In cooperation with

Anesthesia Case of the Month

History

A 5-month-old sexually intact female Yorkshire Terrier mix weighing 4.4 kg (9.68 lb) was evaluated at Ross University Teaching Hospital for elective ovariohysterectomy. Physical examination revealed no remarkable findings, and results of a CBC and serum biochemical panel were within reference limits. No important history was elicited, and the patient was approved for surgery.

Prior to anesthesia, the dog had a heart rate of 110 beats/min, a respiratory rate of 60 breaths/min, a rectal temperature of 38.8°C (101.9°F), and pink mucous membranes with a capillary refill time of < 2 seconds. The dog was premedicated with acepromazine (0.025 mg/kg [0.011 mg/lb], IM) and hydromorphone (0.1 mg/kg [0.045 mg/lb], IM), and a 22-gauge catheter was aseptically placed in the left cephalic vein. Anesthesia was induced with propofol given to effect (3.7 mg/kg [1.7 mg/lb], IV), after which a 5.5-mm endotracheal tube was inserted. The cuff on the endotracheal tube was inflated, and the patient was connected to a Mapleson D nonrebreathing system with a Bain modification and was positioned in dorsal recumbency. The flow meter was turned on to a fresh gas flow rate of 1 L/min, and the system was checked for leaks by closing the adjustable pressure-limiting valve and delivering a breath. No leak was heard at a peak inspiratory airway pressure of 20 cm H_2O, and the isoflurane vaporizer was set to deliver a concentration of 2%. The patient was instrumented with monitoring equipment,[a,b] including a side-stream capnograph, ECG, esophageal temperature probe, and Doppler ultrasonographic probe placed over the palmar metatarsal artery with an appropriately sized cuff. The dog was allowed to breathe spontaneously and received lactated Ringer's solution at a rate of 10 mL/kg/h (4.5 mL/lb/h).

After the capnograph was connected, it was noted that the P_{CO_2} at the end of inspiration was 20 mm Hg and visual inspection of the capnogram revealed that the tracing did not return to baseline during inspiration (**Figure 1**). The P_{ETCO_2} was approximately 46 mm Hg. Concurrent measurements from the other monitors revealed a heart rate of 77 beats/min, respiratory rate of 18 breaths/min, and systolic arterial blood pressure of 70 mm Hg.

This report was submitted by Jennifer E. Carter, DVM, DACVA; Jason L. Nordaune, BA; Eric C. Pienschke, BS; and Soyna Tingle, BS; from the Department of Clinical Sciences (Carter, Tingle), School of Veterinary Medicine (Nordaune, Pienschke), Ross University, St Kitts, West Indies.

Mr. Nordaune and Mr. Pienschke were third-year veterinary students at the time of manuscript submission.

Address correspondence to Dr. Carter (JCarter@rossvet.edu.kn).

Abbreviation

P_{ETCO_2}	End-tidal partial pressure of carbon dioxide

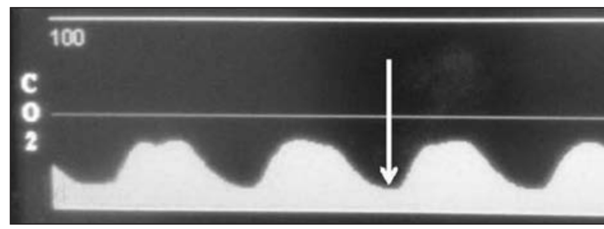

Figure 1—Capnogram (P_{CO_2} in the anesthetic circuit) obtained from a 5-month-old 4.4-kg (9.68-lb) sexually intact female Yorkshire Terrier mix undergoing elective ovariohysterectomy. Notice that P_{CO_2} does not return to baseline (zero) at the end of inspiration (arrow).

Question

What was the most likely cause of the high end-inspiratory P_{CO_2} and the change in the shape of the capnogram? How did this occur?

Answer

The most likely cause of the high end-inspiratory P_{CO_2} and the change in shape of the capnogram was rebreathing of CO_2. This can occur with a Mapleson D nonrebreathing system with the Bain modification as a result of inappropriately low fresh gas flow rates or incompetency of the inspiratory tube.

Treatment and Outcome

After the rebreathing was noted, the fresh gas flow rate was increased to 3 L/min, which effectively eliminated rebreathing of CO_2, reduced the end-inspiratory P_{CO_2} to 0 mm Hg, and normalized the capnogram so that the tracing returned to baseline with each inspiration. Given that the patient was stable and the surgical procedure had already begun, it was decided not to replace the anesthetic breathing circuit. With the fresh gas flow at 3 L/min, the remainder of the anesthetic period proceeded without complication.

At the end of the surgical procedure but before the dog was allowed to wake up, the fresh gas flow rate was decreased to 1 L/min. Immediately, the end-inspiratory P_{CO_2} again increased to 20 mm Hg and the capnogram demonstrated rebreathing. At that time, the breathing circuit was exchanged for a new Mapleson D nonrebreathing system with a Bain modification. Immediately, the capnogram normalized and the end-inspiratory P_{CO_2} returned to 0 mm Hg. The dog recovered without complications and was discharged the following day. Visual inspection of the breathing circuit revealed a tear

Figure 2—Photograph of the machine end of the Mapleson D breathing system with Bain coaxial adaptation used during anesthesia of the dog in Figure 1. Visual inspection revealed a tear in the inspiratory tube.

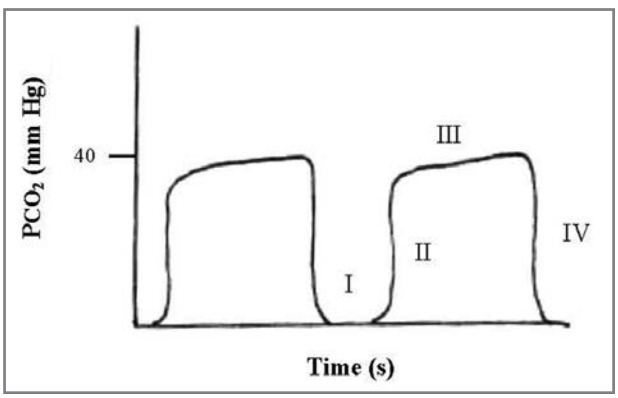

Figure 3—Schematic of the typical capnogram in an anesthetized dog with the 4 phases of respiration illustrated. Phase I represents the end of inhalation and the pause before exhalation. Phase II represents the beginning of exhalation of a mixture of dead space and later alveolar gases. Phase III represents the exhalation of alveolar gases at the very end of the exhalation period and is when the P_{ETCO_2} reading is established. Phase IV represents the beginning of inhalation.

of approximately 50% of the diameter of the inspiratory tube at the end of the tube nearest to the anesthesia machine (**Figure 2**).

Discussion

Failure to properly monitor anesthesia has been implicated as a risk factor for anesthetic morbidity and death in several veterinary studies.[1–4] Good monitoring can help to identify changes in the patient's plane of anesthesia or cardiopulmonary stability prior to the development of an emergency. The present case report illustrates the usefulness of capnography in monitoring general anesthesia in canine patients. Capnography can be useful in monitoring changes in metabolism, circulation, and respiration and can be used to detect problems in the patient breathing circuit. The height, frequency, baseline, rhythm, and shape of the waveform displayed on the capnograph can be evaluated, and P_{ETCO_2} can be measured.[5] Continued and uncorrected elevations in P_{ETCO_2} and end-inspiratory P_{CO_2} can cause several complications. High P_{CO_2} may lead to deepening anesthetic depth and acid-base disturbances. Hypercapnia directly inhibits cardiac and vascular muscle contractility, which may lead to cardiovascular collapse and respiratory dysfunction. Although no comparable studies exist in the veterinary literature, the human literature has several studies[6–10] demonstrating the benefits of capnography in anesthetized patients.

Typically, the P_{ETCO_2} is approximately 35 to 45 mm Hg, and with an end-inspiratory P_{CO_2} of 20 mm Hg, one would reasonably expect P_{ETCO_2} to be between 55 and 75 mm Hg. However, side-stream capnography presents 2 major challenges in small patients such as this dog. First, side-stream capnography relies on actively withdrawing a sample of air from the breathing system for analysis. The machine does this via a suctioning mechanism. With a high fresh gas flow entering immediately adjacent to the capnograph adapter, this often results in dilution of the sample with fresh gas. Consequently, the displayed P_{CO_2} may be lower than the actual P_{CO_2}. This was the likely reason why, despite an end-inspiratory P_{CO_2} of 20 mm Hg, the P_{ETCO_2} was only 46 mm Hg. Arterial blood gas monitoring would have been helpful in confirming this suspicion. Second, if the flow rate of the capnograph is greater than the patient's minute volume, the machine could actually pull air from the patient's airway. However, the flow rate of this capnograph was 150 mL/min, and the patient's minute volume was estimated to be between 720 and 1,080 mL/min. Thus, it is unlikely that this complication was occurring. In addition to these challenges associated with side-stream capnography, placement of a capnograph adapter in the patient airway contributes to the mechanical dead space of the system, which can also contribute to rebreathing and may have accounted for a portion of the rebreathing seen in this case.

A normal capnogram demonstrates 4 phases (**Figure 3**). Phases I and IV are of particular interest in this case because the dramatic decrease in P_{CO_2} during phase IV represents the beginning of inhalation, when the P_{CO_2} should return to zero, and phase I represents the remainder of inhalation and the pause between the end of inhalation and the beginning of exhalation. The P_{CO_2} during phase I should be 0 mm Hg.

In the present case, high P_{ETCO_2} and end-inspiratory P_{CO_2} were seen. High P_{ETCO_2} and end-inspiratory P_{CO_2} can be seen with increases in apparatus dead space, inadequate fresh gas flow rate with a Mapleson breathing system, inappropriate assembly of a Mapleson breathing system, and incompetency of the inner tube of the Bain coaxial modification of a Mapleson D breathing system. With a circle rebreathing system, high P_{ETCO_2} and end-inspiratory P_{CO_2} can also be a result of exhaustion or bypass of the CO_2 absorbent or dysfunction of the 1-way valve system.[5]

Mapleson D breathing systems with a Bain modification are considered nonrebreathing systems, meaning that all of the exhaled gases are directed to a scavenging system rather than routed through a CO_2 absorbent and mixed with the inspiratory gases. The Bain modification consists of a coaxial breathing system and is often mounted on a metal block that is attached to the anesthesia machine. The inner tube of the coaxial system is the inspiratory limb, and the outer tube is the expiratory limb. Nonrebreathing systems are reliant on a high fresh gas flow rate to prevent rebreathing of CO_2 during inspiration. During expiration, the high fresh gas flow rate functions to push the exhaled gases down the corrugated tubing to either the reservoir bag or the scavenging system.

Recommendations for fresh gas flow rate with this anesthetic circuit vary from source to source and species to species. Recommendations for humans anesthetized with the Bain coaxial system range from 100 to 300 mL/kg/min (45 to 136 mL/lb/min),[11] and flow rates of 100 to 150 mL/kg/min (45 to 68 mL/lb/min) have been suggested for veterinary patients.[12,13] Considering that our patient weighed only 4.4 kg, our planned fresh gas flow rate of 1 L/min should have been more than sufficient to prevent rebreathing of CO_2, so we were confidently able to rule out inadequate flow rate as the cause of rebreathing in this case. In addition, the assembly of the breathing system was checked and found to be correct, also making it possible to rule out incorrect assembly as the cause of rebreathing.

Therefore, we suspected that the inner tube of the coaxial breathing system was incompetent. A hole in the inner tube of the system would cause the entire limb to become dead space owing to mixing of inspired and expired gases.[11] At the original flow rate of 1 L/min, exhaled gases from the outer tube were entrained through the defect in the inner tube because of the vacuum created by air flow in the inner tube as a result of the Venturi effect. By increasing the fresh gas flow rate to 3 L/min, we were able to overcome this effect and, instead of gas flowing from the expiratory tube into the inspiratory tube, some of the gas from the inspiratory tube flowed through the defect into the expiratory tube.

A special technique has been reported for assessing the competency of the Mapleson D breathing system with a Bain modification. The need for the special technique lies in the fact that the breathing tubes are in a coaxial formation. If one were to close the adjustable pressure-limiting valve, occlude the patient end of the system, and pressurize the system as one does with a traditional preanesthetic leak check, it would not be possible to ascertain whether the inner tube of the system was intact. Instead, the described technique involves occluding the patient end of the inspiratory inner tube only, setting the oxygen flow meter to a low setting, and observing the indicator on the flow meter falling.[14–16] Because there are no unidirectional valves in Mapleson systems, the flow meter indicator will fall owing to back pressure created when the inspiratory tube is occluded. After questioning, it was determined that the breathing system preanesthetic check in this case did not include the special technique necessary for the Bain coaxial system and therefore failed to demonstrate the incompetent inner tube. In addition, because the leak was in the inner tube, it would not have been discovered during the patient leak test provided that the outer tube was competent and the endotracheal cuff was properly inflated.

Ideally, a proper preanesthetic system leak check should be performed before every anesthetic event. However, improper leak checks can miss problems in the system, causing consequences for patients, such as rebreathing of CO_2 and potentially high P_{CO_2} in the blood. Use of diligent anesthetic monitoring with capnography allowed us to quickly identify and correct the problem with the system. In retrospect, the breathing system should have been exchanged at the time when the problem was identified to provide the best patient care.

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a. Advisor Vital Signs Monitor, Smiths Medical, Dublin, Ohio.
b. Parks Doppler, model 811-B, Parks Medical Electronics Inc, Aloha, Ore.

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