Towards building an anatomically correct solid eye model with volumetric representation of retinal morphology

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ABSTRACT

An accurate solid eye model (with volumetric retinal morphology) has many applications in the field of ophthalmology, including evaluation of ophthalmic instruments and optometry/ophthalmology training. We present a method that uses volumetric OCT retinal data sets to produce an anatomically correct representation of three-dimensional (3D) retinal layers. This information is exported to a laser scan system to re-create it within solid eye retinal morphology of the eye used in OCT testing. The solid optical model eye is constructed from PMMA acrylic, with equivalent optical power to that of the human eye (~58D). Additionally we tested a water bath eye model from Eyetech Ltd. with a customized retina consisting of five layers of ~60 μm thick biaxial polypropylene film and hot melt rubber adhesive.

Keywords: Optical coherence tomography; Imaging system; Ophthalmology; Solid eye model; Laser scan systems

1. INTRODUCTION

Recent progress in OCT instrumentation has made possible acquisition of volumetric retinal structures within a few seconds, depending on the OCT system's speed and lateral sampling density. This technological evolution is responsible for increasing interest in accurate representation and modeling of volumetric retinal morphology. Over the past five years, our group has been actively developing custom volume visualization software that allows recreation of anatomically correct retinal morphology [1]. An accurate solid eye model (with volumetric retinal morphology) should have many applications in the field of ophthalmology including evaluation of ophthalmic instruments as well as optometry/ophthalmology training. We considered two eye models with volumetric retinal representation. One with anatomically correct representation of three-dimensional (3D) retina layers re-created within PMMA acrylic by a laser scan system and the second with a retina consisting of five layers of ~60 μm thick biaxial polypropylene film and hot melt rubber adhesive placed inside a water bath eye model from Eyetech Ltd. Images in the water bath eye model with layered retina are presented.

2. MATERIALS AND METHODS

Two different eye models that mimic volumetric representations of retinal structures are described briefly.

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2.1. Solid Eye Model

The solid optical model eye is constructed from PMMA acrylic, with equivalent optical power (~58D) and axial length of the human eye (see Figure 1). Although PMMA is not a close match to any of the human ocular tissues from an index of refraction standpoint (n=1.485 vs. ~1.35 @ λ=780 nm), its dispersion Abbe values are (v_d = 57.4) [2]. A Coddington style pupil provides for an apparent 8 mm clear aperture, large enough for easy imaging by any ophthalmic instrument. It has one refracting surface and one scanning surface. The scanning surface is slightly aspherical, mirroring the curve of best focus over a 50 degree internal field of view (IFOV), with a base curvature of 12 mm, nearly equivalent to the nominal human eye's retinal curvature [3]. The optical focus curve was designed to be some 300-500 μm anterior to the actual scanning surface, and corresponds to the location of the scanned nerve fiber layer (NFL).

The retina on the model eye is constructed by scanning data, layer by layer, from the curvature-corrected 3D model data via a laser scanning system through the scanning surface into the model eye. The shallow depths of material to scan through, plus the fact that the scanning surface is always normal to the internal imaged retinal surface at any given point allows for highly accurate reproduction of the retinal anatomy. Figure 1 shows a visualization of the solid model eye.
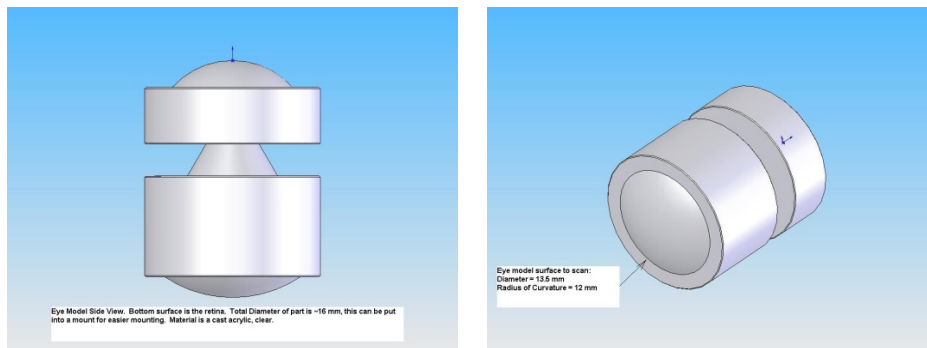

Fig. 1 Visualization of the solid eye model. Left: Side view; Right: View at the surface to scan.

2.1.1   Volumetric Retina Data Set.

The volumetric representation of the retina that was used as an input for the solid optical model was obtained from 3D OCT data acquired *in vivo* on a normal volunteer eye. We used our standard OCT clinical system [4] to obtain these data. Figure 2 shows a 3D visualization of this data set with the corresponding corrected volume (corrected for OCT scanning beam geometry) that has to be used for the solid optical eye model.
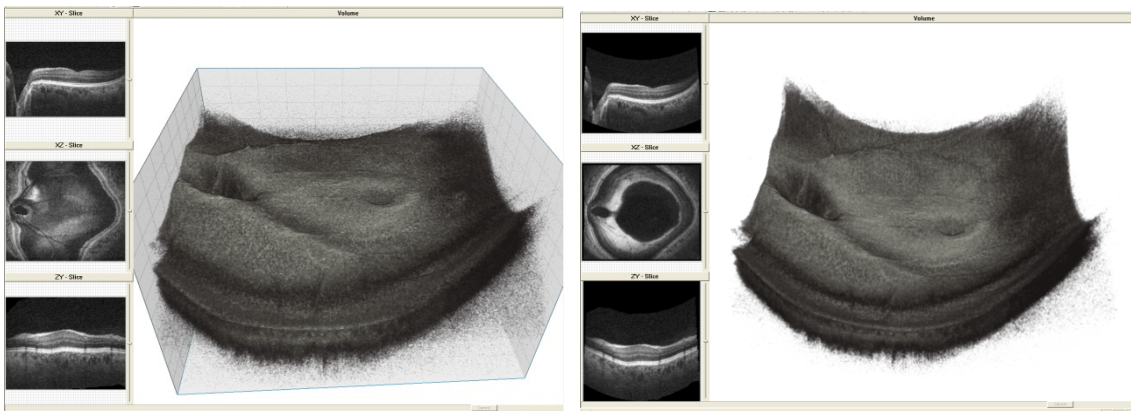

Fig. 2 3D Visualization of the retina acquired *in vivo*. Left: original view; Right: Corrected de-warped volume.

It is essential to use a de-warped (corrected for OCT scanning beam geometry) volumetric representation of the retina. Otherwise during model eye imaging the retinal structure will appear distorted. When we receive the eye model we plan to use it to confirm our OCT imaging system parameters and de-warping algorithm performance [1]. The image below shows the source of OCT B-scan geometry distortion.
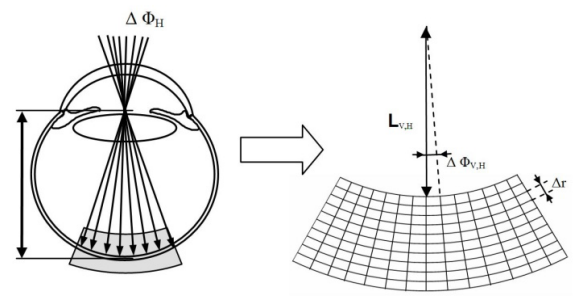

Fig. 3 Scanning geometry and sampling grid of the OCT retinal system; Left: schematic of the ray's path inside subject's eye for horizontal scanning plane. Right: 2D sampling grid of the OCT system with the axial sampling (Δr) and radial sampling ($\Delta\Phi$) for vertical (V) and horizontal (H) scanning pattern.

In order to use the OCT data set for the laser scanning system we had to segment retinal layers and represent them in the solid model format that could be exported to the laser scanning system. Figure 4 shows an OCT B-scan with the corresponding representation that was used in the first round of retina engraving. Additionally the orientation of optical and visual axes with respect to the modeled retina are presented.
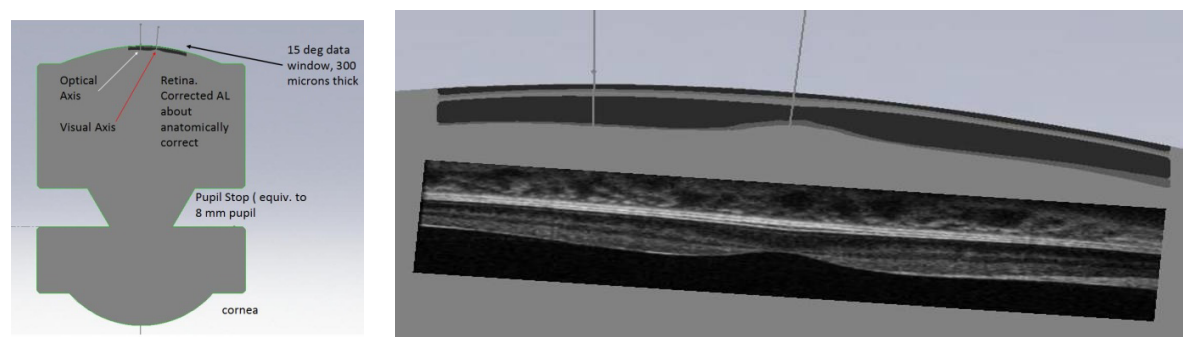

Fig. 4 Cross-sectional view of the solid eye model (left) and five retinal layers modeled for laser scanner (right)

Once we have available the eye model with engraved retina layers we will image it with our OCT system. Figure 5 shows the mechanical components that will allow mounting of the model eye in front of virtually any clinical retinal imaging instrument.
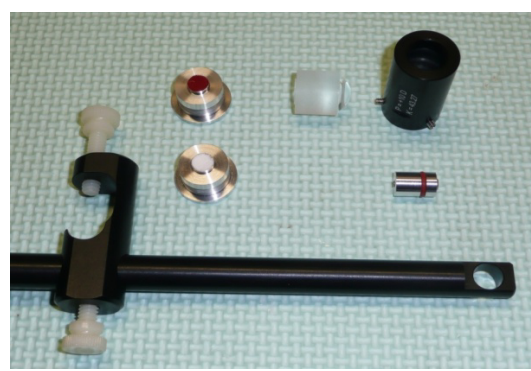

Fig. 5 Components of the Solid Eye Model that will be used to mount it in front of any clinical instrument.

2.1.2 The Laser Scanning System.

The laser scanning system re-creates an optical retina within the PMMA by extremely precise, localized (spot dia. < 4 µm) changes in index of refraction. The index changes occur by local heating and polymeric cross-linking changes to the PMMA, controlled by both the scan rate and laser power. High power or low scan rates cause micro-vacuoles to be created, thus effectively creating a high local value of Δn at that point (pixel). Smaller values of Δn's can be created by lower power or higher scan rates, and can approximate the values of Δn's present within the retinal layers. Figure 2 shows two examples of art created in both glass and PMMA where this effect is used.
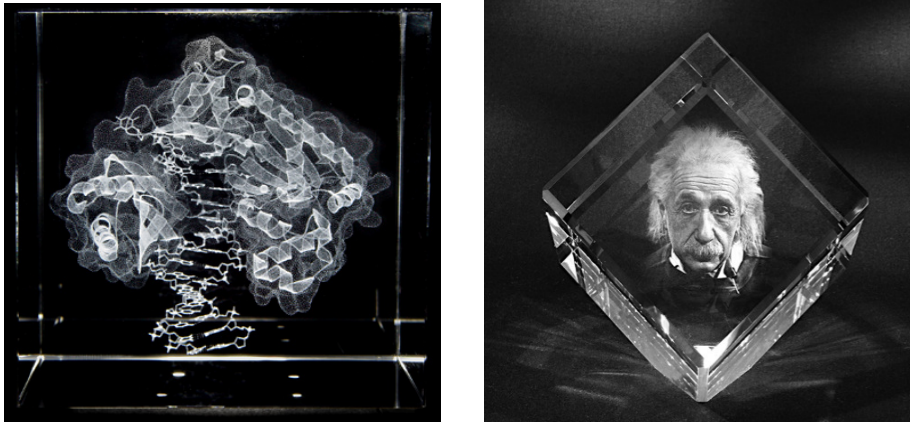

Fig. 6 Examples of laser crystal art [5,6], demonstrating the complexity of the structures that can be created by scanning laser.

2.2. Water Bath Eye Model

As a second eye model with volumetric retinal representation we tested a modified water bath eye model from Eyetech Ltd with a custom-layered retina. This retina consists of five layers of ~60 µm thick biaxial polypropylene film and hot melt rubber adhesive placed inside water. Figure 7 shows the schematic organization of these retinal layers.
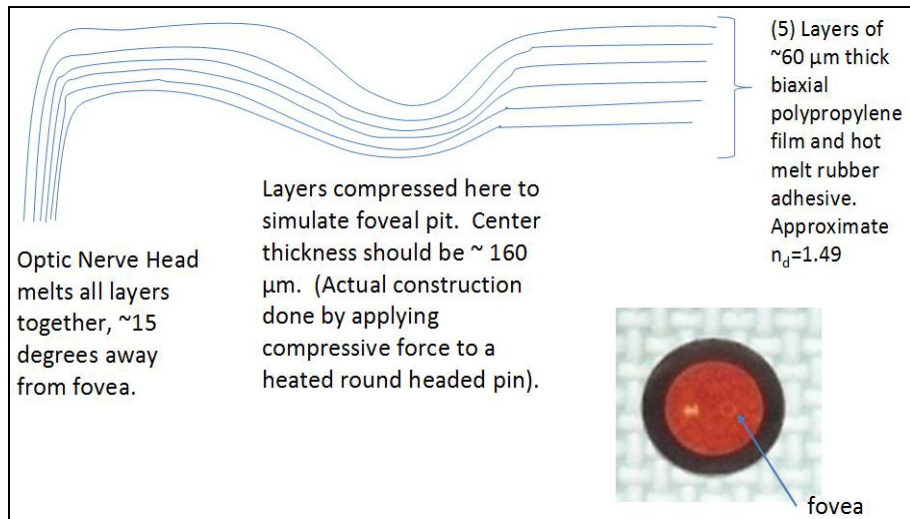

Fig. 7 Cross-sectional view of the retina for water bath eye model.

This modified retina is placed inside the water bath eye model replacing its standard retinal plane. Figure 8 shows the water bath eye model and mechanical components that will allow mounting this model eye in front of virtually any clinical retinal imaging instrument.
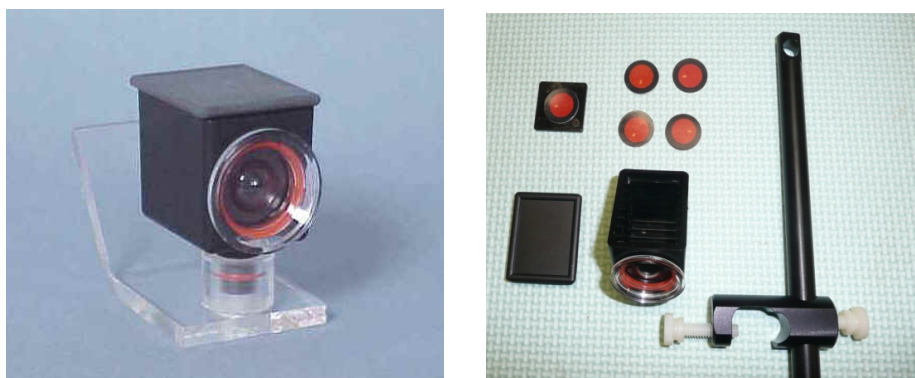

Fig. 8 Left: Water Bath Eye model from Eyetech Ltd. Right: Components of the water bath eye model that are used to mount it in front of any clinical instrument.

3. RESULTS

So far, only the water bath eye model could be tested with our OCT system for accuracy of volumetric representation of retinal layers. However before imaging it placed inside the eye model, we imaged it with our OCT microscope [7] which moves the sample on a stage to minimize scanning beam distortions. The image below shows a single OCT B-scan of the layered retina imaged by the OCT microscope (outside model eye) and its 3D visualization.
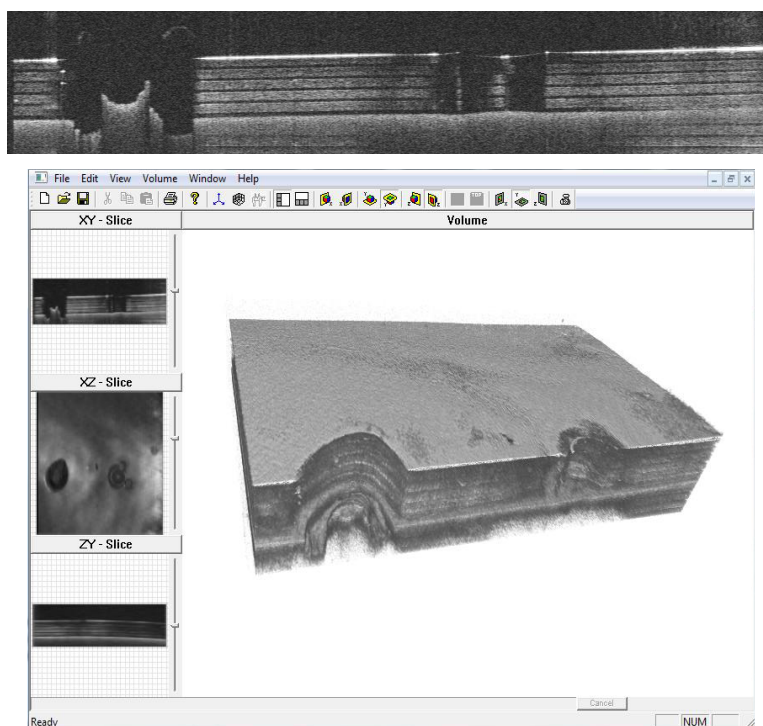

Fig. 9 OCT B-scan of the layered retina imaged by OCT microscope (outside model eye) - top. Visualization of the 3D data set of the layered retina imaged by OCT microscope - bottom.

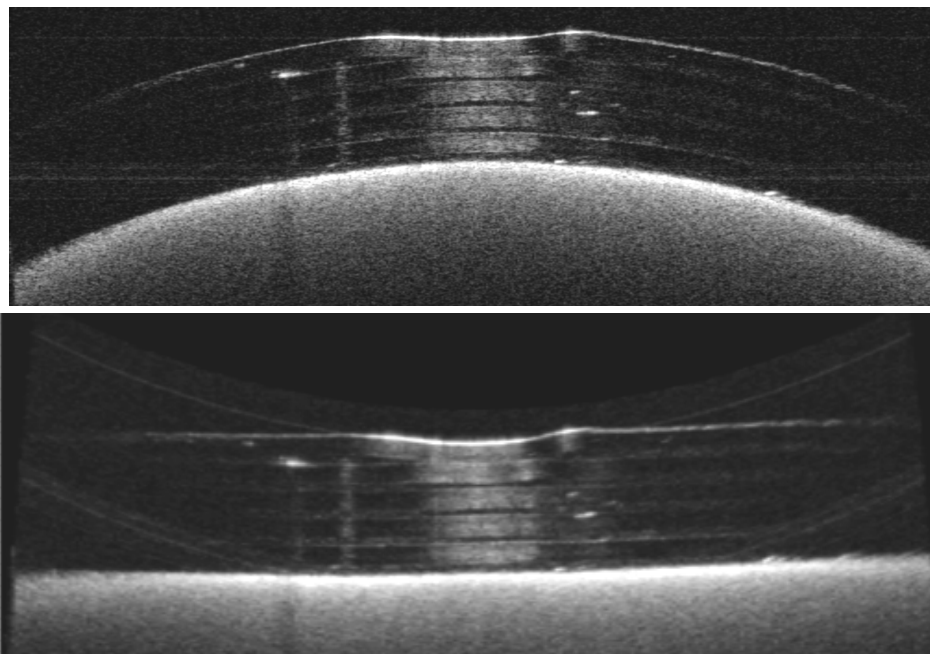We placed the layered retina inside the water bath model eye and imaged it with our clinical OCT system.

Fig. 10 OCT B-scan of the layered retina imaged inside water bath eye model (top). Scanning beam geometry corrected OCT B-scan of the layered retina shown above.

Figure 10 shows native and de-warped B-scans of the volumetric model retina (using our customized visualization software). As can be seen, most of the image distortion could be corrected and an image similar to that obtained with the OCT microscope could be generated. Note that the change in layer appearance is caused by a difference in the OCT focusing plane as well as the presence of surrounding water.

4. CONCLUSIONS

We presented two eye models with volumetric representation of the retina to better simulate the real structure of the human eye. Only one of the eye models (water bath eye model) was imaged with OCT and showed potential for representing retinal layers accurately. Several improvements including a curved rather than flat artificial retinal plane should be considered in the next version of this model. Additionally, we were able to test our de-warping software and acquire OCT scanning artifact-free images of retinal structures.

ACKNOWLEDGEMENTS

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