Microprocessor Controlled Tonometry

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Summary

Microprocessors have enabled new techniques to be applied to the design of tonometers. Three new microprocessor controlled tonometers, one operating to the principle of Mackay-Marg (Tono-Pen) and two non-contact airstream tonometers (Pulsair and CT-10) have been examined using as a reference Goldmann and the Hand Held Applanation Tonometers (Draeger-HAT) which used the Goldmann applanation principle. The non-contact tonometers produce a conically formed airstream with top speeds of 90 m/s (CT-10) and 70 m/s (Pulsair) which at the moment of pressure measurement applanates the cornea exactly with a diameter of 4 mm. The readings of the microprocessor controlled tonometers correlate well with the readings of HAT (Tono-Pen $r = 0.8414$ and $s = 3.783$, CT-10 $r = 0.8606$ and $s = 4.5477$, Pulsair $r = 0.8968$ and $s = 3.2641$, where r is the correlation coefficient and s is the standard deviation in mmHg). Repeated measurements with one tonometer give the following standard deviations (HAT 1.6617, Tono-Pen 3.4969, CT-10 2.9179, Pulsair 2.9434). Although the three new instruments are able to measure the intraocular pressure in a wide range they do not work with the same precision as the classical applanation tonometer.

Traditional applanation tonometry is based on the law of Imbert⁶ and Fick.² According to Goldmann^{4,5} the pressure which is necessary to flatten the cornea gives the intraocular pressure only if the applanated area has a diameter of 2.5 to 4 mm because it is only in this range that the adhesive force of tears and the force necessary to overcome the rigidity of the cornea are in balance. In recent times, microprocessor controlled tonometers have been developed which operate according to applanation principles but do not fulfil Goldmann's criteria. The Tono-Pen is a little tonometer conveniently held in the hand and operating according to the principle of Mackay and Marg.⁷ It uses only the middle part of the applanation area for pressure measurement, and thus neither the adhesive force of the tears nor the rigidity of the cornea may influence the result. This does not mean

however that the intraocular pressure cannot be transferred through the applanated cornea. The airstream of the non-contact tonometers³ applanates the cornea without being influenced by the adhesives force of the tears and therefore the requirement of a balance between this adhesive force and the rigidity of the cornea can be disregarded.

An estimation of the practical use of new tonometers should include not only a comparison with traditional tonometry but also a presentation of their physical characteristics.

Materials and Methods

The new microprocessor controlled tonometer (the non-contact tonometers Pulsair (Fig. 1) and CT-10 (Fig. 2) and the Tono-Pen operating to the principle of Mackay-Marg (Fig. 3) were compared with the hand-held applanation tonometer HAT (Fig. 4) which

Fig. 1. *Pulsair-Tonometer.*

Fig. 2. *CT-10.*

Fig. 3. *Tono-Pen.*

Fig. 4. *Hand-held applanation tonometer (HAT).*

operates according to the principle of Goldmann. In a randomised sequence two physicians took six readings of every eye of the 99 patients using the different tonometers (see protocol in Fig. 5). The interval between two readings was always three minutes, local anaesthesia was applied just before the first measurement with a contact tonometer. The readings were evaluated by means of the regression analysis in two ways. To determine the accuracy of the instrument regressions and correlations were made between certain microprocessor controlled tonometers on test and the HAT. To determine the precision of each instrument, values were obtained with the tonometer under test using multiple readings on the same eye at different times.

To eliminate the influence of pulse and respiration on intraocular pressure of all three microprocessor controlled tonometers the mean value of three (Pulsair), four (CT-10) or several (Tono-Pen) single measurements were taken as the definite pressure readings.

In Tono-Pen the single values were not used but rather the relative variation coefficient. Only such measurements with variation coefficient of 5% or less were used. With non-contact tonometers the observer writes down the single values (Pulsair) or the single values are printed on a small label (CT-10).

The airstream of the non-contact tonometers was studied by use of a Constant Temperature Anaemometer. The measuring tip of the anaemometer was moved through the emitted air in horizontal and vertical directions taking steps of 0.25 mm and keeping the instrument at the normal working distance at the nozzle (Pulsair 14.5 mm and CT-10 11 mm). Because the profile of airstream alone cannot lead to precise information about the corneal figuration at the moment when pressure value is taken, we therefore installed a camera over a special interface with the CT-10 and a flash light generator in order to take photographs of the corneal surface during the deforming process.

A typical protocol

Patient: Any Person

Measurement No.	1	2	3	4	5	6
Right eye	HAT	CT-10	HAT	PULSAIR	TONO-PEN	TONO-PEN
Physician	A	B	A	A	B	A
Left eye	PULSAIR	HAT	HAT	CT-10	CT-10	PULSAIR
Physician	A	A	A	B	B	A

Fig. 5. A protocol label.

Fig. 6. Profiles of velocity of airstreams measured by a constant temperature anemometer. The anemometer wire was moved horizontally ($\square$ CT-10, $\diamond$ Pulsair) and vertically ($+$ CT-10, $\triangle$ Pulsair) to the emitting direction of the airstream.

Results

The airstream study

The non-contact tonometers produced a conically formed airstream (Fig. 6) with top speeds of 93 m/s (CT-10) and of 69 m/s (Pulsair). At the moment of pressure measurement the airstream applanates the cornea exactly. The diameter of the applanated circle is 4 mm (Fig. 7).

The clinical study

In a sequence of four Pulsair or three CT-10 measurements the single values should either be arranged at random or they should decrease sequentially because of the decreasing effect of repeating measurements on intraocular pressure. With the Pulsair however the contrary is the case. The simple sign test of Dixon and Moon shows that before the cornea is anaesthetised the first value of a sequence is smaller than the mean value of this sequence ($p < 0.01$). After anaesthesia the

Fig. 7. The applanated cornea at time of pressure measurement. The flashlight was triggered by the microprocessor of the CT-10. The diameter of the applanated area amounts to 4 mm.

first value is distributed randomly as is also the case in CT-10.

The regressions between new tonometers and HAT are shown in Table I and the standard deviations are considerable. There is a statistically significant difference between CT-10 and Pulsair ($p < 0.001$) and with both tonometers anaesthesia increases the standard deviation (CT-10 $p < 0.001$ and Pulsair $p < 0.005$). The Tono-Pen especially shows a very high intersection and a very small regression coefficient.

The most precise readings are obtained by the HAT and the worst by Tono-Pen (Table II). This depends on the presence or absence of anaesthesia. While Pulsair gives a bigger deviation before than after anaesthesia, CT-10 shows the opposite effect (Table II). With HAT, CT-10 and Pulsair the standard deviation is significantly smaller if the values are obtained from one observer rather than those obtained by both observers, even

Table I *Correlation between a new tonometer and HAT*

Tonometer	n	r	s	Equation of regression		Remarks
				New	Hat	
1 CT-10	136	0.8606	4.5477	$Y = 1.1494X - 2.6187$		all values
2 CT-10	33	0.9411	3.1840	$Y = 1.0497X - 0.4314$		before an.
3 CT-10	88	0.8110	5.4033	$Y = 1.0891X - 2.2240$		after an.
4 Pulsair	150	0.8968	3.2641	$Y = 0.9223X + 0.0347$		all values
5 Pulsair	49	0.9749	2.4021	$Y = 0.9899X - 0.6532$		before an.
6 Pulsair	93	0.8651	3.5324	$Y = 0.8995X - 0.1005$		after an.
7 Tono-Pen	143	0.8414	3.7830	$Y = 0.8393X + 5.0657$		all values

n: number of eyes, r: correlation coefficient, s: standard deviation (mmHg), an: anaesthesia.

Table II *Autocorrelation of values obtained from one eye with a particular tonometer*

Tonometer	n	r	s	Equation of regression		Remarks
				New	Hat	
1 HAT	65	0.9849	1.6617	$Y = 0.9576X + 0.4474$		A against B
2 HAT	38	0.9925	0.9334	$Y = 0.9406X + 0.563$		A
3 HAT	37	0.9939	0.9799	$Y = 1.0090X - 0.5874$		B
4 CT-10	64	0.9080	2.9179	$Y = 0.7775X + 2.3128$		A against B
5 CT-10	42	0.9782	1.8905	$Y = 0.9598X - 0.1618$		A
6 CT-10	35	0.8497	2.3372	$Y = 1.0163X - 0.8302$		B
7 CT-10	20	0.9366	1.2209	$Y = 0.9695X - 0.6133$		before an.
8 CT-10	65	0.9738	1.8770	$Y = 0.9638X + 0.2527$		after an.
9 Pulsair	78	0.9062	2.9434	$Y = 1.0292X - 0.4796$		A against B
10 Pulsair	44	0.9159	2.0992	$Y = 0.7240X + 3.2308$		A
11 Pulsair	41	0.8919	2.2330	$Y = 0.8450X + 1.8354$		B
12 Pulsair	24	0.9331	3.6030	$Y = 0.9866X - 0.1530$		before an.
13 Pulsair	75	0.8586	2.5843	$Y = 0.8748X + 1.4240$		after an.
14 Tono-Pen	57	0.8004	3.4969	$Y = 0.9261X + 0.8813$		A against B
15 Tono-Pen	45	0.7830	3.3947	$Y = 0.6797X + 6.0182$		A
16 Tono-Pen	31	0.8285	2.7235	$Y = 0.8285X + 1.8751$		B

n: number of eyes, r: correlation coefficient, s: standard deviation (mmHg), A and B: Observers, an: anaesthesia.

though there is no difference between the observers. However, the correlation of HAT values obtained by one observer with that obtained by the other shows a smaller deviation than the autocorrelation obtained by the microprocessor controlled tonometers.

Discussion

The readings of the new microprocessor controlled tonometers correlate with those of conventional tonometers. The applanation tonometry using the Goldmann principle has a greater reliability of values than the new tonometers.

Although CT-10 and Pulsair work by the same principle there are striking differences between both instruments in regard to the sensitivity to temporary alterations of the cornea. The Pulsair especially is very sensitive to such variations.

For control of glaucoma close monitoring of intraocular pressure is considered to be important. This is obviously best achieved if tonometry can be performed independently of an observing physician. The new microprocessor controlled tonometers are a step in this direction. Further research is being undertaken to combine the Goldmann principle with microelectric technology.

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