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Artificial eye simulator for gonioscopy

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Abstract: Glaucoma is the second highest cause of world blindness after cataract. It predominantly occurs as open angle followed by angle closure glaucoma. Since it is a silent, chronic disease with no clinical signs at the beginning of illness, it is often undiagnosed and underestimated. Prevention by early screening by gonioscopy has a great potential towards precluding the disease. Producing an additively, manufactured human eye model is a great avenue for gonioscopy training as a substitute to the currently used animal models.

I. Introduction

Glaucoma is a chronic, progressive, heterogeneous optic neuropathy which leads to visual field loss, disabilities and irreversible blindness if not diagnosed and treated at the right time [1]. Globally, 60.5 million people had glaucoma in 2010 and considering the aging of the world's population, this number may increase to approximately 80 million by 2020. It occurs in two main forms- open angle and angle closure glaucoma, latter being an emergency situation [2, 3]. Primary angle closure glaucoma may be diagnosed on routine clinical examination with gonioscopy [3, 4]. This prevents its progression to glaucoma and allows prophylactic laser iridotomy [5]. In this regard, artificial eye models prove helpful to acquire diagnostic and surgical skills [6]. Animal models are widely in use, however, they are accompanied by bioethical issues, dissimilarity from human anatomy and cumbersome preparations [7] . Thus, it is implausible to translate the acquired skills and importance of the procured medical devices into humans [8]. Additively manufactured human eye model appears to be a promising tool to eliminate these issues.

II. Material and methods

The design and production of our eye simulator for gonioscopy is a combination of different mechanical techniques. The whole system consists of two main parts, an electronic barometer and the eye model (Fig.1).

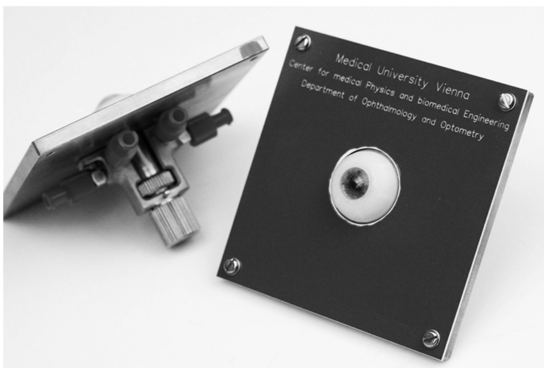

Figure 1: Eye simulator for gonioscopy

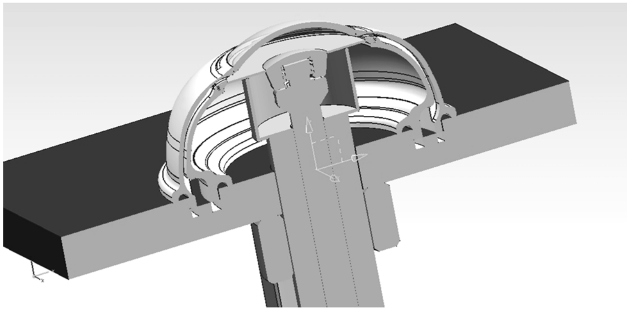

Figure 2: Cross section of the eye simulator

The eye model is based on biometric data [9, 10], which was adopted into the technical design inside the CAD Software (NX5, Siemens PLM Software, Plano TX, USA). The cross section displays the model being an assembly of different parts, replicating sclera, cornea and the iris with the lens (Fig.2). To mimic the human tissue function and properties we used heat cured two-component silicon LSR40 (Applied Silicon, USA) for the iris with the lens. This material has hardness of Shore A 40, Tensile strength of >900 psi, elongation at break of >450%, modulus of elasticity 200% and tear strength of >140 psi [11]. We used a CNC manufactured brass device for molding iris and cornea geometry, followed by heat curing at 100^{o} C for 1 hour. The silicon was meticulously polished manually with a woven cloth for high transparency of the surface. Finally, bulbus with six macro channels were additively manufactured for establishing the fluid connection to the anterior chamber. These channels had a rectangular dimension of 1.3x0.3 mm^2 and a total length of 11.3 mm and were placed inside the sclera with a wall thickness of 1.2 mm. We used our MJM printer Objet Eden350 (Stratasys, Rechovot, Israel) to print the design of the white sclera with the UV-cured material VeroWhitePlus RGD835. After the printout we carefully removed the support material (SUP705) from the sclera model with wooden tooth sticks, tooth brush and waterjet. In the following step, we added a fine cleaning by placing the parts into a 2% NaOH solution and rewash with water. The small channels were cleaned manually with flexible nitinol, and by flushing the channels with a syringe. The flexible and transparent cornea and iris with the lens was built using the same silicon with a polished

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brazen mold to get highly transparent components. In the assembly, the silicon parts were glued together with Loctite 4850 (Henkel, Germany) to form the fluid isolated anterior chamber (AC) and posterior chamber (PC) as well as the hollow vitreous body. Inside the vitreous body we placed the CNC manufactured driving system for the axial and independent positioning of the lens and the elasticity of the ciliary ring with a diameter of 13,8mm. Within the vitreous body (behind the iris) a circular ring, with a diameter of 10,3mm, was inserted to mimic the force of an anteriorly rotated ciliary body on the lens-iris membrane near the peripheral iris insertion. The assembled body was mounted on a base plate, which held the positioning system and the fluid connectors for the two eye chambers.

The dual electronic barometer was built using a calibrated pressure sensor MPXV4006GW7U (Freescale, USA), an amplifier and a digital voltmeter EMV1025S for each pressure channel. The two channels were connected to the two isolated eye chambers to adjust the fluid pressure to simulate the different eye pathologies and camber angle.

III. Results and discussion

The research showed that it was possible to create a functional eye model, which can be used in education and training for dynamic gonioscopy. The eye simulator, which was reproduced in a series of 16 models, allows to simulate different healthy and pathological anatomic configurations of the chamber angle: deep anterior chamber (AC) with widely open angle and straight iris, shallow AC with open angle and straight or convex iris, angle block with convex iris simulating pupil block, angle block without convex iris but with anteriorly pushing ciliary ring to simulate plateau iris, deep AC with concave iris as in pigment dispersion syndrome. These configurations could be achieved by independently changing the axial positions of the lens and the ciliary ring, and independently changing the pressure inside the AC and the PC. The eye simulators were used for wet labs as part of practical gonioscopy training courses

Polyjet technology offered the creation of small structures like fluid channels, which could be integrated into a thin wall without leakage. Similarly, waterproof results were achieved for the glued connection between silicon and the UV-curing material. In total, the success rate to materialize such a design was 87%. However, the models showed some shortcomings for long time usage. The main problem was the long-time stability of the attached silicon cornea on the sclera along the conjunctiva. This circular area was susceptible for leakage based on the mechanical stress during the dynamic gonioscopy. The ongoing activities in this project were concentrated to solve this problem by testing different glues and to test the additional possibilities with the polyjet technology. With our new MJM system Connex3 500 (M3DRES project funded by the Austrian Research Promotion Agency (FFG): Project Nr. 858060) it will be possible to print with different materials and their combinations, which will allow us to build a smooth change of the material properties within an additively manufactured part.

IV. Conclusion

The additively manufactured human eye model closely mimics human tissues and intra-optic pressure, offering clinicians the acquisition of dynamic gonioscopy skills. With the possibility to variate the pressure of the anterior and posterior chamber, several eye pathologies can be replicated and hence, their diagnostic criteria established. This model is a valuable platform for educational, experimental and surgical management of the cases.

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AUTHOR'S STATEMENT

Conflict of interest: Authors state no conflict of interest. Ethical approval: The related research did not involve either human studies or animal experimentation. Therefore, no institutional review board application was necessary. Informed consent: informed consent has been obtained from all individuals included in this study.

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