Eur J Ophthalmol 2012; 22 (1): 55-62 DOI: 10.5301/ejo.5000067

Dynamic contour tonometry and Goldmann applanation tonometry: correlation with intracameral assessment of intraocular pressure

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Purpose. *To compare intraocular pressure (IOP) measured using a dynamic contour tonometer (DCT) and a Goldmann applanation tonometer (GAT) with in vivo intracameral IOP, and establish the relationship between DCT, GAT and central corneal thickness (CCT) in patients with primary open-angle glaucoma (POAG).*
Materials and Methods. *We examined 50 eyes of 50 patients with POAG scheduled for glaucoma or cataract surgery. Immediately before surgery, CCT, GAT and DCT IOP were assessed, after which manometry of the anterior chamber was performed. A Bland-Altman plot was used to test the agreement among the 3 measurements of IOP, and univariate and multivariate regression analyses were used to evaluate the effect of CCT on DCT and GAT.*
Results. *On average, the DCT readings were 4.0±1.6 mmHg higher than the GAT readings and 2.3±2.4 mmHg higher than the manometric readings; the GAT measurements were generally a mean 1.7±1.8 mmHg lower than the manometric readings. The CCT had an almost similar influence on DCT and GAT measurements (p=0.84).*
Conclusions. *The DCT-measured IOP was significantly higher than that measured by means of GAT and anterior chamber manometry. The DCT and GAT readings were both influenced by CCT to the same extent.*

Key Words. *Applanation tonometry, Central corneal thickness, Dynamic contour tonometry, Glaucoma, Intraocular pressure, Manometry*

Accepted: September 18, 2011

INTRODUCTION

Introduced towards the end of the 1950s, Goldmann applanation tonometer (GAT) is considered the gold standard in tonometry, and currently the most widely used method of measuring intraocular pressure (IOP) in everyday clinical practice. However, it is well known that central corneal thickness (CCT) and other corneal parameters can affect GAT measurements because IOP is calculated assuming a fixed CCT of 520 µm and disregarding interindividual variability (1). As a result of this approximation, GAT underestimates IOP in patients with a thin cornea, and overestimates it in those with a thick cornea. A review of the literature has shown variations in GAT IOP measurements ranging from 0.11 to 0.71 mmHg for every 10 µm change in CCT (2, 3).
A number of studies have shown that CCT varies considerably between healthy subjects and subjects diagnosed with glaucoma or ocular hypertension (4, 5). In particular, patients with normal tension glaucoma (NTG) seem to have a thinner cornea than those with primary open-angle glaucoma (POAG), and patients with POAG seem to have a

thinner cornea than those with ocular hypertension (OHT) (6). These differences can partially explain a systematic error in GAT IOP measurements (e.g., patients with POAG with a particularly thin cornea may be classified as having NTG, or healthy subjects with a thick cornea may be considered as having OHT) (7, 8).

There is no consensus concerning the correction factor that should be used for GAT measurements in clinical practice, although a recent meta-analysis by Doughty and Zaman suggested a correction factor of 2–3 mmHg per 50 µm, starting from a CCT of 535 µm (9).

The Pascal dynamic contour tonometer (DCT, Swiss Microtechnology AG, Zurich, Switzerland) is a new digital tonometer that has been introduced as an alternative means of measuring IOP regardless of corneal properties. The physical hypothesis and theoretical considerations underlying the DCT have been extensively described elsewhere but, briefly, it is a contact tonometer whose tip has a concave contour that closely matches corneal shape and thus minimizes the amount of corneal deformation during IOP assessments (10). When the tip of the tonometer is applied to the cornea, the tight-fitting shell between the tip and the corneal surface compensates for the force exerted by IOP, and a pressure-sensing device embedded in the concave surface of the tip is capable of recording IOP through the shell.

It has been found that DCT IOP measurements are closer to manometric readings of cadaver human eyes than those of GAT (11, 12). However, it is not clear whether DCT is completely independent of CCT, as some studies have found that DCT readings are less affected by corneal properties than GAT (13-15), and others that their dependency on CCT is similar (16-18).

The aim of this study was to evaluate the correlation between DCT, GAT, and intracameral IOP measurements in the eyes of human subjects, and assess whether DCT readings are affected by CCT.

MATERIALS AND METHODS

The units of observation in this prospective clinical trial were the eyes of glaucomatous patients scheduled for glaucoma or cataract surgery. The exclusion criteria were congenital ocular anomalies (e.g., irido-corneal dysgenesis, congenital ectropion uveae, aniridia); past ocular surgery other than argon laser trabeculoplasty (ALT) or selective laser trabeculoplasty (SLT); and corneal abnormalities that could affect IOP measurements (e.g., corneal edema). Informed consent was obtained from all of the participants after the nature and possible consequences of the study had been explained. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the local institutional review board. All of the patients were of white ethnicity.

The patients enrolled in the study had to undergo glaucoma surgery (e.g., trabeculectomy) if targeted IOP could not be reached by means of the administration of topical drugs, or if they were clinically judged to have progressive visual field loss confirmed by at least 2 consecutive examinations despite maximum tolerated therapy. The indication for cataract surgery was a reduction in visual acuity regardless of glaucoma.

On the day of the scheduled procedure, the patients were hospitalized at 7 AM, and all of the presurgical measurements were made at 8 AM (±1 hour). After topical anesthesia with lidocaine 4% (Alpha Intes, Casoria, Italy), CCT was measured by means of an ultrasonic pachymeter (DGH500, DGH Technology Inc., Exton, PA, USA) and, immediately afterwards, IOP was assessed by means of both GAT and DCT with the patient seated at a slit-lamp installed in the operating theater for study purposes. The sequence of the IOP measurements was randomized. The DCT readings were considered for statistical analysis when their Q value (reliability index) was ≤2 (Q1 and Q2: optimal IOP readings). Two GAT and two DCT readings were acquired; if the 2 readings differed by >2 mmHg, a third measurement was made and the mean value of the closest 2 readings was recorded.

After the 2 noninvasive IOP assessments, invasive intracameral manometry of the anterior chamber was performed under the same conditions (i.e., with the patients seated at the slit-lamp) using a fluid-filled system that is frequently used for invasive intravascular (venous and arterial) pressure monitoring. The plumbing system (Edwards Lifesciences LLC, Irvine, CA, USA) consisted of a small catheter (22 gauge) and a transducer, connected to each other by a noncompliant pressure tube filled with a sterile saline solution. The catheter was inserted into the anterior chamber of the eye through clear cornea incision at the temporal site (3 o'clock in the right eye, 9 o'clock in the left eye), about 1 mm beyond the corneal limbus. The transducer (a resistive device that converts diaphragm movements into electrical signals) was positioned at the

level of the eye, connected to an amplifier with a dedicated monitor. The catheter was left inside the anterior chamber for about 10 seconds, in order to allow the assessment of the patient's IOP waveform. The sensitivity of the pressure transducer is fixed at 5.0 mV per volt of excitation for each mmHg of pressure applied and, as it permits continuous monitoring of arterial blood pressure as well as central venous pressure (range -2 to +6 mmHg), it was judged suitable for this application (19).

Before starting the study, we made manometric IOP measurements in a pilot group of 10 patients (not included in the analysis) to avoid bias due to a learning effect. Particular care was taken when positioning the intracameral catheter in order to avoid stress upon the penetration of the corneal needle, a factor that has previously been found to correlate with poor quality measurements (20). The catheter was left in place for about 10 seconds, in order to monitor any significant IOP drop due to an eventual leakage from the incision (an IOP drop $\geq$1 mmHg caused exclusion of the patient from the study). The DCT and manometric diastolic and systolic IOP were recorded continuously. All of the DCT and manometric IOP values used in this study are diastolic IOP values, which were averaged over 3 to 4 heart cycles to reduce variations.

A paired sample *t* test was used to compare the DCT and GAT measurements, and these with the manometric measurements. In addition, a Bland-Altman plot was used to describe the agreement between the measuring methods (21). Univariate and multivariate linear regression models were used to evaluate the effects of different factors (CCT, age, gender, type of surgery, sequence of measurements) on the DCT and GAT values. Furthermore, the same approach was used to evaluate the effect of manometric IOP, CCT, age, gender, type of surgery, and sequence of measurements on the difference between DCT and GAT (DCT-GAT). The Zeta test (Z) was used to compare the regression lines slope to test the difference of dependence of DCT and GAT on CCT. A p value <0.05 was considered statistically significant.

The analyses were made using SAS software (Statistical Analysis System, version 9.1; SAS Institute Inc., Cary, NC, USA).

RESULTS

The total number of recruited patients was 55, but only 50 eyes of 50 patients were included in the analysis. Five eyes were excluded because of unreliable DCT (Q>2) and/or manometry readings. Table I shows the general characteristics of the studied population.

The DCT readings were higher than the manometric measurements (mean=21.1, SD=3.0 mmHg vs mean=18.8, SD=2.8 mmHg, respectively, *t* test p<0.001) with the Bland-Altman plot showing a mean difference of 2.3, SD=2.4 mmHg (95% limits of agreement between –2.5 and 7.1 mmHg) (Fig. 1).

The GAT readings were generally lower than the manometric readings (mean=17.1, SD=3.2 mmHg vs mean=18.8, SD=2.8 mmHg, respectively, *t* test p<0.001), with the

TABLE I - CHARACTERISTICS OF THE ENROLLED PATIENTS

	All patients	Glaucoma surgery patients	Cataract surgery patients	p value (glaucoma vs cataract)
No. of patients	50	21	29	0.25
Mean age (SD)	71.6 (6.8)	70.7 (6.1)	72.3 (7.3)	0.42
M/F	25/25	10/11	15/14	0.77
GAT IOP (SD)	17.1 (3.2)	18.4 (3.1)	16.1 (2.9)	0.01
DCT IOP (SD)	21.1 (3.0)	22.4 (2.8)	20.1 (2.9)	<0.01
Manometric IOP (SD)	18.8 (2.8)	19.9 (2.8)	18.0 (2.5)	0.01
CCT (SD)	549.6 (32.9)	554.8 (35.2)	546.4 (31.3)	0.38

CCT = central corneal thickness; DCT = dynamic contour tonometer; GAT = Goldmann applanation tonometer; IOP = intraocular pressure.

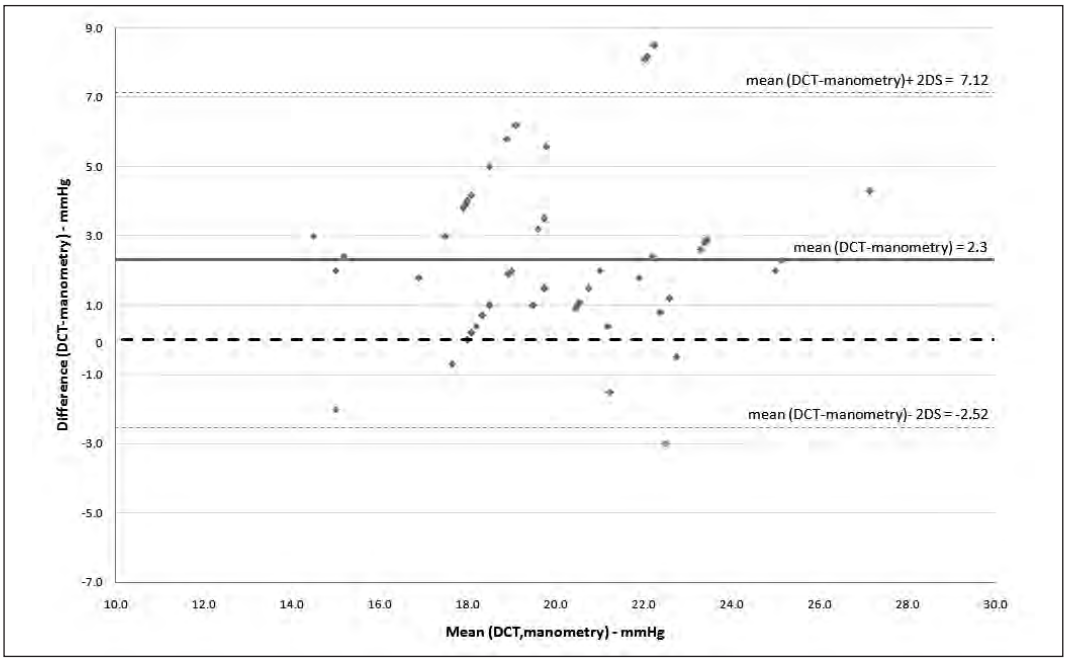

Fig. 1 - *Bland-Altman plot for dynamic contour tonometer (DCT) vs manometry readings.*

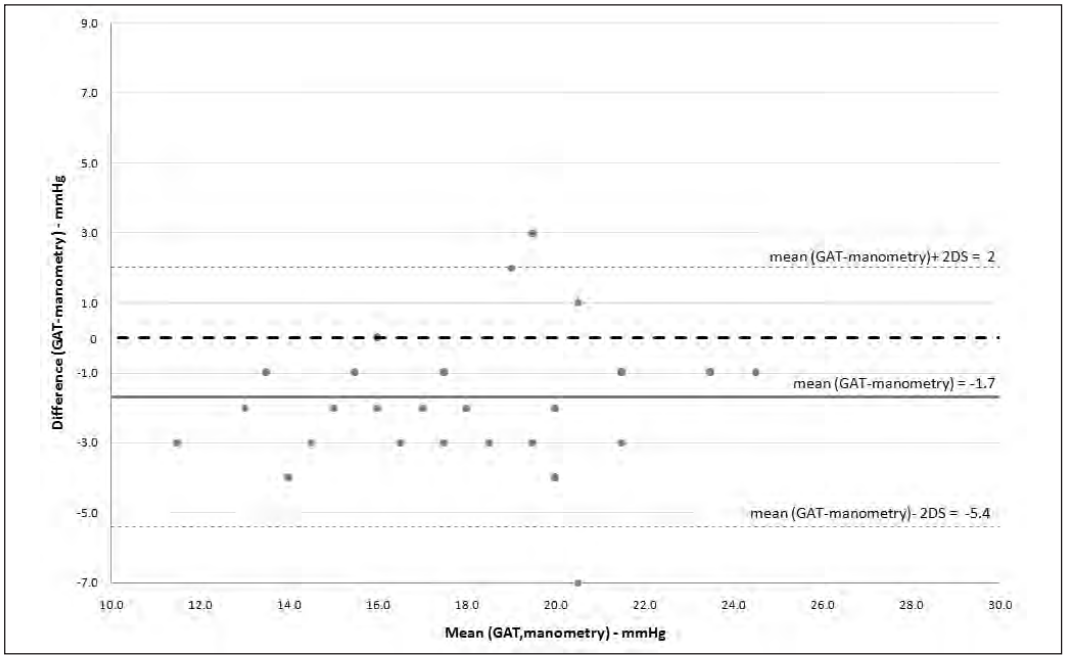

Fig. 2 - *Bland-Altman plot for Goldmann applanation tonometer (GAT) vs manometry readings.*

Bland-Altman plot showing a mean difference of –1.7, SD=1.8 mmHg (95% limits of agreement between –5.4 and 2 mmHg) (Fig. 2).

The DCT readings were generally higher than the GAT readings (mean=21.1, SD=3.0 mmHg vs mean=17.1, SD=3.2 mmHg, respectively, *t* test p<0.001), and the Bland-Altman plot showed that the difference was an average of 4.0, SD=1.6 mmHg (95% limits of agreement between 0.64 and 7.36 mmHg) (Fig. 3).

The results were similar when the glaucoma and cataract surgery groups were considered separately (Tab. II).

The overall GAT and DCT measurements correlated with CCT at both univariate analysis (β=0.048, p=0.0003, and β=0.049, p=0.0001; Fig. 4) and multivariate analysis (β=0.045, p=0.001, and β=0.047, p<0.001; Tab. III). The comparison of the slope of regression lines showed that

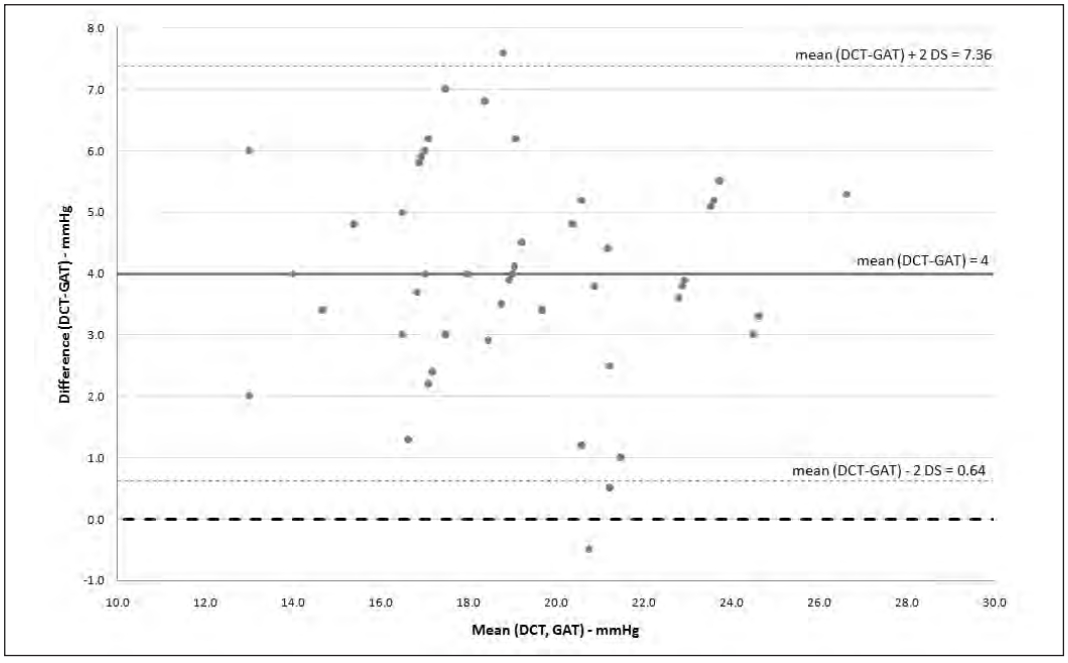

Fig. 3 - *Bland-Altman plot for dynamic contour tonometer (DCT) vs Goldmann applanation tonometer (GAT) readings.*

TABLE II - AGREEMENT AMONG GAT, DCT, AND MANOMETRY READINGS IN THE CATARACT AND GLAUCOMA SURGERY GROUPS

	Mean difference (mmHg)	SD (mmHg)	Minimum (mmHg)	Maximum (mmHg)	p value[a]
Cataract group					
DCT vs GAT	4.0	1.6	1.0	7.6	<0.01
DCT vs MAN	2.1	2.6	–3.0	8.5	<0.01
GAT vs MAN	–1.8	2.0	–7.0	3.0	<0.01
Glaucoma group					
DCT vs GAT	3.9	1.8	–0.5	7.0	<0.01
DCT vs MAN	2.5	2.1	–1.5	8.1	<0.01
GAT vs MAN	–1.4	1.5	–4.0	3.0	<0.01

DCT = dynamic contour tonometer; GAT = Goldmann applanation tonometer; MAN = manometry.
[a] Student *t* test.

CCT had an almost similar influence on DCT and GAT (Z=–0.19, p=0.849).

At multivariate regression analysis, only CCT and the type of surgery (glaucoma or cataract) were significantly associated with the GAT and DCT readings (Tab. III), whereas no association was found for age, gender, or the sequence of IOP measurements.

When DCT-GAT values were analyzed, no significant associations were found except for the level of manometric IOP (β=–0.331, p=0.002). This association is explained by the different correlation between manometry and GAT measurements and between manometry and DCT measurements described in Figure 5. The difference between manometry and GAT was almost constant for all manometric IOP readings (β=0.065, p=0.496), while the overestimate of DCT decreased at the increase of manometric IOP levels (β=0.2015, p=0.017).

DISCUSSION

Our results suggest that DCT tends to overestimate IOP by an average of 4.0±1.6 mmHg in comparison with GAT,

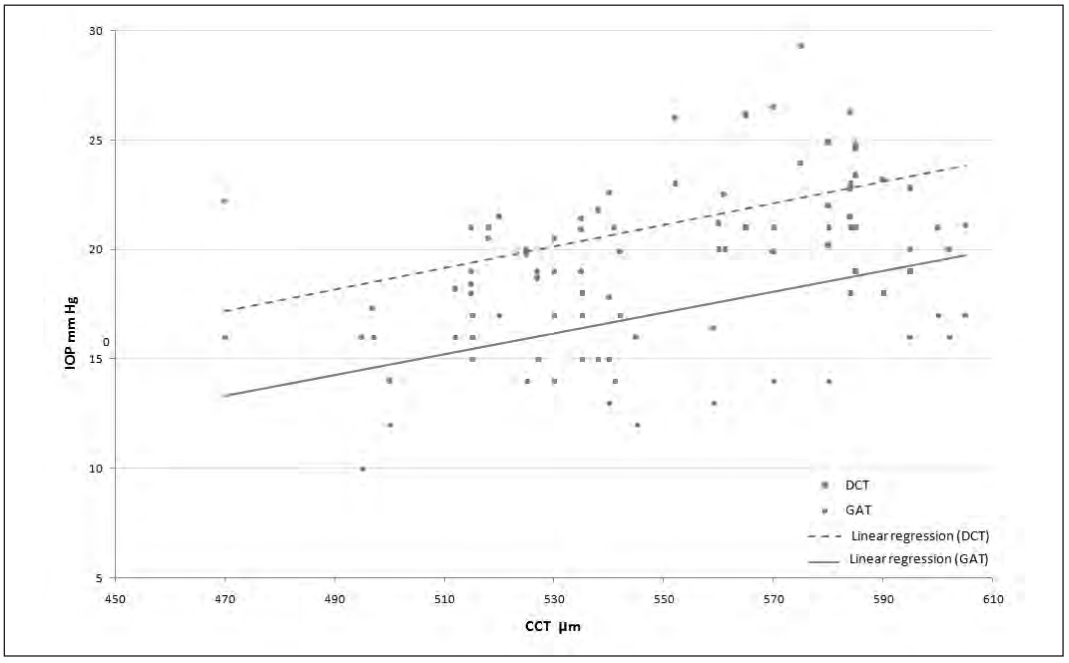

Fig. 4 - *Scatterplot for central corneal thickness (CCT) vs dynamic contour tonometer (DCT) and Goldmann applanation tonometer (GAT) readings. IOP = intraocular pressure.*

TABLE III - MULTIVARIATE REGRESSION ANALYSES FOR GAT IOP, DCT IOP, AND DCT-GAT IOP

Variable	GAT IOP		DCT IOP		DCT-GAT IOP	
	Beta (SE)	p value	Beta (SE)	p value	Beta (SE)	p value
CCT (µm)	0.045 (0.012)	0.001	0.047 (0.011)	<0.001	0.013 (0.008)	0.112
Sequence of readings	–0.703 (0.787)	0.377	–0.560 (0.721)	0.442	0.248 (0.461)	0.594
Age (years)	–0.022 (0.060)	0.721	–0.019 (0.055)	0.733	–0.016 (0.035)	0.656
Type of surgery (cataract vs glaucoma)	–1.903 (0.796)	0.021	–1.831 (0.730)	0.016	–0.425 (0.489)	0.389
Sex (male/female)	0.981 (0.777)	0.214	1.347 (0.712)	0.065	0.732 (0.467)	0.125
Manometry	ND	ND	ND	ND	–0.331 (0.099)	0.002

CCT = central corneal thickness; DCT = dynamic contour tonometer; GAT = Goldmann applanation tonometer; IOP = intraocular pressure; ND = not determined.

and by an average of 2.3±2.4 mmHg in comparison with manometry. A number of studies have confirmed that DCT overestimates IOP in comparison with GAT, but the differences range from 0.1 to 4.4 mmHg (18, 22). We found a mean difference of 4.0±1.6 mmHg, which is similar to the findings of Martinez-de-la-Casa et al (4.4±2.6 mmHg) and those of Grieshaber et al (3.9±2.3 mmHg) (22, 17). However, the mean difference found in these studies is considerably higher than that generally reported in the literature, usually within 2.5 mmHg (14, 23, 24). The reason for this difference is unknown, but it is worth noting that all of our enrolled patients were affected by glaucoma and had been undergoing treatment with one or more topical drugs for months or years, and we cannot exclude the possibility that this may have affected corneal biomechanics, and consequently corneal rigidity, as it seems that antiglaucoma drugs modulate the extracellular matrix in the long term (17, 25-27).

We also found that DCT overestimates IOP in comparison with manometry by 2.3±2.4 mmHg. There are few published data comparing DCT and manometry. Kniestedt et al compared DCT and manometric IOP in human cadaver eyes in 2 studies, and did not find any significant difference between the 2 techniques (11, 12). However, assessing IOP in enucleated eyes may lead to study biases due to alterations in corneal biomechanics and ocular structures.

Boehm et al (20) used DCT and anterior chamber manom-

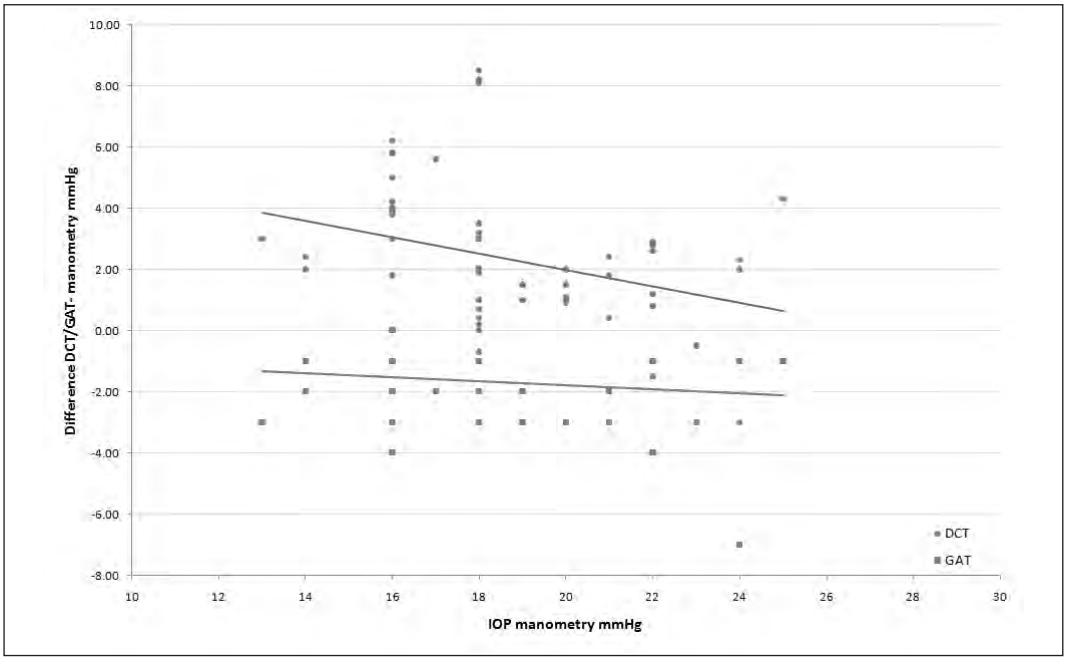

Fig. 5 - *Scatterplot for the differences of dynamic contour tonometer (DCT) – manometry readings and Goldmann applanation tonometer (GAT) – manometry readings vs manometry readings. IOP = intraocular pressure.*

etry in 60 healthy patients scheduled for cataract surgery. There were no clinically relevant differences between the 2 measurements, even if DCT showed a statistically significant underestimation of the IOP at the level of 35 mmHg (0.89 mmHg, p=0.01) (20). Our data showed that difference between GAT and manometry tends to remain constant for all manometry-measured IOP; on the contrary, the difference in IOP readings between DCT and manometry tends to decrease at the increase of manometric IOP levels. There are a number of differences between this study and ours: first of all, Boehm et al used a closed manometry system to make simultaneous DCT and manometry measurements at fixed IOP levels, whereas we used DCT and closed manometry separately and recorded in vivo manometric IOP without artificially setting IOP levels. Secondly, they assessed supine IOP using a hand-held DCT designed for the study, whereas we used a standard DCT and assessed sitting IOP at the slit-lamp, thus reflecting the real clinical setting.

There is still no agreement in the literature concerning the relationship between CCT and DCT. Most studies have found that DCT is less dependent on CCT than GAT (13-15), but some have found that both methods are similarly dependent (16-18). Our analyses showed that CCT has an almost similar influence on DCT and GAT.

The methodologic limitations of the present study mainly concern the manometric environment. Manometric IOP in a closed system fluctuates with heart cycles. The manometer measures this fluctuation as an ocular pulse and provides a diastolic and systolic IOP. As DCT records IOP during the diastolic phase of the cardiac cycle, we decided to use manometric diastolic IOP for our analyses. However, although always performed by the same experienced surgeon, the insertion of the catheter into the anterior chamber was not ideal because of the inevitable slight differences in corneal incision, and the fact that incorrect catheter insertion can stress the cannula and cause measurement errors (20). Although particular care was taken in this phase of the study, this bias cannot be fully excluded.

In conclusion, our comparison of GAT and DCT measurements with each other and manometric IOP showed that DCT tended to overestimate IOP in comparison with both the other techniques. Moreover, both GAT and DCT were similarly dependent on CCT. To our knowledge, this is the first study directly comparing DCT, GAT, and manometry in an in vivo environment but, given its small sample size, further studies are needed to clarify the role of DCT in clinical practice.

The authors report no proprietary interest or financial support.

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