EMVPO2012_5667_031

Kinematics of eyelid movement and eye retraction in the blinking

J. Pérez[1,2], J. Espinosa[1,2], A.B. Roig[1], B. Domenech[1,2], D. Mas[1,2];
[1]University of Alicante, Dept. Optics, Pharmacology and Anatomy (ES); [2]University of Alicante, IUFACyT, San Vicente del Raspeig - Alicante, 03690 (ES).
Email: julian.espinosa@ua.es

Summary
A non-invasive technique is used to measure the eyelid closure and simultaneous eye retraction. We have fitted the displacement of the eyelid to an analytical function and have extended the kinematic model to the eye retraction movements. As a result, some dynamic parameters have been presented.

Introduction
Mas et al. [1] presented a non invasive technique for high speed measuring some of the dynamic processes that occur during blinking. The technique allows simultaneously measuring the corneal retraction and the eyelid motion during a spontaneous blink. We propose here an analytical model of the eye blinking including lid movement and ocular retraction. The setup for illuminating, capturing and processing the image of the anterior corneal segment was described in [1]. Briefly, the system consists on a slit lamp and an external fast camera working at 512 fps.
Lid displacement was monitored by studying the saturation of the frames in the sequence. Camera is adjusted to detect the light diffused from the cornea, therefore, light diffused by the eyelid saturates the sensor. By counting the number of saturated pixels in each frame, we can reconstruct the position of the eyelid. Eye retraction is evaluated by analysing a scanning line perpendicular to the inferior part of the cornea. After binarizing the image, cornea is detected from the presence of a white to black border. Pixel to millimetre calibration allows measuring the eye retraction.

Discussion
Upper eyelid motion starts when the Levator Palpebral Superioris muscle (LPSM) is inhibited and the eyelid performs a passive movement downwards. Simultaneous to the LPSM inhibition, the Orbicularis Oculi muscle (OOM) starts a fast contraction thus producing a strong active force. This combination of inhibition and activation of muscular action produces the closure phase of the eyelid. After the action of the OOM, the LPSM starts a restoration force which pulls up the lid to its initial position. Nevertheless, when the OOM action ceases, the upper lid keeps its movement down due to its inertia. The acceleration in the opposite direction makes that the absolute value of the velocity is slowly decreasing until the movement is reversed (Figure 1a).
We divide the blink process in two parts defined by the sign of the eyelid acceleration. The first one, the *active* part, goes from the start to the point of maximum absolute velocity and coincides with the active muscular action. The second part, the *recovery* part, covers the time from the peak velocity to the end of the blinking, being in this part when the forces pull back the lid to its original position. The mechanism for eye retraction inside the orbit is not so well known. Although our method does not permit visualization of the whole eye trajectory, we assume the presence of an *active* and a *recovery* phases. Both eyelid movement and eye retraction are therefore divided in two parts according to the sign of the acceleration, which can be described following (1)

$$X_l^a(t)=\frac{1}{12}bt^3(t-2\tau); \quad X_e^a(t)=\frac{1}{12}bt^4; \quad X_{e,l}^r(t)=A\exp(-\mu t)\cos(\omega t+\varphi) \qquad (1)$$

Parameters b, τ, ω and μ represent the strength of the muscle force, its actuation time, frequency of the oscillation and the attenuation constant of the system. Indexes l and e stand for lid and eye retraction, and a and r refer to *active* and *recovery* phase, respectively. The fitting function does not have any physical meaning; it is used to determine the instant of maximum absolute velocity, which happens at $t = \tau$.
The lack of data in the eye retraction analysis (Figure 1b) impedes the determination of the point with maximum velocity.

Results and Conclusions

Data from blinking of six subjects have been experimentally fitted to the equations (1). Results (mean ± standard deviation) are shown in (2).

$$
\begin{aligned}
&b_i=(11.7\pm15.4)\times10^3\,mm/s^4; && b_e=(-0.488\pm0.471)\times10^3\,mm/s^4;\\
&\tau_i=(51.1\pm16.5)\,ms; && \mu_e=(17.0\pm2.7)\,s^{-1};\\
&\mu_i=(10.8\pm2.4)\,s^{-1}; && \omega_e=(2.2\pm0.9)\,s^{-1};\\
&\omega_i=(12.5\pm2.6)\,s^{-1}; &&
\end{aligned}
\qquad (2)
$$

According to Figures 1a and 1b, matching between active and recovery phases occurred at the same time, but, while at that moment the eyelid has started the recovery phase, the eye is still under the effect of a pulling force.

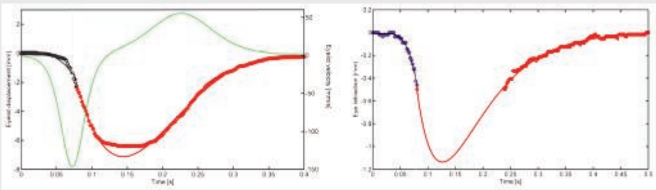

Fig. 1 a)Eyelid position and fitting to the model for one typical case. Green line shows eyelid velocity during blinking. b) Anterior corneal position and fitting to the model for one typical case. The vertical dashed lines marks the link between the two fitting curves (active and the recovery phases).

The method is non-invasive and provides accurate results and can be easily extended to the analysis of contact lens behaviour during blinking, which can be of importance in designing new compensation elements. In addition, obtained parameters can be of interest for analysis of biomechanical modelling of the eye or in neurophysiology due to the deep connection between blinking and neural activity.

References

[1] D. Mas, B. Domenech, J. Espinosa, J. Perez, C., Hernandez, C. Illueca, *Opt. Lett.*, **35**, 1884–1886, 2010.

[2] J. Perez, J. Espinosa, B. Domenech, D. Mas, C. Illueca, *J. Mod. Opt.,* **58**, 1857-1863, 2011.

Aknowledgements

Thanks to Spanish Ministerio de Ciencia e Innovación through the project FIS2009-05639-ET and BIA2011-22704, the Generalitat Valenciana through the project PROMETEO/2011/021 and the University of Alicante through the project GRE10-09. A.B. Roig thanks Fundación Cajamurcia the grant “Beca de investigación Cajamurcia 2010”