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Negative arterial to end-tidal gradients

To the Editor:

We read with interest the article by Drs. Russell, Graybeal and Strout.¹ May we be permitted to comment on this subject.

Firstly, in the introduction, the authors state that the $P(a-ET)CO_2$ is primarily a reflection of respiratory deadspace, increasing as deadspace increases. This was an earlier belief but it has now been shown to be no longer true.^{2,3} The relation between the two variables ($PaCO_2$ and $PETCO_2$) is complicated, being determined by the slope of the “alveolar plateau,” phase III of single breath test. It has been shown that alveolar deadspace increased by the end of cardiac bypass surgery, but so too had the slope of phase III resulting in no significant change in $P(a-ET)CO_2$.^{3,4} Thus, increasing the alveolar deadspace may not increase $P(a-ET)CO_2$. Furthermore, $P(a-ET)PCO_2$ values may be negative or zero as a normal physiological variant during anaesthesia,⁵ exercise,⁶ or in pregnancy^{7–9} in the presence of a significant alveolar deadspace.

Secondly, $PETCO_2$ measurements were corrected for humidity, but not for the effect of positive airway pressure. With some capnometers positive airway pressure influences the $PETCO_2$ measurements. Therefore the measurements should be corrected for the presence of positive airway pressures.

Thirdly, the authors have expressed a doubt that the meaning of negative $P(a-ET)PCO_2$ is not totally clear. We think that the recent literature on this subject should clear any doubts.^{2,5,7–9} Negative (a-ET) PCO_2 values were observed more than 30 yr ago by Nunn *et al.*¹⁰ although no explanation was offered at that stage. Fletcher *et al.*

observed negative or zero (a-ET) PCO_2 values in 12% of non-pregnant patients during anaesthesia/IPPV using large tidal volumes and low frequencies.⁵ Increases in tidal volumes and low frequency result in (i) gas emptying from slow alveoli can reach the mouth, whereas it would have remained in the airways with small tidal volumes; (ii) relatively better ventilation of dependent, well-perfused alveoli. Under these circumstances the low $\dot{V}/\dot{Q}$ compartments (alveoli with higher CO_2 concentrations) make a more substantial contribution to gas exchange. Normally, there are differences in the emptying patterns among various compartments in the lung. Therefore, more gas with an above average alveolar PCO_2 can now reach the airway opening from “late” or “slow” compartments. This results in $PETCO_2$ exceeding mean $PaCO_2$. On a capnogram, the slope of phase III crosses the mean $PaCO_2$ (alveolar PCO_2).¹¹ The physiological changes in pregnancy increase the number of alveoli with low $\dot{V}/\dot{Q}$ ratios (alveoli with high CO_2 concentration). Therefore we stated that there is increased incidence of negative (a-ET) PCO_2 values in pregnancy.^{7–9}

After CPB, one may expect a range of ventilation/perfusion mismatching. There is a reduction of functional residual capacity and haemodilution following CPB.^{4,12} These may result in several alveoli with low $\dot{V}/\dot{Q}$ ratios (alveoli with higher CO_2 concentration). Because the tendency to airway closure is increased after CPB, these alveoli do not have a chance to empty. However, with the use of high tidal volume ventilation and added PEEP alveoli with high CO_2 concentration are now allowed to empty and thus contribute to an increased phase III slope and higher $PETCO_2$. This may result in negative (a-ET) PCO_2 values as were observed in the study by Russell *et al.*¹

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REPLY

Thank you for the opportunity to reply to Drs. Shankar, Mosely, and Kumar. It is always worthwhile when one realizes that a paper is not only read, but also read critically.

There are several points raised with which we are all in agreement. The 8.1% incidence of negative arterial to end-tidal carbon dioxide gradients, $P(a-ET)CO_2$, is in keeping with previously reported data. Emptying of previously closed "slow" emptying alveolar units can result in the peak-expired carbon dioxide, or $ETCO_2$, exceeding $PaCO_2$. As stated by Shankar et al., "... the slope of phase III crosses the mean $PaCO_2$ (alveolar PCO_2). As stated in our paper "The positive slope of the expired carbon dioxide results in the peak expired value exceeding the temporal mean alveolar concentration, represented by the $PaCO_2$." The full range of conditions and situations in which negative $P(a-ET)CO_2$ is present have not been fully elucidated, and, we feel, leaves room for further physiological clarification.

We stated that the $P(a-ET)CO_2$ was "... primarily a reflection of respiratory deadspace" and less so of venous admixture. It is true that substitution of $ETCO_2$ for mixed expired CO_2 ($PECO_2$) into the Bohr equation can give markedly erroneous deadspace values depending on the slope of phase III of the capnograph. It will give the minimum deadspace possible, which can be quite different. However, $P(a-ET)CO_2$ almost always increases as deadspace increases and reflects this change. It just does not allow accurate deadspace calculation.

We have not found a need to calibrate the capnometers used in this study for positive pressure ventilation after the initial calibration is done for atmospheric pressure relative to site altitude. This has been the case when this site was used as a clinical testing centre for the capnometers before widespread clinical release. It was also found in the present study that there was no difference in the $P(a-ET)CO_2$ during spontaneous ventilation with 5 cmH_2O CPAP compared with full mechanical ventilation without spontaneous respiratory efforts.

The writers state that the "... reduction of functional residual capacity and haemodilution following CPB ... may result in substantial alveoli with low $\dot{V}/\dot{Q}$ ratio." This is true for reduced FRC. However, "no worsening of regional distribution of ventilation to perfusion occurs during haemodilution."

Our paper was an evaluation of $P(a-ET)CO_2$ in acute, rapidly changing clinical conditions. For individual patients, we found there was marked variability, despite good correlation between $PaCO_2$ and $ETCO_2$ in the whole population. This relationship may be different under different conditions and should not be taken for granted.

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Intubation with lighted stylet

To the Editor:

Over the past two years, we have used the Tube Stat[®]* lighted oral intubation stylet without a laryngoscope for over 1200 elective intubations. The lighted stylet is especially useful in patients with extensive or expensive dental work, poor teeth, limited mouth opening or limited range of neck movement.

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