Modern Spirometry Supports Anesthetic Management in Small Animal Clinical Practice: A Case Series

Ivana Calice, DVM, Yves Moens, Prof. Dr., DECVAA

ABSTRACT

Modern spirometry, like no other monitoring technique, allows insight into breath-to-breath respiratory mechanics. Spirometers continuously measure volume, airway pressure, and flow while calculating and continuously displaying respiratory system compliance and resistance in the form of loops. The aim of this case series is to show how observation of spirometric loops, similar to electrocardiogram or CO₂ curve monitoring, can improve safety of anesthetic management in small animals. Spirometric monitoring cases described in this case series are based on use of the anaesthesia monitor Capnomac Ultima with a side stream spirometry sensor. The cases illustrate how recognition and understanding of spirometric loops allows for easy diagnosis of iatrogenic pneumothorax, incorrect ventilator settings, leaks in the system, kinked or partially obstructed endotracheal tube, and spontaneous breathing interfering with intermittent positive-pressure ventilation. The case series demonstrates the potential of spirometry to improve the quality and safety of anesthetic management, and, hence, its use can be recommended during intermittent positive-pressure ventilation and procedures in which interference with ventilation can be expected. (J Am Anim Hosp Assoc 2016; 52:305–311. DOI 10.5326/JAAHA-MS-6374)

Introduction

General anesthesia is a common practice in veterinary medicine, and many drugs used for this purpose possess respiratory depressant effects. These effects are dose-dependent but also depend on the individual susceptibility and health status of the animal. Therefore, during anesthetic procedures, the anesthetist must always be able to evaluate and monitor ventilatory function in order to promptly recognize dangerous deviations from normal and to take corrective measures before the situation deteriorates.

The efficiency of ventilation can best be evaluated using blood gas analysis (BGA), preferably from an arterial blood sample. However, in practice, for routine anesthetic procedures, the invasiveness and the cost of this technology are often prohibitive. Therefore, the use of clinical skills in general and observation of excursions of the chest and the breathing bag in particular remain of utmost importance. In the last few decades, functional assessment of ventilation has been facilitated by new non-invasive monitoring methods such as capnography and pulse oximetry. These technologies are now increasingly also used in veterinary practice and provide indirect information about CO₂ removal and oxygenation of blood, respectively.¹,² In contrast, measuring of in-and-out movement of the air from the lungs—spirometry—still receives little attention. In human anesthesia, mechanical spirometers are widely used for this purpose, but not in veterinary anesthesia.

Spirometry instruments provide breath-to-breath measurement of the respiratory volumes during spontaneous breathing and intermittent positive-pressure ventilation (IPPV). Newer electronic developments in spirometry coupled with specific sensors allow...
continuous measurement of respiratory airflow, volume, and airway pressures. Additionally, these instruments offer continuous measurement and graphic display of indices of respiratory mechanics, particularly useful during IPPV.3–5

This case series illustrates the utility of a modern spirometer for monitoring and managing of ventilation in potentially dangerous situations during clinical veterinary anesthesia.

Materials and Methods

The cases presented were referred to the Animal Hospital at the University of Veterinary Medicine Vienna. Drug combinations for premedication were chosen based on physical status, clinical signs, blood work, and planned procedures. Subsequently, anesthesia was induced by intravenous injection of propofol and maintained by inhalation anesthesia with and without the use of IPPV. Monitoring of anesthesia was supported by the use of multiparameter anesthetic monitors of different brands. This always included continuous measurement of heart rate and respiratory rate, inspiratory and expiratory respiratory gas composition, non-invasive blood pressure, continuous electrocardiogram, pulse oximetry, and esophageal temperature.

Spirometric monitoring was done using an anesthesia monitora with a side stream spirometry option. The pitot principle is additionally used in this spirometric sensor, which relies on the measurement of pressure differences created by a resistor placed in the airflow. The signal is enhanced by the combination with the pitot tubes, which measures gas velocity.6

The appropriate-sized spirometric sensorb was placed between the endotracheal tube (ETT) and the Y-piece of the breathing circuit. The monitor displays breath-to-breath values for respiratory volume (ml), flow (L/min), and airway pressures (peak pressure, plateau pressure, and positive end-expiratory pressure [PEEP, cmH2O]) and dynamic compliance (Cdyn, ml/cmH2O). The latter reflects the elastic property of the lung and thoracic cage and is calculated as tidal volume (TV) divided by the difference in end-inspiratory to end-expiratory pressure. In clinical settings, physiological values in anesthetized and mechanically ventilated dogs can be estimated using the simplified equation Cdyn = body weight (kg) + nine.7 The pressure volume (PV) and flow volume (FV) loops allow the assessment of Cdyn (lungs and chest wall) and airway resistance measured during one respiratory cycle. Comparison of these loops over time allows one to determine if there is a change in respiratory compliance and resistance over time.

Normal Spirometric Loops

Schematic diagrams of the typical PV loop during IPPV are shown in Figure 1A. During IPPV, the loop is elliptical in shape and plotted at about a 45° angle on the x/y graph. At the beginning of
inspiration, airway pressure builds up (x-axis) and volume is delivered to the lungs (y-axis). When peak inspiratory pressure is reached, expiration begins and pressure returns to zero except when PEEP exists (Figure 1A). During spontaneous respiration, the PV loop is elliptical and arranged around the y-axis, and compliance is not calculated (Figure 1B).

During spontaneous breathing, the FV loop, which starts at the end of expiration (volume zero on the x-axis) is drawn from right to left, inspiratory and expiratory limb being labeled negative and positive by convention (Figure 1C). Normally, the inspiratory limb is curved, whereas the expiratory limb presents a triangular shape. The shape of the FV curves during IPPV depends on the ventilator and its operational mode: pressure-controlled ventilation (PCV) versus volume-controlled ventilation (VCV). During PCV, the FV loop is egg-shaped (not shown). During VCV, the FV loop displays rectangular inspiratory and triangular expiratory limbs (Figure 2).

**Case Series**

**Leaks in the System**

Figure 2 and Figure 3 show spirometric data and loops recorded in cases in which a leak in the connection of the patient with the breathing system was present. Loops do not close because there is marked difference in inspiratory and expiratory TV. Very often, the cause of this discrepancy is the insufficient tracheal seal. Following additional inflation of the ETT cuff, the loops closed, suggesting an airtight seal.

**Spontaneous breathing interfering with IPPV**

Figure 4 shows a case of spontaneous breathing efforts interfering with IPPV. The typical elliptical PV loop (L1) is replaced by loops with distorted appearance and a fish-like form (L2). This pattern is a result of the negative airway pressure generated by spontaneous breathing efforts. The underlying cause for a fish loop can be any process or condition that increases ventilatory drive (hypercarbia or hypoxia, as well as the use of analeptics, such as doxapram), which then overrides breathing sequence implemented by the ventilator and therefore causes distortion of the PV loop. In the case presented here, sudden rotation of the eyeball and the return of palpebral reflex suggested insufficient anesthesia depth. The increase in inspired isoflurane concentration resulted in return of normal PV loops, demonstrating that spirometry during IPPV can be helpful in maintaining adequate depth of anesthesia and sufficient analgesia. In cases where neuromuscular blocking agents are used, the appearance of fish loops suggests that the neuromuscular blocking effects are wearing off. Spirometry can be further useful for monitoring the effect of neuromuscular blocking agents on the respiratory muscles and returning to spontaneous breathing after reversal of the neuromuscular blockade.
Changes in Respiratory System Compliance and Resistance

Changes induced by airflow limitation

Figure 5 shows a case with typical changes of the PV loop (L2) during PCV due to diminished airflow caused by gradual obstruction of the ETT. Changes during IPPV can include a decreased slope due to a decrease in compliance with lower TV delivered, right shift of the loop (spontaneous PEEP), and increase in airway pressure, as well as enlarged area under the curve. Spirometry helps in rapid detection of compromised airway patency not only due to obstruction by blood and mucus, but also due to kinking of the ETT. Specific configurations of the PV
Spirometry can help the clinician manage optimal ventilator settings and abdominal pressure levels during these procedures while allowing immediate diagnosis of a life-threatening pneumothorax.

Discussion
The presented case series illustrates how modern spirometry can be a valuable monitoring tool to aid and improve anesthetic management during diverse diagnostic and surgical procedures.

Availability of two sensor sizes with low dead space (9.2 ml for D-lite and 2.5 ml for Pedi-lite) allows measurements of tidal volumes as low as 15 ml. Hence, it can be used for a variety of animal sizes, for example, small cats as well as large dogs. In our patient population, Pedi-lite was used in patients under 10 kg and D-lite for patients over 10 kg.

During anesthesia, spirometry is useful for detecting respiratory volumes effectively delivered to and received back from the patient. It allows monitoring of changes in numerical values of TV and Cdyn as well as changes in PV and FV loops, estimating the
patient’s minute ventilation during spontaneous breathing, common causes of which are insufficient or excessive anesthetic depth. When a ventilator is used for IPPV, minute-volume is determined by the anesthetist. Selected TV does not necessarily reflect the effective volume delivered to the patient because of the Cdyn of breathing hoses. In contrast, TV at the patient level can be accurately measured by spirometry, as used in this case series. Spirometers provide the clinician with valuable information that helps determine the appropriate tidal volumes and minute volumes likely to realize normocapnia (to be confirmed by capnography, but ultimately by BGA) and avoid hyperinflation and the risk of barotrauma. However, spirometry does not replace the need for confirmation of the ventilatory status by arterial BGA.

Additionally, modern spirometry measures airway pressure and flow, which allows continuous insight into respiratory mechanics and respiratory system compliance. Changes in Cdyn during anesthesia can happen for a variety of reasons, and moderate changes are difficult to detect clinically. However, their detection is important because they can indicate changing conditions of the patient and the connection with the anesthetic system, and they can influence the performance of mechanical ventilators. A decrease in Cdyn (or increase in resistance) will cause a decrease in delivered TV when PCV is used, whereas with VCV, the chosen TV is delivered, but at a high and possibly dangerous airway pressure. Therefore, monitoring compliance is useful in procedures and conditions that are likely to interfere with ventilation. This is the case for intrathoracic procedures (classic or thoracoscopic) or during procedures in the presence of increased abdominal pressure, such as gastric volvulus, tympanism, head-down tilt, and laparoscopy with abdominal inflation.

Furthermore, spirometry allows prompt recognition of life-threatening iatrogenic pneumothorax, which can occur during laparoscopy, bronchoscopy, or esophagoscopy.

Spirometric monitoring can also detect several common technical mishaps, allowing corrective measures to be taken before the situation deteriorates. Examples include leaks in the system as well as complications such as kinked or partially obstructed ET and an inadvertently closed APL valve.

The detection of a variety of changes is greatly simplified by the continuous display of loops, especially the “compliance” PV loop that is usually a default setting during IPPV. Another advantage is the option to store loops for comparison purposes. When respiratory function becomes severely compromised, changes in compliance are recognized earlier, compared to decreases in oxygen saturation and end tidal CO2 shown by pulse oximetry and capnography, respectively.

Conclusions

Modern spirometry at the patient side provides noninvasive, continuous, easy-to-use, and accurate monitoring of ventilation and respiratory mechanics, especially during IPPV. This is greatly facilitated by display of loops and recognition of specific patterns, which allow quick identification of site, type, and severity of problems that arise. Spirometry is complementary to capnography and pulse oximetry and is especially useful during procedures in which interference with ventilation can be expected. As changes in spirometric parameters often precede changes in hemodynamics and oxygenation, the clinician is provided with means to ensure a high level of safety in such anesthetic procedures.

FOOTNOTES

a Capnomac Ultima; Datex-Ohmeda Corp., Helsinki, Finland
b Spirometric sensor (D-lite or Pedi-lite); Datex-Ohmeda Corp., Helsinki, Finland

REFERENCES