CREATION OF A BIOMECHANICAL 3D MODEL OF THE OCULAR BULB USING THE FINITE ELEMENT METHOD (FEM)

Tatiana T. Velloso, tatyterenzi@hotmail.com
Escola de Medicina, Universidade Federal de Minas Gerais, Minas Gerais (MG), Brasil

Nathalia C. F. Menezes, nathalicarol@hotmail.com
Daniel N. Rocha, daniel_neves_rocha@hotmail.com
Marcos Pinotti, pinotti@demec.ufmg.br
Escola de Engenharia, Universidade Federal de Minas Gerais, Minas Gerais (MG), Brasil

Abstract. *In the field of medicine and bioengineering, actual anatomical images are used for the construction of computational models in 3D, with the purpose of conducting biomechanical analysis of the human body. The simulation of the eye biomechanical function and its structures is of great medical importance and the need of building computational biomechanical models in Ophthalmology is growing, especially for eye disorders studies, such as dyslexia, and for ophthalmic chirurgical planning. The aim of this work was to create the eyeball and its six extrinsic muscles geometry 3D computational model to perform biomechanical analysis using the finite element method (FEM). To construct the eyeball and its extrinsic muscles model, were used anatomical cross sections cadavers images (made at intervals of 0.3 mm) provided by Visible Human Project ® program. These images were imported into the software Solid Works ® in which they were bounded by polynomial interpolation curves and placed on parallel planes, thus creating the geometric model. Once created, the eye model was imported into the software ABAQUS® and finite element solid meshes were generated . The obtained eyeball, its extrinsic musclesand fat tissue model has geometry very similar to the real eye structures. Biomechanical simulations were performed and the results demonstrated that this 3D computational model can be used in biomechanical analysis of the eye for the its disorders study, chirurgical planning and other scientific and medical analysis.*

Keywords*: finite element method, biomechanical model 3D, eye study.*

1. INTRODUCTION

The use of computational methods for solving biodynamic models has increased along with computing technological advances, allowing greater scope in the types of analysis performed. This feature has a special importance in bioengineering since it avoids humans being exposed to more complex tests or greater health risks (Ferreira *et* Duarte, 2010). 3D reconstructions of the human body were first developed in the 70s for ergonomics tests performed in automotive and aeronautics. Human body 3D models obtained nowadays are quite realistic and constitute a topic of great interest to practical use in many areas such as virtual reality, manufacturing, design or biomedical applications (Azevedo *et al.*, 2007). In the field of medicine and bioengineering, actual anatomical images are used in construction of 3D computational models with the purpose of conducting biomechanical analysis of the human body. From this analysis, students and researchers can conduct simulations of surgery procedures, thus preventing the use of human patients. The use of Finite Element Methods (FEM) has been an evolution in creating models for biomechanical analysis of human body. This method is a mathematical analysis which consists in the discretization of a continue media in small parts while maintaining the same original media properties. The simulation of the eye and the biomechanical functioning of its structures, from a model constructed using real images and MEF, is of great medical importance and the necessity for preparing this type of model in ophthalmology is increasing, mainly for eye disorders studies, such as dyslexia, and for ophthalmic chirurgical planning, thus the final results and possible chirurgical complications can be expected during the simulation. The aim of this work was to create the 3D computational models of the eyeball, the extrinsic muscles and fat tissue from real images, in order to perform biomechanical analysis using the Finite Element Method (FEM), employing a methodology already adopted by the Bioengineering Laboratory, UFMG-LABBIO, in the construction of other biomechanical models such as the hand, joint elbow and coronary arteries.

2. METHODOLOGY

Some authors use imaging tests such as computed tomography (CT) and magnetic resonance imaging (MRI) to identify the geometry that would be used in the 3D modeling creation (ALEXANDRE *et al.*, 2006;PIMENTA *et al.*, 2006). This work has used real images from cadavers transversal sections “Fig. 1” provided by the Visible Human Project ® through a license agreement approved between the Department of Mechanical Engineering (DEMEC), Federal University of Minas Gerais (UFMG) and the National Library of Medicine (The Visible Human Project, 2009).

Figure 1. Image acquired from the Visible Human Project

The methodology was developed by LABBIO and has been used to create other biomechanical models. The process of creating the eyeball and the extrinsic muscles biomechanical model consisted of three main steps: the geometries identification, the 3D model creation and the finite element model creation

2.1. Geometries Identification

The geometries represented in the built model were the eyeball, crystalline lens and the extrinsic muscles (medial rectus, lateral rectus, inferior rectus, superior rectus, inferior oblique and superior oblique). "Figure 2" shows the ocular muscles and the extrinsic muscle.

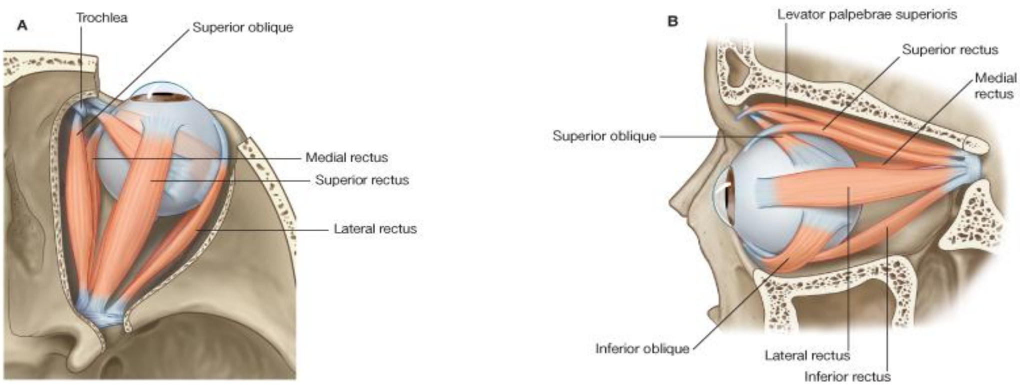

Figure 2. Eyeball and extrinsic muscles (Drake *et al.*, 2011)

The anatomical structures were identified and delimited by points on the images provided. The process of identifying the geometry is very complex and requires advanced anatomy knowledge; "Fig. 3" shows the performed delimitation details. The eyeball was identified with green dots, crystalline with light pink dots and the extrinsic muscles with blue dots.

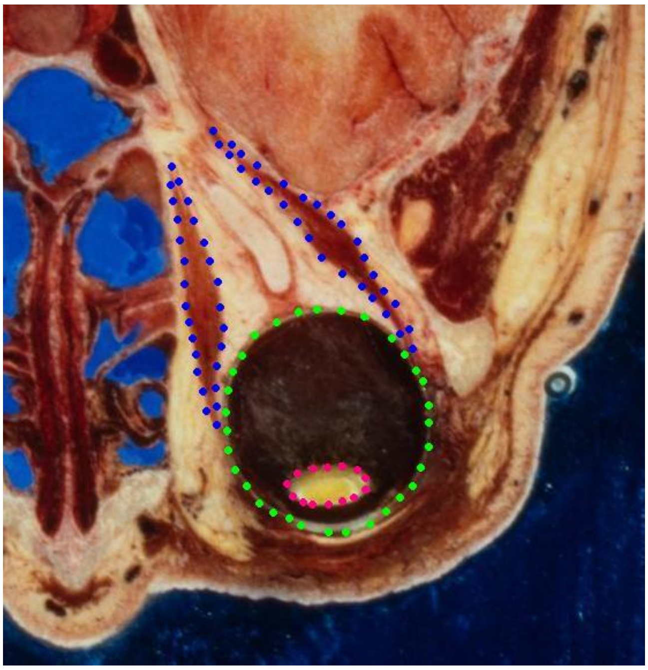

Figure 3. Geometries identification

2.2. Creating the 3D model

To create the 3D model, the marked images were imported into SolidWorks® and subsequently were placed on parallel planes. Polynomial interpolation curves were then created to unite the points previously marked, thus generating the ocular and extrinsic muscles representative profile. “Figure 4” shows the structures obtained from the plotted curves, after being removed the original images.

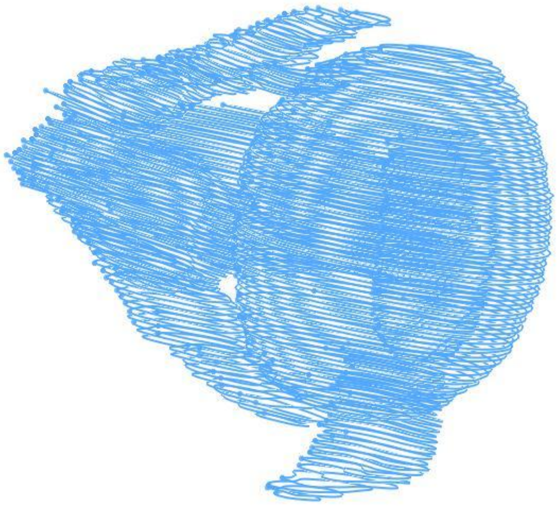

Figure 4. Structures obtained from the plotted curves

After the creation of the representative structures curves, many features of SolidWorks® were used for the union of these curves and the construction of 3D geometric solid “Fig. 5”.The same process was used in the construction of the fat tissue geometry.

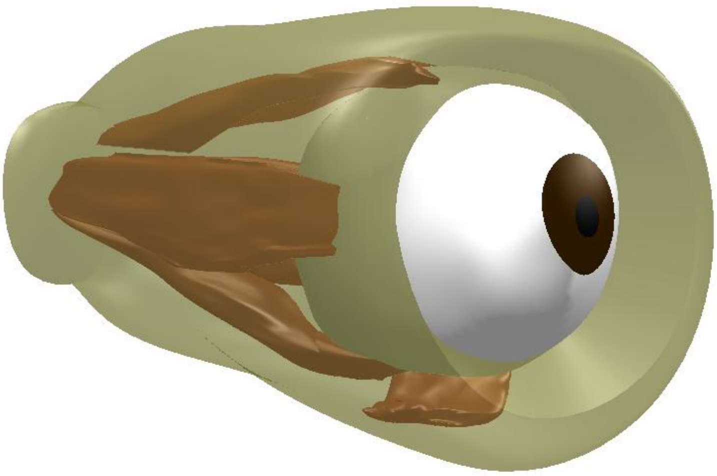

Figure 5. 3D geometric solid

2.3. The finite element model creation

To create the finite element model, the 3D solid created in SolidWorks® was imported into Abaqus® in which was conducted a discretization of the model, generating a mesh of finite elements. “Figure 6” shows the geometries mesh. The 3D mesh were created using solid element tetrahedral (C3D4).

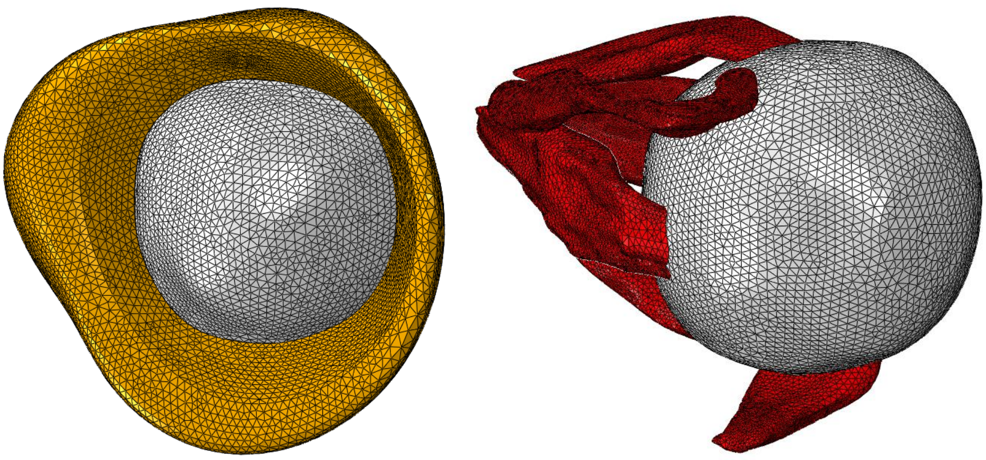

Figure 6. Geometries mesh

Linear mechanical properties were applied in the geometries, Young’s modulus (E) and Poisson’s ratio (ρ), from the representative tissue. The Young’s modulus used for fat tissue, muscles and eye were 1 kPa, 40kPa and 500kPa respectively. The Poisson’s ratio for every tissue were the same with value of 0, 48 (SCHUTTE *et al*. 2006).

3. BIOMECHANICAL SIMULATION

After creating the finite element model, simulations were conducted to evaluate the created model behavior. During the simulation, the external surface of the fat tissue received displacement’s restrictions “Fig. 7”. Posteriorly, a strength of 1 N was applied on the opposite end of the insertion of the rectus muscle with the eyeball, in order to simulate its strength of contraction. The use of 1 N strength is based on the fact that this value is the maximum strength which this muscle can apply (Collins *et al*., 1981).

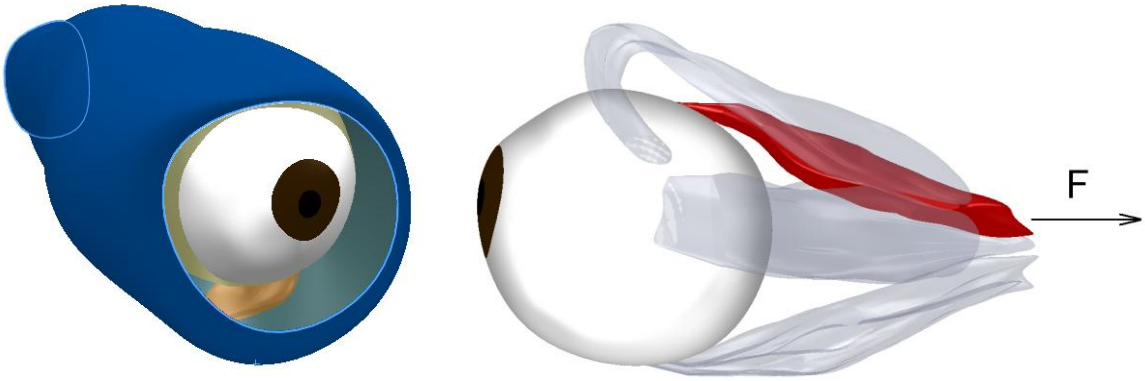

Figure 7. Biomechanical simulation

4. RESULTS

In the biomechanical study performed, the medial rectus muscle movement was achieved, resulting in adduction of the eyeball which is consistent with expectations according to the medical literature. It was possible to verify the rotation of the eyeball, when comparing its original position with the position in the end of the biomechanical simulation "Figs. 8a and 8b". The use of FEM allowed the stress analysis to verify witch tissue is more solicited as well as its part is more solicited "Fig. 8c". In this figure it is possible to identify the region of the rectus muscles close to the eyeball as the region of greater stress. In "Fig. 8b and 8c" the light blue color represents regions of greater stress, the dark blue color represents regions of less stress.

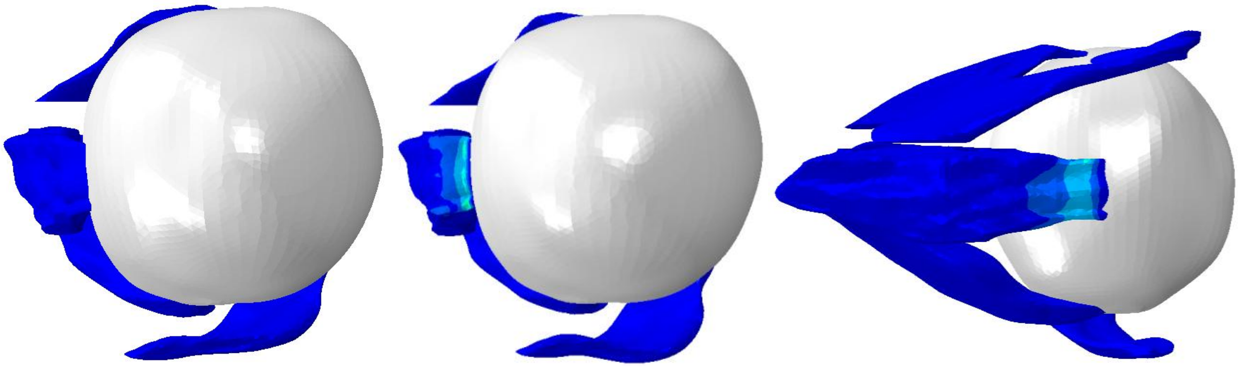

Figure 8 (a,b,c). Results: rotation of the eye ball

5. CONCLUSION

This study demonstrated only one of the possibilities of using the eye biomechanical model, using the FEM and other computational tools. Due to the use of the methodology adopted by LABBIO, based on the use of cadavers and anatomical images, besides engineering softwares, the model obtained on this study presents geometry and biomechanical behavior very similar to the real eye structures. Biomechanical simulations were performed and the results demonstrated that 3D computer model can be used in biomechanical analysis of the eye to its disorders study, chirurgical and other medical and scientific analysis.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE

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