Identification and analysis of critical respiratory alarms during use of an advanced anesthesia workstation is essential in the intraoperative period. We present and discuss a scenario in which there was activation of a fresh gas flow alarm during low-flow anesthesia intraoperatively and use of oxygen flush to counteract it led to a diluted concentration of the inspired anesthetic agent.

Keywords: Dräger Primus ventilator, fresh gas decoupling, low-flow anesthesia, oxygen flush.

Case Summary
A 9-year-old child weighing 30 kg presented to the hospital with headache, vomiting, and frequent falls when walking. Posterior fossa medulloblastoma was diagnosed after a magnetic resonance image of the brain. The patient's baseline hemoglobin level was 12.3 g/dL, and other biochemical parameters were within normal limits. The child was scheduled for suboccipital craniotomy and decompression of the tumor under general anesthesia in the prone position. The child was premedicated with 1 mg of midazolam in the preanesthetic holding area before transferal to the operating room. Before the anesthesiologist proceeded with induction, the anesthesia machine was checked according to standard automated self-test guidelines provided in the machine manual. No faults were detected, and ventilator alarm limits were set.

Anesthesia was induced with 40 µg of fentanyl, 100 mg of thiopentone, and 10 mg of atracurium. The airway was secured with a 5.0-mm cuffed endotracheal tube (ET) fixed at 15 cm and confirmed by auscultation for bilateral equal air entry and capnography. The ET cuff was inflated to a pressure of 20 cm H2O. Anesthesia was maintained with oxygen and nitrous oxide in a 1:1 ratio and isoflurane with a fresh gas flow of 1 L/min. However, after 1 hour into the surgery, surgeons slightly extended the patient's neck for better surgical access, after which a cuff leak was noted with a set tidal volume ($V_T$) of 280 mL and delivered $V_T$ of 200 mL. At the same time, the ventilator screen (Dräger Primus, Dräger Medical) started giving an alarm for a low fresh gas flow. There was no change in the oxygen saturation, peak airway pressure, or end-tidal carbon dioxide (ETCO2). We reinflated the ET cuff to a pressure of 30 cm H2O, and the delivered $V_T$ increased to 265 mL, but the alarm persisted. We also noted that the reservoir bag was empty at this stage. Therefore, we pressed the oxygen flush valve to refill the reservoir bag based on our knowledge that the fresh gas decoupling valve in the Dräger ventilators will not allow this gas flow to enter the patient's inspiratory limb. The low fresh gas flow alarm stopped, but we noted that the fraction of inspired oxygen ($F_{iO2}$) increased to 69%, inspired isoflurane concentration decreased to 0.7 from 1.0, and the minimum alveolar concentration (MAC) fell to 0.7 (Figure, part A). This persisted for about 3 minutes. Meanwhile, we increased the fresh gas flow to 6 L/min to increase the inspired isoflurane concentration.

Discussion
The possible cause for the alarm that triggered in our case can be explained by the working principle of the Dräger Primus ventilator, which uses an electrically powered, piston-driven, electronically controlled device with fresh gas decoupling. This fresh gas decoupling device is used to prevent the fresh gas flow from affecting the $V_T$. This is achieved by isolating the fresh gas flow in such a way that it does not enter the inspiratory limb of the breathing circuit or the piston during inspiration. The main disadvantage with ventilators that use fresh gas decoupling is the possibility of entraining room air into the patient's breathing circuit. The ventilator pressure is monitored by a pressure transducer, the main function of which is to allow the software to sense threshold, which can lead to activation of a medium-
priority low fresh gas flow alarm. The importance of this alarm is to alert the operator of the existence of a condition that can lead to opening of the negative pressure relief valve and dilution of inspiratory gas.

In our case, there was no evidence of dilution of gases due to entrainment of room air because the inspiratory oxygen concentration and inhalational anesthetic agent concentrations were normal. However, activation of oxygen flush to fill the reservoir bag when even increasing the cuff pressure did not solve the problem led to an increased $F_{io2}$ and decreased isoflurane concentration. This is explained by the working principle of the Dräger ventilator, as shown in the schematic diagram (Figure, part B). In our case, we pressed the oxygen flush (100% $F_{io2}$) to refill the breathing bag. When the fresh gas decoupling valve is closed, the gas fills up the breathing bag, and remaining gas passes through the anesthesia gas scavenging system to the evacuation system. After pressing the oxygen flush when the mechanical ventilation or manual ventilation is continued, the gas concentration in the circle system (40% oxygen) mixes with the gas filled from the breathing bag (100% oxygen), leading to dilution of inspired anesthetic agent and nitrous oxide concentration and an increase in the oxygen concentration. Because we used low-flow anesthesia, this dilutional effect on the concentration of the inspired agent was probably more pronounced. This inspired oxygen concentration had a stepwise decrease to the former level before we pressed the oxygen flush, because more and more gas with 40% oxygen entered the circle system. Because a flow rate of 1 L/min was used, equilibration took about 10 minutes.

Also, it is important to note that activating the oxygen flush valve in ventilatory modes will never give rise to hyperinflation of the lungs, as the gases will always be diverted to the reservoir bag. The disadvantage is that changes made to the fresh gas flow are reflected late in the inspiratory gas composition because of mixing. This does not happen in anesthesia machines without a fresh gas decoupling valve, such as the GE Aisys (GE Healthcare), in which the fresh gas flow is directly added to the inspiratory limb of the breathing circuit.4,5

The cause for the cuff leak can be explained by the change in head and neck position, which caused a decrease in intracuff pressure and volume.6 In our case, although the leak was not large enough to interfere with oxygenation, it did activate the low fresh gas flow alarm at low flow. Also, the use of oxygen flush to solve the problem led to a decreased concentration of inspired isoflurane, putting the patient at risk of light plane of anes-
The attending anesthesia provider must be aware of this potential interaction in gas flows under low-flow anesthesia intraoperatively to prevent light plane of anesthesia.

REFERENCES


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DISCLOSURES

The authors have declared they have no financial relationships with any commercial interest related to the content of this activity. The authors did not discuss off-label use within the article.