History

A 10-year-old 45-kg (99-lb) castrated male English Pointer with body condition score of 5 of 6 was evaluated for removal of a subcutaneous mass in the left thoracic wall diagnosed as a mast cell tumor on the basis of results of examination of fine-needle aspirates. Additionally, the dog had an 8-week history of reverse sneezing, coughing, and purulent nasal discharge with episodes of dyspnea and cyanosis. On physical examination, the patient was bright, alert, and responsive but appeared stressed and was panting heavily; therefore, thoracic auscultation and body temperature measurement were not performed. Heart rate was 120 beats/min; mucous membranes were pink and moist. The dog was premedicated with acepromazine maleate (0.015 mg/kg [0.0068 mg/lb]) and methadone hydrochloride (0.2 mg/kg [0.09 mg/lb]) IM. Additionally, diphenhydramine hydrochloride (2 mg/kg [0.9 mg/lb]) was administrated IM. Following IV catheterization and preoxygenation via face mask, general anesthesia was induced with propofol administered IV to effect (total dose, 120 mg) and the trachea was intubated with an 11-mm-inner diameter endotracheal tube (ETT). Following cuff inflation, the ETT was connected to the anesthetic machine and patient monitoring system and administration of isoflurane in oxygen was initiated. An IV constant rate infusion of fentanyl hydrochloride at 0.015 mg/kg/h commenced immediately. Five minutes after anesthetic induction, the dog received intermittent positive-pressure ventilation, first manually and then via the mechanical ventilator. After 15 minutes, the dog was transferred to the operating room and the ETT was connected to a second anesthetic machine. Patient monitoring consisted of ECG, noninvasive arterial blood pressure (oscillometric) measurement, pulse oximetry, respiratory gas composition analysis including isoflurane concentration, and spirometry. Intermittent positive-pressure ventilation was performed in volume-controlled, pressure-limited mode with the tidal volume set to 400 mL, respiratory rate to 10 breaths/min, and maximal peak inspiratory pressure to 15 cm H2O. Subsequently, the ventilator displayed an alarm message indicating the presence of a leak and inability to administer the selected tidal volume. Although no audible indication of a leak at the level of the ETT was present, insufficient inflation of the ETT cuff could not be excluded. Therefore, the ETT cuff was additionally inflated but the ventilator alarm persisted. Problems with the ETT itself were then considered, and the decision was made to change the ETT. After intubation with a 12-mm ETT and appropriate inflation of its cuff, the ventilator alarms still continued. The first ETT and its cuff were examined and found to be intact. At this time, it was noticed that the capnograph displayed atypical capnographic waveforms characterized by a low expiratory plateau with an upsurge of CO2 at the end of the plateau (tails-up; Figure 1) with an end-tidal $PaCO_2$ of 37 mm Hg. A short period of manual ventilation did not influence the capnographic waveforms. An abnormally high difference (> 20%) between inspiratory and expiratory oxygen concentrations was also noticed. Although the capnogram characteristics were not typical for bronchoconstriction, bronchospasm associated with histamine release because of external manipulation of the mastocytoma during presurgical preparation could not be excluded. Bronchodilator treatment with terbutaline (0.01 mg/kg [0.0045 mg/lb], SC) was initiated. This caused the patient’s heart rate to increase from 67 to 130 beats/min after 15 minutes, but the abnormal capnographic waveform persisted.

Questions

What could be the etiology of the abnormal capnographic waveform? Why was the inspiratory-to-expiratory O2 concentration difference abnormally high? What type of intervention is indicated to manage this patient?

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The presence of a leak in the anesthetic circuit was suspected because of the alarm message indicating the presence of a leak, the inability of the ventilator to administer the selected tidal volume, detection of an abnormal capnographic waveform, and the high inspiratory-to-expiratory $O_2$ concentration difference. The following actions were taken but were unsuccessful in changing the capnographic waveform: verification of the security and patency of all connections in the anesthetic machine and breathing circuit, replacement of the endotracheal tube (a leaking cuff could not be excluded), and replacement of the capnographic sampling line with a new line.

Finally, it was noticed that the water trap of the capnography sampling line was slightly dislodged at the connection to the capnograph. The position of the water trap was corrected, and this resulted in the capnogram resuming its normal shape. The normal shape is characterized by the classic appearance featuring the inspiratory upstroke, alveolar plateau, inspiratory downstroke, and baseline (Figure 1). The inspiratory-to-expiratory $O_2$ concentration difference returned to $\pm 6\%$ (in the presence of an end-tidal $PCO_2$ of approx 50 mm Hg, which represents approx 6 vol%). The anesthesia and surgery continued without any further complications for the following 100 minutes, and the dog recovered from anesthesia without incident 13 minutes after anesthesia administration was discontinued.

**Discussion**

In the patient described in the present report, an abnormal capnographic waveform caused by a dislodged water trap of a capnography sampling line was misinterpreted and led to initiation of unnecessary interventions (ETT exchange and manual ventilation) and administration of an unnecessary treatment (bronchodilator treatment). Similar cases of a leaking or broken water trap resulting in misinterpretation of the capnogram have been reported in the human literature.5,2 To our knowledge, such an error has not been reported in veterinary medicine. Although in some cases, medical errors may not cause serious harm, they may be associated with increased morbidity and mortality rates.6,9 An error of commission in the case described in the present report could potentially have had a negative effect on the patient but fortunately did not.

A capnogram similar to the atypical tails-up capnogram (Figure 1) results whenever there is a leak between the sampling tube and the gas analyzer.3,5,10 Side-stream anesthetic gas monitors continuously aspirate a sample of respiratory gases via the sampling tube. Any loose connections between the ETT and the gas monitor will lead to aspiration of atmospheric air, diluting the sampled respiratory gas and resulting in the so-called tails-up capnogram2 (also called steeple of the church capnograph or roof of the church capnogram).10 When the atypical capnographic waveforms were noticed, knowledge of the fact that gas monitoring lines can be a cause of a serious leak11 prompted close inspection of the line but no obvious damage could be seen. However, visual inspection does not detect very small defects and therefore tests such as submerging the sampling line in water have been advocated.12

The presence of a leak was also supported by the abnormally large inspiratory-to-expiratory $O_2$ concentration difference. In the steady state, the inspiratory-to-expiratory $O_2$ concentration difference and inspiratory-to-expiratory $CO_2$ concentration difference are similar1 and can be used to monitor the integrity of a breathing system. An obvious large difference between these 2 indices indicated to us the entrainment of air.2 Tripathi and Pandey5 reported a case where a large difference between the inspiratory and expiratory sevoflurane concentrations led to discovery of a breach in the sampling tube of their side-stream capnograph.

Abnormal capnographic waveforms resulting from a leak can vary with the ventilation mode. Positive-pressure inspiration causes a pressure gradient across the sampling line, resulting in increased flow of undiluted end-expiratory gas in the sampling line (from the previous breath) and less entrainment of room air. Therefore, the maximal peak inspiratory pressure determines the height of the brief $CO_2$ peak. The duration depends on the time it takes to sample the volume of gas in the sampling line. In contrast, the height of the long $CO_2$ plateau is unaffected by maximal peak inspiratory pressure.11 Our patient was ventilated with continuous parameters from the beginning of the case, and therefore, we did not see the influence of varying airway pressures on the effect of the leaking water trap.

The anesthetic machine used for this patient consisted of an integrated ventilator and complete monitoring system and was used routinely in our clinic. During the preoperative evaluation of the machine, the water trap was set up and its proper fit was not further examined. The machine performed an automatic safety test including the leak test, and it passed all safety tests at the start of the case, despite the presence of a dislodged water trap causing a leak.

Given the fact that changing the sampling line had no effect, the tails-up capnogram in this particular case was erroneously taken as a sign of bronchoconstriction, a possible complication caused by histamine release from a surgically manipulated mast cell tumor. Accordingly, treatment with the $\beta$-adrenergic agonist bronchodilator terbutaline was initiated. In anesthetized, spontaneously breathing dogs in which bronchospasm was induced via inhalation of acetylcholine solution, terbutaline inhibited the bronchospasms by 10% to 70% for 2 hours after its administration.13 Terbutaline can cause dose-related $\beta$-adrenergic stimulation that can result in tachycardia, tachyarrhythmias, and tremors.14 In this case, tachycardia up to 150 beats/min did develop; however, no adverse effects associated with tachycardia were seen.

The typical capnographic waveform as well as the common deviations that can occur during monitoring of anesthesia are widely known among veterinary anesthesiologists. However, to our knowledge, neither the atypical waveform caused by a dislodged water trap, nor subsequent misinterpretation and erroneous treatment of a veterinary patient have been reported previously. In the present case, an anesthetic machine was used after an automatic leak test had been successfully passed.
Therefore, it remains important to always visually inspect the sampling line system, which includes the connection with the breathing circuit, the line itself, and the water trap and its proper fit. After this critical incident, the routine preanesthetic evaluation of the machine in our hospital has been changed to always include inspection of the capnography sampling line system.

References