DOI: https://doi.org/10.17816/OV321245
Research Article

Comparison and comparability of pneumotonometry and rebound tonometry results with Maklakov's applanation tonometry

Dmitrii F. Belov [1, 2], Nataliya G. Zumbulidze [3], Amina I. Yusupova [3], Farhod O. Kasymov [1, 3]

[1] St. Petersburg Multifield Hospital No. 2, Saint Petersburg, Russia;
[2] Saint Petersburg State University, Saint Petersburg, Russia;
[3] North-Western State Medical University named after I.I. Mechnikov, Saint Petersburg, Russia

BACKGROUND: Introduction and use of various tonometry methods can lead to misinterpretation of intraocular pressure results and influence the choice of treating approaches by ophthalmologist in a glaucoma patient.

AIM: To compare pneumotonometry and rebound tonometry results with Maklakov's applanation tonometry and to develop corrections for their comparability.

MATERIALS AND METHODS: The study included 75 patients. All subjects underwent Maklakov applanation tonometry (10 g) and pachymetry (Topcon SP-3000P). In 48 patients (94 eyes) of the 1st group, pneumotonometry (TONOREF™ II Nidek) was performed, and 27 patients of the 2nd group (52 eyes) underwent rebound tonometry (iCare™ IC-100).

RESULTS: The mean difference in intraocular pressure level in the 1st group was –4.81 ($p < 0.001$), and in the 2nd –0.98 mmHg ($p = 0.399$). Both methods — pneumo- and rebound tonometry showed underestimated results with intraocular pressure less than 23.0 and 22.5 mmHg (respectively) relative to applanation tonometry and, conversely, overestimated intraocular pressure when these values were exceeded. A significant ($p < 0.001$) strong ($R^2 = 0.86$) relationship between applanation and rebound tonometry was obtained, which made it possible, using regression analysis, to develop a formula for recalculating results of iCare tonometry into those of Maklakov tonometry: $P_{Maklakov} = 0.40 \times P_{iCare} + 13.44$.

CONCLUSIONS: Both pneumo- and rebound tonometry demonstrate adequate results of P_0 with intraocular pressure below 23.0 and 22.5 mmHg (respectively) and overestimate the results when these values are exceeded. The developed formula allows converting the results of iCare tonometry into the values of the Maklakov's tonometry.

Keywords: tonometry; Maklakov; intraocular pressure; glaucoma; iCare; pneumotonometry; rebound tonometry; central corneal thickness.

To cite this article:
Belov DF, Zumbulidze NG, Yusupova AI, Kasymov FO. Comparison and comparability of pneumotonometry and rebound tonometry results with Maklakov's applanation tonometry. *Ophthalmology Reports*. 2023;16(1):39–46. DOI: https://doi.org/10.17816/OV321245

Received: 10.03.2023 **Accepted:** 20.03.2023 **Published:** 31.03.2023

DOI: https://doi.org/10.17816/OV321245
Научная статья

Сравнение и сопоставимость результатов пневмо- и рикошетной тонометрии с аппланационной тонометрией по Маклакову

Д.Ф. Белов [1, 2], Н.Г. Зумбулидзе [3], А.И. Юсупова [3], Ф.О. Касымов [1, 3]

[1] Городская многопрофильная больница № 2, Санкт-Петербург, Россия;
[2] Санкт-Петербургский государственный университет, Санкт-Петербург, Россия;
[3] Северо-Западный государственный медицинский университет им. И.И. Мечникова, Санкт-Петербург, Россия

Актуальность. Внедрение и использование различных методик тонометрии может приводить к неясности в оценке внутриглазного давления и влиять на выбор врачом-офтальмологом тактики лечения пациента с глаукомой.

Цель работы — сравнение данных пневмо- и рикошетной тонометрии с аппланационной тонометрией по Маклакову и разработка поправок для их сопоставимости.

Материалы и методы. В исследование вошли 75 пациентов (146 глаз). Всем участникам эксперимента проводилась аппланационная тонометрия по Маклакову (10 г) и пахиметрия (Topcon SP-3000P). 48 пациентам первой группы (94 глаза) выполнялась пневмотонометрия (TONOREF™ II Nidek), а 27 пациентам второй группы (52 глаза) — рикошетная тонометрия (iCare™ IC-100).

Результаты. Средняя разница уровня внутриглазного давления в первой группе пациентов составила –4,81 ($p < 0{,}001$), а во второй –0,98 мм рт. ст. ($p = 0{,}399$). Оба метода — пневмо- и рикошетная тонометрия — демонстрировали заниженные результаты при внутриглазном давлении менее 23,0 и 22,5 мм рт. ст. соответственно относительно аппланационной тонометрии и, наоборот, более высокие цифры — при превышении этих значений. Была получена значимая ($p < 0{,}001$) сильная ($R^2 = 0{,}86$) связь аппланационной и рикошетной тонометрии, позволившая с помощью регрессионного анализа выработать формулу для перерасчёта результатов тонометрии iCare в тонометрию по Маклакову: $P_{\text{Маклаков}} = 0{,}40 \cdot P_{\text{iCare}} + 13{,}44$.

Выводы. Пневмо- и рикошетная тонометрия демонстрируют адекватные результаты истинного внутриглазного давления при офтальмотонусе ниже 23,0 и 22,5 мм рт. ст. соответственно и завышают результаты при превышении этих значений. Выработанная формула позволяет преобразовывать результаты тонометрии iCare в значения аппланационного тонометра Маклакова.

Ключевые слова: тонометрия; Маклаков; внутриглазное давление; глаукома; iCare; пневмотонометрия; рикошетная тонометрия; пахиметрия.

Как цитировать:
Белов Д.Ф., Зумбулидзе Н.Г., Юсупова А.И., Касымов Ф.О. Сравнение и сопоставимость результатов пневмо- и рикошетной тонометрии с аппланационной тонометрией по Маклакову // Офтальмологические ведомости. 2023. Т. 16. № 1. С. 39–46. DOI: https://doi.org/10.17816/OV321245

Рукопись получена: 10.03.2023 **Рукопись одобрена:** 20.03.2023 **Опубликована:** 31.03.2023

BACKGROUND

Intraocular pressure (IOP) is the only modifiable risk factor of glaucoma progression, at which the main treatment methods are aimed [1–3]. The primary diagnosis and the glaucoma therapy efficacy evaluation in common with perimetry and examination of the optic nerve state in the first instance are based on ophthalmotonometric measurements [4].

The most common in Russia and CIS countries became the method of applanation tonometry, proposed by A.N. Maklakov in as far back as in 1884. Due to its low cost and high accuracy, it became for many years a gold standard for intraocular pressure measurement [1]. However, the fact known unto few that at the start of its implementation into the practice of ophthalmology, it encountered a fierce resistance and rejection by the author's colleagues. About "...how difficult for walking are untrodden paths...", the author tells in his monography of 1892. We'll take the liberty to cite several passages out of it: "...actually, I stopped (it was necessary to stop sooner or later anyhow) on the number of 3670 studied eyes, and relying on this rather large number, I can give corresponding conclusions. The way that led me to these conclusions, was not easy and pleasant. Among specialists, with whom I shared the obtained data, I encountered only a theoretical sympathy, more often an indifference or, finally, a totally incomprehensible reluctance and hostility".

Alexei Nikolaevich emotionally describes his attitude to the subjective Bowmen method of pressure measurement (which is still used in certain conditions and circumstances). And given the fact that at that historical period, it was practically the main method of IOP examination, the attitude of Alexei Nikolaevich to such tough rejection of the objective method he proposed becomes comprehensible: "the modern medicine in its pursuit of getting rid from all undetermined and suppositional, bound the modern physician to be free handed to use everything what applied physical sciences could give to establish accurate examination methods. The estimation of temperature to the touch is replaced by thermometry. Examination of respiration and blood circulation organs relies on acoustic modes, the pulse wave is recorded; the visual field is put on paper; the interior of the eyeball is examined using an ocular mirror; various endoscopes are invented; visual acuity is brought to a certain norm; the visual power is brought to numeric values, accessible for checking and comprehensible for specialists across the globe. Thus, all examination methods moved forward, and only the problem of measuring the hardness of the eyeball stays at its primary degree. Both before and now, one continues to palpate the eyes, the obtained tactile sensations are kept in mind and denoted as a T symbol (Tensio). <...> I understand that one gram of weight, one degree of warmth, one Ohm, one Wolt, 1.0 of visual acuity, etc. are equal anywhere in the world, but T n + 1 being the same everywhere not only in hands of different researchers but even in hands of the same person — here I have the right to have strong doubts a priori. <...> However, in spite of an evident inadequacy, this method still encounters violent defenders in persons of rather serious scientists, who convincingly prove the superiority of their fingers upon all other measuring devices. I am sure that such convinced people could be able to do their shopping without weighing device, just weighing in hand, if only there were no resistance from the part of salesmen. <...> Could there be a doubt that if the Bowmen's formula still holds on, it is only due to the fact that there is still nothing better". [5]. And obviously something very painful: "In the Vestnik Oftalmologii, prof. Khodin acknowledged that a tonometer made according to the principle I propose would hardly reach the goal at all. This death warrant to my not yet born tonometer is given based on by the theoretical reasoning as well". Finally, as a conclusion, take-home message to the generations to come: "...my article could stir up an interest in further observations over tensio bulbi; it could make think about possible ways of tonometric studies... the subject is new, and there is such low confidence in it that a lot of sustained work is needed to gain a corresponding attention to it". We know now that Professor A.N. Maklakov's dream — "...I hope that the principle I proposed will once be accepted even by those who reacted undeservingly severe to it, and not taking on the labor to applicate it to practice, predicted a total inapplicability to it, perhaps, someday, grateful descendants could duly appreciate my work..." — came true to the fullest extent, and his method stayed the leading one during more than 120 years, and is still relevant. Anyhow, it is even now the only one, which has a documented proof as "prints" in our case histories and patient charts, is used to solve professional conflicts, when there are doubts in accuracy of our measurements using other, more modern methods. However, of course, the science moves forward, and in recent decades, new methods of the IOP measurement are actively implemented, which take less of time, do not demand anesthesia and dye use to obtain prints of the cornea, including non-contact pneumotonometry and rebound tonometry (iCare) [6, 7].

The implementation of new methods may lead to (and often leads to, generating discords) certain confusion in intraocular pressure evaluation, because measuring IOP by Maklakov method, the physician receives data characterizing the tonometric IOP (P_t) [1], and using pneumo- and rebound tonometry — a true IOP (P_0) [8, 9]. Besides, such factors, as orthostatic difference in IOP [10] (IOP in supine position is in average 4 mm Hg higher, than in sitting position [11]), corneal thickness and its viscous-elastic features [12], may contribute to additional

conflicts in IOP interpretation and influence the choice of the ophthalmologist in treatment tactics. This demands working out an comparability algorithm for the results of various tonometry types.

The aim — to compare pneumo- and rebound tonometry data with those of Maklakov applanation tonometry and to work out adjustments for their comparability.

MATERIALS AND METHODS

The work was performed as a prospective cohort study on the basis of the ophthalmological center of the St. Petersburg State Budgetary Healthcare Institution "City multifunctional hospital No. 2".

The study included two groups of patients. The first one consisted of 48 individuals (94 eyes, mean age 72.23 ± 6.67 years). The second one — of 27 patients (52 eyes, mean age 62.72 ± 6.92 years). In all patients, Maklakov applanation tonometry was performed (10 g weight) and pachymetry of the corneal central area (Topcon SP-3000P, Japan). In the first group, pneumotonometry on the autorefkeratometer Tonoref™ II Nidek (Japan), in the second group — rebound tonometry using the iCare™ IC-100 (Finland).

To obtain reliable results, the following diagnosis algorithm was respected — in the first instance, examinations were performed not requiring epibulbar anesthesia (pachymetry, pneumo- and rebound tonometry), then (during 1–2 min) IOP was measured using Maklakov tonometry.

Inclusion criteria: patient's willingness to respect the study protocol.

Exclusion criteria: history of ophthalmic surgeries, corneal diseases of various etiology, acute and exacerbation of chronic inflammatory diseases of the ocular surface and adnexa, low visual acuity precluding the fixation of gaze.

It is to be noted that in patients with pressure higher than 30 mm Hg (Maklakov tonometry) it was not often possible to evaluate the IOP using the autorefkeratometer Tonoref II Nidek, and this could influence the study results.

Statistical processing

Using the created database of patients, a statistical processing was performed in the Jamovi program (The jamovi project, 2021), Jamovi v. 2.2.5 (Computer Software). Data are presented as mean value (*M*) and its standard deviation (*SD*). The Shapiro–Wilk criterion was used to establish the normality of sample distribution. At the comparison of normally distributed samples, Student's criterion was used. Analyzing the linear regression, the corrected determination index R^2 was used. At group comparison — the non-parametric Kruskal–Wallis parameter was used. Differences at $p < 0.05$ were considered as statistically significant ones. The irregularity of groups in number of followed patients is to be noted, and this could introduce errors in the obtained results.

RESULTS

In the Table 1, mean IOP values in groups are presented as well as intraocular pressure distribution in accordance to the real IOP level.

The analysis of obtained results allowed to draw a conclusion that both methods — pneumo- and rebound tonometry — demonstrate somewhat underreported results at the IOP level lower than 23.0 and 22.5 mm Hg (for Tonoref and iCare, respectively) against applanation tonometry (Maklakov), and vice versa, overrate the IOP at values higher than those mentioned above. To evaluate this pattern, a regression analysis of dependence of

Table 1. Mean intraocular pressure values in groups and it is distribution depending on the P_0 level

Таблица 1. Средние значения внутриглазного давления в группах и его распределение в зависимости от уровня истинного внутриглазного давления

Parameter	Group 1				Group 2			
	Maklakov	Tonoref II	Δ	*p*	Maklakov	iCare	Δ	*p*
Mean intraocular pressure, mm Hg	19.68 ± 2.59	14.87 ± 3.85	–4.81	<0.001	21.65 ± 5.66	20.67 ± 13.18	–0.98	0.399
				P_0, pneumotonometry, mm Hg				
6.00–12.00	17.77 ± 1.66	10.45 ± 1.03	–7.33	<0.001	17.07 ± 1.62	9.67 ± 2.02	–7.40	<0.001
12.10–15.00	19.54 ± 2.64	13.51 ± 0.82	–6.03		19.00 ± 1.73	14.00 ± 0.00	–5.00	
15.10–18.00	19.83 ± 1.63	16.10 ± 1.44	–3.72		20.25 ± 2.60	16.42 ± 1.08	–3.83	
18.10–21.00	22.82 ± 2.44	20.25 ± 1.19	–2.56		21.67 ± 1.97	19.17 ± 1.17	–2.50	
21.10–25.00	20.33 ± 3.51	22.80 ± 1.44	2.47		21.67 ± 2.52	23.00 ± 1.00	1.33	
>25.00	25.00	29.00	4.00		29.42 ± 5.78	40.50 ± 12.41	11.08	

DOI: https://doi.org/10.17816/OV321245

Maklakov tonometry from pneumo- (Fig. 1) and rebound (iCare) tonometry (Fig. 2).

At linear regression analysis, the presence of significant ($p < 0.001$) weak ($R^2 = 0.37$) relationship between applanation tonometry (Maklakov) and pneumotonometry was established (Fig. 1).

The linear regression analysis revealed the presence of significant ($p < 0.001$) strong ($R^2 = 0.86$) relationship between applanation tonometry (Maklakov) and rebound (iCare) tonometry (Fig. 2).

Based on the regression analysis, corrections for conversion of pneumotonometry data (P_0) into those of applanation tonometry (Maklakov, P_t):

$$P_{t\ \text{appl}} = 0.41 \cdot P_{0\ \text{pneum}} + 13.59, \quad (1)$$

where $P_{t\ \text{appl}}$ — applanation tonometric IOP, mm Hg; $P_{0\ \text{pneum}}$ — real IOP according to pneumotonometry data, mm Hg.

As well as rebound tonometry (iCare) into the applanation tonometry (Maklakov):

$$P_{t\ \text{appl}} = 0.41 \cdot P_{0\ \text{pneum}} + 13.59, \quad (2)$$

where $P_{t\ \text{appl}}$ — applanation tonometric IOP, mm Hg; $P_{0\ \text{pneum}}$ — real IOP according to rebound tonometry data (iCare), mm Hg.

In the Table. 2, IOP results in groups are given, depending on pachymetry. Fig. 3 and 4 demonstrate the dependence of pneumo- and rebound tonomertry upon the corneal thickness in the central area.

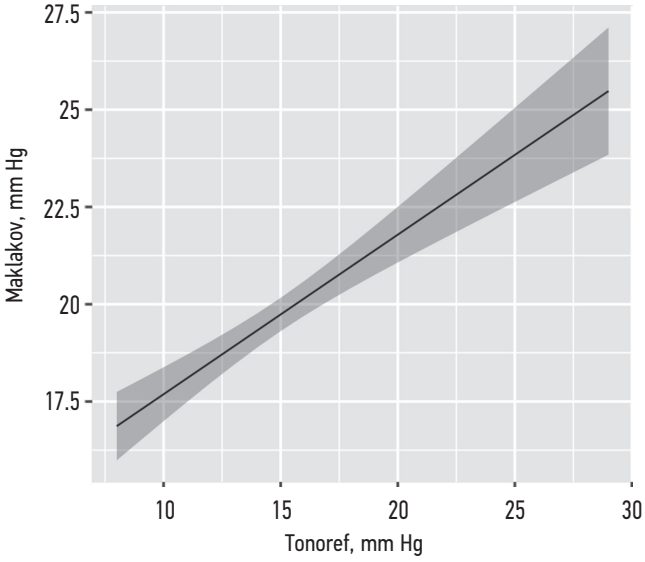

Fig. 1. Dependence of Maklakov's applanation tonometry from pneumotonometry

Рис. 1. Зависимость аппланационной (Маклаков) тонометрии от пневмотонометрии

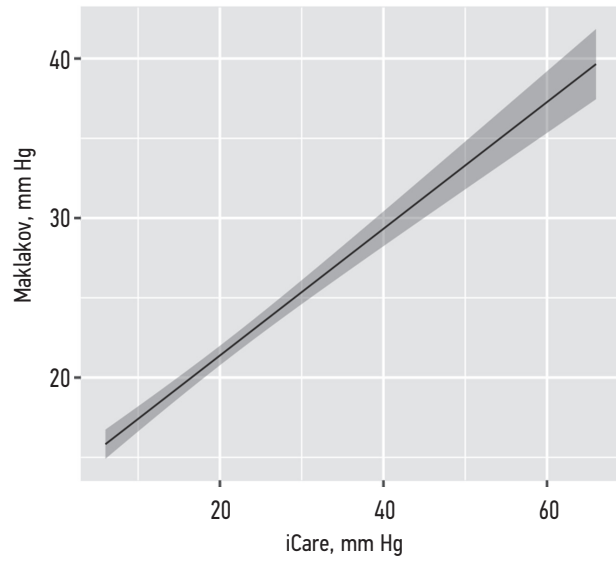

Fig. 2. Dependence of Maklakov's applanation tonometry from rebound tonometry (iCare)

Рис. 2. Зависимость аппланационной (Маклаков) тонометрии от рикошетной тонометрии (iCare)

Table 2. Intraocular pressure dependence from central corneal thickness in groups

Таблица 2. Зависимость внутриглазного давления от толщины центральной зоны роговицы в группах

Corneal thickness characteristic	Group 1				Group 2			
	Maklakov mm Hg	Tonoref II mm Hg	Δ	*p*	Maklakov mm Hg	iCare, mm Hg	Δ	*p*
"Thin" and "ultrathin" (less than 520 μm)	20.50 ± 3.25	14.10 ± 3.74	–6.41 ± 2.68		23.13 ± 5.78	22.13 ± 11.22	–1.00 ± 5.75	
"Mean" (521–560 μm)	19.50 ± 2.02	15.30 ± 3.55	–4.16 ± 3.25	0.013	20.12 ± 3.87	17.81 ± 9.55	–2.31 ± 6.78	0.463
"Thick" (more than 561 μm)	20.00 ± 2.36	15.90 ± 4.66	–4.11 ± 2.81		23.44 ± 8.65	26.33 ± 22.31	2.89 ± 13.95	

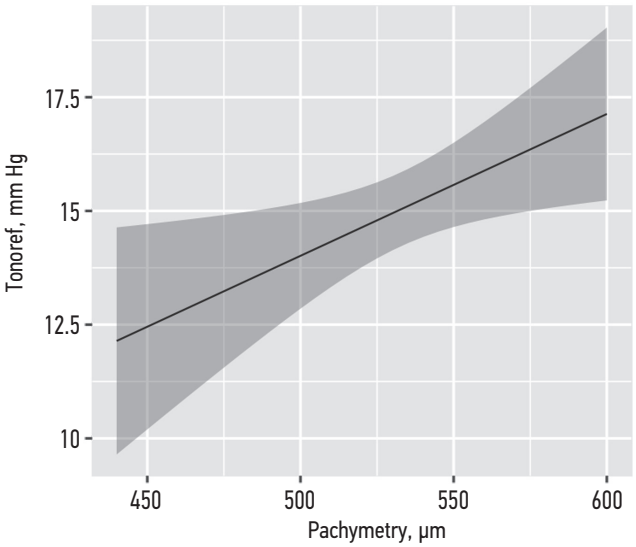

Fig. 3. Dependence of pneumotonometry values from central corneal thickness (R^2 = 0.07; p = 0.017)

Рис. 3. Зависимость пневмотонометрии от центральной толщины роговицы (R^2 = 0,07; p = 0,017)

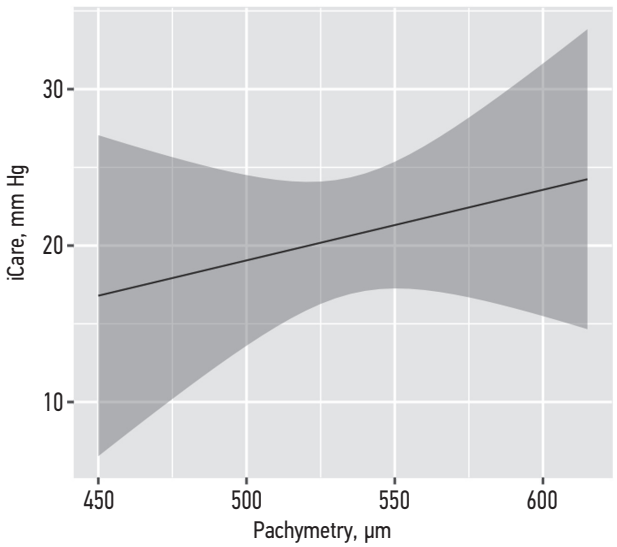

Fig. 4. Dependence of rebound tonometry (iCare) values from central corneal thickness (R^2 = 0.01; p = 0.420)

Рис. 4. Зависимость рикошетной тонометрии (iCare) от центральной толщины роговицы (R^2 = 0,01; p = 0,420)

DISCUSSION

Analyzing the obtained results, we revealed similar dynamics in comparability of pneumo (Tonoref) — and rebound (iCare) tonometry wit applanation one (Maklakov), which expressed itself in underreported P_t (Maklakov) results at IOP levels of less than 23 and 22.5 mm Hg (for the methods, respectively) and vice versa, in their overrating when the data were higher than those mentioned above. In a similar study, it was shown that the difference between P_0 (pneumotonometry Reichert 7CR) and P_t (Maklakov) at P_t less than 18–19 mm Hg was 3.5–8.2 mm Hg, and at P_t 22 mm Hg significant errors arose leading to substantial tamperings of the P_0 towards their overrating. Over all, the authors recommend to use applanation tonometry (Maklakov) at P_t higher than 22 mm Hg, instead of pneumotonometry [13].

The mean difference of the IOP level in the first group of patients was about –5 mm Hg, and in the second one — –1 mm Hg. This difference could be explained by a small number of the first group patients with increased IOP (P_t, higher than 30 mm Hg). The iCare device did not have such drawbacks and was able to measure mean intraocular pressure values even at its significant rise (more than 29 mm Hg). However, at high IOP values, the difference between iCare and Maklakov measurements was substantial (up to 11 mm Hg at P_t higher than 25 mm Hg). The data we received do not correspond to the results of a similar work [7], in which a difference between rebound tonometry (iCare) and applanation tonometry (Maklakov) in 6.7 ± 2.7 mm Hg; this could be explained by authors using absolute values of IOP difference. Nevertheless, in this study, the attention was also drawn to the fact that in patients with “high” normal IOP (23–26 mm Hg) the rebound tonometry (iCare) demonstrates higher difference to applanation tonometry (Maklakov) accompanied by increasing standard deviation, evidencing the decrease in method’s (iCare) accuracy in presence of ophthalmic hypertension. The authors made a conclusion that rebound tonometry is incorrect at high IOP level (23–26 mm Hg) and should be replaced by other accurate methods of IOP evaluation (Goldman, Maklakov), but at the same time could be recommended as a screening method, as well as for IOP evaluation in patients at the early post-op period after an IOP-lowering surgical procedure. In another study [4], an even more prominent difference between applanation (Maklakov 10 g) and rebound (iCare) tonometry, which amounted to 9.7 ± 4.6 mm Hg; this is explained by the orthostatic difference in IOP when Maklakov tonometry is performed, as well as by particularities of the iCare device calibration.

The carried-out regression analysis of the dependence of applanation tonometry (Maklakov) from reboun tonometry (iCare) revealed the presence of a significant strong relationship; this allows to use the equation of linear regression (2) for the conversion of iCare data into the familiar for many ophthalmologists tonometric IOP (Maklakov). The authors of the above-mentioned article used a similar method of rebound tonometry (iCare) conversion into applanation tonometry (Maklakov) [7]. In the first group of patients (a comparison of pneumotonometry and of applanation tonometry), this relationship was significant as well, but the determination index described this relationship as a weak one; this does not allow using the formula (1) for conversion pneumotonometry parameters into those of applanation tonometry.

DOI: https://doi.org/10.17816/OV321245

The estimation of the influence of the central corneal thickness on tonometric parameters (Tonoref and iCare) revealed a weak positive relationship, manifesting by an IOP increase at pachymetry increase. However, this relationship was extremely weak and not significant in the second group. Multiple publications on this subject are evidence of similar pattern of IOP rise during pneumotonometry [14], as well as during rebound (iCare) tonometry [15].

CONCLUSION

Pneumotonometry (Tonoref) results were in average 5 mm Hg lower than the IOP obtained using applanation tonometry (Maklakov), and those of rebound tonometry (iCare) — 1 mm Hg lower. Both methods (Tonoref and iCare), in comparison with the Maklakov method, demonstrate underestimated IOP values at P_t lower than 23 and 22.5 mm Hg (for both methods, respectively), and at P_t higher than 23 and 22.5 mm Hg, to the contrary, overestimate the IOP. The revealed trend based on linear regression, allowed to elaborate a recalculation formula for the transition of rebound tonometry (iCare) results into those of applanation tonometry (Maklakov).

ADDITIONAL INFORMATION

Authors' contribution. Thereby, all authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study. Contribution of each author: D.F. Belov — research concept and design, text writing, statistical data processing, literature review; N.G. Zumbulidze — research concept and design, text writing; A.I. Yusupova — text writing, data analysis, literature review; F.O. Kasymov — text writing, literature review.

Competing interests. The authors declare that they have no competing interests.

Funding source. This study was not supported by any external sources of funding.

Consent for publication. Written consent was obtained from the patient for publication of relevant medical information and all of accompanying images within the manuscript.

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AUTHORS' INFO

***Dmitrii F. Belov,** MD, Cand. Sci. (Med.), ophthalmologist; address: 2, Uchebnyi lane, Saint Petersburg, 194354, Russia; ORCID: https://orcid.org/0000-0003-0776-4065; eLibrary SPIN: 2380-2273; e-mail: belovd1990@gmail.com

Natalia G. Zumbulidze, MD, Cand. Sci. (Med.), assistant professor, Ophthalmology Department; ORCID: https://orcid.org/0000-0002-7729-097X; eLibrary SPIN: 4439-8855; e-mail: guramovna@gmail.com

Amina I. Yusupova, resident doctor; ORCID: https://orcid.org/0009-0004-5562-204X; eLibrary SPIN: 7522-8060; e-mail: aminausupova4821@gmail.com

Farhod O. Kasymov, MD, Cand. Sci. (Med.), ophthalmologist; ORCID: https://orcid.org/0009-0004-4368-143X; eLibrary SPIN: 7778-6309; e-mail: farkkas@yahoo.com

ОБ АВТОРАХ

***Дмитрий Федорович Белов,** канд. мед. наук, врач-офтальмолог; адрес: Россия, 194354, Санкт-Петербург, пер. Учебный, д. 5; ORCID: https://orcid.org/0000-0003-0776-4065; eLibrary SPIN: 2380-2273; e-mail: belovd1990@gmail.com

Наталия Гурамовна Зумбулидзе, канд. мед. наук, доцент кафедры офтальмологии; ORCID: https://orcid.org/0000-0002-7729-097X; eLibrary SPIN: 4439-8855; e-mail: guramovna@gmail.com

Амина Исаевна Юсупова, врач-ординатор; ORCID: https://orcid.org/0009-0004-5562-204X; eLibrary SPIN: 7522-8060; e-mail: aminausupova4821@gmail.com

Фарход Олимджанович Касымов, канд. мед. наук, врач-офтальмолог; ORCID: https://orcid.org/0009-0004-4368-143X; eLibrary SPIN: 7778-6309; e-mail: farkkas@yahoo.com

* Corresponding author / Автор, ответственный за переписку