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Precise measurement of scleral radius using anterior eye profilometry

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ABSTRACT

Purpose: To develop a new and precise methodology to measure the scleral radius based on anterior eye surface.
Methods: Eye Surface Profiler (ESP, Eaglet-Eye, Netherlands) was used to acquire the anterior eye surface of 23 emmetropic subjects aged 28.1 ± 6.6 years (mean ± standard deviation) ranging from 20 to 45. Scleral radius was obtained based on the approximation of the topographical scleral data to a sphere using least squares fitting and considering the axial length as a reference point. To better understand the role of scleral radius in ocular biometry, measurements of corneal radius, central corneal thickness, anterior chamber depth and white-to-white corneal diameter were acquired with IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany).
Results: The estimated scleral radius (11.2 ± 0.3 mm) was shown to be highly precise with a coefficient of variation of 0.4%. A statistically significant correlation between axial length and scleral radius ($R^2 = 0.957$, $p < 0.001$) was observed. Moreover, corneal radius ($R^2 = 0.420$, $p < 0.001$), anterior chamber depth ($R^2 = 0.141$, $p = 0.039$) and white-to-white corneal diameter ($R^2 = 0.146$, $p = 0.036$) have also shown statistically significant correlations with the scleral radius. Lastly, no correlation was observed comparing scleral radius to the central corneal thickness ($R^2 = 0.047$, $p = 0.161$).
Conclusions: Three-dimensional topography of anterior eye acquired with Eye Surface Profiler together with a given estimate of the axial length, can be used to calculate the scleral radius with high precision.

1. Introduction

The human eye is an ocular globe that, in the first approximation, can be composed of two spherical components, a small one related to corneal curvature and a larger one that estimates the scleral surface with a well-blended transition [1]. In contrast to corneal tissue, less is known about the variance of the scleral geometrical parameters. It is known to be nearly spherical in shape with an approximate surface of 16.3 cm^2 and a typical mean radius of 11.5 mm [2–4]. The latter is difficult to measure in-vivo due to the lack of means of doing so. However, scleral radius may play an important role in many different applications such as scleral contact lens design, as they are entirely supported by scleral tissue [5,6], or in the LASIK surgery, where information on scleral radius can enhance safety of the procedure by selecting an appropriate scleral suction ring [7]. Some authors have also shown that scleral curvature may be related to intraocular pressure (IOP). A study performed in porcine eyes by Pierscionek et al. showed that elevation of IOP changes the scleral curvature and not the cornea [8]. Therefore, a precise measurement of scleral radius may contribute to a better understanding of the IOP progress [8,9].

Recent advances in corneal imaging with the optical coherence tomography (OCT) [10,11], Scheimpflug cameras [12,13] and Fourier based profilometry [14,15] have provided means for assessing the corneo-scleral topography. In 2013, Hall et al. obtained the scleral radius with the *built-in* callipers in Visante OCT from 204 subjects [1]. In their study, the scleral radius ranges from −57 to 313 mm showing that it is a difficult task to estimate the scleral radius manually based on one single cross section of the anterior eye. More recently, Choi et al. investigated more precise methods for measuring the radius of anterior scleral curvature using OCT [16]. They considered the best circular fitting of scleral points obtained from a cross section image of the anterior eye. However, their method requires a manual assembly of three OCT images into one single image. Such methodology gives rise to a considerable variance, larger than 5% and requires multiple acquisitions. Therefore, more precise techniques are needed to obtain the scleral radius for the purpose of practical clinical use.

As an alternative, Fourier based profilometry, has shown to be a promising technique to accurately obtain the three-dimensional (3D) topography of the anterior eye including cornea, limbus and

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for the first time, the outermost sclera [14]. The usefulness of the scleral data acquired three-dimensionally with such high quality, for the propose of ocular biometry, has not been explored so far. Hence, this study proposes a new and precise methodology for estimating the scleral radius based on 3D corneoscleral topography measurements. Moreover, the role of the scleral radius in ocular biometry is explored by comparing it with measurements of corneal radius, central corneal thickness, anterior chamber depth and white-to-white corneal diameter.

2. Methods

This prospective study included 23 Caucasian emmetropes (11 male and 12 female) where both eyes were assessed and averaged. All the parameters were independent of the naso-temporal symmetry of the eyes. The mean (±standard deviation) age of the participants was 28.1 (±6.6) years ranging from 20 to 45. All subjects had mean refractive power of ±0.5 dioptres (D) or less and astigmatism of ±0.25D or less. They were treated in accordance with the Declaration of Helsinki and informed consent was obtained after the goals of research and consequences of participation had been discussed. Only subjects without any reported eye disease were considered for this study. Matlab (Mathworks, Natic, MA) was used to develop the algorithm. The statistical analysis, also performed with Matlab, included the coefficient of variation and the regression analysis based on linear least squares.

2.1. Data acquisition

Eye Surface Profiler (ESP, Eaglet-Eye, Netherlands) was used to acquire the 3D topography of the anterior eye. It is a Fourier domain profilometer that consists of two blue-light fringe projectors and a centrally positioned camera equipped with a yellow filter. In order to capture an image of the anterior eye, sodium fluorescein needs to be instilled into the eye. This was achieved by using a drop of lubricating ophthalmic solution (Hylo-Parin, Ursapharm, USA) to wet the fluorescein sterile strip (BioGlo, HUB Pharmaceuticals, LCC) that was subsequently applied to a bulbar conjunctiva of the subject's eye. The instrument measures an area of up to 20 mm in diameter with more than 250,000 points, covering all corneal tissue, the limbus and large part of the sclera (conjunctiva) [14]. Fig. 1 shows an example of the grayscale image and the respective raw elevation data acquired with ESP. To access the repeatability of the method, multiple ESP measurements were acquired for each subject in a subgroup of 10 subjects. A sequence of 10 measurements acquired with a single instillation of fluorescein was performed for each subject. In addition to ESP, IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany) was used to measure the axial length of the eye globe and other biometrical parameters such as corneal radius (CR), central corneal thickness (CCT), anterior chamber depth (ACD) and white-to-white (WTW) corneal diameter. A standard protocol was used with a single acquisition of biometry data that automatically includes multiple measurements of particular biometry parameters. To date, IOL-Master 500 has been the gold standard in optical biometry. However, the agreement between the gold standard and the IOLMaster 700 has shown to be excellent [17].

2.2. Data processing

In general, the anterior eye surface can be divided into three distinct areas: cornea, limbus and sclera. Corneal and scleral tissues are easy to identify as the cornea is transparent to allow light propagation into the eye and the sclera is opaque in order to prevent internal light scattering within the eye globe. The limbus is a corneoscleral transition and it is often identified from the anterior eye imaging as a band of approximately one to two millimetres surrounding the corneal periphery of the visible iris [18,19]. Topographically, the limbus is characterized by a change of the curvature that occurs between cornea and sclera which is, in general, steeper on the nasal side [20] and has an average horizontal diameter of approximately 12.2 ± 0.4 mm for Caucasian eyes [21]. Therefore, in order to have an automatic routine for all measurements and to ensure that scleral fitting was performed on scleral topographical data, a circular band between 5 and 6.5 mm from corneal apex was removed from the original raw elevation data. This approximately corresponds to the population minimum and maximum HVID [1]. Fig. 2 shows a bird's eye view example of the split data where the corneal and scleral elevation are represented by the red and blue colour respectively. Such division can be done converting the data from Cartesian coordinates to Polar coordinates and establishing limiting radii for both segments. Axial length obtained from IOLMaster 700 is then added to the scleral topographical data as a reference point.

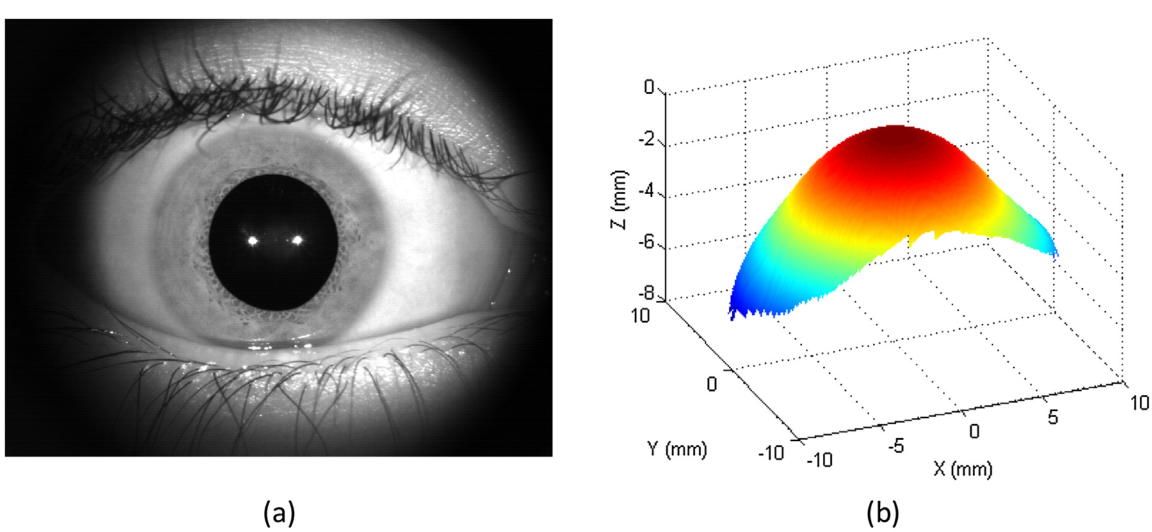

Fig. 1. An example of the grayscale image of anterior eye (a) and its raw elevation data (b) acquired with an Eye Surface Profiler.