

Rebound Tonometry over Soft Contact Lenses

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ABSTRACT

Introduction: Goldmann applanation tonometry (GAT) is named as a gold standard for intraocular pressure (IOP) measurement. **Aim:** To assess the accuracy of intraocular pressure (IOP) measurements using rebound tonometry over hydrogel and silicone hydrogel contact lenses (CLs) of different powers. **Methods:** This study included 117 eyes of 61 patients (12 male, 49 female), all habitual wearers of hydrogel and silicone hydrogel CLs, and none previously diagnosed with glaucoma, ocular hypertension or anterior surface disease. Five IOP measurements were taken over each eye using a rebound tonometer (Icare): with soft CLs in situ and then repeated without CLs. Lens power ranged from -9.50 to +10.00 spherical diopters and to a maximum of -0.75 cylinder diopters. **Results:** A significant positive correlation was found between IOP measurements with and without CLs. The difference between IOP measurements with (mean 20.74±5.19 mmHg) and without (mean 18.79±4.36 mmHg) CLs was found to be 1.95 mmHg (P <0.01). Statistical analysis was performed using the paired t-test and a correlation coefficient was calculated (r = 0.59; P <0.001). We have observed that increase in central corneal thickness (CCT) correlates positively with increase of measurement error of rebound tonometry (r = 0.43; P <0.001). **Conclusion:** We have shown good reliability of IOP measurements over CLs of different materials and thickness profiles while using rebound tonometer which makes it a feasible and accurate method for clinical purposes.

Keywords: Contact Lens, Rebound Tonometry, Icare, Hydrogel, Silicone Hydrogel.

1. INTRODUCTION

Goldmann applanation tonometry (GAT) is named as a gold standard for intraocular pressure (IOP) measurement. Goldmann and Schmidt presented their applanation tonometer in 1957 (1). Applanation tonometers measure the IOP by flattening the underlying cornea. Limitation of IOP measurement using GAT is that its accuracy depends on biomechanical properties of the cornea, including central corneal thickness (CCT) and corneal curvature (2). On the other hand, rebound tonometers (RT) are used routinely for IOP measurements and do not require anaesthetic or fluorescein administration. Icare rebound tonometer became available in a year 2005 (3,4). Being a portable handheld tonometer, it is also mobile and independent of a slit lamp, which speeds up

the process of the IOP measurement. Pakrou et al. showed a good correlation between the two methods of IOP measurement, even at IOP extremes (5). RT measurements have also been reported as influenced by CCT. Analysis showed that a CCT change of 10 µm resulted in an Icare reading deviation of 0.7 mm Hg (6). As the CCT got thicker, Icare considerably overestimated GAT and Tonopen XL (7). For every 100 µm increase in CCT, the difference (Icare vs. GAT) increased by 1 mmHg (5). Icare instrument was easy to use and recorded rapid and consistent readings with minimal training (8).

IOP is carefully regulated, and disturbances are often implicated in the development of pathologies such as glaucoma, uveitis, and retinal detachment (9). By increasing the knowledge of the importance of

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IOP measuring we pose ourselves a question whether it can be reliably obtained over contact lenses (CLs).

CLs are medical devices primarily used for correction of refractive errors, as well as for cosmetic and therapeutic reasons. It has been estimated that there are approximately 140 million wearers of CL worldwide (10). Most common cases of IOP measuring over CLs include usage of therapeutic contacts, glaucoma screening and rapid eye examinations as after-care visits.

2. AIM

The aim of this study was to assess the accuracy of IOP measurements using RT over soft CLs and to determine whether their material and different power had any influence on the results.

3. METHODS

Study included 117 eyes of 61 hydrogel and silicone hydrogel CL wearers that had no history of glaucoma, ocular hypertension, ocular surface or corneal disease, nor previous anterior segment surgery. Included lens power ranged from -9.50 to +10.00 spherical diopters (Dsph), with corneal astigmatism no more than 0.75 diopters (Dcyl). All patients were enrolled in the study in period from January to June 2017 in Contact lens Unit at the Department of Ophthalmology, University Hospital Center Sestre milosrdnice, Zagreb, Croatia.

IOP measurements were performed by two ophthalmologists, independent of each other. The patients were randomly selected and RT was performed using Icare (Icare TAO1i, Icare Finland Oy, Helsinki, Finland) on both eyes over CL and 15 minutes after its removal, without any local anesthetics administered. Five measurements were taken over each eye and only those within a standard deviation of the norm were accepted. After measuring IOP without CLs, CCT measurements were obtained with contact ultrasound pachymeter (Quantel Medical Pocket II, Quantel medical, Paris, France), following instillation of local anaesthetic Tetracain. All measurements were taken between 11.00 a.m. and 1.00 p.m. in order to minimize the effect of diurnal variation of IOP on the results.

The study was approved by the local ethics committee and was performed according to Declaration of Helsinki.

Results were analyzed with standard statistical methods using Statistical Package for the Social Sciences (SPSS) software for statistical analysis version 13.0. Results are presented as median and interquartile range (25-75 percentile), as mean ± SEM, and as percentage value (%). To test the significance of the difference in deviation from the normal distribution, Kolmogorov-Smirnov test was used. The results are analyzed by appropriate non-parametric tests (Wilcoxon and Friedman Tests). Values of $p < 0,05$ are considered as statistically significant, and values of $p < 0,001$ as statistically highly significant.

4. RESULTS

Among the subjects, 12 (19.7%) were male and 49 (80.3%) were female with mean age of 32.75 ± 15.16 years.

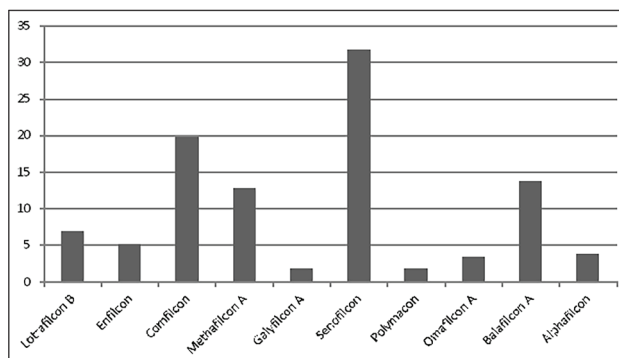


Figure 1. The distribution of CL materials included in study (%)

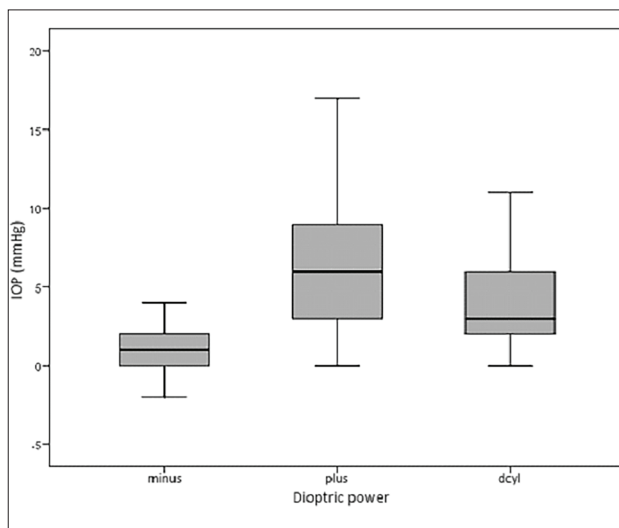


Figure 2. IOP values with and without CLs compared between three dioptric powers (minus, plus and cylindrical dioptic power [dcyl]).

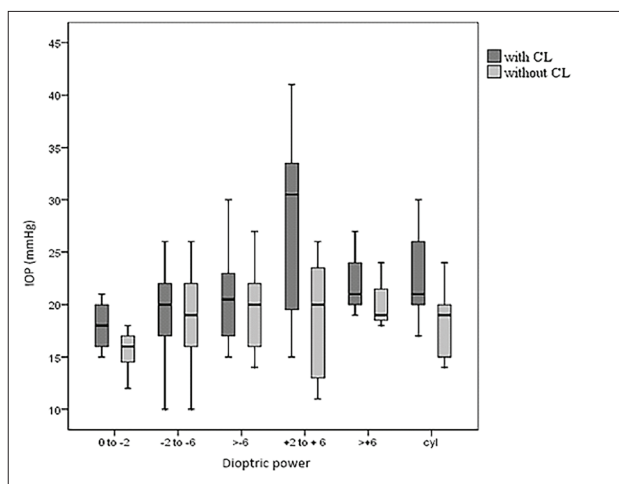


Figure 3. Differences of measured IOP with and without CLs in groups of different dioptric power.

Analysing the refractive error, 89 eyes (76.1%) were myopic, 15 (12.8%) were hyperopic and 13 (11.1%) of them had astigmatism. Lens materials are reported in Figure 1.

The average IOP values were analyzed in eyes with and without the CLs. Mean IOP value measured by RT over the CL in situ (RTCL) was 20.74 ± 5.19 mmHg. In comparison, the mean value of native IOP measurement (RTn) was 18.79 ± 4.36 mmHg. Correlation of Icare IOP measurements with and without the CL has proven to be statistically positively significant (r -Pearson Correlation = 0.59; $P < 0.001$). The difference in IOP RTCL and RTn measure-

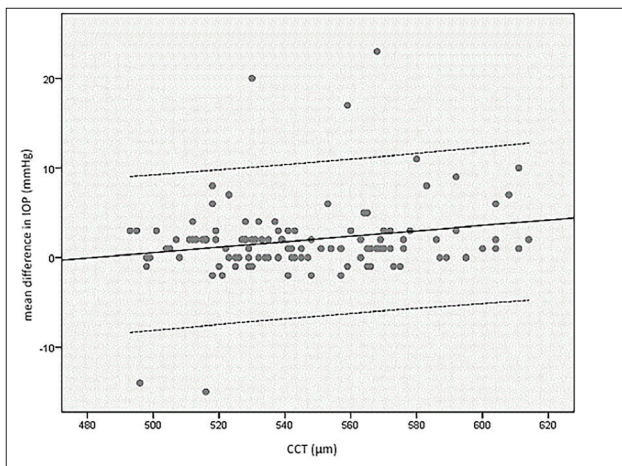


Figure 4. Bland-Altman plot where influence of CCT on difference between two IOP measurements (Δ IOP), with and without CLs, is presented. Increase in CCT correlates positively with increase of measurement error of RT.

Lens	Material	Water content (%)	Modulus (MPa)	Dk/t	Diameter (mm)	Central thickness (mm)
CL 1	Methafilcon A	55	0.50	23.5	14.2	0.15
CL 2	Balafilcon A	36	1.50	112	14.0	0.09

Table 1. Two groups of CLs that comparing had largest differences in water content and modulus.

		n	mean	SD	T	P
Icare WITH	CL 1	15	19.1	± 2.3	3.42	0.002
	CL 2	15	26.1	± 7.6		
Icare WITHOUT	CL 1	15	20.5	± 6.4	0.21	0.827

Table 2. Influence of soft lens material (rigidity) on difference between two IOP measurements (with and without CLs). Larger deviations in IOP measurements over materials with bigger modulus and smaller water content (CL 2).

ments (Δ IOP) was 1.95 mmHg ($t = 4.79$; $P < 0.001$).

In relation to labelled lens power, our studied sample contained more lenses with minus power as oppose to plus spherical and toric lenses. Statistical analysis showed that IOP values with or without CLs are more variable in people with plus spherical power comparing to minuses and torics (Figure 2).

Eyes were divided into several categories according to dioptric powers (Figure 3). Most of variations in IOP measurements were shown in diopter powers from +2.00 to +6.00 Dsph (Δ IOP Kruskal Wallis $\chi^2 = 48.25$, $P < 0.001$). The value of the measured IOP RTCL was proven to be statistically significantly higher than the measured IOP RTn in following groups: powers to -2.00 Dsph (for 2.1 mmHg; $t = 5.67$; $P < 0.001$), powers over -6.00 Dsph (for 0.9 mmHg; $t = 2.23$; $P = 0.039$), powers from +2.00 to +6.00 Dsph (for 9.4 mmHg; $t = 4.68$; $P = 0.001$). The differences in the values of the IOP RTCL and RTn were not statistically significant in following groups: powers between -2.00 and -6.00 Dsph (0.2 mmHg; $t = 0.33$; $P = 0.744$) and powers over +6.00 Dsph (3.8 mmHg; $t = 2.00$, $P = 0.184$). The values of the measured IOP RTCL were statistically significantly higher for 4.3 mmHg in comparison with IOP RTn in toric CLs of not more than 0.75 Dcyl ($t = 4.67$;

$P = 0.001$).

Furthermore, we examined the influence of CCT on difference between two measurements (with/without CL). The measurement error of RT over soft CLs increased as the CCT increased. For every 100 microns of CCT increase, IOP values over CLs will increase for 5 mmHg comparing to those without them. As it is shown on Figure 4, increase in CCT shows statistically significant positive correlation with increase of measurement error of RT ($r = 0.43$; $P < 0.001$).

Finally, we also measured the influence of soft lens material (rigidity) on difference between two IOP measurements (with and without CL). We divided our study participants regarding the type of CL material in 10 groups (Figure 1). Among them, we singled out two groups that comparing had largest differences in water content and modulus, Methafilcon B and Balafilcon A (Table 1).

Statistical analysis showed larger deviations in IOP measurements over materials with bigger modulus and smaller water content. As opposed to that, IOP measurements obtained over materials with smaller modulus and bigger water content equaled those obtained without contacts (Table 2).

5. DISCUSSION

Rebound tonometer is used routinely for IOP measurements, while being reproducible and reasonably accurate. Kontiola in 2000 composed and explained a detailed description of RT principle (3). In this study we wanted to analyse the impact of soft CLs' characteristics and the accuracy of Icare RT in measuring IOP over them.

Fernandes has shown that with the RT it is possible to measure IOP over soft CLs and that Icare overestimates the IOP value by 1.34 mmHg on average when compared with Goldmann tonometer (11). Martinez de la Casa found that RT readings were consistently higher than GAT measurements (median difference, 1.8 ± 2.8 mmHg) (12). Other studies have found that the accuracy of RT procedure is lens power, thickness and material dependent. IOP measurements with hydrogel CLs were lower than those without CLs (13). Zeri published the data of comparison of mean IOP without CLs, with +2.00 dioptic CL power and +6.00 dioptic CL power. Mean IOP values in his study were 19.0 ± 4.1 mmHg, 17.6 ± 4.6 mmHg and 17.8 ± 4.1 mmHg respectively (4). Nacaroglou (14) and Anton (15) have found in their studies that the measurements over CL by RT were found to be significantly higher than measurements without CLs, 15.68 ± 3.75 mmHg vs. 14.50 ± 3.41 mmHg ($P < 0.001$) and 17.5 ± 4.3 vs. 16.4 ± 3.5 mmHg ($P = 0.05$) respectively.

Several studies showed that measurement of IOP can be performed over soft CLs using non-contact airpuff tonometer, GAT, Tono-Pen and the dynamic contour tonometer (DCT).

Anton has found that the Airpuff tonometer did not show statistically significant difference between the lens and the native measurement (15.6 ± 2.6 vs. 15.3 ± 2.6 mmHg; $p = 0.42$) (15). Allen has found in his study that the mean difference between IOP measurement by applanation tonometry with (mean 15.55 ± 1.70 mmHg) and without

(mean 16.05 ± 1.90 mmHg) CL was found to be -0.5 ± 0.89 mmHg (16). Also Zeri did not find significant differences for the IOP measurements with and without CL ($t < 1$; $p = 0.63$) by GAT over a daily disposable soft CL (17). Lester (18) found in his study that the IOP measurement with the lens in place underestimates the value by about 1.5 mmHg measured by Tonopen, while Schornack (19) showed that Tonopen measurement through high-power silicon hydrogel lens materials with relatively high modulus may overestimate the IOP. The study conducted by Lam and Tse (20) demonstrated the feasibility of DCT over silicone hydrogel lenses; low lens modulus silicone hydrogel CL in situ has no clinical effect on DCT. Nosch (21) found similar IOP measurement with and without soft hydrogel CL using the DCT; the average value for the IOP measurements without CL was 16.51 ± 3.20 mmHg, and with CL in situ it was 16.10 ± 3.10 mmHg, the mean difference was 0.41 mmHg and not found to be statistically significant.

Our results were in concordance with the results of the study published by Anton and Nacaroglou. The difference in IOP measured by RT over CLs and RTn (Δ IOP) was statistically significant 1.95 mmHg ($t = 4.79$; $P < 0.001$). Study has shown that RT can be used in IOP measurement over many different types of soft CL materials. The results shown larger deviations in IOP measurements over materials with smaller water content and bigger modulus, what eye care practitioners should keep in mind, as well as that true IOP will be overestimated in eyes with thicker corneas.

The modulus is the force per unit area required to produce a deformation on the CL material and the modulus is physical characteristic of the CLs material like oxygen permeability (Dk), water content, wettability and others (Young's modulus). The relationship between the amount of water and Young's modulus is mostly associated with the type of the material, the value of modulus decreases as the amount of water increases (22). Zeri found the reason for larger deviations in IOP measurements in the fact that CLs with bigger modulus should offer more resistance to the deformation of the CL (13). We also found similar increment in soft CLs characterized by a water content of 36% (Balafilcon A). Lens with bigger water content (of 55%) and smaller modulus (Methafilcon A) had smaller deviations in IOP measurements what can be attributed to low resistance to deformation.

In our study, increase in CCT shows statistically significant correlation with increase of measurement error of RT ($r = 0.43$; $P < 0.001$). For every 100 microns of CCT increase, IOP values over CLs increased for 5 mmHg comparing to those without them. Anton found in his study that RT depends on the CCT (15). In his study, for each 100 microns of increase in CCT, the IOP measured over CL increased by 3 mmHg ($P = 0.04$ in a linear regression model). Nacaroglou and authors have observed that CCT increase did not show any correlation with the differences of the measurements: between RT with and without CL ($P = 0.329$), between RT and GAT with CLs ($P = 0.07$) as well as between RT and GAT without CLs ($P = 0.189$) in linear regression model (14). When a soft CL is fitted, the "new" body composed of cornea and CL has a

greater central thickness than the cornea alone, a possible different external surface curvature depending on the CL power and, presumably, different biomechanical characteristics, depending on the lens material mechanical properties as in Young's modulus (13).

Several studies measured influence of CCT on IOP in RT, Airpuff tonometer and GAT measurements. Jorge and authors concluded that IOP values obtained with the RT are higher in thicker corneas and are positively correlated with biomechanical corneal parameters, namely corneal resistance factor (23). CCT, as well as elastic and viscous properties of the cornea seem to play a significant role in the interaction of the RT probe with the ocular surface. Brusini found in his study that a CCT change of 10 μ m resulted in an Icare reading deviation of 0.7 mmHg (6). Rao and authors found that the difference in IOP obtained by the 2 measurements (RT/GAT) was significantly influenced by CCT increasing maximally by 1 mmHg for every 10 μ m increase in CCT (24). Anton showed that the difference between the native measurement and the CL measurement was not dependent on the corneal thickness in non-contact tonometer (NCT) (15).

Results of our study have shown that most of the variations in IOP measurements were in diopter powers from +2.00 to +6.00 Dsph. Patel explained that eyes with plus diopter lenses will have steeper front surface compared with minus lenses and the volume of material compressed during applanation on a +6.00 Dsph lens is approximately 30% greater than the material applanated on -6.00 Dsph lens over a 3.6 mm diameter of applanation. Also, he concluded that non-contact tonometry (Nidek NT 3000) can be performed with sufficient accuracy over a soft lens on condition: (a) lens centre thickness is no more 0.30 mm and (b) power is not greater than +3.00 Dsph (25). Gogniat revealed that dynamic contour tonometry (DCT) over silicone hydrogel CL was not influenced by lens power, but only a small but statistically significant difference of 0.62 mmHg was found for the IOP measurement with the hydrogel CL of +5.00 Dsph compared with "no CL" (26). Burvenich revealed in his study that DCT principle of IOP measurement is totally independent of the biomechanical properties of the cornea. His study had shown that in statistical calculation there is no correlation between DCT and CCT, while applanation tonometry performed with a non-contact tonometer (NCT) is influenced by CCT (27). Briceno and authors have shown that NCT is significantly more affected by the CCT than the DCT and therefore these methods are not interchangeable (28).

6. CONCLUSION

Our study showed that contact lenses with plus dioptric power are associated with increased variation of IOP, especially in a group from +2.00 to +6.00 diopters. IOP measurements over soft CLs with high modulus and low water content were shown to be higher. Rebound tonometry can be a reliable method for IOP measuring over soft CLs with tendency to overestimate the IOP values for 2 mmHg over contacts.

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the study.

- **Declaration of patient consent:** The authors certify that they have obtained all appropriate patient consent forms.
- **Author's contribution:** KI and MB gave a substantial contribution to the conception and design of the work. ŠHJ and MRM gave a substantial contribution of data. KI, MB, ŠHJ and MRM gave a substantial contribution to the acquisition, analysis, and interpretation of data for the work. KA and MB had a part in article preparing for drafting or revising it critically for important intellectual content. All authors gave final approval of the version to be published and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
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