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The variability of corneal and anterior segment parameters in keratoconus

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ABSTRACT

Purpose: To analyse, describe and test diverse corneal and anterior segment parameters in normal and keratoconic eyes to better understand the geometry of the keratoconic cornea.

Method: 44 eyes from 44 keratoconic patients and 44 eyes from 44 healthy patients were included in the study. The Pentacam System was used for the analysis of the anterior segment parameters. New *ad-hoc* parameters were defined by measuring the distances on the Scheimpflug image at the horizontal diameter, with chamber depth now comprising of two distinctive distances: corneal sagittal depth and the distance from the endpoint of this segment to the anterior surface of the lens (DL).

Results: Statistically significant differences ($p < 0.05$) between normal and keratoconic eyes were found in all of the analysed corneal parameters. Anterior chamber depth presented statistical differences between normal and keratoconic eyes (3.06 ± 0.43 mm versus 3.34 ± 0.45 mm, respectively; $p = 0.004$). This difference was found to originate in an increase of the DL distance (0.40 ± 0.33 mm in normal eyes against 0.61 ± 0.45 mm in keratoconic eyes; $p = 0.014$), rather than in the changes in corneal sagittal depth.

Conclusion: These findings indicate that keratoconus results in central and peripheral corneal manifestations, as well as changes in the shape of the scleral limbus. The DL parameter was useful in describing the forward elongation and advance of the scleral tissue in keratoconic eyes. This finding may help in the monitoring of disease progression and contact lens design and fitting.

1. Introduction

Keratoconus is an ectatic corneal disorder, characterized by progressive thinning of the stroma and cone-like protrusion, which may lead to irregular astigmatism, myopia and severe visual impairments [1]. Several topographical descriptors have been introduced to characterize the anterior corneal shape in keratoconus, thus aiding in the detection of this condition [2]. However, early keratoconus detection has been found to require the combined analysis of anterior and posterior topographic parameters, as well as, several specific indices and descriptors, usually software or hardware dependent [2,3]. Tools, such as the Scheimpflug Imaging System, have been used in several studies to measure corneal curvature parameters [4–6], corneal thickness in healthy [7,8] and keratoconic eyes [9] and other anterior segment parameters in keratoconic eyes, including the depth of the anterior chamber [6].

The anterior corneal surface sagittal concept has been traditionally used to describe the relationship between the change in corneal power and the ablation depth in refractive surgery techniques, as well as the changes in corneal thickness associated with orthokeratology [10]. Although corneal sagittal assessment has been introduced in the fitting of soft contact lens of healthy corneas [11], many contact lens fitting guides still rely on corneal radii as the parameter to be considered for the selection of the first trial lens, even in keratoconic eyes [12]. In searching for better parameters, corneal sagittal depth, as measured by optical coherence tomography (OCT), has been used to fit scleral contact lenses [13] and to improve the description of the shape of the peripheral cornea in healthy [14] and keratoconic eyes [15].

The present study aimed at examining a selected range of corneal and anterior segment parameters in the keratoconus detection framework. Although many of these parameters are provided by the Pentacam software, additional anterior segment parameters were manually measured on Scheimpflug images or derived from others. To the best of our knowledge, some of these additional parameters have not been described as tools to differentiate between healthy and keratoconic eyes. The purpose of the present analysis was to gain a better understanding of the

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overall corneal geometry in keratoconus, in particular to explore whether structural changes are predominantly corneal, limbal/scleral, or a combination of both. This information should be useful when designing new contact lens fitting strategies for keratoconic eyes, either as an alternative or to complement the traditional approach based on the assessment of corneal radii.

2. Method

2.1. Study sample

A group of patients with keratoconus was selected. The same corneal specialist diagnosed and classified all keratoconic eyes according to the Amsler-Krumeich classification [16]. For comparison purposes, an age and corneal diameter-matched control group of healthy patients was recruited. In order to match for age and corneal diameter, first a data base search was conducted to identify normal subjects with the same age (±2 years) as each of the keratoconus subjects. Subsequently, within the same age, eyes with similar corneal diameter (±0.2 mm) to the target keratoconus eyes were included in the control group. Eyes with a history of ocular or refractive surgery, ocular trauma, wearing contact lenses or suffering from a corneal pathology, other than keratoconus, were excluded from the study. All participants provided written informed consent after an explanation of the nature and possible risks and consequences of the study. The study was conducted in accordance with the Declaration of Helsinki tenets of 1975 (as revised in Tokyo in 2004).

2.1.1. Corneal and anterior segment parameters

The Pentacam Scheimpflug system (software version 1:18, Optikgeräte Oculus GmbH, Wetzlar, Germany) was used to analyse anterior and posterior corneal, as well as anterior segment parameters. All Pentacam measurements were conducted following the guidelines of the manufacturer. An experienced optometrist, masked to the purpose of the study and of the status of the participants (keratoconus or normal) conducted all Scheimpflug measurements. Three consecutive measurements were obtained of each eye and the best captures were selected for data analysis.

Although most of the parameters that underwent evaluation were collected from the Pentacam output display, others required additional calculation, based on manual measurements conducted on the Scheimpflug images. Table 1 displays a summary of the parameters that were under consideration.

The Scheimpflug image closest to the horizontal meridian (180°) was chosen for image analysis. Given the difficulties for data acquisition without manually retracting the upper eyelid, the vertical corneal meridian was not explored. Firstly, a line was drawn from limbus to limbus, approximately parallel to the lens. The limbus was identified by the loss of corneal transparency, that is, by the white tone in the Scheimpflug image that marks the start of the sclera. For this purpose, the Pentacam software option “Show Pixel Edge” was employed to mark the boundary of the structures in the Scheimpflug images, selecting as a reference the first pixel belonging to the cornea at both limbi. The length of this line was defined as the horizontal white to white diameter (Øww). Secondly, starting from the highest corneal point of the image, which is identified by the software with a white line, a second line was drawn perpendicularly to the previous one, defining the 180° meridian sagittal height (SAGT_180). Finally, a third line was drawn from the end point of this sagitta to the anterior surface of the lens (distance to the lens, DL). The “Show Fitted Curve” option was used to define the boundary of the anterior surface of the lens when the line of pixels was interrupted. This option displays the mathematic curve, which better describes the previously detected edges of the image. In addition, the sagittal distance from the corneal endothelium at the horizontal meridian (SAGI_180) was also calculated by subtracting the corneal central thickness, provided by the software, from the corresponding sagittal values measured

Table 1
Corneal and anterior segment parameters assessed in keratoconus and healthy eyes. Parameters were provided by the Pentacam software, manually measured on the Scheimpflug images or derived from other parameters.

Parameter	Abbreviation
Corneal parameters (provided by the Pentacam software)	
Anterior flat keratometry (D)	Kmin_A
Anterior steep keratometry (D)	Kmax_A
Posterior flat keratometry (D)	Kmin_P
Posterior steep keratometry (D)	Kmax_P
Anterior central astigmatism (D)	Ant Ast
Anterior best-fit-sphere (mm)	BFS
Maximum anterior corneal elevation (μm)	Elev_A
Maximum posterior corneal elevation (μm)	Elev_P
Maximum anterior refractive power (D)	RP
Eccentricity	Ecc
Central corneal thickness (mm)	Ct_central
Corneal thickness at the thinnest point (mm)	Ct_min
Corneal volume (mm^3)	CV
Distance from the pupil centre to the corneal apex (mm)	C_A
Anterior segment parameters (provided by the Pentacam software)	
Anterior chamber angle (degrees)	ACA
Anterior chamber volume (mm^3)	ACV
Anterior chamber depth from corneal endothelium (mm)	ACD_end
Anterior segment parameters (derived from the Scheimpflug image)	
White-to-white horizontal diameter (mm)	Øww
Sagitta (180° meridian) from corneal endothelium (mm)	SAGI_180
Distance to the lens[a] (mm)	DL_180
Distance from corneal endothelium to the lens (180° meridian) (mm)	ACD_end_180

[a] Distance from the endpoint of the sagitta measurement (180° meridian) to the lens.

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