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The shape of the anterior and posterior surface of the aging human cornea

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Abstract

Purpose: To determine the shape and astigmatism of the posterior corneal surface in a healthy population with age, using Scheimpflug photography corrected for distortion due to the geometry of the Scheimpflug imaging system and the refraction of the anterior corneal surface.

Methods: Scheimpflug imaging was used to measure in six meridians the cornea of the right eye of 114 subjects, ranging in age from 18 to 65 years.

Results: The average radius of the anterior corneal surface was 7.79 ± 0.27 (SD) mm and the average radius of the posterior corneal surface was 6.53 ± 0.25 (SD) mm. Both surfaces were found to be flatter horizontally than vertically. The cylindrical component of the posterior surface of 0.33 mm is twice that of the anterior surface (0.16 mm).

The asphericity of both the anterior and the posterior surface was independent of the radius of curvature at the vertex, refractive error and gender. In contrast with that of the anterior corneal surface, the asphericity of the posterior corneal surface varied significantly between meridians. With age, the asphericity of both the anterior and the posterior corneal surface changes significantly, which results in a slight peripheral thinning of the cornea.

Conclusion: On average, the astigmatism of the posterior corneal surface (−0.305 D) compensates the astigmatism of the anterior corneal surface (0.99 D) with 31%. The results show that the effective refractive index is 1.329, which is lower than values commonly used. There is no correlation between the asphericity of the anterior and the posterior corneal surface. As a result, the shape of the anterior corneal surface provides no definitive basis for knowing the asphericity of the posterior surface.

Keywords: Posterior cornea; Scheimpflug; Astigmatism; Asphericity; Schematic eye; Radius; Effective refractive index; Aging

1. Introduction

Although the anterior corneal surface has been frequently described in the literature, accurate data on the shape of the posterior surface of the cornea is scarce. This is mainly because imaging of this surface must always be performed through the anterior surface of the cornea, which acts as a magnifying glass and distorts the perceived shape of the posterior cornea. During the past two decades, interest in the exact shape of the corneal surface has increased, especially due to new developments such as refractive surgery, for which a complete description of the whole cornea is required. More accurate data on the shape of the posterior surface could improve the optical modeling of the eye. The radius of the posterior corneal surface in the schematic eye of Gullstrand is 6.8 mm (Atchison & Smith, 2000), while in the schematic eye of Le Grand and El Hage (1980) and Liou and Brennan (1997), it is 6.5 and 6.4 mm, respectively. The asphericity of the posterior corneal surface is needed in order to model the higher order aberrations, but different values have been used due to the lack of accurate data. Kooijman (1983) used the same asphericity as that of the anterior corneal surface, while Lotmar

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(1971) and Navarro et al. (1985) assumed the posterior corneal surface to be spherical. Liou and Brennan (1997) entered the asphericity of the posterior corneal surface as a variable in the modeling of their schematic eye, which resulted in a shape factor 'p' of 0.4 (Q value of −0.6). Furthermore, post-surgical refractive power after cataract surgery could be predicted more accurately if more was known about the posterior surface. In IOL calculations, the cornea is regarded as a single refractive surface with an effective refractive index, which varies from 1.332 to 1.3375, because there is usually no knowledge of corneal thickness and radius of the posterior corneal surface (Bennet & Rabbets, 1998). For this effective refractive index, it is assumed that there consists a fixed ratio between the radius of the anterior and posterior corneal surface. This is also the reason that the calculation of corneal power sometimes fails after previous refractive surgery of the cornea, because this ratio has been changed (Gimbel, Sun, & Kaye, 2000). Finally, it is important to know whether the shape of the cornea changes with age, because this could influence the stability of the corneal shape after refraction surgery.

The radius of curvature of the posterior cornea has most frequently been measured on the basis of the size and location of Purkinje images (Dunne, Royston, & Barnes, 1992; Garner, Owens, Yap, Frith, & Kinnear, 1997; Lam & Douthwaite, 2000; Royston, Dunne, & Barnes, 1990). Dunne et al. (1992) found that the posterior surface exhibited more toricity than the anterior surface. The asphericity of the posterior corneal surface cannot be measured using Purkinje imaging, so it was measured by combining videokeratoscopy with pachymetric thickness measurements (Lam & Douthwaite, 1997; Patel, Marshall, & Fitzke, 1993). Lam and Douthwaite (1997) found a significant relationship between anterior and posterior asphericity in the vertical meridian. Patel et al. (1993) measured the asphericity in the vertical and horizontal meridian and found some difference in asphericity. Nevertheless, this combination of videokeratoscopy with subsequent thickness measurements is quite sensitive to misalignment, and is rather time-consuming.

Scheimpflug photography has the advantage of being a non-contact technique whereby the anterior surface, the thickness profile, and the posterior surface are determined in one step (Brown, 1973). This eliminates alignment errors that may occur when combining videokeratoscopy and pachymetry, and accelerates the measurement procedure. However, standard Scheimpflug photography suffers from distortion of the images due to the geometry of the Scheimpflug imaging system and the refraction of the anterior corneal surface. To obtain an accurate measurement of the anterior and posterior corneal surfaces, we developed a method to correct for these two types of distortion (Dubbelman & Van der Heijde, 2001; Dubbelman, Van der Heijde, & Weeber, 2005). In an earlier study (Dubbelman, Weeber, Van der Heijde, & Völker-Dieben, 2002), this method was used to measure the age-dependency of the shape of the posterior corneal surface in the vertical meridian. In contrast with the radius, the asphericity appeared to be age-dependent. Nevertheless, only the vertical meridian was measured, and because of the reflections of the iris, especially in the older subjects, the Scheimpflug image was occasionally saturated in the periphery of the cornea.

In the present study, a CCD camera with a higher dynamic range and a higher resolution (25% higher than the camera used in our earlier study). Furthermore, a larger group of subjects was measured, and the shape of the corneal surface was investigated in six meridians instead of only the vertical meridian. This makes it possible to measure the change in radius, asphericity and thickness of the whole cornea as a function of age.

2. Methods

Scheimpflug images of the anterior eye segment were made of the right eye of 114 subjects, ranging from 18 to 65 years of age (average age ± SD: 39 ± 14 years). The group consisted of 57 females (average age: 38 ± 14 years) and 57 males (average age: 39.5 ± 15). The measurements were performed with the full understanding of the subjects and written consent was obtained from each subject. None of the subjects had suffered from diabetes mellitus, had undergone ocular surgery, or had worn contact lenses in the previous 2 years.

The radius and astigmatism of the anterior corneal surface and the ocular refractive error of the right eye were measured with a Topcon KR-3500 auto kerato-refractometer. The equivalent refractive error (ERE) varied between −6.88 and +3.5 D (average ± SD: −1.33 ± 2.18). No difference in refractive error was found between males and females, and there was no correlation between ERE and age.

Two series of Scheimpflug images were made in six meridians (90°, 60°, 30°, 0°, 150°,120°) and the time interval between each series varied from 1 to 3 min (2 × 6 images in total). Images were obtained with the Topcon SL-45 Scheimpflug camera, the film of which was replaced by a CCD-camera (St-9XE, SBIG astronomical instruments) with a dynamic range of 16 bits of grey values (512 × 512 pixels, pixel size 20 × 20 μm, magnification: 1×). All measurements were performed between 10 a.m. and 4 p.m.

The Topcon SL-45 Scheimpflug camera is equipped with a fixation target (a green blinking LED). The intensity of the LED can be increased, which makes fixation less difficult for the subject and increases the reproducibility of the measurements. In order to correct for the angle between the optical and the visual axis (Dragomirescu, Hockwin, & Koch, 1980), the fixation target is displaced 5° nasally from the slitbeam, which is in accordance with the average value for the angle alpha. The visual axis is also downwards relative to the optical axis by 2–3° (Atchison & Smith, 2000). Because of the variation in the angle between subjects (3–8°), the Scheimpflug camera was adapted to make it possible to change the position of the fixation target between 1° and 8° in both the horizontal and the