Effect of Intraocular Pressure on Aerosol Density Generated by Noncontact Tonometer Measurement

Yuan Tang, MS,† Chunchun Li, MS,‡ Yanyan Chen, MS,*†
Zhangyan Chen, MS,‡ Peihua Zhang, BS,† Aisun Wang, BS,†
Xiaoqiong Huang, PhD,‡ Jia Qu, OD, PhD,*‡ Mengchen Li, MS,†
Siwen Ma, MS,* and Balamurali Vasudevan, PhD‡

Precis: Aerosols generated by a noncontact tonometer (NCT) were quantified. There was a positive correlation between aerosols and intraocular pressure (IOP), and the concentration of aerosols beside the air jet port was the highest.

Purpose: To investigate the effects of IOP on the aerosol density generated during the use of an NCT and provide references and suggestions for daily protection of ophthalmic medical staff during the coronavirus disease-19 (COVID-19) outbreak.

Objective and Methods: This cross-sectional clinical trial included 214 eyes of 140 patients from a hospital in Wenzhou city, Zhejiang Province. All subjects’ IOPs were measured by an NCT (39 eyes with low IOP, 90 eyes with normal IOP, 37 eyes with moderately high IOP, and 48 eyes with very high IOP) between March 7 and June 17, 2020. The density of particulate matter (PM) 2.5 and PM10 generated during the process of IOP measurement with an NCT was analyzed. IOP values were recorded simultaneously. The aerosols generated during different IOP measurements were plotted in scatter plots.

Results: PM2.5 was generated more at the air jet port of the tonometer during the process of IOP measurement (H = 2.731, P = 0.019). Larger quantities of PM2.5 and PM10 were generated when the IOP was higher, and these differences were statistically significant (PM2.5: H = 119.476, P < 0.001; PM10: H = 160.801, P < 0.001). Linear correlation analysis with one variable demonstrated that IOP had significantly positive correlations with PM2.5 (r = 0.756, P < 0.001) and PM10 (r = 0.864, P < 0.001).

Conclusions: Aerosols can be generated while using an NCT to measure IOP, and aerosols and IOP are positively correlated. Patients with moderately high IOP or very high IOP tend to generate more aerosols during the IOP measurement. The concentration of aerosols beside the air jet port was the highest.

Key Words: noncontact tonometer, aerosol, glaucoma, infection, coronavirus disease-19

Received for publication July 9, 2020; accepted September 7, 2020.

From the *School of Optometry and Ophthalmology; †The Eye Hospital, National Clinical Research Center for Ocular Diseases, Wenzhou Medical University, Wenzhou, Zhejiang, China; and ‡College of Optometry, Midwestern University, Glendale, AZ.

Y.T. and C.L. are co-first authors.

This study was funded by the scientific research fund of the National Health and Family Planning Commission - Key Project of Zhejiang Province Major Medical and Health Science and Technology Plan (WKJ-ZH-1727) and Wenzhou Municipal City Emergency Research Grant for the Prevention of SARS-CoV-2 (ZJY 2020001).

Disclosure: The authors declare no conflict of interest.

Reprints: Yanyan Chen, MS, The Eye Hospital, Wenzhou Medical University, National Clinical Research Center for Ocular Diseases, Zhejiang Province, Wenzhou city, Xueyuan road #270, Zhejiang 325027, China (e-mail: wzcyymail@163.com).

Copyright © 2020 Wolters Kluwer Health, Inc. All rights reserved.

DOI: 10.1097/IJG.0000000000001669

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the pathogen responsible for coronavirus disease-19 (COVID-19), and the COVID-19 outbreak, which started in December 2019, has evolved to a pandemic. Its main transmission pathways include respiratory droplets and close contact. There is a possibility of aerosol transmission under conditions of prolonged exposure to high concentrations of aerosol particles in a relatively confined environment.1 Multiple studies have suggested that COVID-19 can be comorbid with ocular conjunctivitis, and confirmed cases of conjunctivitis as the first symptom of COVID-19 have been reported.2,3 Moreover, it has been proven by several studies that human tears may contain a variety of viruses, such as hepatitis B virus (HBV), hepatitis C virus (HCV), human immunodeficiency virus (HIV), Epstein-Barr virus (EBV), mumps virus, and measles virus.4–6 Although SARS-CoV-2 has not been confirmed to exist in tears, a significant number of previous studies have reported the presence of SARS and the Middle East respiratory syndrome in human tears.7,8

A noncontact tonometer (NCT) is one of the most common instruments used in ophthalmic examinations. It uses a compressed gas pulse to measure the intraocular pressure (IOP) in the center of the corneal surface. With the help of a camera, Britt et al9 observed that the tear film on the corneal surface ruptured and expelled outward under the impact of the air pressure generated by the NCT gas jet, resulting in the formation of large aerosol particles. Our previous study confirmed their observation, demonstrating that the NCT gas jet can generate aerosols. In addition, these aerosols show an increasing expulsion tendency as the number of gas jet increases, resulting in a cumulative effect.10 Sterilization procedures are not typically performed as no contact exists between the NCT and the eye. However, potentially infective aerosols may be ejected with each pressurized pulse of air.9 When SARS-CoV-2 adheres to aerosols, it forms viral aerosols and can lead to aerosol transmission of the virus. Particulate matter (PM)2.5 and PM10 are the 2 common aerosols that are closely related to the occurrence of respiratory and cardiovascular diseases.11

The current study performed an in-depth investigation of the effects of IOP on PM2.5 and PM10 during the use of an NCT and provides recommendations for the protection of eye care providers during the COVID-19 outbreak.

OBJECTIVE AND METHODS

Objective

A total of 140 patients (214 eyes) were recruited from a hospital located in Wenzhou, China, between March 7, 2020...
and June 17, 2020. The subjects included 80 male and 60 female individuals aged between 18 and 84 years. Data were collected from 99 left eyes and 115 right eyes; 138 eyes were diagnosed with glaucoma, 13 eyes with cataracts, 13 eyes with keratoconus, and 13 eyes with keratitis. Eight eyes were normal, and the remainder of the eyes had other eye diseases. The inclusion criteria were as follows: (1) no infectious diseases; (2) able to cooperate with eye examinations; and (3) good compliance. Before entering the study cohort, all the subjects were informed of the methods along with the purpose of this study, and they voluntarily signed a written consent form. This study was reviewed and approved by the Ethics Committee (2020-018-K-16).

Method

Method of Measurement

Effect of IOP on Aerosol Density. Based on IOP measurement values, subjects were divided into 3 subgroups: the low IOP group (≤10 mm Hg), normal IOP group (10 mm Hg < IOP ≤ 21 mm Hg), moderately high IOP group (21 mm Hg < IOP ≤ 30 mm Hg), and very high IOP group (>30 mm Hg). Baseline and terminal values of aerosol density were recorded before and after IOP measurement in each subject.

Method of IOP Measurement. IOP was measured in all the subjects with an NCT (TX-20 Automatic Noncontact Tonometer, Canon Co, Japan). Subjects were required to maintain a seated posture, wear face masks, and remain silent during the course of the measurement duration. They kept their lower jaw fixed on the tonometer bracket and focused on the light source in the binocular lens. This measurement was repeated 3 times, and the average IOP was recorded.

Method of Aerosol Density Measurement. Three air quality detectors (1000S+ Air Quality Detector, Temtop Co, USA) were used to assess aerosol density, including PM2.5 and PM10 density, in real time. The detectors were initiated and calibrated by placing them in a ventilated space for 24 hours. During the assessments, 3 detectors were fixed at 3 detection points (left side of the tonometer mandible bracket, beside the tonometer air jet port, and right side of the tonometer mandible bracket) (Fig. 1). The aerosol density values at the 3 detection points before and after the IOP measurements in each participant were recorded. The aerosol density value generated by IOP measurements in each participant was calculated as the difference between terminal value and baseline value, and the mean value of the results of 3 air quality detectors was calculated.

Standardization of the Testing Site. The experiment was carried out in a consulting room with an area of 6.10 m×3.60 m×2.85 m. Researchers cleaned the floor, work table, and other surfaces of the consulting room before and after the experiment. An air circulation system that sterilized the circulated air was used for 1 hour before and after the experiment to disinfect the consulting room. After each IOP measurement, the nurse or the doctor cleaned the mandible bracket, frontal bracket, and air jet port of the NCT with alcohol-soaked cotton balls. To ensure the stability of the aerosol density results on different experimental days, experiments were conducted on sunny days with a temperature of 26 ± 2°C and a humidity of 70% ± 3%.

Evaluation Indicators

(1) PM2.5 refers to particles with an aerodynamic equivalent diameter ≤ 2.5 μm, also known as fine particles; the unit is μg/m³.

(2) PM10 refers to particles with an aerodynamic equivalent diameter <10 μm; the unit is μg/m³.

Statistical Methods

EpiData 3.1 was utilized to establish a database for parallel double entry and a verification file for computer logic verification. SPSS 25.0 statistical software was used for the statistical analyses. The Shapiro-Wilk test indicated that the measurement indicators in this study were nonnormally distributed. The differences in PM2.5 and PM10 measured in each group were compared using the rank-sum test, and P < 0.05 was considered statistically significant. In addition, the correlations between IOP and aerosol densities were analyzed by bivariate Spearman correlation, and a scatter plot was constructed.

RESULT

Comparisons of Aerosols at Different Detection Points

The median PM2.5 concentrations at the detection 3 points were 0.40, 0.50, and 0.40 μg/m³, respectively, and the differences were statistically significant (H = 8.863, P = 0.012) (Table 1). The concentration at point B was significantly higher than that at point A (H = 2.731, P = 0.019). However, there were no differences between point A and point C (H = 0.033, P = 0.100) and point B and point C (H = 0.604, P = 1.000). The median PM10 concentrations at the 3 detection points were 1.10, 1.05, and 0.90 μg/m³, respectively, and the difference was not statistically significant (H = 4.222, P = 0.121).

Comparisons of Aerosol Produced During Different IOP Measurements

Of the 214 eyes included in this study, 39 eyes had low IOP, 90 eyes had normal IOP, 37 eyes had moderately high IOP, and 48 eyes had very high IOP (Fig. 2).
Correlations Between Different IOPs and Produced Aerosols

The aerosols produced in different IOP measurements were plotted in scatter plots (Fig. 3). Bivariate Spearman correlation analysis demonstrated that IOP had significantly positive correlations with PM2.5 ($r = 0.756$, $P < 0.001$) and PM10 ($r = 0.864$, $P < 0.001$).

DISCUSSION

PM2.5 and PM10 are the main pollutants in ambient air and can contain pathogenic microorganisms such as viruses, including SARS-CoV-2, bacteria, and fungi. Furthermore, when viruses attach to aerosols, viral aerosols form and can remain airborne for hours. Viral aerosols may cause human illness through respiration or direct contact, as they can fall on surfaces and contaminate surfaces within a diameter of 1 m (3 feet).13

Current information about SARS-CoV-2 is limited.14 Although it has been confirmed that the risk of infection is positively correlated with the concentration of virus in aerosols,15 the quantitative relationship between them has not been clarified.16 Although little is known about the aerodynamic characteristics and transmission pathways of SARS-CoV-2 on aerosols, the risk cannot be ignored.16 Therefore, how to effectively block aerosol transmission has become an urgent problem in need of solving.

The Relations Between IOP and Generated Aerosols

IOP measurement is an important clinical diagnosis and therapeutic observation technique in ophthalmology, especially for glaucoma patients. This study showed that aerosols were generated while using NCTs to measure IOP, and they had a positive correlation with IOP. To measure the changes in IOP, an NCT uses a compressed gas pulse to

TABLE 1. Comparisons of Aerosols at Different Detection Points ($n = 214$) ($\mu g/m^3$)

| Detection Point | PM2.5 M IQR | PM2.5 M IQR | PM10 M IQR | H | P |
|-----------------|-------------|-------------|-------------|---|---|
| PM2.5           | 0.40 0.70   | 0.50 0.80   | 0.40 0.70   | 8.863 0.012 |
| PM10            | 1.10 1.20   | 1.05 1.00   | 0.90 1.20   | 4.222 0.121 |

The median (M) was calculated for the centralized trend, and the interquartile range (IQR) was calculated for the discrete trend.

More PM2.5 was generated when the IOP was higher; these differences were statistically significant ($H = 119.476$, $P < 0.001$) in the moderately high IOP (M = 0.70, interquartile range (IQR) = 0.40) and very high IOP (M = 1.10, IQR = 0.60) groups. Significant differences were also observed in the low IOP versus normal IOP ($H = -3.983$, $P < 0.001$); low IOP versus moderately high IOP ($H = -7.330$, $P < 0.001$); low IOP versus very high IOP ($H = -9.817$, $P < 0.001$); normal IOP versus moderately high IOP ($H = -4.705$, $P < 0.001$); and normal IOP versus very high IOP ($H = -7.570$, $P < 0.001$) groups. None of the comparisons between other groups were significant.

The results of PM10 were similar to those of PM2.5. The differences were statistically significant ($H = 160.801$, $P < 0.001$). There was no significant difference between the moderately high IOP (M = 1.50, IQR = 0.55) and very high IOP (M = 2.05, IQR = 0.70) groups ($H = -2.183$, $P = 0.174$). The differences between the low IOP versus normal IOP ($H = -4.980$, $P < 0.001$); low IOP versus moderately high IOP ($H = -8.700$, $P < 0.001$); low IOP versus very high IOP ($H = -11.478$, $P < 0.001$); normal IOP versus moderately high IOP ($H = -5.336$, $P < 0.001$); and normal IOP versus very high IOP ($H = -8.503$, $P < 0.001$) groups were statistically significant.

FIGURE 2. Comparisons of aerosols generated during different IOP measurements. Boxplot representation of PM2.5 (A) and PM10 (B) generated in low, normal, moderately high, and very high IOP measurements. Boxes represent interquartile ranges. Whiskers represent the lowest or highest data point still within a 1.5 multiple of the interquartile range. ***$P < 0.001$. IOP indicates intraocular pressure; ns, no significance; PM, particulate matter.
expel gas onto the central surface of the cornea. Britt and colleagues reported that the IOP measurement by an NCT generates large aerosol particles. Furthermore, they also noted that when IOP > 30 mm Hg, the gas pulses were stronger and therefore formed larger aerosol particles. This study quantifies aerosol density. As shown in Figures 2 and 3, the IOP value was proportional to the values of aerosols generated during the IOP measurement. Moreover, the densities of PM2.5 and PM10 generated in the group with moderately high or very high IOP were significantly higher than those in the normal and low IOP group. In addition, PM2.5 produced by the NCT was highest at point B (beside the tonometer air jet port).

Effective Prevention of Aerosol Production During IOP Measurement

First, medical personnel should ensure self-protection when measuring the IOP of patients by following all safety protocols, including hand sanitizing and wearing medical protective suits or isolation clothing, protective medical masks, working caps, face screens, goggles, and double-layer gloves.

Second, the sanitation of surfaces of objects in the clinic should be enhanced. Sanitation procedures should be strictly implemented after each measurement. More specifically, the tonometer air jet port and mandible, forehead, and hand rest of the tonometer should be cleaned with 75% alcohol cotton balls. After completion of the daily operation of the instrument, the 2 sides of the isolation plate on the base of the tonometer surface should be cleaned with 1000 mg/L chlorine-containing disinfectant and then rinsed with clean water; the tonometer surface should be cleaned with 75% alcohol cotton balls. After collection of the daily operation of the instrument, the 2 sides of the isolation plate on the base of the tonometer surface should be cleaned with 1000 mg/L chlorine-containing disinfectant and then rinsed with clean water; the protective eyepiece sleeve should be unscrewed and sprayed with 75% ethanol to sanitize the lens. After volatilization, the sleeve can be replaced. The air in the clinic should be sterilized using a dynamic sterilizer or ultraviolet light for a minimum of 30 minutes in the morning, afternoon, and evening.

Third, the principles of “one doctor, one patient, one consultation room” and “scheduled appointments for examinations” should be followed. The interval between IOP measurements should be extended appropriately to reduce the accumulation of aerosols. Moreover, the tonometer should be placed in a well-ventilated place to increase the flow of ambient air and airflow exchange.

Fourth, a transparent isolation plate, such as a self-prepared x-ray film, should be placed between the tonometer eyepiece and the forehead bracket. This is important. In particular, locations that treat patients with high IOP who attend regular visits, such as glaucoma clinics, should be equipped with an NCT with a protective isolation plate to restrict aerosol particle expulsion and therefore prevent and reduce the possibility of iatrogenic cross-infection.

ACKNOWLEDGMENTS

The trial was designed jointly by the investigators. The first draft of the manuscript was written by Yuan Tang, MS. All authors reviewed and provided feedback on the manuscript drafts and made the decision to submit the manuscript for publication. All authors assure the completeness and accuracy of the data and analyses.

REFERENCES

1. Diagnosis and treatment of corona virus disease-19 (Trial edition 7). J Chinese Med. 2020;15:801–805.
2. Zheng MQ, Wu WC, Chen W, et al. Necessity and feasibility of viral RNA detection in specialist ophthalmic institute during the COVID-19 epidemic. Clin J Exp Ophthalmol. 2020:3, 257–260.
3. Jin XM, Lin L, Huang XD. 2019 novel coronavirus transmission mechanism and prevention measures through ocular surface. Clin J Ophthalmol. 2020;56:477–480.
4. Komatsu H, Inui A, Sogo T, et al. Tears from children with chronic hepatitis B virus (HBV) infection are infectious vehicles of HBV transmission: experimental transmission of HBV by tears, using mice with chimeric human livers. J Infect Dis. 2012;206:478–485.
5. Pfaender S, Helfritz FA, Siddharta A, et al. Environmental stability and infectivity of hepatitis C Virus (HCV) in different human body fluids. Front Microbiol. 2018;9:504.
6. Han Y, Wu N, Zhu WJ, et al. Detection of HIV-1 viruses in tears of patients even under long-term HAART. AIDS. 2011; 25:1925–1927.
7. Bonn D. SARS virus in tears. Lancet Infect Dis. 2004;4:480.
8. Wu QM, Wang M. A review of research progress on animal coronaviruses. J Agric Sci Tech China. 2003;5:17–24.
9. Britt JM, Clifton BC, Barneby HS, et al. Microaerosol formation in noncontact ‘air-puff’ tonometry. Arch Ophthalmol. 1991;109:225–228.
10. Li CC, Tang Y, Chen ZY, et al. Aerosol formation during non-contact air-puff tonometry and its significance for prevention of COVID-19. Clin J Exp Ophthalmol. 2020;38:212–216.
11. Cao C, Jiang W, Wang B, et al. Inhalable microorganisms in Beijing’s PM2.5 and PM10 pollutants during a severe smog event. Environ Sci Technol. 2014;48:1499–1507.
12. Wang BY. Comparison of intraocular pressure measurements between two non-contact tonometers. Liaoning: China Medical University; 2014.
13. Zemouri C, de Soet H, Crielaard W, et al. A scoping review on bio-aerosols in healthcare and the dental environment. PLoS One. 2017;12:e0178007.
14. Tang S, Mao Y, Jones RM, et al. Aerosol transmission of 2019-nCoV? Evidence, prevention and control. Environ Int. 2020;144:106039–106048.
15. Wilson NM, Norton A, Young FP, et al. Airborne transmission of severe acute respiratory syndrome coronavirus-2 to healthcare workers: a narrative review. Anaesthesia. 2020;75:1086–1095.
16. Liu Y, Ning Z, Chen Y, et al. Aerodynamic analysis of 2019-nCoV in two Wuhan hospitals. Nature. 2020;582:557–560.
17. Wang YL, Guo SL, Zhang TM, et al. Significance of intraocular pressure with non-contact tonometer before and after laser assisted in situ keratomileusis. J Clin Rehabil Tis Eng Res. 2007;11:934–935.