Title : VENTILATION OF HUMANS BY HIGH FREQUENCY OSCILLATION

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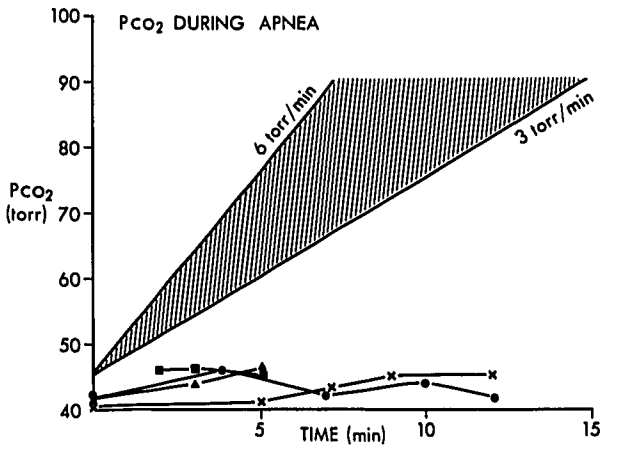
Introduction. Conventional ventilators deliver fresh gas cyclicly to the alveoli primarily by bulk flow, usually at normal breathing frequencies. Existing high frequency variations have been based on the same fundamental approach, with the difference that large minute volumes of fresh gas are divided into small volumes at very high rates. However, we have recently shown[1] that normal gas exchange can be achieved for many hours in apneic dogs using a fundamentally different method not based on convective transport (i.e. bulk flow). Instead, a high frequency sine wave oscillation with a volume much smaller than the dead space volume is applied at the endotracheal tube to induce gas mixing within the entire lung volume. This paper demonstrates that this principle is equally effective in human volunteers and in patients.

Methods. Oscillations were generated by a piston pump of variable stroke and frequency. In these studies the frequency was kept constant at 15 Hz; the stroke volume depended on the circuit in use. To date we have oscillated 4 physician volunteers and 3 patients requiring mechanical ventilation. The normal subjects were intubated under local anesthesia and blood samples were obtained from a radial artery line. Maximum breath-hold time awake was measured with and without oscillation. Thiopental (3-5 mg/kg) was then administered IV and both the duration of the resulting apnea and arterial blood gas tensions were monitored. In the patient group, two were being electively ventilated following vascular surgery and had reasonably normal lungs. The third patient had extensive pulmonary consolidation, a large hemothorax, a calculated Qs/Qt = .75 and septic shock. Each patient while sedated and paralyzed was oscillated for one hour. A Bird manometer measured mean airway pressure at the endotracheal tube. Oxygen saturation was continuously monitored with an ear oximeter, blood samples were obtained from an arterial line for analysis and cardiac output was measured every 20 mins. by the thermodilution technique. The experiment was approved by the Human Ethics Committee of the University of Toronto and informed consent was obtained for each subject.

Results. In the human subjects the awake breath-hold time at FRC increased from 45-80 sec unassisted up to 5-7 minutes while oscillated. The loss of consciousness induced by thiopental was accompanied by the abrupt onset of apnea that lasted 5-15 min (duration varied with individual dose-response). Fig 1 demonstrates the maintenance of normal $PaCO_2$ tensions during this apneic oscillation.



For comparison, the shaded area depicts the degree of CO_2 retention predicted during apnea of this duration. In the patients Po_2 was appropriate for their F_IO_2 and Pco_2 tensions and cardiac outputs were unchanged from values obtained during conventional ventilation. Mean airway pressure ranged from 5-10 cmH_2O.

Discussion. The major advantage of this new form of ventilation is that CO_2 exchange can be achieved at low mean airway pressures. Oxygen tension can be controlled by manipulating F_IO_2 and mean airway pressure. The mechanism by which high frequency oscillation effects gas exchange is not totally clear. It is not merely apneic oxygenation since that technique is limited by accumulation of CO_2. We believe that the high frequency oscillating sine wave facilitates diffusion in a manner analagous to cardiogenic oscillation. It is known that the beating action of the heart enhances the diffusive transport of CO_2 up the airways. Facilitation of diffusion by sinusoidal oscillation is also well established in the physical sciences [2]. This study demonstrates that high frequency oscillation in humans offers an alternate strategy for maintaining gas exchange at relatively low airway pressures.

References.

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2. Scotter DR, Thurtell GW, and Raats PAC. Dispersion resulting from sinusoidal gas flow in porous materials. Soil Science 104, 306-308, 1967.

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