• COVID-19 and Ophthalmology •

Effects of baffle and intraocular pressure on aerosols generated in the noncontact tonometer measurement during COVID-19

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Abstract

● **AIM:** To investigate the effects of baffle and intraocular pressure (IOP) on the aerosols generated in the noncontact tonometer (NCT) measurement and provide recommendations for the standardized use of the NCT during coronavirus disease 2019 (COVID-19).

● **METHODS:** This clinical trial included 252 subjects (312 eyes) in The Eye Hospital, Wenzhou Medical University from March 7, 2020, to March 28, 2020. Sixty subjects (120 eyes) with normal IOP were divided into two groups. One group used an NCT without a baffle, another group used an NCT with a baffle. Another 192 subjects (192 eyes) were divided into four groups: Group A_1 (without a baffle+normal IOP), Group A_2 (without a baffle+high IOP), Group B_1 (with a baffle+normal IOP) and Group B_2 (with a baffle+high IOP). Particulate matter (PM) 2.5 and PM10 generated by all subjects were quantified during the NCT measurement. The IOP values were recorded simultaneously. Effects of baffle and IOP on aerosols generated during the NCT measurement were analyzed.

● **RESULTS:** In the normal eye group with a baffle, the aerosol density decreased in a wave-like shape near the NCT with the increase in the number of people measured for IOP, demonstrating no cumulative effect. However, in the normal eye group without a baffle, there was a cumulative effect. PM2.5 and PM10 in Group A_2 were higher than Group A_1 (both P<0.001). The PM2.5 and PM10 in Group B_2 were higher than Group B_1 (P<0.01, P<0.001 respectively). The PM10 of Group B_1 was lower than Group A_1 (P<0.01). PM2.5 in Group B_2 were lower than Group A_2 (P<0.01). The median of per capita PM2.5 and PM10 in the combined Group A_1+A_2 were 0.80 and 1.10 μg/m^3 respectively, which were higher than 0.20 and 0.60 μg/m^3 in the combined Group B_1+B_2 (both P<0.01). The median of per capita PM2.5 and PM10 in the combined Group A_1+B_1 were 0.10 and 0.20 μg/m^3 respectively, which were lower than 1.30 and 1.70 μg/m^3 in the combined Group A_2+B_2 (both P<0.001).

● **CONCLUSION:** More aerosols could be generated in patients with high IOP. After the NCT is equipped with a baffle, per capita aerosol density generated decreased significantly near the NCT; And with the increase in the number of people measured for IOP, the aerosols gradually dissipated near the NCT, demonstrating no cumulative effect. Therefore, it is suggested that the NCT should be equipped with a baffle, especially for patients with high IOP.

● **KEYWORDS:** noncontact tonometry; aerosol; baffle; intraocular pressure; coronavirus disease 2019
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INTRODUCTION

Aerosol is a dispersion system of solid or liquid particles suspended in gas medium with a particle size of 0.01-10.00 μm. Pathogenic microorganisms (bacteria, fungus, virus, *etc*.) can attach to aerosols to form pathogenic microorganism aerosols[1]. Some pathogens carried by aerosols are toxic and pathogenic causing infections for human body. A recent research shows that severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) can spread through aerosols, which can cause severe respiratory symptoms and even death[2]. Mehmood *et al*[3] have further strengthened the evidence linking coronavirus disease 2019 (COVID-19) cases with aerosol density.

The noncontact tonometry (NCT) is the most commonly used examination equipment in ophthalmology[4]. It uses pulse air to flatten the constant central surface of cornea (3.60 mm diameter) to measure intraocular pressure (IOP)[5]. Aerosol generation occurs when air accelerates across a fluid surface[6]. In 1991, Britt *et al*[7] used color fluorescence photography to film the moment when IOP was measured by an NCT. Most eyes revealed some degree of tear film dehiscence and microaerosol formation. Our previous research used an air quality detector to quantify aerosols, confirming that aerosols could be generated during the IOP measurement[8-9]. Several literatures have reported that human tears and conjunctival secretions contain SARS-CoV-2[10-12]. Therefore, if an asymptomatic COVID-19 patient with an eye condition undergoes an NCT examination, the aerosols containing SARS-CoV-2 may be formed, and thus may be transmitted to the ophthalmologists and the patients with compromised or no protective gear[6]. According to this, several experts suggested that the baffles should be set up during the use of NCTs to resist aerosols splashing[13-15], but the clinical effect has not been reported yet. Additionally, the specific relationship between IOP and aerosol density during the IOP measurement has not been clarified. Based on our previous study[8-9], this study conducted an in-depth study on the effect of IOP on aerosols generated during the NCT measurement and the effect of baffle on aerosols distribution near the NCT, in order to provide recommendations for the prevention of COVID-19 in ophthalmology clinic.

SUBJECTS AND METHODS

Ethical Approval This study followed the tenets of the Declaration of Helsinki and was approved by the Ethical Committee of The Eye Hospital, Wenzhou Medical University, China (No.2020-018-K-16). Prior to entering the study cohort, all subjects were notified of the methods along with the purpose of this study and signed a written consent form voluntarily. Throughout the course of clinical trial, all subjects wore same facial masks according to the prevention and control management measures of the hospital.

Subjects This cross-sectional clinical trial included 312 eyes of 252 subjects in The Eye Hospital, Wenzhou Medical University from March 7, 2020 to March 28, 2020. The inclusion criteria were as follows: no COVID-19 (the results of novel coronavirus nucleic acid test are negative); able to cooperate with eye examinations. The exclusion criteria were as follows: patients with epiphora or dry eye or corneal diseases; patients had just used artificial tears or other eyedrops before the IOP measurement; contact lens wears.

Methods This study was divided into two parts: effect of baffle on aerosols accumulation, and effects of baffle and IOP on per capita aerosol density.

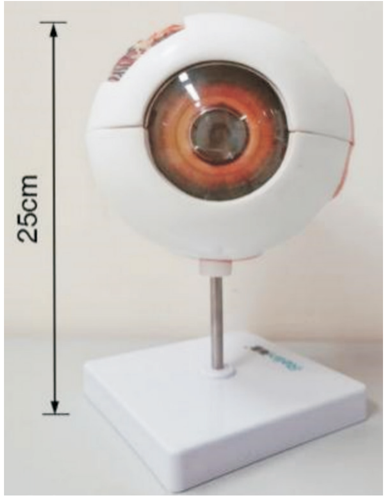

Figure 1 A frontal diagram of the model eye The height of the model eye is 25.0 cm, the eyeball diameter is 13.5 cm, the iris diameter is 6.0 cm and the pupil diameter is 2.5 cm.

Effect of baffle on aerosols accumulation In normal eye groups, 60 subjects with normal IOP (120 eyes) were randomly divided into two groups. One group used an NCT without a baffle, another group used an NCT with a baffle. Subjects of both groups performed binocular IOP measurement in turn. Terminal values of aerosol density near the NCT were quantified by the air quality detectors after the IOP measurement in each subject. In model eye groups, one model eye group used an NCT without a baffle, another group used an NCT with a baffle. The two identical model eyes used in this study were the eyeball anatomical models without lubrication. During the trial, the model eyes were placed in front of the air jet port of the NCT and air jet frequency was the same as that of the normal eye groups (Figure 1). The values of aerosol density were recorded simultaneously. Compared with normal eyes, the surface of the model eye has no tear film. The purpose of using the model eye is to prove that the tear film of human body will rupture under the airflow impact of the NCT to form aerosols.

The duration of four groups was same (about 30min).

Effects of baffle and IOP on per capita aerosol density Totally 192 subjects (192 eyes) were divided into four groups according to whether the NCT was equipped with a baffle and whether the IOP values of the patients were normal: Group A_1 (without a baffle+normal IOP, *n*=59), Group A_2 (without a baffle+high IOP, *n*=58), Group B_1 (with a baffle+normal IOP, *n*=40) and Group B_2 (with a baffle+high IOP, *n*=35). Subjects of four groups performed monocular IOP measurement in turn. The baseline and terminal values of aerosol density were recorded before and after the IOP measurement in each eye.

IOP Measurement IOP was measured in all subjects with two identical NCTs (TX-20 Automatic NCT, Canon Co., Japan). Subjects will need to remain seated, wear face masks, and

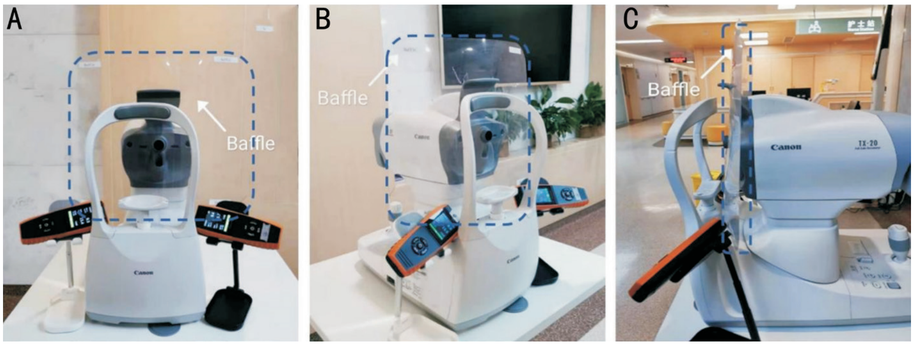

Figure 2 Location of two air quality detectors A: Anterior; B: Left lateral; C: Right lateral. During the trial, both air quality detectors were fixed at the groove between the jet port and the chin rest. When the baffle was installed (dotted blue outline), the detectors were fixed in the same position in front of the baffle, leaning towards the side of patient.

remain silent during the IOP measurement. They fixed their chin to the rest of the NCT and focused on the light source in the jet port. They opened their eyes naturally and exposed the cornea. The IOP of each eye was measured 3 times (3 times of air-puff for one eye), and the average IOP value of each eye was recorded. IOP values of the subjects in 10 mm Hg<IOP≤ 21 mm Hg were normal IOP, IOP>21 mm Hg were high IOP. The mean duration of the IOP measurement was about 1min for each subject. In the experiment to study the effect of baffle on aerosols accumulation, subjects were required to perform binocular IOP measurement in the order of right eye first and left eye later.

Aerosol Density Measurement Two identical air quality detectors (1000S+ Air Quality Detector, Temtop Co., USA) were used to quantify aerosol density, including particulate matter (PM) 2.5 and PM10, in real time. Both air quality detectors were turned on and calibrated by placing them in a ventilated space for 24h before the trial. During the trial, the detectors were fixed at the groove between the jet port and the chin rest. When the baffle was installed, the detectors were fixed in the same position in front of the baffle, leaning towards the side of patient (Figure 2). The difference between terminal value and baseline value was calculated as the actual aerosol density value generated during the IOP measurement in each subject, and the average value of the results of two air quality detectors was calculated.

Test Preparation

Standardization of test site The trial was conducted in a consulting room of more than 100 m^2. Prior to the trial, the floor, countertops and other surfaces were cleaned. Before the trial, the air circulation system was used to disinfect the circulated air for 30min, and it was closed during the trial. After each subject of IOP measurement, the ophthalmologist sterilized the rest chin, frontal rest and air jet port of the NCT with alcohol-soaked cotton balls. In addition, in order to maintain the stability of the air flow formed by the air jet of the NCT during the trial, other people were not allowed to enter the test site; In order to ensure the stability of the results of aerosol density over the different testing days, the ambient temperature should be maintained at 24℃±3℃ and the humidity at 68%±5%.

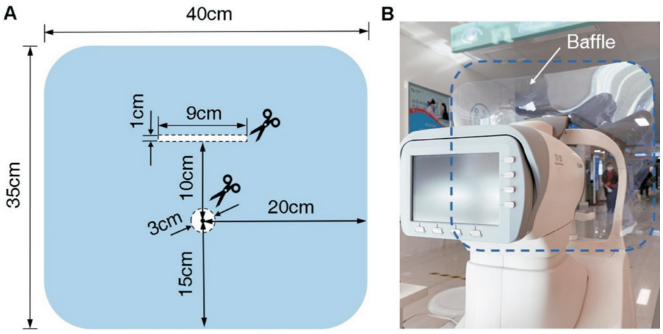

Figure 3 Production and installation of the baffle A: Select a plate made of transparent plastic, cut according to the dotted line and grind the four corners to be blunt; B: Install and fix the baffle at the jet port (the air jet of the NCT passes through the round hole of the baffle), between the display screen and the head rest of the patient (dotted blue outline).

Production and installation of the baffle A transparent plastic material was used to make a baffle with an area of 35×40 cm^2, which was installed and fixed at the jet port of the NCT, between the display screen and the head rest of the patient (Figure 3).

Evaluation Indicators PM2.5 means that particles with an aerodynamic equivalent diameter are less than 2.5 μm, also known as fine particulate matter; the unit is μg/m^3. PM10 means that particles with an aerodynamic equivalent diameter are less than 10 μm, also known as inhalable particles; the unit is μg/m^3.

Statistical Analysis EpiData 3.1 was used to establish the database for parallel double entries and the verification file for computer logic verification. SPSS 25.0 statistical software was used for the statistical analysis. Quantitative data were expressed as mean±standard deviation (SD) or median, interquartile range; and independent sample *t*-test or *F*-test was

Table 1 Comparison of subject characteristics of experiments on aerosols accumulation

Group	*n* (eyes)	Male/female, *n* (%)	Age (y, mean±SD)	IOP (mm Hg, mean±SD)
Without a baffle	30 (60)	18 (60.00)/12 (40.00)	38.23±14.28	13.36±2.63
With a baffle	30 (60)	19 (63.33)/11 (36.67)	45.03±15.61	12.83±2.54
Statistical value		0.071[a]	-1.760[b]	1.105[b]
P		0.791	0.084	0.271

[a]Chi-square test; [b]*t*-test.

Table 2 Comparison of subject characteristics of experiments on the per capita aerosol density

Group	*n* (eyes)	Male/female, *n* (%)	Age (y, mean±SD)	Right/left eye, *n* (%)	IOP (mm Hg, mean±SD)	Glaucoma/normal eye/others[a], *n* (%)
A_1	59 (59)	28 (47.46)/31 (52.54)	45.07±19.76	28 (47.46)/31 (52.54)	13.97±3.80	49 (83.05)/6 (10.17)/4 (6.78)
A_2	58 (58)	25 (43.10)/33 (56.90)	51.83±20.92	23 (39.66)/35 (60.34)	31.26±6.57	52 (89.66)/0/6 (10.34)
B_1	40 (40)	26 (65.00)/14 (35.00)	51.78±20.54	24 (60.00)/16 (40.00)	13.95±3.48	31 (77.50)/5 (12.50)/4 (10.00)
B_2	35 (35)	17 (48.57)/18 (51.43)	52.03±21.73	17 (48.57)/18 (51.43)	34.00±11.13	32 (91.43)/0/3 (8.57)
Statistical value		4.885[b]	1.478[c]	3.937[b]	127.824[c]	11.656[b]
P		0.180	0.222	0.268	< 0.001	0.070

[a]Others: Cataract, vitreous hemorrhage, strabismus, *etc*.; [b]Chi-square test; [c]*F*-test.

used for comparison between groups. Qualitative data were expressed as percentages; and Chi-square test was used for comparison between groups. The Shapiro-Wilk test showed that the evaluation indicators in this study were nonnormally distributed, and the differences in PM2.5 and PM10 in each group were compared using the rank-sum test. *P* value less than 0.05 was considered statistically significant. A plot of the cumulative change curve of aerosol density generated during the use of an NCT with and without a baffle for 30 subjects was drawn.

RESULTS

Subjects Characteristics

Subjects of experiments on aerosols accumulation Comparisons of subject characteristics such as gender, age, and IOP between the group with a baffle and the group without a baffle demonstrated no statistically significant differences (P>0.05; Table 1).

Subjects of experiments on the per capita aerosol density There were no statistically significant differences in gender, age, eye, diagnosis and other subject characteristics between the four groups (P>0.05). Comparison of IOP values between the four groups demonstrated that no statistically significant differences were observed in Group A_1 *vs* Group B_1 (P=0.985); Group A_2 *vs* Group B_2 (P=0.51), but the comparisons between other groups were statistically significant (P<0.05; Table 2).

Effect of Baffle on Aerosols Accumulation Binocular IOP measurements were performed in turn in both normal eye groups. In the normal eye group without a baffle, PM2.5 and PM10 increased in a wave-like shape near the NCT with the increase in the number of people measured for IOP, demonstrating a cumulative effect. However, there was not a cumulative effect in the normal eye group with a baffle.

In this study, two model eye groups were set up, one with a baffle and another without a baffle. The PM2.5 and PM10 of both model eye groups fluctuated around the baseline. The two model eye groups were designed to eliminate the influence of pure air jet of the NCT on aerosol density, which indirectly proved that aerosols could be generated when the NCT was used to measure the IOP for subjects (Figure 4).

Effects of Baffle and IOP on Per Capita Aerosol Density Monocular IOP measurements were performed in turn in four groups. PM2.5 and PM10 in Group A_2 were higher than Group A_1 (Z=7.023, 6.034, both P<0.001). The PM2.5 and PM10 in Group B_2 were higher than Group B_1 (Z=3.131, 3.586, P<0.01, P<0.001 respectively). The PM10 of Group B_1 was lower than Group A_1 (Z=-2.622, P<0.01). PM2.5 in Group B_2 were lower than Group A_2 (Z=-2.664, P<0.01).

Results from the Group A_1 and Group A_2, Group B_1 and Group B_2 were combined. The median of per capita PM2.5 and PM10 in the combined Group A_1+A_2 were 0.80 and 1.10 μg/m^3 respectively, which were higher than 0.20 and 0.60 μg/m^3 in the combined Group B_1+B_2 (Z=2.722, 2.812, both P<0.01).

Results from the Group A_1 and Group B_1, Group A_2 and Group B_2 were combined. The median of per capita PM2.5 and PM10 in the combined Group A_1+B_1 were 0.10 and 0.20 μg/m^3 respectively, which were lower than 1.30 and 1.70 μg/m^3 in the combined Group A_2+B_2 (Z=-7.309, -6.858, both P<0.001; Figures 5 and 6).

DISCUSSION

The NCT is a more commonly used equipment for the IOP measurement. In the past, it was believed that the NCT did not contact the cornea directly, which could avoid cross-infection of diseases. However, through this study, we found that, with the increase in the number of people measured for IOP, PM2.5 and PM10 increased in a wave-like shape near the NCT and had a cumulative effect, which was similar to the findings of Li *et al*[8].

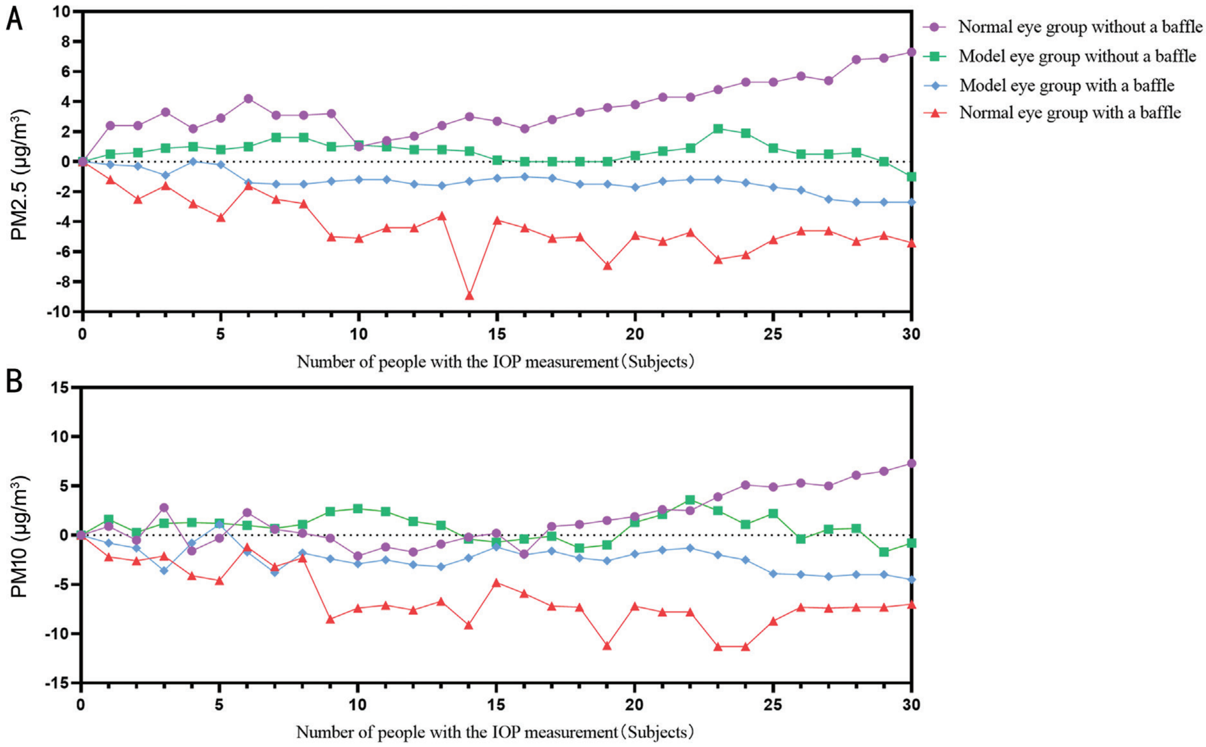

Figure 4 Comparison of effect of baffle on aerosols accumulation A: PM2.5; B: PM10. The 0 value of each y-axis indicates the initial aerosol density before the IOP measurement. The negative value of each y-axis indicates that the aerosol density after IOP measurement is lower than the initial density. The positive value of each y-axis indicates that aerosol density after IOP measurement is higher than the initial density.

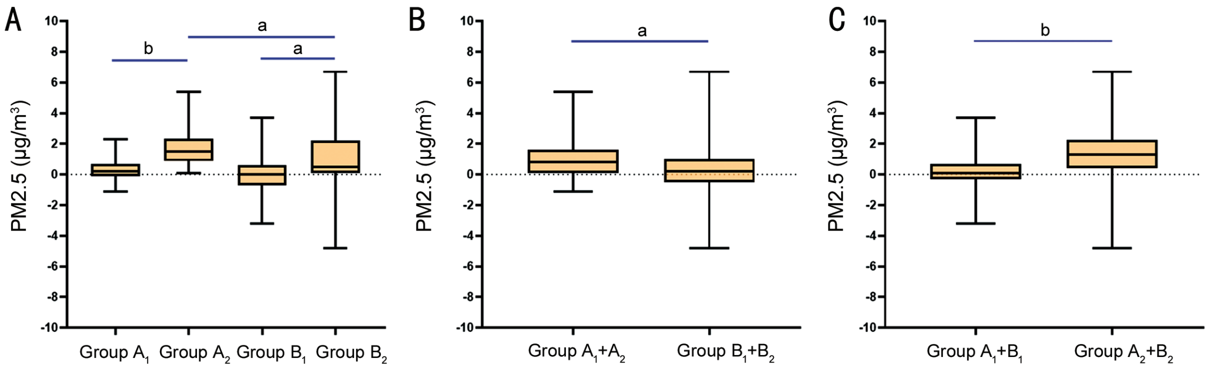

Figure 5 Comparison of effects of baffle and IOP on per capita PM2.5 A: Comparison of four groups; B: Group A_1+A_2 versus Group B_1+B_2; C: Group A_1+B_1 versus Group A_2+B_2. Boxes represent interquartile ranges. Whiskers represent the lowest or highest data point still within a 1.5 multiple of the interquartile range. $^aP<0.01$, $^bP<0.001$.

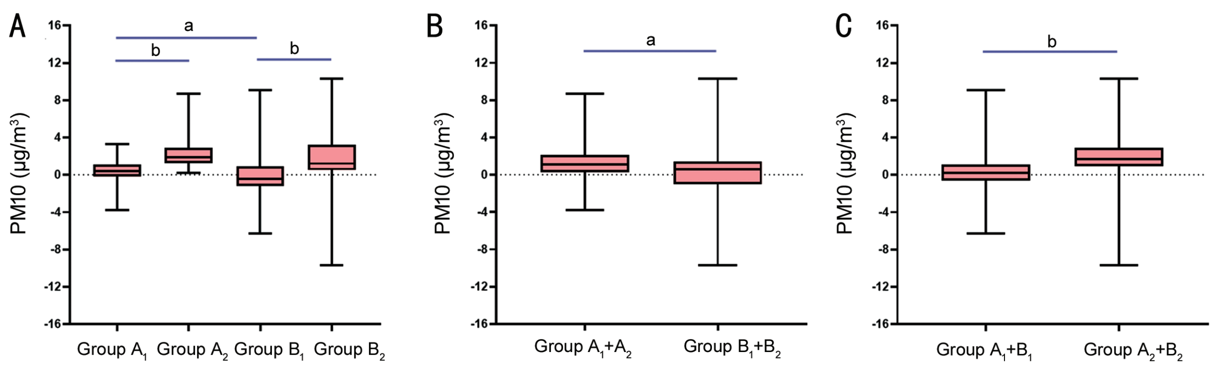

Figure 6 Comparison of effects of baffle and IOP on per capita PM10 A: Comparison of four groups; B: Group A_1+A_2 versus Group B_1+B_2; C: Group A_1+B_1 versus Group A_2+B_2. Boxes represent interquartile ranges. Whiskers represent the lowest or highest data point still within a 1.5 multiple of the interquartile range. $^aP<0.01$, $^bP<0.001$.

Although it is not known for certain whether aerosols of different density generated during the IOP measurement are capable of transmitting COVID-19, existing virology literatures proved that human tears could contain one or several pathogenic substances, such as hepatitis B virus, hepatitis C virus, herpes simplex virus, Epstein-Barr virus, measles virus, mumps virus, human immunodeficiency virus, severe acute respiratory syndrome virus, middle east respiratory syndrome virus, SARS-CoV-2, and bacteria and fungi[16-25]. These pathogenic microorganisms could adhere to the aerosols generated by tear film rupture. A recent study suggested that more than ten strains of microbes, all of which were non-pathogenic, were detected and identified during the IOP measurement[6]. Hence, the NCT maybe a potential source of aerosols containing microorganisms that could lead to transmission of pathogens. Therefore, we suggest that each patient should accept the novel coronavirus nucleic acid test before the IOP measurement during the great pandemics of COVID-19 worldwide. If the testing result is negative, he/she can be measured for IOP by the NCT; if the testing result is positive, the NCT examination should be avoided. For patients with COVID-19, the rebound tonometer is recommended, and the probe should be replaced as soon as it is used.

In this study, a baffle was added to the NCT, and the results showed that with the increase in the number of people measured for IOP, the aerosols decreased in a wave-like shape near the NCT and had no cumulative effect. The normal eye group without a baffle, however, still demonstrated a cumulative effect. Besides, we found that the per capita aerosols generated in the group with a baffle were reduced by almost half compared with the group without a baffle. Therefore, the setting of a baffle was effective during the IOP measurement. We speculated that the possible reasons were as follows: The baffle adsorbed some aerosols; The baffle changed the trajectory of aerosols. Shetty *et al*[26] made the similar proposals by quantifying aerosols and droplets generated during the IOP measurement and assessing the spread distance of the same. Chen *et al*[27] and Lokesh *et al*[28] also have confirmed that a simple barrier drape significantly reduced particulate dispersion in mastoidectomy and temporal bone surgery. Therefore, we strongly recommend that during the great pandemics of COVID-19 worldwide, all ophthalmic clinics should install a transparent baffle between the NCT display screen and the head rest of the patient, such as homemade X-ray film, especially for the high IOP measurement, to reduce the spread of infectious diseases caused by aerosols. Additionally, the local public health policy for ventilation and disinfection should be followed, to dilute and inactivate pathogenic microorganism aerosols.

After grouping and comparing according to the IOP of the subjects, it was found that those with high IOP (IOP>21 mm Hg) generated more aerosols. Britt *et al*[7] also confirmed that the subjects with high IOP (IOP>30 mm Hg) generated more aerosols. It was speculated that the possible reason was that the cornea of the subjects with high IOP bore more jet force when they were measured for IOP, which made the tear film break and release more aerosols[6]. Therefore, we recommend that during the IOP measurement, patients should be carried out in batches and the time interval between patients should be extended appropriately, especially for glaucoma patients or other patients with high IOP.

In addition, this study found that the results of PM2.5 and PM10 were synchronous, and there was no significant difference. From the definition of both, we could easily find PM10 includes PM2.5, but the range is much larger than PM2.5. PM10 can enter the upper respiratory tract, but some can be discharged from the human body through sputum, *etc*. Others will be blocked by the villi inside the nasal cavity. PM2.5 has a small particle size, larger than surface area, strong activity, prone to toxic and harmful substances (such as heavy metals, microorganisms, *etc*.), and a long stay in the atmosphere and a long transport distance, which has a greater impact on human health and atmospheric environmental quality[29-31].

In summary, this study quantified the aerosol density. Aerosols could be generated during the IOP measurement, and more aerosols could be generated by patients with high IOP, which could be one of the potential transmission routes of pathogenic microorganisms in ophthalmology clinic. The installation of the baffle was efficient in changing the distribution of aerosols near the NCT and reducing aerosol aggregation. Therefore, it is suggested that NCTs should be equipped with baffles, especially for patients with high IOP. The NCT should not be used if a patient has COVID-19 or any other infectious disease. This is fundamental in the control and prevention of viral transmission and protection of both the ophthalmologists and the patients during and after the prevalence of COVID-19.

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