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Exposure of dental anesthesiologists to sevoflurane during general anesthesia and measures to minimize this exposure

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We investigated the level of exposure of dental anesthesiologists to sevoflurane during induction of general anesthesia, designed countermeasures against this exposure, and evaluated their usefulness. We first measured the sevoflurane level in samples collected in vacuum bottles using a gas chromatograph, and then evaluated countermeasures against sevoflurane exposure for four conditions. Sevoflurane was detected in 5 of 40 cases of general anesthesia for which samples were collected. However, it was not detected with the double method group in our second experiment. This method minimized exposure, clarifying its usefulness as a countermeasure against sevoflurane exposure. (J Osaka Dent Univ 2020 ; 54 : 45-50)

Key words : Sevoflurane ; Anesthesia, General ; Anesthesiologists

INTRODUCTION

Healthcare workers in operating rooms are exposed to inhalation anesthetics used for general anesthesia. The American Society of Anesthesiologists (ASA) reported that exposure to anesthetic gas damages their health,[1] and Hoerauf *et al.* reported that the inhalation anesthetic exposure level is high during mask ventilation in slow induction using inhalation anesthetics.[2] We previously established and reported a method using electron capture detector-equipped gas chromatograph (ECD-GC) to measure the sevoflurane level in the air.[3] In Experiment 1 of this study, we used this method to investigate the amount of sevoflurane exposure to dental anesthesiologists during the induction of general anesthesia, and in Experiment 2 evaluated the usefulness of countermeasures against sevoflurane exposure that we designed.

MATERIALS AND METHODS

Experiment 1

We collected air in the operating room during the induction of general anesthesia and measured its sevoflurane level to investigate its exposure to dental anesthesiologists. We collected air at approximately 20 cm above the oral cavity of the patient, which corresponds to the breathing area of the dental anesthesiologists, and measured the sevoflurane level. Samples were continuously collected 5 times after anesthesia induction at one-minute intervals designated as measurement points 1 to 5. Measurement points 1 to 3 corresponded to mask ventilation during induction of general anesthesia, measurement point 4 corresponded to confirmation of nasal cavity patency using a cotton swab, and measurement point 5 corresponded to tracheal intubation. For sample collection, the pressure in 50-mL vacuum collection bottles (GL Sciences, Tokyo, Japan) was reduced to -0.095 Mpa using a vacuum pump.

The sevoflurane level in the collected samples was measured using an electron capture detector-equipped gas chromatograph. For the liquid phase, a mid-polar column (Rtx®-200 ; Restek Corporation, Bellefronte, PA, USA) consisting of chemically bonded trifluoropropyl(methyl)siloxane was used. After sample collection, 20 μL of the sample was collected from the collection bottle using a 25-μL micro syringe (Terumo, Tokyo, Japan) and ana-

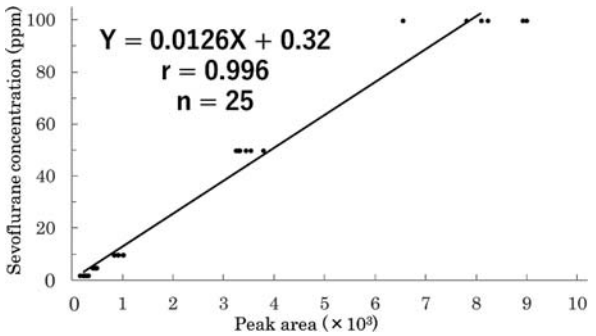

Fig. 1 Calibration curve. The line is an approximate curve of the peak area at each sevoflurane concentration (2, 5, 10, 50 and 100 ppm).

lyzed by gas chromatography. Measurement was repeated 5 times per collection bottle and the mean was adopted as the measured value. The gas chromatographic measurement conditions were set as follows, referring to reports from Kovatsi *et al.*[4] and Ghimenti *et al* :[5] carrier gas, nitrogen (N2 Grade 1, TI Medical, Osaka, Japan) ; inflow pressure, 80 kPa ; total flow rate, 23.2 mL · min^{-1} ; column flow rate, 0.96 mL · min^{-1} ; sample inlet temperature, 200℃ ; column thermostat temperature, 40℃ ; detector temperature, 250℃ ; and split ratio, 1 : 20.0. The peak area was calculated from the measured values using data analysis software and converted to a level using a calibration curve.

The calibration curve was an approximate curve of the peak area prepared by measuring 2, 5, 10, 50 and 100 ppm sevoflurane 5 times using the formula Y＝0.0126 X＋0.32, where Y represents the sevoflurane level (ppm) and X represents the peak area (Fig. 1). The value r was 0.996. The detection limit was 2 ppm, which corresponded to the sevoflurane exposure standards established by the National Institute for Occupational Safety and Health (NIOSH).[6] Accordingly, a sevoflurane level below 2 ppm was regarded as 0.

EXPERIMENT 2

Since Experiment 1 confirmed that dental anesthesiologists are exposed to sevoflurane during the induction of general anesthesia, we designed countermeasures against sevoflurane exposure and investigated their usefulness. The three designed

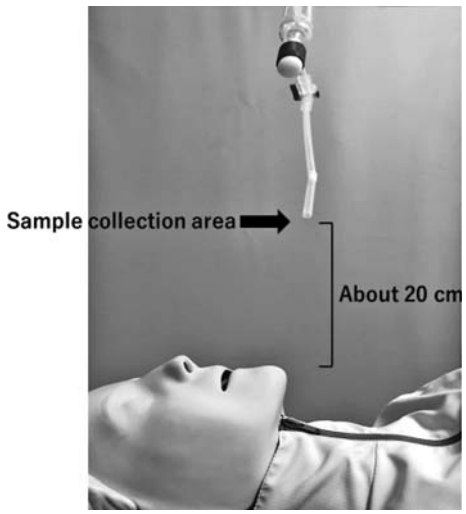

Fig. 3 Sample collection being carried out at the level where the dental anesthesiologist would be breathing.

countermeasures were : A, the suction method, where the air near the patient's oral cavity was suctioned using a suction tube during the induction of general anesthesia ; B, the end of halation method, where the mask was removed after the completion of expiration followed by intubation ; and C, the double method, which was a combination of the suction and end of halation methods. A model reproducing the induction of general anesthesia using Resusci Anne First Aid (Laerdal Medical, Tokyo, Japan) was prepared and each countermeasure was investigated. An artificial respirator (ARF-900 II ; Acoma Medical, Tokyo, Japan), and an anesthesia apparatus (PRO-45 ; Acoma Medical) were used for this model. The ventilation conditions were a tidal volume of 400 mL, a ventilation frequency of 10/min, an I : E ratio of 1 : 2, oxygen at 6 L/min, and sevoflurane at 5% which were the same as in Experiment 1. The suction volume of the suction tube used in the suction method was 20 L/min. Samples were collected with and without (control) the countermeasures in the breathing area of the dental anesthesiologists, similar to that in Experiment 1 (Fig. 3). In Experiment 2, regarding the initiation of the use of sevoflurane as the initiation of general anesthesia induction, samples were continuously collected 5 times after anesthesia induction at one-minute intervals, which were designated

as measurement points 1 to 5. Mask ventilation was assumed for measurement points 1 to 3, confirmation of nasal cavity patency using a cotton swab was assumed for measurement point 4, and tracheal intubation was assumed for measurement point 5. Samples were collected in vacuum collection bottles with reduced pressure and subjected to gas chromatographic measurement, similar to those in Experiment 1. Experiment 2 was performed for 20 cases for each countermeasure. Repeated measures ANOVA and Bonferroni correction were used for statistical analysis.

RESULTS

Experiment 1

In Experiment 1, the sample was the air in the room during the induction of general anesthesia. The samples were collected from 40 cases of general anesthesia with sevoflurane. No samples were collected for cases of anesthesia induction entirely by intravenous administration. In all of the 40 cases, no sevoflurane was detected at measurement points 1 or 2 (1 and 2 minutes after initiation of general anesthesia induction during mask ventilation) (Fig. 2). Sevoflurane was detected at 17.09 ppm in one of the 40 cases at measurement point 3 (3 minutes after the initiation of general anesthesia induction during mask ventilation), and in 3 cases at 19.80, 38.69 and 12.39 ppm, respectively, at measurement point 4 (4 minutes after the initiation of general anesthesia induction during confirmation of nasal cavity patency). In addition, sevoflurane was detected in one case each at measurement point 3 at 17.00 ppm and at measurement point 5 (5 minutes after initiation during tracheal intubation) at 17.08 ppm.

Experiment 2

In the control group, sevoflurane was detected in 8 of the 20 cases of sample collection. It was detected at measurement point 4 (during confirmation of nasal cavity patency) in 4 of the 8 cases at 8.28, 3.78, 3.43 and 4.18 ppm, respectively. It was detected at a total of 4 on 8 cases at measurement point 4, which was during confirmation of nasal cavity patency, and at point 5 which was during tracheal intubation. The levels at measurement point 4 were 27.3, 4.83, 48.64 and 11.32 ppm, respectively, and at measurement point 5 they were 11.40, 14.61, 14.36 and 58.66 ppm, respectively. No sevoflurane was detected in any of the 8 cases at measurement points 1, 2 or 3, which was during mask ventilation (Fig. 4). Sevoflurane was detected in 3 of the 20 cases of sample collection using the suction method. No sevoflurane was detected in any of the 3 cases at measurement points 1, 2 or 3 which was during mask ventilation, whereas it was detected at measurement point 4, which was during confirmation of nasal cavity patency, and in 2 of the 3 cases at point 5, which was during tracheal intubation. The levels were 7.10 and 9.67 ppm, respectively, at measurement point 4, and 14.16 and 33.43 ppm, at measurement point 5. No sevoflurane was detected in 1 of 3 cases at measurement

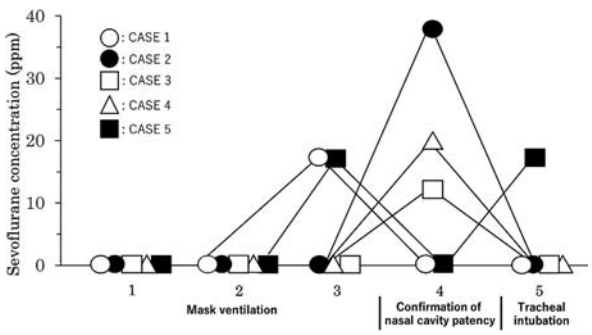

Fig. 2 Results of sevoflurane exposure to dental anesthesiologists. We detected sevoflurane in 5 of 40 cases. The maximum detected concentration was 38.69 ppm.

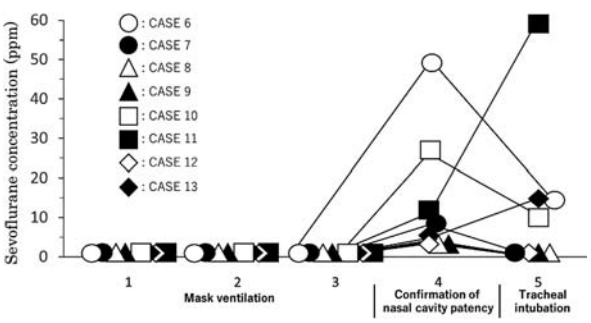

Fig. 4 Control results showing that sevoflurane was detected in 8 of 20 cases. The maximum detected concentration was 58.66 ppm.

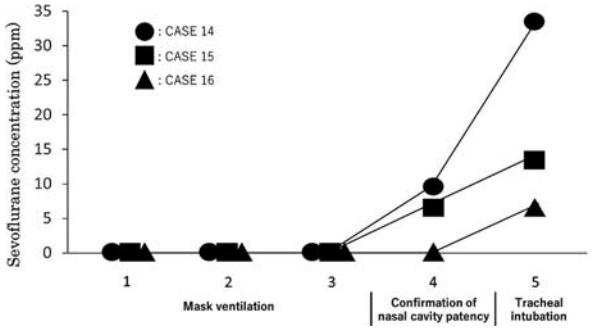

Fig. 5 Suction method results showing that sevoflurane was detected in 3 of 20 cases. The maximum detected concentration was 33.43 ppm.

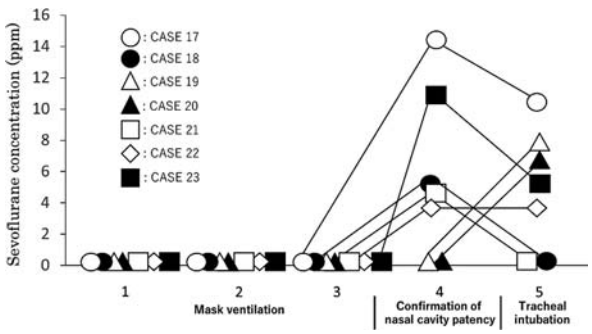

Fig. 6 End of halation method results showing that sevoflurane was detected in 7 of 20 cases. The maximum detected concentration was 14.42 ppm.

points 1, 2, 3 or 4, while it was detected at only 6.91 ppm at measurement point 5 (Fig. 5).

Sevoflurane was detected in 7 of the 20 cases of sample collection using the end of halation method. At measurement point 4, sevoflurane was detected in 2 of the 7 cases at 4.66 and 4.81 ppm, respectively. At measurement point 5, sevoflurane was detected in 2 of the 7 cases at 7.58 and 6.39 ppm, respectively. It was detected at measurement points 4 and 5 in 3 cases at 4.01, 14.42 and 11.06 ppm, respectively, at point 4 at 3.63, 10.56 and 5.62 ppm, respectively, and at point 5. In all 7 cases, sevoflurane was not detected at measurement points 1, 2 or 3 (Fig. 6). Sevoflurane was not detected in any case in the double method group.

DISCUSSION

There have been many reports on health damage in operating rooms. The ASA reported in a nationwide survey in the US involving 49,585 healthcare workers in operating rooms that the incidence of liver disorder was 1.3-2.2-times greater in those with long-term exposure to anesthetic gas in operating rooms than in the non-exposure group, and the incidence of renal disorders was 1.2-1.4-times greater in exposed females.[1] In a survey of health damage by anesthetic gas performed by Guirguis *et al.,* the miscarriage rate was 1.4% in the group without anesthetic gas exposure, it significantly increased to 16.55% in the exposure group.[7] Cohen *et al.* surveyed internists and anesthesiologists, and reported that although the miscarriage rate was 10.3% for internists, but it was 37.8% for anesthesiologists.[8] Therefore, anesthetic gas is considered a health hazard for healthcare workers in operating rooms. NIOSH has specified 2 ppm as the limit of occupational exposure to halogenated anesthetics. However, the American Conference of Governmental Industrial Hygienists has not specified the limit of occupational sevoflurane exposure.[9] It has been specified in Sweden, Finland and Norway, but not in England, Ireland, Switzerland[6] or Japan. We performed this study to better understand the occupational risk of sevoflurane exposure and to better protect the health of dental anesthesiologists.

In Experiment 1, dental anesthesiologists were exposed to sevoflurane in 5 of the 40 cases. When only sevoflurane-detected cases were included in the calculation, the sevoflurane level was 17.05±0.05 ppm at measurement point 3, 23.63±11.07 ppm at measurement point 4, and 17.08±0 ppm at measurement point 5, demonstrating that the sevoflurane level exceeded the limit of 2 ppm for occupational exposure specified by NIOSH in the sevoflurane-detected cases at points 3, 4 and 5, which may damage the health of dental anesthesiologists. Koda *et al.* investigated anesthetic gas diffusion in an operating room in which 6 ppm sevoflurane was detected near the anesthesiologist immediately after the induction of general anesthesia.[10] Herzog *et al.* investigated the level of sevoflurane that anesthesiologists were exposed to from tubes used for tracheal intubation and for general anesthesia induction methods, and detected a

maximum of 1.36±0.56 ppm sevoflurane during general anesthesia induction.[11] Hasei *et al.* examined the occupational exposure to anesthesiologists during general anesthesia induction using inhalation anesthetics, and detected a maximum of 15.91± 22.64 ppm sevoflurane during tracheal intubation.[12] Hasei *et al.* reported that healthcare workers are exposed to sevoflurane even during mask ventilation and that the level was 2.25±2.25 ppm.[12] Sevoflurane was also detected during mask ventilation (measurement point 3) in our study, suggesting that the mask may not fit well on the face.

Byhahn *et al.* investigated sevoflurane exposure to anesthesiologists during slow induction and detected 3.35±4.23 ppm sevoflurane.[13] When Gentili *et al.* examined the occupational exposure of pediatric anesthesiologists during slow induction, sevoflurane was detected in 4 (18.1%) of 22 cases at levels that exceeded the standard limit of 2 ppm for occupational sevoflurane exposure specified by NIOSH.[14] As slow induction was performed in some cases in our study, the cause of sevoflurane exposure during mask ventilation may have been slow induction. When Yamazaki *et al.* assessed the results of physicians unskilled in mask ventilation performing artificial respiration, they observed that exposure mostly occurred in cases with a poor mask fit or poor airway control.[15] In our study, because anesthesiologists experienced in dental anesthesia performed the general anesthesia, no poor mask ventilation was noted. However, dental anesthesiologists may be exposed to sevoflurane in cases requiring slow induction, such as pediatric cases, to which more attention should be paid.

When the sevoflurane level was calculated only for sevoflurane-detected cases in the control group in Experiment 2, it was 13.97±15.06 ppm at measurement point 4 and 24.76±19.61 ppm at point 5. The sevoflurane levels at measurement points 4 and 5 were 8.39±1.29 and 18.17±11.19 ppm, respectively, with the suction method, and 7.79±4.19 and 6.76±2.30 ppm, respectively, with the end of halation method. We then compared the measured value for sevoflurane exposure for each measurement point. At point 4, the measured value of

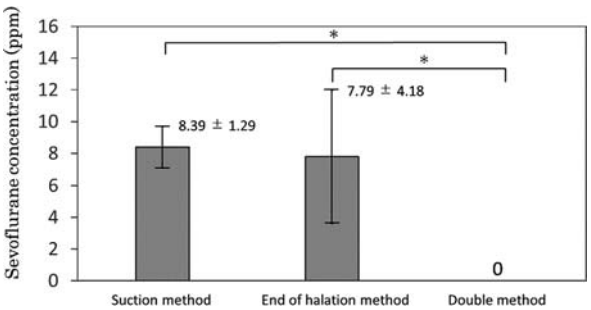

Fig. 7 The mean and standard deviation of the sevoflurane concentration for each method. Use of the double method significantly reduced sevoflurane exposure (*p＜0.05).

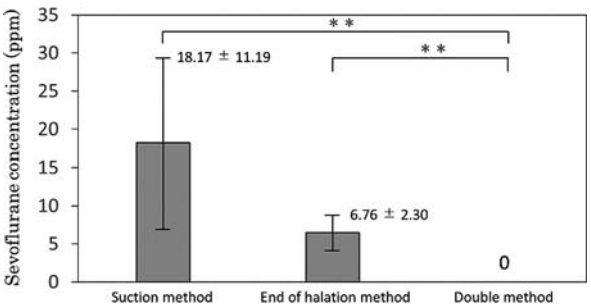

Fig. 8 The mean and standard deviation of the sevoflurane concentration for each method. Use of the double method significantly reduced sevoflurane exposure (**p＜0.05).

sevoflurane significantly decreased when the double method was used compared with the use of other countermeasures (Fig. 7). The measured value also significantly decreased at point 5 when the double method was used compared with the use of other countermeasures (Fig. 8).

The level of sevoflurane that dental anesthesiologists were exposed to was reduced to a level lower than the limit specified by NIOSH when we used the double method that we designed, confirming it to be a useful countermeasure against occupational sevoflurane exposure during the induction of general anesthesia. The measured value was high at measurement point 5 when the suction method was used, whereas it was low when the end of halation method was used, despite suction not being performed. This may have been caused by the expiration and inspiration of air containing sevoflurane when the mask was removed.

The sevoflurane level measured at 1-5 minutes after the induction of general anesthesia was con-

sidered the level of occupational exposure for dental anesthesiologists. However, exposure during surgery is also possible, although that level is low. Herzoq-Niescery *et al.* investigated sevoflurane exposure for surgeons during surgery using a tracheal tube equipped with or without a laryngeal mask cuff, and found the level to be 0.33±0.20 ppm when the cuff-equipped tube was used.[16] Tanko *et al.* examined sevoflurane exposure near the patient's oral cavity (within 5 cm) during brain surgery and detected 1.54±0.55 ppm sevoflurane.[17] Accordingly, oral surgeons who perform surgery on the oral cavity should be careful about intraoperative sevoflurane exposure. Designing countermeasures against intraoperative sevoflurane exposure is a future task.

CONCLUSION

We investigated the level of sevoflurane that dental anesthesiologists are exposed to during the induction of general anesthesia and designed countermeasures. After evaluating their usefulness, the double method (suction of air near the patient's oral cavity during induction combined with removal of the mask after the completion of expiration of mask ventilation followed by tracheal intubation) was suggested to be useful. However, even though a low level of sevoflurane exposure also occurs during surgery, intraoperative countermeasures are still necessary.

This study was presented at the 564th Meeting of the Osaka Odontological Society, October 19, 2019, Hirakata, Osaka, Japan, and at the 47th Annual meeting of the Japanese Dental Society of Anesthesiology, October 25-27, 2019, Okayama, Japan. The authors have no conflicts of interest to declare with respect to this paper.

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