Medical Engineering and Physics 000 (2016) 1–9

Contents lists available at ScienceDirect

Medical Engineering and Physics

journal homepage: www.elsevier.com/locate/medengphy

Progress in anterior chamber angle imaging for glaucoma risk prediction – A review on clinical equipment, practice and research

V.K. Shinoj[a], Xun Jie Jeesmond Hong[a,*], V.M. Murukeshan[a,*], M. Baskaran[b,c], Tin Aung[b,c]

[a] Center for Optical and Laser Engineering, School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore, Singapore 639798, Singapore
[b] Singapore Eye Research Institute (SERI) & Singapore National Eye Center (SNEC), Singapore, Singapore 168751, Singapore
[c] Yong Loo Lin School of Medicine, National University of Singapore, Singapore, Singapore 119228, Singapore

ARTICLE INFO

Article history:
Received 22 March 2016
Revised 23 August 2016
Accepted 23 September 2016
Available online xxx

Keywords:
Glaucoma
Gonioscopy
RetCam
Pentacam
Ultrasound biomicroscopy
Optical coherence tomography
Photoacoustic
Gel-assisted imaging probe
Integrated hand-held probe

ABSTRACT

The visualization capabilities of various ocular imaging instruments can generally be categorized into photographic (e.g. gonioscopy, Pentacam, RetCam) and optical tomographic (e.g. optical coherence tomography (OCT), photoacoustic (PA) imaging, ultrasound biomicriscopy (UBM)) methods. These imaging instruments allow vision researchers and clinicians to visualize the iridocorneal angle, and are essential in the diagnosis and management of glaucoma. Each of these imaging modalities has particular benefits and associated drawbacks in obtaining repeatable and reliable measurement in the evaluation of the angle. This review article in this context summarized recent progresses in anterior chamber imaging techniques in glaucoma diagnosis and follow-up procedures.

1. Introduction

Glaucoma is an eye disease normally associated with an increase in intraocular pressure. It can ultimately lead to irreversible blindness if left untreated [1,2]. Closed-angle or angle-closure glaucoma is related to the closure of iridocorneal angle (ICA), corresponding to the area between the iris and cornea [3]. Primary angle closure glaucoma and acute angle closure glaucoma are characterized by the anatomical predisposition of narrow angles with iridocorneal contact. In the latter, eye pressure may be in the range of 30–80 mm Hg and is an ophthalmic emergency [4–6]. The normal eye pressure is between 12 mm Hg and 22 mm Hg. Aqueous humor (nutritive fluid actively secreted in the eye) 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 [7]. The width of the ICA is associated with the drainage of aqueous humour from the eye's anterior chamber. A wide angle permits adequate drainage of aqueous humour through the TM region, provided that the TM region is not obstructed [8]. A narrow angle may obstruct the drainage system and lead to acute angle-closure glaucoma. The management of narrow angles differs from open angle glaucoma, with a possibility of prevention of progression using laser treatment in the former. The most common type of laser glaucoma management is laser iridotomy, where a small opening is made in the peripheral iris in an attempt to "open" the narrow angle, thus equalizing the pressure between the eye chambers. The imaging of the region associated with the ICA has created immense interest among scientific community as it facilitate the diagnosis and monitoring of progressing eye conditions associated with glaucoma [5,9,10]. The sclera extending into the cornea near the ICA however obstructs any direct view of the angle. In contrast to western countries, angle closure glaucoma is a major form of glaucoma in Asia, accounting for the majority of bilateral blindness in India, China and Singapore.

Since glaucomatous damage is mostly irreversible, it is crucial to identify precisely eyes with early structural changes. The earlier glaucoma is identified and treated, the greater the possibility that medical or surgical management can be useful in preventing severe visual loss [1,11]. Assessment of anterior chamber angle is an essential part in the detection and diagnosis of angle closure glaucoma. Traditional imaging techniques to assess the drainage angle

* Corresponding author.
E-mail address: mmurukeshan@ntu.edu.sg (V.M. Murukeshan).

http://dx.doi.org/10.1016/j.medengphy.2016.09.014
1350-4533/

inside eye can be generally classified into photographic and optical tomographic methods. This paper in this context reviews the recent progress in anterior chamber angle imaging techniques for angle-closure glaucoma detection and follow-up procedures. The detailed description and classification of each technique are given below.

2. Photographic methods

In photographic methods, the iridocorneal region is captured using a camera and the images are stored in a database. It allows the monitoring of treatment responses overtime, and tracks anatomical changes in the angle structures as the disease progresses. Different types of photographic methods for evaluating angle closure condition are discussed in the following subsections.

2.1. Pentacam

Pentacam is based on Scheimpflug photography principle [12,13], where an obliquely tilted object is imaged with least distortion and maximum depth of focus under given conditions. Fig. 1 shows an illustration of the Scheimpflug principle. It shows the orientation of the plane of focus in an optical system where the lens plane is not parallel to the image plane. If the object plane is not parallel to the image plane, the lens focuses along the line where it intersects the plane of focus. Scheimpflug principle is employed in Pentacam and utilized in ophthalmology through a rotating measurement to obtain the optical sections of the entire anterior segment of eye. It images the anterior segment from the cornea to the posterior surface of the lens in three dimensions (3D). A Pentacam image of the anterior segment of a human eye is shown in Fig. 2.

This non-contact device offers rapid 3D analysis of the anterior chamber and can be used to measure corneal pachymetry, corneal diameter, radius of curvature, lens position, anterior chamber angle, volume, and depth [14]. The imaging lasts less than 2 s and the center of cornea; its anterior and posterior surfaces can be measured accurately. It can be used as the primary assessment tool to evaluate angle closure disease condition. However, the direct visualization of angle recession is not possible. This is because of the inability of visible light to penetrate deep into the tissues. In addition, the iris plane in Pentacam is defined using a straight line, rather than a curved plane. This results in inaccurate measurement of the angle width.

2.2. Gonioscopic photography

Gonioscopy is the fundamental part of eye examination. It is needed to differentiate an open angle from a closed angle, and to note other pathological conditions. Direct examination of the angle is not possible due to the total internal reflection of light emerging from the angle of the eye into air. Gonioscopy utilizes a lens or prism with a different refractive index to overcome this problem. At any time, a quadrant of the anterior chamber angle can be visualized using conventional gonioscopy instruments. The angle structures are documented to make a decision regarding openness or closure of the angle. The structures seen include, from posterior to anterior – iris root (IR), ciliary body band (CBB), scleral spur (SS), trabecular meshwork (TM) (divided into pigmented posterior and non-pigmented anterior TM), and Schwalbes' line (SL). Commonly used definition for angle closure is the non-visibility of posterior pigmented TM in at least two quadrants. Fig. 3(a) and (b) correspond to open and closed angle of a human eye using gonioscopic approach.

Gonioscopy is a subjective methodology whereby the iridocorneal angle is documented by various grading procedures. The

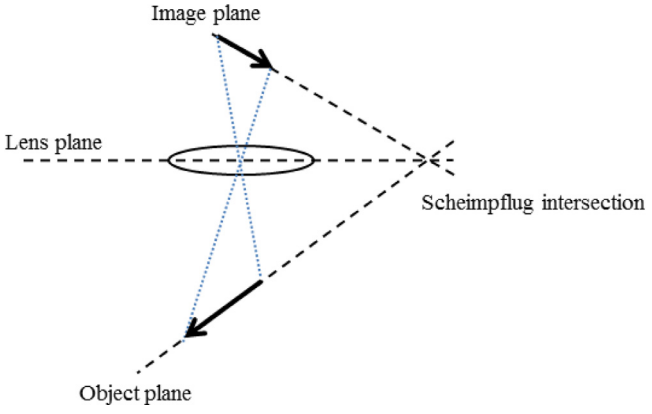

Fig. 1. Illustration of the Scheimpflug principle.

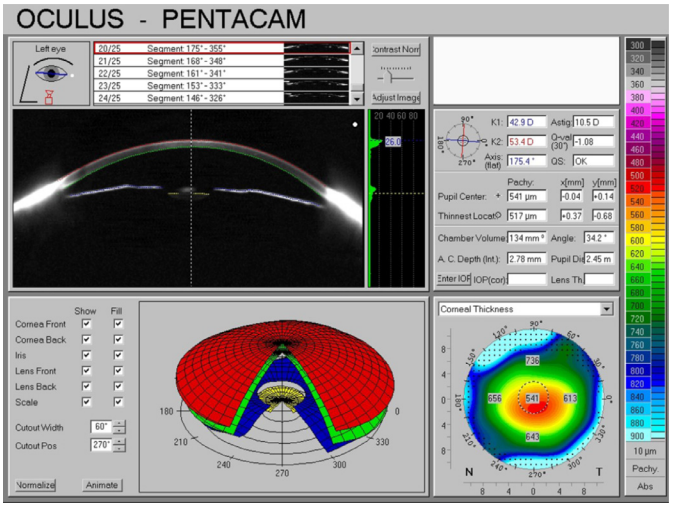

Fig. 2. Pentacam image of anterior chamber in human eye and quantitative measurements using the in-built software.

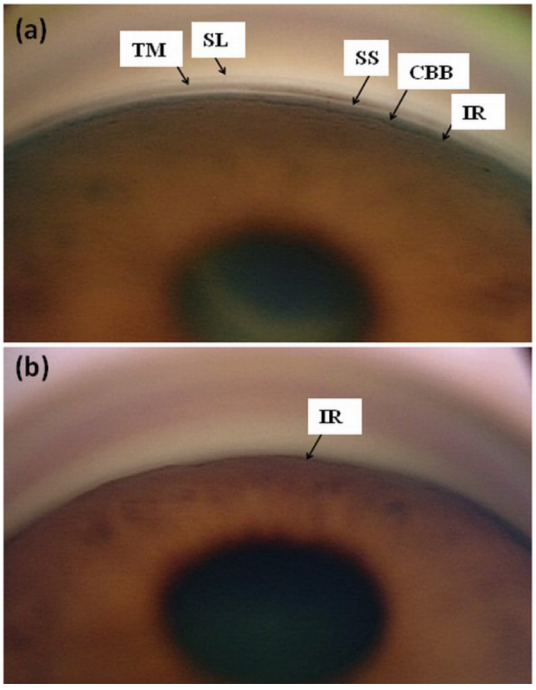

Fig. 3. Gonioscopic results: (a) open angle and (b) closed angle.

Please cite this article as: V.K. Shinoj et al., Progress in anterior chamber angle imaging for glaucoma risk prediction – A review on clinical equipment, practice and research, Medical Engineering and Physics (2016), http://dx.doi.org/10.1016/j.medengphy.2016.09.014