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Note: A gel based imaging technique of the iridocorneal angle for evaluation of angle-closure glaucoma

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Noninvasive medical imaging techniques have high potential in the field of ocular imaging research. Angle closure glaucoma is a major disease causing blindness and a possible way of detection is the examination of the anterior chamber angle in eyes. Here, a simple optical method for the evaluation of angle-closure glaucoma is proposed and illustrated. The light propagation from the region associated with the iridocorneal angle to the exterior of eye is considered analytically. The design of the gel assisted probe prototype is carried out and the imaging of iridocorneal angle is performed on an eye model. © 2014 AIP Publishing LLC. [<http://dx.doi.org/10.1063/1.4882335>]

Glaucoma is an eye disease normally associated with an increase in intraocular pressure that, if untreated, can ultimately lead to blindness.^{1–3} The closed-angle or angle-closure glaucoma is related to closure of iridocorneal angle (ICA) corresponding to the area between the iris and cornea.^{4,5} The aqueous humor leaves the anterior chamber through the trabecular meshwork (TM), and passes through Schlemm's canal and collector channels before finally draining into aqueous veins and episcleral vessels.⁶ The width of the ICA is associated with the drainage of aqueous humour from eye's anterior chamber. A wide angle permits adequate drainage of aqueous humour through the TM region provided the TM region is not obstructed.⁷ A narrow angle may obstruct the drainage system and can lead to acute angle-closure glaucoma. Hence the imaging of the region associated with the ICA has created immense interest among scientific community as it facilitate diagnosing and monitoring of various eye conditions associated with glaucoma.^{8,9} The sclera extending into the cornea near ICA however obstructs any direct view of the angle.

In a conventional screening procedure, the opening of the iridocorneal angle is assessed by means of a contact gonioscopic lens.¹⁰ TM imaging in porcine eyes is carried out through multiphoton gonioscopy method.¹¹ The evaluation using gonioscopic lens involves contact with the cornea and often results in patient discomfort. Furthermore, gonioscopic data can be affected by inadvertent pressure on the gonioscopic lens during the inspection.¹² Since most clinicians record the results in charts without images or photographic records, the documentation of the gonioscopic outcomes are often poor.¹³ Though ultrasound biomicroscopy (UBM) imaging technique produces high-resolution, quantitative cross-sectional images of the anterior chamber angle, it is not without disadvantages. Besides time-consuming, this technique is not readily available, is relatively invasive, and requires a highly skilled operator.^{14,15}

Different optical probe imaging configurations have been investigated for their miniaturized size and flexibility for various disease diagnostic applications in our group.^{16–19} An optical interferometric based method for the measurement of axial eye length has been reported.²⁰ Also, multispectral optical imaging of the human ocular fundus has been carried out in the recent past using LED illumination.²¹ An endoscope based method has been used to obtain retinal images and iridocorneal angle in larger mammals;²² however, the need for mechanical contact of probe distal end with the cornea by extreme pressure could cause abrasions of the corneal epithelium even with the presence of the gel on the cornea. This paper, in this context, proposes a low-cost clinical probe and related instrumentation that can image the structures of iridocorneal region with good resolution.

Since the direct view of ICA is obstructed due to the sclera overlap, the best approach to observe the TM region is to view from the opposite angle. Consider light transmission from anterior chamber to cornea and then to the outside medium. The angle at which light is refracted is in accordance with Snell's Law as follows:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2, \quad (1)$$

$$n_2 \sin \phi = n_3 \sin \theta_3, \quad (2)$$

where n_1 , n_2 , and n_3 are the indices of anterior chamber (aqueous humor), cornea, and outside medium, respectively. The angles θ_1 , θ_2 , and θ_3 depicted in Figure 1 are the respective angles for light incident, and light refracted to corneal and transmitted to outside media at corresponding interfaces, relative to the normal plane of the interface. Since the thickness of cornea (≈ 0.55 mm) is comparatively small, $\theta_2 = \phi$. Hence,

$$\theta_3 = \sin^{-1} \left(\frac{n_2}{n_3} \sin \left(\sin^{-1} \left(\frac{n_1}{n_2} \sin \theta_1 \right) \right) \right) \quad (3)$$

$$\theta_3 = \sin^{-1} \left(\frac{n_1}{n_3} \sin \theta_1 \right).$$

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FIG. 1. Schematic diagram showing light transmission from the region of iridocorneal angle to the exterior of eye.

The variations in the real and imaginary part of θ_3 are plotted using Eq. (3) for various incident angles (40° – 90°) and outside medium indices (n_3). The obtained result is shown in Figure 2. In order to have a good view of the trabecular meshwork region, the incident angle is estimated to be within 50° – 65° using Snell's law. When the outside medium index is air ($n_3 = 1$) or media with indices close to one, the transmitted angle (θ_3) becomes imaginary as depicted in Figure 2. In this case, the complex angle represents the existence of total internal reflection (TIR) at the cornea-air interface. This obstructs the lateral view of iridocorneal angle region. By changing the outside medium index (n_3), the TIR can be avoided. Therefore, to have a clear view of TM region, the immediate media outside the corneal region has to be tailored. Different ocular gel media are available in the market that can be used to track light from the ICA region back to the exterior of the corneal region. In order to avoid further TIR at the gel-air interface, the angle of incidence at this interface has to be minimized. In this viewpoint, we propose an objective lens based probe configuration as shown in Figure 3 where a mirror is employed at the distal end to alter the angle of incidence at the gel-air interface.

A schematic of the proposed configuration is shown in Figure 3(a). The imaging of opposite iridocorneal angle is performed on an ocular eye model (OEM-7; Ocular Instruments Inc., Bellevue, WA) without and with gel. The photograph of eye model is given in Figure 3(b). The eye model includes natural surfaces of human eye including anterior chamber and crystalline lens.¹⁵ A fiber-optic broadband light source is collimated and redirected to illuminate the iridocorneal region. The light reflected from the ICA region is collected through an objective lens and directed to a CCD camera (PL-A741; PixeLINK, Ottawa, Canada). A long working distance (20 mm), infinity-corrected objective lens (Mitutoyo; 20X, 0.4NA) is employed in this study.

The photograph of distal end is given in Figure 3(c). A mirror is used to redirect the beam to the objective lens. The mirror can be rotated to have a clear view of the ICA region.

FIG. 2. The variations in the (a) real and (b) imaginary part of θ_3 are plotted using Eq. (3) for various incident angles (θ_1) and at various filling material indices.

FIG. 3. (a) Schematic of the proposed experimental setup, (b) photograph of Ocular Imaging Eye Model (OEMI-7), and (c) photograph of the distal end of the proposed system.

FIG. 4. Imaging of opposite iridocorneal angle region: (a)–(d) Iridocorneal angle is not visible in absence of gel (the images are taken at different objective planes); (e)–(h) Iridocorneal angle is visible with gel (these images are also taken at different objective planes).

The imaging of the region is performed without gel at different objective planes and the obtained result is shown in Figures 4(a)–4(d). It shows that the ICA region view is restricted due to the total internal reflection at the cornea-air interface as expected from the analytical results (Figure 2). A sterile coupling gel (Vidisc gel; Mann, Germany), of refractive index 1.338, was applied to a glass cover slip and pressed to the region between the mirror and the eye model such that a gel-filled coupling medium is formed as shown in Figure 3. This would minimize reflection of light by refractive index matching, thereby optimizing light transmission. In this scheme, the angle of incidence at the gel-air interface is a minimum such that light can be guided to the camera through the objective lens. The results obtained in the presence of gel are shown in Figures 4(e)–4(h). These figures were taken at objective planes corresponding to those in Figures 4(a)–4(d), respectively. The width of the iridocorneal angle region is indicated using arrows, between the margin of cornea and base of iris.

An optical method to examine the iridocorneal angle region that will be promising in the evaluation of angle-closure glaucoma is proposed and illustrated. The light transmission from the anterior chamber to the exterior of eye is analytically considered using Snell's law. Based on this, an experimental probe system is developed for imaging the iridocorneal angle region. The images saved into the computer allow the clinicians to evaluate and compare the changes in angle if se-

rial examinations are to be done over a period of time which would be particularly advantageous in tracking both disease progression as well as treatment effects.

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