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CLINICAL REPORT

Inadequate gas supply to patients with an adjustable pressure-limiting valve in the fully opened position

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Abstract With spontaneous ventilation, sufficient exhaust resistance at the adjustable pressure-limiting (APL) valve when fully opened ensures that the reservoir bag fills and adequately supplies gas to patients. A lack of exhaust resistance with the APL valve fully open caused inadequate gas supply to patients with four types of anesthesia machines: SA2 (Dräger), Excel-210 SE (GE), Fabius (Dräger), and Cato (Dräger). Mechanically, the SA2 and Excel-210 SE APL valve systems, which are of the spring-loaded disc type positioned horizontally, cannot maintain sufficient exhaust resistance with the APL valve fully open. As for the Fabius and Cato, an exhaust valve independent of the APL valve should maintain sufficient exhaust resistance continuously. However, accumulated viscous substances on the thin diaphragm of the exhaust valve contributed to hindrance of diaphragm closure.

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Introduction

When resistance at the inspiratory valve of the anesthesia breathing circuit is larger than resistance at the adjustable pressure-limiting (APL) valve to the exhaust, the fresh gas is exhausted through the APL valve, resulting in inadequate gas supply to the patient. Lack of exhaust resistance with the APL valve open causes negative airway pressure with a collapsed reservoir bag when using a tight-fitting face mask or tracheal intubation, and causes inadequate gas supply to the patient because of exhaust through the APL valve when using a loose-fitting face mask. To supply gas to the patient reliably during spontaneous ventilation, we should use a tight-fitting face mask with the APL valve open, otherwise the APL valve should be closed when using a loose-fitting face mask. In 1993, the International Organization for Standardization (ISO) mandated that a pressure drop across the APL valve with the APL valve fully open should be between 0.1 and 0.3 kPa (1.0 and 3.0 cm H_2O) at an air flow of 3 L/min and between 0.1 and 0.5 kPa (1.0 and 5.0 cm H_2O) at an air flow of 30 L/min [1]. This sufficient exhaust resistance with the APL valve fully open ensures that the reservoir bag fills. With sufficient exhaust resistance, and provided there is no unusually increased resistance of the inspiratory valve or heat moisture exchanging filter, there should be a proper supply of fresh gas to the patient. In recent years, many anesthesiologists have failed to suspect the possibility of inadequate gas supply with an APL valve fully open, and often use a loose-fitting face mask with an APL valve fully open.

Case reports

We report cases involving lack of exhaust resistance with the APL valve fully open, causing inadequate gas supply to patients, in four types of anesthesia machines.

Spring-loaded disc type APL valve positioned horizontally: SA2 (Dräger, Lübeck, Germany), Excel-210 SE (GE Healthcare/Datex-Ohmeda, Madison, WI)

The anesthesia machine SA2, which we used from 1994 until 2007, is a bellows-in-box type ventilator with suspended bellows arrangement. The Excel-210 SE, which we used from 1996 until 2007, is a bellows-in-box type ventilator with floating ascending bellows arrangement. During spontaneous ventilation, the gas is exhausted from the APL valve to the exhaust port. Both APL valves, which are of the spring-loaded disc type, are positioned horizontally.

The anesthesia machine was checked using standard guidelines [2] and no faults were detected. During spontaneous ventilation, 6 L/min of oxygen as fresh gas was supplied to the anesthesia circuit with a loose-fitting face mask with the APL valve in the fully opened position. However, the pulse oximeter reading (SpO_2) decreased to less than 90% despite adequate chest wall movement and breath sounds. The sampling gas from the Y-piece showed FIO_2 of 0.16 only, which was less than that of the room air, and the capnogram showed between 20 and 30 mmHg (Fig. 1). These phenomena indicated that oxygen was not adequately supplied to the patient and that expiratory gas at the face mask could not be washed out, and were found almost any time during the induction of anesthesia or after extubation. When the APL valve was in the closed position, FIO_2 increased to more than 0.95, CO_2 concentration decreased to baseline (zero) immediately (Fig. 2), and SpO_2 increased smoothly. When a tight-fitting face mask or tracheal tube was used with the APL valve in the fully open position under spontaneous ventilation, the reservoir bag was collapsed and the airway pressure indicated negative pressure. We had to adjust the APL valve resistance to keep the reservoir bag filled adequately. These phenomena were seen for several patients and were subsequently also confirmed by volunteers or one of the authors (GH).

In old-type anesthesia machines, for example the SA2 and Excel-210 SE, which were approved before ISO 1993, it is difficult to maintain sufficient exhaust resistance with the APL valve fully open because they were not designed to maintain it. Mechanically, the APL valve system of the SA2 and Excel-210 SE, which is of the spring-loaded disc type positioned horizontally, cannot maintain sufficient exhaust resistance with the APL valve fully open (Fig. 3).

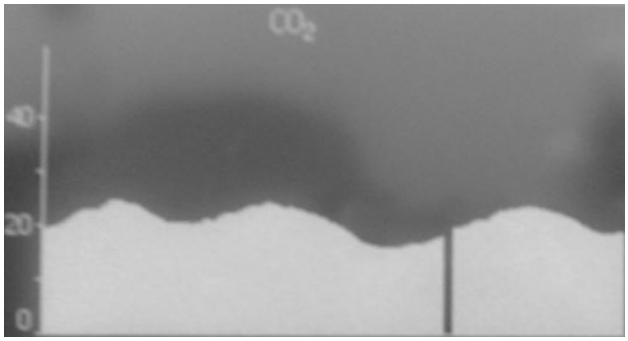

Fig. 1 An example of the capnogram indicating inadequate gas supply

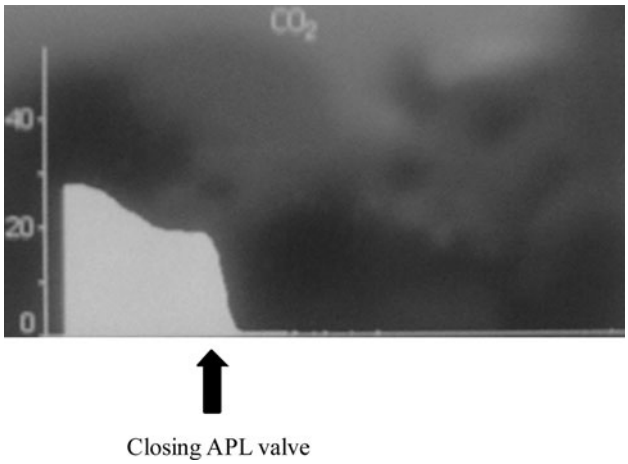

Fig. 2 An example of the capnogram indicating that closing the APL valve improves gas supply

Exhaust valve type: Fabius and Cato (Dräger, Lübeck, Germany)

The current anesthesia machines approved after ISO 1993 usually have a sufficient exhaust resistance maintenance mechanism independent of the APL valve condition. Various methods are used to maintain sufficient exhaust resistance—diaphragm, double spring, exhaust valve, and the APL disc using its own gravity. As for the Fabius and Cato, an exhaust valve is positioned between the APL valve and scavenging interface, and it continuously maintains sufficient exhaust resistance, independent of the APL valve condition.

We have used the Fabius since 2001 and the Cato since 1999. The anesthesia machine was checked using standard guidelines [2] and no faults were detected. During spontaneous ventilation, 6 L/min of oxygen as fresh gas was supplied to the anesthesia circuit with a loose-fitting face mask with the APL valve in the fully opened position. The Fabius and Cato also caused inadequate gas supply to patients with the APL valve fully open, but not constantly. We usually experienced inadequate gas supply after

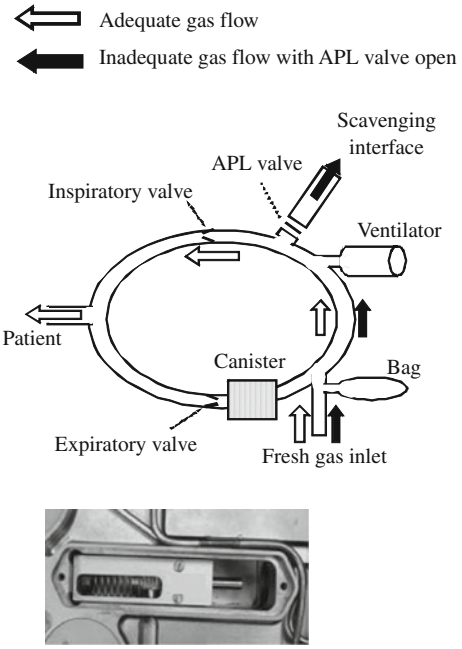

Fig. 3 Diagram of the direction of gas flow and spring-loaded disc type APL valve of the SA2 (Excel-210 SE is not shown). The spring-loaded disc was not closed completely with the APL valve opened

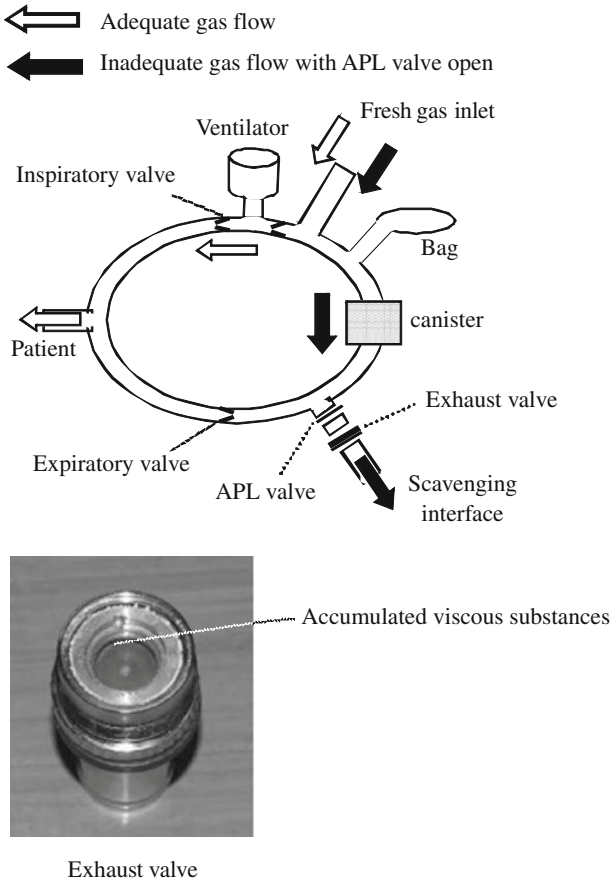

Fig. 4 Diagram of the direction of gas flow and exhaust valve of Fabius (the Cato is not shown). Exhaust valve was not closed completely with a buildup of viscous substance on the thin diaphragm

extubation, but not during induction of anesthesia. As soon as these phenomena were detected with patients, we conducted tests on volunteers and found these phenomena at high frequency just after opening the exhaust valve, flushing oxygen gas while occluding the patient end of the circuit. It seems to take a long time to close an exhaust valve after opening it. Unlike the SA2 and Excel-210 SE, we did not see collapse of the reservoir bag or negative airway pressure, even under spontaneous ventilation with a tight-fitting face mask or tracheal tube with the APL valve in the fully open position.

After experiencing problems, examination of the exhaust valves revealed a buildup of viscous substance on the thin diaphragm, which could not be closed completely (Fig. 4). For over 6 or 9 years, these exhaust valves were not changed. We speculate that this sticky grayish mass had accumulated over time, and that water condensation might have contributed to hindrance of diaphragm closure. Changing these exhaust valves enabled further use of the Fabius and Cato without further problems with the APL valve.

Discussion

Old-type anesthesia machines including the SA2 and Excel-210 SE, or inappropriately maintained current anesthesia machines including the Fabius and Cato may cause inadequate gas supply to patients because of lack of exhaust resistance with the APL valve fully open. Even when this happens, many anesthesiologists may fail to notice the inadequate gas supply. This may cause inadequate pre-oxygenation at induction of anesthesia or a hypoxic condition of unknown origin after extubation.

There are no requirements to ensure exhaust resistance with an APL valve fully open during manual ventilation in standard guidelines [2]. We make the following recommendations for testing the lack of exhaust resistance with an APL valve fully open. Close the patient end of the circuit and use 3 L/min of fresh gas flow with the APL valve fully open. After a while, check the reservoir bag expansion.

For anesthesiologists, it is important to know how to identify inadequate gas supply. We also make the following recommendations for identifying inadequate gas supply. Supply fresh gas with a loose-fitting face mask to the spontaneously ventilating patient. After a while, check the gas monitor. If the sampling gas from the Y-piece shows an FIO_2 lower than that of the room air, and a continuous high

range of CO_2 concentration, it indicates that oxygen is not supplied to the patient adequately and expiratory gas at the face mask cannot be washed out. Inadequate gas supply may be caused by disconnection of the breathing tube, lack of fresh gas supply, increased resistance to opening the inspiratory valve, excessive negative pressure of the scavenging interface, and lack of exhaust resistance with the APL valve fully open.

Further, we need to check the reservoir bag expansion, and movement synchronous to the patient's ventilation, when we attach a tight-fitting face mask to a spontaneously ventilating patient.

References

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