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Measurement and Analysis of the Air Pressure Curve on the Rigid Lenses by Use of Ocular Response Analyzer

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Purpose: Pressure curves obtained from Ocular Response Analyzer (ORA) differ for the same patient in form and height. In some cases measurements on the subject show significant differences between recorded pressure curves. The purpose of the paper is to examine if the differences result from the corneal properties or from the device operation.

Methods: Examination of air pressure curves was carried out on four plano-convex glass lenses with radii of curvature close to the central corneal radius. Lenses were mounted in front of the air jet of the ORA analyzer. Series of 30 measurements on each lenses were recorded with 20 s and 60 s time interval between measurements. Results were exported to computer and analyzed numerically.

Results: Results show much higher reproducibility of pressure curves in every series of measurements in comparison to pressure curves recorded on the patients eye. This demonstrates that ORA produces air pulses with high reproducibility.

Conclusions: Differences in air pressure pulses for the real eye can indicate the dynamics of ocular properties during measurements. Obtained pressure curves are not symmetrical and not well fitted by Gaussian curve. Type of asymmetry of air pressure curves may be explained by viscoelasticity of air.

Key words: *ORA, ocular viscoelasticity, intraocular pressure, air pressure curve*

1. Introduction

Ocular Response Analyzer (ORA, Reichert Ophthalmic Instruments) is the developed type of applanation air-puff ophthalmic instruments, which provides intraocular pressures (IOPg – Goldmann Correlated and IOPcc – Corneal Compensated), biomechanical properties of the cornea (corneal hysteresis – CH and corneal resistance factor – CRF) and about 40 more new parameters. It was demonstrated that basic data given by ORA could be useful in different ophthalmic diagnostics like glaucoma [10], [13], [15], keratoconus [1], [11] and others [12]. Thus, there has been many studies conducted in order to analyze accuracy and repeatability of measurements by elimination of undesirable external factors impact [6], [8], [14]. The great advantage of ORA is possibility to measure biomechanical properties of the cornea which can open new areas of ophthalmic diagnosis [3], [5]. However, 37 new parameters offered by ORA are not often used in ophthalmic practice [6].

All parameters given by ORA are calculated based on two curves given by the instrument software – air pressure and applanation curves. Each curve is represented by 400 data points, recorded within 25 ms. Almost all measured parameters are calculated from the applanation curve before or after its smoothing. However, not much attention is paid for the air pressure curve. Gatinel assumes [2] the pressure curve to be Gaussian shaped, Luce – the ORA inventor describes [4] the temporal and spatial pressure properties of an air jet. According to him, air pulse is repeatable and precise stimulus and can be characterized

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as a constant width Gaussian pressure distribution. Symmetrical shape of the pressure curve is also mentioned by Sathi Devi [9].

Pressure curve shape depends on intraocular pressure value according to the Main Guide of ORA, which means that maximum of the curve is higher for patients with higher intraocular pressure. Dianne Glass et al. [3] claim that higher pressure curve maximum value is associated with higher CH value.

While the most of ORA investigators are focusing on the applanation curve properties, there are not many articles, besides Luce's one, mentioned above, whose main subject would be pressure curve analysis. As it was mentioned, maximum value of the pressure curve depends on intraocular pressure value, and more particularly on the first applanation pressure value [9]. The first corneal applanation gives a signal to the device to stop applying air pulse to the object surface. Assuming constant intraocular pressure, the air pressure curve should have very similar form for every measurement on the same eye.

Aim of the paper was to analyze more precisely the form of pressure curves and their reproducibility, when no applanation appears during measurement and the air pump applies its full ejection pressure.

2. Materials and methods

Our observations of ORA's results exhibit that pressure curves can differ quite significantly for the same patient measurements. Figure 1 shows two groups of 8 pressure curves and their derivatives, measured by ORA on two patients in frame of our research grant. Pressure curves were smoothed using Gaussian kernel with bandwidth 7 before derivatives calculations.

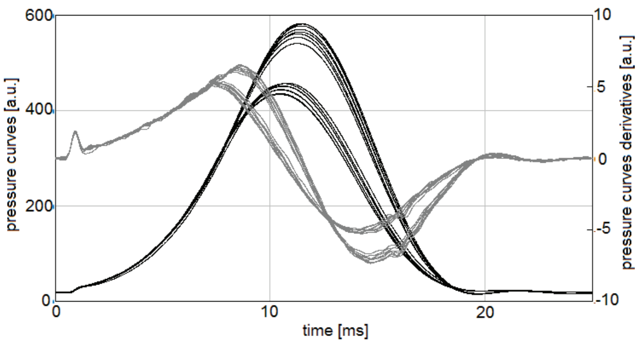

Fig. 1. Two groups of 8 pressure curves and their derivatives recorded on two patients

We used four plano-convex lenses made of optical glass BK7, prepared in our optical workshop with radii of curvature close to the corneal ones. Curvature radii of lenses were measured using MEDMONT E300 videokeratometer. Table 1 gives values of curvature radius of the each lens. Accuracy of curvature radius was about 0.1 mm.

Table 1. Radii of curvature of glass lenses

Lens number	1	2	3	4
radius [mm]	8.9	9.0	8.7	8.9

Each lens was mounted in metallic enclosure with a dark hole in the back, resembling the eye pupil. The lens was fixed in a mechanical stand, placed in front of ORA's head. The stand with the lens was aligned along the jet axis with the accuracy of about ±10°. Due to sphericity of the lens surface, such accuracy of alignment was sufficient since the ORA's head aligns automatically to the measured surface. Glass et al. [4] used also the corneal phantom in their examinations in form of the soft contact lens. However, in our case the applanation curves given by the device were almost constant.

There were 30 measurements taken in one set for each lens in the same laboratory conditions. Two series were taken for each lens, with two various intervals: 20 s and 60 s between single measurements in order to identify the impact of the nozzle heating during air pulse pushing out. It means that eight folders were obtained, each containing series of 30 measurements. The external dim lighting conditions were constant. Surroundings temperature or external air pressure was also constant during examination. The PC computer was used to control the device operation and to obtain and display the results. The results contain the applanation and the pressure curve, four main parameters, i.e., IOPg, IOPcc, CH, CRF and the waveform score (WS), which was very low because of unrealistic applanation curve. Numerical data describing the pressure curves were exported to Matlab and processed. Statistical analysis included standard descriptive statistics. Normality was rejected in the majority of cased ($p < 0.05$) as the data distributions were often skewed. Hence, multicomparison for independent groups has been performed using Kruskal–Wallis test (Statistica, ver. 10, StatSoft, Inc., USA).

The obtained pressure curves shape was first approximated by use of Gaussian form distribution

$$pg(t) = a \cdot \exp[-b \cdot (t-\tau)^2] + d \, . \qquad (1)$$

Numerical modeling of obtained results shows better approximation of the same pressure curve with the function based on superposition of two hyperbolic tangent functions

$$p(t) = c \cdot [\tanh[a_1 \cdot (t - b_1)] - \tanh[a_2 \cdot (t - b_2)]] + g. \quad (2)$$

Both functions were used for experimental data approximation.

3. Results

Figure 2 shows series of 30 overlapping pressure curves and their derivatives, recorded for the first lens, with the time interval 20 s. One can see very high reproducibility of pressure curves. Such high reproducibility was observed for each series of measurements. Maximal value of pressure curve in one series was independent on the measurement number (k = 1 – 30) and was almost randomly distributed in time. Also in case of pressure curves derivatives no significant disparities were noticed for each of four lenses and for both intervals considered. Reproducibility of derivative curves presented in Fig. 2 is much higher than that one's observed for the real eye. No distinct impact of intervals between measurements was noticed (Fig. 3). The pressure curves obtained for these two intervals were almost overlapped. The same effect was observed for other lenses.

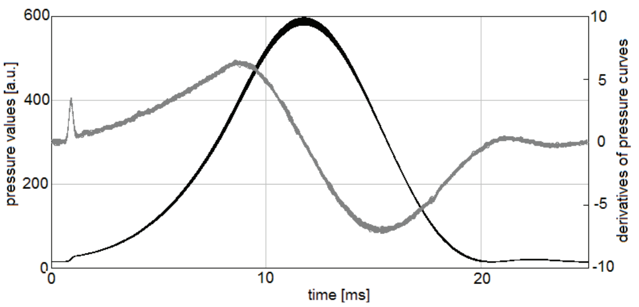

Fig. 2. 30 pressure curves for the glass lens #1, obtained with 20 s interval between measurements and their derivatives

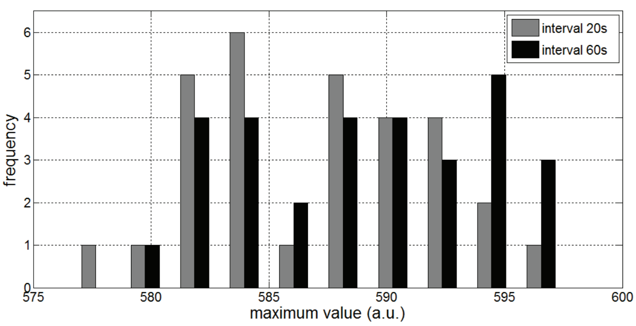

Fig. 3. Distribution of maximal values of the pressure curves for two intervals between measurements for the lens #1

However, for distribution of maximal values of pressure curves MP (Fig. 4) significant differences ($p < 0.01$) using the Kruskal–Wallis test were found for three considered values of curvature radii of particular lens. Analysis of MP values shows linear dependence between curvature radius of the lens and the mean value of MP – Pearson correlation coefficient was $R = 0.86$.

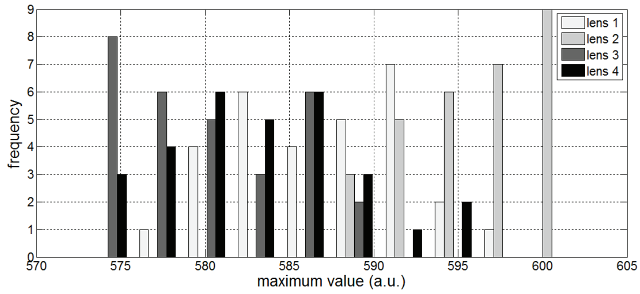

Fig. 4. Distribution of maximum values of the pressure curves for four lenses for interval 20 s

These differences are likely due to some small differences in curvature radii of particular lens. System of automatic positioning of the device head before the air ejection may indicate some sensitivity for the curvature of measured surface.

Combining both of them in one phase graph given in Fig. 5 one sees very clear asymmetry of the graph.

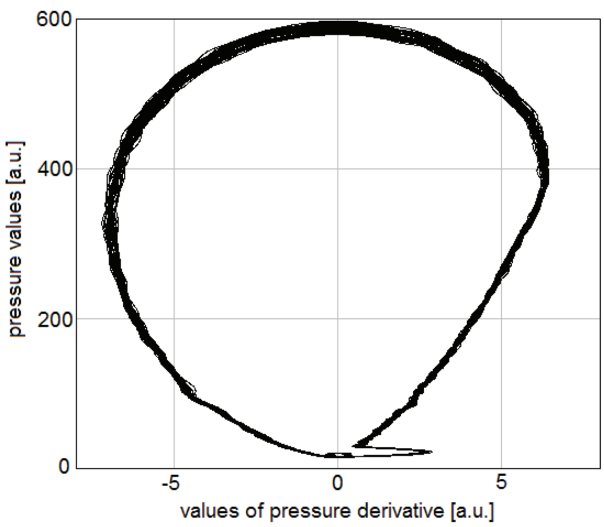

Fig. 5. Phase graph showing 30 curves of the pressure values versus their derivatives for the lens #1

In order to analyze the asymmetry degree of pressure curves, the first – ascending parts of the curves were reflected around the vertical broken lines (passing through the maximal value of pressure curves) and overlapped with their descending parts as shown in Fig. 6. Differences between both groups of curves shown in Fig. 7 indicate their asymmetry. Analysis of pressure curves for patients eyes demonstrates similar asymmetry form, however distribution of their difference curves indicates much higher variance than presented in Fig. 7 for the glass lens.

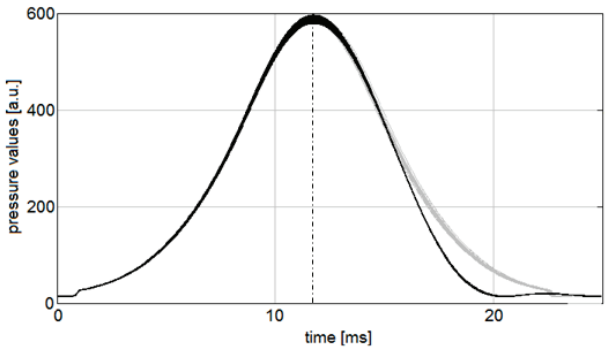

Fig. 6. 30 pressure curves with symmetrical reflections of their ascending parts around vertical axis passing through the maximal values of pressure curves

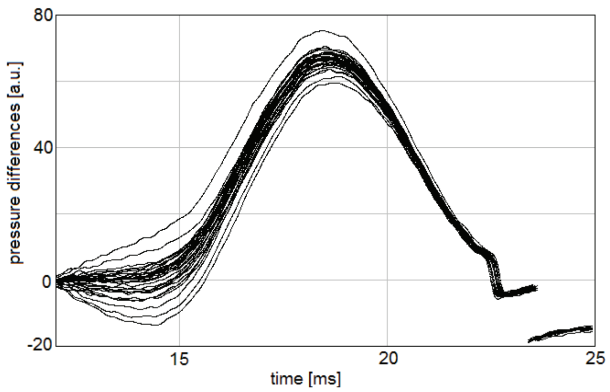

Fig. 7. Differences between 30 reflections of ascending parts of pressure curves from Fig. 6 and real pressure curves

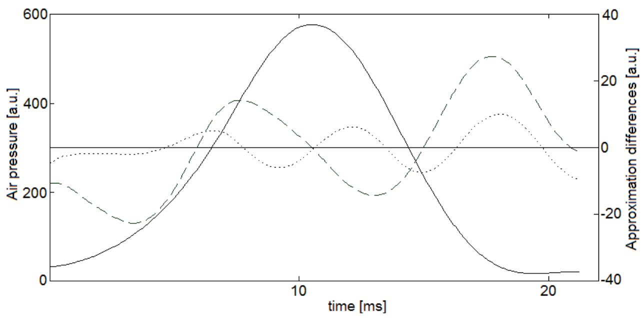

Fig. 8. Measured air pressure curve (solid line) and its difference with the approximation (1) (broken line) and approximation (2) (doted line)

Our modeling showed that even though pressure curve function has symmetrical form (decreasing part is the mirror reflection of its increasing part) it is better approximated by the function of the second approximation (2) than that of Gaussian one (1). Figure 8 shows example of measured air pressure curve (left scale – solid line) and its difference with the approximation (1) (right scale – broken line) and approximation (2) (right scale – doted line).

4. Discussion

The study of pressure curve provided many interesting results. High repeatability of pressure curve obtained during glass lenses measuring in comparison to patients' data was demonstrated. These results show high reproducibility of air pressure distribution in every ejection from the jet of ORA. Significantly higher differences in pressure curves given on patients eyes can be explained by dynamical properties of ocular conditions, and by switching off the air pump just after the first applanation in different time – depending on the momentaneous properties of anterior chamber.

Some authors characterize pressure curves to be symmetrical [3], [5], [9], [14] or even Gaussian shape [2]. The study results showed inaccuracy of such assumptions both for the rigid glass lenses and the human cornea. More detailed analysis of pressure curves form given in Fig. 2 shows their asymmetry and in consequence not complete antysymmetry of their derivatives. The analysis of variability of the pressure curve shape for the cornea can give an interesting information about the corneal or anterior eye dynamics and their influence on the curve form.

Specific asymmetry of the pressure curves appearing as slower their increasing and faster decreasing could be caused by viscoelastic air properties. Thus, Fig. 7 can indicate viscoelastic properties of air. If it is so, air viscosity is somehow influencing ORA measurements. It would be interesting to continue the study of air pulse pressure curves and their correlation with applanation curves. Figure 8 shows better approximation of the air pressure curve with superposition of two hyperbolic tangent functions in comparison to Gaussian approximation. More complex function can approximate measured curves much better.

Observed linear dependence between curvature radius of lenses and the mean (and the median) values of maximal pressure MP is not obvious and shows some additional correlations. We believe that these correlations are much deeper than we expect at the moment. Fortunately ORA gives numerical values of both air pressure and applanation curves which enables such deeper analysis.

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