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RESEARCH PAPER

A novel flow partition device for spirometry during large animal anaesthesia

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Abstract

Objective We describe and test a novel device for large animal anaesthesia monitoring that uses standard human medicine spirometry sensors.

Study design *In-vitro* study.

Methods The device consists of two adapters that enable the flow to be split evenly into four tubes in parallel, each tube containing a D-lite sensor. The performance of this flow partitioning device (FPD) over a range of flows from 100 to 700 L minute^{-1} was determined and the pressure versus flow relation, resistance and dead space was compared with a Horse-lite (Moens 2010).

Results Equipped with four D-lite sensors, and a flow of 700 L minute^{-1} the pressure drop of the FPD was 13.5 cmH_2O, resistance 1.17 cmH_2O second L^{-1} and volume (potential dead space) 182 mL, compared to 2.8 cmH_2O, 0.24 cmH_2O second L^{-1} and 54 mL respectively for the Horse-lite. The predicted value of the flow partition of ¼ could be confirmed. Limits of agreement were found to be 4.2% in inspiratory direction and 7.1% in expiratory direction.

Conclusions and clinical relevance The FPD is an affordable device that extends the specification of any commercially available human spirometry sensors to large animal applications. However, an increase in total resistance and dead space has to be taken into account. Therefore, the new device could be useful during equine anaesthesia.

Keywords large animal anaesthesia, monitoring, spirometry.

Introduction

Monitoring of ventilation is an important aspect of anaesthesia management in small and large animals (Hall & Clarke 1991). During spontaneous breathing and mechanical ventilation, the measurement of tidal and minute volumes gives essential information of the patients' respiratory function. For respiratory monitoring of small animals, spirometric equipment and sensors from human medicine can be used because the range of flow and tidal volume remains within the specification of standard paediatric or adult human sensors. Different types of spirometric sensors can be positioned at different places in an anaesthetic machine and ventilator (Dorsch & Dorsch 2011). Positioning the sensor directly between the endotracheal tube (ETT) and the breathing circuit provides the highest accuracy and is mandatory if mainstream volumetric capnography is also performed. Spirometric sensors have individual advantages and drawbacks. For example, the Fleisch pneumotachometer (Fleisch 1925) is highly accurate but sensitive to fluid accumulation as well as gas composition and is hence less suitable for clinical application. Many sensors used for clinical anaesthesia apply the Pitot-tube principle in combination with a resistive structure to generate

a flow dependent pressure difference. Such constructions are cheap, robust but have to be used with dedicated hard- and software that convert the pressure difference into flow and volume considering the non-linear transfer function as well as corrections for the gas composition and temperature (Moens et al. 1994). Examples are the D-lite sensor (Meriläinen et al. 1993; GE Healthcare, Finland), the Hamilton Flow sensor (Hamilton Medical AG, Switzerland) and the NICO$_2$ CO_2/Flow sensor (Respironics Inc., MA, USA). However, above-mentioned sensors are designed for human use to be attached to the standard 15 mm diameter conical connection system and would create too much resistance when inserted in the large bore circle system for large animal anaesthesia. Thus they do not meet the flow and volume requirements encountered during large animal anaesthesia monitoring.

Moens et al. (1994) remodelled a D-lite sensor to a larger diameter (Horse-lite) and documented its accuracy by determining an appropriate conversion factor to calculate flow and volume values. Such a device enables the veterinary anaesthetist to optimize ventilatory management of large animals (Moens 2010). However, the Horse-lite needs to be custom made and individually tested *in situ* to determine an appropriate conversion factor to be applied to the readings of the monitor. The principle of enlargement of a human sensor is difficult to apply for mainstream capnography because of the integration of the optical pathway for a given CO_2 detector such as the NICO$_2$ Capnostat (Respironics Inc.) or the IRMA CO_2 sensor (Phasein AB, Sweden). As an alternative solution, we propose a universal flow partitioning device (FPD) which allows the use of any type of standard human sensors with or without a CO_2 detector for large animal anaesthesia monitoring. The aim of this study was to investigate the FPD equipped with four standard D-lite sensors in comparison with the Horse-lite sensor *in-vitro*.

Materials and methods

Working principle

Using a single bypass channel parallel to a conventional sensor will reduce the flow through the measuring device and may keep the flow within the specification limits even during large animal anaesthesia. The split ratio of the flows is a function of the individual resistances in the branches. Unfortunately, this ratio may not be constant over the required flow range. The flow pattern is likely to be turbulent in particular in the sensor device itself. Hence the split ratio is not constant and is a function of the flow value and may also be dependent on the flow direction. A more robust solution is to connect multiple identical sensors in parallel providing matched resistances in every branch independent of the applied flow. Theoretically, this approach results in a constant split ratio independent of the flow value. A custom-made highly symmetrical flow partitioning adapter that connects four identical human sensors in parallel is a practicable compromise, based upon the geometric considerations that the four 15 mm diameter bore holes arranged in a circle will fit closely in the 36 mm bore of the largest ETT size for horses. The spirometry monitor is connected only to one sensor and will measure therefore ¼ of the total flow. Flow reading as well as calculated parameters such as volume and compliance have to be multiplied by a factor of four to achieve a correct value. However, pressure measurement is not affected by such an arrangement and need not to be converted.

Description of the device

The flow partitioning device (FPD) consists of two almost identical adapters made of polyoxymethylene (Fig. 1 upper left and upper right). One adapter partitions the airflow into four equal parts and directs the flow through four D-lite spirometry sensors (a) The 15 mm female conical port of the sensors fits to the brass-made 15 mm male connector (b) of the adapter. Transparent silicone tubes (18 mm × 2 mm) (c) connect the sensors to the second adapter that serves to direct all flows back to one. A metal rod (d) in the middle of the device keeps both adaptors in the appropriate distance. To achieve minimal extra resistance, the construction is made highly symmetrical considering aerodynamic requirements. Outside connectivity (e) is designed to fit to the Y-piece which in turn connects to the ETT. This arrangement provides a closely matched resistance in each of the four branches. A spirometry monitor dedicated for D-lite sensors is connected to one of the sensors measuring ports (two for the pressure difference, and one for gas sampling). The measuring- and sampling ports of the three other D-lite sensors need to be closed to prevent leakage.