Automatic determination of anterior and posterior corneal limbi from OCT images, based on corneal shape analysis

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ABSTRACT

We present two versatile and reliable methods of determination of the corneal limbi localization from OCT images. These methods are fully automatic and are based on the purely geometrical dependencies of corneal shape, backgrounded by anatomical structure of the corneoscleral area. The first method enables to estimate the position of the point of corneoscleral junction (CSJ) at the anterior surface of the cornea. The second method can be used for automatic retrieval of the limbal point at the posterior surface of the cornea, which plays an important role in quantification of the irido-corneal angle.

Keywords: optical coherence tomography, anterior segment, cornea, limbus, scleral spur

1. INTRODUCTION

The limbal area is the junction area of the light-transparent cornea and opaque sclera and conjunctiva. Its role in ophthalmic physiology cannot be overestimated, since there are several structures located in the limbal area, which are crucial for proper functioning of the eyeball and the entire visual system. Among all the functions it has¹, the most important is the drainage of the aqueous humor through the trabecular meshwork located in the inner layer of the corneoscleral limbus. The reliable determination of the position of the limbus is also important for proper fitting the contact lenses².

There exist several methods of determining the corneoscleral limbus^{3,4}, but most of them are based on visual evaluation of the images and manual (or semi-manual) estimation of the CSJ⁵. For this reason the manual methods are considered to be subjective, laborious and time-consuming and therefore poorly suitable for dynamic measurements.

The optical coherence tomography (OCT) has become an irreplaceable tool for medical applications, in optometry and ophthalmology, in particular. It provides both qualitative and quantitative information on the geometrical properties of both the external and internal structures of the eye⁶. Therefore it can be used for visualization of the CSJ both at the anterior surface of the cornea and in the area of irido-corneal angle. Moreover, the proper analysis of the segmented data obtained from anterior segment OCT and corrected from optical distortion can lead to reliable and repeatable estimation of the location of the corneoscleral junction points both at the anterior and posterior surface of the cornea. We present two fully automatic methods of estimation of these points, based on the anatomical background of these structures of the eye.

2. METHODOLOGY AND RESULTS

2.1 OCT data preparation

The horizontal OCT images of the anterior segment used in the study were captured with use of a commercial OCT device (Casia 2, Tomey Corporation). The device provides the raw images of the whole anterior segment of the eye, including both nasal and temporal angles. The images were processed by means of a custom procedure in order to obtain the segmented data of the structures of the eye. Then the data referred to refracting surfaces of the cornea and crystalline lens

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were smoothed⁷. Finally the data was processed for the purpose of the optical distortion correction. The original tomogram and the segmented and processed data are presented in Figure 1.

Figure 1. a) Raw OCT image of the anterior segment of the eye with segmented surfaces of several structures. b) Comparison of the distorted OCT data segmented from the raw OCT image (solid lines) and the real geometry of the anterior segment obtained after distortion correction (dashed lines).

2.2 Anterior limbus estimation

Let us consider an ideal case, where both the anterior surface of the cornea and the anterior surface of sclera are smooth, but have different (but **both positive**) local curvatures. The anterior limbal area – as the junction between these two surfaces – should be also smooth, but its curvature is supposed to have an **opposite sign**. This is schematically illustrated in Figure 2a. Figure 2b presents the curvature profile (obtained numerically) of the whole anterior surface segmented from OCT data (marked as yellow line in Figure 1). There are two distinctive points at both sides of the profile, for which the local curvature equals to zero (marked with red vertical lines). At these particular points the anterior surface is locally flat. These points can be associated with the positions of the medial boundary points of the nasal and temporal anterior limbal areas.

Figure 2. a) Schematic representation of the radii of curvature of the anterior surface of the eye. b) Curvature profile of the first eye of the eye surface obtained from the real OCT data.

2.3 Posterior limbus estimation

The second method refers to the posterior limbus (at the posterior surface of the cornea) and is based on the numerical analysis of the thickness profile of the cornea. It needs to be emphasized that the thickness can be calculated only from the data corrected from the optical distortion, as the distance between the two surfaces segmented from the OCT data associated with the cornea, that is between the anterior surface, in Figure 3a marked in yellow, and posterior surface, marked in red. To be precise: the distance should be calculated along the line perpendicular to the anterior surface. Figure 3b presents the profile of the corneal thickness calculated according this scheme. The plot manifests the two local maxima, associated with the places of local maximal thickness in the nasal and temporal parts of the data.

Figure 3 a) Explanation of the method for determining the corneal thickness numerical estimation. b) Profile of the corneal thickness obtained from the real OCT data. t_{max} denotes the local maximal values of corneal thickness profile. The position of the posterior limbus is marked with asterisk.

According to the literature³, the maximal thickness of the cornea is unambiguously related to boundary points of the corneoscleral limbus at the posterior surface of the cornea. In other words, the line perpendicular to the anterior surface of the cornea at the point of maximal thickness, indicates the limbal point at the posterior surface.

3. CONCLUSIONS AND DISCUSSION

We presented two methods of analysis of the data retrieved originally from the OCT images which can be successfully used for estimation of the limbal points at both the anterior and posterior surface of the cornea. The methods are fully automatic, and therefore arbitrary, providing reliable results. The test performed on numerous OCT data showed that the results are very reproducible and independent of the alignment of the eye in relation to the device, as expected. To the best knowledge, these are the first automatic methods of limbus estimation to be used with the OCT data corrected from optical distortion. Automaticity of the methods presented in this study and their independence from the operator's experience make them suitable for processing the large sets of data. We expect their high effectiveness in the further studies, aimed to estimate the rapid, dynamic changes in the geometry of the anterior chamber.

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