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GLAUCOMA VS. BIOMECHANICAL PROPERTIES OF CORNEA

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Abstract: The paper deals with the influence of various biomechanical parameters on the intraocular pressure (IOP). The IOP is a very important factor in more accurate diagnosis and better management of glaucoma. To get a more realistic value of IOP the measurement methodology must reflect the patient´s individual biometric and biomechanical parameters, for example age, sex, race, biomechanical properties of cornea, etc. Many measuring methods are based on the applanation of cornea during its loading by the measuring device - tonometers. These tonometers apply the Imbert – Fick law [1], which determines their size. This work also addresses the current approaches to creating more realistic IOP data.

KEYWORDS: cornea, IOP, stiffness, parameter, modification

1 Introduction

The higher mean value of IOP – ocular hypertension (OHT) is a significant risk factor for glaucoma development and its progression [1]. IOP is known as a dynamical variable. It can fluctuate during the day. The highest value of IOP can be measured in the morning and it will decrease during day-time period. There is no sufficient evidence to support 24-hour IOP fluctuation as a risk factor for glaucoma development or progression. The posture is an important variable in the measurement of IOP. The IOP in the sitting position is generally lower than in the supine position [1].

The relationship between glaucoma and the corneal biomechanical properties has gained increasing attention during the last decades. [1 - 14]. Better understanding of the corneal parameters can lead to a more accurate diagnosis and better management of glaucoma.

IOP can be measured by applying tonometry: contact or non-contact. The most well-known tonometry devices is the Goldmann applanation tonometer (GAT), TonoPen XL, ocular blood flow tonograph (OBF), and non-contact tonometer (NCT) – for example ocular response analyser (ORA) [3, 21, 22].

Recent research has focused on developing non-contact techniques to measure the biomechanical properties in vivo, on determining structural and molecular abnormalities in pathological corneas, developing and optimising techniques to reinforce the corneal tissue and on the computational simulation of surgical interventions [7 - 13].

This paper deals with results obtained with GAT, its modification and the numerical simulation based on ORA [15].

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2 Biomechanical properties of cornea

The biomechanical properties contain information about geometrical and mechanical properties. An excellent review of geometrical properties of cornea can be found in [11]. The basic geometrical corneal parameters are: corneal diameter (CD) – measured, from limbus to limbus, anterior corneal curvature (ACC) – relative to the shape of the front surface of the cornea which also characterizes the optical properties of the cornea, central corneal thickness (CCT), posterior corneal curvature (PCC), and peripheral corneal thickness (PCT), see Fig. 1.

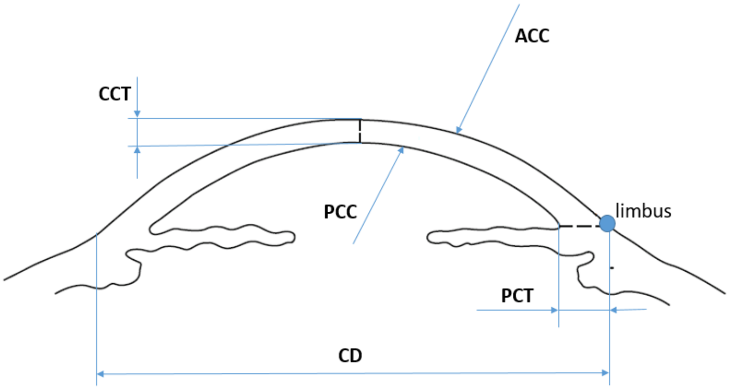

Fig. 1 Basic geometrical parameters of cornea

The ACC and CCT provide information about the healthy cornea and possible changes associated with ocular diseases. For example, low CCT values may lead to the glaucoma which may in turn lead to visual impairment and blindness. Normal values for the CD ranges from 10.50 to 12.75 mm, the ACC ranges from 7.06 to 8.66 mm, the PCC ranges from 6.15 to 7.38 mm, the PCT reaches value of 1.2 mm at limbus and the CCT ranges from 512 to 569.5 μm. These corneal parameters vary with age, gender, ethnicity, refractive state, stature and anthropometric factors [11].

There are many different mechanical models of cornea properties [16]; from isotropic elastic models to viscoelastic and anisotropic [4, 12] models. The simplest mechanical model is the elastic one. The basic mechanical parameters are Young´s modulus and Poisson´s ratio. Young´s modulus ranges from 0.054 to 0.359 MPa, Poisson´s ratio has the constant value of 0.48 [16, 17]. The average value of Young´s modulus (0.207 MPa) was applied in our mechanical model proposed in [15].

The mechanics of materials can accumulate both geometrical and mechanical properties into a common parameter – the stiffness. From the point of mechanics, the cornea can be represented by a thin walled membrane subjected to internal pressure – in our case with IOP. The stiffness matrix of the given membrane with constant thickness in terms of finite element method (FEM) [18, 19, 20] can be calculated as

$$S = t\frac{E}{1-\nu^2}\begin{pmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \dfrac{1-\nu}{2} \end{pmatrix} \tag{1}$$

where t is the thickness, E is Young´s modulus, ν is Poisson´s ratio. The thickness of the membrane corresponds to CCT. Thus, the stiffness integrates CCT as a geometrical parameter and material parameters: Young´s modulus and Poisson´s. The influence of CCT was discussed above.

The typical result from non-contact measuring IOP by ORA is represented in Fig. 2. Due to air puff loading the response is typically viscoelastic with hysteresis. We can observe two applanation pressures p_1, p_2. The primary applanation pressure p_1 is greater than the secondary applanation pressure p_2 . The observed pressure difference is called the hysteresis $\Delta p = p_1 - p_2$. For GAT measuring we usually get only the average value of pressure $IOP = \frac{p_1+p_2}{2}$ and we can not find this hysteresis.

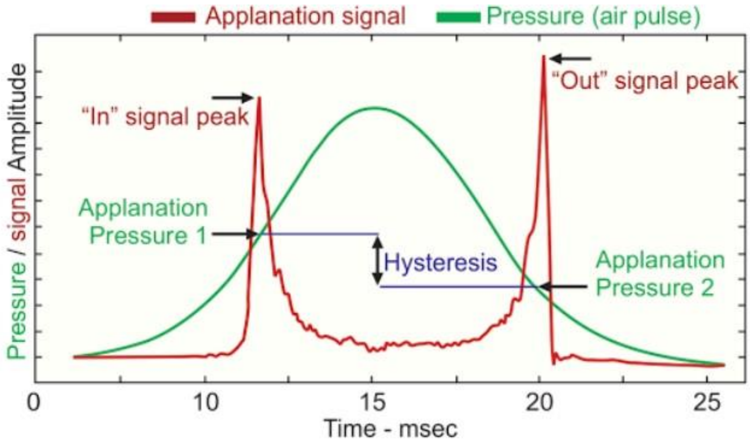

Fig. 2 Applanation measuring – ORA diagram [21]

3 Comparison of GAT and its modification with simulation

We selected 7 subjects treated on glaucoma for measuring IOP by GAT and their geometrical properties by pachymetry. Their individual parameters are presented in Tab. 1.

Tab. 1 Individual parameters of measured subjects and their IOP

Patient	Age [years]	Left eye IOP [mmHg]	CCT [µm]	ACC [mm]
1	74	19	571	7,9
2	80	28	460	7,8
3	72	18	568	7,9
4	66	22	476	7,8
5	81	13	506	7,5
6	77	14	522	7,6
7	69	11	416	7,6

Subsequently we applied five modifications or corrections reviewed in [14] and our simple numerical simulation method based on ORA and proposed in [15]. The obtained results are presented in Fig. 3.

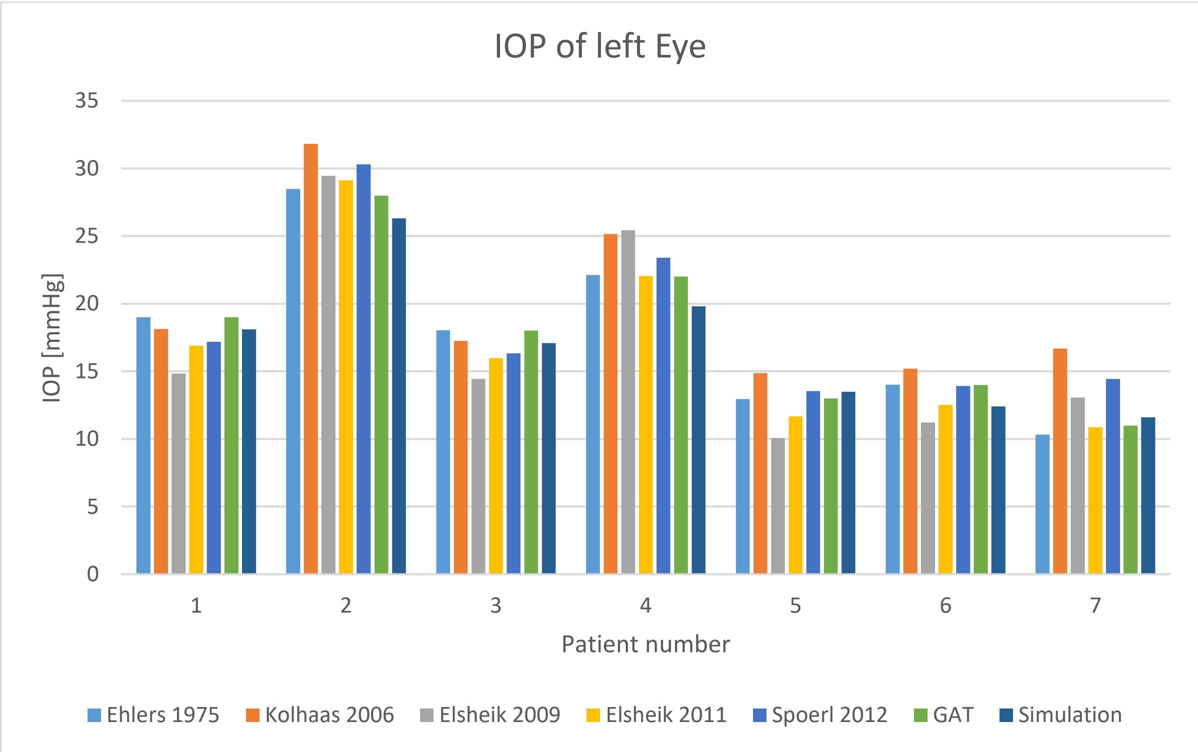

Fig. 3 Obtained results for GAT, its modification and numerical simulation

CONCLUSION

The results of IOP presented in Fig. 3 show relatively significant fluctuation in modifications of GAT. The maximum fluctuation is about 50% for subject 7. The presented modifications reflected only biomechanical parameters: age, CCT and ACC. The mechanical parameters are missing. Therefore, due to obtained results we can conclude that these parameters must be included in any modifications or improvements. The stiffness seems to be the best way. The corneal stiffness has been the focus of many researchers [4, 5, 8, 9, 13]. Stiffness can be determined experimentally for each individual patient during the diagnostics of glaucoma, for example by the indentation method [8, 13]. This method allows to measure the stiffness repeatedly at different places and at different times. Using the dynamic contour tonometry provides an IOP measurement that is less dependent on corneal factors than GAT [10].

There is a good agreement between GAT and the simulation method based on ORA [15]. These results are in a good agreement with [2].

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