

# Comparison of intraocular pressure measurements using Goldmann tonometer, I-care pro, Tonopen XL, and Schiøtz tonometer in patients after Descemet stripping endothelial keratoplasty

Oded Ohana, David Varssano, Gabi Shemesh

**Purpose:** Post-Descemet stripping endothelial keratoplasty (DSEK) patients are prone for intraocular pressure (IOP) elevations and glaucoma. Corneal characteristics influence various IOP measuring devices in various ways. The aim of this study was to evaluate the agreement between four different IOP measuring devices: Goldmann applanation tonometer (GAT), I-care pro, Tonopen XL, and Schiøtz tonometer in patients who underwent DSEK. **Methods:** This was a prospective comparative study using a convenience cohort of post-DSEK patients with compact grafts. Post-DSEK patients had IOP measured using GAT, I-care Pro, Tonopen XL, and Schiøtz tonometer. Measurements were compared and agreement assessed. Wilcoxon signed-rank test was used for comparison of means as variables did not show a normal distribution. Bland-Altman plots were used for assessing agreement. **Results:** Thirty eyes of 24 patients were included in the study. Mean time from DSEK surgery was  $25.31 \pm 13.05$  months. Mean IOP with GAT, I-care pro, Tonopen XL, and Schiøtz tonometer was  $13.99 \pm 3.76$ ,  $13.92 \pm 3.36$ ,  $13.31 \pm 3.89$ , and  $12.83 \pm 4.07$ , respectively. GAT, I-care pro, and Tonopen XL had similar mean IOP measurements ( $P = 0.135$  and  $P = 0.551$ , respectively), while Schiøtz tonometry measurements were higher ( $P = 0.046$ ). Bland-Altman plots show good agreement between GAT, Tonopen XL, and I-care pro. GAT and Schiøtz tonometry show less agreement, with large variations in the differences of measured IOP. **Conclusions:** IOP measurements in post-DSEK patients showed good agreement between GAT and either Tonopen XL or I-care pro. Schiøtz tonometer has large variations in this patient group. IOP measurements and IOP difference between devices were not dependent on central corneal thickness.

**Key words:** Descemet stripping endothelial keratoplasty, I-care, intraocular pressure, rebound tonometry, Schiøtz, Tonometry, Tonopen

Descemet's stripping epithelial keratoplasty (DSEK) is the most common form of endothelial corneal transplantation.<sup>[1]</sup> DSEK is complicated by ocular hypertension or glaucoma in 11%–47% of the cases.<sup>[2–4]</sup> Moreover, corneal graft rejection is more common in eyes with glaucoma.<sup>[5]</sup>

Goldmann applanation tonometer (GAT) is the gold standard for intraocular pressure (IOP) measurement. GAT is influenced by corneal characteristics including central corneal thickness (CCT), corneal curvature, corneal rigidity, and corneal hydration.<sup>[6–8]</sup> DSEK modifies some of these parameters.

There are conflicting results concerning the agreement between GAT and different IOP measuring devices in post-DSEK eyes. We compared IOP readings taken with GAT, I-care pro, Tonopen XL, and Schiøtz tonometer in post-DSEK patients and assessed agreement between these devices.

## Methods

We conducted a prospective, comparative, single-center study. A convenience cohort of 30 eyes of 24 consecutive patients was used.

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The study was performed in accordance with the tenets of the Declaration of Helsinki. After receiving detailed explanations regarding the nature of the examinations, all patients signed written informed consent.

We included patients who underwent DSEK, had a clear and compact graft, at least 3 months postoperatively. Grafts were considered compact if the entire graft was attached to the receiving cornea, had no Descemet folds and no apparent edema on slit-lamp examination. Patients were excluded if they had an edematous graft, residual corneal sutures, previous corneal refractive surgery, or blepharospasm. Since we intended to examine agreement between devices prior glaucoma surgery, current antiglaucoma agents use or elevated IOP were not considered to be exclusion criteria.

All eyes underwent slit-lamp examination, IOP measurement using GAT (Haag Streit, Koeniz, Switzerland), I-care pro (I-care Finland Oy, Vantaa, Finland), Tonopen XL (Reichert, Depew,

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New York, USA), and Schiøtz tonometer (Sklar, West Chester, PA, USA). All devices were calibrated at the beginning of the examination day. GAT, Tonopen XL, and I-care pro measurements were obtained sitting, while Schiøtz was performed in the supine position. Ultrasound (US) pachymetry was obtained using the AccuPach VI (Accutome, Malverne, PA, USA).

The order of the examinations was slit-lamp evaluation, followed by IOP measurement by I-care pro, Tonopen XL, GAT, and Schiøtz tonometer. The order of examinations was constant as we did not want to possibly influence the measured IOP by recent postural changes (in case of the Schiøtz tonometry); the order of examinations was of increasing corneal interference, attempting to minimize possible influences on further testing. GAT was repeated three times with 1-min intervals, without reinstating anesthetic drops. GAT measurements were read from the device's knob by an assistant. I-care pro measurements were repeated twice, with 1-min interval between examinations. Tonopen XL measurements were repeated twice, with a 1-min interval between examinations. Schiøtz tonometry was performed thrice: without added weights, with a 5.5 g weight, and with a 7.5 g weight. Measurements were converted to mmHg readings using the company's conversion chart. IOP readings of each of the devices were averaged. US corneal pachymetry was obtained last. If difficulties arose, or the measurement quality was poor, the measurement was repeated.

GAT readings were taken as the gold standard. Each device average IOP was compared with GAT readings using the Wilcoxon signed test as variables did not follow a normal distribution. The deviation of each device from the GAT value was calculated and correlated with CCT variable using a linear regression model. The agreement between the GAT and I-care pro, Tonopen XL, and Schiøtz tonometry was assessed by the Bland-Altman method.<sup>[9]</sup> All data were coded into SPSS statistics 20.0 (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY, USA). Statistical analyses were two-sided, a  $P < 0.05$  was considered statistically significant.

## Results

We examined thirty eyes of 24 patients who had a successful DSEK at least 3 months before examination (mean  $25.31 \pm 13.05$  months; range 4.76–54.21 months). The mean age was  $74.27 \pm 9.34$  years. Sixty percent were female. Six patients had bilateral DSEK. Antiglaucoma medication was used in 40% (12/30) of eyes at the time of the study. Multiple agents were used in ten patients (33%), with most (9/12, 75%) using beta blockers. One patient used oral acetazolamide (3%). One patient had prior glaucoma surgery (trabeculectomy).

Mean IOP readings are presented in Table 1. There was no statistically significant difference between GAT and Tonopen XL or I-care pro ( $P = 0.135$  and  $P = 0.551$ , respectively; Wilcoxon signed test). GAT and Schiøtz tonometry had a statistically significant difference, with a mean difference of  $1.15 \pm 3.04$  mmHg ( $P = 0.046$ , Wilcoxon signed test). IOP measured with GAT, Tonopen XL, I-care pro, and Schiøtz tonometer was not correlated with CCT ( $P$  values of 0.096, 0.112, 0.402, and 0.083, respectively).

We viewed differences of 2 mmHg or less as acceptable, factoring GAT's intrasession repeatability.<sup>[10]</sup> Differences between 2 and 3 mmHg were viewed as borderline and differences larger than 3 mmHg as significant. Differences in IOP readings between devices are presented in Table 2.

Seven out of thirty I-care pro readings (23.3%) showed differences larger than 3 mmHg compared to GAT: two measurements underestimated GAT and five of measurements overestimated GAT. Tonopen XL readings showed large differences in 5/30 (16.7%) examinations: 3 readings underestimated GAT and 2 readings overestimated GAT. Schiøtz tonometry showed large differences in 11/30 (36.7%) of the readings: 8 readings underestimated GAT and 3 readings overestimated GAT.

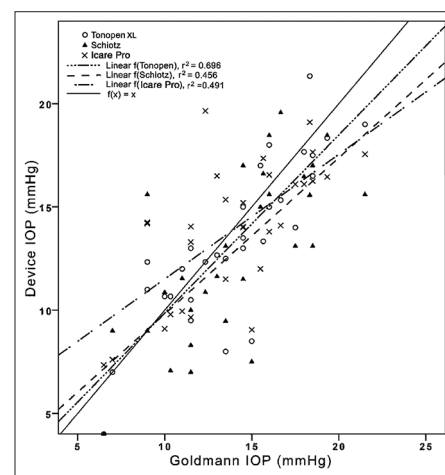
Concordance is presented in Fig. 1. Mean IOP values obtained in all devices were significantly correlated with GAT (GAT and Tonopen XL [ $R = 0.834$ ,  $P < 0.001$ ], GAT and I-care pro [ $R = 0.675$ ,  $P < 0.001$ ], GAT and Schiøtz [ $R = 0.70$ ,  $P < 0.001$ ]).

The difference in IOP readings between devices was not significantly correlated to CCT. We did not find a correlation between different IOP levels (measured with GAT) and the difference between Tonopen XL or Schiøtz and GAT. Care pro increasingly underestimated GAT as IOP became higher ( $R = -0.515$ ,  $P = 0.004$ ).

**Table 1: Mean intraocular pressure measurements**

	Mean±SD (mmHg)	95% CI
GAT	13.99±3.76	12.58-15.39
Tonopen XL	13.31±3.89	11.85-14.75
Schiøtz tonometry	12.83±4.07	11.31-14.35
I-care pro	13.92±3.36	12.66-15.17

GAT: Goldmann applanation tonometer, SD: Standard deviation, CI: Confidence interval



**Figure 1: Concordance between intraocular pressure measurements (mmHg) obtained by different devices. Concordance between intraocular pressure measurements (mmHg) obtained by Goldmann applanation tonometry, Tonopen XL, I-care pro, Schiøtz tonometry. Solid line: Reference line, Broken lines: Linear function of the data**

Bland–Altman plots, in which the average of the IOP measurement by two devices is plotted on the X-axis and the difference between devices (Tonopen XL– GAT, Schiottz– GAT, I-care pro– GAT) is plotted on the Y-axis, are presented in Figs. 2-4. There seems to be a reasonable agreement between GAT and Tonopen XL or I-care pro and less agreement between GAT and Schiottz tonometer. Each device had two readings outside  $\pm 1.96$  standard deviation (SD) boundary limit. The difference between GAT and Tonopen XL showed the smallest SD (2.20), followed by I-care pro (2.89). Schiottz tonometry had the largest SD (3.04).

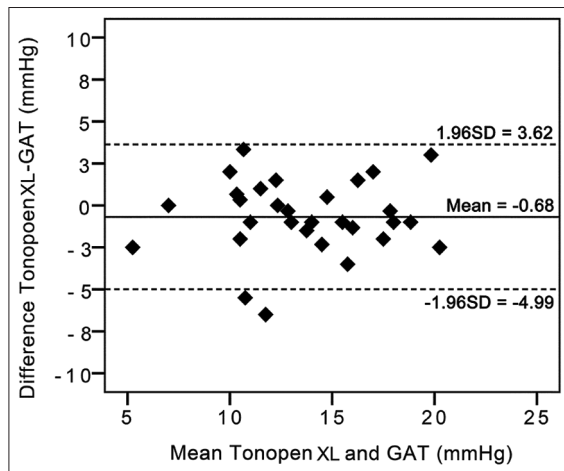
### Discussion

Considering the abundance of glaucoma in post-DSEK patients, which reaches almost 50% in some series,<sup>[3]</sup> accurate IOP readings are important for monitoring patients and influencing treatment decisions. Other than the study by Vajaranant,<sup>[11]</sup> that evaluated 50 eyes, agreement between IOP measuring devices in post-DSEK patients is addressed in only a number of small studies.<sup>[12-14]</sup> Tonopen XL, which uses a modified applanation technique, showed good agreement with GAT in a small study of 11 eyes,<sup>[14]</sup> with a mean difference of 1.2 mmHg. We found that the agreement between GAT and Tonopen XL was better than that of GAT and other devices. Tonopen XL readings were closest to GAT readings, had fewer occasions of large deviations from the GAT, and had the smallest SD of IOP differences from GAT. The Tonopen’s small contact diameter (1.0 mm) is less affected by corneal irregularities,<sup>[15]</sup> possibly improving agreement with GAT. Both devices utilize the applanation technique so that corneal changes induced by DSEK possibly influence the devices in a similar way.

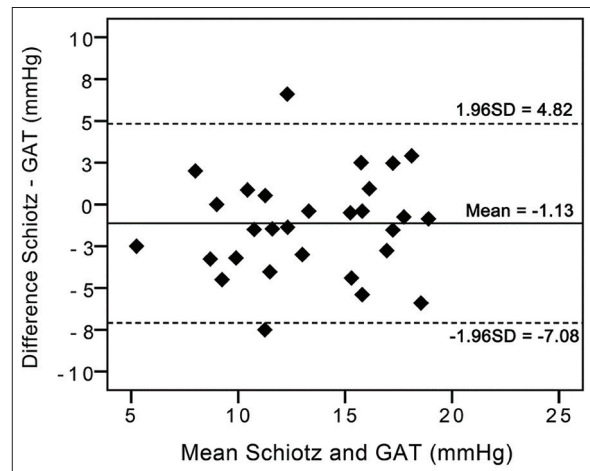
The I-care pro uses rebound tonometry, measuring the device’s probe deceleration after contacting the cornea to calculate IOP.<sup>[16]</sup> While measuring nearly identical IOP in normal and glaucomatous eyes,<sup>[17]</sup> I-care had contradicting results in patients with corneal pathologies, showing good agreement in one study,<sup>[18]</sup> but underestimating GAT readings in patients with other corneal abnormalities<sup>[19]</sup> and specifically measuring significantly lower IOP than GAT in post-DSEK eyes ( $4.0 \pm 3.3$  mmHg lower, 19 patients).<sup>[20]</sup> This underestimation could stem from difficulties in using GAT accurately in pathologic corneas.<sup>[6]</sup> One of the advantages of DSEK over penetrating keratoplasty is less corneal astigmatism,<sup>[21]</sup> making GAT measurement more accurate, boosting agreement with I-care. While we did not find a difference between I-care and GAT in general, we did find an underestimation bias in higher IOP levels.

Schiottz tonometry is being less utilized today as other means of IOP measuring became available. Schiottz tonometer measures the indentation created on the cornea by a plunger of known weight to assess IOP. Our results support other studies which found Schiottz tonometer to have a low agreement with GAT and show a large variability in IOP readings in post-DSEK patients.<sup>[12]</sup> In addition, Schiottz tonometry is performed in the supine position, which could rise the IOP, contributing to the low agreement noticed.<sup>[22]</sup>

CCT is a known modifier of GAT, Tonopen XL, and I-care readings.<sup>[23]</sup> Post-DSEK patients show an increase in CCT, attributed to the added thickness of the corneal graft. This artificial increase in CCT is not associated with a change in IOP that is seen in normal corneas.<sup>[11,12]</sup> This might occur as



**Figure 2:** Bland–Altman plot of the agreement between Goldmann applanation tonometry and Tonopen XL measurements. Broken lines: 95% limits of agreement

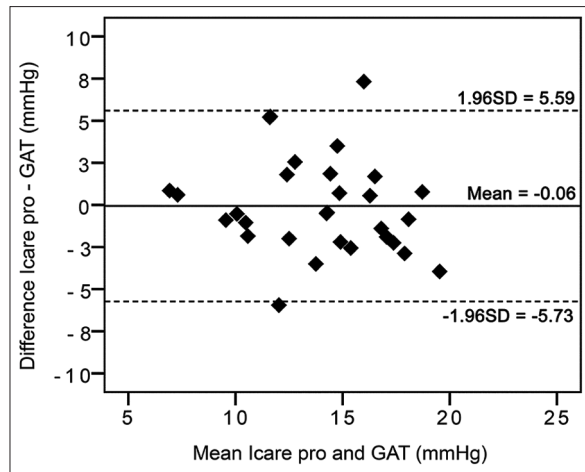


**Figure 3:** Bland–Altman plot of the agreement between Goldmann applanation tonometry and Schiottz tonometry intraocular pressure measurements. Broken lines: 95% limits of agreement

**Table 2: Differences in intraocular pressure measurements**

	Mean±SD (mmHg)	Measurements within $\pm 2$ mmHg (%)	Measurements between $\pm 2$ and $\pm 3$ mmHg (%)	Measurements over $\pm 3$ mmHg (%)
GAT versus Tonopen XL	$-0.68 \pm 2.20$	22/30 (73.3)	4/30 (13.3)	4/30 (13.3)
GAT versus I-care pro	$-0.06 \pm 2.89$	18/30 (60.0)	5/30 (16.7)	7/30 (23.3)
GAT versus Schiottz tonometry	$-1.13 \pm 3.04$	14/30 (46.7)	7/30 (23.3)	9/30 (30.0)

GAT: Goldmann applanation tonometer, SD: Standard deviation



**Figure 4:** Bland–Altman plot of the agreement between Goldmann applanation tonometry and I-care pro intraocular pressure measurements. Broken lines: 95% limits of agreement

the added thickness measured does not change the mechanical properties of the cornea the same as would occur in a normal cornea of the same thickness. In our cohort, neither device was correlated with CCT, highlighting this finding.

Several correction formulas, mainly incorporating CCT measurement, were reported.<sup>[24]</sup> The use of such correction formulas is debatable, and a recent report found that the application such formulas did not yield better agreement between GAT and DCT.<sup>[25,26]</sup> As our primary goal was agreement between devices, no such correction was utilized in our study.

Our study has several limitations, a relatively small cohort, a nonhomogenized patient population, different time intervals from DSEK surgery, and no specific corneal biomechanics information tests, such as corneal hysteresis (measured with an Ocular Resposne Analyser [ORA]) or measurements taken with dynamic contour tonometry (DCT). This, however, does not hamper the levels of agreement between the device. In addition, ORA and DCT measurements are not yet widely spread and are not available in many institutions. Several reports utilizing DCT showed increased accuracy across different CCTs<sup>[27]</sup> and could potentially be more accurate in aberrated corneas. Yet, this study is still one of the largest reports of agreement of IOP measuring devices in post-DSEK eyes, with all eyes having a compact graft.

## Conclusions

We found good agreement between GAT, Tonopen XL, and I-care pro, making all devices useful for measuring IOP in post-DSEK patients, preferably consistently using one method for a specific patient. Schiøtz tonometry had greater variability in IOP readings and should preferably be avoided. Further studies are needed to better examine the relation between the different IOP measuring methods.

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Nil.

## Conflicts of interest

There are no conflicts of interest.

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