Chapter 4

Newer Intraocular Pressure Measurement Techniques

Maria Letizia Salvetat, Marco Zeppieri and
Paolo Brusini

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/66260

Abstract

An elevated intraocular pressure (IOP) has been shown to be one of the major risk factors for glaucoma. It is of utmost importance to obtain accurate and precise IOP when dealing with patients with ocular hypertension and glaucoma, especially patients who have undergone ocular surgery. Goldmann applanation tonometer (GAT) was first introduced in the 1950s and is still currently considered as the gold standard to measure IOP. Although the reproducibility of GAT has shown to be quite good, its accuracy provides several limitations. In particular, IOP measurements taken with GAT have been demonstrated to be influenced by many corneal parameters, including central thickness, curvature, astigmatism and biomechanics. Other disadvantages of GAT include the need for local anesthetic drops, for fluorescein and for a slitlamp. Several different methods have been proposed to overcome the disadvantages found in GAT. The newer devices used as alternative tonometric methods include the iCare rebound tonometer, the BioResonator applanation resonance tonometer, the Pascal dynamic contour tonometer, the ocular response analyzer, the Corvis ST pachy-tonometer and Ocuton S. The precision and accuracy of these alternative tonometric methods in comparison with GAT have been reported and discussed.

Keywords: tonometry, intraocular pressure, precision, accuracy, central corneal thickness, corneal biomechanical properties

1. Introduction

1.1. Importance of the intraocular pressure (IOP) measurement

Accurate and reproducible IOP evaluation is crucial with regard to the classification, management and follow-up of patients with ocular hypertension and glaucoma, and in patients that have undergone ocular surgical procedures.

Elevated intraocular pressure (IOP) has been shown to be one of the major risk factors for glaucoma [1]. Although the vulnerability of the optic nerve can vary among patients, longitudinal randomized controlled population-based trials have provided strong evidence that the reduction in the mean IOP of only 1 mmHg is significantly effective in preventing the development [2] and in delaying the progression [3] of the glaucomatous damage. Goldmann applanation tonometer (GAT) has been considered as the clinical gold standard for IOP measurement since it was introduced in the 1950s [4]. Although the reproducibility of GAT has shown to be quite good, its accuracy provides several limitations. In particular, IOP measurements taken with GAT have been shown to be influenced by many corneal parameters, including central thickness, curvature, astigmatism and biomechanics. Other disadvantages of GAT include need for local anesthetic drops, fluorescein and a slitlamp. Several different methods have been proposed to overcome the disadvantages found in GAT. The newer alternative tonometric methods include the iCare rebound tonometer, the BioResonator applanation resonance tonometer, the Pascal dynamic contour tonometer, the ocular response analyzer and the Corvis ST pachy-tonometer.

The purpose of this chapter is to discuss the advantages, disadvantages, precision and accuracy of the "newer" alternative tonometric methods.

Newer tonometers covered in this chapter include the following:

i. ***Rebound tonometry***

ii. ***BioResonator applanation resonance tonometer (ART)***

iii. ***Pascal dynamic contour tonometer (DCT)***

iv. ***Ocular response analyzer (ORA)***

v. ***Corvis ST pachy-tonometer***

vi. ***Ocuton S***

I. Rebound tonometry

Rebound tonometry, also known as "impact" or "dynamic tonometry," was first introduced by Obbink about 60 years ago [5]. In 1997, Kontiola introduced an improved and simpler new rebound tonometer, better known as an induction-based impact tonometer [6], that became commercially available as the iCare tonometer in 2003 (**Figure 1**). The method is based on the use of a moving probe that collides with the eye: the motion parameters of the probe, which vary according to eye pressure, are monitored and used in the calculation of IOP [6].

http://dx.doi.org/10.5772/66260

Figure 1. The iCare rebound tonometer.

The iCare (Tiolat Oy, Helsinki, Finland) is routinely used in clinical practice in several clinics nowadays. The device is handy and light-weighed (250 g) [7]. It is composed of a small disposable thin metal probe (about 5 cm in length and 1 mm in diameter) and a solenoid and magnet housed in a metal case. The tonometer is placed in front of the eye, using the forehead to properly position the tip of the probe about 5 mm from the central cornea. The button is pressed in taking IOP measurements, which activates an electric signal that is sent to the solenoid and magnet to move the probe forward. The tip of the probe hits the cornea, rebounds and induces a voltage in the solenoid, which amplifies the signal to a microprocessor. It is advisable to take at least six readings, so that a mean IOP can be calculated by the built-in software [7].

The iCare PRO is a new version, which provides advantages not offered in the previous model, such as measuring IOP also in a supine position, thus useful in bedridden and surgical patients. The iCare one is a simplified version, which has recently been introduced. It can be used independently by patients for at-home autotonometry [8].

The iCare tonometer has shown good reproducibility [9] and correlation with GAT and other tonometers in healthy and glaucomatous eyes [9], and in eyes after keratoplasty [10]. A tendency of the iCare to overestimate the IOP measurements taken with GAT, with a similar trend at different IOP levels, has been reported by several authors [11, 12].

Although iCare was designed not to be influenced by corneal properties, studies have shown that CCT and other corneal structural characteristics affect IOP readings [9, 10, 13]. The iCare tonometer appeared less influenced by corneal edema when compared to GAT [10, 14].

The main advantages of this tonometric method are that the instrument is small, lightweight and portable, easy to use; slitlamp, local anesthesia and fluorescein are not required; IOP is taken in a comfortable sitting position and with the iCare PRO also in the supine position; the rapid measurement enables monitoring in noncompliant subjects. The probes are disposable, and thus, the risk of microbiological contaminations is avoided.

II. BioResonator applanation resonance tonometer (ART)

The applanation resonance tonometer (ART) is a new tonometer based on the resonance technique (**Figure 2**) proposed by Eklund et al. in 2003 [15]. The ART estimates IOP by combining simultaneous continuous sampling of both parameters considered in the applanation principle, which include the force needed to applanate the cornea and the corresponding contact area [15]. The current commercial version of ART, known as the BioResonator ART (Medical sensors and Instruments, BioResonator AB, Sweden), has been recently released and is available in a manual and automatic servo-controlled version [16]. The instrument is made up of a sensor and transducer that can measure the contact force in a continuous manner. The resonance sensor is made up of a cylindrical piezoelectric element that has a known resonance frequency. When the sensor is brought in contact with the cornea, the acoustic impedance of the cornea mechanically loads the sensor and modifies the resonance frequency, with a frequency shift, which is proportional to the contact area between sensor and cornea [15]. IOP is calculated from the slope of the relationship between force and frequency evaluated in a specific frequency shift interval corresponding to an interval applanation area between 4.9 and 11.0 mm^2 [15]. The sensor module of the ART is attached to a standard slitlamp in a similar position as the GAT probe. The ART probe is disinfected with 70% ethanol before each subject, and local anesthetic drop (0.4% benoxinate hydrochloride) is required before IOP measurements. ART is available in two versions: the manual one (BioResonator ART manual), in which the sensor is manually pushed toward the cornea, and the automatic servo-controlled version (BioResonator ART servo), in which a small motor provides the sensor movement. The device provides the median of repeated IOP values, in addition to a Quality Index (QI >2 should be excluded) that reflects the standard deviation of the data. The ART is self-calibrated.

Figure 2. The bioresonator applanation resonance tonometer (ART).

BioResonator ART IOP measurements have been demonstrated to be affected by CCT [15, 17]. The overestimation of the IOP measurements obtained with ART relative to GAT has been demonstrated in previous studies [17].

III. Pascal dynamic contour tonometer (DCT)

The pascal dynamic contour tonometer (DCT) (**Figure 3**), developed by Kaufmann et al. [18], is not based on corneal applanation. It has a concave measuring tip, which is applied on the corneal surface to provide a "contour matching" with the aid of a built-in sensor, which is representative of the pressure inside the eye. The Pascal DCT should be therefore less influenced by corneal properties. Previous studies have shown that there is a good concordance between Pascal DCT and GAT in eyes with normal corneas [19]. In eyes that have undergone laser *in situ* keratomileusis (LASIK), the Pascal DCT appears to provide a more reliable measurement of IOP than GAT, which tends to measure artificially lower IOP values [20].

Figure 3. The pascal dynamic contour tonometer (DCT).

The Pascal DCT (SMT Swiss Microtechnology AG, Zurich, Switzerland) [18] is slitlamp mounted and is calibrated automatically. The tonometer has a 10 mm concave radius tip and a built-in 1 mm sensor. The device beeps when the correct position on the corneal surface is obtained. The instrument measures IOP with the use of anesthetic drops in about 5 s and provides digital outcomes in addition to ocular pulse amplitude and quality score (Q that ranges from 1 to 6) data. Acceptable data are defined as $Q < 4$.

The Pascal DCT has shown high reproducibility [21]. As reported by several authors, the Pascal DCT measurements tend to be higher than GAT readings [22].

The Pascal DCT measurement seems to be not significantly affected by CCT [19]. Moreover, studies conducted on cadaver eyes and in patients who had undergone LASIK showed a significantly lower correlation of CCT with measured IOP values with Pascal DCT than with GAT [18].

IV. Ocular response analyzer (ORA)

The ocular response analyzer (ORA) (**Figure 4**) was introduced by Luce in 2005 [23]. It is an air-puff tonometer that, in addition to the traditional IOP measurement supplied, further indents the cornea with air pressure and measures the point at which the cornea recovers from

applanation. This device is based on the principle that information on corneal biomechanics can be obtained by measuring the corneal deformation in response to an air impulse. The ORA uses an electro-optical infrared system to monitor the 3-mm central cornea [23]. The puff of air moves the cornea in an inward fashion, which is considered as the first inward applanation creating a mild concave form. As the force generated by the air decreases, the surface of the cornea takes on the normal convex form in this second outward applanation phase.

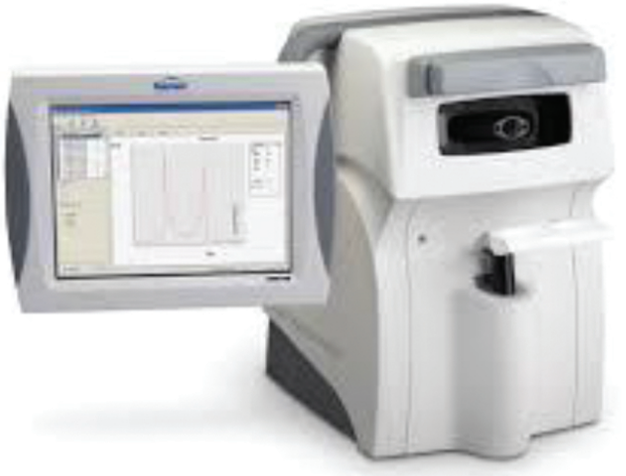

Figure 4. The ocular response analyzer (ORA).

The ORA provides interesting information on the biomechanical characteristics of the cornea. The rapid deformation of the cornea during the air impulse absorbs energy that causes a time delay in the occurrence of the applanation events that are the result of viscous damping in the corneal tissue. The difference between two independent pressure values derived from the two applanation events is defined as "hysteresis" (CH). The instruments provide the corneal compensated IOP (IOPcc) that utilizes information of individual corneal biomechanics, and it is reported to be less affected by corneal properties, such as CCT, in comparison with GAT [23].

Previous authors demonstrated that the ORA significantly overestimated IOP compared with GAT, especially at high IOP levels. Moreover, ORA IOP readings have been demonstrated to be affected by CCT [24].

V. Corvis ST

The Corvis ST (Oculus, Wetzlar, Germany) (**Figure 5**) [25] is a current used instrument that utilizes air-puff noncontact technology with built-in ultra-high-speed Scheimpflug technology. This instrument provides IOP measurements in addition to optical pachymetry data and *in vivo* corneal biomechanical parameters. The device measures corneal biomechanics data based on corneal deformation due to an applied force of air.

http://dx.doi.org/10.5772/66260

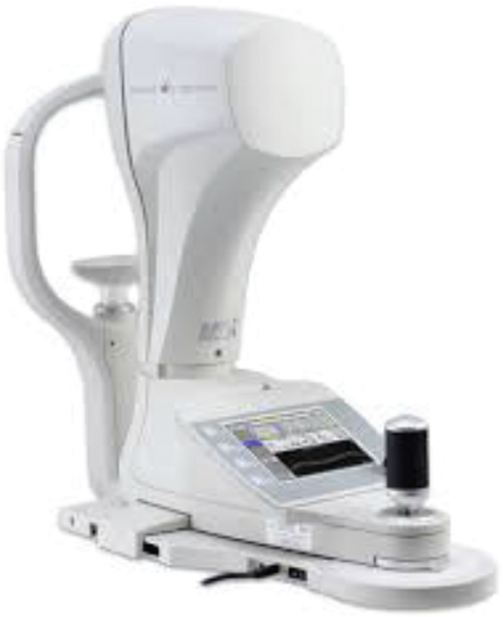

Figure 5. The Corvis ST pachy-tonometer.

The Corvis ST (Oculus, Wetzlar, Germany) released in 2013 [25] uses a quick burst of air (with a Gaussian distributed intensity and duration of 25 ms) on the center of the cornea that causes the initial inward applanation. The cornea then returns to a normal convex shape as the force of the air decreases to provide outward applanation. The Scheimpflug camera precisely records the corneal movements and records more than 100 images in about a half of a second with a resolution >600 × 400 pixels, for a central corneal surface of about 8.5 mm. The numerous corneal scans without the influence of the air puff are used to provide pachymetry readings. The first applanation phase is used to determine IOP measurements, which is not corrected for CCT and corneal deformation parameters (CDPs). The Corvis ST printout provides IOP and CCT measurements and 10 numerical corneal deformation parameters (CDPs), whose importance remains to be fully elucidated. They have been demonstrated to be highly sensitive to IOP that suggests their variation in relation to normal and pathological short- and long-term IOP fluctuations [26]. On the other hand, they are also known to be affected by IOP-independent variables, including patient age, CCT, corneal hydration, corneal stiffness and boundary conditions related to the sclera and the ocular muscles [26].

The precision of Corvis ST has been demonstrated to be excellent for the IOP and CCT values, but decreased for the CDPs [26]. The Corvis ST showed a tendency to underestimate IOP readings compared to GAT in some studies [25, 26]. IOP readings taken with Corvis ST seem to be significantly affected by CCT [25, 26].

VI. Ocuton S

The Ocuton S (EPSa GmbH, Saalfeld, Germany) (**Figure 6**) [27] is a handheld self-tonometer that works according to the principle of applanation tonometry established by Goldmann.

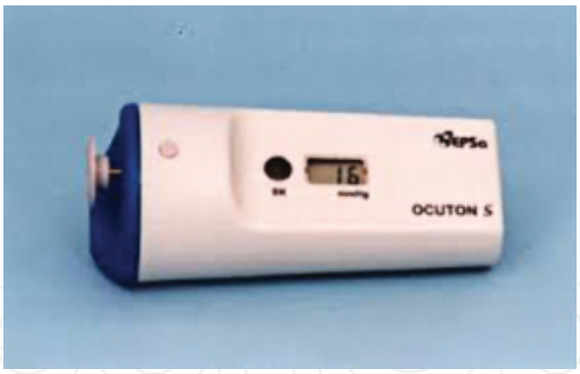

Figure 6. The Ocuton S self-tonometer.

After applying topical anesthesia, the patient holds the tonometer and applies the measuring prism directly to his cornea. The device provides a digital display of his IOP. Considering that the Ocuton S is based on the applanation principle, it should thus be influenced by the corneal thickness, although it is still unclear whether this influence is of a similar extent to that in Goldmann applanation tonometry [28].

The newer version Ocuton S*TT-MV automatically verifies the applanated area. Lanfermann and coworkers showed that the Ocuton S*TT-MV improves measuring accuracy significantly and approaches the accuracy achieved using GAT [29].

There is no "perfect" tonometer till date, and the clinicians must choose a tonometer wisely, balancing precision, accuracy, convenience and cost. IOP is a widely varying physiologic parameter; therefore, a series of IOP measurements should be taken, and the IOP data should only be used in the context of the overall clinical picture.

Conflict of Interest and Source of Funding

None.

Author details

Maria Letizia Salvetat[1*], Marco Zeppieri[2] and Paolo Brusini[3]

*Address all correspondence to: mlsalvetat@hotmail.it

1 Department of Ophthalmology, Azienda Ospedaliero-Universitaria "Santa Maria degli Angeli", Pordenone, Italy

2 Department of Ophthalmology, Azienda Ospedaliero-Universitaria "Santa Maria della Misericordia", Udine, Italy

3 Glaucoma Unit, "Città di Udine" Health Center, Udine, Italy

References

[1] Coleman AL, Miglior S. Risk factors for glaucoma onset and progression. Surv Ophthalmol 2008;53:S3–S10.

[2] Kass MA, Heuer DK, Higginbotham EJ, Johnson CA, Keltner JL, Miller JP, Parrish RK 2nd, Wilson MR, Gordon MO. The Ocular Hypertension Treatment Study: a randomized trial determines that topical ocular hypotensive medication delays or prevents the onset of primary open-angle glaucoma. Arch Ophthalmol 2002;120:701–713.

[3] Heijl A, Leske MC, Bengtsson B, Hyman L, Bengtsson B, Hussein M. Early Manifest Glaucoma Trial Group. Reduction of intraocular pressure and glaucoma progression: results from the Early Manifest Glaucoma Trial. Arch Ophthalmol 2002;120:1268–1279.

[4] Goldmann H, Schmidt T. Ueber applanationstonometrie. Ophthalmologica 1957;134:221–242.

[5] Obbink J. Onderzoek naar het verband tusschen inwendigen oogdruk en ballistische reacties. Thesis, Utrecht, The Netherlands, 1931.

[6] Kontiola AI. A new electromechanical method for measuring intraocular pressure. Doc Ophthalmol 1997;93:265–276.

[7] Kontiola AI. A new induction-based impact method for measuring intraocular pressure. Acta Ophthalmol Scand 2000;78:142–145.

[8] Halkiadakis I, Stratos A, Stergiopoulos G, et al. Evaluation of the Icare-ONE rebound tonometer as a self-measuring intraocular pressure device in normal subjects. Graefes Arch Clin Exp Ophthalmol 2012;250(8):1207–1211.

[9] Martinez-de-la-Casa JM, Garcia-Feijoo J, Castillo A, Garcia-Sanchez J. Reproducibility and clinical evaluation of rebound tonometry. Invest Ophthalmol Vis Sci 2005;46:4578–4580.

[10] Salvetat ML, Zeppieri M, Miani F, Tosoni C, Parisi L, Brusini P. Comparison of iCare tonometer and Goldmann applanation tonometry in normal corneas and in eyes with automated lamellar and penetrating keratoplasty. Eye (Lond) 2011;25(5):642–650.

[11] Cook JA, Botello AP, Elders A, et al. Systematic review of the agreement of tonometers with Goldmann applanation tonometry. Ophthalomology 2012;119:1552–1557.

[12] Johannesson G, Hallberg P, Eklund A, Linden C. Pascal. ICare and Goldmann applanation tonometry—a comparative study. Acta Ophthalmol 2008;6:614–621.

[13] Brusini P, Salvetat ML, Zeppieri M, Tosoni C, Parisi L. Comparison of ICare tonometer with Goldmann applanation tonometer in glaucoma patients. J Glaucoma 2006;15:213–217.

[14] Neuburger M, Maier P, Böhringer D, Reinhard T, Jordan JF. The impact of corneal edema on intraocular pressure measurements using goldmann applanation tonometry, Tono-Pen XL, iCare, and ORA: an *in vitro* model. J Glaucoma 2013;22(7):584–590.

[15] Eklund A, Hallberg P, Linden C, Lindahl OA. An applanation resonator sensor for measuring intraocular using combined continuous force and area measurement. Invest Ophthalmol Vis Sci 2003;44:3017–3024.

[16] Johannesson G, Hallberg P, Eklund A, Linden C. Introduction and clinical evaluation of servo-controlled applanation resonance tonometry. Acta Ophthalmol 2012;90:677–682.

[17] Salvetat ML, Zeppieri M, Tosoni C, Brusini P. Repeatability and accuracy of the applanation resonance tonometry in healthy subjects and patients with glaucoma. Acta Ophthalmol 2014;92(1):e66–e77.

[18] Kaufmann C, Bachmann LM, Thiel MA. Intraocular pressure measurements using dynamic contour tonometry after laser *in situ* keratomileusis. Invest Ophthalmol Vis Sci 2003;44:3790–3794.

[19] Pache M, Wilmsmeyer S, Lautebach S, Funk J. Dynamic contour tonometry versus Goldmann applanation tonometry: a comparative study. Graefe's Arch Clin Exp Ophthalmol 2005;243:763–767.

[20] Park HJ, Uhm KB, Hong C. Reduction in intraocular pressure after laser *in situ* keratomileusis. J Cataract Refract Surg 2001;27:303–309.

[21] Wang AS, Alencar LM, Weinreb RN, et al. Repeatability and reproducibility of Goldmann applanation, dynamic contour, and ocular response analyzer tonometry. J Glaucoma 2013;22(2):127–132.

[22] Salvetat ML, Zeppieri M, Tosoni C, Brusini P. Comparison between Pascal dynamic contour tonometry, the TonoPen, and Goldmann applanation tonokmetry in patients with glaucoma. Acta Ophthalmol Scand 2007;85(3):272–279.

[23] Luce DA. Determining in vivo biomechanical properties of the cornea with an ocular response analyzer. J Cataract Refract Surg 2005;31:156–162.

[24] Matinez-de-la-Casa JM, Garcia-Feijoo J, Fernandez-Vidal A, et al. Ocular Response Analyzer versus Goldmann applanation tonometry for intraocular pressure measurements. Invest Ophthalmol Vis Sci 2006;47:4410–4414.

[25] Reznicek L, Muth D, Kampik A, et al. Evaluation of a novel Scheimpflug-based non-contact tonometer in healthy subjects and patients with ocular hypertension and glaucoma. Br J Ophthalmol 1013; 97: 1410–1414.

[26] Salvetat ML, Zeppieri M, Tosoni C, Felletti M, Grasso L, Brusini P. Corneal deformation parameters provided by the Corvis-ST Pachy-Tonometer in healthy subjects and glaucoma patients. J Glaucoma 2015;24(8):568–574.

[27] Draeger J, Schwartz R, Deutsch C, Groenhoff S. Clinical and experimental results with a new fully automatic self-tonometer. Fortschr Ophthalmol 1991;88(3):304–307.

[28] Sacu S, Vass C, Schemper M, Rainer G. Self-tonometry with the Ocuton S: evaluation of accuracy in glaucoma patients. Acta Ophthalmol Scand 2004;82:405–409.

[29] Lanfermann E, Jürgens C, Grossjohann R, Antal S, Tost F. Intraocular pressure measurements with the newly reconfigured Ocuton S*TT-MV self-tonometer in comparison to Goldmann applanation tonometry in glaucoma patients. Med Sci Monit 2009 Nov; 15(11):CR556–562.

IntechOpen