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Short communications

A case of accidental hypercapnia caused by a malpositioned expiratory valve disc, and experimental models for its prevention

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We encountered accidental hypercapnia in a patient resulting from rebreathing exhaled carbon dioxide caused by an expiratory valve disc stuck in the open position. This disc malposition seemed to have been caused by numerous bands of moisture in the expiratory valve assembly. We describe briefly this case of hypercapnia and discuss experimental models for its prevention.

The case involved a 62-year-old male patient scheduled for rectal resection. Blood gas analysis obtained 60 min later after tracheal intubation showed a marked hypercapnia: PCO_2 115.9 mmHg, pH 7.04. We noted the numerous bands of moisture in the expiratory dome cover and discovered that the expiratory disc vacillated between a transient open position and free movement, which suggested that the patient was rebreathing exhaled carbon dioxide. We exchanged the anesthetic gas machine for a dry breathing circuit as soon as possible. Based on this case, we designed experimental models to study what kind of situations might produce this type of valve malfunction and how the malfunction occurred. We then assessed the ability of three different types of discs and dome covers to prevent it.

In experiment 1, the following three unidirectional valve discs were tested: a phenol formaldehyde resin disc (0.4 mm thick, 0.31 g, 0.4 PF), an epoxide resin disc (0.4 mm thick, 0.45 g, 0.4 Ep), and a heavy epoxide resin disc (0.8 mm thick, 0.9 g, 0.8 Ep). A 0.4 PF disc was of the same type as that involved in this expiratory valve malfunction. An epoxide resin disc was less hydrophilic than a phenol formaldehyde disc. They were placed in the inspiratory and the expiratory valve assemblies. The following circuit conditions were set: dry-fresh oxygen flow (dry flow) at $6 \ell \cdot min^{-1}$ for 50 h, wet-fresh oxygen flow (wet flow) at $6 \ell \cdot min^{-1}$ for 50 h, and high air-flow (high flow) at approximately $100 \ell \cdot min^{-1}$. An anesthetic machine (Acoma PH-5F II, Acoma, Oumiya, Japan) and ventilator (Acoma ARF 900-II) were used. The dome cover in the valve assembly incorporated a 5.5-mm retaining pin arranged in the center of the round ceiling in combination with six 13.5-mm retaining cages arranged hexagonally in the corner of the round ceiling (Fig. 1a). Carbon dioxide gas was applied into the circuit from the tail of the test bag at $100 ml \cdot min^{-1}$. The carbon dioxide waveform was monitored (Acoma AD-1) and recorded. Wet flow was provided with the maximum nebulization (Acoma EN-II) to produce condensation in the valve assembly. The 2-ℓ silicon rubber bag in combination with the flowsensor (Metabo model 529, Metabo SA, Eppalinges, Switzerland) and flowmeter (Acoma model VFT III) was connected to the upstream side of the expiratory valve assembly (Fig. 1b). A target flow of $100 \ell \cdot min^{-1}$ was supplied instantaneously by manually compressing this bag, while checking the flow rate. In experiment 2, since the valve disc sloped to one side in the open position, we sought to determine whether a lesser slope of the disc in the open position could reduce the incidence of the disc malposition. Another two dome covers incorporating the following retaining pins were tested: a 6.5-mm retaining pin, and three 5.5-mm retaining pins arranged in a triangle. A 6.5-mm retaining pin was modified to lessen the maximum slope of the disc in the open position to less than that of a 5.5-mm retaining pin. Three 5.5-mm retaining pins were modified to open a disc horizontally. Two circuit conditions were set as dry and wet flows. In experiment 3, the draft resistance test for these discs was performed in accordance with the Japanese Industrial Standard (JIS) [1]. Both the peak

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and constant opening pressures were measured at the near side of the expiratory disc at a dry-oxygen flow of 60 ℓ·min^{-1}. This test was repeated five times per disc, and the maximum values of the peak and constant opening pressures were determined and recorded.

The results of the experiments are summarized in Table 1. In experiment 1, all discs moved freely during dry-gas flow. However, during wet and high flow, both the expiratory 0.4 PF and the 0.4 Ep discs became fixed in the open position, whereas in contrast, the expiratory 0.8 Ep disc moved freely. During wet flow, both the expiratory 0.4 PF and the 0.4 Ep discs showed a gradual restriction in their movements as the amount of moisture increased, and then ultimately adhered to the head of the 5.5-mm retaining pin, resulting in both discs becoming fixed in the open position. These disc malpositions were observed only in the expiratory, not in the inspiratory, valve assembly. The inspiratory gas flowed so slowly that the disc opened gently. However, in the expiratory assembly, the gas from the bulging test bag flowed with such great force that the disc rapidly and vigorously opened. During high flow, both the expiratory 0.4 PF and the 0.4 Ep discs consequently remained half open and slid laterally, and then the lower side wedged into a gap between the valve seat and the retaining cage of the dome cover, resulting in both discs becoming fixed in the open position. In experiment 2, with the dome cover incorporating a 6.5-mm retaining pin, all discs moved freely during dry-gas flow. However, during wet flow, both the 0.4 PF and the 0.4 Ep discs also became fixed in the open position during several respiratory cycles of mechanical ventilation, although the 0.8 Ep disc moved freely. In the dome cover incorporating three 5.5-mm retaining pins, all discs opened smoothly during dry flow; however, they were fixed in the open position during several respiratory cycles of mechanical ventilation during wet flow. In experiment 3 with the valve assembly set up with the 0.4 PF and the 0.4 Ep discs, the peak and constant opening pressures were 0.9 cmH_2O and 0.6 cmH_2O, respectively, both less than the standard value (which must not exceed 1.5 cmH_2O). In the valve assembly set up with the 0.8 Ep disc, the peak opening pressure slightly exceeded the standard value (increased to 1.52 cmH_2O); however, the value remained above standard for only a brief 0.02-s period, then decreased quickly to 0.7 cmH_2O.

We have rarely encountered a disc malposition in clinical situations. Therefore, we set up more rigorous circuit conditions, wet and high flow, to reconfirm a disc malposition in the present experimental models. We introduced an amount of moisture into the breathing circuit with the maximum nebulization to produce suf-

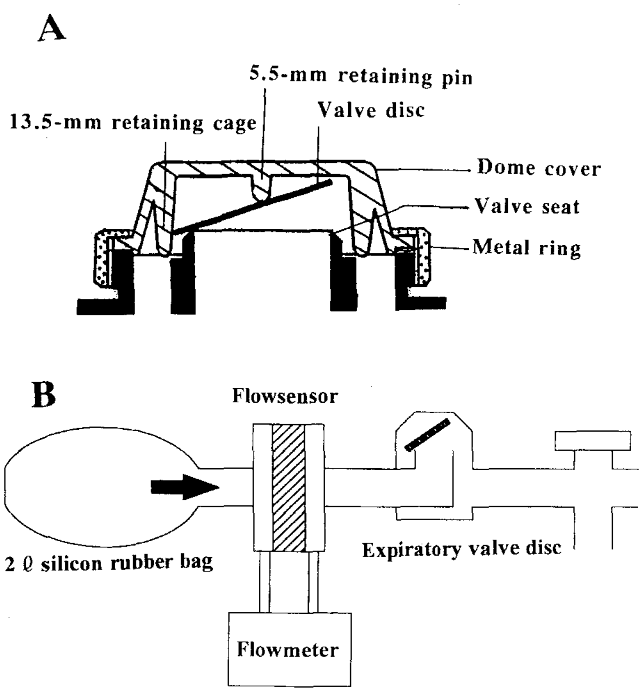

Fig. 1. **a** Schema of the longitudinal section of the dome cover showing the malpositioned valve disc. The disc adhered to the tip of the retaining pin because of excessive moisture during the wet flow condition, and also wedged into the gap between the valve seat and the retaining cage of the dome cover during the high flow condition. **b** Set-up for reproducing the malpositioned valve disc during high air flow of approximately 100 ℓ·min^{-1}

Table 1. Results of experiments 1 and 2

	5.5-mm retaining pin			6.5-mm retaining pin		3 5.5-mm retaining pins	
Disc construction	Dry	Wet	High	Dry	Wet	Dry	Wet
0.4-mm phenol formaldehyde resin	—	Fixed open	Fixed open	—	Fixed open	—	Fixed open
0.4-mm epoxide resin	—	Fixed open	Fixed open	—	Fixed open	—	Fixed open
0.8-mm epoxide resin	—	—	—	—	—	—	Fixed open

—, Disc moves freely.

ficient condensation in the valve assembly for the wet flow condition. Since expiratory flow values of $60\,\ell\cdot min^{-1}$ are instantaneously obtainable during artificial ventilation [2], and constitute an acceptable physiological condition for the draft resistance test [3], we introduced a faster expiratory flow value of approximately $100\,\ell\cdot min^{-1}$, resulting in the disc opening more rapidly and vigorously. Experiment 1 reproduced the actual valve disc malposition of both the expiratory 0.4 PF and the 0.4 Ep discs during wet and high flows. The heaviness of the 0.8 Ep disc itself brought about the closed position required to prevent disc malposition. Since a disc sloped to one side in the open position, we sought to determine whether a lesser slope of a disc in the open position could reduce the incidence of disc malposition. Experiment 2 demonstrated that all discs in the dome covers with a 6.5-mm retaining pin and three 5.5-mm retaining pins became more easily fixed in the open position during wet flow. This suggested that a large amount of moisture, rather than modification of the retaining pins, might strongly affect disc movement, resulting in disc malposition. In experiment 3, the 0.8 Ep disc showed that the peak opening pressure increased slightly above the standard value, but for only a short time. These results suggested that the 0.8 Ep disc might be practical for preventing disc malposition, especially in combination with dome covers with either a 5.5-mm or 6.5-mm retaining pin. In the present experiments, we only discussed focusing on the relationship between a disc and a retaining pin. However, several factors involved in a disc and a retaining pin affect the incidence of disc malposition: the shapes of a disc and the tip of a retaining pin, the surface area of the tip in contact with a disc, and their materials. The present result has no universality and does not apply to every anesthetic machine. However, we should pay special attention to the valve assembly as a hazardous part whose valve may become stuck in the closed or open position, leading to serious anesthetic complications [4]. A disc should be lightweight and offer little respiratory resistance, airtight without permitting reverse flow, and resistant to erosion by inhalational anesthetics and heat. The JIS, however, requires only the following evaluation regarding the valve assembly: a measurement of the opening pressure of a disc by the draft resistance test and the reverse-flow test in the unidirectional inspiratory and expiratory discs, and checking for disc dislocation from the valve seat. Several types of discs are currently used in clinical practice, but we have no precise information about their endurance. Depending upon the secular deterioration in the qualities of a disc and physical damages or deformities, the life of a disc should be considered to be a few years. All valve assemblies need to be routinely checked and carefully cleaned, and used discs should be periodically replaced with new ones.

In conclusion, experimental models revealed that the disc could have adhered to the retaining pin as a result of excess moisture during the wet flow condition, and also could have become wedged in the gap between the valve seat and the retaining cage of the dome cover during the high flow condition. The combination of a 0.8 Ep disc and a dome cover with a 5.5-mm or 6.5-mm retaining pin seems to be preferable for preventing this valve disc malposition.

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