Title: A VENTILATORY STANDARD FOR HIGH FREQUENCY VENTILATION


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Introduction. High frequency ventilation (HFV) has been applied to many clinical situations, yet ventilatory standards for HFV have not been determined. The Radford nomogram can be used for respiratory rates below 50 bpm and a nomogram provided by Bong et al. is only applied to specific bronchoscopies at 60 bpm. In the present study, a ventilatory standard for a wide range of respiratory rates from conventional IPPV to HFV was calculated theoretically based on traditional concept of ventilation and applied to patients during surgery to test its validity.

Theory. A mathematical lung model shown in Figure 1 was used to derive equations. The value of carbon dioxide production (VCO₂), desired PaCO₂, anatomical dead space (Vₐₕ) and alveolar dead space (Vₐₛ) were given. The following assumptions were made: 1) equilibrium between PaCO₂ and CO₂ tension in perfused alveoli; 2) F/C0₂=0; 3) rebreathed CO₂ from anatomical dead space enters perfused alveolii and alveolar dead space in proportion to each ventilatory volume; 4) both perfused alveoli and alveolar dead space are ventilated synchronously.

From these assumptions, the following equations are derived

\[
\dot{V}_E = \frac{(\dot{V}_{AE} + \dot{V}_{DF})}{2} \sqrt{\frac{V_{AE} + V_{DF}}{2}} - 4r_A V_{AE} V_{DF}
\]

(1)

\[
\dot{V}_{AE} = V_{CO₂} (1-r_A) (PaCO₂/713)
\]

(2)

Where

- \( \dot{V}_{AE} \): effective alveolar ventilation when alveolar dead space exists
- \( r_A \): respiratory rate

To calculate the ventilatory volume to maintain a desired PaCO₂, the following assumptions were made: 1) anatomical dead space ratio \( r_A = 1 \) for normal lung function; 2) anatomical dead space was estimated as \( V_{DF} (\text{mL}) = 0.977 \times 8 \times \text{BW} (\text{lbs}) = 2.15 \times \text{BW} (\text{kg}) \)

(3)

3) PaCO₂=40 torr. When the increase in alveolar dead space due to various lung diseases is supposed, greater \( r_A \) values, such as 0.2, 0.3, ..., can be assumed to calculate larger ventilatory volume. The VCO₂ values were derived from the Radford's paper.

Figure 2 shows an example of minute ventilation and tidal volume calculated for a 70 kg male subject. Minute volume increases proportionally to respiratory rate due to the increase in dead space ventilation (shaded area) while alveolar ventilation remains unchanged. Tidal volume decreases inversely proportional to rate and converges to anatomical dead space at infinite rate. Although at HF tidal volume approaches anatomical dead space, the former is always larger than the latter.

Methods. The ventilatory standard calculated as above was applied to ventilate sixteen patients during halothane-nitrous oxide general anesthesia for various surgeries. Informed consent and institutional approval for the study were obtained. Respiratory rate was changed to 14, 40, 80, 120, 160 and 200 bpm and patient’s exhaled volume was monitored by a Wright respirometer and set to the value of the standard based on patient’s body weight. PaCO₂ was analyzed 30 minutes after changing respiratory rate.

Results. Figure 3 shows the measured PaCO₂ at each respiratory rate. PaCO₂ was maintained at normal level between 33.5 and 38.2 torr (mean values) and normal PaO₂ corresponding to F₂O₂ was obtained in the above range of respiratory rates.

Discussion. The result shows the validity of our ventilatory standard. This ventilatory standard was derived based on the traditional concept of ventilation and could maintain normal PaCO₂ and PaO₂. This fact suggests that gas exchange at HFV might be explained well by the conventional ventilatory mechanism up to at least 200 bpm.

References: