tear film, interferometry,
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ANALYSIS OF THE TEAR FILM KINETICS BY NUMERICAL FILTERING OF INTERFEROGRAMS

The purpose of this paper is to test the kinetics of precorneal tear film stability and the stabilisation process during the short period after blink. The interferometric measurement was used to register the distribution of the tear film over the cornea with frequency of 25Hz. The information about tear film smoothness is coded in interference fringes. Three stages of the tear film stability can be distinguished. For numerical assessment of the first stage – the build-up time – the fast Fourier transform and low-pass filter were applied. Immediately after every eye blink a bright structure under the interference fringes is observed on healthy eyes. It disappears after a few seconds. This paper describes an attempt to verify the origin of this structure. It is similar to the corneal mosaic, however its changes in time, and vertical oriented lines indicate that the observed structure is very likely to be connected with eyelid movement and the spread of tears.

1. INTRODUCTION

The normal cornea *in vivo* is always covered by the thin tear film. It is a three-layered structure consisting of mucin, water and the most external lipid layer which retards evaporation of the aqueous layer [1]. From the optical point of view the role of the tear film is to create smooth refractive surface over the irregular corneal epithelium. However, the precorneal tear film is not stable in time. Immediately after the blink the tear film is redistributed across the ocular surface for a brief period. Evaporation then starts; the tear film becomes thinner and finally breaks up [1].

Following a blink it takes the tear film a certain time to build up and achieve the most regular surface [5,7,9]. The time interval has been termed “build-up time” by Nemeth [7]. Studies by Nemeth using the High-Speed Videotopographic device indicated clearly a 5-7 second period needed to reach the most regular tear film surface in healthy eyes. The stabilisation time was also observed by Iskander et al. [5] who applied the High-Speed Videokeratoscopy and calculated the indicator based on the statistic error between the measured surface and its statistic model. In the case of a healthy eye the result of estimation was in the range of 1.5-7 seconds. Applying an interferometric method [9] and analysing the smoothness of the interference fringes depended on the regularity of the tear film surface, the increase of the tear film regularity was also observed as taking 1-3 seconds.

In this paper we try to consider the kinetics of the tear film smoothness. There are several suggestions about the reason for the stabilisation time. It has been found in *in vitro* [3] and *in vivo*

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[2] studies, that the tear film covers the corneal surface in two steps. First the mucin and water layers are spread and next the superficial lipid layer spreads over the surface. The tear film build-up time might be related to the regularity of the outermost layer of the tear film [7]. However, this process has not been well studied so far. Bron suggested that in the first seconds the irregular topography of the cornea might be observed, which he called the corneal mosaic. The mosaic is evidently seen on a dried cornea as a polygonal groove pattern [1].

2. METHOD

The tear film stability was measured using the lateral shearing interferometer proposed by Licznerski et al. [6]. The information about the distribution of the tear film over the cornea is coded in interference fringes. Evaporation of tears, their instability and the appearance of the breakups cause changes in fringe regularity. For quantitative assessment of the tear film surface the fast Fourier transform (FFT) was applied and parameters *M* were calculated [8, 9].

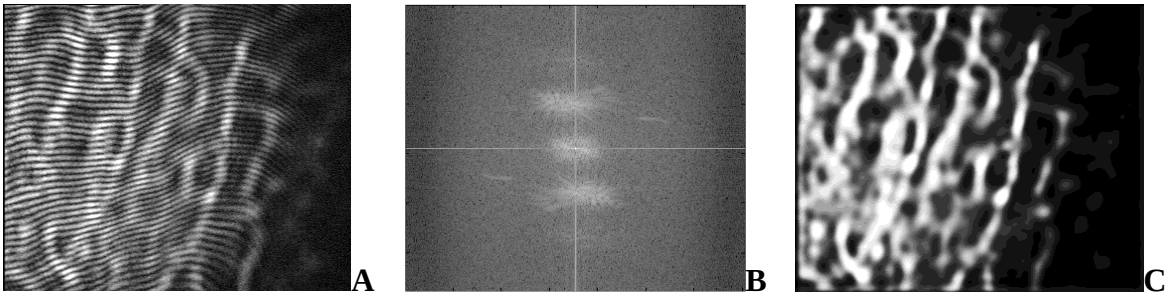

Fig.1 The method of the build-up time analysis. The frame from the sequence recorded 0.12sec after a blink (A), its Fourier spectrum (B) and the frame after filtering higher frequency (C).

The video sequences were recorded and then the frames with the selected time interval were pulled out for further analysis [9]. In order to verify the structures observed in the background of interference fringes just after a blink, a low-pass filter was applied (Fig. 1), using a Bartlett's window. Leaving only the zero order of the Fourier spectrum, which carries information about the background, the inverse fast Fourier transform was calculated ~~next~~. By this method we received the structure of bright lines for each frame, recorded every 0.04sec, in the first 1.2 sec. All the following frames were compared with the frame recorded 0.12 sec after a blink. By imposing two frames onto each other and their mutual shift, the computer program searches the position of their highest similarity by calculating the *rms* coefficient (equation 1.):

$$rms = 1 - \frac{\sqrt{\frac{1}{XY}\sum_{x}\sum_{y}\left((F_1(x_1, y_1) - F_2(x_2, y_2)\right)^2}}{255}, \tag{1}$$

where: F_1, F_2 are intensities of a given pixel, $x_{1,2}$, $y_{1,2}$ are co-ordinates of a given pixel, XY is the size of the similar area in the two images.

The higher the value of *rms*, the more similar are the compared frames.

3. RESULTS

Three stages of tear film kinetics can be distinguished (Fig. 2). The first one is build-up time, where interference fringes are disturbed and a bright structure is observed (Fig. 2A). After about 1-3 second the fringes become smooth and regular. This period we termed tear film stability (Fig. 2B). In the last stage a deterioration of the stability is observed. Bright lines appear where the fringes change direction. These areas are probably the break-ups (Fig. 2C).

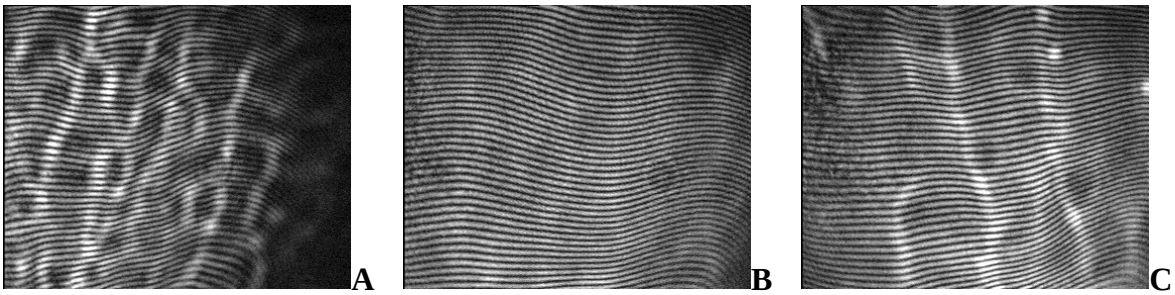

Fig. 2 Three stages of tear film stability. Sequence of frames recorded on the tear film of healthy eye 0.16 sec (A), 3.72 sec (B) and 18.52 sec (C) after blink.

The first stage is of most interest to us in this paper. Immediately after an eye blink the tear film stabilises. The sequence of frames after filtering the interference fringes is shown in figure 3. The white structure in both sequences has a vertical orientation. However, it becomes less evident through time. Comparing these images of the sequence with the first one, recorded 0.12 sec after a blink, we get the diagram presented in figure 4. The similarity of the next images decreases in time. The polynomial function of the sixth order was used for approximation. The rate of descent of the curve is different for both sequences.

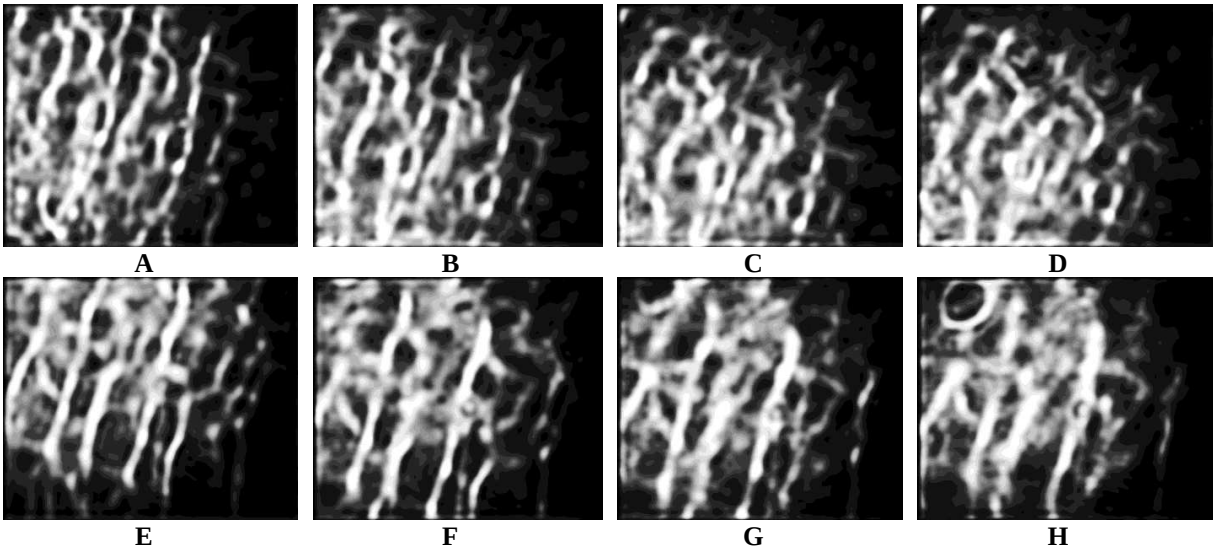

Fig. 3 Two sequences of frames after filtering, recorded on the tear film of the same healthy eye. Frames recorded 0.12 sec (A, E), 0.20 sec (B, F), 0.32 sec (C, G) and 0.52 sec (D, H) after blink.

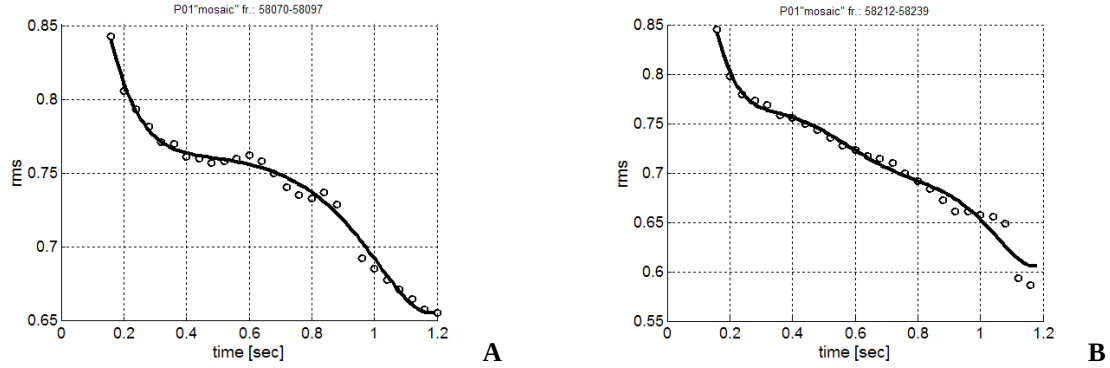

Fig. 4 The value of the *rms* coefficient as a result of comparing every subsequent frame with the frame recorded 0.12sec after a blink. The first sequence (A), the second sequence (B). The black line is a polynomial approximation.

5. DISCUSSION AND CONCLUSIONS

Our aim was to check if the observed structure under the interference fringes is related to the corneal mosaic or rather refers to the spread of tears. The observed bright structure can resemble the corneal mosaic in its shape. However, analysing the sequences just after the blink, we can notice that the bright structure become more blurred in time. If a corneal mosaic had been seen, it should not change in time, and a similar structure should be seen after each blink. The *rms* parameter illustrates the decrease of similarity of subsequent images. In addition, the frames recorded on the same eye in the same time after a blink, but from other sequences, differ from each other. The only common feature are vertical oriented bright lines, this probably indicates the movement of the eyelid during blinking. Our hypothesis correlates the structure with the spread of the inner layers of tears just after a blink, because the interference fringes, giving information mainly about the regularity of the lipid layer, are quite smooth.

BIBLIOGRAPHY

[1] BRON A.J., TRIPATHI R.C., The anterior corneal mosaic, British Journal of Physiological Optics Vol. 25, No. 1, pp.8-13, 1970.

[2] BENEDETTO D.A., CLINCH T.E., LAIBSON P.R., In vivo observation of tear film dynamics using fluorophotometry. Arch Ophthalmology, Vol. 102, No. 3, pp.410–412, 1984.

[3] BROWN S.I., DERVICHIAN D.G., In vitro study of the interaction of the superficial oily layer and the tears. Arch Ophthalmology, Vol. 82, No. 4, pp.541–547, 1969.

[4] HOLLY F.J., Tear film physiology, American Journal of Optometry and Physiological Optics, Vol. 57, No. 4, pp.252-257, 1980.

[5] ISKANDER R., COLLINS M.J., DAVIS B., Evaluating tear film stability in the human eye with high-speed videokeratoscopy. IEEE Transactions on Biomedical Engineering Vol. 52, No. 11, pp.1939-1949, 2005.

[6] LICZNERSKI T., KASPRZAK H., KOWALIK W., Analysis of shearing interferograms of tear film using Fast Fourier Transform, Journal of Biomedical Optics, Vol. 3, No. 1 , pp.32–37, 1998.

[7] NEMETH J., ERDELYI B., CSAKANY B., GASPAR P., SOUMELIDIS A., KAHLESZ F., LANG Z., High speed videokeratometric measurements of tear film build-up time, Investigative Ophthalmology and Visual Science, Vol. 43, No. 6 , pp.1783–1790, 2002.

[8] SZCZĘSNA D.H., JAROŃSKI J., KASPRZAK H.T., STENEVI U., Interferometric measurements of the tear film irregularities on the human cornea, Proc. SPIE Optics and Optoelectronics. Vol. 5959, pp.47-56, 2005.

[9] SZCZĘSNA D.H., JAROŃSKI J., KASPRZAK H.T., STENEVI U., Interferometric measurements of dynamic changes of the tear film. Journal of Biomedical Optics, Vol. 11, No. 3, 2006, i*n press*.