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ORIGINAL PAPER

# Intraocular pressure measurement with Corvis ST in comparison with applanation tonometry and Tomey non-contact tonometry

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**Abstract**

*Purpose* Intraocular pressure (IOP) measurement can be performed with different methods. Newer methods have to be compared to the standard method, the Goldmann applanation tonometry (GAT). We herein compare two air-puff tonometers, the non-contact tonometer (Tomey NCT) and the Corvis ST (CST) with GAT in eyes with a broad spectrum of IOP.

*Methods* Two hundred and forty-nine eyes of 249 patients (with diagnosis of either glaucoma or ocular hypertension) were included in this monocenter prospective cohort study. Each eye underwent IOP measurements via GAT, NCT and CST. Bland–Altman plots were calculated to compare the different methods in the three groups. Paired *t* tests were used for statistical comparison between the three measurement methods. The difference between the different methods was tested on correlation against central corneal thickness (CCT).

*Results* Mean IOP in GAT was 17.6 mmHg (standard deviation (SD) 5.9), 16.3 mmHg (SD 5.6) in NCT and 18.0 mmHg (SD 5.5) in CST. Comparisons between GAT and CST vs. NCT showed significant differences ($p < 0.001$), while GAT vs. CST showed no significant difference ($p = 0.1162$). Mean CCT was 538.7 μm (SD 35.1).

*Conclusions* Mean values of GAT and CST show comparable results. However, both GAT and CST differ significantly from NCT. NCT shows lower IOP values compared to both other methods.

**Keywords** Glaucoma · Intraocular pressure · Corvis ST · NCT · GAT

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## Introduction

In intraocular pressure (IOP) measurement, Goldmann applanation tonometry (GAT) is still seen as the "gold standard" although it was first described as early as in 1957 [1]. All newer methods have to be compared with this standard [2]. In GAT, the IOP is measured through the applanation of the cornea in a precisely defined area. The IOP is derived from the amount of force that is needed to flatten the cornea in a defined area [1]. GAT has its disadvantages such as the need of corneal surface anesthesia and a dependence of the corneal thickness and variabilities from the examiner's interpretation of the applanation area [3, 4]. In recent years, computerized methods have been introduced that can measure the IOP with only minor eye contact or even contact-free and examiner independently [5–7]. These newer methods include the non-contact tonometer (NCT) which measures IOP through an air puff that is reflected by the cornea. The velocity of this reflected air is then measured and varies upon different IOPs [2, 8]. One of the latest methods introduced, the Corvis ST (CST), also works through the indentation of the cornea by an air puff and captures the deformation of the cornea with a high-speed Scheimpflug camera [9]. The IOP can be derived from the dynamics of this deformation. Both methods are contact-free and do not need corneal surface anesthesia.

So far, only few studies of small size have compared these new methods to the classical GAT. Our study aims to compare these three measurement technologies in a larger cohort.

## Materials and methods

This prospective study was approved by the Ethics Board of the University of Freiburg (vote number 146/13). All participants gave written consent.

In the period from January 2014 to the end of June of 2015, participants were recruited from the outpatients' glaucoma consultation hours at the Eye Center of the University Hospital of Freiburg. All participants had been diagnosed with either a glaucoma or ocular hypertension.

All participants underwent intraocular pressure measurement by Corvis ST (Oculus, Wetzlar, Germany), Tomey FT-1000 NCT (Tomey, Erlangen, Germany) and Goldmann applanation tonometry (Haag-Streit, Koeniz, Switzerland). The order of the measurements was randomized for every participant.

For all patients, the age, sex and if glaucoma was recorded, glaucoma type (primary open-angle glaucoma (POAG), pseudoexfoliation glaucoma (PEX), normal tension glaucoma (NTG), ocular hypertension (OHT) and the central corneal thickness (CCT, measured by Corvis ST) were documented. In the statistical analyses, only the right eyes of the participants were included to rule out clustering issues.

For comparison between the measurements (CST vs. GAT, CST vs. NCT, GAT vs. NCT), Bland–Altman plots and paired *t* tests were calculated. These comparisons were performed for the whole groups of right eyes. For the Bland–Altman plots, 95% limits of agreement were set as acceptable values.

The difference between the three different groups was tested on correlation against CCT with Spearman's correlation test.

Descriptive data are reported as means with standard deviation unless stated otherwise.

All statistical analysis was performed using the R language [10]. R is a non-profit and open-source programming environment which can be used for data processing and statistical comparisons.

## Results

A total of 249 patients were included in this study. Table 1 shows the descriptive data for the right eyes.

One patient showed very low intraocular pressure (3.7–5.5 mmHg depending on the method). In this case, the cornea was thin (438 µm), the patient suffered from NTG and was using four different medications to lower the IOP.

Table 2 shows the pairwise statistical comparison between the different measuring methods. All comparisons hint toward a systematic deviation of the measuring instruments.

For the complete groups, Bland–Altman plots are shown in Figs. 1, 2 and 3.

The Bland–Altman plots for the comparison between GAT vs. CST and GAT vs. NCT hint toward that the new instruments show some systematic deviation from GAT: CST and NCT seem to measure higher than GAT in lower pressure levels but lower than GAT in higher pressure levels.

**Table 1** Descriptive data for the measurements (GAT, NCT and CST) and CCT in means with SD

| | Total ($n$ = 249) |
|---|---|
| Age (years) | 66.9 (12.6) |
| Female | 60% |
| GAT (mmHg) | 17.6 (± 5.9) |
| | Range 5–45 |
| NCT (mmHg) | 16.3 (± 5.6) |
| | Range 3.7–41.3 |
| CST (mmHg) | 18.0 (± 5.5) |
| | Range 5.5–43 |
| CCT (µm) | 538.7 (± 35.1) |
| Spectrum of diagnoses | |
| NTG (%) | 16% |
| OHT (%) | 10% |
| PEX (%) | 11% |
| POAG (%) | 63% |

For the pressure values, ranges are given

Correlation analysis on the difference between the measurement methods showed no statistically significant correlation depending on CCT (Table 3).

## Discussion

This study aimed to compare three different methods of intraocular pressure measurement. The overall comparison showed significant differences between GAT vs. NCT and CST vs. NCT. We found a tendency for CST to measure higher values than GAT for the group of lower intraocular pressure while the tendency turned toward lower values for CST in comparison with GAT for the group of higher intraocular pressure. The same tendency was observed in the comparison between NCT and GAT.

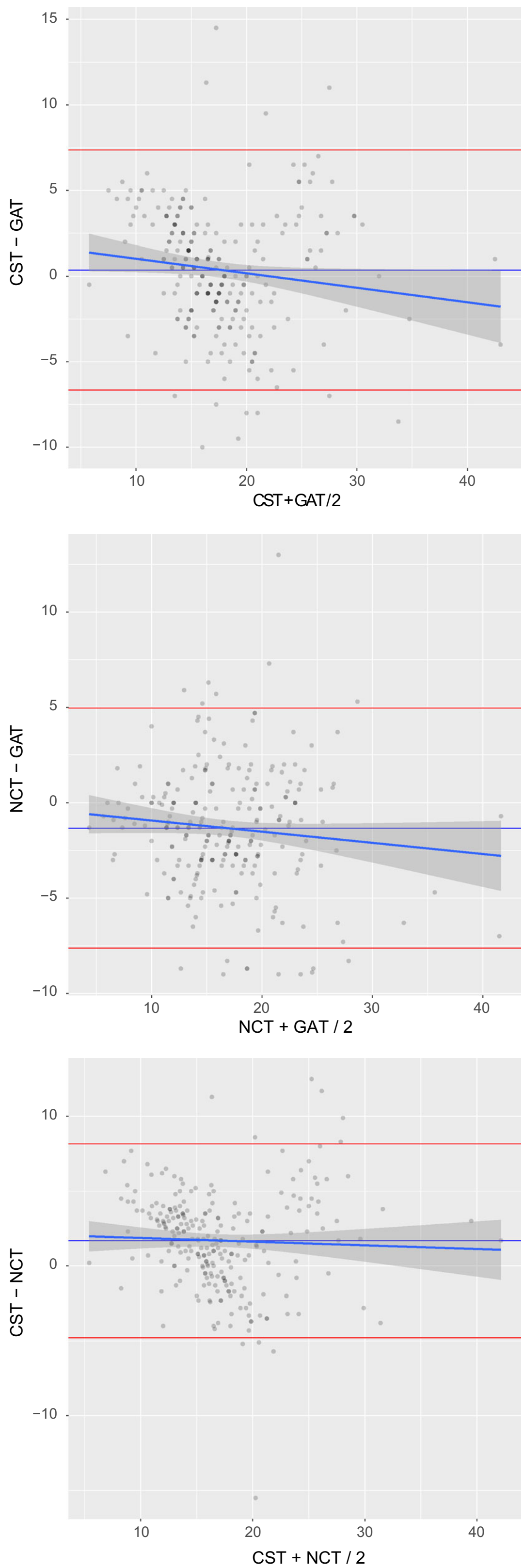
**Table 2** Paired $t$ tests of pairwise comparisons of the three measuring methods

| | Mean difference | $p$ Value |
|---|---|---|
| GAT vs. CST | − 0.36 | 0.1162 |
| GAT vs. NCT | 1.33 | **< 0.001** |
| CST vs. NCT | 1.69 | **< 0.001** |

Bold represents level of significance is < 0.05

These findings go beyond other studies that compared different methods of intraocular pressure measurement. Most are limited to comparing only overall mean IOP values [7, 9, 11, 12]. One study by Hohmann et al. compared different IOP levels but used the iCare tonometer in comparison with GAT. These authors reported larger variations between the two methods for IOP values higher than 23 mmHg [5]. Previous comparisons between CST and GAT observed significant differences in the mean IOP [7, 12, 13]. Our data do not suggest this difference in the same extent. Interestingly, Reznicek et al. stated that the CST measurements and their accuracy might be dependent on the IOP level (higher vs. lower levels). They assumed a tendency for CST values to be higher than GAT with increasing IOP [7]. Our data show the opposite tendency. Hong et al. compared CST with GAT and NCT as we did in our study but included only 59 patients [9]. They observed only relevant differences between GAT and NCT while NCT showed the overall highest mean IOP values. This finding is in contrary with our results. We rather observed systematically lower IOP readings from NCT. Our findings might be more robust due to the much larger group of eyes (59 vs. 249 in our investigation). Cook et al. stated that NCT measures within the range of ± 2 mmHg around the GAT values [14]. Our data share these findings since we found a mean difference of 1.33 mmHg between GAT and NCT.

The biomechanical properties of the cornea are reported to affect the intraocular pressure measurement [15, 16]. CST and NCT rely on these biomechanical properties to a different extent that could explain the difference between these two measuring methods. These properties may be influenced by different intraocular pressure levels, so that a lower or higher pressure level might cause inaccurate values. Interestingly, both non-contact tonometer methods showed the tendency to measure slightly higher than GAT in lower pressure levels and lower than GAT in higher pressure levels. Neuburger et al. showed an in vitro model of donor corneas in an artificial anterior chamber that the reliability of intraocular pressure values obtained with the Ocular Response Analyzer, which is another non-contact tonometer, is highly dependent on the intraocular pressure level and tends to be more inaccurate in higher levels [17].




◀**Figs. 1, 2 and 3** Bland–Altman plots for the comparison of the complete groups according to the different measurement method (**a** GAT vs. CST, **b** GAT vs. NCT, **c** NCT vs. CST). Red lines represent the standard deviation of the mean difference between the two measurement methods (horizontal blue line) multiplied by 1.96 in both directions. Darker dots represent more measurements for one value. A line of best fit with a confidence interval of 95% is represented by the thick blue line and the darker area around it

Still, we cannot be certain about the "real" IOP since we did not compare the obtained values to a pressure measured with an intraocular method. As long as no intraocular method of IOP measurement is not performed, GAT is widely accepted as the gold standard in IOP measurement and so, all other methods have to be compared to it [18, 19]. Regarding this, CST measurements do not differ significantly from GAT according to our data and therefore might be as exact as GAT.

Since, the differences between the different methods are only of minor nature, they might not be highly relevant for the clinical routine. From former glaucoma studies, we know that the IOP is one of the major risk factors for developing the disease or its progression [20, 21]. The ocular hypertension treatment study (OHTS) stated that an IOP reduction of 3 mmHg resulted in a 50% less risk of converting from ocular hypertension to manifest glaucoma [21, 22]. This suggests that an exact measurement of the IOP is crucial for determining the need and the success of a therapy. This said the nonsignificant difference of CST to GAT as the gold standard suggests that CST might be used as a feasible method for IOP measurement.

## Conclusion

The CST shows a good overall comparability to GAT. CST seems to overestimate IOP in lower and

**Table 3** Spearman's correlation test results for the comparisons between the different methods depending on CCT

| | Rho correlation | *p* Value |
|---|---|---|
| GAT vs. CST | 0.07 | 0.30 |
| GAT vs. NCT | 0.11 | 0.11 |
| CST vs. NCT | − 0.09 | 0.15 |

underestimate IOP in higher IOP levels compared to GAT and NCT. However, the differences were of minor nature and might therefore not be clinically relevant. The two non-contact methods and especially the CST might be used for IOP screening.

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