DYNAMIC CONTOUR TONOMETRY

IN COMPARISON TO GOLDMANN APPLANATION TONOMETRY AND PNEUMATONOMETRY

A Comparative Study On Human Cadaver Eyes

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BACKGROUND:

Dynamic Contour Tonometry (DCT) has been developed (Kanngiesser, ARVO 2002) as the first non-invasive procedure for the direct measurement of intra-ocular pressure (IOP). DCT promises to furnish IOP measurements that are independent of central corneal thickness (CCT), whereas correlation with corneal radius seems to be likely.

OBJECTIVE:

To validate the basic assumptions and the theoretical underpinnings of DCT, pressure measurements taken with an experimental DCT device are compared with direct intra-cameral, manometric pressure measurements on human cadaver eyes. For comparison, IOP was also measured with two established types of tonometers, the Goldmann Applanation Tonometer (GAT) and the Pneumatonograph (PTG) according to Langham. To study the influence of corneal parameters on IOP measurements, central corneal thickness (CCT), corneal radius (CR), and astigmatism (AS) were determined.

METHODS:

14 freshly enucleated human cadaver eyes were de-epithelialized. A 22 ga. intubation needle was placed in the anterior chamber. The corneas were then dehydrated with Dextrane 20% externally by continuous dropping and internally through the tube until stable CCT was achieved. The cannula was then connected, via a BSS–filled tubing system (Fig. 1), to a manometer (pressure transducer: Neonate Kit W30/ML, Abbot Critical Care Systems). IOP was controlled by placing an open reservoir bottle at a suitable level above the bulbus to generate a static pressure between 5 mmHg and 38 mmHg.

For DCT measurements, an experimental DCT device was used. The contoured tip's dimensions were optimized in preceeding studies and feature a concave surface with 10.5 mm radius, a contact surface of approx. 7 mm, and a miniaturized piezo-resistive pressure sensor of 1.7 mm diameter built flush into the center of the contact surface (Fig. 2). Pressure readings are sampled and digitized at 100 Hz. Data points are transferred to a microprocessor-based control unit, which computes and displays the pressure measured. The DCT tip was mounted in the tip holder of a Goldmann Tonometer (Fig. 3), which provided for a constant appositional force of 1 gram.

For GAT and PTG measurements, a Goldmann Applanation Tonometer (Haag-Streit) and a Pneumatonograph (Solan-Medtronic Model 30 Classic) were used, respectively.

Five consecutive readings each from DCT, GAT, and PTG devices were taken in randomised order at nine different pre-set manometric pressures. Manometric pressure was noted for each tonometer measurement. CCT was monitored between IOP measurements using ultrasound pachymetry. CR and AS were measured using an Orbscan keratometer (Bausch & Lomb).

RESULTS:

The characteristics (CCT, CR, and AS) of the bulbi used for IOP measurements are summarized in Table 1.

The results of IOP measurement by DCT, GAT, and PTG are summarized in Table 2 and in Figs 4 – 7.

Table 1. **Characteristics of the bulbi used:**

	range	median	IQR	mean	std.dev.	dim.
CCT before dehydration				719	±137	µm
CCT after dehydration	380 – 517	459	410 – 482	450	±40	µm
CR	7.4 – 9.0	7.94	7.70 – 8.43		±	mm
AS	0.3 – 2.2	1.40	1.10 – 1.65		±	mm

Table 2. **Results and comparison of IOP measurements:**

	DCT	GAT	PTG	dim.
IOP bias, relative to manometric pressure				
correlation: slope	0.00	0.98	0.84	
R^2	1.00	0.97	0.96	
p	<0.001	<0.001	<0.001	
average	+0.396	-3.80	-3.87	mmHg
CI95 of average	±0.085	±0.26	±0.35	mmHg
LOA95	±0.98	±2.98	±4.05	mmHg
Dependence of IOP measurements on CCT				
correlation: slope	-0.0007	-0.0028	-0.0008	mmHg/µm
R^2	0.0027	0.0051	0.0002	mmHg/µm
p	0.54	0.39	0.86	mmHg/µm
	(not significant)	(not significant)	(not significant)	
Dependence of IOP measurements on CR				
correlation: slope	0.028	0.41	1.08	mmHg/mm
R^2	0.0011	0.031	0.08	mmHg/mm
p	0.76	0.1	<0.01	mmHg/mm
	(not significant)	(not significant)	significant	
Dependence of IOP measurements on AS				
correlation: slope	-0.1	-1.63	-1.29	mmHg/mm
R^2	0.014	0.35	0.13	mmHg/mm
p	0.28	<0.001	<0.001	mmHg/mm
	(not significant)	significant	significant	
Variability (5 consecutive measurements per method)				
CI95	±1.13	±1.65	±1.81	mmHg

Among the three types of tonometers studied, DCT matches manometric, "true" IOP best. A linear bias of less than 0.5 mmHg was found for all DCT measurements, without any significant correlation with either CCT, CR, or AS. In contrast, both GAT and PTG exhibit a substantial bias of almost 4 mmHg. Furthermore, the bias in the case of PTG is not linear but changes proportionally with changing manometric pressure.

In the bulbi used for the study, CCT ranged from 380 to 517 µm. Across this range, GAT and PTG readings varied widely but showed no significant correlation with CCT. DCT results show less variation but are also not significantly correlated.

CR of our bulbi were in the range 7.4 to 9 mm. No significant correlations were found between DCT, GAT, or PTG readings and these CR values. For AS, which varied between 0.3 and 2.2 mm, significant correlations were found for GAT (slope: -1.6 mmHg/mm) and for PTG (slope: -1.29 mmHg/mm), but not for DCT.

Reproducibility, i.e. intra-observer variability, of tonometric readings was assessed for the three devices by examining the spread of the 5 consecutive readings taken by each technique. DCT scores best with a 95% confidence interval of ±1.28 mmHg, compared with ±1.65 and ±1.81 mmHg for GAT and PTG, respectively.

CONCLUSIONS:

In the experimental set-up chosen for this study, **DCT measures closer to manometric, "true" IOP than GAT and PTG**, who both furnish low results. We have preferred an "open bottle system" for maintaining a constant pressure during the entire set of consecutive measurements taken on a given bulbus. With this set-up, provocation of the bulbus by application of the tonometer tip does not result in a pressure increase. In contrast, in a closed system such as a real living eye, any tonometer will sense a pressure corresponding to basic IOP plus an incremental pressure due to provocation. As shown elsewhere (Kanngiesser, 2003, to be submitted), pressure provocation by a tip with matched contour, applied with minimal force, is intrinsically smaller than the provocation generated by any flat tip. However, we note that provocation strongly depends on how the bulbus is suspended. In the orbita, padded with soft tissue, forces acting on the bulbus are perfectly distributed. This situation cannot be modeled satisfactorily in an experimental setup with cadaver eyes.

Furthermore, practical experimental problems preclude use of a truly "closed bottle system". Due to continuous leakage, manometric pressure in a closed system declines continuously, rendering a valid comparison of consecutive measurements difficult.

Our data support the conclusion that **DCT readings are influenced to a lesser degree by corneal structure than GAT and PTG measurements**. However, it should be borne in mind that the cadaver corneae examined in this study are structurally quite different from live corneæ: Corneal thickness changes dramatically by hydration. Subsequent dehydration prior to performing our experiments reduces CCT to values lower than physiologically normal (mean: 450 µm, as compared to a standard CCT in healthy eyes of approx. 530µm). Furthermore, astigmatism in the prepared bulbi varies widely due mainly to physical deformation of the bulbi by the cannulation and manipulations associated with preparation. And finally, the corneae used lack an epithelium and a tear film. All these phenomena may contribute to measurement errors in tonometers that are sensitive to structural changes in the cornea, and at least partially explain the maybe surprisingly large deviations of GAT and PTG readings from manometric IOP. We also note that these errors are likely to be more pronounced in our *in-vitro* experiment than what will be encountered *in-vivo*.

However, we feel that these observations underline the need for a tonometer that is less dependent of corneal variations. DCT seems to be a promising candidate for meeting this requirement.

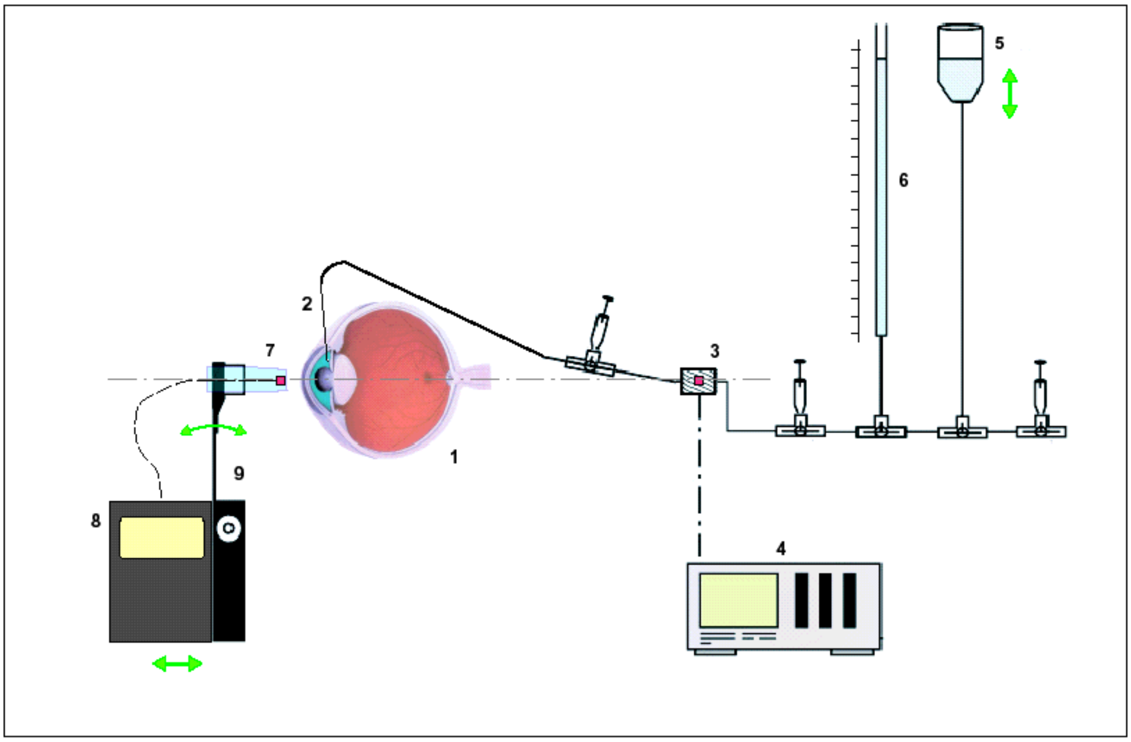

Fig. 1 Experimental setup for pressurizing bulbi and for measuring internal bulbus pressure.
(1) Bulbus mounted in upright position; (2) intubation needle connected to tubing system, inserted into anterior chamber; (3) pressure transducer, placed in tubing system at level of bulbus; (4) recorder; (5) open bottle serving as BSS reservoir; adjustable level; (6) burette with scale for reading BSS level relative to bulbus; (7) contour tonometer tip with integrated digital pressure sensor; (8) tonometer control unit with digital pressure readout; (9) tonometer base mounted on slitlamp (not shown).

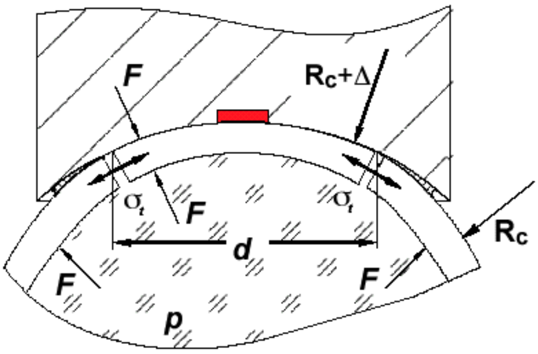

Fig. 2 Schematic diagram of Dynamic Contour Tonometer tip.
Contour of tip matches contour of cornea across contact diameter d. Tangential forces cancel; internal and external forces orthogonal to cornea are matched.
Pressure sensor (red square) detects intra-ocular pressure.

Fig. 3 Experimental DCT device.
Custom-built contour tonometer tip is mounted on base of a Goldmann Tonometer, which is set to provide 1 gram appositional force. Pressure measured by sensor is read from LCD display and may be transmitted to a connected PC.

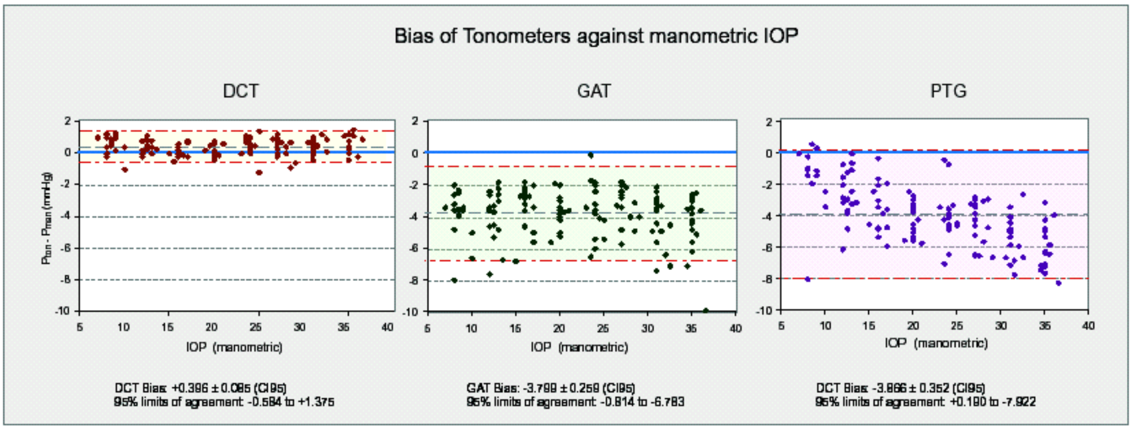

Fig. 4 Bias of tonometer readings, relative to manometric IOP.
Difference between tonometer reading and manometric pressure, plotted against manometric pressure serving as a reference. Colored band between red lines designates 95% confidence interval. (a) Dynamic Contour Tonometer; (b) Goldmann Tonometer; (c) Pneumatonograph.

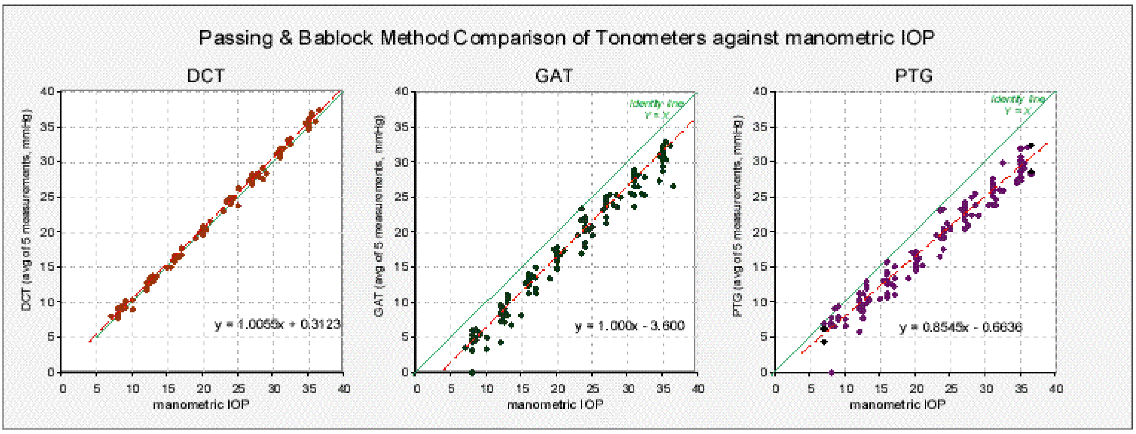

Fig. 5 Method comparison of tonometers against manometric IOP, according to Passing & Bablock.
Average of five tonometer readings, plotted against manometric pressure. For an ideal tonometer, all points should be on the diagonal (green line). Red dotted line denotes best linear fit according to Passing & Bablock. (a) Dynamic Contour Tonometer; (b) Goldmann Tonometer, parallel correlation line suggests constant bias; (c) Pneumatonograph; slanted correlation line indicates bias increasing proportionally at higher pressures.

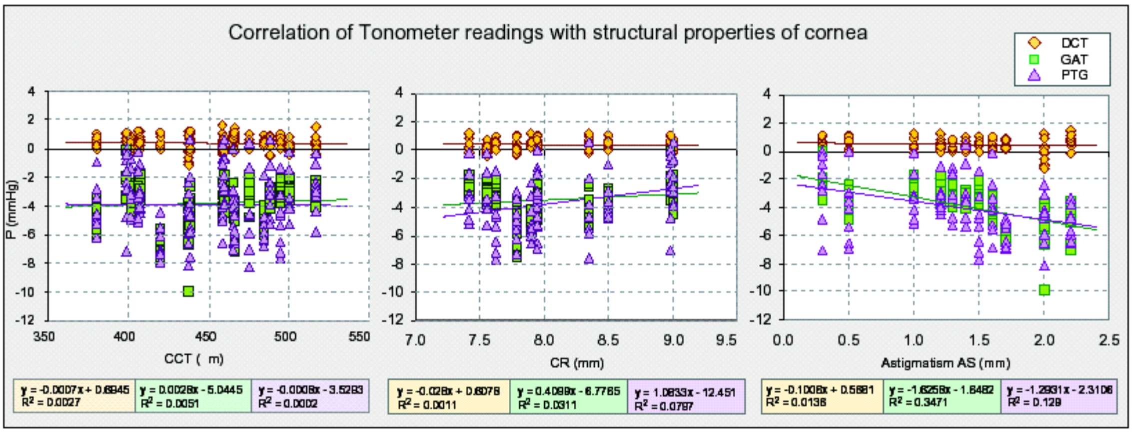

Fig. 6 Correlation of tonometer readings with CCT, CR, and AS.
Due to high scatter of data, correlation of tonometer readings with corneal thickness (CCT), corneal radius (CR), and astigmatism (AS) are not significant or marginally significant (see text and *Table 2*).

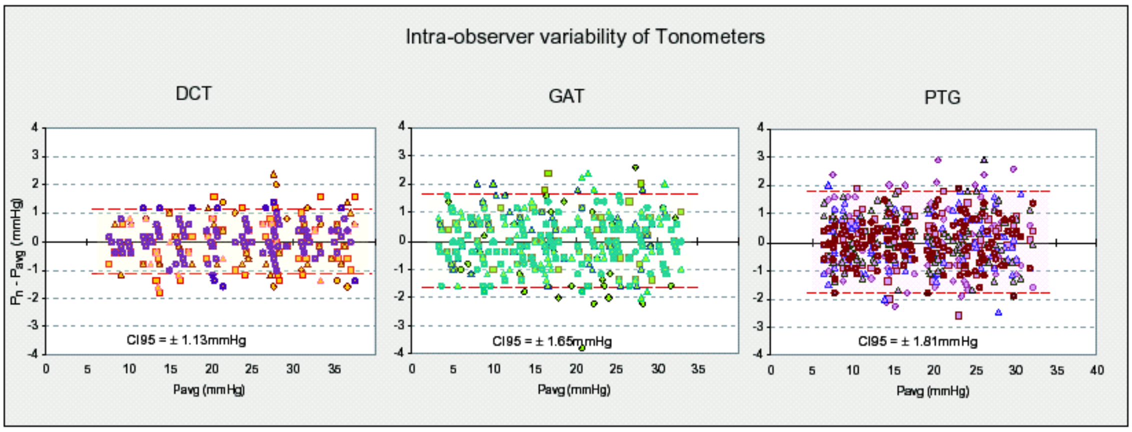

Fig. 7 Intra-observer variability of tonometers.
Difference of individual tonometer readings P_n (n=1…5) to their average P_{avg}, plotted against P_{avg}. Colored band in-between red lines designates 96% confidence interval of tonometer readings obtained by the same operator and is a measure for reproducibility of the procedure.

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