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Original Article

Impact of N95 Mask Induced Carbon Dioxide Retention on Intraocular Pressure in Glaucoma Versus Non-Glaucoma Individuals

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ABSTRACT

Background: Prolonged N95 mask wear may alter respiratory effort and the local mask microenvironment, raising concern about possible intraocular pressure changes in individuals with glaucoma. Because glaucoma patients may be more vulnerable to pressure fluctuation, comparative evidence between glaucomatous and non-glaucomatous individuals is clinically relevant. Objective: To compare serial intraocular pressure changes during prolonged N95 mask wear in glaucomatous and non-glaucomatous adults. Methods: This quasi-experimental comparative study included 50 participants, with 25 glaucomatous and 25 non-glaucomatous individuals. Intraocular pressure was measured using Goldmann applanation tonometry before N95 mask wear and after 5 minutes, 1 hour, and 4 hours of continuous mask use. Baseline clinical characteristics and serial intraocular pressure values were compared between groups, and change from baseline was calculated. Results: The mean age was 32.58 ± 12.44 years, and 29 participants were female. Baseline intraocular pressure was higher in the glaucomatous group than in the non-glaucomatous group (19.32 ± 1.61 vs. 15.03 ± 1.58 mmHg). After 4 hours, intraocular pressure increased to 23.14 ± 1.52 mmHg in the glaucomatous group and 16.52 ± 1.70 mmHg in the non-glaucomatous group, corresponding to mean increases of 3.82 and 1.49 mmHg, respectively. Conclusion: Prolonged N95 mask wear was associated with progressive intraocular pressure elevation, with a larger increase among glaucomatous individuals. Because carbon dioxide was not directly measured, mechanism-related conclusions should remain cautious. Keywords: Glaucoma; Intraocular Pressure; N95 Respirator; Goldmann Applanation Tonometry; Carbon Dioxide; Mask Wear.

INTRODUCTION

Glaucoma is a progressive optic neuropathy characterized by structural damage to the optic nerve head and corresponding visual field loss, with intraocular pressure representing the most important modifiable risk factor for disease onset, progression, and long-term visual prognosis (1,2). Although elevated intraocular pressure is not the only determinant of glaucomatous damage, patients with glaucoma are clinically vulnerable to sustained or repeated pressure fluctuations because even modest increases in intraocular pressure may contribute to optic nerve stress, particularly in eyes with compromised outflow regulation, vascular susceptibility, or advanced optic nerve damage. Therefore, identifying common environmental or occupational exposures that may transiently increase intraocular pressure has practical relevance for glaucoma monitoring and patient counseling.

External periocular compression and altered respiratory physiology have both been investigated as possible contributors to short-term intraocular pressure variation. Previous studies have shown that swimming goggles and other tight-fitting facial equipment may affect intraocular pressure through periocular compression or changes in venous dynamics, although the magnitude and direction of this effect may vary according to device type, fit, duration of use, and participant characteristics (3–5). Respiratory protective masks, particularly N95 respirators, differ from ordinary surgical masks because they are designed to achieve a closer facial seal and higher filtration efficiency, which may increase breathing resistance and alter the microenvironment between the mask and face during prolonged use (6–8). The widespread use of N95 masks during and after the COVID-19 pandemic has therefore raised questions about their possible physiological effects beyond respiratory protection, especially in individuals with pre-existing ocular disease.

The N95 respirator is widely used in clinical and community settings because it is designed to filter at least 95% of airborne particles under standard testing conditions, providing greater protection against small aerosolized particles than loose-fitting surgical masks (9–11). However, prolonged use may increase respiratory effort and in-mask carbon dioxide concentration, particularly when the mask fit is tight or the duration of wear is extended (12,13). These changes do not necessarily indicate clinically significant systemic hypercapnia in all users, and direct measurement of carbon dioxide is required before attributing physiological outcomes to carbon dioxide retention. Nevertheless, increased breathing resistance, altered intrathoracic pressure, mild hypoxic or hypercapnic responses, and venous pressure changes have been proposed as plausible pathways through which prolonged respirator use could influence ocular blood flow, episcleral venous pressure, choroidal vascular congestion, aqueous humor dynamics, and ultimately intraocular pressure (14–16).

Existing evidence on mask use and intraocular pressure remains limited and heterogeneous. Some studies have evaluated healthy participants or healthcare workers during routine mask wear, while others have assessed intraocular pressure during exercise or walking while using surgical or FFP2/N95 masks (17,18). These studies suggest that mask-related effects on intraocular pressure may be small in healthy individuals but could become more relevant during prolonged exposure, physical activity, or in populations with impaired ocular pressure regulation. Patients with primary open-angle glaucoma may be particularly susceptible because their baseline intraocular pressure is often higher, their optic nerves are more vulnerable to pressure-related damage, and their capacity to tolerate additional pressure fluctuation may be reduced. However, direct comparative evidence between glaucomatous and non-glaucomatous individuals during prolonged N95 mask wear remains insufficient.

The present study was designed according to a PICO framework in which the population comprised glaucomatous and non-glaucomatous adults, the exposure was continuous N95 mask wear, the comparison was between glaucoma-status groups, and the outcome was serial change in intraocular pressure measured at baseline, 5 minutes, 1 hour, and 4 hours. This study aimed to compare the pattern and magnitude of intraocular pressure change during prolonged N95 mask wear in glaucomatous versus non-glaucomatous individuals. The working hypothesis was that intraocular pressure would increase over time during N95 mask use and that the magnitude of increase would be greater among glaucomatous individuals than among non-glaucomatous individuals.

MATERIAL AND METHODS

This prospective quasi-experimental comparative study with repeated intraocular pressure measurements was conducted from February 2026 to May 2026 at Superior University, Lahore. The study was designed to compare serial changes in intraocular pressure during prolonged N95 mask wear between adults with primary open-angle glaucoma and adults without glaucoma. A total of 50 participants were enrolled, including 25 glaucomatous and 25 non-glaucomatous individuals. The sample size was calculated using 80% statistical power and a 5% level of significance, based on previously reported changes in intraocular pressure associated with prolonged N95 mask use. The calculation was performed using the formula $n = 2\sigma^2(Z1-\alpha/2 + Z1-\beta)^2/(\mu1 - \mu2)^2$, where σ represented the expected standard deviation and $\mu1 - \mu2$ represented the anticipated mean difference in intraocular pressure between comparison groups.

Participants were recruited from ophthalmology outpatient settings after screening for eligibility. Adults aged 18 years or older were eligible for inclusion in the non-glaucomatous group if they had normal baseline ocular examination findings and no history of systemic or ocular disease likely to influence intraocular pressure measurement. Adults aged 18 years or older were eligible for inclusion in the glaucomatous group if they had primary open-angle glaucoma diagnosed on the basis of glaucomatous optic nerve head changes, corresponding visual field defects, and open anterior chamber angles on gonioscopy. Glaucomatous participants were required to be on stable anti-glaucoma treatment for at least three months with controlled intraocular pressure on their current treatment regimen. Participants were excluded if they were younger than 18 years, had high refractive error including astigmatism greater than 3 diopters, myopia greater than 5 diopters, or hyperopia greater than 5 diopters, had undergone ocular surgery or ocular procedures within the previous six months, had ocular scars or corneal pathology that could interfere with Goldmann applanation tonometry, were unable to tolerate or correctly wear an N95 mask, or had uncontrolled cardiac or respiratory disease.

Ethical approval was obtained from the Institutional Ethical Review Committee before participant recruitment. The objectives, procedures, potential discomforts, and voluntary nature of participation were explained to all eligible participants, and written informed consent was obtained before enrollment. Demographic information, including age, sex, and relevant systemic disease history, was recorded on a structured proforma. Each participant underwent ocular assessment including refraction, best-corrected visual acuity, and intraocular pressure measurement. Best-corrected visual acuity was recorded during the baseline examination, while intraocular pressure was measured serially in the same study eye at four time points: before N95 mask wear, after 5 minutes of mask wear, after 1 hour of mask wear, and after 4 hours of mask wear.

Intraocular pressure was measured using Goldmann applanation tonometry under standardized clinical conditions. To reduce measurement variability, all intraocular pressure assessments were performed using the same tonometer by the same investigator and, as far as possible, at approximately the same time of day to minimize the influence of diurnal intraocular pressure variation. Before baseline measurement, participants were seated comfortably and remained without a face mask for at least 10 minutes. After baseline intraocular pressure was recorded, each participant wore a conventional N95 mask covering the nose and mouth. The mask was positioned to achieve an appropriate facial fit and seal. The second intraocular pressure measurement was obtained after 5 minutes of continuous mask wear. Participants then continued wearing the N95 mask and returned for repeat intraocular pressure assessment after 1 hour and again after 4 hours. During the observation period, participants were allowed to continue routine low-intensity activities, including eating, drinking, talking, and walking, and these conditions were kept consistent with the pragmatic clinical nature of the study.

The primary outcome variable was change in intraocular pressure from baseline during continuous N95 mask wear. Secondary comparisons included between-group differences in intraocular pressure at each time point and the temporal pattern of intraocular pressure change across baseline, 5 minutes, 1 hour, and 4 hours. The main exposure variable was duration of N95 mask wear, and the main grouping variable was glaucoma status. Other recorded variables included age, sex, systemic disease history, best-corrected visual acuity, and baseline intraocular pressure. To reduce information bias, the same measurement instrument and investigator were used for all intraocular pressure assessments, and measurements were obtained under consistent clinical conditions. To reduce confounding by recent ocular intervention or corneal measurement error, participants with recent ocular procedures, corneal pathology, ocular scars, and high refractive errors were excluded.

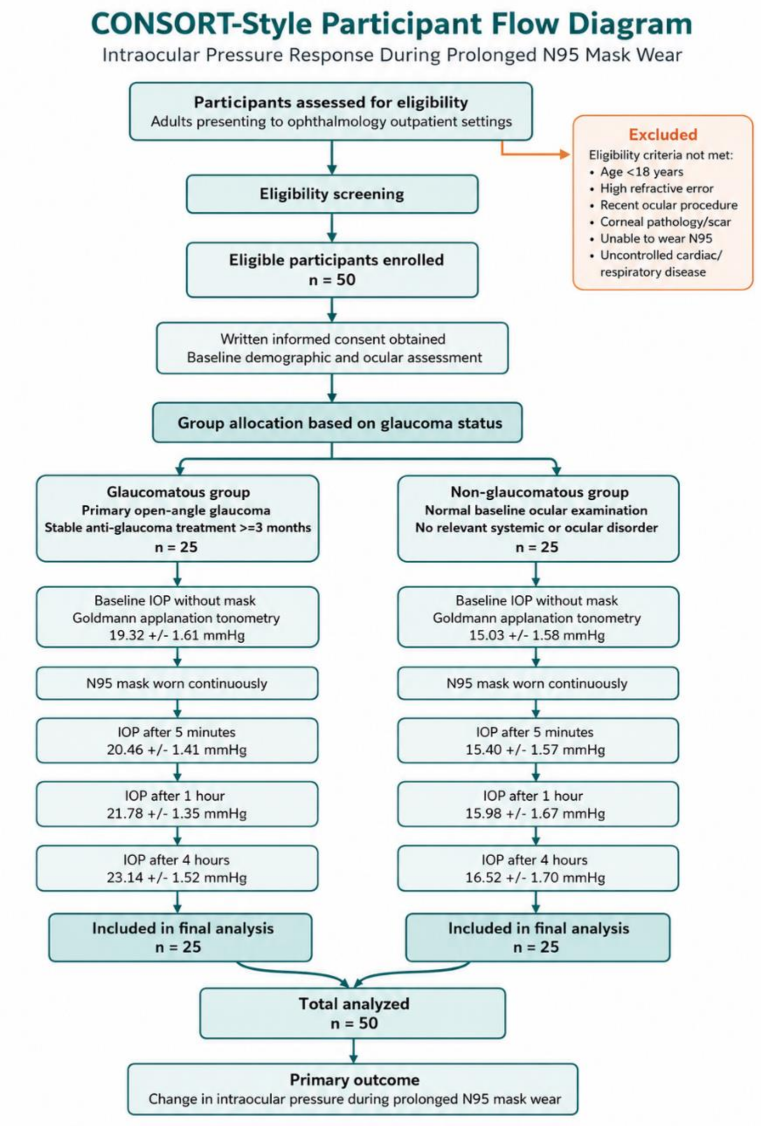

Figure 1 CONSORT Flowchart

Data were entered into a structured database and checked for completeness and consistency before analysis. Continuous variables were assessed for distributional normality using the Shapiro–Wilk test. Normally distributed continuous variables were summarized as mean ± standard deviation, while non-normally distributed variables were to be summarized using median and interquartile range. Categorical variables were summarized as frequencies and percentages. Baseline demographic and clinical characteristics were compared between glaucomatous and non-glaucomatous groups using independent-samples t-tests for normally distributed continuous variables, Mann–Whitney U tests for non-normally distributed continuous variables, and chi-square or Fisher's exact tests for categorical variables, as appropriate. Because intraocular pressure was measured repeatedly over time in the same participants, the primary analysis was planned using a repeated-measures approach to evaluate the effects of time, group, and the group-by-time interaction. A repeated-measures analysis of variance or linear mixed-effects model was considered appropriate for determining whether intraocular pressure changed significantly over time and whether the magnitude of change differed between glaucomatous and non-glaucomatous individuals. Where relevant, change from baseline was calculated for each follow-up time point, and between-group differences in change were interpreted with corresponding p-values and confidence intervals. Statistical significance was set at $p < 0.05$.

RESULTS

A total of 50 participants were included in the study, with 25 participants in the glaucomatous group and 25 participants in the non-glaucomatous group. The overall mean age of the participants was 32.58 ± 12.44 years, with an age range of 19 to 65 years. Of the total sample, 21 participants were male and 29 were female. Normality assessment using the Shapiro–Wilk test indicated that most continuous variables were normally distributed, whereas best-corrected visual acuity was non-normally distributed.

Table 1. Baseline Demographic and Clinical Characteristics of the Study Participants

Variable	Total Sample (n = 50)
Age, years	32.58 ± 12.44
Age range, years	19–65
Male	21 (42.0)
Female	29 (58.0)

Values are presented as mean ± SD, range, or n (%).

The study population included a slightly higher proportion of female participants than male participants, with females comprising 58.0% of the total sample. The mean age was 32.58 ± 12.44 years, indicating that the sample mainly represented young to middle-aged adults, although participants ranged from 19 to 65 years.

Table 2. Comparison of Best-Corrected Visual Acuity Between Glaucomatous and Non-Glaucomatous Participants

Variable	Glaucomatous Group (n = 25), Mean ± SD	Non-Glaucomatous Group (n = 25), Mean ± SD	Mean Difference	95% CI	p-value	Cohen's d
Best-corrected visual acuity	17.52 ± 13.21	8.40 ± 2.29	9.12	3.73 to 14.51	0.002	0.96

CI: confidence interval. Cohen's d was calculated using pooled standard deviation

Best-corrected visual acuity differed between groups, with the glaucomatous group showing a higher recorded mean value than the non-glaucomatous group. The between-group mean difference was 9.12, with a 95% CI of 3.73 to 14.51 and p = 0.002. The calculated Cohen's d was 0.96, indicating a large standardized between-group difference. However, because the manuscript identified this variable as non-normally distributed, future reporting should preferably use median and interquartile range, with a non-parametric comparison.

Table 3. Serial Intraocular Pressure Measurements During N95 Mask Wear by Glaucoma Status

Time Point	Glaucomatous Group (n = 25), Mean ± SD, mmHg	Non-Glaucomatous Group (n = 25), Mean ± SD, mmHg	Mean Difference, mmHg	95% CI, mmHg	p-value	Cohen's d
Baseline	19.32 ± 1.61	15.03 ± 1.58	4.29	3.38 to 5.20	<0.001	2.69
After 5 minutes	20.46 ± 1.41	15.40 ± 1.57	5.06	4.21 to 5.91	<0.001	3.39
After 1 hour	21.78 ± 1.35	15.98 ± 1.67	5.80	4.94 to 6.66	<0.001	3.82
After 4 hours	23.14 ± 1.52	16.52 ± 1.70	6.62	5.70 to 7.54	<0.001	4.11

CI: confidence interval. IOP: intraocular pressure. Cohen's d was calculated using pooled standard deviation. Between-group comparisons are based on the reported independent group values at each time point.

Table 4. Change in Intraocular Pressure From Baseline During N95 Mask Wear

Time Point	Glaucomatous Group, Change From Baseline, mmHg	Non-Glaucomatous Group, Change From Baseline, mmHg	Difference
After 5 minutes	1.14	0.37	0.77
After 1 hour	2.46	0.95	1.51
After 4 hours	3.82	1.49	2.33

At baseline, the glaucomatous group had a higher mean intraocular pressure than the non-glaucomatous group, with a mean difference of 4.29 mmHg and a 95% CI of 3.38 to 5.20 mmHg. This baseline difference persisted and widened during N95 mask wear. After 5 minutes, the between-group difference increased to 5.06 mmHg; after 1 hour, it increased to 5.80 mmHg; and after 4 hours, it reached 6.62 mmHg. The calculated standardized differences were large at all time points, with Cohen's d increasing from 2.69 at baseline to 4.11 after 4 hours. These findings indicate that glaucomatous participants had consistently higher intraocular pressure than non-glaucomatous participants throughout the observation period, although interpretation of post-mask differences should account for the already higher baseline intraocular pressure in the glaucomatous group.

Intraocular pressure increased progressively from baseline in both groups, but the magnitude of increase was greater among glaucomatous participants. After 5 minutes of N95 mask wear, mean intraocular pressure increased by 1.14 mmHg in the glaucomatous group and 0.37 mmHg in the non-glaucomatous group, giving a between-group difference in change of 0.77 mmHg. After 1 hour, the increase from baseline was 2.46 mmHg in the glaucomatous group and 0.95 mmHg in the non-glaucomatous group. After 4 hours, the glaucomatous group showed a mean increase of 3.82 mmHg, compared with 1.49 mmHg in the non-glaucomatous group, producing a between-group difference in change of 2.33 mmHg. This pattern suggests a larger time-dependent intraocular pressure rise among glaucomatous participants during prolonged N95 mask wear.

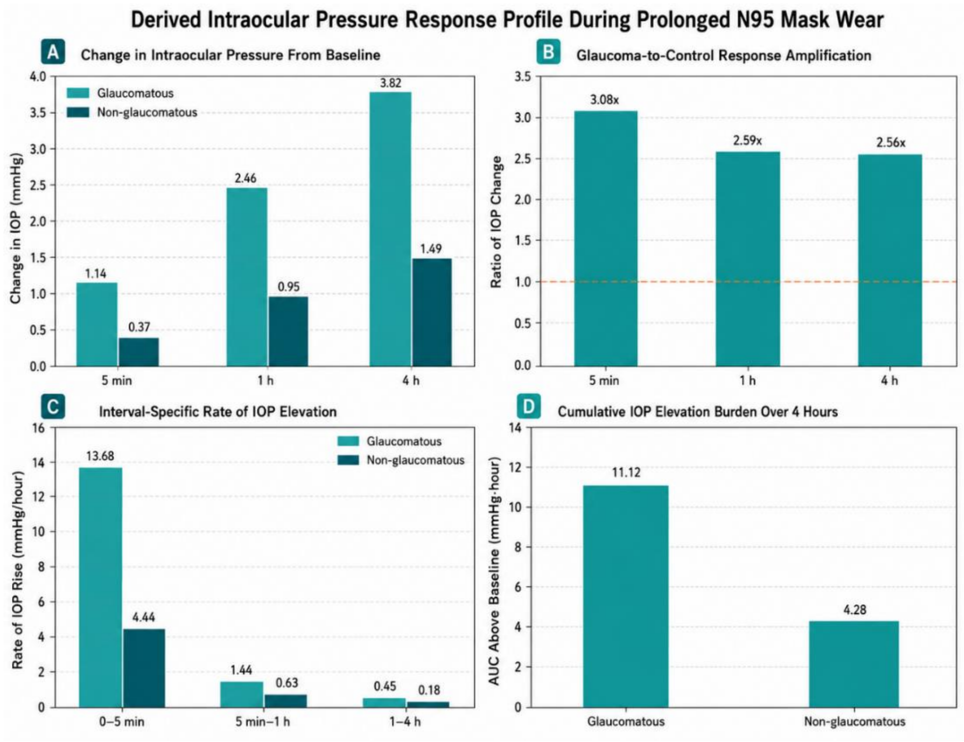

Figure 2 Derived Intraocular Pressure Response Profile During Prolonged N95 Mask Wear

The panelled figure demonstrates a consistently greater intraocular pressure response among glaucomatous participants during prolonged N95 mask wear. Change from baseline increased from 1.14 mmHg at 5 minutes to 3.82 mmHg at 4 hours in the glaucomatous group, compared with 0.37 mmHg to 1.49 mmHg in the non-glaucomatous group. The glaucoma-to-control response amplification remained above twofold at all post-mask intervals, with the highest relative amplification at 5 minutes (3.08×) and persistent amplification at 1 hour (2.59×) and 4 hours (2.56×). The cumulative intraocular pressure elevation burden over 4 hours was also higher in the glaucomatous group (11.12 mmHg·hour) than in the non-glaucomatous group (4.28 mmHg·hour), suggesting that prolonged N95 mask exposure was associated with both greater magnitude and greater cumulative pressure load in glaucomatous eyes.

Overall, the results demonstrate that participants with glaucoma had higher intraocular pressure at baseline and at all post-mask time points. More importantly, the change-from-baseline analysis showed that the magnitude of intraocular pressure increase during N95 mask wear was greater in the glaucomatous group than in the non-glaucomatous group. Because the study used repeated measurements from the same participants, the most appropriate confirmatory analysis would be a repeated-measures ANOVA or linear mixed-effects model assessing time, group, and group-by-time interaction. Such an analysis would determine whether the observed widening difference over time represents a sttistically significant differential intraocular pressure response between groups.

DISCUSSION

The present study compared serial intraocular pressure responses during prolonged N95 mask wear in glaucomatous and non-glaucomatous individuals. The principal finding was that intraocular pressure increased over time in both groups, but the magnitude of increase was greater among participants with glaucoma. The glaucomatous group had a higher baseline intraocular pressure than the non-glaucomatous group, and this difference widened progressively during mask wear. Mean intraocular pressure in the glaucomatous group increased from 19.32 ± 1.61 mmHg at baseline to 23.14 ± 1.52 mmHg after 4 hours, representing a mean increase of 3.82 mmHg. In comparison, the non-glaucomatous group increased from 15.03 ± 1.58 mmHg to 16.52 ± 1.70 mmHg over the same period, representing a mean increase of 1.49 mmHg. These findings suggest that prolonged N95 mask wear may be associated with a greater time-dependent intraocular pressure response in glaucomatous eyes than in non-glaucomatous eyes.

The higher baseline intraocular pressure observed in the glaucomatous group is expected because intraocular pressure is a major modifiable risk factor in glaucoma and remains central to clinical monitoring and disease control (1,2). However, interpretation of the post-mask differences requires caution because the two groups were not equivalent at baseline. The absolute between-group differences at 5 minutes, 1 hour, and 4 hours partly reflect the pre-existing baseline difference between glaucomatous and non-glaucomatous eyes. For this reason, the more clinically meaningful finding is not simply that the glaucomatous group had higher intraocular pressure at each time point, but that the change from baseline was larger in that group. The between-group difference in change increased from 0.77 mmHg after 5 minutes to 1.51 mmHg after 1 hour and 2.33 mmHg after 4 hours. This pattern indicates a progressively greater intraocular pressure response in glaucomatous participants during prolonged N95 mask wear.

Several physiological mechanisms may explain the observed pattern, although this study did not directly measure carbon dioxide concentration, oxygen saturation, end-tidal carbon dioxide, arterial blood gases, intrathoracic pressure, or episcleral venous pressure. N95 masks are designed to form a closer facial seal and provide greater filtration efficiency than loose-fitting surgical masks, but this tighter fit may increase breathing resistance and alter the local respiratory microenvironment during prolonged use (6,8,13). Previous evidence suggests that mask type, fit, and duration of use can influence respiratory parameters, including in-mask carbon dioxide concentration and breathing workload (13,20). Increased respiratory effort may affect intrathoracic and venous pressure, while hypercapnia-related vasodilation has been proposed as a pathway that may increase ocular vascular volume, episcleral venous pressure, choroidal thickness, and intraocular pressure (12,16–18). These mechanisms remain biologically plausible, but they should be interpreted as explanatory hypotheses rather than confirmed pathways in the present study because carbon dioxide retention was not objectively assessed.

The findings are broadly consistent with previous research reporting intraocular pressure alterations during mask use and respiratory loading. Granada et al. reported that N95 respirator use among healthcare workers was associated with increased intraocular pressure over time, particularly after longer durations of mask wear (22). Janicijevic et al. evaluated primary open-angle glaucoma patients during a 400-meter walking protocol and reported that FFP2/N95 mask use produced a small but significant intraocular pressure response during physical activity compared with surgical mask and control conditions (7). The present study extends this line of evidence by directly comparing glaucomatous and non-glaucomatous participants during a 4-hour N95 mask exposure period under routine conditions. Unlike studies involving structured exercise, the present design suggests that intraocular pressure elevation may occur even during ordinary activity when N95 mask wear is prolonged.

The larger response among glaucomatous participants is clinically relevant because glaucomatous optic nerves may be less tolerant of repeated or sustained intraocular pressure fluctuations. Although a short-term rise of a few millimeters of mercury may not be clinically important in healthy individuals, it may be more meaningful in patients with advanced glaucoma, poorly controlled intraocular pressure, narrow therapeutic margins, or progressive optic nerve damage. The 4-hour increase of 3.82 mmHg in the glaucomatous group should therefore be interpreted as a potential monitoring concern rather than as definitive evidence that N95 mask use causes glaucoma progression. In clinical practice, the findings support a cautious individualized approach for glaucoma patients who require prolonged N95 use, particularly healthcare workers or individuals exposed to high-risk respiratory environments. Temporary breaks when safe, avoidance of unnecessary prolonged continuous wear, and routine intraocular pressure monitoring may be reasonable considerations for patients with severe or unstable glaucoma.

The study has several limitations that should be considered when interpreting the findings. First, carbon dioxide retention was not directly measured, so the manuscript cannot conclude that the observed intraocular pressure changes were caused by hypercapnia. Future studies should include end-tidal carbon dioxide, in-mask carbon dioxide, pulse oximetry, or arterial or venous blood gas assessment where ethically and practically feasible. Second, the sample size was limited to 50 participants, which may restrict generalizability and reduce the ability to perform subgroup analysis by age, sex, glaucoma severity, medication class, or baseline intraocular pressure category. Third, participants were allowed to eat, drink, talk, walk, and continue routine activities during the observation period. Although this reflects a pragmatic clinical situation, it introduces potential variation in physical activity, hydration, posture, respiratory rate, and mask fit. Fourth, the analysis should ideally use a repeated-measures model or linear mixed-effects model to assess time, group, and group-by-time interaction, rather than relying only on independent comparisons at each time point. Fifth, information on glaucoma stage, disease duration, visual field severity, medication type, adherence, corneal thickness, and eye-selection criteria was not fully reported, and these factors may influence intraocular pressure response.

Despite these limitations, the study addresses an important practical question in ophthalmic and occupational-health contexts. The observed pattern suggests that prolonged N95 mask wear is associated with progressive intraocular pressure elevation, with a larger response among glaucomatous individuals. The results should not discourage appropriate respiratory protection when clinically indicated, but they highlight the need for risk-aware counseling in patients with glaucoma, especially those requiring extended mask use. Larger prospective studies using standardized exposure conditions, objective respiratory monitoring, glaucoma severity stratification, and repeated-measures statistical modeling are needed to confirm whether prolonged N95 use produces clinically meaningful intraocular pressure changes and whether these changes differ across glaucoma phenotypes.

CONCLUSION

Prolonged N95 mask wear was associated with a progressive increase in intraocular pressure in both glaucomatous and non-glaucomatous individuals, with a larger rise observed among participants with glaucoma. Over 4 hours, mean intraocular pressure increased by 3.82 mmHg in the glaucomatous group compared with 1.49 mmHg in the non-glaucomatous group, suggesting greater susceptibility to pressure elevation among glaucomatous eyes. Because carbon dioxide levels were not directly measured, the findings should be interpreted as evidence of an observed intraocular pressure response during N95 mask wear rather than proof of carbon dioxide-mediated causation. Prolonged N95 use may remain safe for many individuals, but patients with glaucoma, particularly those with severe or unstable disease, may benefit from individualized counseling, appropriate breaks when feasible, and routine intraocular pressure monitoring during periods of extended respirator use.

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