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Comparison between applanation tonometry and rebound tonometry in different body positions

Benedetta Colizzi
Eye Clinic, ASST Santi Paolo e Carlo, University of Milan
Dario Romano
dario.romano1@unimi.it

Eye Clinic, ASST Santi Paolo e Carlo, University of Milan
Amir Ali Aminoleslami
Eye Clinic, ASST Santi Paolo e Carlo, University of Milan
Luca Mario Rossetti
Eye Clinic, ASST Santi Paolo e Carlo, University of Milan

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Comparison between applanation tonometry and rebound tonometry in different body positions

Authors

Benedetta Colizzi[1], MD; Dario Romano[1], MD; Amir Ali Aminoleslami[1], MD; Luca Mario Rossetti[1], MD

Eye Clinic, ASST Santi Paolo e Carlo – San Paolo Hospital, University of Milan, Milan, Italy

Corresponding Author:

Dario Romano, MD

Eye Clinic, ASST Santi Paolo e Carlo – San Paolo Hospital

University of Milan

Via di Rudinì 8, 20141 Milan, Italy

Phone: +39 349 313 4006

Email: dario.romano1@unimi.it

Abstract

Background

To compare applanation and rebound tonometry in different body positions and assess the reliability and repeatability of clinician-measured and self-measured intraocular pressure (IOP).

Methods

Sixty-four glaucoma patients and glaucoma suspects underwent two consecutive IOP measurements using Goldmann applanation tonometry (GAT), iCare IC200 and self-tonometry with iCare HOME2 in seated position, and two measurements in supine position with Perkins tonometry (PAT), iCare IC200 and iCare HOME2. Central corneal thickness (CCT), lens status and other clinical variables were recorded. Agreement, repeatability, and the influence of CCT were evaluated using Bland–Altman analysis, paired t-tests, and linear regression.

Results

iCare HOME2 showed excellent agreement with applanation tonometry (mean difference: −0.39 mmHg seated, −0.33 mmHg supine; both $p > 0.05$). iCare IC200 consistently overestimated IOP (−0.68 mmHg vs. GAT, −1.94 mmHg vs. PAT; $p < 0.05$), with a non-significant but evident trend toward increased overestimation at higher IOP levels. All devices demonstrated high repeatability in both positions (absolute Limits of Repeatability ≤ 2.73 mmHg). A negative correlation was found between CCT and IOP difference, indicating greater overestimation by rebound tonometers, particularly iCare IC200, in thicker corneas.

Conclusions

Rebound tonometry, especially iCare HOME2, offers reliable and repeatable IOP measurements across body positions and may represent a practical tool for self-monitoring, including in non-standard settings. CCT and IOP levels should be considered when interpreting rebound readings.

Keywords:

glaucoma; intraocular pressure; rebound tonometry; self-tonometry; body position

Background

Intraocular pressure (IOP) is the most important modifiable risk factor for both the development and progression of glaucomatous optic neuropathy. Accurate and consistent IOP measurement is therefore critical in clinical practice **[1,2**]. However, several factors can introduce variability or error in IOP readings, as current methods rely on indirect measurement techniques influenced by corneal and ocular biomechanics. IOP fluctuates over time in response to physiological factors such as aqueous humor dynamics, respiration, the cardiac cycle, and body posture **[3,4].** Studies have consistently reported higher IOP values in the supine position, with differences of up to 6 mmHg compared with seated measurements **[5,6].** This variation may be clinically relevant, as individuals spend a substantial portion of the day lying down, and nocturnal IOP peaks are more frequently observed in glaucoma patients**. [7]** Although the specific role of IOP fluctuations in glaucoma progression is difficult to isolate due to multiple confounding variables **[8],** capturing these variations may help reveal pressure peaks that go undetected during standard clinical assessments. Moreover, supine IOP evaluation is also important in populations for whom seated measurements are not feasible, such as bedridden or pediatric patients.

Despite the relevance of posture-related IOP changes, measuring IOP in the supine position remains technically challenging. The Goldmann applanation tonometer (GAT), which is considered the gold standard, is designed for use in seated patients. The Perkins applanation tonometer (PAT), a portable version of the GAT, allows measurements in both seated and supine positions **[9,10].** However, both require topical anesthesia, fluorescein staining, and an experienced examiner, which may limit their use in some settings **[11].**

Rebound tonometry has emerged as a practical and patient-friendly alternative. Devices such as the iCare IC200 and iCare HOME2 enable IOP measurement without anesthesia or fluorescein and can be used in various body positions. The iCare HOME2, in particular, allows patients to perform self-tonometry outside the clinic and across different postures, offering a more comprehensive profile of

daily IOP fluctuations. Although both devices have demonstrated good reliability in seated assessments **[12]**, data on their accuracy in the supine position remain limited. In this study, we aim to assess the reliability and repeatability of self-measured IOP with the iCare HOME2 in the supine position and to compare these values with clinician-acquired measurements using the iCare IC200 and the Perkins tonometer. We also evaluate IOP variation between the seated and supine positions across the three instruments and explore clinical factors associated with posture-related IOP changes.

Methods

Participants were recruited among glaucoma patients and glaucoma suspects at ASST Santi Paolo e Carlo, Milan, Italy, following the acquisition of informed consent. The protocol for this study was approved by the Institutional Review Board (Comitato Etico Milano Area 1, No. 0034559, 31/07/2023) and conducted in accordance with the principles outlined in the Declaration of Helsinki. Exclusion criteria included individuals with corneal abnormalities that could affect IOP measurements, as well as those with physical or mental impairments affecting their ability to use the tonometer. For each patient, only one eye randomly chosen was included in the study.

Devices

For this study, four devices were used: two applanation tonometers, the GAT (Haag-Streit AT900, Koeniz, Switzerland) and Perkins Mk3 applanation tonometer (Haag-Streit, Koeniz, Switzerland), and two rebound tonometers, the iCare IC200 and HOME2 (iCare, Vantaa, Finland)
. GAT and PAT have been used in seated and supine position, respectively. On the other hand, Rebound tonometers were used in both positions: the iCare IC200 by the clinician and the iCare HOME2 by the patient him- or herself.

The Goldmann and Perkins tonometers are based on the principle of applanation tonometry, as they estimate the intraocular pressure from the force needed to flatten a corneal surface of known area (Imbert-Fick law). They both require topical anesthesia, qualified personnel, and patient cooperation, as the contact between the probe and the cornea may last a few seconds.

The iCare IC200 and HOME2 are based on the principle of rebound tonometry. During measurements, the small plastic tip of the magnetic probe hits the cornea and bounces back. The movements of the probe are detected by some sensors and motion parameters are used to estimate the intraocular pressure. The IC200 is designed for use by eye-care professionals, whereas the HOME2 has a specific design with two adjustable facial supports and three positioning sensors that enable easy and accurate self-measurements.

Moreover, the magnetic mechanism keeps the probe in position even if the device is upside down, thus allowing for measurements in different body positions.

Procedure

Intraocular pressure (IOP) measurements were obtained using the four instruments (GAT, PAT, iCare IC200 and iCare HOME2) in a random order. IOP was measured with GAT, PAT and IC200 by an ophthalmologist masked to the IOP readings, in order to reduce bias. After appropriate training, the patient performed self-tonometry with iCare HOME2. All measurements were repeated twice to assess test-retest variability.

Training was supervised by an experienced ophthalmologist, and patients were required to demonstrate proficiency with the device before performing independent measurements. Any unreliable measurements, as flagged by the device, were discarded and repeated. After the training, if two consecutive iCare HOME2 measurements were unreliable, the patient was excluded from the study.

For supine measurements, patients were asked to lie down and remain in a supine position for 5 minutes prior to the measurements. The operator took two consecutive measurements with both IC200 and PAT, while the patients took two consecutive self-measurements with the iCare HOME2. In all participants central corneal thickness was measured using a specular microscope (Konan CellChek SL, Konan Medical Inc). Additional data regarding the participants' ocular history was obtained from clinical charts.

Statistical analysis

Statistical analyses were performed using R (R Foundation for Statistical Computing, ver. 4.3.3). Limits of Agreement (LoA) and Limits of Repeatability (LoR) were calculated using Bland-Altman analysis, and proportional bias was assessed through linear regression of the differences against the means. **[13]**. Paired Student's t-tests were used to compare IOP measurements between devices and across test-retest sessions. The association between central corneal thickness (CCT) and IOP differences between devices was evaluated using simple linear regression. Multiple linear regression models were used to explore the influence of clinical variables (e.g., age, glaucoma status, lens status) on posture-induced IOP changes. A p-value <0.05 was considered statistically significant.

Results

A total of 68 patients were initially enrolled in the study. Four patients were excluded due to unreliable iCare HOME2 self-measurements after training. In the final analysis, data from 64 patients were included. For each patient, one eye was randomly selected for measurement. The demographic characteristics of the study population are summarized in Table 1.

Table 1 — Demographic and Clinical Characteristics

N of patients	64
Age (y ± SD) / Range (y)	62.3 ± 16.97 / 19-87
CCT (µm ± SD) / Range (µm)	553.62 ± 45.45 / 440-668
Sex M/F (%)	56.2/43.8
PFK (%)	40.6
Glaucoma (%)	46.9

Abbreviations: SD = standard deviation; µm = micrometers.

The mean IOP measurements obtained with the three instruments in both seated and supine positions, along with the range of IOP values, and the average difference in IOP between the seated and supine positions, are shown in Table 2

Table 2 — Intraocular Pressure Measurements in Seated and Supine Positions

Instrument	IOP seated (mmHg)	IOP supine (mmHg)	Δ IOP supine-seated
GAT/PAT	17.00 ± 8.96 [8-65]	18.44 ± 9.46 [8-65]	1.44± 1.73
IC200	17.68 ± 9.12 [8.6-65.6]	20.38 ± 9.78 [9.8 - 64]	2.70± 2.11
HOME2	17.39± 9.03 [9-63]	18.77 ± 9.55 [9-63]	1.38 ±2.08

Abbreviations: IOP = intraocular pressure; GAT = Goldmann Applanation Tonometer; PAT = Perkins Applanation Tonometer.

In the seated position, the mean difference between GAT and iCare HOME2 was −0.39 ± 1.65 mmHg ($p = 0.06$), with 95% Limits of Agreement [−3.63, 2.85 mmHg]. The mean difference between GAT and iCare IC200 was −0.68 ± 1.83 mmHg ($p < 0.05$), with 95% LoA [−4.27, 2.92 mmHg]. The comparison between iCare HOME2 and IC200 showed a mean difference of −0.29 ± 1.49 mmHg ($p = 0.12$), with 95% LoA [−3.21, 2.64 mmHg].

No significant proportional bias was found for GAT vs iCare HOME2 ($\beta = -0.008$, $p = 0.74$), for GAT vs iCare IC200 ($\beta = -0.018$, $p = 0.49$), or for iCare HOME2 vs IC200 ($\beta = -0.010$, $p = 0.63$) (Figure 1).

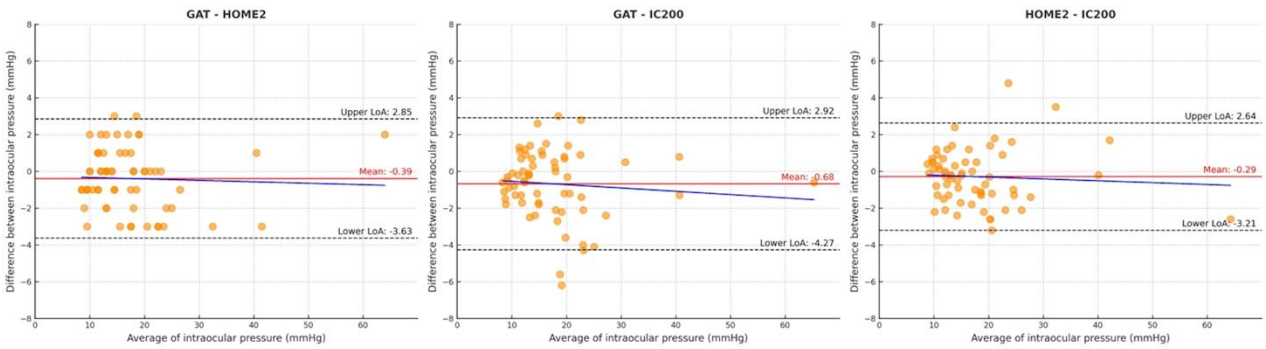


Fig. 1 Bland–Altman plots showing agreement among Goldmann applanation tonometry (GAT), iCare HOME2, and iCare IC200 in the seated position. The plots illustrate mean differences and 95% limits of agreement (LoA) for each instrument comparison.

Test–retest repeatability was high across all instruments, with mean differences of 0.00 mmHg for GAT ($p = 1.00$), −0.22 mmHg for iCare HOME2 ($p = 0.09$), and −0.33 mmHg for iCare IC200 ($p = 0.03$). The corresponding 95% LoR were [−1.47, 1.47 mmHg], [−2.22, 1.79 mmHg], and [−2.73, 2.06 mmHg] , respectively. Seated repeatability data are shown in Online Resource 1.

In the supine position, the mean difference between PAT and I Care HOME2 was -0.33 ± 1.45 mmHg ($p=0.07$), with 95% Limits of Agreement (LoA) [-3.17, 2.51 mmHg]. In the same conditions, the mean difference between PAT and iCare IC200 was -1.94 ± 1.86 mmHg ($p<0.05$), with 95%-LoA [-5.59, 1.71 mmHg]. The mean difference between the patient and the physician-handled iCare was -1.61 ± 1.51 mmHg ($p<0.05$), 95%-LoA [-4.58, 1.36mmHg]. A non-significant proportional bias was found for paired PAT and HOME2 measurements ($\beta = -0.010$, $p = 0.62$) , for PAT and IC200 ($\beta = -0.033$, $p = 0.18$), and for HOME2 and IC200 ($\beta = -0.024$, $p = 0.24$). The differences among different devices appear to be negligible for IOP below 20 mmHg, while IC200 tends to overestimate when compared with PAT and HOME2 for higher pressures (Figure 2).

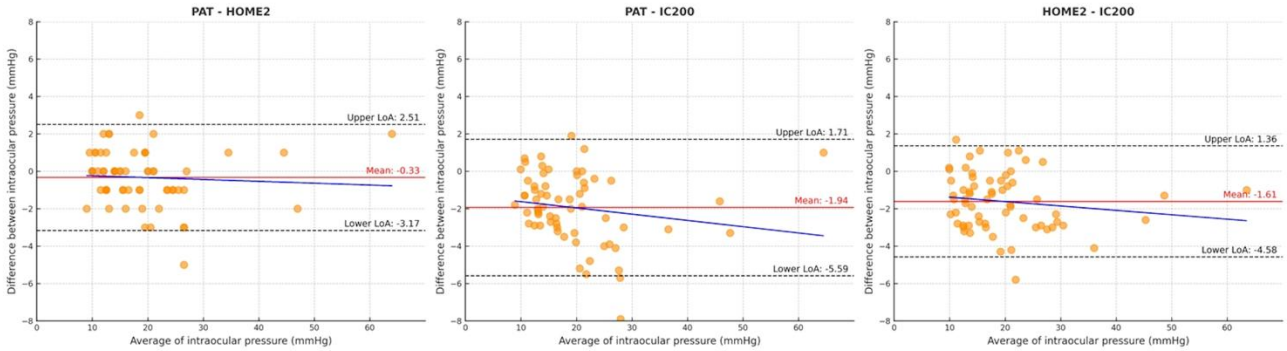


Fig. 2 Bland–Altman plots showing agreement among Perkins applanation tonometry (PAT), iCare HOME2, and iCare IC200 in the supine position. The plots illustrate mean differences and 95% limits of agreement for each device comparison.

The mean difference between the first and second measurements with PAT, iCare HOME2, and iCare IC200 in the supine position was -0.12 ± 0.84 mmHg, 95% LoR [-1.80, 1.55 mmHg], -0.08 ± 1.07 mmHg, 95% LoR: [-2.17, 2.01 mmHg], and -0.36 ± 0.94 mmHg, 95% LoR: [-2.19, 1.47 mmHg], respectively. The test-retest difference was statistically significant for iCare IC200 (p = 0.003), but not for PAT (p = 0.25) or iCare HOME2 (p = 0.56). Despite the statistically significant test-retest difference with iCare IC200, the variations remain within a clinically acceptable range of ±2 mmHg. Bland-Altman plots illustrating the test-retest variability for PAT, iCare HOME2, and iCare IC200 are shown in Figure 3.

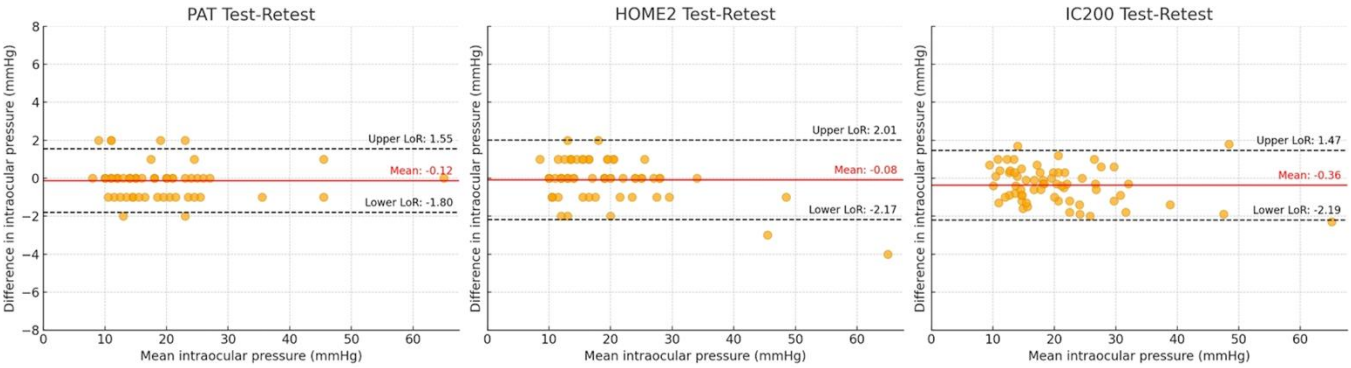


Fig 3 Bland–Altman plots illustrating test–retest repeatability of intraocular pressure measurements in the supine position using PAT, iCare HOME2, and iCare IC200. Dashed lines indicate 95% limits of repeatability.

The mean difference in IOP between supine and seated positions was 1.44 ± 1.73 mmHg for GAT/PAT (95% LoA: -1.92 to 4.79 mmHg), 1.38 ± 2.08 mmHg for iCare HOME2 (95% LoA: -2.67 to 5.42 mmHg), and 2.70 ± 2.11 mmHg for iCare IC200 (95% LoA: -1.40 to 6.80 mmHg). All differences were statistically significant, confirming a consistent trend toward higher IOP in the supine position across all instruments. Bland-Altman plots (Figure 4) illustrate this postural effect and further reveal a significant proportional bias for each device, with greater supine–seated differences at higher IOP levels (GAT/PAT: $\beta = 0.054$, $p = 0.021$; HOME2: $\beta = 0.057$, $p = 0.045$; IC200: $\beta = 0.070$, $p = 0.012$).

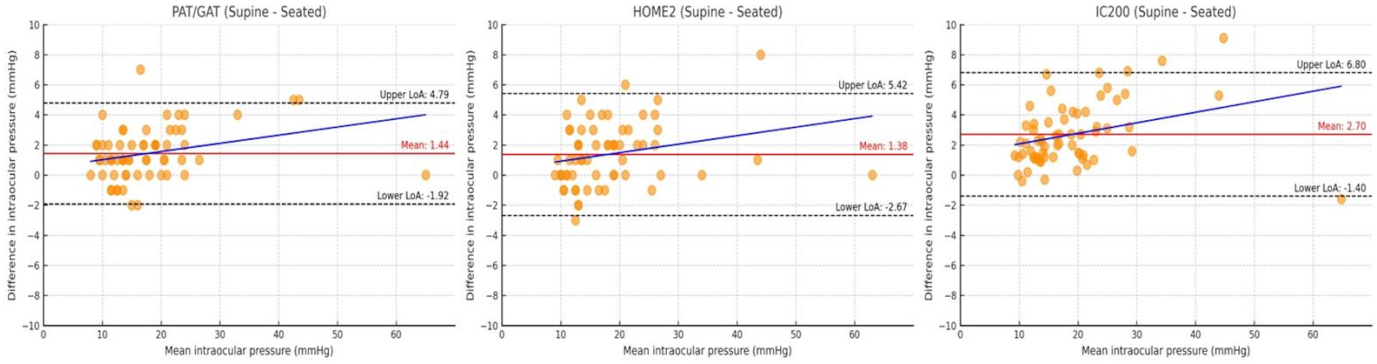


Fig 4 Changes in intraocular pressure between seated and supine positions measured with applanation tonometry (GAT and PAT), iCare HOME2, and iCare IC200.

In this cohort, CCT ranged from 440 μm to 668 μm. Scatter plots depicting the correlation between CCT and the differences in IOP measurements between PAT and iCare HOME2, PAT and iCare IC200, and iCare HOME2 and iCare IC200 are shown in Figure 5.

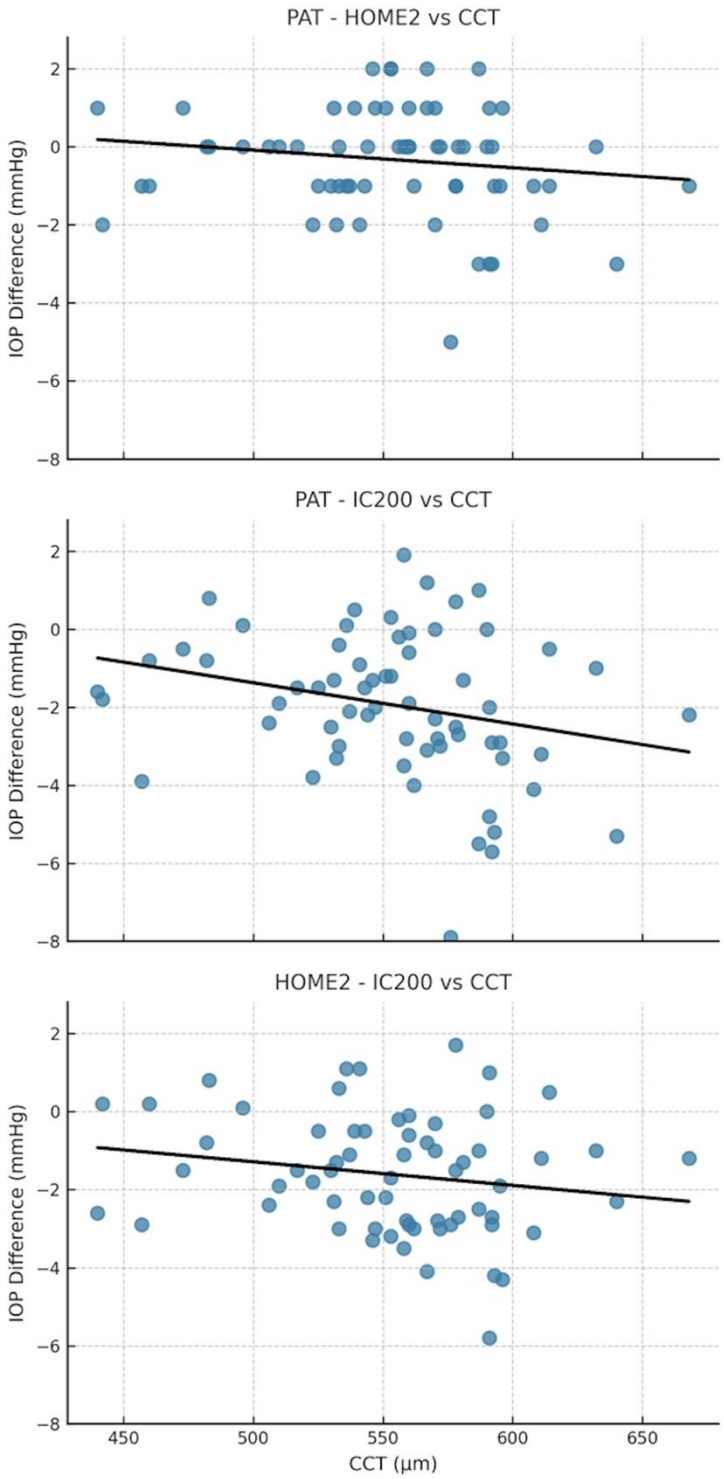


Fig 5 Scatter plots depicting the correlation between central corneal thickness (CCT) and the differences in IOP measurements between PAT and iCare HOME2, PAT and iCare IC200, and iCare HOME2 and iCare IC200. Regression lines indicate the trend for each comparison.

The findings demonstrated a consistent negative correlation between CCT and the differences in IOP measurements across all comparisons, indicating that the rebound tonometers, and especially the IC200, give higher readings with thicker corneas. However, only the correlation between PAT and IC200 reached statistical significance ($\beta = -0.01$, $p=0.04$), while those between PAT and HOME2 ($\beta = -0.004$, $p=0.27$) and HOME2 versus iCare IC200 ($\beta = -0.006$, $p=0.15$) were weaker and not statistically significant. From a clinical perspective, for patients with CCT around 440–500 μm, the predicted difference in IOP between PAT and HOME2, PAT and IC200 and HOME2 and IC200, is respectively 0.05 mmHg, -1.06 mmHg and -1.11 mmHg. For patients with CCT values above 600 μm, the differences increase to -0.54 mmHg between PAT and HOME2, -2.43 mmHg between PAT and IC200, and -1.89 mmHg between HOME2 and IC200.

Multiple linear regression analyses were conducted to evaluate the influence of lens status, presence of glaucoma, and age on the variation in IOP with body position across the three instruments. Glaucoma was consistently associated with an increase in the IOP difference between supine and seated positions across all instruments, with statistically significant effects for the IC200 ($p=0.03$) and HOME2 ($p=0.04$), but a non-significant trend for PAT/GAT ($p=0.19$). Lens status showed a non-significant trend toward reducing the supine-seated IOP difference in pseudophakic eyes, with $\beta = 0.34$ ($p = 0.53$) for PAT/GAT, $\beta = 0.13$ ($p = 0.84$) for HOME2, and $\beta = 0.78$ ($p = 0.23$) for IC200. Age was not associated with any meaningful effect on the IOP difference, as evidenced by both minimal coefficients and non-significant p-values ($p=0.20–0.79$).

Discussion

In this study, we evaluated the reliability and repeatability of self-measured intraocular pressure using the iCare HOME2 rebound tonometer in both seated and supine positions, comparing it with clinician-measured IOP obtained using the iCare IC200 and applanation tonometers (GAT and PAT). Self-tonometry with HOME2 showed excellent agreement with applanation tonometry across body positions, with minimal mean differences and high repeatability, confirming its reliability and accuracy for patient-performed IOP assessment.

The results obtained in the seated position are consistent with those reported by Romano et al. [12], who evaluated the same three tonometers under similar conditions, finding a mean difference between GAT and iCare HOME2 of −0.28 ± 1.57 mmHg ($p = 0.07$) and between GAT and iCare IC200 of −1.20 ± 1.63 mmHg ($p < 0.01$). In our study, the corresponding mean differences were −0.39 ± 1.65 mmHg ($p = 0.06$) for HOME2 and −0.68 ± 1.83 mmHg ($p < 0.05$) for IC200. In both analyses, the difference between IC200 and applanation tonometry reached statistical significance, confirming the device's consistent tendency to slightly overestimate IOP, whereas the iCare HOME2 maintained close agreement with GAT in both studies.

The comparable magnitude and direction of these differences across studies confirm the reproducibility of inter-device comparisons in seated conditions. The absence of significant proportional bias in either dataset indicates that this agreement remains stable across different IOP ranges.

In the supine position, IC200 again yielded higher IOP readings compared to both PAT and iCare HOME2, with statistically significant mean differences of 1.94 mmHg and 1.61 mmHg, respectively ($p < 0.05$). The agreement between PAT and iCare HOME2 remained good, with a non-significant mean difference of −0.33 mmHg ($p = 0.07$). Comparing the 95% limits of agreement between seated and supine measurements revealed no major differences in variability, indicating stable inter-device agreement across body positions. However, a consistent downward shift in the LoA was noted for iCare IC200 in supine setting, reflecting a greater systematic overestimation of IOP relative to both PAT and iCare HOME2. Overall, these results highlight the

consistency of rebound tonometry across body positions and reinforce the reliability of self-measurement for IOP assessment outside standard clinical settings.

Test–retest variability in the seated position had previously demonstrated high repeatability for all three devices [12], a finding confirmed in our current analysis. In the supine position, repeatability remained excellent, with mean differences between the first and second measurement of 0.08 mmHg for iCare HOME2, 0.13 mmHg for PAT, and 0.36 mmHg for iCare IC200. Although the test–retest difference reached statistical significance for iCare IC200 ($p = 0.003$), the limits of repeatability (LoR) for all devices remained within the clinically acceptable range of approximately ±2 mmHg, indicating stable measurement performance across positions.

It is well established that CCT affects IOP readings across all tonometric techniques [14], with rebound tonometers tending to overestimate values in thicker corneas [15,16]. Our findings confirmed this trend: a negative correlation was observed between CCT and the IOP differences obtained with rebound versus applanation tonometry in the supine position. This association reached statistical significance only for iCare IC200 versus Perkins ($\beta = -0.01$, $p = 0.04$), suggesting a greater sensitivity of the iCAre IC200 to corneal properties. These observations align with those reported by Romano et al. [12], who described a similar pattern in the seated position, again with statistical significance limited to the IC200. Although the clinical relevance of this effect appears modest—particularly for self-tonometry, CCT should nonetheless be considered when interpreting rebound tonometry measurements.

Posture-induced IOP elevation was consistently observed across all devices, with a mean increase of 1.83 mmHg from the seated to the supine position. This phenomenon is well documented in the literature and is likely related to an increase in episcleral venous pressure, which reduces aqueous humor outflow when lying down [17]. The largest postural difference was found with the IC200 (2.7 mmHg), compared with PAT (1.4 mmHg) and iCare HOME2 (1.3 mmHg), reflecting the IC200's known tendency to overestimate IOP, particularly at higher pressure levels.

Glaucoma status was significantly associated with greater posture-related IOP changes across all devices, reaching statistical significance for iCare IC200 ($p = 0.03$) and iCare HOME2 ($p = 0.04$). On average, glaucomatous eyes exhibited a 2.28 mmHg increase in IOP when moving from the seated to the supine position, compared with 1.45 mmHg in non-glaucomatous eyes ($p < 0.05$). These findings are consistent with previous reports, highlighting the greater susceptibility of glaucomatous eyes to posture-induced IOP fluctuations, a factor that may contribute to disease progression [18–20].

In our cohort, five patients had previously undergone glaucoma surgery. As expected, they showed lower mean IOP values (12.4 mmHg vs. 17 mmHg in the rest of the cohort, $p < 0.01$) and smaller posture-related changes (0.32 mmHg vs. 1.84 mmHg, $p < 0.01$) [21]. This may reflect the altered outflow dynamics in filtering blebs, which bypass the increase in episcleral venous pressure that occurs in the supine position.

Our findings may have important clinical implications. The ability of patients to reliably perform self-tonometry in different body positions enables a more complete assessment of circadian IOP fluctuations, including nocturnal peaks often missed during office visits. Since short-term IOP variations could be linked to glaucoma progression, capturing out-of-office readings offers added value. Previous studies have shown that iCare HOME2 provides accurate and repeatable self-measurements in seated conditions; our results confirm its reliability and extend its applicability to non-standard positions, supporting the versatility of rebound tonometry in glaucoma management.

Nonetheless, some limitations should be acknowledged. Although the sample size was sufficient for assessing agreement and repeatability across devices and positions, further studies are needed to validate subgroup observations and long-term relevance. All self-measurements were performed in a supervised clinical setting; while patients executed the procedures independently, adherence and accuracy in real-world home settings remain to be verified. Finally, all data were collected during daytime hours; since aqueous humor dynamics are influenced by circadian rhythms, nighttime measurements might reveal additional fluctuations not captured in this study.

Future research should aim to incorporate 24-hour IOP monitoring into long-term follow-up, evaluating its predictive value for glaucoma progression and optimizing individualized treatment strategies.

Conclusions

iCare HOME2 demonstrated close agreement with applanation tonometry and good test–retest repeatability in both seated and supine positions. These findings support the reliability of self-tonometry in the supine position and highlight its potential clinical utility for capturing physiologically relevant IOP variations in glaucoma management. Further studies in unsupervised home settings are needed to confirm its clinical applicability.

List of abbreviations

IOP: Intraocular pressure

GAT: Goldmann applanation tonometry

PAT: Perkins applanation tonometry

CCT: Central corneal thickness

LoA: Limits of agreement

LoR: Limits of repeatability

SD: Standard deviation

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Review Board (Comitato Etico Milano Area 1, No. 0034559, 31 July 2023). Informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

L.M.R. reports consultancy for CenterVue-iCare, AbbVie, and Omikron. The remaining authors declare no relevant financial or non-financial competing interests.

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Authors' contributions

B.C. and D.R. contributed to the study conception and design, data collection and analysis, and manuscript drafting. A.A.A. contributed to data collection and interpretation of the results. L.M.R. contributed to the study conception and design, supervision, and interpretation of the results. All authors critically reviewed the manuscript and approved the final version.

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List of Supplemental Digital Content

Additional file 1. Figure. Bland–Altman plots showing test–retest repeatability of intraocular pressure measurements obtained in the seated position using GAT, iCare HOME2, and iCare IC200.

Supplementary Files

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