CORRESPONDENCE

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A New, Simple Method of Measuring Physiologic Deadspace ($V_d$phys) and $V_d$phys/V_t Ratio in Patients Whose Lungs Are Mechanically Ventilated

To the Editor:—Determination of physiologic deadspace ($V_d$phys) and dead space/tidal volume ratio ($V_d$phys/V_t) in critically ill patients whose lungs are mechanically ventilated becomes imperative in certain pathophysiologic events such as pulmonary embolism, bronchial asthma, chronic obstructive pulmonary disease (COPD), interstitial lung disease, and circulatory insufficiency.[1,2] In these situations, measurement of $V_d$phys/V_t provides important information concerning the extent of the underlying pathophysiologic process and may be useful in adjusting the ventilator parameters. The method currently used is based on Bohr's equation ($V_d\text{phys}/V_t = (PA_{CO_2} - PE_{CO_2})/PA_{CO_2}$) and requires the use of equipment such as a carbon dioxide analyzer and a Douglas bag[3,4] (where PA_{CO_2} is the alveolar carbon dioxide partial pressure assumed equal to arterial P_{CO_2}, and PE_{CO_2} is the mixed expired P_{CO_2}).

Our purpose has been to establish a simple, accurate, and inexpensive method of measuring $V_d$phys and $V_d$phys/V_t ratio that bypasses the need to measure the partial pressure of mixed expired carbon dioxide (PE_{CO_2}).

(It is known that $Pa_{CO_2} = k \cdot \dot{V}_{CO_2}/\dot{V}_A = (k/f) \cdot \dot{V}_{CO_2}/(V_t - V_d\text{phys})$ where Pa_{CO_2} is the carbon dioxide partial pressure in arterial blood, $\dot{V}_{CO_2}$ is the carbon dioxide production per minute, $\dot{V}_A$ is the minute alveolar ventilation, and f is the respiratory frequency). If, in a patient whose lungs are mechanically ventilated under known conditions (f, V_t, Pa_{CO_2}), we change V_t to a new tidal volume setting (V_t'), resulting in a new Pa_{CO_2}', we have $Pa_{CO_2} = (k/f) \cdot \dot{V}_{CO_2}/(V_t - V_d\text{phys})$ and $Pa_{CO_2}' = (k/f) \cdot \dot{V}'_{CO_2}/(V_t' - V_d\text{phys}')$. Assuming that (1) $V_d$phys remains almost stable ($V_d\text{phys} = V_d\text{phys}'$), although it is known that changes in tidal volume may result in minimal physiologic deadspace alterations[5,6]; (2) $\dot{V}_{CO_2}$ remains constant ($\dot{V}_{CO_2} = \dot{V}_{CO_2}'$), because no change is expected to occur in the metabolic status of the patient, within the few minutes between consecutive measurements (15–20 min); and (3) $PA_{CO_2} = Pa_{CO_2}$, the above equations can be transformed into $V_d\text{phys} = [(Pa_{CO_2}' \cdot V_t') - (Pa_{CO_2} \cdot V_t)]/(Pa_{CO_2}' - Pa_{CO_2})$.

Ten patients aged 24–74 yr whose lungs were mechanically ventilated because of acute respiratory failure of various pulmonary or extrapulmonary origin were studied. The study protocol was approved by the Institutional Ethics Committee. Mechanical ventilation was performed *via* a tracheal tubing using Engstrom Erica volume ventilators (Sweden) connected with Engstrom Elisa carbon dioxide analyzers. We have divided total minute ventilation (indicated by the ventilator) by the respiratory frequency to obtain V_t and V_t' values. Arterial blood gases were obtained with the initial tidal volume setting and 15–20 min after an increase in tidal volume ranging 10–30% of its initial value. Continuous monitoring of expired carbon dioxide is performed by sampling gas from the expiratory line of the circuit and submitting the gas to an infrared absorption carbon dioxide analyzer. Inspiratory and expiratory lines are separated by a shutter, therefore gas mixing does not occur. The analyzer signal is then passed to a storage oscilloscope. The breath-by-breath carbon dioxide waveforms may be displayed either individually or as a series of peaks representing end-tidal P_{CO_2}. End-tidal P_{CO_2} may be obtained by a simple peak detector and displayed digitally. Mixed expired P_{CO_2} is computed automatically as the mean value from the breath-by-breath carbon dioxide waveform as a function of expired tidal volume. The breath-by-breath signals were integrated to yield 1-min averages of end-tidal P_{CO_2} and mixed expired P_{CO_2}. $V_d$phys/V_t values first were displayed

Table 1. Individual Values and Mean Values ± SD of $V_d$phys and $V_d$phys/V_t Ratio Calculated by Bohr's Method (Carbon Dioxide Analyzer) and Derived by Our Equation in Each Patient

Patient	$V_d$phys—Bohr's (ml)	$V_d$phys—Equation (ml)	$V_d$phys/V_t—Bohr's	$V_d$phys/V_t—Equation
1	432	442	0.66	0.68
2	281	284	0.42	0.43
3	284	292	0.40	0.42
4	263	254	0.61	0.59
5	177	181	0.44	0.45
6	318	323	0.45	0.46
7	240	238	0.48	0.48
8	246	253	0.49	0.51
9	189	189	0.38	0.38
10	241	240	0.44	0.44
Mean ± SD	267 ± 72	270 ± 74	0.47 ± 0.09	0.48 ± 0.09

on the digital screen of the carbon dioxide analyzer, which uses end-tidal (assumed equal to alveolar) and mixed expired P_{CO_2} to fit Bohr's equation and second were calculated using our equation (table 1).

Our hypothesis has been that $V_d$phys/V_t ratio calculated by our equation should not differ substantially from $V_d$phys/V_t ratio obtained by Bohr's equation. If this is confirmed, our equation would be acceptable and usable in clinical practice. Although the proposed equation is derivatively related to Bohr's equation, it is independent of the value of $P_{E_{CO_2}}$.

Linear regression analysis of 1st order was used to confirm the interrelationship of $V_d$phys/V_t ratios derived by both methods. A strong relationship has been shown ($r = 0.98$, $P < 0.001$; fig. 1).

Two of our patients had been receiving positive end-expiratory pressure (PEEP) for 1 day. However, acute application of PEEP does not affect $V_d$phys for unclear reasons, despite the fact that prolonged use of PEEP causes an increase in deadspace.[7] It also is well known that prolongation of inspiration reduces deadspace by allowing gas mixing to take place between deadspace and alveolar space.[5] In our patients, inspiratory:expiratory time ratio (1:2) was kept constant during the experiment.

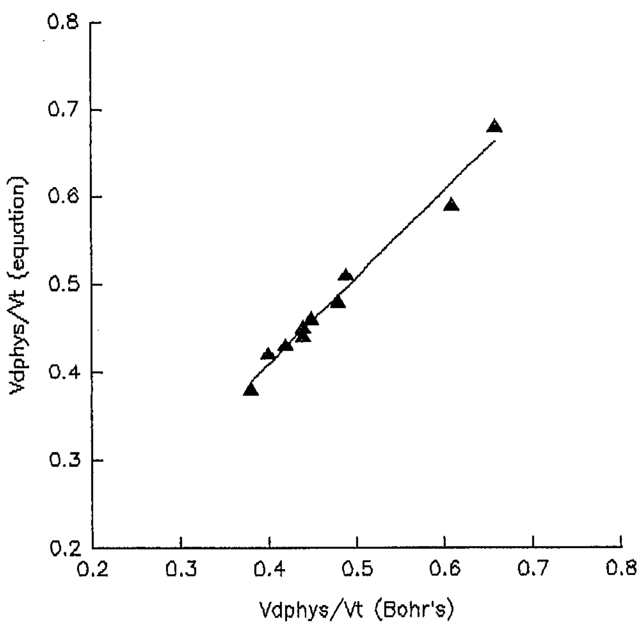

Fig. 1. Correlation between $V_d$phys/V_t calculated by Bohr's method (carbon dioxide analyzer) and $V_d$phys/V_t derived by our equation ($r = 0.98$, $P < 0.001$). Each data point represents a single patient.

Obviously, this new method can be performed only in patients whose lungs are mechanically ventilated, who are sedated and paralyzed, who do not exhibit severe derangement of their total respiratory impedance, or who are not at risk for barotrauma during tidal volume manipulations. Our method seems to offer an easy and practical access to $V_d$phys/V_t measurements and, therefore, it merits further study. At present, the limits under which the equation is satisfactory have not yet been defined. The proposed method might fail in cases when the patient's ventilation is not synchronized with the ventilator, or inequality of alveolar gas mixing is present because of either bronchospasm or inequality of time constants in different lung units. It seems that the proposed method can be applied much more reliably in patients suffering from acute respiratory failure of extrapulmonary origin.

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