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Original article

# THE CORNEA AND METHODS FOR MEASURING INTRAOCULAR PRESSURE

**Jordanova Elena**,[1] Hentova-Sencanic Paraskeva,[2] Marjanovic Ivan,[3, 4] Sencanin Ivan,[5] Stefanovic Ivana,[6] Baralic Marko[4, 7]

[1] Department of Nephrology, Clinic for Internal Medicine, Clinical Hospital Center Zemun, Belgrade, Serbia
[2] Medigroup-ophthalmology infirmary Oftalmika, Belgrade, Serbia
[3] Clinic for Eye Disease, Clinical Center of Serbia, Belgrade, Serbia
[4] Faculty of Medicine, University of Belgrade, Belgrade, Serbia
[5] Clinic for Eye Disease, Clinical Hospital Center Zvezdara, Belgrade, Serbia
[6] Municipal Institute for Emergency Medical Aid, Belgrade, Serbia
[7] Clinic of Nephrology, Clinical Center of Serbia, Belgrade, Serbia

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***Abstract:*** **Introduction**:The study aimed to assert the relationship between central corneal thickness (CCT) and intraocular pressure (IOP) measured by: Goldmann applanation tonometry (GAT) and Dynamic contour tonometry (DCT).

**Materials and Methods**:The study included 150 patients with a mean age of 59.39 ± 13.12 years. Patients were divided into three groups: 50 primary open-angle glaucoma (POAG) patients, 50 ocular hypertension (OHT) patients, and 50 normal tension glaucoma (NTG) patients. IOP was determined using GAT and DCT. CCT was measured by ultrasound pachymetry.

**Results**: IOP measured with DCT was higher than IOP measured with GAT (19.80 ± 3.67 mmHg vs 17.71 ± 3.35 mmHg). A significant positive association between IOP measured with GAT and IOP measured with DCT was found in all patients ($r = 0.867$, $p < 0.01$). A significantly positive association between IOP measured with GAT and IOP measured with DCT in POAG ($r = 0.855$, $p < 0.01$), OHT ($r = 0.826$, $p < 0.01$), and NTG patients ($r = 0.832$, $p < 0.01$) were found. A significant positive correlation between CCT and IOP measured with GAT ($r = 0.198$, $p < 0.01$), as well as a significant positive correlation between CCT and IOP measured with DCT was found ($r = 0.198$, $p < 0.01$) in all patients. There was no correlation between CCT and IOP measured neither with GAT nor with DCT separately in three patient groups ($p > 0.05$).

**Conclusion**: CCT-influenced IOP was measured by both methods, GAT and DCT. DCT can not replace GAT, but it is very useful, especially in cases where errors are in the IOP GAT measurement.

***Keywords:*** Cornea, Intraocular pressure, Pachymetry.

## INTRODUCTION

Glaucoma is a chronic progressive optic neuropathy with morphological (excavation of the optic nerve head) and functional disturbances (defects in the field of vision) (1). Glaucoma is the second cause of blindness after cataracts in underdeveloped countries and after senile degeneration of the yellow spot in developed countries. It is estimated that in 2020 this disease in the world has 80 million people, and 111 million people will have it by 2040 (2).

In everyday ophthalmological practice, Goldmann applanation tonometry (GAT) is the standard method for determining intraocular pressure (IOP). GAT was first introduced by Goldmann and Theo Schmidt in 1957. Measurement of IOP with this method is done based on the force required to perform the plan, i.e. decomposition of the certain cornea (3). The Dynamic Contour Tonometer (DCT) is a contact, non-applanation method of IOP measurement based on the principle of tonometer and corneal head counts so that the head of the tonometer takes over the role of the bulb shell. This way, it directly measures the force transmitted to the bulb shell and comes from the IOP. DCT is commercially available since 2004, designed for direct and non-invasive IOP measurement, relatively

independent of inter-individual variations of corneal biomechanics (4). The value of the IOP obtained by the DCT method is the result of a four-force equilibrium: IOP, corneal rigidity, the adhesion force of the tear film, and aposition force of the tonometer (4). A piezoelectric sensor (1.2 mm diameter), mounted on the top of the tonometer head (the diameter of the head is 10.5 mm, contact diameter of 7 mm), is used for direct measuring the dynamic pulsed fluctuations in the IOP by DCT method. DCT head is similar to the GAT head and produces a constant aposition force of LG. For practical and hygienic reasons, DCT has a special silicone overlay on its head-tip (4, 5). The impact of CCT on IOP is the greatest in non-contact tonometry and the smallest in DCT (4-7).

The present study aimed to evaluate the relationship of central corneal thickness (CCT) measured by ultrasound pachymetry and IOP readings, measured with GAT and DCT, in open-angle glaucoma patients.

## MATERIALS AND METHODS

The study included 150 patients with a mean age of 59.39 ± 13.12 years (range 19-83 years). Patients were divided into three groups: 50 primary open-angle glaucoma (POAG) patients, 50 ocular hypertension (OHT) patients, and 50 normal tension glaucoma (NTG) patients. The research adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from all patients.

Including criteria in the study were: 1) POAG patients with elevated IOP > 21 mmHg without glaucomatous visual field defects and glaucomatous cupping of the optic disk, 2) OHT patients were with elevated intraocular pressure (> 22 mm Hg), normal visual fields and normal-appearing optic nerve heads, 3) NTG patients were with normal intraocular pressure (≤ 22 mm Hg), open angle on gonioscopy, glaucomatous visual field defects and glaucomatous cupping of the optic disk. Excluding criteria from the study were: previous intraocular surgery, corneal dystrophy or edema, pigmentary dispersion syndrome, and end-stage of glaucoma (absolute or fere absolute glaucoma).

### *Operating technique*

Topical anaesthesia (Sol. Tetracaine 1%) was used for all measurements. IOP was determined 3 times, each consecutively, using GAT (Goldmann tonometer, Haag- Streit International AT 900, Swiss Made) and DCT (Pascal Dynamic Contour Tonometer SMT Swiss Microtechnology AG a Ziemer Ophthalmics Group Company, CH- 2562 P011 Switzerland). Tip preservative was changed before every exam during DCT measurements (Figure 1) (3). CCT was measured

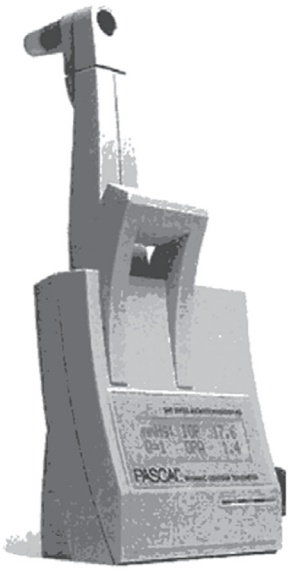

***Figure 1.*** *Dynamic contour tonometry*

3 times consecutively using Ultrasound Pachymetry (Micro Medical Devices, Palm Scan AP 2000 Ophthalmic Ultrasound, Device Mode P2000, password 64711773, Serial # 3102, Made in USA) (4, 8).

### *Statistics*

SPSS software 17.0. the application was used for all analyses. Statistical significance was assumed at $p < 0.05$. Data were analyzed using Student's t-test (or Mann-Whitney U test due to distribution) and Pearson's $\chi$ test (for nominal data). Variables were assessed by Pearson's parametric correlation method. When comparing three or more data sets, Fischer's variance analysis (ANOVA) was used.

## RESULTS

In all patients the mean IOP measured with GAT was 17.7 ± 3.35 mmHg, and the mean IOP measured with DCT was 19.80 ± 3.67 mmHg. OHT patients had the highest mean IOP measured both with GAT and DCT, and NTG patients had the lowest mean IOP measured both with GAT and DCT (Table 1). There was a significant difference between the three groups of patients in mean IOP measured both with GAT ($F_{POAG, OHT} = 5.134$, $p < 0.05$, $F_{POAG, NTG} = 5.516$, $p < 0.05$, $F_{NTG, OHT} = 9.707$, $p < 0.01$) and DCT ($F_{POAG, OHT} = 5.220$, $p < 0.05$, $F_{POAG, NTG} = 5.341$, $p < 0.05$, $F_{NTG, OHT} = 9.644$, $p < 0.01$). The mean difference between DCT and GAT readings was 2.09 ± 1.84 mmHg. The mean difference between DCT and GAT readings was almost the same in OHT (2.16 ± 1.87 mmHg) and NTG patients (2.14 ± 1.79 mmHg), the lowest in POAG patients (1.97 ± 1.85 mmHg) (Table 2).

***Table 1.*** *Intraocular pressure measured with Goldmann applanation tonometry and Dynamic contour tonometry in all patients and three patient groups*

| Variable | Groups | Mean ± SD (mmHg) | Minimal value | Maximal value |
|---|---|---|---|---|
| **GAT"** | POAG* | 17.89 ± 3.35 | 10 | 27 |
| | OHT& | 19.45 ± 2.87 | 14 | 31 |
| | NTG | 15.79 ± 2.78 | 8 | 22 |
| | All patients | 17.71 ± 3.35 | 8 | 31 |
| **DCT±** | POAG* | 19.86 ± 3.53 | 12.6 | 29.4 |
| | OHT& | 21.61 ± 3.31 | 14.8 | 34.3 |
| | NTG@ | 17.93 ± 3.23 | 6.8 | 24.1 |
| | All patients | 19.80 ± 3.67 | 6.8 | 34.3 |

*"GAT = Goldmann applanation tonometry, ±DCT = Dynamic contour tonometry, *POAG = open-angle glaucoma, &OHT = ocular hypertension,@NTG = normal tension glaucoma.*

***Table 2.*** *Mean difference between Dynamic contour tonometry and Goldmann applanation tonometry readings in all patients and three patient groups*

| Variable | Groups | Mean ± SD (mmHg) | Minimal value | Maximal value |
|---|---|---|---|---|
| **Mean difference DCT- GAT** | POAG* | 1.97 ± 1.85 | -4.60 | 6.60 |
| | OHT& | 2.16 ± 1.87 | -2.00 | 7.80 |
| | NTG@ | 2.14 ± 1.79 | -1.80 | 6.80 |
| | All patients | 2.09 ± 1.84 | -4.60 | 7.80 |

*"GAT = Goldmann applanation tonometry, ±DCT = Dynamic contour tonometry, *POAG = open-angle glaucoma, &OHT = ocular hypertension,@NTG = normal tension glaucoma.*

***Table 3.*** *Central corneal thickness in all patients and three patient groups*

| Variable | Groups | Mean ± SD (µm) | Minimal value | Maximal value |
|---|---|---|---|---|
| **Central corneal thickness** | POAG* | 551.76 ± 29.58 | 508 | 622 |
| | OHT& | 596.41 ± 28.32 | 535 | 684 |
| | NTG@ | 544.01 ± 26.75 | 485 | 596 |
| | All patients | 564.06 ± 36.43 | 485 | 684 |

**POAG = open- angle glaucoma, &OHT = ocular hypertension, @NTG = normal tension glaucoma.*

A significant positive association between IOP measured with GAT and IOP measured with DCT in all patients was found ($r = 0.867$, $p < 0.01$) (Figure 2). Also, a significant positive association between IOP measured with GAT and IOP measured with DCT in POAG patients ($r = 0.855$, $p < 0.01$), OHT patients ($r = 0.826$, $p < 0.01$) and NTG patients ($r = 0.832$, $p < 0.01$) were found.

The mean CCT in all patients was 564.06 ± 36.43 µm. OHT patients had the highest mean CCT (596.41 ± 28.32 µm), and NTG patients had the lowest mean CCT (544.01 ± 26.75 µm) (Table 3). There was no significant difference in mean CCT between POAG and NTG patients ($F_{POAG, OHT} = 13.449$, $p < 0.01$, $F_{POAG, NTG} = 2.041$, $p > 0.05$, $F_{NTG, OHT} = 15.043$, $p < 0.01$). A significant positive correlation between CCT and IOP measured with GAT ($r = 0.198$, $p < 0.01$) and a significant positive correlation between CCT and IOP measured with DCT ($r = 0.198$, $p < 0.01$) were found. There is no significant correlation between CCT and IOP measured with GAT individually in POAG ($r = -0.017$, $p > 0.05$), OHT ($r = -0.096$, $p > 0.05$) and NTG patients ($r = -0.147$, $p > 0.05$), as well as CCT and IOP, measured with DCT in POAG ($r = -0.052$, $p > 0.05$), OHT ($r = -0.032$, $p > 0.05$) and NTG patients ($r = - 0.175$, $p > 0.05$). Figure 3 shows a significant positive correlation between CCT and the mean difference between DCT and GAT readings in all patients ($r = -0.288$, $p < 0.01$).

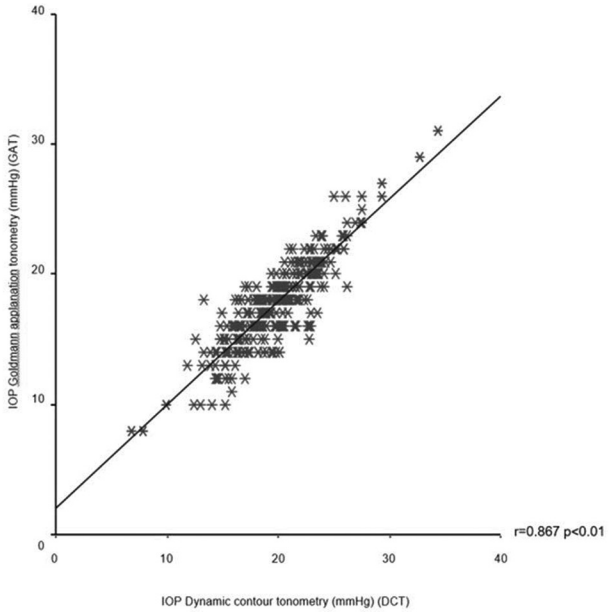


***Figure 2**. Correlation between IOP measured with Goldmann applanation tonometry and IOP measured with Dynamic contour tonometry*

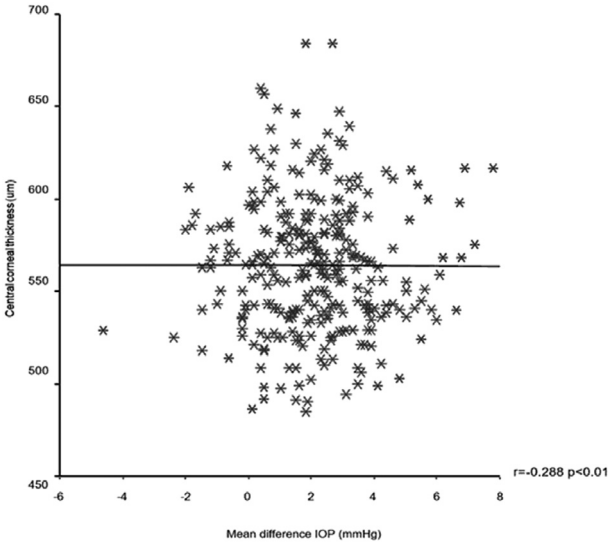


***Figure 3.** Correlation between central corneal thickness and mean the difference between Dynamic contour tonometry and Goldmann applanation tonometry readings*

But in the three groups, a significant correlation was not found. (POAG patients: r = -0.169, p > 0.05, OHT: r = 0.189, p > 0.05, NTG: r = -0.118, p> 0.05).

## DISCUSSION

In the present study mean IOP measured with GAT in all patients was 17.7 ± 3.35 mmHg, mean IOP measured with DCT was 19.80 ± 3.67 mmHg which is in agreement with the findings of Ku et al. (9), Schneider and Grehn (10) while it is not in agreement with Realini et al. (11) and Barleon et al. (12) study. In our study OHT, patients had the highest mean IOP measured both with GAT and DCT, and NTG patients had the lowest mean IOP measured both with GAT and DCT, which is in agreement with the findings of Punjabi et al. (13). In the present study, the mean difference between DCT and GAT readings IOP was in agreement with findings of other authors (9, 10). In the Punjabi et al. study (13), pseudoexfoliative glaucoma patients had IOP higher and OHT patients had lower compared to our IOP findings. They conclude that the mean difference between DCT and GAT readings was higher at lower IOP values and that this difference decreases as the IOP grows. This mean difference between DCT and GAT readings obtained in our study indicates the possibility of the DCT as an adequate supplement to GAT. IOP measurement with DCT is independent of innate CCT and indicates the importance of its introduction into standard clinical practice in order to achieve an accurate diagnosis, monitoring, and glaucoma therapy. DCT is based on a completely new physical principle: when the contours of the corneal surface and the tonometer match, the pressure measured at the surface of the eye equals the pressure inside the eye. But, DCT also has deficiencies: the prolonged contact time of this tonometer and cornea head.

In the present study, a significant positive association between IOP measured with GAT and IOP measured with DCT was found in all patients and in each group. Our findings agree with the findings of other authors (9, 10, 12). Punjabi et al. (13) found a significant positive association between IOP measured with GAT and IOP measured with DCT in all groups of patients (POAG, NTG, pseudoexfoliative glaucoma, normal controls) except in OHT patients. They show that for IOP values (GAT) of 8-20 mmHg IOP (DCT) values are greater than IOP(GAT), while for IOP values > 25mmHg IOP (DCT) values are lower than IOP (GAT) (13).

Pachymetry as a method of measuring CCT is very important in diagnosing glaucoma. When Goldmann and Schmidt introduced the GAT method, they were aware that the accuracy of GAT depends on CCT. IOP measured with GAT are most precise at the CCT value of 552 μm. Various CCT-based correction tables have been proposed for the GAT (correction value of 2.5-5 mmHg per 100 μm). CCT and other biomechanical properties of the cornea have an effect on IOP measured with GAT. In clinical practice, it has been shown that the effect of CCT on IOP is the greatest in non-contact tonometry and the smallest in DCT. We found a significant positive correlation between CCT and IOP measured with GAT in all patients, which is in agreement with the findings of Ku et al. (9), Schneider and Grehn

(10), Kniestedt et al. (14). Patients with higher CCT have higher IOP measured with GAT. A significant positive correlation between CCT and IOP measured with DCT in all patients was found, which is not in agreement with the findings of Ku et al. (9), Schneider and Grehn (10), Kniestedt et al. (14). There is no significant correlation between CCT and IOP measured with GAT as well as CCT and IOP measured with DCT separately in our three patient groups which are in agreement with findings of other authors (12, 13, 15, 16).

The clinical trial has shown that by applying the GAT method on patients with thicker cornea greater IOP values are recorded compared to the standard IOP values, while in patients with thinner cornea lower IOP values are recorded. The thicker cornea and falsely recorded higher IOP indicate that there is room for the possible OHT, which had already been proven in the multicentric study: Ocular Hypertension Treatment Study (15, 16, 17). The presence of thinner cornea and falsely recorded lower IOP indicate the presence of NTG, therefore the OHT patients can be falsely diagnosed as glaucoma patients and unnecessarily treated with antiglaucoma drugs, while the NTG patients can be regarded as healthy humans that do not require treatment. In order to make the right diagnosis and apply the adequate treatment of patients suffering from glaucoma, the corneal pachymetry test is proven to be a successful method not only in clinical trials but also in every ophthalmic practice (16).

In the present study, a significant positive correlation between CCT and the mean difference between DCT and GAT readings was found that is in agreement with the findings of Ku et al. (9), Kniestadt et al. (14), De Castro OJMA et al. (18), Gvozdenovic et al. (19), Ayyildiz et al. **(**20). But when we separated patients in three groups, a significant correlation that agrees with findings of Barleon et al. was not found (12).

## CONCLUSION

CCT measurement had an influence on IOP values measured by both methods, GAT and DCT. The correlation between CCT and IOP measured with DCT was small compared to the correlation between CCT and IOP measured with GAT. IOP values measured with DCT were higher in comparison with IOP values measured with GAT. GAT is still a gold standard for routine measurements of IOP. DCT can not replace GAT, but in clinical practice, DCT should become a useful complement to the classic method of IOP measurements, especially when there are errors in the IOP (GAT) measurements.

## Abbreviations

**CCT** — central corneal thickness
**DCT** — Dynamic Contour Tonometer
**GAT** — oldmann applanation tonometry
**IOP** — intraocular pressure
**NTG** — normal-tension glaucoma
**OHT** — ocular hypertension
**POAG** — primary open-angle glaucoma.

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## Licensing



## Sažetak

# ROŽNJAČA I METODE MERENJA INTRAOKULARNOG PRITISKA

**Jordanova Elena**,[1] Hentova-Sencanic Paraskeva,[2] Marjanovic Ivan,[3, 4] Sencanin Ivan,[5] Stefanovic Ivana,[6] Baralic Marko[4, 7]

[1] Služba nefrologije, Klinika za internu medicine, Kliničko bolnički centar Zemun, Beograd, Srbija
[2] Medigrup-ambulanta oftalmologije Oftalmika, Beograd, Srbija
[3] Klinika za očne bolesti, Klinički centar Srbije, Beograd, Srbija
[4] Medicinski fakultet Univerziteta u Beogradu, Beograd, Srbija
[5] Klinika za očne bolesti, Kliničko bolnički centar Zvezdara, Beograd, Srbija
[6] Gradski zavod za hitnu medicinsku pomoć, Beograd, Srbija
[7] Klinika za nefrologiju, Klinički centar Srbije, Beograd, Srbija

**Uvod:** Cilj ove studije je utvrditi povezanost centralne debljine rožnjače (CCT) i intraokularnog pritiska (IOP-a) izmerenog Goldmanovom aplanacionom tonometrijom (GAT) i Dinamičkom konturnom tonometrijom (DCT).

**Materijal i Metode:** Studija je obuhvatila 150 pacijenata prosečne starosti 59,39 ± 13,12 godina. Pacijenti su podeljeni u tri grupe: 50 pacijenata sa primarnim glaukomom otvorenog ugla (POAG), 50 pacijenata sa okularnom hipertenzijom (OHT), 50 pa-

cijenata sa normotenzivnim glaukomom (NTG). IOP je određen GAT i DCT metodom. CCT je određena ultrazvučnim pahimetrom.

**Rezultati:** IOP izmeren DCT metodom bio je viši u poređenju sa IOP izmerenim GAT (19,80 ± 3,67mmHg vs 17,71 ± 3,35 mmHg). Pronađena je statistički značajna povezanost IOP izmernog GAT i IOP izmerenog DCT kod svih pacijenata ($r = 0,867$, $p < 0,01$). Statistički značajna povezanost IOP izmernog GAT i IOP izmernog DCT metodom nađena je kod POAG ($r = 0,855$, $p < 0,01$), OHT ($r = 0,826$, $p < 0,01$) i NTG ($r = 0,832$, $p < 0,01$) pacijenata. Povezanost CCT i IOP izmerenog GAT ($r = 0,198$, $p < 0,01$) kao i povezanost CCT i IOP izmerenog DCT metodom ($r = 0,198$, $p < 0,01$) bila je statistički značajna kod svih ispitanika. Nije nađena statistički značajna povezanost CCT i IOP izmerenog GAT kao i CCT i IOP izmerenog DCT ($p > 0,05$) posebno u tri grupe ispitanika.

**Zaključak:** CCT ima uticaj na IOP izmeren obema metodama: GAT i DCT. DCT ne može da zameni GAT ali može biti jako koristan u slučajevima kada se javljaju greške prilikom merenja IOP GAT metodom.

**Ključne reči:** Intraokularni pritisak, Pahimetrija, Rožnjača.

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**Correspondence to/Autor za korespondenciju**
Elena Jordanova, MD, PhD
Department of Nephrology, Clinic for Internal Medicine,
Clinical Hospital Center Zemun
Vukova 9, 11080 Zemun, Belgrade, Serbia
Email: jordanova.elena@gmail.com
Phone: +381 11 3772- 716

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