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LETTER TO THE EDITOR

Exposure to high concentrations of carbon dioxide during transporting a cadaver preserved with dry ice inside an ambulance vehicle

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Dear Editor,

Carbon dioxide (CO_2) is usually found in the atmosphere at a concentration of approximately 400 parts-per-million (ppm) (0.04%). High CO_2 concentrations affect human health. Beyond 40,000 ppm, elevated pulse, dizziness, and nausea have been reported [1]. At levels higher than 100,000 ppm and 200,000 ppm, syncope and death, respectively, have been reported. The Japan Society for Occupational Health recommends a CO_2 occupational exposure limit at 5000 ppm [2].

Industrial accidents involving dry ice often cause acute CO_2 poisoning, sometimes leading to death [3, 4]. In Japan, dry ice is frequently used upon transporting fresh-frozen plasma to medical facilities or for preventing cadavers from decomposition. Limited facilities can perform autopsies with emerging infectious diseases, such as COVID-19. Therefore, when a patient dies of an emerging infectious disease in a hospital or facility that cannot perform the autopsy, the cadaver is needed to be transported to another facility, where the autopsy of such kinds of cadavers in permitted. If it takes relatively a long time for transporting a cadaver, it is usual to use dry ice for preserving the cadaver. In large-scale disasters, it is presumed a large number of CO_2 poisonings due to consumption of large amount of dry ice for preserving many cadavers [5, 6].

In this article, we report a near miss accident, in which we were exposed to high CO_2 concentrations inside a vehicle transporting a cadaver preserved with dry ice.

In May 2021, a patient died of COVID-19 in our hospital. An autopsy was requested owing to a unique clinical course; the family of the patient consented to transporting the cadaver to an institution for pathological autopsy. Two of the authors, IO and YT, got on the ambulance vehicle for transportation and the cadaver was preserved with dry ice. Before departure, we made literature search with our medical databases about relationship between dry ice amount for preserving cadaver and CO_2 concentrations in the air of the cabin. However, we were unable to find the data about CO_2 concentrations in the air inside the vehicle transporting a cadaver preserved with dry ice. Therefore, for our safety, we needed to carry the device for monitoring the CO_2 concentrations in the ambulance cabin. We used a CO_2 monitor (MonotaRo Co., Ltd., Amagasaki, Japan) that was usually used in the hospital. The measurable range of CO_2 concentration was 0–3000 ppm (accuracy: under 25 ℃, ± 80 ppm or 5% reading at < 2,000 ppm, and 7% reading at > 2,000 ppm), the measurable range of temperature was 0–50 ℃, and that of relative humidity was 20–90%. The double-body bags used were JC-01 (J-Chemical Inc., Tokyo), which were arranged into inner and outer bags. Since the exact validation of the CO_2 monitor was not performed, the concentration data depicted in Figs. 1 and 2 should be regarded as semiquantitative CO_2 concentrations.

The ambulance vehicle was of a paramedical type, manufactured by the Nissan Motor Corporation (Yokohama Japan). It had a volume of approximately 9.6 m^3, with a partition between the front and rear cabins and a ventilation fan.

Each size of dry ice was a plate of approximately 23 × 12 × 4 cm, weighing approximately 2 kg, and was wrapped in a thick cloth.

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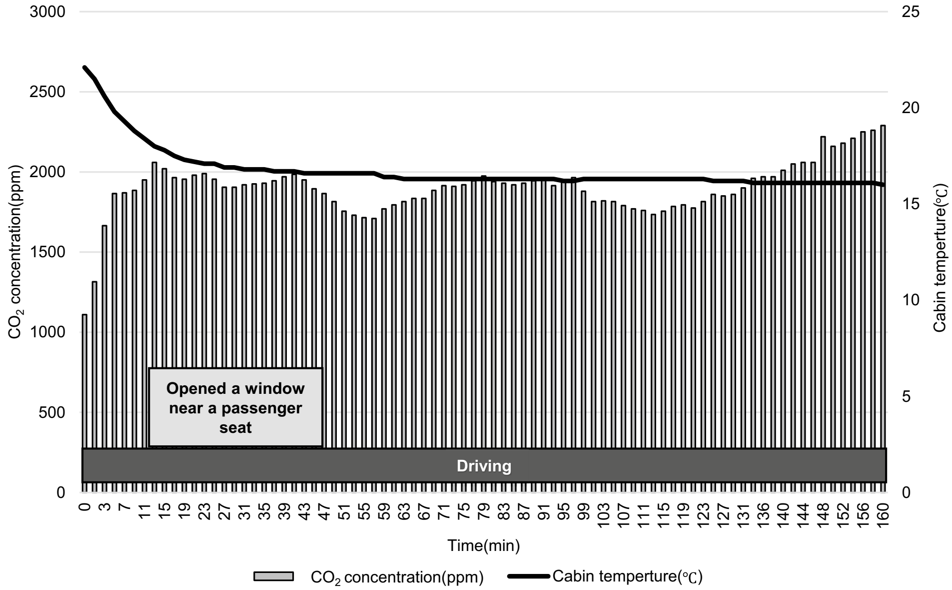

Fig. 1 CO_2 concentrations in the ambulance during the way to the autopsy institution. The CO_2 concentrations stabilized between 1700 and 2000 ppm. The CO_2 concentrations became higher when the ambulance arrived at the city and the driving speed was low

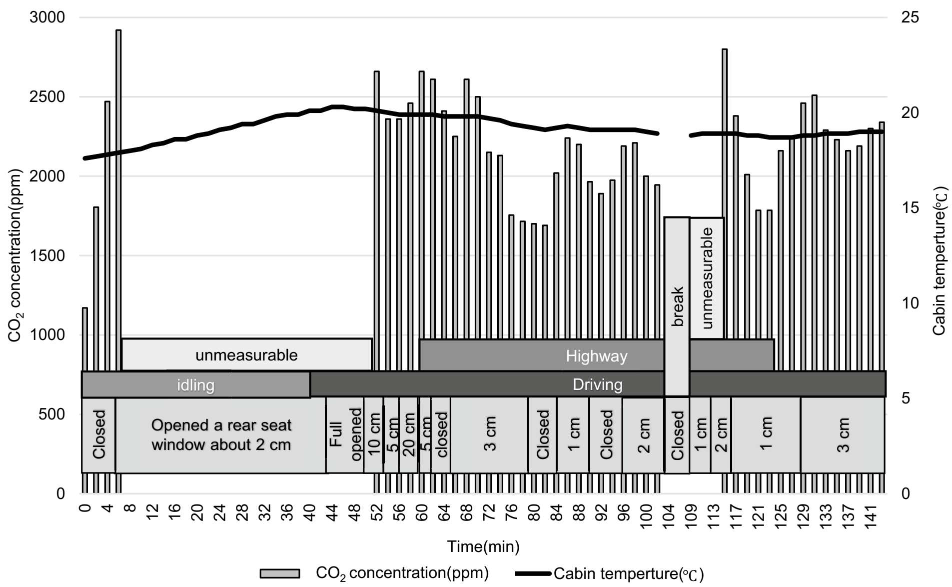

Fig. 2 CO_2 concentrations in the ambulance during the return journey. The CO_2 concentrations sometimes exceeded the measurable range of 3000 ppm. We opened the rear cabin window to reduce the CO_2 concentrations

We placed the cadaver in a double-body bag and placed six plates of the dry ice (total weight 12 kg), in the inner body bag for overnight preservation. The next morning, the cadaver plus the remaining dry ice was loaded on to the ambulance with three people on board, including a driver. One of the authors sat in the rear seat beside the cadaver and the other sat in the front. The CO_2 monitor was placed 62 cm from the floor, near the rear seat. The air conditioner, ventilation, and rear fans were set in the fresh air introduction mode. We recorded the CO_2 concentrations and temperatures inside the ambulance at 2 min of intervals with measurements for approximately 160 min from departure.

The recorded CO_2 concentrations, temperature, and humidity in the ambulance vehicle cabin during the driving ahead from our hospital to an institution for pathological autopsy are shown in Fig. 1. The CO_2 concentration was beyond 2000 ppm at 15 min after the departure. Thereafter, it stabilized between 1700 and 2000 ppm. However, after 140 min, the concentration increased, and a maximum of 2290 ppm was recorded on arrival. The humidity was 40–50% during driving from our hospital to the autopsy institution.

For the return driving, we used six new plates of dry ice, the total weight was 12 kg, for the autopsied cadaver, and we recorded the CO_2 concentrations and temperature in the ambulance vehicle cabin at 2-min intervals. The ambulance was idling for 40 min and running for approximately 90 min, respectively, during which the rear cabin window was opened and closed. We stopped recording for a few min to take a break during the back-and-forth drivings. During the return driving, the CO_2 concentration inside the ambulance sometimes exceeded the measurable limit of 3000 ppm. The maximum CO_2 concentration might have exceeded the occupational exposure limit of 5000 ppm if we had not opened the window. A study showed that decision-making ability in subjects exposed to a CO_2 concentration at 2500 ppm was lower than that in those exposed to 600 ppm [7]. The ventilation in the rear cabin was insufficient, even with the air conditioner set in the fresh air introduction mode. The rear window was opened to a width of at least 1 cm on the highway and 3 cm on the general road to decrease the CO_2 concentration in the cabin. Although cadavers are rarely transported with dry ice in an ambulance, it is quite often that a situation like this could occur for funeral service vehicles. We need to alert such workers to such hazards.

The potential explanation for the higher CO_2 concentrations during the return driving than during the driving ahead to the autopsy institution was that the amount of CO_2 produced was related to the conditions of the cloth wrapping the dry ice. During the driving ahead to the autopsy institution, it was probable that the moisture in the air condensed on the cloth and then froze it which hindered the vaporization of dry ice. Therefore, the difference in the CO_2 concentration between the drivings ahead and back might take place.

On the way to the autopsy institution, the CO_2 concentration in the ambulance loaded with used dry ice increased after 120 min from the start. Factors affecting the amount of CO_2 produced in the ambulance include that produced by the passengers, the amount of cabin ventilation, the amount of CO_2 produced by the dry ice, temperature, and humidity. In the ambulance, there was no change in the passengers themselves, or in the human activities. Therefore, the amount of CO_2 emitted by the passengers is considered to have been constant. In addition, the air conditioner setting in the car was fixed; the temperature, humidity, and main ventilation in the vehicle did not change. However, the speed of the ambulance was changed.

In this case, it was not emergency transportation; the speed of the ambulance was affected by the traffic conditions. When the increase in CO_2 was recorded, the ambulance had entered the city from the highway and was traveling at a reduced speed. It was previously reported that "vehicles traveling at high speeds above 90 km/h had lower CO_2 concentrations than those traveling at low speeds" [8]. Therefore, the recorded increase in CO_2 concentration was considered to be due to the reduced vehicle speed, resulting in the reduction of introduction of fresh air into the inside of the vehicle.

To prevent elevated CO_2 concentration in running ambulance with dry ice, this case suggests that we should set the intake fresh air mode, the ventilation fan should be turned on, and the rear window should be open at least 3 cm. Furthermore, on such an occasion, the passengers should bring CO_2 monitor device to watch CO_2 concentrations in the cabin air; it should be kept in mind that CO_2 concentration more than 2000 ppm (0.2%) is hazardous to human health.

In this case, we used a CO_2 monitor with a limit of detection at 3,000 ppm; therefore, we could not record the maximum CO_2 concentration in the ambulance. We did not measure the concentration in the front area near the driver as we had placed the CO_2 monitor near the rear seat, because we were able to prepare only one CO_2 monitor on the day of the transportation. In addition, low O_2 concentrations in the vehicle also affect the health and the performance of the driver and passengers. In closed spaces, human respiration causes oxygen levels to decrease and CO_2 concentrations to increase. The previous study has shown that the recirculation mode in the vehicle inhibits the inflow of fresh air, the O_2 concentration is decreased and the concentration of CO_2 increases in the vehicle [9]. We used the fresh air introduction mode, but we did not measure the O_2 concentration and the driving speed of the ambulance. Therefore, the relationship between this speed of the vehicle and the increase in CO_2 and O_2 concentration is unclear.

Our report suggests that when transport vehicles of cadavers are loaded with dry ice for cadaver preservation, ventilation only is insufficient. Special attention is needed for the CO_2 concentration when workers load with dry ice in a vehicle cabin, especially for people with the occupations involved in transporting cadavers.

Declarations

Conflict of interest There are no financial or other relations that could lead to a conflict of interest.

Ethical approval The Hamamatsu Medical Center Research Ethics Committee has confirmed that no ethical approval is required for this study. The family of this cadaver consented to the pathological autopsy.

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