Clinical Case Report

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Misinterpretation of carbon dioxide monitoring because of deadspace of heat and moisture exchanger with a filter in pediatric anesthesia

A case report

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Abstract

Rationale: When patients are intubated and treated with mechanical ventilation, the upper respiratory tract is bypassed by the flow of dry and cold air. To prevent disturbances of airway homeostasis, a heat and moisture exchanger filter (HMEF) has been applied to breathing circuit.

Patient concerns: A 4-month-old male infant was ventilated with the pediatric HMEF. We report the impact of ignoring the direct influence of a filter containing deadspace in pediatric mechanical ventilation.

Diagnoses: The breathing circuit with HMEF leads to unexpected complications such as mechanical obstructions owing to respiratory secretions, bleeding, inhaled drugs, and moisture. Besides these complications, we generally ignored the deadspace as the internal volume of the filters in breathing circuit for pediatric patients.

Interventions: After we noticed the influence of filter deadspace for pediatric patient, we removed the filter for effective respiratory circulation.

Outcomes: The operation was completed without any specific incidents and the patient's voluntary breathing was well-maintained. The patient was discharged without any other complications.

Lessons: The increase in breathing apparatus deadspace should be minimized, and the clinicians should keep in mind that HMEF can causes respiratory acidosis with hypercapnia by apparatus deadspace rebreathing, especially for infants.

Abbreviations: ABGA = arterial blood gas analysis, CO_2 = carbon dioxide, $ETCO_2$= end tidal carbon dioxide concentration, HMEF = heat and moisture exchanger filter, $PiCO_2$ = partial pressure of inspired carbon dioxide, PIP = peak inspiratory pressure, SpO_2 = oxygen saturation on pulse oximetry, V_D/V_T = deadspace to tidal volume ratio, V_T = tidal volume.

Keywords: air filters, humidity, respiratory system

1. Introduction

The important functions of the normal upper respiratory tract, including the nose and pharynx, are providing warmth, filtration, and humidification of the inhaled air during spontaneous ventilation.[1] However, when the upper respiratory tract is bypassed through the endotracheal tube, cold and dry air continues to flow into the respiratory tract, which leads to loss of the bronchial cilia movement, and alveolar secretions, such as mucus and sputum, are impacted in the terminal respiratory tract. Furthermore, postoperative pulmonary complications, such as atelectasis, bronchiolitis, or pneumonia, may occur because of inspissated secretions.

Breathing circuits with various filters were developed to prevent biological hazards, and a heat and moisture exchanger filter (HMEF) has been used to prevent loss of moisture and heat generated during mechanical ventilation. However, increased use of HMEF leads to problems, such as accidental disconnection of the circuit, over-heating damage to the respiratory tract, pathogenic infections, increase in airway resistance owing to excessive moisture saturation in the breathing circuit, and interference with the flow-meter function.[2]

Although numerous cases of mechanical obstruction owing to respiratory secretion, bleeding, inhalation agents, and moisture in the circuit with a filter during general anesthesia have been reported, there has been no report on the respiratory complications that are caused by the deadspace of filter during mechanical ventilation in healthy adults under general anesthesia. This is because although there is a deadspace of approximately 100 mL owing to an adult HMEF, the physiologic deadspace to tidal volume ratio (V_D/V_T) is low in the respiratory function of healthy adults, and therefore, the impact on the patient's assisted ventilation is not significant. However, for infants or patients who are respired by the help of a ventilator in the intensive care unit, the use of a filter can increase the V_D/V_T ratio so that not only re-breathing of carbon dioxide (CO_2) occur, but also the

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respiratory monitors are affected by the distorted status of patient, which eventually leads to inaccurate diagnosis of the patient's condition, incorrect change of setting in ventilator, unnecessary treatment, and even delayed weaning off the ventilator. We report a case with hypercapnia and respiratory acidosis in a pediatric patient because of the filter of a heated wire circuit, which was routinely used without considering the internal volume of the HMEF.

2. Case report

Approval for the study by the institutional review board of Kyungpook National University Hospital was not necessary because it was a case report, based on the institutional policy. The parents of the patient provided informed consent for publication of this case and we anonymized the presented data. A 4-month-old male infant, weighing 8.2 kg, underwent bilateral craniectomy 4 months ago, and craniotomy and distraction operation for craniosynostosis were scheduled. He had no other congenital diseases, and the physical examinations were normal, with no specific findings in the respiratory system. All his vital signs were normal before surgery.

The patient was premedicated by 0.4 mg midazolam and 0.12 mg glycopyrrolate intravenously in the pretreatment room. In the operating room, an oxygen 5 L/min was used for preoxygenation, electrocardiography, noninvasive blood pressure, and oxygen saturation on pulse oximetry (SpO_2) were monitored. During the manual mask ventilation with peak airway pressures of 20 cmH_2O, there were no significant abnormal signs and the SpO_2 level was also maintained at 100%. After injection of 5-mg rocuronium, 3 vol% sevoflurane was maintained, and the intubation was performed using a 3.0 mm inner diameter conventional endotracheal tube. The endotracheal tube was fixed at 12 cm and both lung sounds were checked with no specific findings from auscultation. After tracheal intubation, the pediatric HMEF was connected to a pediatric heated wire circuit and HMEF was installed between the endotracheal tube and Y-piece connection area. Anesthesia was maintained with 3 vol% sevoflurane under the setting of tidal volume (V_T) of 80 mL and respiratory rate of 22 breaths/min in 50% oxygen in air.

After induction, ventilation was continued with V_T 57 mL, peak inspiratory pressure (PIP) 13 cmH_2O, and end-tidal carbon dioxide concentration ($ETCO_2$) 42 mmHg was observed on capnography, and an abnormal waveform was seen, with a baseline of >0 mmHg in the shape of capnography (Fig. 1A and B).

Even under these conditions, the SpO_2 level was maintained at 100%, and we checked the bilateral respiratory sound, CO_2 absorber status, moisture removal in the circuit, and re-conducted the leakage test including HMEF. We tried to ascertain the cause of the abnormal waveform in capnography, but no specific problem was detected. We also checked endotracheal tube leakage, but the tube size was appropriate, whereas tidal volume was checked from 55 to 67 mL.

The patient was correctly ventilated, except for the abnormal capnography, and to proceed with the operation, we continued to cannulate the left radial artery and central venous access first.

Figure 1. (A) Abnormal wave form of capnography monitoring. (B). Ventilator monitoring during filter connecting state.

After 5 minutes followed by tracheal intubation, when the head was turned to the left to cannulate the center venous access device in the right internal jugular vein, PIP 46 cmH_2O, V_T 32 mL, and $ETCO_2$ 74 mmHg were found and the SpO_2 level was decreased to 87%. Patency of endotracheal tube was intact. Thus, endotracheal suction was performed, there was no secretion, and the breathing sounds were slightly reduced while wheezing was not auscultated in both lungs. During this event, the arterial blood gas analysis (ABGA) showed pH 7.195, pCO_2 65.4 mmHg, pO_2 121.4 mmHg, and SaO_2 97.4%.

Lastly, when re-breathing of CO_2 through the HMEF deadspace was suspected, the HMEF, which was located close to the endotracheal tube was removed, and the patient was ventilated with V_T 67 mL and PIP 14 cmH_2O (Fig. 2). At 30 minutes after the HMEF removal, $ETCO_2$ decreased to 27 mmHg and the SpO_2 level was maintained with 98%. The ABGA implemented at that time showed pH 7.418, pCO_2 35 mmHg, pO_2 97.9 mmHg, and SpO_2 97.6%.

General anesthesia was maintained with inspired fraction of oxygen of 0.5, 3.0 vol% sevoflurane, V_T 60 mL, and respiratory rate of 30 breaths/min, and the mechanical ventilation was implemented, whereas the SpO_2 level was maintained at 97% to 100%. After 2 hours, pH 7.417, pCO_2 31.7 mmHg, pO_2 201.2 mmHg, and SpO_2 99.4% were verified on the ABGA.

The operation was completed without any specific incidents and the patient was extubated in the operating room after sufficient voluntary breathing was confirmed. The patient's voluntary breathing was well-maintained after extubation, and he was transferred to the pediatric intensive care unit for neurologic care after surgery. After 3 days, the patient was discharged without any other complications.

3. Discussion

During mechanical ventilation, fresh dry gas is inhaled continuously into the lower respiratory tract through an endotracheal tube directly to promote loss of moisture and heat, which leads to decrease in the body temperature and causes adverse effects on the airway homeostasis. To avoid such complications of mechanical ventilation for pediatric patients, HMEF was introduced with the circuit to provide artificial warming and humidification. Many studies have been performed by measuring the airway heating and humidification using HMEF or an active humidifier to determine the efficacy in respiratory tract of infants.[3–7] As a result, Bissonnette and Sessler[3] illustrated that passive humidifiers, namely HME and HMEF, increase the humidification of the airway and maintain the body temperature in infants for surgery taking >1 hour, compared to no additional treatment. Although HMEF has several advantages, it also has disadvantages, such as breathing circuit disconnection because of filter weight and obstruction because of fluid condensation in the filter, and therefore, care should be taken during use.

In general, there are no fixed guidelines for using HMEF; however, when using respiratory nebulizer drugs or artificial warming and humidifier, which supplies moisture continuously, the filter becomes wet and the accidental obstruction of the breathing circuit can occur, and therefore, it is preferable to avoid the filter. Recently, hydrophobic HMEF improves the frequent airway obstruction caused by moisture, depending on the filter pore size, membrane thickness, hydrophobicity, surface area, and structure. However, the hydrophobic nature cannot completely protect filter from the moisture, and thus, the transmissible function is reduced.[8]

Nevertheless, HMEF functions effectively in maintenance of airway temperature and humidity from 1 hour after mechanical ventilation, and the ideal location of the filter is between the endotracheal tube and Y-piece.[2] In this case, we used a pediatric heated wire circuit to maintain airway humidity and body temperature for a prolonged period of general anesthesia, >1 hour for craniotomy. Hydrophobic HMEF was placed between the endotracheal tube end and Y-piece. When the heated wire circuit is not used in pediatric anesthesia, we used HMEF in the expiratory limb to prevent contamination of the circuit and CO_2 absorption. Previously, the deadspace of the filter did not pose a

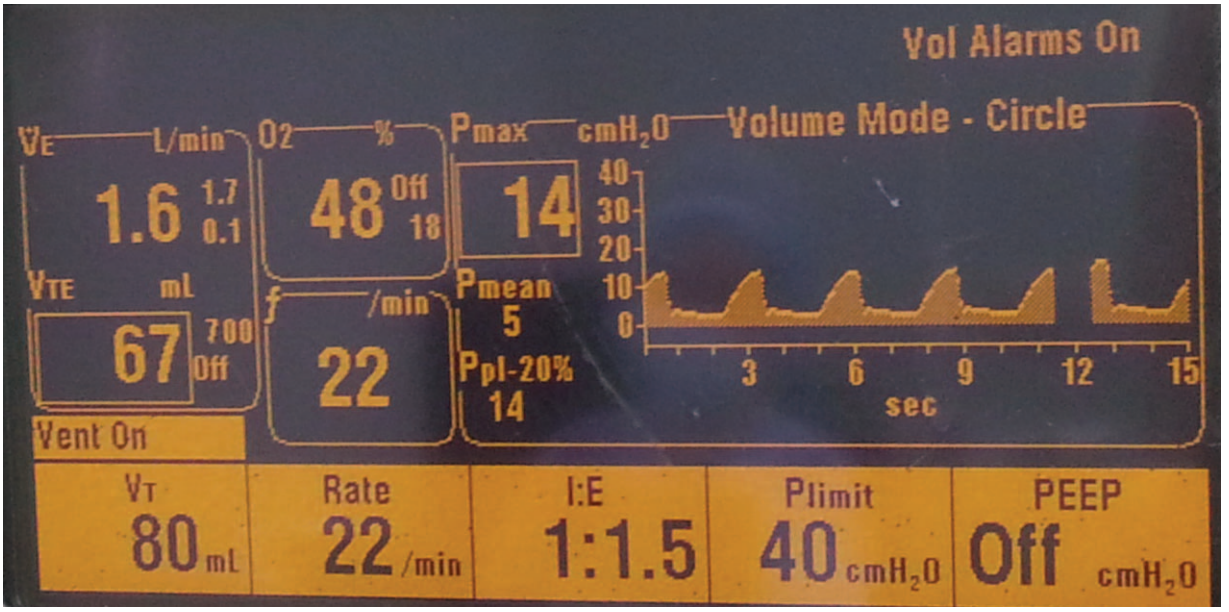

Figure 2. Ventilator monitoring after filter removal.

problem to infants younger than 2 years when we used a filter in the pediatric expiratory limb. We overlooked the internal volume of HMEF, which added 12 mL deadspace in the breathing circuit.

After induction, despite the normal lung sound of the patient, $ETCO_2$ was increased, and on examination owing to a possibility of obstruction of the breathing circuit, the filter was found to be dry and no obstruction was observed, even in manual ventilation mode. In addition, after mechanical ventilation, there were no abnormal findings, such as decrease in the V_T or increase in PIP. Until rotating the head for central venous access, there was no trend of obstruction by HMEF, and it appears that CO_2 re-breathing slowly progressed without significant reduction in T_V.

When increased partial pressure of CO_2 from the patient was found, as in the case of the former hygroscopic HMEF, many cases with respiratory failure of filter obstruction were encountered because of respiratory secretions. We only focused on the possibility of filter obstruction, even in the case of a hydrophobic filter. The filter was then removed because of suspected re-breathing of CO_2, the cause was identified, and the partial pressure of CO_2 was dramatically reduced.

As observed in this case, the use of pediatric HMEF can affect not only mechanical occlusion, which was mostly encountered as a complication but also re-breathing of CO_2 because of an increase in the deadspace especially in pediatric anesthesia. Re-breathing of expiratory gas was triggered within the internal volume of HMEF, immediately after induction, and the filter did not function properly compared to initial mechanical ventilation; therefore, the $ETCO_2$ increased sharply 5 minutes after induction.

Wilkinson et al[9] showed that the deadspace increased by 5 types of pediatric hygroscopic HMEF filter in pediatric anesthesia was an average of approximately 12 mL. Although the increase in the resistance was not statistically significant when HMEF was completely soaked with water, the important thing is the fact that the work of breathing increases because of resistance of filter in infants. Newborns or infants have less amount of expiratory reserve volume for alveolar ventilation compared to adults, and a high compliance for a thoracic cage. Therefore, their functional residual volume is decreased. In addition, as there are differences in the configuration of diaphragmatic and intercostal muscles, the infants experience fatigue and develop hypoxia easily.

Although the deadspace of HMEF is constant, the impact on infants is different depending on the tidal volume of the patient and the proportion of deadspace, which is already created in the breathing circuit. With regard to the use of HMEF, especially in low-weight infants weighing <10 kg, the effort of decreasing the deadspace to as small as possible is required because scanty increase of deadspace makes infants use more inspiratory work through an increase in V_T and respiratory rate to maintain a constant partial pressure of CO_2.[10]

In addition, the effect by filter location also cannot be ignored during the use of HMEF. Initially, we thought that there was no particular effect of deadspace on the HMEF, which is usually located between the expiratory limb and ventilator in pediatric anesthesia. However, the $ETCO_2$, which is measured by a flow sensor in the breathing circuit was found to be lower than the actual partial pressure of inspired CO_2 ($PiCO_2$), so that the re-breathing of CO_2 would be increased in the patient. The re-breathing volume of CO_2 would be different depending on the connected location of the filter. Because re-breathing CO_2 is diluted with fresh gas when a filter is located in the Y-piece. However, depending on the respiratory status and operation time, the $PiCO_2$ elevation can lead to increased intracranial pressure due to cerebral vasodilatation, and hypercapnia also causes pulmonary vasoconstriction and respiratory acidosis.

We have been using HMEF in infants, which was considered not particularly different from adults, and therefore, we did not recognize the hazard of the HMEF internal volume as apparatus deadspace. Generally, when using HMEF in mechanical ventilation the resistance of the airway increases by only 30% even in the case of adult patients, it was observed that total inspiratory work increases up to 60%.[11] Especially in anesthesia of infants younger than 2 years, when the deadspace increases because of the incomplete development of respiratory muscles and the apparatus attached to the breathing circuit, 1.42 L/min of flow should be additionally inhaled to maintain a constant $ETCO_2$.[5]

Furthermore, Costigan and Snowdon[12] reported the case of a patient where the capnography signal and tidal volume of ventilation monitor could not be detected when laryngeal mask airway with breathing circuit filter was inserted in the adult patient. This report documented that accuracy and implementation of anesthetic monitors are inevitably affected by the breathing circuit filter, even though adult patients have relatively low proportion of apparatus deadspace. In the case of a commonly used filter, it is expected that the lower fresh gas flow and tidal volume are used in patients, it will increase the impact of the apparatus deadspace. When HMEF is included in the respiratory circuit, increase in the total inspiratory work or deadspace re-breathing can occur, even if there is no change in the pressure gradient of filter itself. The filter used in this case has an average pediatric deadspace capacity with the patient, but it was found that the influence of deadspace re-breathing also varies depending on the location of the filter.

As the expiratory reserve volume for alveolar ventilation is low in pediatric anesthesia, if a quick decision is not taken and troubleshooting is not conducted in the respiratory system-related problem, this may lead to serious consequences, such as cardiac arrest or hypoxic brain damage. Through this case, we have learned that HMEF should be used carefully in pediatric anesthesia depending on the placement location and internal volume, no matter how small the deadspace of the HMEF is.

4. Conclusion

When using HMEF for the patients with decreased respiratory function or during ventilator weaning in addition to pediatric patients, the clinicians should keep in mind that HMEF causes complications, such as mechanical occlusion of breathing circuit by the filter and respiratory acidosis with hypercapnia by apparatus deadspace rebreathing. The increase in breathing apparatus deadspace should be minimized, and we must weigh the gains and losses before applying HMEF.

This case is not a clinical trial and just incidental interventional process so ethical approval was not necessary.

Author contributions

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Writing – review & editing: Jeong Eun Lee.

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