ORIGINAL ARTICLE

Contemporary Possibilities of Intraocular Pressure Measurement

Hornová J., Baxant A.

Eye Clinic, 3rd Faculty of Medicine, Charles University, Prague,
Head prof. MUDr. Pavel Kuchynka, CSc.

SUMMARY

Authors introduced current possibilities of measuring intraocular pressure (IOP). A list of available methods of monitoring IOP is published; contact measurement method IOP directly on the cornea, but also over upper lid, methodology of minimal contact and non-contact measurement. Following contact methods are described; former measurements of IOP by impression Schiotz tonometer and the current methodology applanation. So far as the gold standard measurement Goldmann applanation tonometer (GAT) is considered, another methodology with applanation measurements are compared: Pascal dynamic contoured tonometer (DCT), BioResonator – resonant applanation tonometer (ART), digital applanation tonometer Tonopen and last hit: continuous measurement of IOP by Sensimed Triggerfish. Orientation and rapid assessment is palpation pressure control over the lid and measuring by tonometer Diaton. Rebound tonometer (RBT) iCare belongs to measurements with minimal contact, no need anesthetic drops and fluorescein, therefore a self – home version of IOP measurements (Icare ONE) is developed. Non-contact measurement of IOP by different pneumotonometers is popular for screening assessment of IOP. Reichert Ocular Response Analyzer (ORA) is a non-contact applanation IOP measurement and reveals additional properties of the cornea. In the discussion of a range methodology is evaluated, the experience of other authors and their own experience is compared. For monitoring of patients is necessary to select the most suitable methodology, measure repeatedly and **accurately to allow long-term monitoring of intraocular pressure.**

Key words: measurement of intraocular pressure, non-contact methods, contact methods, continuous measurement, minimal contact

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First author:
MUDr. Jara Hornová, CSc.

Eye Clinic, 3rd Faculty of Medicine, Charles University, Prague,
Šrobárova 50
100 34 Praha 10 - Vinohrady
e-mail: jara.hornova@fnkv.cz

INTRODUCTION

Increased intraocular pressure (IOP) has hitherto been and is still considered one of the main risks factors of glaucoma. In 50% of patients with increased IOP, glaucoma develops. However, there is no precise boundary which would determine the value to which IOP is still within the norm, and beyond which further measured values are pathological. The level of intraocular pressure should be judged individually with regard to the ocular finding, the general condition of the patient, and family anamnesis should also be taken into account.

Measurement of the level of IOP ranks amongst the most common and most frequent examinations in patients with glaucoma, in addition to monitoring of the optic nerve and the nerve fibres of the retina and evaluation of the visual field. This is also because we can quickly influence the level of IOP by local instillation therapy, general therapy, laser and operative, and thus immediately check the effects of the treatment.

There is a question of how intraocular pressure is measured and whether the measured value genuinely corresponds to the level of actual IOP. Successful glaucoma treatment requires a good understanding of the physiological mechanisms of circulation of the intraocular fluid and the biomechanical characteristics of the cornea upon measurement of IOP. Knowledge of the existing methods of measuring IOP can lead to both an improvement in the prevention of glaucoma and to the optimisation of the treatment of this disease.

We divide the options of measuring intraocular pressure according to the type and methods of measurement. We differentiate between direct and indirect measurement of IOP. IOP is measured directly in the bulb using manometry. This concerns an invasive method with direct observation of IOP, which can be used only in laboratory conditions. IOP is measured on the corneoscleral surface using indirect tonometry. A separate group is formed by measurement of intraocular pressure through the eyelid. This represents a regular palpation estimate of the level of IOP and measurement on the Diaton tonometer.

Contact methods, touch measurements, determine the value of IOP following prior local anaesthesia of the cornea. The principle of measurement is such that the instrument is in contact with the central cornea and we deduct the amount of pressure needed for deformation of the central surface of the cornea.

IOP is measured by this method on a Schiotz impression tonometer, Goldmann applanation tonometer (GAT), Pascal dynamic contour tonometer (DCT), Bio-Resonator ART (applanation resonation tonometer), Tonopen, Perkins tonometer, and reports are appearing of continuous scanning of IOP.

The advantage of this contact method is precision, and as a result these measurements are suitable for long-term observation of patients. The disadvantage of the contact method is the possibility of transmission of infection and the possibility of causing erosion of the cornea. The majority of measurements are performed with the patient in sitting position, and as a result it cannot be used upon monitoring IOP when the patient is lying and for immobile patients.

Schiotzimpression tonometer. This rarely but still used instrument for measuring IOP was introduced into clinical practice by the Norwegian ophthalmologist Hjalmar Schiotz in 1881 [40]. Measurement of IOP uses the method known as impression (indentation) tonometry, which can be used to measure IOP only when the patient is lying or semi-sitting with the head bent backward. The tonometer is placed on the anaesthetised cornea by means of the concave surface, which approximately corresponds to the curvature of the cornea. In the centre of this surface is an opening in which a rod of precisely specified diameter and mass opens out, and this rod is connected by a lever system to an axis which shows the incurvation (impression) on the cornea on a scale. The scale of the meter is divided into 20 sections, which correspond to one mm of the central impression of the cornea [34]. The softer the eye, the greater the impression the rod causes in the cornea and the dial on the scale shows a greater deviation. If IOP is too high, the impression is minimal; the deviation on the scale likewise. For this reason we place a weight on the rod, which is then heavier, causing a greater impression on the cornea. We then measure the greater deviation on the cornea. According to the used weight (5.5-7.5 and 10 g) we seek the value of the deviation on the normogram, and by this method we determine the level of IOP in mmHg [11].

Goldmann applanation tonometer (GAT) is currently regarded as the gold standard in the measurement of intraocular pressure and has been used consistently in the diagnosis of glaucoma since 1950, when it was introduced into clinical ophthalmological practice. The tonometer functions on the principle of applanation of the central surface of the cornea using a special prism with a diameter of 3.06 mm. Goldmann's theory presupposes that the force of 1 g required for applanation is equal to IOP of 10 mmHg. For precision of the performed measurement of IOP, Hans Goldmann proposed calibration of the instrument to an average thickness of the cornea of 520 µm and curvature of 7.8 mm [35]. The instrument is affixed to a slit lamp, measurement of IOP is conducted with the patient seated and IOP is deducted via a blue filter following prior local anaesthesia and staining of the cornea using 5% fluorescein. Upon contact with the cornea, the blue filter displays two green fluorescing semicircles on the surface of the cornea. Pressure is added using a wheel, thus increasing the pressure of the spring on the applanation prism, until the entire surface of the cornea is flattened. We then see two green (fluorescing) semicircles, which meet inside, and on the wheel we deduct the amount of force which was required for flattening of the cornea.

Pascal dynamic contoured tonometer (DCT) is a supplementary measuring instrument for a slit lamp, which is designated for diagnosis of glaucoma. This device measures IOP directly on the surface of the cornea continually (dynamically), and also shows ocular amplitude, regulation of IOP caused by cardiac pulsation. The measurement is performed in a sitting position, following prior anaesthesia of the cornea; fluorescein is not applied. The instrument is equipped with an end piece with a contoured concave contact surface with a diameter of 7 mm, which is covered with a single-use transparent silicon cap against contamination. In the centre there is a sensor with a diameter of 1.2 mm, which is applied to the centre of the cornea with small contact force and creates electrical signals, intensity of which is proportional to the IOP values. The measurement takes place for approximately 5 to 7 seconds and corresponds to five to ten systoles; the end piece is then removed from the eye and these signals are displayed on the LCD display in numbers. During the measurement the pressure signal is recorded 100 times per second and saved in the memory of the instrument. The level of the signal is continuously monitored. When the tonometer is removed from the eye, the level of the electrical signal drops to a value approaching "0", and the instrument then calculates this value as the referential value for the calculation of IOP. After the measurement the IOP value in mmHg is read on the instrument display, and so is OPA (ocular pulse amplitude) value and the quality index of the entire measurement. The measurement range of IOP is from 5 to 80 mmHg and the measurement should not be influenced by the central thickness of the cornea [38].

BioResonator ART – applanation resonance tonometer is an instrument compatible with all regular slit lamps and is an alternative to GAT. The instrument functions on the principle of patented technology using a piezoelectric sensor. A piezoelectric sensor with a cone extension piece, which transmits a frequency around 1 kHz, is capable of applanating the anaesthetised cornea after configuration, whilst at the same time measuring the size of flattening of the cornea with the help of the degree of resonance frequency of the applanated surface. During applanation of the cornea, the instrument measures approximately 256 values within two seconds, calculates and averages the obtained data, which is displayed on the instrument display together with the quality index of the measurement. This type of gauge has the capability of auto-calibration and the manufacturer declares that the obtained IOP values are less dependent on the biomechanical characteristics of the cornea in comparison with GAT [18]. For precise measurement it is important to ensure correct centring of the cone piece during measurement. As with GAT, it is necessary to anaesthetise the cornea, disinfect the cone piece, as a rule the measurement is performed three times, though fluorescein is not required. Applanation can be performed manually, use of a remote control device for measurement appears to be appropriate [18].

Digital applanation tonometer Tonopen: manual tonometer functioning on the principle of GAT. This instrument is small and light, weighing only 60 g, is held in the hand like a pencil and can be used to measure children. Measurement is not dependent on the patient's position [35]. The measured values are comparable to GAT for the average level of IOP [24]. Following local anaesthesia, applanation is performed by a light touch with the sensor head, which is applied to the centre of the cornea. Upon change of the position of the sensor a change of tension occurs in the sensor head, which is registered by a microchip and converted into the IOP vale. The individual measurements are acousti-

cally and optically signalled, and after the longer bleep the calculation of the average value is displayed, together with denotation of the validity of the measurement. The measurement is repeated. This measuring system is capable of automatically calculating and checking the statistical deviation of the measurement, and thus to ensure realistic and reliable values of intraocular pressure, which should be less dependent upon incorrect manipulation of the instrument during measurement than in the case of GAT [39]. A latex end piece is used for measurement, which limits the transmission of infection and acts as protection of the actual measuring sensor [39]. With regard to the small applanation surface, this examination should not be influenced by sclera rigidity, and the measurement can be performed also in the case of an irregular surface of the cornea [6, 7, 35].

The latest hit in measurement of IOP is **continuous measurement,** which records the IOP of the patient throughout the whole 24 hours, i.e. also outside of surgery hours, in the night and during all the possible day and night activities of the patient. These parameters are met by a continual ocular telemetric sensor built into a hydrophilic silicon contact lens, which is produced by the company Sensimed AG Lansane. This measuring instrument was introduced into clinical use in 2009.

SENSIMED Triggerfish. This telemetric contact sensor is developed by the Swiss group in Lausanne. A fine hydrophilic silicon contact lens is placed in the patient's eye for 24 hours, with a platinum-titanium sensor and microprocessor (reader) built in around the periphery. Changes of pressure are recorded around the perimeter of the corneo-scleral connection and are picked up via the reader by an antenna, which is affixed around the eye. The antenna is then connected via a cable to a portable, battery-powered digital recording device. The measurement is recorded for a period of one minute and repeated every 10 minutes; by this method 144 measurements are obtained over the course of 24 hours [12, 26-28].

Contact measurement of IOP (through eyelid)

Palpation measurement is the simplest referential measurement of IOP. During the examination the patient has a raised chin, with eyes looking downwards. Fluctuation of the bulb is tested through the soft part of the upper eyelid alternately with two index fingers. Using measurement by this method we can quickly and easily assess whether IOP is normal, increased or reduced [11]. The method is quick, local anaesthesia and fluorescein are not required. This method enables referential examination of patients with allergies, inflammations following operations and patients with contact lenses. Examination with the patient looking downwards is possible in virtually all positions and all age categories. The method is influenced by the subject of the examiner and requires practical experience.

Diaton tonometer is a digital, easily portable instrument in the shape of a pencil, which measures intraocular pressure through the upper eyelid. This "trans-palpebral" tonometer calculates the dynamic elastic reaction of the eye upon the free fall of an object with a given weight. The given object is a tonometer which has a small spike on the measuring end with two supports (freely sliding along the axis), and following application to the edge of the eyelid it provides a constant static burden on the eye. Inside is a sliding rod, which responds sensitively to changes through the eyelid (tarsal part). Measurement is conducted in a lying or sitting position, with the head bent back horizontally and with the view under an angle of 45 degrees. The measuring part is attached vertically to the edge of the eyelid, parallel to its edge, measurement is recorded via the tarsus in the area of the anterior part of the corona ciliaris. The measured result is shown on the display within 30 seconds, reliability may be lower [33].

Minimal contact

Upon this type of measurement contact is on the minimum surface of the cornea, thus it is not felt and neither local anaesthesia nor fluorescien are necessary. A new touch surface for measurement is applied, or it can be routinely disinfected.

Rebound Tonometer RBT iCARE was developed in Finland. Two versions are on sale [37]. The first is the self-operated "home" variant, in which the instrument is used to measure intraocular pressure only in a horizontal position, but following instructions the patient can perform this measurement himself/herself at any time of the day or night. The instrument has two modes of measurement: 1. Automatic, in which the average IOP value of six sequential measurements is displayed, and 2. Normal, where the results of the measurements are displayed separately. The results can be read immediately on the display of the tonometer, and are also recorded into the memory, after which it is possible to store all the measured values on a computer, including the produced IOP curve. The second variant of the instrument is for measurement of IOP in a sitting and lying position. Measurement is easy, the principle of examination is the same. Both instruments use a fine, light plastic head piece with a diameter of 0.9 mm, which is surrounded by a magnetic field. The instruments measure the slowing of the probe at the moment of contact with the cornea. The instruments are held 5 mm from the top of the cornea and are then switched on to enable measurement. Repeated measurements are recommended, the highest and lowest values are eliminated, and the average of the measured IOP is calculated from the remaining measurements. The instruments are light, portable, connected to a recording device and with a memory. The authors state that measurements on RBT iCARE are influenced by corneal hysteresis (CH) and corneal resistance factor (CRF), but not by the central corneal thickness (CCT) [5, 10, 16, 37].

Noncontact measurement

Noncontact measurement was invented by the American ophthalmologist Bernard Grolman from Reichert. The measurement uses a fast air pulse for flattening of the cornea. The flattening of the cornea is then recorded and evaluated using an electro-optic system. Intraocular pressure is measured by recording the force of the air current and the time at the moment of flattening of the cornea [31].

IOP can be measured by this method on pneumo-tonometers and on an ORA (Reichert Ocular Response Analyzer) instrument.

Pneutonometers use an air current for measurement. The tonometer contains a source of air jet and light rays, which are transmitted to the centre of the cornea. A special detector measures the precise time (to thousandths of a second) of starting of the air jet up to the end of applanation of the cornea [31]. Measurements are performed in a sitting position with fixation of the instrument to a mobile table, the patient

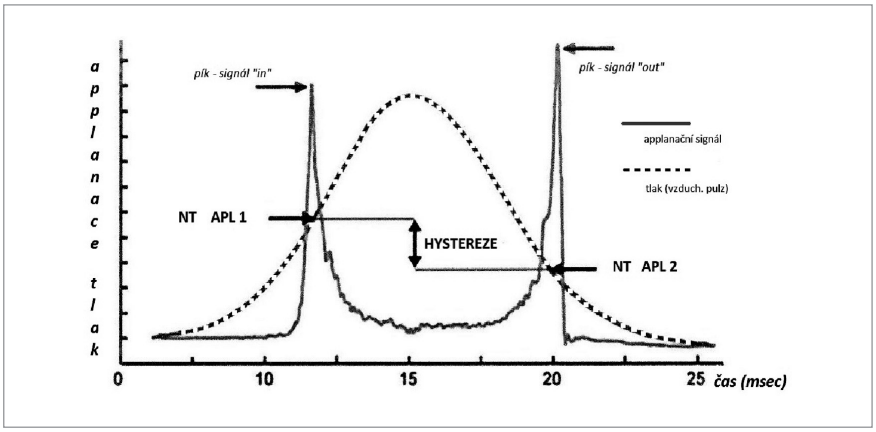


Fig. 1 Schema of ORA curve

has the head and chin leant on rests, the examined eye is fixed by a light fixation point. Measurement can be started automatically or manually, and for precision of measurement it is necessary to perform the measurement repeatedly [31].

Reichert Ocular Response Analyzer (ORA). This is the first automatic system which uses a dynamic two-way applanation process of measurement, which provides a non-invasive measurement of both intraocular pressure and of the biomechanical characteristics of the cornea: ocular hysteresis – viscous corneal absorption (CH) and Corneal Resistance Factor (CRF), and measures the level of IOP adjusted (correlated) by these parameters [9, 19, 22].

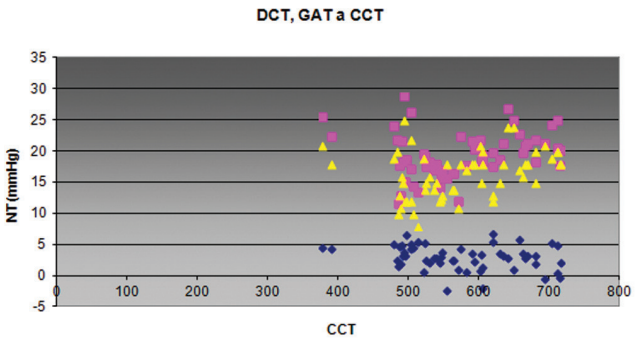
The ORA instrument uses a fast air impulse for applanation of the cornea and an electro-optical infrared system for observation of deformation of the cornea. The air impact causes a deformation inside the cornea (first applanation-flattening). After reducing the air pressure, the cornea is returned to its original position (secondary applanation). These two applanations correspond to the two peaks from the internal and external applanation of the cornea and are recorded in a graph, see Fig. 1. The time in milliseconds is recorded on axis X [9, 19]. The force of the air impact (dashed) which acted on the surface of the cornea is on axis Y, and the peaks of the curve indicate the pressure which was recorded during measurement by infrared light. During this process the cornea dynamically resists the air pulse, which causes its incurvation and entasis, leading to the measurement of two different values of intraocular pressure [9, 19]. The average of these two values ensures the quantity known as Goldmann's correlating intraocular pressure (IOPG). The difference between these two pressure values is called the corneal hysteresis, which is the result of the viscous absorption of the corneal tissue [9]. Hysteresis as an independent phenomenon was first described in 1890 by the Scottish Lord J. A. Ewing [9]. Hysteresis is a description of the visco-elastic characteristics and physical systems which are distinguished by the nature of the response to applied forces. These systems respond slowly and do not return immediately to their original shape, since they absorb part of the impacting mechanical energy. Measurement of corneal hysteresis enables the determination of additional two new parameters: corneal compensated IOP (IOPcc) and corneal resistance factor (CRF) [9, 19, 22].

DISCUSSION

Upon checking the level of intraocular pressure we must consider the patient's condition, the finding in the eye and according to this choose the optimum method of checking IOP. It is suitable to use the same instrument in order to ensure adequate monitoring of IOP. Today we have a whole range of methods available for measuring intraocular pressure. Regular contact methods require local anaesthesia of the cornea, upon contact of the instrument there is a danger of scratching of the cornea and transmission of infection.

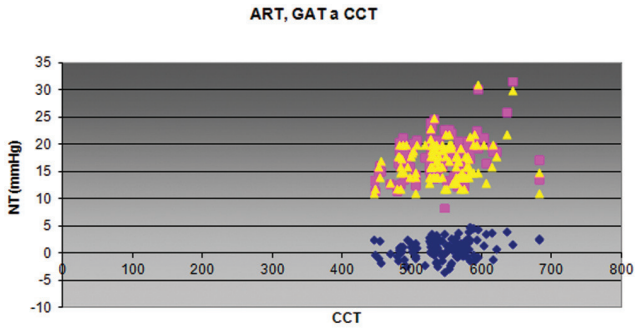
Impression measurement of IOP using a Schoitz tonometer is practically no longer used these days. The disadvantage of this method resides in the imprecision of measurement with regard to the different sclera rigidity [30] of individual eyes and the influence of the weight of the instrument acting on the bulb, and a role is also played by changes in the blood content of the bulb and the characteristics of the cornea [24, 29]. Short-sighted patients [34] and children have lower scleral rigidity, and as a result we measure a lower IOP value than is the case in reality. By measuring with various weights (differential tonometry) we can reduce the error rate of measurement [20].

Although applanation measurement by GAT is still considered the gold standard, here also the result of measurement is influenced. Erroneous measurements may be caused by



Graph 1 Measurement of intraocular pressure with DCT and GAT in relation to CCT and differences of measurement

■ DCT ▲ GAT ♦ difference in measurement of DCT-GAT



Graph 2 Measurement of intraocular pressure with BioR and GAT in relation to CCT and differences of measurement

■ DCT ▲ GAT ♦ difference in measurement of BioR-GAT

irregularities of the cornea, inadequate results are frequently produced in the case of high astigmatism, corneal scars and corneal oedema. Central corneal thickness (CCT) influences the final measured value. In the case of a chick cornea a higher IOP value is measured as a rule, whilst conversely in the case of thin corneas the result of the measurement is lower than in reality; conversion of IOP according to CCT is only referential [12, 13]. The Perkins tonometer and the KOWA tonometer, which is portable, does not require a slit lamp and can be used for measurement when the patient is in a lying position, work on the same principle of applanation. Tonopen is suitable for children, can be used for measurement in various positions, the latex extension piece limits the transmission of infection [4, 6, 7]. According to the manuals, the results of measurements of IOP by a Pascal dynamic contoured tonometer (DCT) and BioResonator ART should not be influenced by CCT [39]. DCT should then eliminate the error of measurement especially in the case of smaller and also medium values of IOP [8]. According to our experience and also those from abroad, DCT measures a higher IOP value than on GAT [2]. In our sample group the measured IOP value was 4 mmHg higher than with GAT in the case of thin and thick corneas similarly, see graph 1 [14]. Using a BioResonator we measured IOP on average 0.95 mmHg higher than with GAT, on thin and thick corneas similarly, see graph 2 [15]. The work of Johannesson et al. [17] states that after two years reduced IOP following LASEK was measured only in the case of ART, in contrast with GAT and DCT. Measurement of IOP on a minimal surface of the cornea is offered by the Rebount Tonometer RBT iCare (ICRBT), thus local anaesthesia and fluorescien are not necessary. The results of the measurement positively correlate with CCT, from which it ensues that in the case of a greater thickness of the cornea there are larger differences in measurement of IOP between GAT and ICBRT [10]. According to the version of the instrument it is possible to measure in both sitting and lying position, the self-operated version measures IOP only in a sitting position. This variant of measurement is new and promising, but requires further verification in practice, and according to our experiences the self-operated version requires very good co-operation and trained patients.

Upon indirect contact through the eyelid it is possible to evaluate the level of IOP also in eyes with allergies to anaesthetic and in the case of damaged corneas. These measurements have lower reliability, the palpation estimate of the level of IOP requires a high degree of experience on the part of the examining physician. We can measure IOP by this method in both a sitting and lying position [11, 14].

The advantage of noncontact methods is fast measurement of IOP, in which anaesthetic and fluorescin are not required. Thanks to the fact that there is no contact with the cornea, infections cannot be transmitted and the surface of the cornea cannot be damaged. Using manual pneumotonometers we can evaluate the level of IOP in a sitting or lying position also on small children. However, the measurements generally are not entirely precise; precision is usually lower than using classic GAT [32]. The IOP value is accepted after three measurements which correspond mutually. The largest divergence of IOP values was in the case of low IOP values, where the lowest pressures were measured [32]. Noncontact measurement is suitable for screening examinations of IOP. Non-invasive measurement using an ORA instrument provides us with a new perspective for corneal qualities; we can determine corneal hysteresis, IOP compensated by cornea (IOPcc) and corneal resistance factor (CRF). Examination of patients with corneal oedema or examination of patients with corneal irregularities is difficult or even impossible due to the imprecise reflection of light [30]. ORA serves for measurements of IOP using corrected corneal characteristics (visco-elasticity of cornea) [3]. Low corneal hysteresis exists in patients with keratoconus, Fuchs dystrophy and in patients after LASIK. Studies show that patients with glaucoma have a significantly lower average of corneal hysteresis in comparison with healthy individuals [1, 3, 19, 22, 23, 25, 36].

Corneal thickness and other biochemical characteristics of the cornea slightly influence the resulting measured level of IOP. If we compare the measured values on the same instrument, we discover fluctuations of IOP, even if with a small error, and we are well able to evaluate the patient's reaction to the burden on the organism, to new treatment, and together with the examination of the optic nerve and the perimeter we can also determine target IOP.

Continuous measurement of IOP appears to be promising, although a disadvantage of this measurement is its high price, at present tens of thousands of Czech crowns for one contact lens in one eye for 24 hours, which is now a limiting factor for a significant extension into the regular clinical practice and for dispensing to patients.

CONCLUSION

One IOP measurement = no measurement. After measurement of IOP value we must consider whether the measurement was conducted adequately and whether it was influenced by an error of measurement or influenced by the patient. In the case of a suspicious finding we must repeat the IOP measurement under the same conditions and choose such a type of instrument which enables the most precise possible monitoring of the level of IOP for the individual in question.

So far contact methods are considered to be more precise. By contrast, noncontact methods are suitable for screening examinations; the three measured IOP values should be analogous. The future shall belong to continuous monitoring of the IOP level. This "eye Holter" method detects change of IOP during the course of the day and night activities of the patient and reveals which activities reduce or increase the level of IOP.

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