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Analysis of tear film break-up time based on the tear film surface quality obtained using Placido rings images

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ABSTRACT

Dry eye is one of the most reported eye health conditions and it is characterized by dryness, decreased tear production, or increased tear film evaporation. Middle-aged and elderly people are most commonly affected because of the high prevalence of contact lens usage, systemic drug effects, autoimmune diseases, and refractive surgeries. Corneal topography images have been recently used for noninvasive assessment, based on the Placido rings pattern. The rings in normal eyes are smooth and have no distortion, whereas they are distorted in affected eyes. We developed a method of analysis that process the corneal topography image to determine the Tear Break-up Time (TBUT), using the Tear Film Surface Quality (TFSQ) measurement. To avoid distortions not caused by the tear film break-up, the method dynamically removes eyelashes shadows from the image processing area. The results show that the proposed analysis is able to determine the TBUT based on the graphical analysis, and it can be used to help eye care specialists to diagnose dry eye disease.

Keywords: Tear break-up time, tear surface quality, Placido rings image

1. INTRODUCTION

Tear film, or tear, is a fluid produced by a set of glands and cells, responsible for ocular nutrition, protection against microorganisms, and lubrication of the eye.¹ The healthy maintenance of the tear depends on the balanced production of each of its three layers: lipid, aqueous, and mucoid. The outermost lipid layer is responsible for protecting and preventing early evaporation of the aqueous layer, which contains substances and nutrients to maintain eye health. The mucoid layer, on the other hand, ensures even tear spread on the surface of the eye.

The Dry Eye Disease (DED) is a tear-producing dysfunction, causing deficiency in some of the tear film layers, which often leads to early tear evaporation. This syndrome is considered very common among eye-related problems, and its symptoms range from eye discomfort to blurred vision and sensitivity to light.

There are different techniques to measure the tear film quality, and they are classified in two categories: invasive and noninvasive methods. Invasive techniques consist of the insertion of some substance or artifact into the patient's eye in order to measure the tear film quality; these techniques, however, present a high risk of contamination as well as low repeatability and sensitivity, providing an unreliable diagnosis.² Noninvasive techniques, on the other hand, eliminate contact between the eye and the measuring instrument, and do not require the introduction of any substance into the eye or even forced blinking.³

Among the noninvasive techniques, High-Speed Videokeratography (HSV) has emerged as a potential tool for the analysis of the integrity of the tear film.³ This technique uses the Placid Disc, which consists of concentric rings, distributed along a cone which, on corneal topographers, are projected over the cornea and reflected by the tear film. One way to evaluate the tear film quality using a noninvasive technique is measuring the Tear Break-up Time (TBUT), proposed by Norn,⁴ that is defined as the time between a full blink and the first considerable spot of dryness; on the HSV method this dryness is detected by distortions of the reflected rings.

This study explores the possibility of determining the TBUT using both the Tear Film Surface Quality (TFSQ) index, proposed by Downie,⁵ and a graphical analysis of this index. It may be useful for eye care specialists since the analysis is able to show the evolution of the measurement over time.

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2. METHODOLOGY

To determine the TBUT, a video of the evolution of the Placido Rings is taken and the images are individually analyzed. The images were obtained from both eyes of seven patients using the Saturn 32 (EYETEC, Brazil), which contains 32 Placido rings. These images were processed and a resulting parameter was computed for each of them. The evolution of this parameter was fitted over time, making it possible to determine the TBUT value from the graphical analysis.

2.1 Image Processing and Measurement Extraction

The process of obtaining data for the proposed analysis consists of three steps: (i) definition of the area of analysis in the image to remove interference caused by the shadows of the eyelashes; (ii) edge detection; (iii) calculation of the TFSQ index. The corneal topographer used to acquire the images was Saturn 32 (EYETEC, Brazil), composed of 32 Placido rings.

The area of analysis is calculated according the processing techniques proposed by Alonso-Caneiro and colleagues.⁶ The first step of the method consists of a set of statistical image processing techniques that normalize the image, perform frequency estimation, Gabor filtering, and image segmentation to locate the areas of potential instabilities in the videokeratoscopic image. In this filter, the potential areas of instabilities in the videokeratoscopic image are related to the corresponding areas in the originally estimated corneal topography map and excluded from further analysis. This method maximizes the area of analysis by excluding interference related to eyelashes shadows. The resulting image is shown in Figure 1b. After the definition of the area of analysis, the image is transformed to polar coordinates and an edge detection algorithm is applied. The result of this step is an edged image, shown in Figure 1c.

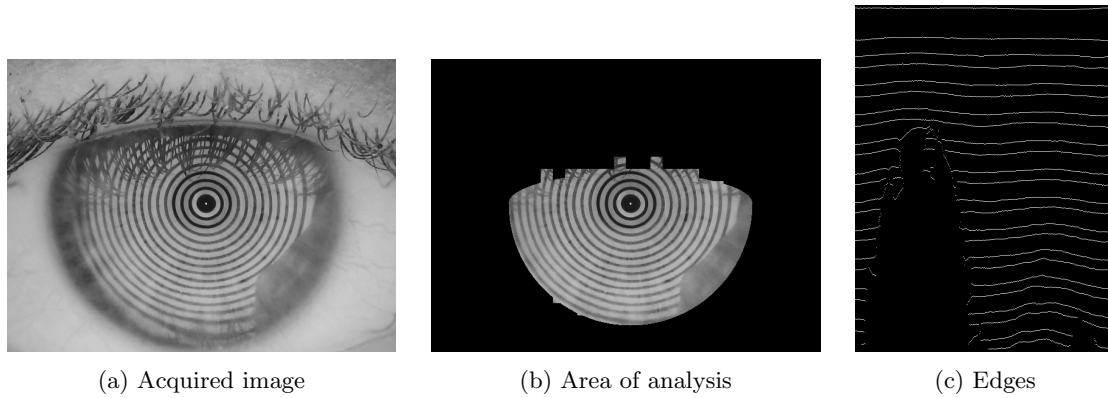


Figure 1: Videokeratotomy image processing steps

From the resulting edges the software calculates TFSQ index using the approach described by Downie.⁵ For a given image k , the $TFSQ_{k,i}$ value is calculated for each pixel of edge by finding the standard deviation of the $n = 4$ neighbors either side of the analysis point. First, the average ring width at the pixel i is calculated as (the k index is suppressed in the following equations to keep clearer equations).

$$w_{av_i} = \frac{\sum_{j=i-n}^{i+n} w_j}{n} \quad (1)$$

Then the standard deviation of the $n = 4$ neighbors either side is calculated by

$$SD_i = \sqrt{\frac{\sum_{j=i-n}^{i+n} (w_j - w_{av_i})^2}{n}} \quad (2)$$

Finally, the TFSQ index for each pixel of the image ($TFSQ_i$) is calculated considering w_{av_i} and SD_i values

$$TFSQ_{k,i} = 100 \left(\frac{SD_i}{w_{av_i}} \right)^2 \quad (3)$$

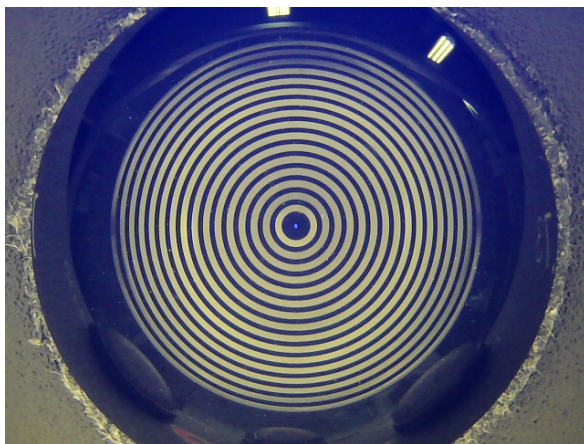
According to Downie,⁵ a $TFSQ_{k,i}$ value of 0.30 or greater corresponds to visible distortion in the ring pattern. Therefore, the TFSQ index for each image ($TFSQ_k$) is given by the percentage of all $TFSQ_i$ of the image that are greater than 0.30 as

$$TFSQ_k = \frac{1}{n} \sum_{i=0}^n (TFSQ_{k,i} \geq 0.3) \quad (4)$$

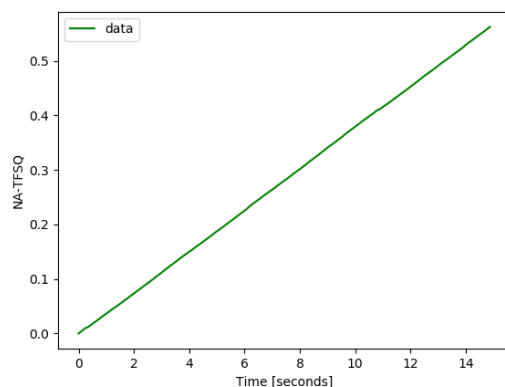
To determine the TBUT, we introduced the Normalized Accumulated Tear-film Surface Quality (NA-TFSQ), which is the accumulated values of $TFSQ_k$ ($k = 0..m$, where m is the number of images) through time. The plot of the NA-TFSQ shows dynamic changes on the TFSQ, since this parameter changes according to the quality of the tear film. For a healthy eye, the NA-TFSQ should be linear, since no significant changes on the TFSQ are observed, while for a dry eye, the NA-TFSQ may present a non-linear behavior, as the accumulated TFSQ drastically increases when the tear film breaks up. Therefore, the TBUT can be determined when the NA-TFSQ behavior starts a non-linear through time.

2.2 Data Analysis

In order to determine the TBUT using the NA-TFSQ measure, an auxiliary line is fitted using the Least Squares method incrementally. In cases that there is no tear break-up, the NA-TFSQ values have linear behavior over time as the TFSQ value must be the same for all videokeratometry images. Due to the mentioned linear behavior, the fitted line used for the proposed data analysis consists of a line of type $y = \alpha x + \beta$. Since the first value of NA-TFSQ is zero, the point (0,0) has been fixed for use on all fits, so that all auxiliary lines cross this point and therefore, $\beta = 0$. Figure 2 shows an example of graphical behavior for a set of videokeratometry images that present smooth and well oriented rings pattern.



(a) Smooth and well oriented rings



(b) NA-TFSQ values for a non break-up example

Figure 2: NA-TFSQ behavior for non break-up videokeratometry images

The analysis proposed in this study consists of increasing iteratively the number of points considered in the Least Squares method; at each iteration, i , it is determined the value d_i as

$$d_i = NA-TFSQ_i - \alpha x_i \quad (5)$$

While value of d_i is below a certain threshold, the number of points considered is increased. When the threshold is reached or exceeded, then the TBUT is determined as x_T . Figure 3 shows an example of analysis: the green curve is the NA-TFSQ taken from videokeratometry images of a 15 seconds video; the red line is the result of the Least Squares method for all points in the range $[0, x_T]$; and the blue line is the x_T , that represents the TBUT. The considered threshold was empirically defined as $t = 0.005$, considering previous diagnostic observations.

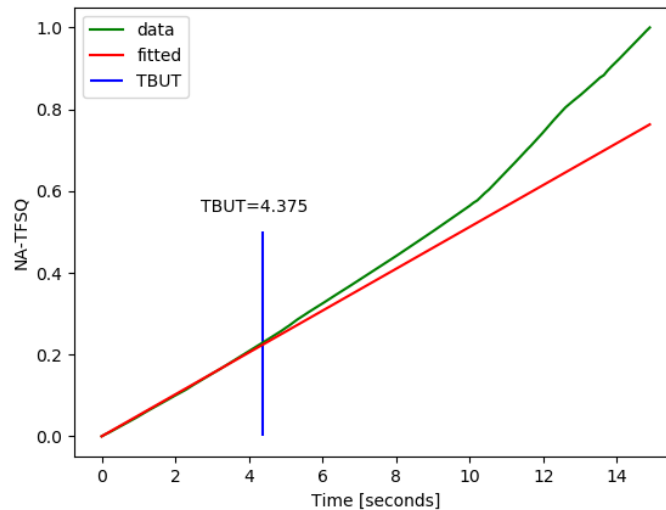


Figure 3: Example of analysis considering the NA-TFSQ value and the auxiliary line

2.3 Data acquisition

To acquire the videos, the patients were asked to blink twice and keep the eye opened as long as they could. As soon as they finished the second blink, the video recording was started and stopped after 15 seconds of test. In cases where the patients were not able to keep the eye opened during the whole test, the video was stopped at that point and the result was still considered as valid.

3. RESULTS AND DISCUSSION

Figure 2b shows the NA-TFSQ for a reference glass sphere. The linear behavior is observed due to the TFSQ keeps unchanged during time. In Figure 4a the NA-TFSQ starts drastically increasing in 2.6 seconds after the beginning of the test, showing a non-linear curve after this point. The Figures 4b and 4c show TBUT of 5.24 and 5.31, respectively. These patients were diagnosed with dry eye disease by ophthalmologist and their TBUT agreed with the TBUT obtained using the presented method.

Figure 4d, on the other hand, shows a result of a healthy eye without break-up occurrence. It is possible to observe that the NA-TFSQ has a linear behavior during the whole test, with low dispersion of the fitted line. In other words, the parameter d is lower than the threshold for all the points, meaning there was no tear film break up during this test. Although the NA-TFSQ seems to be greater in Figure 4d than in Figure 4a-4c for time of 15 seconds, it is only the normalization method, that normalize data by the last value of NA-TFSQ of each test.

4. CONCLUSION

The NA-TFSQ shows linear and non-linear behaviors for healthy and dry eyes, respectively. According to the results, the point where it starts a non-linear behavior determines the TBUT. This method was tested and agreed with the TBUT measured by an ophthalmologist, showing it can be used to help eye care specialists to diagnose dry eye disease. Using the NA-TFSQ for this diagnosis is important since it contains information of the TFSQ

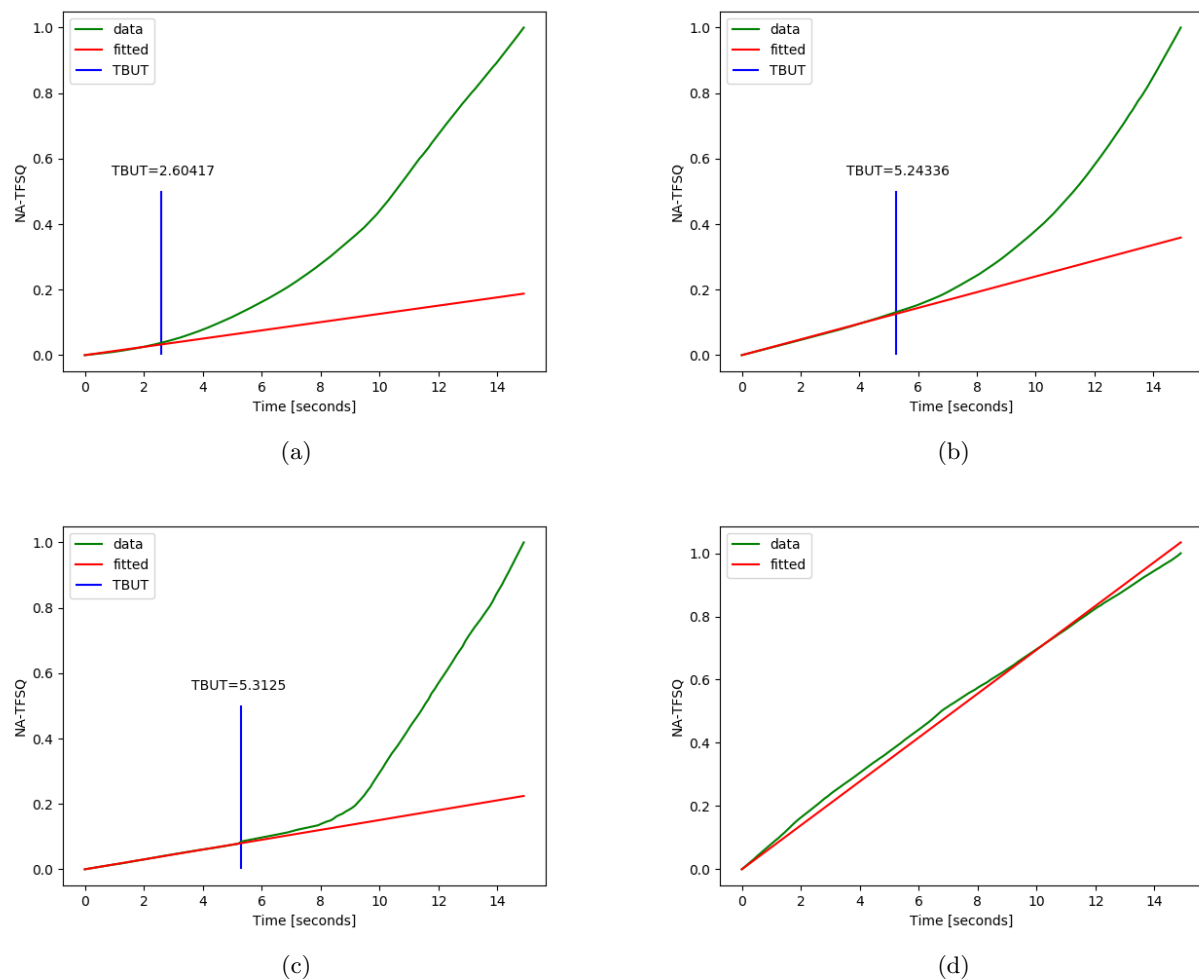


Figure 4: Results obtained by the proposed analysis

thorough time and keeps a correlation between the images of the test. This makes the method more reliable on determining the TBUT.

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