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SHORT COMMUNICATION

# Determination of physiological dead space in anaesthetized horses: a method-comparison study Q5

Q4 **Zuzana Drábková[a], Johannes P Schramel[b] & Radovan Kabeš[a]**

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## Abstract

**Objective** To compare two methods of Bohr−Enghoff physiological dead space to tidal volume ratio ($V_D/V_{TBohr-Enghoff}$) determination using a mixing chamber and an E-CAiOVX metabolic monitor.

**Study design** Prospective, clinical, method-comparison study.

**Animals** Twenty horses anaesthetized for elective orthopaedic procedures.

**Methods** Horses were anaesthetized with isoflurane in oxygen and the lungs were mechanically ventilated ($V_T$ 15 ± 2 mL kg$^{-1}$). Arterial blood was sampled to provide arterial partial pressure of carbon dioxide ($PaCO_2$) for dead space calculation using a metabolic monitor. Mixed expired partial pressure of carbon dioxide ($P\bar{E}CO_2$) obtained from the custom-made mixing chamber was recorded at the time of arterial blood sampling. Dead space fraction was calculated using the Enghoff modification of the Bohr equation. Agreement between the methods was assessed by Bland−Altman test. A clinically acceptable error was defined to be ≤ 10%.

**Results** Forty-nine simultaneous $V_D/V_{TBohr-Enghoff}$ results were obtained. There was no clinically significant bias between the mixing chamber and E-CAiOVX. The limits of agreement were within *a priori* defined error (bias ± 95% limits of agreement: −0.022 ± 0.078).

**Conclusions and clinical relevance** Acceptable agreement was found between the two methods. The E-CAiOVX metabolic monitor might be a suitable device for measuring $V_D/V_{TBohr-Enghoff}$ in anaesthetized horses. Q1

## Introduction

Physiological dead space ($V_{Dphys}$) is the inhaled volume of air that does not participate in gas exchange (wasted ventilation). It can be further partitioned into airway dead space ($V_{Daw}$ − consisting of the volume in conducting airways) and alveolar dead space ($V_{Dalv}$ − caused by variable amount of non-perfused alveoli). For clinical use $V_{Dphys}$ is expressed as a fraction of the tidal volume ($V_D/V_T$). The dead space fraction can be calculated by Bohr equation or by Enghoff modification of the latter. Both require mixed expired partial pressure of carbon dioxide ($P\bar{E}CO_2$). Original Bohr equation uses mean alveolar partial pressure of carbon dioxide ($PACO_2$) for the calculation, and results in Bohr dead space ($V_D/V_T$Bohr). Enghoff modification of the Bohr equation uses arterial partial pressure of carbon dioxide ($PaCO_2$) instead, and results in Bohr−Enghoff dead space ($V_D/V_{TBohr-Enghoff}$; Siobal et al. 2013).

As the Enghoff modification of the Bohr formula uses $PaCO_2$, $V_D/V_{TBohr-Enghoff}$ represents all causes of ventilation−perfusion mismatch including intrapulmonary shunt and diffusion impairments. It is a global index of ineffective gas exchange rather than physical dead space (Tusman et al. 2012).

To determine $P\bar{E}CO_2$ with the traditional Douglas bag method, exhaled gas is collected over several minutes to be analysed *post hoc*. Nowadays, alternative types of mixing chambers have been developed, replacing the Douglas bag (Breen and Serina 1997).





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In contrast to the gas sampling over a certain time, the technique of volumetric capnography integrates the area under the curve of a single exhalation (Tusman et al. 2012). More advanced metabolic monitor methods use indirect calorimetry instead (Siobal et al. 2013).

The E-CAiOVX metabolic module in the S/5 Monitor (GE Healthcare/Datex-Ohmeda, Finland) is a metabolic monitor that uses breath-by-breath gas exchange monitoring (Briassoulis et al. 2009). E-CAiOVX determines $V_D/V_{TBohr-Enghoff}$ based on the data measured by the monitor and blood gas data.

The aim of this study was to compare $V_D/V_{TBohr-Enghoff}$ measurements with the E-CAiOVX metabolic monitor to the mixing chamber method, which was considered as the gold standard, in anaesthetized and mechanically ventilated horses. Our hypothesis was that there is a good agreement between the two methods.

## Materials and methods

### Animals and anaesthesia

Twenty adult client-owned horses anaesthetized for elective orthopaedic surgeries were included in this prospective clinical study. Physical status was assessed as American Society of Anaesthesiology I or II based on clinical examination. Horses with pulmonary diseases were excluded from the study.

The study was approved by the animal ethics committee of the University of Veterinary and Pharmaceutical Sciences (protocol number: 81/2013). Written client consent was obtained.

The horses were fasted for 8−12 hours before surgery, water was allowed during this period. They were premedicated intravenously (IV) with xylazine 1.1 mg $kg^{-1}$ (Xylazin Ecuphar; Riemser Arzneimittel AG, Germany). Anaesthesia was induced 5 minutes later with ketamine 2.2 mg $kg^{-1}$ (Narkamon 10%; Bioveta a.s., Czech Republic) and diazepam 0.02 mg $kg^{-1}$ (Apaurin; Krka d.d., Slovenia) IV. After endotracheal intubation, the horses were moved onto a bedded surgical table, positioned in dorsal ($n = 12$) or lateral ($n = 8$) recumbency and connected to a large animal anaesthetic circle system equipped with a mechanical ventilator (Stephan-Respirator GT; F. Stephan GmbH, Gackenbach, Germany). Mechanical ventilation was started immediately in pressure controlled mode with an inspiratory/expiratory ratio (I:E ratio) 1:2. The peak inspiratory pressure was set to 20 $cmH_2O$. The respiratory rate was further adjusted to maintain end-tidal carbon dioxide between 5 and 6 kPa (37−45 mmHg). Anaesthesia was maintained with isoflurane (Aeranne; Baxter S.A., Belgium) vaporized in oxygen. End-tidal isoflurane concentration was kept between 1.3−1.5% and adequate depth of anaesthesia was evaluated by clinical and physiological parameters. Saline 0.9% (Baxter S.A., Switzerland) was infused at a rate of 5−10 mL $kg^{-1}$ $hour^{-1}$. Dobutamine (Dobutamin Admeda 250; Admeda Arzneimittel GmbH, Germany) was administered up to 1.5 μg $kg^{-1}$ $minute^{-1}$ to maintain a mean arterial blood pressure (MAP) > 70 mmHg. Ketamine 0.5 mg $kg^{-1}$ IV was administered if the horse showed nystagmus and thiopental (Thiopental Valeant; PharmaSwiss s.r.o., Czech Republic) 1 mg $kg^{-1}$ IV was administered if the horse moved.

The electrocardiogram, heart rate, respiratory rate, inspiratory and expiratory gas concentrations of carbon dioxide ($CO_2$), oxygen ($O_2$) and isoflurane, nasopharyngeal temperature and haemoglobin oxygen saturation were monitored continuously (S/5 Critical Care Monitor). Systolic, diastolic and mean arterial blood pressure were measured invasively (S/5 Critical Care Monitor) after catheterization of the facial artery using a calibrated pressure transducer (TruWave; Edwards Lifesciences LCC, CA, USA) positioned at the level of the right atrium. A Pitot tube-based flowmeter (Moens et al. 2009) combined with a metabolic monitor (S/5 Critical Care Monitor) was used to obtain continuous spirometric data (tidal and minute volume, airway pressure, airway resistance, dynamic compliance, I:E ratio). The first arterial blood sample was collected anaerobically into 2 mL heparinized blood gas syringes after the catheterization of the facial artery; additional samples were taken as needed at intervals of 20−50 minutes. Blood gas analysis was performed immediately after blood collection (ABL 800 Flex Analyser, Radiometer Medical ApS, Denmark).

### Mixing chamber

The custom mixing chamber was constructed by one of the authors (JPS) from a 23 L plastic container (measured by graduated cylinder) with a lid stabilized by a steel frame. Input and output connections were sealed in the lid and were made of 5 cm steel tubes with attached ports for gas sampling. Plastic tubes of different lengths were attached to input and output connections inside the container to prevent a short circuit of the airflow. A small light bulb worked as

 

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