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Carbon dioxide retention associated with a humidifier defect

A case is presented which describes a patient who developed hypercarbia resulting from a defective humidifier. A Puritan-Bennett Cascade I humidifier was incorporated into a circle system between the inspiratory dome one way valve and the patient. A screw which supports the thermal well to the head of the humidifier was missing, thereby allowing an interminant leak to develop in the system. The leak was present when the system pressure dropped to ambient level; however, at positive system pressure the leak sealed. This allowed exhaled gases into the inspiratory limb of the circuit unchecked by the inspiratory valve yet when the breathing circuit was occluded at the patient end and submitted to pressures of 20 and 40 cm H₂O, no leaks were detected. Intraoperatively, PaCO₂ was noted to be as high as 68 mmHg just prior to removing the humidifier from the circuit and corrected to 38 mmHg within 15 minutes of removal of the humidifier.

The adverse effects of inhaling dry anaesthetic gases have been described.^{1,2} The potential benefit of reducing postoperative pulmonary complications with humidification of inspired gases has been reported.³ A variety of humidification systems are available and despite their advantages, they have been associated with various hazards including risk of infection, increased airway resistance, increased dead space, over-hydration, and a source for leaks or disconnections. Rebreathing may occur in various breathing circuits⁴ and has been reported following a humidifier leak in the fresh gas flow of a Mapleson D modification of the Ayres T-piece.⁵ The following is a case report of a humidifier leak in a circle system that resulted in hypercarbia via an unusual mechanism.

Key words

EQUIPMENT: humidifier; COMPLICATIONS: hypercarbia.

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Case report

A 53-year-old, 65 kg male was scheduled for an exploratory laparotomy for severe necrotizing enterocolitis with multiple enteric fistulae. The patient had a history of pancreatic cancer diagnosed four months prior to admission. Preoperative serum electrolytes, haemoglobin, haematocrit and arterial blood gases were all within normal limits. The patient was brought to the operating room following pre-medication with meperidine 75 mg and atropine 0.4 mg IM.

Prior to the induction of anaesthesia the circle system had been pressure tested by occluding the patient end of the circuit and submitting the circuit to 20 and 40 cm H₂O pressure with no additional fresh gas flow and observing no loss of pressure from the system.

Induction and intubation proceeded without difficulty. Anaesthesia was maintained with 40 per cent O₂/N₂O, isoflurane, fentanyl, and pancuronium. An Ohio 30/70 anaesthesia machine was used incorporating a Puritan-Bennett Cascade I humidifier, between the inspiratory dome valve and the patient, within the inspiratory limb of the circuit. The ventilator used was an Air-Shield Model #VC20-1, with an upright bellows which ascended during exhalation.

During the second hour of the procedure the blood pressure and heart rate progressively increased from 115/80 to 160/90 and 103 to 148 respectively. The depth of anaesthesia was increased using additional narcotic and increasing the inspired concentration of isoflurane. Urine output, CVP and the patient's temperature were all normal. The peak airway pressure remained constant at 28 cm H₂O, chest expansion appeared unchanged, and there were no auscultatory changes or abnormalities. An arterial blood gas revealed respiratory acidosis: pH = 7.20, PaO₂ = 103 mmHg, PaCO₂ = 64 mmHg. The minute ventilation was increased from VT = 650 ml, f = 10 to VT 700 ml, f = 14 and 5 cm H₂O PEEP was added. The system was re-checked for leaks. Breath sounds were normal by auscultation and equal bilaterally. There was no apparent obstruction to expiration and a suction catheter passed easily through the endotracheal tube. The CO₂ absorbent was fresh with no gross evidence of channeling and the inspiratory and expiratory valves were operating normally. The patient had no history of

hyperthyroidism or sepsis, was not receiving hyperalimentation and had not received bicarbonate. Although the patient's temperature was not elevated, malignant hyperthermia was considered but not diagnosed due to the paucity of other signs and symptoms. A second arterial blood gas was obtained 15 minutes after the ventilation changes: pH = 7.18, PaO₂ = 250 mmHg, PaCO₂ = 68 mmHg. The breathing circuit and humidifier were replaced with a new circuit on the suspicion of a possible problem with the connections of the humidifier to the circle system. Ten minutes following the replacement of the circuit arterial blood gases returned to normal with pH 7.36, PaO₂ = 253 mmHg, PCO₂ = 38 mmHg.

After the surgery was completed, the circuit was carefully examined and the only defect discovered was a missing screw that normally secures the thermal well to the top of the humidifier (Figure). When the defective humidifier was incorporated into the circle system, the loose heating assembly resulted in an intermittent leak in the system. However, because of the construction of the humidifier and the relation of the heating assembly to the lid of the humidifier, the leak would become sealed during positive pressure, somewhat like a flap valve mechanism. During expiration, when the system pressure returned to ambient, the heating assembly would drop, allowing gas to escape around the thermal well and out of the top of the humidifier. This permitted exhaled gases to enter the inspiratory limb of the circuit. The aberrant function of the humidifier could be directly observed using a five litre breathing bag attached to the patient end of the circuit. The amount of gas lost from the system during ventilation was measured by setting $\dot{V}_T = 700$ ml, $f = 14$ and noting that a fresh gas flow of $2.0 \text{ L} \cdot \text{min}^{-1}$ was required to fill the upright bellows during exhalation. Measurement of inspiratory tidal volume using a Wright's respirometer showed no discrepancy between the delivered volume and the volume indicated on the bellows. Pressure checks performed at 5, 10 and 15 cm H₂O revealed significant leaks at 5 and 10 cm H₂O, a very small leak at 15 cm H₂O, and no leak >15 cm H₂O pressure.

Discussion

In the case presented, the leak was not initially detected due to a failure to notice the humidifier defect during routine equipment maintenance. The problem might also have been detected if the exhaled gases had been directly measured using a respirometer attached to the expiratory limb of the circuit or if a system pressure check had been performed at 10 cm H₂O pressure. Capnography or inspiratory/expiratory carbon dioxide tension measurement would have been helpful in more quickly defining the problem. Also, if the fresh gas flow had been temporarily discontinued, the progressive loss of gas from

FIGURE Puritan-Bennett Cascade I Humidifier with screw missing on thermal well.

the breathing circuit would have resulted in incomplete filling of the ventilator bellows. In the present case, the fresh gas flow ($5 \text{ L} \cdot \text{min}^{-1}$) was sufficient to compensate for gas that may have been lost from the system.

Five other Bennett Cascade humidifiers were tested using a 5 L breathing bag attached to the patient-end of a circle system in a similar setting to determine whether this might be a recurring problem. With the same screw removed from each of the humidifiers only one partially reproduced the flap valve mechanism. From this evaluation, it was determined that worn, non-compliant rubber seals on the original humidifier were partly responsible for its malfunction. This would also suggest that because of the combination of factors required to reproduce this situation, it is less likely to be encountered in the clinical setting.

Notification of the manufacturer concerning this case resulted in recommendations for careful equipment maintenance and consideration for a lower system pressure check when using this humidifier in an anaesthetic breathing circuit. The measurement of exhaled gases by continuous spirometry would enhance the safety of any anaesthetic circuit. Use of this particular humidifier in our operating room is not common; however, they are widely used with mechanical ventilators such as the Puritan-Bennett MA-1 volume cycle ventilator. The manufacturer also reported that the possibility of a similar defect occurring in this mechanical ventilator would be small but if it did occur, detection could be easily accomplished by noting a discrepancy between the set volume and the volume measured on the expiratory bellows.

Conclusion

This case report re-emphasizes the importance of careful maintenance of all equipment.⁶ It is also meant to point out how specific defects in the Bennett Cascade humidifier may result in significant rebreathing. Although this would seem to be an uncommon problem, it can be difficult to detect in the operating room without the use of capnography, measurements of inspired PCO₂ levels, or expiratory spirometry. In the intensive care setting, this problem might be more easily detected in that there would be a discrepancy between the volume set on the ventilator and the volume which returns to the bellows.

References

- 1 Chalton J, Loew D, Malebranche J. Effects of dry anesthetic gases on tracheobronchial ciliated epithelium. *Anesthesiology* 1972; 37: 338–43.
- 2 Boys JE, Howells TH. Humidification in anaesthesia. *Br J Anaesth* 1972; 44: 879–86.
- 3 Chalton J, Patel C, Ali M et al. Humidity and the anesthetized patient. *Anesthesiology* 1979; 50: 195–8.
- 4 Waters DJ, Mapleson WW. Rebreathing during controlled respiration with various semi-closed anaesthetic systems. *Br J Anaesth* 1961; 33: 374–81.
- 5 Nimocks JA, Modell JH, Perry PA. Carbon dioxide retention using a humidified non-rebreathing system. *Anesth Analg* 1975; 54: 271–3.
- 6 Cooper JB, Newbower R, Long CD, McPeck B. Preventable anesthesia mishaps – a study of human factors. *Anesthesiology* 1978; 49: 399–406.

Résumé

On présente un cas qui décrit un patient chez lequel s'est formé une hyperémie résultant d'un humidificateur défectueux. On avait incorporé un humidificateur Puritan-Bennett Cascade I dans un circuit en cercle entre la valve inspiratoire unidirectionnelle et le patient. L'absence d'une vis supportant le puits thermique du sommet de l'humidificateur permettait la formation d'une fuite intermittente dans le circuit. La fuite était présente quand la pression du circuit s'affaissait au niveau ambiant et elle était obturée quand la pression du circuit était positive. De cette façon, les gaz expirés pouvaient entrer dans la partie inspiratoire du circuit qui n'était pas mis en échec par la valve inspiratoire néanmoins lorsque le circuit était obstrué du côté du patient et soumis à des pressions de 20 à 40 cm de H₂O. On ne pouvait déceler aucune fuite. En période intraopératoire, on a observé que la PaCO₂ s'élevait jusqu'à 68 mmHg juste avant de retirer l'humidificateur du circuit et revenait à 38 mmHg dans les 15 minutes après avoir enlevé l'humidificateur.