Fusion of information from Keratoscopic and Scheimpflug images

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ABSTRACT

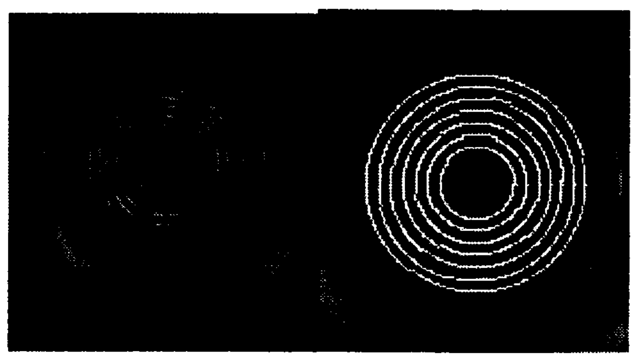
Topographic analysis systems used to analyse the cornea profile have some limitations due to the aspheric nature of the cornea. In many cases the cornea is modelled by a spherocylindrical surface. However the normal cornea is aspheric and flattened from the center to the periphery. Moreover diseased and postsurgical corneas rarely approximate a spherocylindrical surface. Topographic analysis systems based on Keratoscopic images provide quantitative information by comparing the mire diameters from corneas to those reflected from standard reference spheres and by measuring hemichord lengths. In this paper we describe an aproach we have developed to improve the topographic reconstruction of the cornea by combining Keratoscopic and Scheimpflug images.

1. Introduction

Current topographic systems are unable to analyse severely distorted Keratoscope mires. Therefore a number of problems prevent the parametric descriptors of the corneal topography from achieving high precision and accuracy in all cases[1]. We propose to overcome this problem by combining Scheimpflug and Keratoscopic images. Scheimpflug images are obtained from a plane that is a meridian containing the optical axis of the eye. We are using four Scheimpflug images spaced 45° apart, enabling the characterization of the corneal asphericity[2]. We are developing methods to calibrate both Keratoscopic and Scheimpflug images. Keratoscopic images are only geometrically calibrated whereas Scheimpflug are both geometrically and radiometrical calibrated. These methods of calibration use reference eye model and take into account th optical characteristics of the Scheimpflu imaging device and of the Keratoscope.

2. Keratoscopic images

The photokeratoscope is a device that enabl the acquisition of images of the cornea's anteri surface. The photokeratoscope projects sever concentric circular mires on the cornea's anteri surface. The shape of those mires, reflected b the cornea, are imaged (Fig.1).



Imaged Detected circles

Fig.1

A normal cornea is modelled by spherocylindrical surface. The image reflecte by the cornea gives us information regarding th optical power of the anterior corneal surface[3 If the cornea is spherical, the reflected rings c light will appear circular, concentric and equall spaced from each other. If the cornea distorted, then the reflected rings will prese deviations from that shape[4]. The image rings will appear elliptical on astigmatic corneas, will be closer to each other on steeper corneas and will be spread out on flattened corneas. By measuring the radii of the several circles (generated by the rings) along different meridians it is possible to compute the corneal optical power at different points as well as to have an estimate of its topography[3][5].

3. Analysis of the keratoscopic images

From a keratoscopic image it is possible to estimate the tridimensional configuration of the cornea, by using the coordinates of several points located on the rings reflected by the cornea.

Fig.2 represents a schematic cuting, showing the emmited light by the first keratoscopic ring, its incidence on the cornea followed by reflection which is imaged by a camera whose optical axis is oriented along the cornea axis.

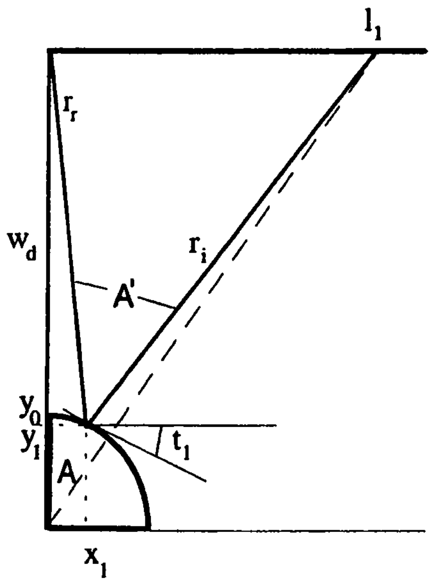


Fig.2

X_1 represents the circle radius reflected in that point, while y_1 is the cornea elevation in the same point, relatively to the plane that passes through the cornea's curvature center and is orthogonal to the cornea axis. The distance l_1 is measured on the instrument, and the distance w_d has a fixed value, assuming that the phototokeratoscope is focused to the middle of the patient's cornea. By inspection of the Fig.2 we can establish the equation:

$$y_i = y_{i-1} - \frac{(x_{i-1} - x_i)(\cos t_{i-1} - \cos t_i)}{\sin t_{i-1} - \sin t_i}$$

in which t_i is the angle between the horizontal and the tangent to the cornea surface in the point (x_i, y_i).

The angle t_i can not be calculated by an exact analytical expression, so it is calculated by an iterative process, being initialized to $A/2$.

Knowing the (x_i, y_i) points and the angles of their meridians, we have the tridimensional characterization of the cornea. The curvature radii (rc_i) in the (x_i, y_i) points are calculated by the expression $rc_i = x_i/\cos(\pi/2 - t_i)$. These radii allow us to get the dioptric power on those points by the expression $D_i = 337.5/rc_i$, in which rc_i is expressed in millimeters, and the numerator is the gradient in refractive index between air and the eye.

The measures obtained from the photokeratoscope images are affected by several sources of error, that we can point out:

- Earlier analyses[3] have considered the cornea's radius of curvature at the center (Y_0) as having a standard value of 7.8mm. This biases the calculations on markedly flattened or steeped corneas. More recent analyses[5] estimate the parameter Y_0 by computing the average radius $(\bar{x}_1)$ from the first keratoscope cornea ring image, and then using the equations:

  $$\bar{y}_0 = \frac{\bar{x}_1}{\sin\theta}\ ; \quad \theta = \frac{\operatorname{atan}\left[\frac{l_1 - \bar{x}_1}{w_d}\right] - \operatorname{atan}\left[\bar{x}_1/w_d\right]}{2}.$$

  This estimated elevation is not very accurate when used with keratoscopes having the innermost ring too large to cover the cornea's central zone.
- Another source of inaccuracy is the incertitude in how well the focusing of the instrument was done by the operator. This originates two sources of lack of precision:
  - A wrong value of w_d in the equations, biasing all the results;
  - Non collinearity of the instrument optical axis relatively to the cornea optical axis,

because there is a radial decentration, or a tilting between the cornea and the orthogonal plane to the instrument optical axis. This causes the appearence of images with elliptical rings, suggesting a false astigmatism.

We propose to extract information from Scheimpflug images to correct the inaccuracy of keratoscopic images.

4. Scheimpflug images

The Scheimpflug is a device that acquires images from a plane containing the optical axis of the eye. The Scheimpflug principle allows us to get images of the ocular structures of the eye's anterior segment, namely cornea, anterior chamber and lens. With this instrument it is possible to get images in any meridian containing the optical axis (Fig.3).

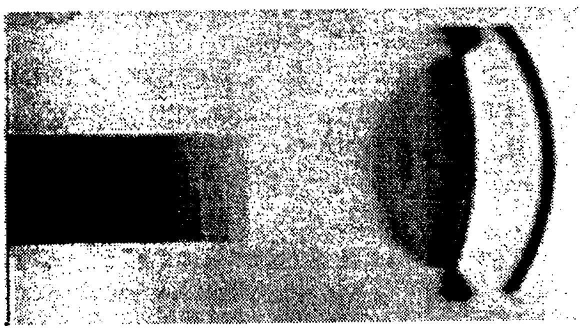


Fig.3

From one single scheimpflug image we can obtain the cornea thickness and the radii of curvature in every point of that meridian with a good accuracy. It is possible too to estimate the location of the optical axis. To obtain this estimate the eye's lens is used. By combining two or more images, we can get more information. Using a set of Scheimpflug images it is possible to verify whether or not the cornea's axis is coincident with the optical axis of the eye's lens and also to compute the angular deviation between the direction of the two axes.

5. Combining data from images

By using the keratoscopic image it is possible to predict the profile of the cornea's external surface along the meridian corresponding to Scheimpflug image. If any deviations are foun out a procedure is then used to decrease the errc in the estimate of the center's location as well ε of the different radii calculated in th keratoscopic image. These parameters were use to improve the accuracy and precision of th various topographic parameters computed froı the Keratoscopic image.

Using four scheimpflug images we hav calculated in each one:

- The cornea axis,
- The radii and dioptric power in severa points of that image's meridian. Thos points are selected so that their distances t the cornea axis (x_i) are the same as th distances of the points selected in th keratoscopic images.

Radius Direction	Image radius	Cornea elevation	Dioptric power	Corrected Dioptric power
000	2.482353	7.412161	43.139545	43.041748
015	2.482353	7.418444	43.141991	43.099850
030	2.482353	7.424314	43.144279	43.102165
045	2.482353	7.428493	43.145908	43.181923
060	2.482353	7.432294	43.147392	43.561913
075	2.482353	7.433647	43.147919	43.562370
090	2.482353	7.430908	43.146851	43.976185
105	2.482353	7.425581	43.144775	43.672050
120	2.482353	7.421442	43.143162	43.670685
135	2.480284	7.418607	43.180878	43.420940
150	2.457530	7.423668	43.614235	43.668293
165	2.459598	7.421751	43.573936	43.627949
180	2.482353	7.414068	43.140285	43.002552
195	2.482353	7.413172	43.139938	43.036991
210	2.482353	7.411943	43.139458	43.036495
225	2.482353	7.410461	43.138882	43.063179
240	2.467873	7.412781	43.412899	43.700207
255	2.436843	7.420558	44.012154	44.303516
270	2.420294	7.424632	44.338005	45.018871
285	2.420294	7.424945	44.338131	44.780910
300	2.420294	7.426154	44.338615	44.781330
315	2.447186	7.421849	43.812252	44.045513
330	2.478216	7.416677	43.219013	43.273182
345	2.482353	7.417455	43.141609	43.195671

Table 1. Dioptric power corrected with data from Keratoscopic and Scheimpflug images

Considering that the measures obtained froı scheimpflug images have a better accuracy tha the measurements obatined from keratoscopi images, they were used to replace th

measurements done in the corresponding locations of the keratoscopic map.
The points on the keratoscopic map that do not have corresponding locations on the scheimpflug map, are corrected by interpolating the measurement differences found on both maps, in the neighborhood of each position[6][7][8]. The computation is performed by means of a weighted average of the six closest neighbors measurements. The weights are inversely proportional to the distances between the neighbors and the point whose measurements are to be computed.

6. Conclusions

By combining cornea images obtained from different devices, we can improve the accuracy in the three-dimensional reconstruction of the cornea. One of the devices provides measurements with good accuracy whereas the other one (the keratoscope) provides dense measurements (but affected by inaccuracies). Using only Scheimpflug images a 3D reconstruction of the cornea would not be very accurate because from each patient only a maximum of 4 images (in normal clinical practice) are acquired. On the other hand a single keratoscopic image provides much more data points, but the measurements are affected by several sources of error that may severely distort any 3D cornea reconstruction performed by using only keratoscopic information. By using the scheimpflug information it it possible to obtain a better quality and better accuracy 3D reconstruction of the cornea.
Another approach we are using is based on a computed keratoscopic map. From this map the steepest and flattest meridians and other representative directions are computed and localized. That information is used to define the orientation of the Scheimpflug images. Based on these Scheimpflug images a new reconstruction of the corneal surface is performed enabling the computation of higher precision and accuracy topographic parameters.
The 3D reconstruction of the cornea surface is extremely useful for several medical procedures namely to the manual or laser excimer surgery of the cornea. It is also important to evaluate the evolution of the cornea after surgery as well as when subjected to different types of treatment.
We have used an heuristic calibration in this work. We are developing models and methods for a more accurate and precise calibration of the images, to achieve a 3D reconstruction of the cornea that may be considered as a safe medical information.

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