CO_2 Levels in the Naso-Buccal Area Due to the Use of Different Face Masks in Different Ventilation Conditions

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Abstracts. In this work, CO_2 levels were estimated in the naso-buccal area due to the use of face masks. Tests were performed on a healthy volunteer subject sitting at rest and breathing regularly, who used five types of face masks in well-ventilated and poorly ventilated rooms. The ventilation conditions were determined by the natural ventilation of the room. Each of the tests lasted one hour. To estimate the CO_2 level, a sensor based on the Non-dispersive Infrared (NDIR) principle was used. The results revealed that while wearing a face mask, the ventilation conditions affected the CO_2 concentration levels in the naso-buccal area of the user, especially in those that offered a higher level of protection, and in those that best fit the face of the subject. A multiple comparison method (Tukey) revealed significant differences in the levels of CO_2 between all the facemask tested ($p < 0.0001$). The CO_2 levels were also compared with the exposure limits recommended by NIOSH, showing that the use of N95 for 1 h exceeded the recommended 5,000 ppm for an 8-h workday. None of the masks tested exceeded the NIOSH-recommended short-term limit in the first 15 min of use.

Keywords: Carbon dioxide · Face mask · COVID-19

1 Introduction

At the end of 2019, in Wuhan, China, cases of viral-type atypical pneumonia with a series of symptoms such as dry cough, fever, headache, and fatigue were reported [1]. These symptoms were attributed to a new type of coronavirus called SARS-CoV-2 which causes a disease called COVID-19. In January 2020, the World Health Organization (WHO) declared an infectious disease pandemic due to the new coronavirus [2]. Although there was much ambiguity at the beginning about the transmission and contagion mechanisms of this new disease, today it is known that the main form of transmission is through small droplets extracted from the carrier of the virus through breathing, when speaking, sneezing, or coughing [3]. Due to the exponential spread around the world, the WHO suggested the use of N95-type face masks to prevent contagion [4]. However, due to

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the high demand, these face masks became scarce, so people had to resort to other alternatives, including surgical or cloth face masks, among others. The effectiveness of the different types of face masks was uncertain, so several studies have been carried out to compare the efficiency of blocking viral particles. Qing-Xia et al. [5] tested the effectiveness of N95, surgical and homemade face masks. For this, an Avian Influenza Virus (AIV)-loaded nebulizer and a sponge on the other side of the mask were used to subsequently quantify the virus by real-time polymerase chain reaction (RT-PCR). It was reported that the N95 mask blocked 99.98% of viral particles, the surgical mask 97.14%, and the cloth mask with 4 layers of kitchen towel 95.15%. In July 2020, concerns were raised about the level of carbon dioxide (CO_2) in the naso-buccal area due to the use of face masks for prolonged periods of time, which could cause health effects like headaches, dizziness, restlessness, difficulty breathing, sweating, tiredness, increased heart rate, among others [6].

For this reason, measurements of the CO_2 concentration have been made in the area covered by the face mask. Geiss [7] used a tube from the naso-buccal area to an air quality (IAQ) sensor to measure the concentrations of CO_2 with 3 different types of masks (KN95 with valve, surgical, and cloth), in a healthy subject in two scenarios: working on a computer and walking on a treadmill, each test lasted 5 min. The results showed a significant increase in CO_2 levels with the use of the three face masks, but in no case, the limit recommended by the National Institute for Occupational Safety and Health (NIOSH) was exceeded. Concentrations were 2,107 $\pm$ 168 ppm for surgical, 2,293 $\pm$ 169 ppm for KN95, and 2,051 $\pm$ 238 ppm for cloth. Likewise, Unoki et al. [8] surveyed 976 healthcare personnel in Japan with questions regarding the routine use of personal protective equipment (PPE) and its adverse effects. They reported an increase of up to 80% in adverse effects, including skin manifestations, high temperature, headaches, and fatigue when they continuously used a face mask for more than 3 h.

Disagreements have been expressed with the strict indications of the authorities regarding the use of PPE due to the inconvenience that the mask fit can cause, such as suffocation sensation, itching, and intolerance [9]. It has been proved that exposure to CO_2 greater than 10,000 ppm can affect cognitive function and may cause a series of symptoms such as dyspnea, dizziness, and headaches due to hypercapnia: the increase of CO_2 in the arteries ($PaCO_2$) [10, 11]. For this reason, other alternatives have been suggested in addition to the N95 mask, which seems to be less uncomfortable, and their use is recommended by the Center for Disease Control and Prevention (CDC), such as surgical masks, thick cloth masks, and even a combination of these two. In addition to the models endorsed by the WHO and CDC, hybrid masks have been developed, in which a unidirectional valve is added to allow the escape of air. Although it has been proved that this type of mask is more comfortable for the user, since it releases the particles exhaled from the mask, it is indicated as an unfavorable resource to reduce the spread of COVID-19 [12].

Due to the variety of face masks used today to prevent the spread of COVID-19, in this study the level of CO_2 in the naso-buccal area is measured when a healthy subject uses five different types of masks. Unlike the work presented by Rhee et al. [11], where the CO_2 level was measured continuously for 1 h for all the face masks tested (15 min for each face mask), namely, the KN95 and Respirator with valve and the JustAir®, here, the CO_2 level was measured when using each face mask for one hour under different ventilation conditions. Besides, other face masks were tested, such as the cloth mask and the surgical mask, in addition to the N95, KN95, and the N95 with valve.

2 Materials and Methods

Figure 1 shows the measurement setup used to estimate the CO_2 level in the naso-buccal area of a test subject. All the tests were performed on one healthy volunteer to avoid possible contagion between different subjects; the volunteer was a female (29 years, 79 kg). The measurement protocol was approved by the institutional ethical committee of the Autonomous University of Ciudad Juárez (CEI-2021-2-91). The written informed consent was signed by the volunteer. The tests consisted of measuring the CO_2 concentration when the subject used, for 1 h, five different face masks (Fig. 2): a) N95, b) KN95, c) surgical, d) N95 with valve, e) cloth, in good and poorly ventilated rooms. During each test, the subject was seated at rest manipulating a cellular phone and breathing regularly. For each face mask, the CO_2 was measured on the same day for the different ventilation conditions. This procedure was repeated on different days at the same time (approximately) for each of the face masks tested. The measurement frequency of the CO_2 was 0.5 Hz. The results were compared with the levels recommended by the NIOSH for an 8-h workday and for a sampling time of 15 min (short-term). The ventilation conditions were defined by the natural ventilation of the room, which had a door and a window. To quantitatively estimate the ventilation of a room, it would be necessary to quantify the air exchange expressed in L/s, but this procedure was not carried out in this study. In our case, the ventilation conditions were subjectively assumed, that is, the room with the door and window closed was considered to have a poor ventilation condition; the room with the door and window opened was considered to have good ventilation conditions. To simplify the manipulation of the sensor, it was placed outside the naso-buccal area of the subject. So, in order to allow the sensor to receive the CO_2, a PVC transparent flexible tube was placed between the subject and the sensor. The CO_2 concentration was measured by a Nondispersive Infrared (NDIR) sensor, the Senseair S8. Its measurement range was from 0 to 10,000 ppm, with an accuracy of $\pm 3\%$. The sensor was connected via USB to a laptop where the UIP5 software (from Senseair) was installed, which enabled the data logging. Before each measurement, a calibration process was achieved by exposing the sensor to fresh air ($CO_2 = 400$ ppm) [13].

Repeated analysis of variance (ANOVA) was performed. The Tukey test was used as a multiple comparison method between different pairs of the face masks tested, considering a p-value < 0.05 as statistically significant.

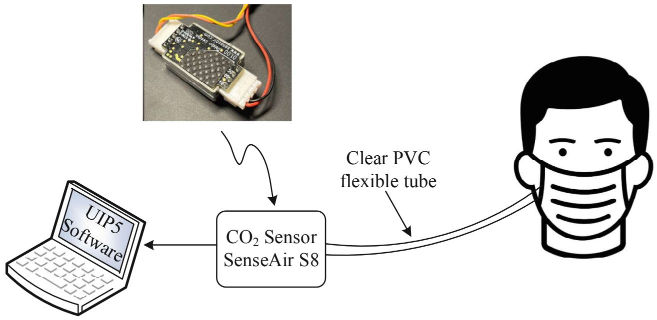

Fig. 1. Measurement setup for estimating the CO2 concentration in the naso-buccal region.

Fig. 2. Volunteer using different face masks: a) N95, b) KN95, c) Surgical, d) N95 with valve, e) Cloth.

3 Results

Figure 3 shows the CO_2 level in the naso-buccal area when the volunteer used five different face masks. Some measurements were saturated because the CO_2 level exceeded the sensor limits. With the exception of the cloth face mask, CO_2 levels were closely linked to the ventilation of the room. That is, in the room with good ventilation, CO_2 levels were lower than those obtained in the poorly ventilated room. Specifically, in the case of the N95 face mask (Fig. 3a), it was observed that in the first 4 min (230 s, approx.) the CO_2 level exceeded 10,000 ppm in the poorly ventilated room. However, in a room with good ventilation, 10,000 ppm was reached after 30 min. Although the KN95 offers the same levels of protection as the N95 [12], Fig. 3b shows that CO_2 levels were lower than those obtained using the N95 mask. With the KN95 mask, 10,000 ppm was not reached even under poor ventilation conditions. The results obtained with the surgical mask were quite remarkable (Fig. 3c). Although these results were reproducible, it was observed that in the poorly ventilated room, CO_2 levels reached 10,000 ppm within the first 7 min. Due to the low level of protection compared to N95 and KN95, CO_2 levels would be expected to be lower. A possible explanation may be that the adjustment of the nose wire caused the space between the end of the flexible PVC tube and the naso-buccal area to be smaller than that of other facemasks. However, we cannot confirm this since the area of the naso-buccal region was not measured in any of the tests. On the other hand, in the room with good ventilation, CO_2 levels with the surgical mask were lower than those obtained with N95 and K95. The N95 with valve showed similar results in both ventilation conditions (Fig. 3d), which is due to the fact that the valve allows the exhaled air to be expelled out of the naso-buccal area but prevents the entry of air. Fluctuations in CO_2 levels can be observed, which was due to the opening and closing action of the valve during exhalation and inhalation, respectively. It is known that this type of face mask is not recommended for COVID-19 infection prevention, but there are people who still use them. The cloth face mask showed lower CO_2 levels than the rest of the face masks tested, at least in the first 1500 s of use (Fig. 3e). During this time, it is also observed how in conditions of good and poor ventilation the results were quite similar. As shown in Fig. 2e, this mask does not fit well in the naso-buccal area, hence all the exhaled air is spread in the environment. That is why the CDC recommends using this type of mask in conjunction with other protective devices to reduce the spread of SARS-CoV-2 [12].

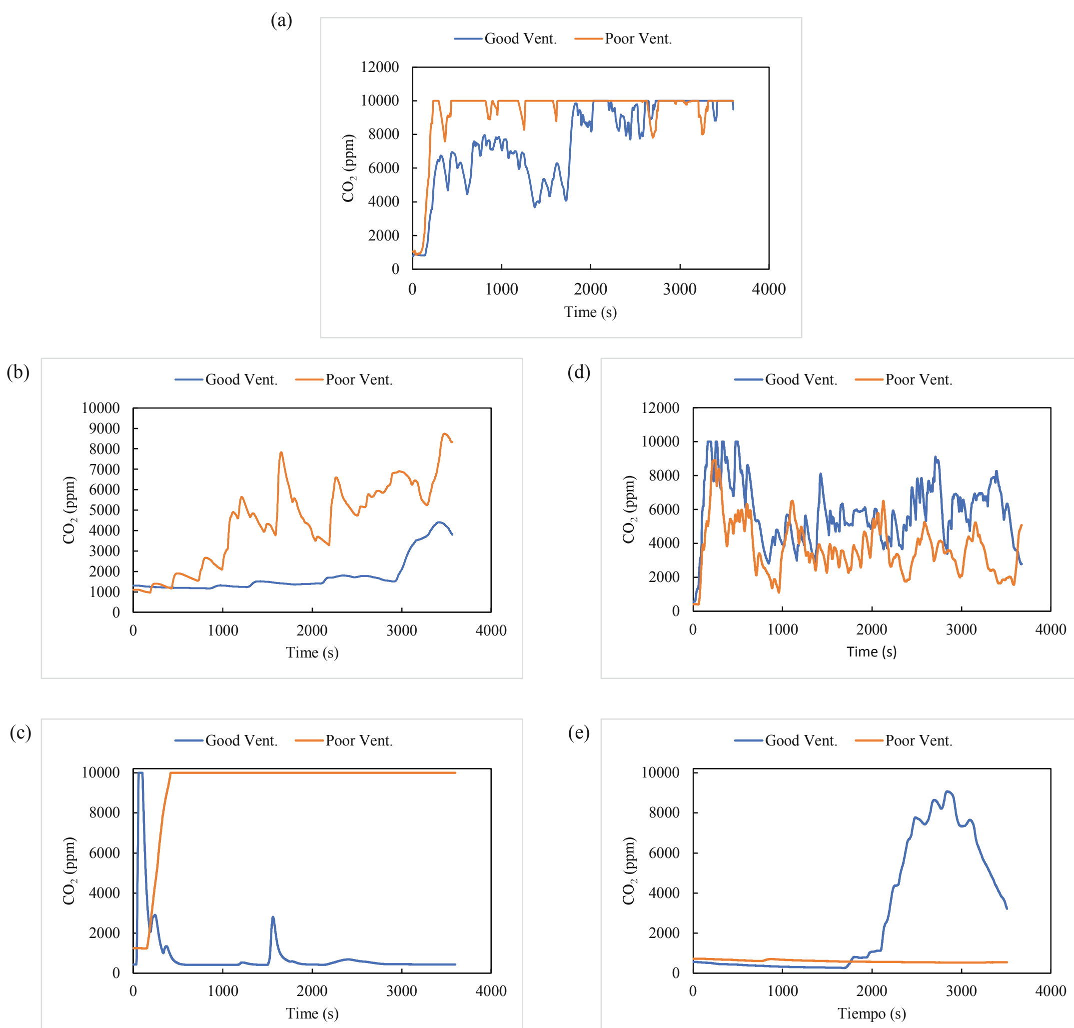

Fig. 3. CO_2 concentration in the naso-buccal area when the subject used different face masks in rooms with good and poorly ventilation: a) N95, b) KN95, c) surgical, d) N95 with valve, e) cloth.

The Tukey test revealed a significant difference ($p < 0.0001$) in the CO_2 concentration in all the pairs tested: N95-KN95, N95-Surgical, N95-N95_valve, N95-Cloth, KN95-Surgical, KN95-N95_valve, KN95-Cloth, Surgical-Cloth. The same statistical significance ($p < 0.0001$) was obtained when the measurements in closed and ventilated conditions were compared for each face mask.

The CO_2 levels obtained with different face masks were compared with the Recommended Exposure Limits (REL) of the NIOSH for an 8-h workday, named Time Weighted Average (TWA), and for 15 min, named Short Term (ST). For this purpose, the mean CO_2 level for each face mask was considered. To compare these levels with the TWA, the average of 1 h of measurement was taken; to compare the data with the ST, the average of the first 15 min of measurement was taken. Figure 4 shows the mean level of CO_2 compared with TWA. The CO_2 level with the N95 face mask exceeded the TWA in both ventilation conditions, which can be attributed to the level of protection it offers and the fit with the subject's naso-buccal area. The concentration of CO_2 with the KN95, the N95 with valve, and the cloth face masks did not exceed the NIOSH TWA levels in the different ventilation conditions tested. The slight exceedance observed with the N95 with valve under good ventilation conditions is not considered significant because it may be due to the low response time of the sensor (2 min), which prevents the sensor output from stabilizing due to the changes seen during inhalation and exhalation (Fig. 3d). In Fig. 5, it can be seen that with none of the face masks used the CO_2 levels exceeded the NIOSH ST, which allows us to deduce that this type of face masks can be used for short periods of time to avoid possible health effects.

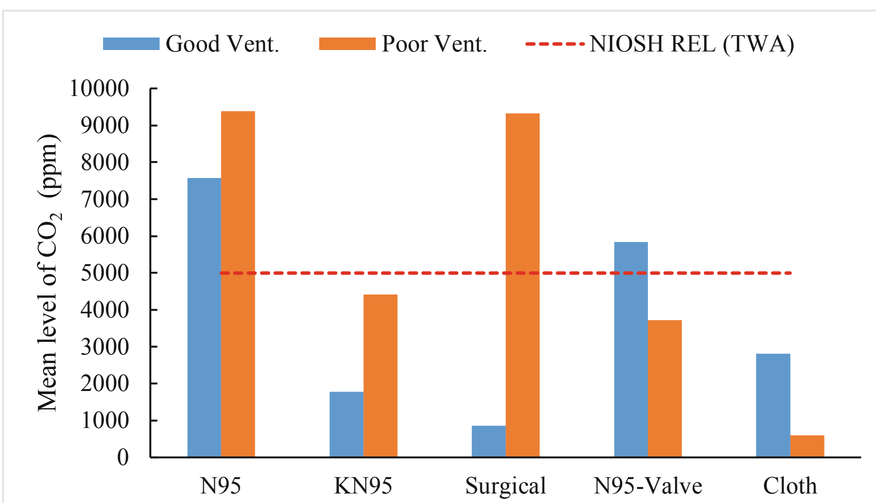

Fig. 4. Mean level of the CO_2 in the naso-buccal region with different face masks under different ventilation conditions. Time = 1 h.

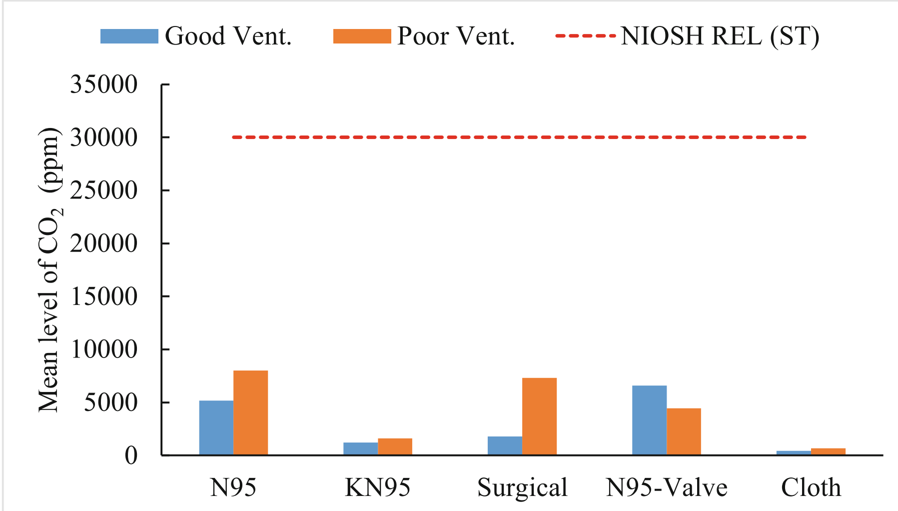

Fig. 5. Mean level of the CO_2 in the naso-buccal region with different face masks under different ventilation conditions. Time = 15 min.

4 Conclusions

In this work, we have estimated the CO_2 levels in the naso-buccal area as a result of the use of five different types of face masks, some of which are recommended by the CDC. In general terms, there is an accumulation of CO_2 in the naso-buccal area even though the molecular diameter of CO_2 is much smaller than the diameter of the pores of the face masks studied. The highest CO_2 concentration was obtained with N95, which offers the highest level of protection and is the one that best fits the naso-buccal area of the user. The ventilation conditions of the environment were determining factors in the levels of CO_2 when using face masks with high levels of protection, such as the N95, KN95, and the surgical mask. In all the tests, the CO_2 levels did not exceed the exposure levels recommended by NIOSH for 15 min, but it was observed an excess of the REL TWA when the N95 was used for 1 h. In short, the use of face masks implies an increase in CO_2 levels in the naso-buccal area, and its use for long periods of time could cause health effects. It is recommended that when some type of mask is used, good ventilation of the environment must be ensured to avoid reaching high levels of CO_2 in the naso-buccal area.

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