

INVITED COMMENTARY

Total dead space in children under general anesthesia

Andrew Wolf, Ehrenfried Schindler, Mona Momeni and Francis Veyckemans

European Journal of Anaesthesiology 2023, 40:459–460

The paper of Gardon *et al.* published in the current issue of the *European Journal of Anaesthesiology*¹ raises some issues. Although it was not the main outcome of this observational study, its main conclusion ‘*the smaller the child the more apparatus deadspace plays a critical role*’ is not new^{2,3}; this is well known and it is surprising that a large heat and moisture exchanger (HME) was routinely used in children less than 10 kg, when smaller airway filters are available specifically for smaller infants. In essence, the authors used volumetric capnometry to explore the age/weight related differences on minute ventilation, tidal volume and the effects of dead space during routine anaesthesia. While this represents new data, the conclusions on alveolar ventilation reported in the paper could lead to misinterpretation and deserve some comments, even if most of the considerations below were already discussed in the ‘Limitations’ section of the manuscript.

A reminder of a few definitions is necessary when reading and interpreting the results of the manuscript. Total dead space is that volume which is not involved in gas transfer and is comprised of the anatomical deadspace of the child (all airways/structures proximal to the respiratory bronchioles) and the apparatus deadspace (that part of the anaesthesia apparatus distal to the point where fresh gas enters and exhaust gas interact). Physiological deadspace also includes alveolar gas that does not take part effectively in oxygen/carbon dioxide exchange. This additional volume is not usually substantial in normal lungs that are ventilating effectively. Clearly, adding large volume tubes and HME filters distal to the fresh gas entry and exhaust gas interface will have much greater effects on the smaller infant because, as the authors rightly point out, the proportion of alveolar ventilation to anatomical deadspace diminishes with decreasing age and weight.

Firstly, in the current study, infants and children up to 25 kg had a paediatric HME with a deadspace of 13 ml while those over 25 kg had an adult HME of 51 ml volume. When ventilating infants under anaesthesia, a compensation for the disproportionate increase of apparatus deadspace is required and it is therefore common practice to set relatively high target tidal volumes to maintain adequate alveolar gas exchange and normal target end-tidal carbon dioxide. Moreover, it is also common practice to reduce all elements of apparatus deadspace to bring the alveolar ventilation/total deadspace ventilation to a more favourable ratio. This can be achieved by the use of small weight-specific HME apparatus, specialised narrow bore/ low volume age adjusted tubing (although this is of less importance when a ventilator compensating for circuit compliance is used) and ensuring that the interface between inflow and exhaust gases is as close to the patient as possible.

Secondly, a note of caution must be made about interpreting measurement values of both time-based end tidal CO₂ estimation and volume-based carbon dioxide excretion (volumetric capnography with its derived function ‘alveolar minute ventilation’) in younger children. End tidal carbon dioxide is difficult to measure accurately in small infants and can have error due to airway leak (prevented here by the use of cuffed tubes), excessive dead space,² airway turbulence that can dilute carbon dioxide in the expiratory breath and transport delay with prolonged dynamic response of the capnometer (only in case of sidestream capnography). Volumetric capnography using Bohr–Fletcher’s method to measure airway volumes assumes that alveolar CO₂ is the midpoint of the line of the slope of phase III of the capnogram: any error in expired CO₂ measurement could thus result in an erroneous calculation of the airway volumes.⁴ In Gardon’s series, 7/20 (35%) of the capnographic waves in the group of the smallest patients were ‘aberrant’ (value? shape?) and not usable for volumetric capnography. In addition, the gradient between arterial and end-tidal CO₂ increases

From the Paediatric Anaesthesia and Intensive Care, Bristol Royal Children’s Hospital (AW), Department Anaesthesiology and Intensive Care Medicine, University Hospital, University of Bonn, Germany (ES), Department of Anaesthesiology, Cliniques universitaires Saint-Luc, and Institut de Recherche Expérimentale et Clinique (IREC); Institute of Neuroscience (IoNS), Université catholique de Louvain (UCLouvain), Brussels, Belgium (MM), UCLouvain, Belgium (FV)

Correspondence to Francis Veyckemans, MD, Retired Paediatric Anaesthetist, UCLouvain, Belgium.
E-mail: veyckemansf@gmail.com

0265-0215 Copyright © 2023 European Society of Anaesthesiology and Intensive Care. Unauthorized reproduction of this article is prohibited.

DOI:10.1097/EJA.0000000000001830

when deadspace increases and or tidal volume decreases. This can result in significant hypercarbia despite a normal end-tidal CO_2 ^{2,5} and make data provided by volumetric capnography less accurate in the smaller infants even assuming that they have normal lungs.^{4,5} Last, the gradient between arterial and end-tidal CO_2 is usually positive but can be negative, and the only way to verify this is to measure arterial blood gases.⁵

Thirdly, although we understand that this was an observational, real life conditions study, some experimental issues are concerning. The absence of a recruitment manoeuvre after intubation could have resulted in variable lung atelectasis, ventilation inhomogeneity⁶ and ventilation/perfusion mismatch. Moreover, positive end expiratory pressure (PEEP) values were variable and probably resulted in differences in lung ventilation homogeneity among the patients. Finally, the I/E ratio was variable too: studies on dynamic alveolar physiology suggest that extending the inspiration time would prevent alveolar collapse and be part of a protective mechanical ventilation strategy as it helps keeping the lung open.⁷ In clinical practice, during pressure-controlled ventilation, a 1:1.5 ratio results in a larger tidal volume than the commonly used 1:2 ratio. These potential causes of inter-individual variation in alveolar ventilation would be controlled in future similar studies by using pressure-regulated, volume-controlled ventilation (PRVC) mode.

The reader must also consider in interpreting these results the use of absolute volumes (minute volume, tidal volume) *versus* weight corrected volumes (minute volume kg^{-1} , tidal volume kg^{-1}). To conclude, although we commend the authors for using volumetric capnography

in anaesthetised children, we recommend interpreting the results of their study with caution due to the methodological issues reported above. Future studies should control better both the apparatus deadspace and the ventilation parameters to improve the reliability of the calculations based on volumetric capnography.

Acknowledgements relating to this article

Assistance with the article: none.

Financial support and sponsorship: none.

Conflict of interest: all authors were involved at some stage in the review process of Gardon's manuscript. MM and AW are members of the Editorial Board of Eur J Anaesthesiol.

This manuscript was handled by Robert Greif.

References

- 1 Gardon A, De Queiroz Siqueira M, Cerceuil E, Bouhami N, Chassard D, Baudin F, et al. Alveolar target ventilation and dead space in children under anesthesia – the Proventiped observational study. *Eur J Anaesthesiol* 2023; **40**:495–500.
- 2 Feldman JM. Optimal ventilation of the anesthetized pediatric patient. *Anesth Analg* 2015; **120**:165–175.
- 3 King MR, Feldman JM. Optimal management of apparatus dead space in the anesthetized infant. *Paediatr Anaesth* 2017; **27**:1185–1192.
- 4 Verscheure S, Massion PB, Verschuren F, Damas P, Magden S. Volumetric capnography: lessons from the past and current clinical applications. *Critical Care* 2016; **20**:184.
- 5 Onodi C, Bühler PK, Thomas J, Schmitz A, Weiss M. Arterial to end-tidal carbon dioxide difference in children undergoing mechanical ventilation of the lungs during general anaesthesia. *Anaesthesia* 2017; **72**:1357–1364.
- 6 Bruins S, Sommerfield D, Fowers N, von Ungern-Sternberg BS. Atelectasis and lung recruitment in pediatric anesthesia: an educational review. *Paediatr Anaesth* 2022; **32**:321–329.
- 7 Nieman GF, Satalin J, Kolisch-Singule M, Andrews P, Aiash H, Habashi NM, Gatto LA. Physiology in medicine: understanding dynamic alveolar physiology to minimize ventilator-induced lung injury. *J Appl Physiol* 2017; **122**:1516–1522.