Measurement of Corneal Thickness By Videopachymetry: Preliminary Results

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ABSTRACT

Corneal thickness measurements find applications in areas such as diagnosis and management of corneal disorders and corneal surgery. We present a technique for the measurement of corneal thickness using a CCD camera mounted on a slit-lamp biomicroscope and common image processing software. Thickness measurements were performed on three RGP contact lenses of known thickness with an average error of 5 µm, SD of 8 µm. Measurements of a living cornea yielded a thickness of 505 µm and a SD of 8 µm for 10 consecutive measurements; this is an acceptable value. [*J Refract Surg* 2000;16:S661-S663]

Precise measurements of corneal thickness are necessary in the diagnosis and management of several corneal disorders, in corneal surgery, as well as the evaluation of corneal tolerance to new contact lens materials.[1,2] Several techniques have been developed for the clinical measurement of corneal thickness, optical pachometry being the most commonly used for many years. This usually consists of a Haag-Streit pachometer mounted on a slit-lamp microscope. However, other techniques are also used to measure corneal thickness.

Non-contact specular microscopes[3], contact specular, and confocal microscopes[4] have been used to measure corneal thickness. Fujimoto and colleagues[5] used the femtosecond optical ranging technique to determine the corneal thickness of anesthetized rabbit eyes in vivo, and Hitzenberger[6] measured corneal thickness by low-coherence interferometry. Hjortdal and colleagues[7], using digital image processing, measured the corneal thickness in vitro.

Ultrasound pachymetry is currently described as a rapid and precise method for the measurement of corneal thickness.[8,9]

In recent years, the optical methods for corneal thickness measurement have improved. The Orbscan Topography System[10] is a new optical-based method that uses anterior and posterior corneal surface profile data to calculate corneal thickness. Recently, a new photo-pachymeter[11], and a new videopachymeter[12] have been developed.

We present a technique for the measurement of corneal thickness using a CCD camera mounted on a slit-lamp biomicroscope and straightforward image processing software. Using a slit-lamp light beam, we obtain an optical section of the cornea, where we can distinguish two bright lines corresponding to the tear film and the endothelium separated by a gray zone corresponding to the stroma. Tear film and endothelial edges are accurately detected by the image processing, and living corneal thickness can be obtained from the image by simple calculus.

METHODS

The system consists of a CCD camera (COU 2252) mounted on the observation arm of a Takagi (model SL 70) slit-lamp biomicroscope. Slit-lamp images are digitized and sent to a computer for processing with appropriate software (Fig 1).

The binocular microscope was placed perpendicularly with respect to the central corneal plane, and the light source had an angular separation of 50° from the microscope. Magnification of the microscope used was 40x for all contact lens images and 25x for corneal images.

To verify the accuracy of the technique, thickness measurements were taken on three RGP contact lenses of known thickness (0.15 mm; 0.17 mm; 0.18 mm) mounted in a support.

After acquiring the image, a vertical edge enhancement algorithm was applied to the original image to enhance the contact lens borders or the tear film and endothelial borders when images were

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taken on a real cornea (Fig 2). The error induced by the assumption of the tear layer as the anterior limit of the cornea can be considered negligible.

With appropriate software, we obtained the light intensity profile across the cornea over the measurement line (Fig 3A). The apparent corneal thickness (AT) was taken as the distance between the two intensity peaks (Fig 3B). Real corneal thickness (RT) was calculated using equations 1 and 2 (Fig 4).

RESULTS AND DISCUSSION

Nominal thickness value, mean, and standard deviations of 10 readings taken on three RGP contact lenses are shown in the Table.

Standard deviation from the 10 measurements for each lens was slightly higher than that reported by other authors who took measurements with optical and ultrasonic pachymeters; 7 and 6 µm, respectively.[13] These authors measured lens thickness with a mechanical gauge, and then compared this with thickness measurement of ultrasonic pachymetry, obtaining values systematically lower with the ultrasound pachymeter.

This also was found when corneas were measured in contact lens wearers.[14] In this case, the videopachymetric technique offered values slightly higher than those reported by the manufacturer.

Ten readings of the central corneal thickness were taken in a male subject. Mean corneal thickness was 505 µm with a standard deviation of 5 µm. This level of precision is in agreement with that of Patel and coworkers[15]—standard deviation ranged from 3 to 12 µm for ten readings of central corneal thickness using optical pachymetry and 12 to 17 µm

Table
Measurement of Contact Lens Thickness

Nominal Value (µm)	Mean (µm)	Standard Deviation (µm)
0.15	0.152	0.009
0.17	0.174	0.008
0.18	0.190	0.008

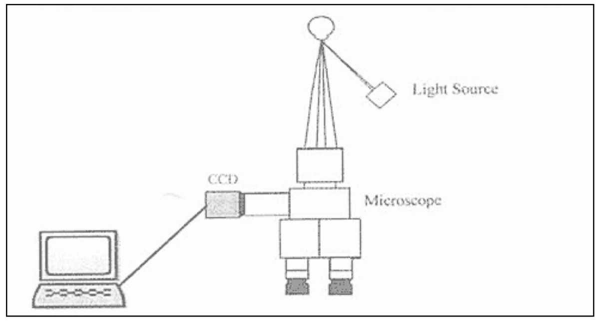

Figure 1. Schematic view of the system.

using ultrasound pachymetry.

Yaylali and colleagues[10] obtained a standard deviation of 7 µm with the Orbscan Topography System and with ultrasonic pachymetry. The same value was found with laser Doppler interferometry.[16]

The preliminary findings for thickness of contact lenses obtained with this simple videopachymetric method are in agreement with values reported by the manufacturer and compare well with those obtained with more complex techniques.

The method needs to be tested on lenses with thickness values closer to normal corneal thickness because, as shown by Ling and colleagues[13], measurement error can be slightly higher with thicker lenses. Different sources of error may be present, such as optical system alignment or insufficient refinement of image processing and edge determination.

Upon elimination of the present error sources, based on these preliminary findings, it is expected that the technique will evolve to an inexpensive procedure for rapid and precise determination of central and peripheral corneal thickness. Some additional advantages with respect to other commonly used pachymetric techniques are the fact that anesthesia is not needed (as in ultrasonic pachymetry) and, compared to optical pachymetry, there is independence from observer intervention in the alignment of the corneal epithelium and endothelium layers, which could be another source of error.[17] Less training is required to utilize this

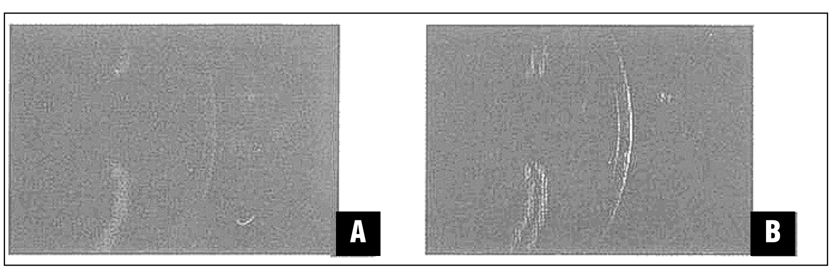

Figure 2. Image of a corneal section **A)** before, and **B)** after vertical edge enhancement.

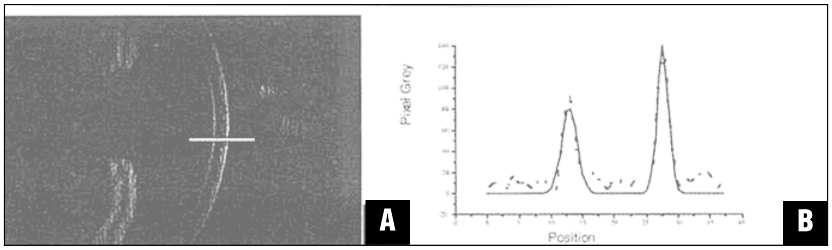

Figure 3. Measurement of corneal thickness. **A)** Profile of the cornea, and **B)** distribution of the intensity along a direction.

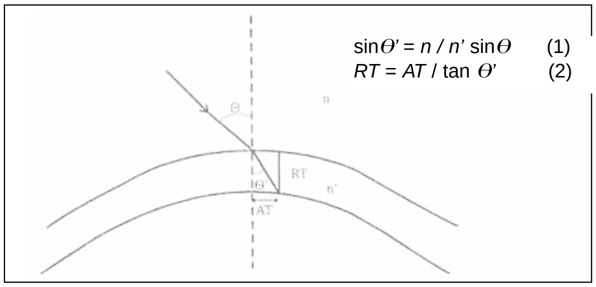

Figure 4. Determination of real corneal thickness.

technique, reducing the variability in optical pachymetry.[18,19]

Present results and other imminent improvements will make the present technique a non-invasive and more objective procedure than ultrasonic pachymetry and classical optical pachymetry. The main applications for this instrument are in the field of corneal physiology related to contact lens research and diagnosis and management of corneal diseases with alterations in corneal thickness.

These preliminary results are encouraging but it is still necessary to evaluate accuracy and reproducibility of this method with corneas. Although the method still needs improvement, the fact that it uses only standard instruments and readily available image processing software makes it attractive and provides a broad field of applications. Remaining problems with the instrument have to do with alignment, which has to be improved so that we know precisely the angle between the light source and the microscope, and with the exact determination of the corneal point that is being measured. This may imply the use of some kind of target. Another application for this system is the study of the curvature of both corneal surfaces using the images of the corneal profile; the processing algorithm is already under development.

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