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FACTORS INFLUENCING TIDAL VOLUME DURING HIGH-FREQUENCY JET VENTILATION

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INTRODUCTION :

During high-frequency jet ventilation (HFJV), tidal volume (V_T) results from the addition to the jet gas volume delivered by the ventilator (Vjet) of an additional volume entrained by the Venturi effect (E). Up to now CO_2 clearance mechanisms during HFJV have not been completely understood, due mainly to the inadequacy of most methods using direct spirometry for measuring V_T and E in clinical conditions. In this study, an external spirometric method (1) was used to determine factors influencing V_T, Vjet, E and CO_2 clearance in patients under HFJV.

METHODS :

Patients and equipment : Twenty two critically ill patients with respiratory failure were studied after informed consent had been obtained. At the time of the study all were sedated with Fentanyl 60 mcg. kg^{-1} and paralysed with Pancuronium 0.1 $mg.kg^{-1}$. HFJV was provided as previously described (2) using an Acutronic Ventilator, a 14 gauge injector cannula and a 3-way swivel adapter allowing a bias flow of additional gases (30 $l.min^{-1}$).

Volumes measurements : An elastic band with a differential linear transformer (DLT) was connected around the thorax at the nipple level in order to measure changes in rib cage perimeter (1). Assuming that the volume measured at the mouth by spirometry is equal to the change in rib cage volume in a paralysed patient, DLT signals were calibrated using a graduated 2 liter-syringe. The displacements corresponding to successive injections of 50 ml were recorded on a Gould ES 1000 recorder and the calibration curve was constructed.

The accuracy of the DLT whose frequency response was 60 Hz, for measuring V_T at high frequencies was assessed in 8 patients. Bias flow and expiratory line were closed and Vjet, which is independant to the out-put mechanical load, was measured using 2 methods: directly by connecting the ventilator to a Tissot spirometer and indirectly with DLT by inflating lung's patients with the ventilator up to 1500 ml above apneic FRC. Inspiratory:Expiratory (I:E) ratio and driving pressure (DP) were kept constant and 4 frequencies were used at random. Measurements were made in tripicate. Results (Table, mean ± SD) show that DLT accurately measured Vjet at any frequency :

Frequency ($B.min^{-1}$)	100	200	400	600
Vjet ml (DLT)	217 ± 10	123 ± 9	69 ± 1	49 ± 1
Vjet ml (Tissot)	209 ± 10	114 ± 10	66 ± 2	45 ± 1

Procedures : Eight different ventilatory settings were used at random in order to determine changes in V_T, Vjet and E induced by increasing I:E ratio (0.25, 0.43 and 0.67), DP (1.8, 2.2 and 2.6 bars) and frequency (100, 200, 400 and $600.min^{-1}$). After a steady state of 15 min at FiO_2 0.4, arterial blood gas, V_T and Vjet were measured using DLT. E (%) was calculated as $\frac{V_T - Vjet}{V_T}$. Data were expressed as mean ± SD and were compared using analysis of variance and Student's paired t-test.

RESULTS :

As shown in fig 1, increasing DP increased V_T, Vjet (■) and E (□) (* $p < 0.05$). PaO_2 unsignificantly increased (63 ± 33 mmHg, 67 ± 29 mmHg, 72 ± 34 mmHg) and $PaCO_2$ significantly decreased (32 ± 10 mmHg, 29 ± 9 mmHg, 26 ± 7 mmHg, * $p < 0.05$).

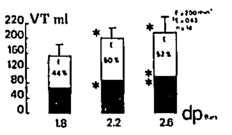

Figure 1

As shown in fig 2, increasing I:E ratio significantly increased Vjet, significantly decreased E and unsignificantly increased V_T. $PaCO_2$ increased (71 ± 40 mmHg, 72 ± 34 mmHg, 84 ± 47 mmHg NS) and $PaCO_2$ decreased (30 ± 8 mmHg, 26 ± 7 mmHg, 25 ± 8 mmHg, * $p < 0.05$).

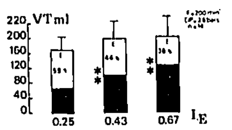

Figure 2

As shown in fig 3, increasing frequency significantly decreased V_T, Vjet and E (* $p < 0.05$). PaO_2 remained unchanged (70 ± 40 mmHg, 72 ± 34 mmHg, 72 ± 32 mmHg, 74 ± 24 mmHg) and $PaCO_2$ increased (21 ± 6 mmHg, 26 ± 7 mmHg, 42 ± 11 mmHg, 53 ± 15 mmHg, * $p < 0.05$).

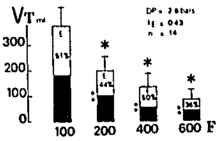

Figure 3

As shown in fig 4, a significant relationship was found between $PaCO_2$ and V_T. No significant relationship was found between $PaCO_2$ and the product V_T x Frequency.

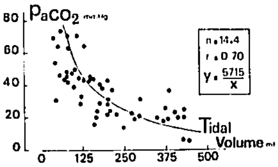

Figure 4

DISCUSSION :

Several conclusions can be drawn from this study : 1) when using a frequency < $200.min^{-1}$ with a DP > 2 bars, HFJV cannot be considered anymore as low tidal volume high-frequency ventilation ; 2) gas entrainement which is mainly dependant on driving pressure, remained important up to frequencies of 10 Hz ; 3) increasing I:E ratio decreases E ; 4) $PaCO_2$ during HFJV is mainly dependant on the absolute level of V_T and not on the product V_T x Frequency. Moreover, since most patients with V_T < 100 ml were hypercapnic it is likely that convection rather than enhanced diffusion or "pendeluft" plays a determinant role in CO_2 elimination during HFJV.

1. G. SIMONNEAU et al. : Diaphragm dysfunction induced by upper abdominal surgery. Role of post-operative pain. Am. Rev. Respir. Dis. 128 : 899, 1983

2. J.J. ROUBY et al. : High-frequency jet ventilation in post-operative respiratory failure : determinants of oxygenation. Anesthesiology 59 : 281,1983