, the sclera, the lens, the ciliary body, the vitreous body and the retina, and extra ocular structures, which represented the bony cavity of the orbit and the six extra ocular muscles: the superior, inferior, medial and lateral rectus muscles, together with the superior and inferior oblique muscles which enable the complex eye movements.

## Material and Method

In order to obtain the virtual model, we analyzed the CT and MRI images of six patients, aged between 21 and 80 years old, dating from

February 2013 until January 2019. These scans totalized 4226 images. The scans were performed at the Emergency County Hospital Craiova using a Emotion 16 (Siemens) equipment consisting of a magnetic resonance and a computer tomography device. After the scan analysis, we selected to use for the reconstruction of the model CT images of a male patient of 54 years old, as the other scans had pathological changes.

The images were imported in InVesalius 3.0 version, a free and open source software, which was used to convert the tomography tissues into three-dimensional geometry, performing the segmentation of the interest region. InVesalius is a medical imaging program for 3D reconstruction, using DICOM 2D image

file sequences obtained with CT or MRI scanners. It allows the export of volumes or 3D surfaces as STL files in order to create the accurate anatomical model of the analyzed region, using three-dimensional scanning. This software is supported by several medical organizations and the Brazilian Ministry of Health. The STL format information was further processed using Geomagic for SolidWork.

## Results

### Three-dimensional modeling of the human eye bone contour

The orbit model was designed using the CT scans of a 54 years old male patient as seen in Figure 1.

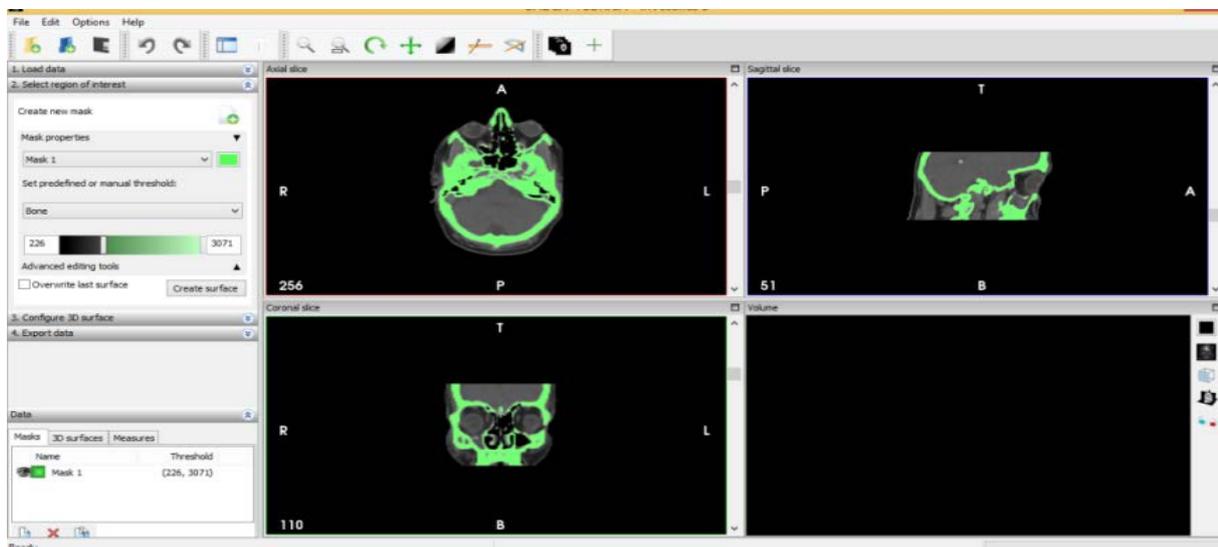


Figure 1. CT scans of a 54 years old male patient.

To acquire the bone geometry, we started by achieving a surface type geometry in STL format (Figure 2).

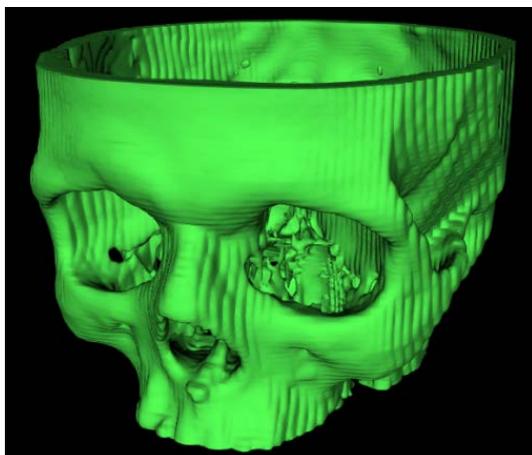
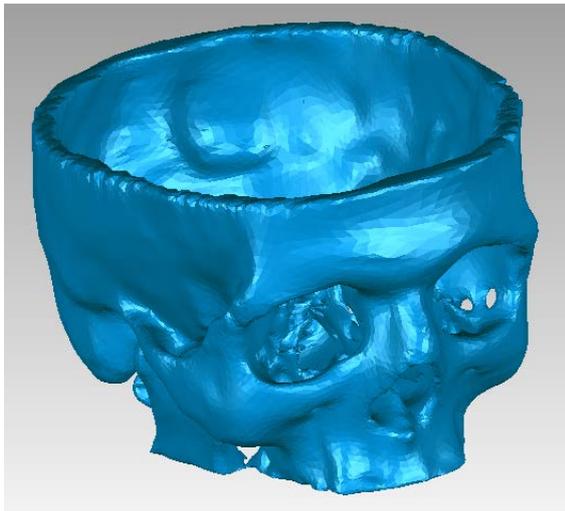


Figure 2. Primary geometry obtained in InVesalius.

This geometry has been processed through certain simplifying software techniques, first obtaining a “point dot” data sequence, which was transformed into triangular surfaces, then into a closed surface, finally forming a virtual solid.

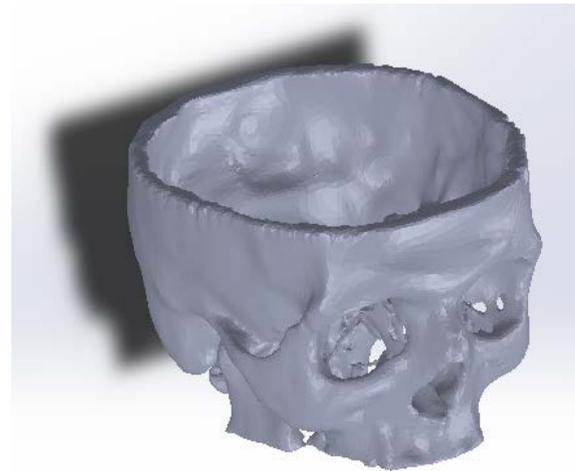
In order to achieve the optimal geometrical properties, we imported the 3D STL formats into Geomagic for SolidWorks program.

The STL format model was automatically transformed into a 3D surface, initially containing 657.768 small triangular surfaces. In the next step, using a decimation algorithm we manage to decrease the initial triangular surfaces number, obtaining a mesh. We perfected the model by aligning the surfaces, correcting the imperfections and excluding the regions that deviated from the desired surface, developing a more accurate model which underwent finishing detailing (Figure 3).



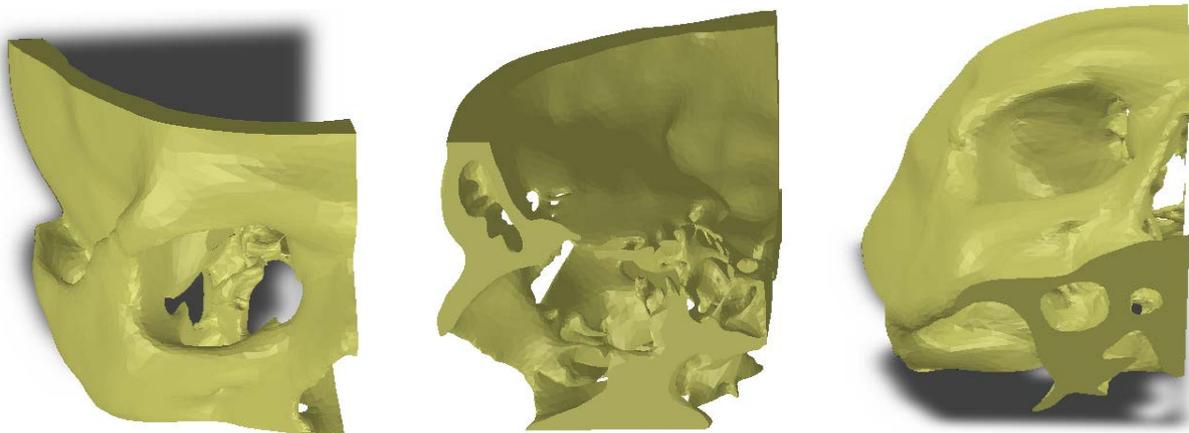
**Figure 3. Geomagic closed surface model.**

This version of the model, containing 125.924 triangular surfaces, was exported in SolidWorks and converted into a solid virtual (Figure 4).



**Figure 4. Solid virtual bone component model imported from SolidWorks.**

As one of our purposes was to create a kinematic of the human eye movements, the initial model has undergone some virtual cutting techniques, in order not to emphasize the interior structures of the eye, but to characterize the eyeball behaviour as a whole as far as movements are concerned. The final bone structure model is depicted in Figure 5.



**Figure 5. Bone Component Model after virtual cutting techniques.**

### **Three dimensional modeling of the intraocular structures**

The outer layer of the eyeball is formed by the cornea and the sclera, with the main purpose of protecting the internal structures. The cornea represents an avascular, transparent structure and the sclera is an opaque, fibrous, protective tissue. Geometrically, the outer layer of the eye has the appearance of two joined spherical surfaces. The cornea represents the smaller, anterior, transparent sphere with a mean radius of curvature of 8mm, the larger, opaque sphere with a mean radius of curvature of 12mm, being

the sclera. An important issue in this stage of our study was to determinate the accurate curvature of these two spheres, to extract the correct contours and to maintain their position and ratio relationship intact, in order to develop a reliable geometrical model. Similar models were obtained by Vanathi in 2018 [10], Stitzel in 2002 [11] and by Weaver in 2012 [12].

We imported the selected CT scans in the InVesalius program, where the Skin setting was used, enabling us to select the corresponding tissue geometry (Figure 6).

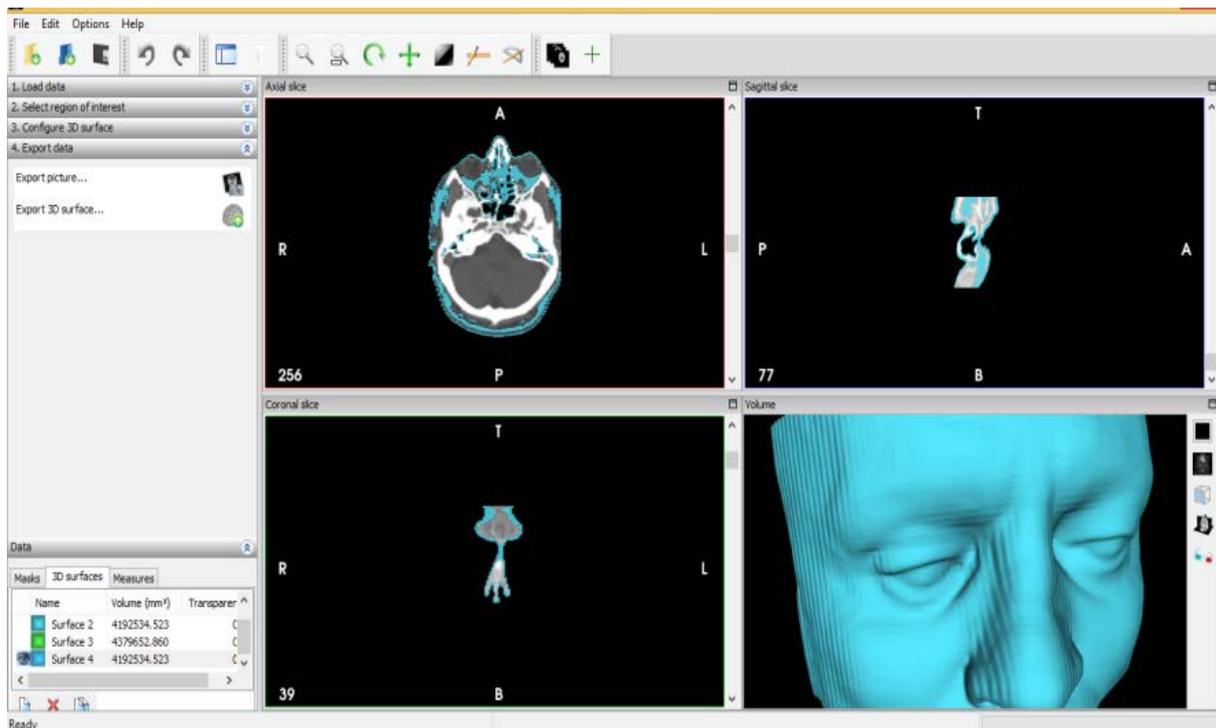


Figure 6. Types of tissues available in InVesalius.

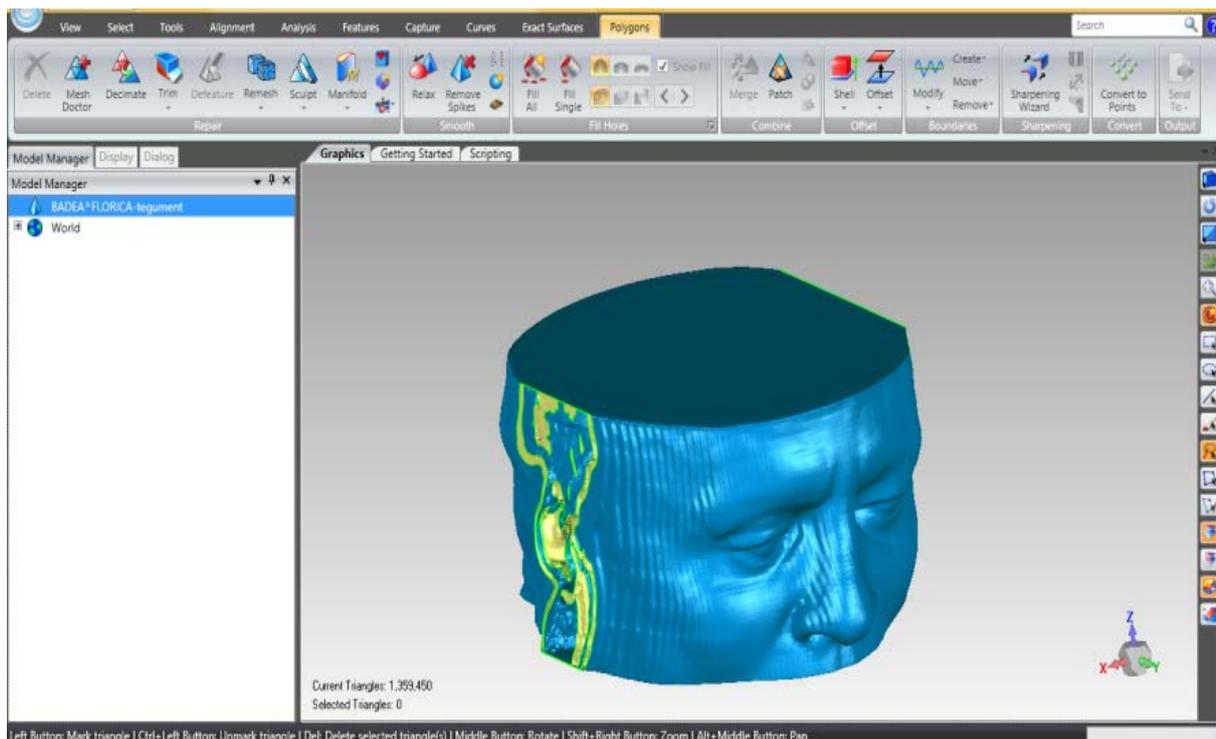
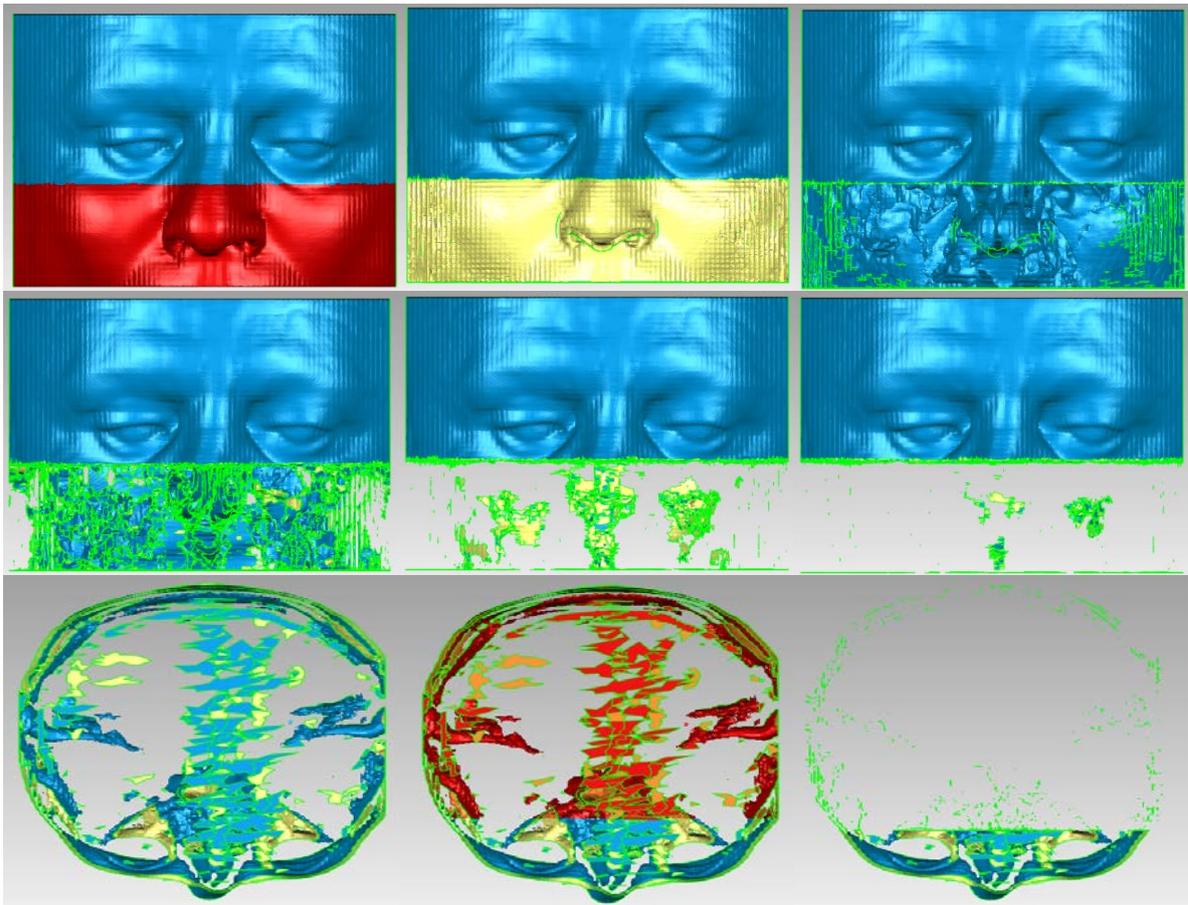


Figure 7. Skin Geometry input in Geomagic program.

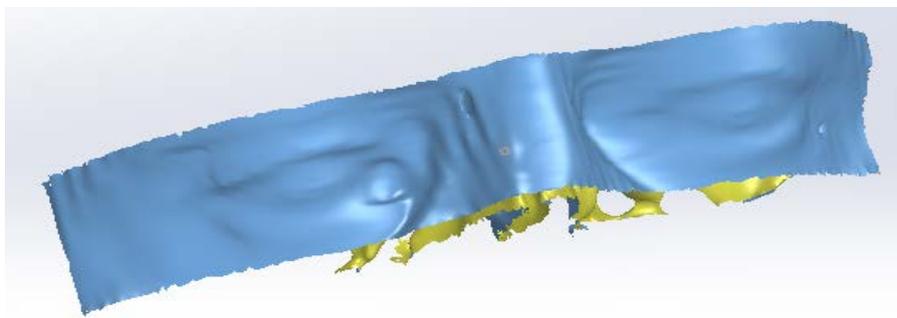
At this point, in order to identify and calculate the intraocular structures parameters, we exported the STL geometry into Geomagic program (Figure 7).

As in the this certain stage of our research only the intraocular structures are concerned, we

choose to base our analyze on the outer layer of the eyeball reconstruction, simplifying the model and demarcating the initial point cloud. Several sequences of this process are shown in Figure 8.



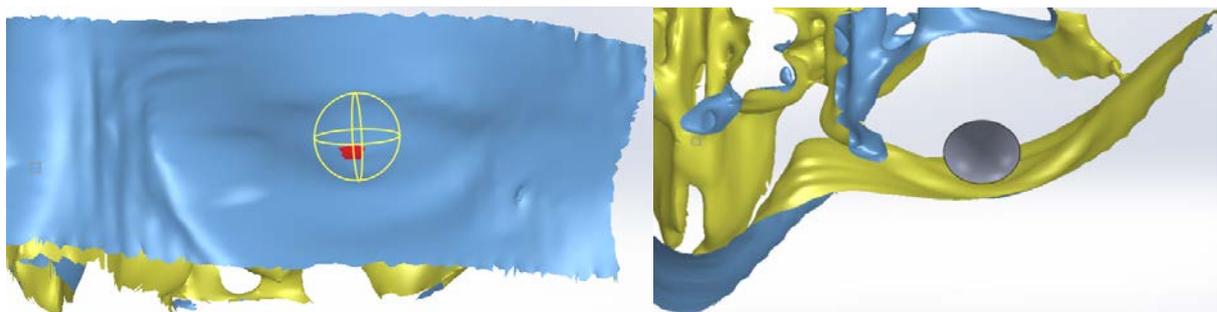
**Figure 8. Simplifying steps of the model.**



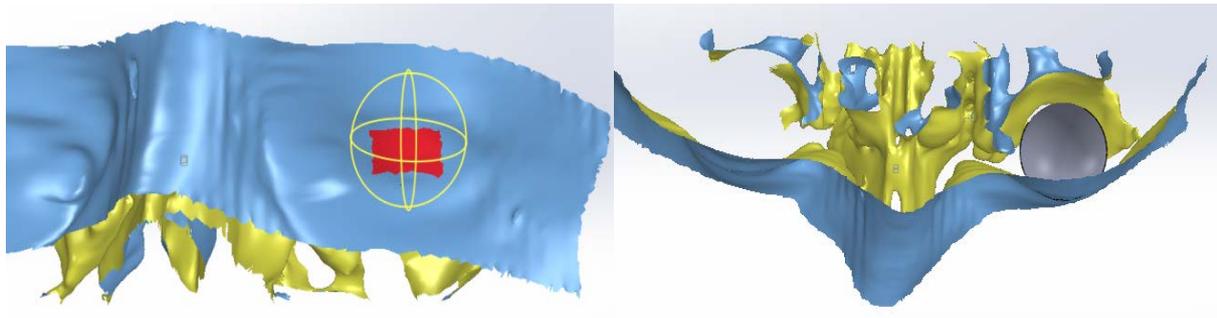
**Figure 9. SolidWorks model.**

After this, we continued by importing the model into Solid Works and implementing an identification process (Figure 9).

Geomagic for SolidWorks has a feature for identifying and generating spherical surfaces, allowing us to reconstruct the corneal (Figure 10) and the scleral (Figure 11) surfaces.



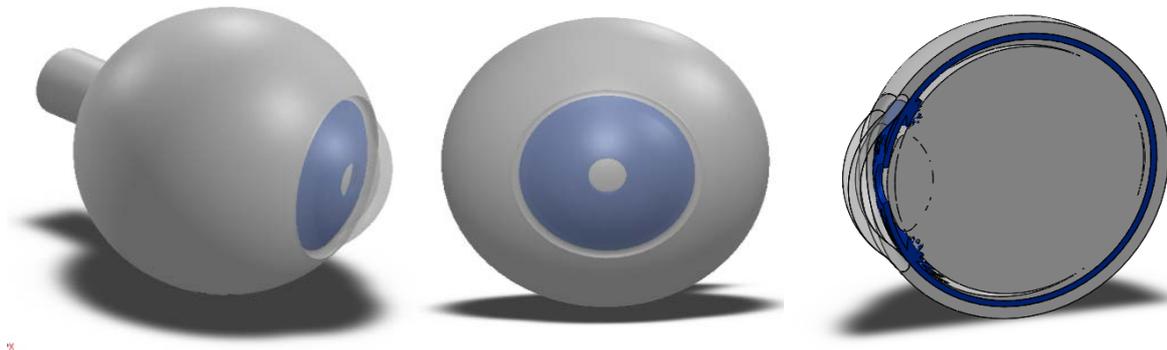
**Figure 10. Corneal surface identification.**



**Figure 11. Scleral surface identification.**

Furthermore, using modeling tools, we refined and optimized the ocular structural

parameters, finally designing the virtual model shown in Figure 12.

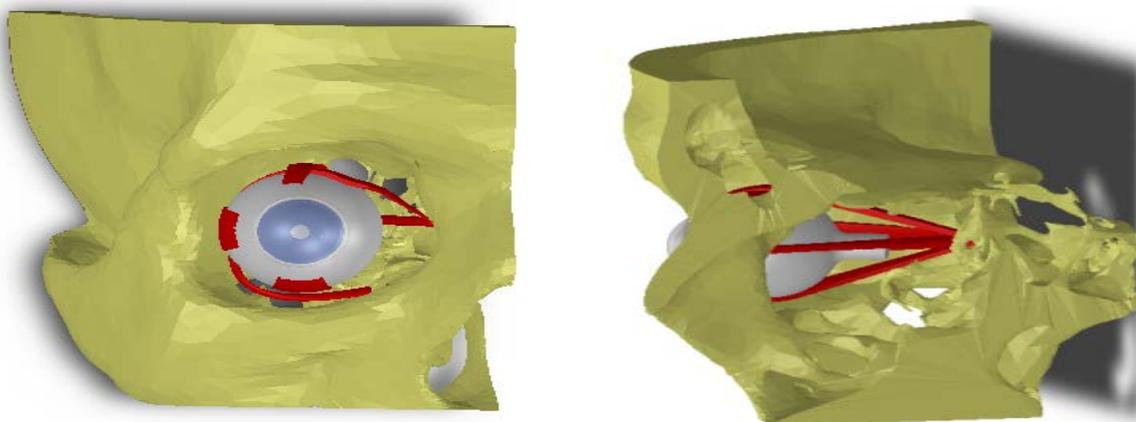


**Figure 12. Human eye final model.**

The two finite elements of the biomechanical system of the eye were loaded in the Assembly module of SolidWorks, positioning them according to the analyzed CT scans and previous anatomy studies.

Regarding the extraocular muscle, we used anatomical and biomechanical information

correlated with the contours acquired from the images used in the research, in order to generate our schematic model of the muscles involved in the ocular movements: superior rectus, inferior rectus, medial rectus, lateral rectus, superior oblique, inferior oblique (Figure 13).



**Figure 13. Complete biomechanical ocular model.**

Our designed model can be used to recreate kinematical simulation of the eyeball movements or dynamic simulation under normal or pathological conditions, as well as to

highlight the location and the amplitude of von Mises stress and strain in the ocular globe with the aid of the Finite Element Analysis.

## Discussions

The aim of this study was to obtain a virtual biomechanical model of the eye that can be used in kinematic simulations or finite element analysis simulations in healthy or diseased eye. The development of this virtual biomechanical model of the human eye is based on “*in vivo*” assessments of anatomical features as well as CT imaging of some patients, obtained by the CT Scan technique. This imaging technique uses X-rays measurements which are taken from different angles, in order to scan the internal structures of the human body and obtain a detailed, cross-sectional image.

The device consist of two components: the X-ray scanner and a controlling computer that processes the acquired data, creating the images and cross-sections of the scanned organs.

The CT scanner enable us to record DicomWorks format images, a specialized medical imaging and management software. Another important feature of the program is the storage of additional data regarding acquisition such as the planning of the scan and the date and time of creation. Similar methods of images acquisition were used in the development of other virtual models [1,13-17].

Using the graphic data provided by the tomographic images, we reconstructed a three-dimensional optimized model with a wide range of applications, such as virtual simulation and teaching purposes. Our model allows analyzing various normal, pathological, pre or post-operative conditions. We analyzed the CT and MRI images of six patients, aged between 21 and 80 years old, scans that totalized 4226 images. We selected to use for the construction of the model the CT images of a male patient of 54 years old.

We reconstructed the skull bone components from tomography images using the InVesalius program [18] software which can generate three-dimensional reconstruction based on DICOM 2D sequences acquired from CT and MRI equipment.

In the present study, STL type geometry of the bone component was initially obtained using InVesalius 3.0, which was then imported into the Geomagic for SolidWorks program.

The Geomagic program is the industry's most comprehensive software for Reverse Engineering, which combines CAD with 3D scanning data so that it can build solid models based on features that are compatible with its own CAD software. Geomagic Design X (Geomagic, 3D Systems USA) is designed to

convert 3D scanning data into high-quality CAD models [19-21].

The SolidWorks program uses the generating solid bodies method, allowing to incorporate material features in their structure and is one of the most commonly used modeling techniques for 3D models. The software uses a 2D drawing contour, from which the base building block is generated. This SolidWorks format has multiple applications in medicine because virtual models can be generated with the actual properties of the respective materials (density, elasticity, Poisson's coefficient) allowing us to observe the behavior of these virtual models in various normal or pathological conditions [22,23].

Parameters analysis of the virtual eye model can enable new breakthroughs in other areas such as robotics and other medical sciences.

Using the kinematic, dynamic simulation program and the finite element method, we are able to acquire static or dynamic results with great precision, similar to real life conditions. Similar patterns and analyzes have been developed on other virtual models of some human body components [13,24-28].

## Conclusions

We proposed a methodology to develop a three dimensional virtual eye model, using CT images obtained from a healthy 54 years old male patient.

Several programs were used in our research process: InVesalius which enabled CT images conversion into STL and Geomagic that made possible the transfer of STL data format into SolidWorks format.

We constructed models of the bony orbit, extraocular muscle and ocular globe, maintaining their position and ratio relationship intact, in order to develop a reliable geometrical model.

Our model has a wide range of application in the biomechanics and allows various simulation of the human eye movements.

Future work will focus on orbital mechanics, analyzing the local strain-stress effect on the ocular globe surface.

## Conflict of interests

None to declare.

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