〔特別講演〕

Measuring of lung mechanics and carbon dioxide elimination during artificial ventilation

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The principles for measurement described here are based on use of the Servo Ventilator[1)], but may be applied to all ventilators that provide flow and pressure signals.

Lung mechanics

When a constant inspiratory flow and an end inspiratory pause are used, inspiratory resistance (R_I, $cmH_2O\ l^{-1}\ sec$) is calculated from maximum pressure and end inspiratory pause pressure (P pause and $\hat{P}$, cmH_2O) and inspiratory flow ($\dot{V}_I$, $l\ sec^{-1}$) : according to the formula $R_I = \frac{\hat{P} - P\ pause}{\dot{V}_I}$ (Fig. 1).

In scientific work P and $\dot{V}$ should be directly recorded. In clinical work with less need of exactness, pressure may be read from the panel meter, and $\dot{V}_I$ calculated from the equation : $\dot{V}_I$ ($l\ sec^{-1}$) = preset minute volume ($l\ min^{-1}$) $\times \frac{100}{INSP\%} \times \frac{1}{60}$.

The R_I measured is the sum of R of the ventilator, humidifier, tracheal tube and the patient's airways.

If expiratory flow approaches zero at the end of expiration, compliane (C, ml cmH_2O^{-1}) is derived from $C = \frac{V_T}{P\ pause}$ (V_T = tidal volume, ml) (Fig. 2).

If expiratory flow has not ceased when the next inspiration starts, a positive end expiratory lung pressure (P_E end) exists :

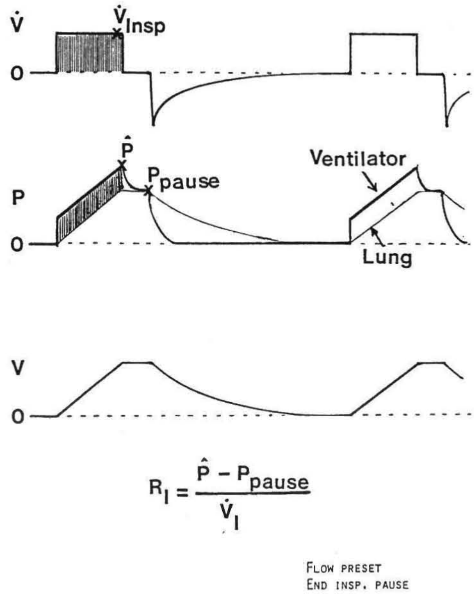

Fig. 1

$C = \frac{V_T}{P\ pause - P_E\ end}$ (Fig. 3).

P_E end is obtained in the Servo Ventilator 900 C by using the end expiratory pause function. In the older models, P_E end is pro duced by blocking off the inspiratory valve manually with a forceps.

P_E end is normally zero. In chronic obstructive lung disease it is often increased to 6～8 cmH_2O and in acute bronchospasm it may exceed 16～20 cmH_2O. PEEP also raises P_E end.

Expiratory resistance (R_E) can be estimated at a moment just after the start of expiration. Most of the compressed gas in the tubings leaves the system quickly. Without

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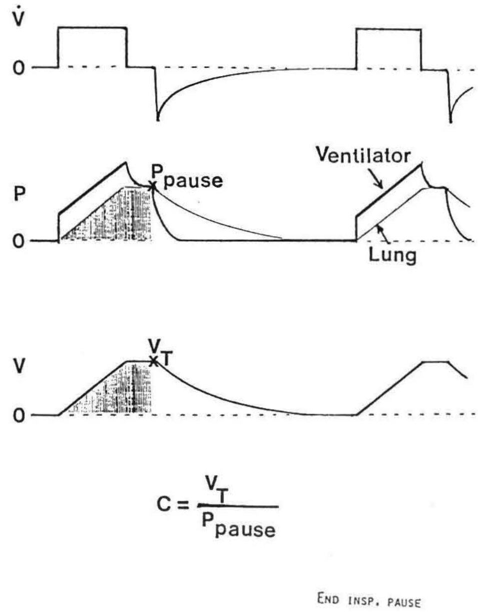


Fig. 2

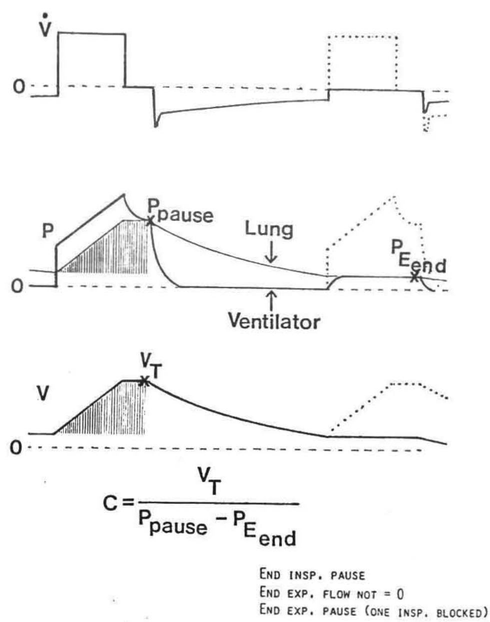


Fig. 3

a humidifier or PEEP valve, the expiratory flow of the patient reaches its peak level in about 100 ms, resistance at that moment, $R_E\,100\,\text{ms} = \frac{P\,\text{pause} - P_E\,100\,\text{ms}}{\dot{V}_E\,100\,\text{ms}}$ (Fig. 4). With a mechanical PEEP valve and large volume humidifier, it may take up to 200 ms

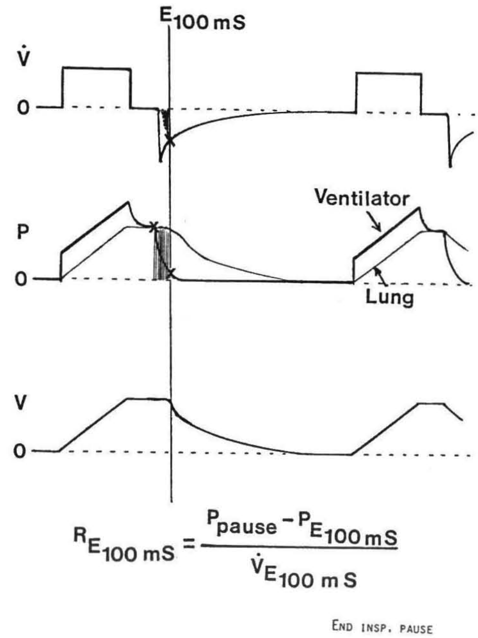


Fig. 4

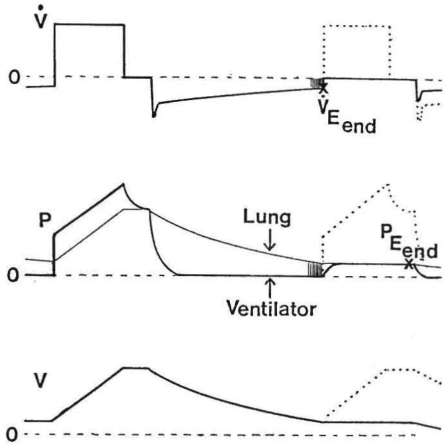
for compressed gas to empty.

It is also possible to measure resistance at the end of expiration (R_E end): $R_E\,\text{end} = \frac{P_E\,\text{end}}{\dot{V}_E\,\text{end}}$ (Fig. 5).

R_E end is often higher than R_E 100 ms, due to airway closure when the lung volume decreases and to the effect of the spread of time constants within different lung regions. Regions with low resistance will have a greater share of the initial expiratory flow, while high resistance regions dominate the end of expiration.

The type of gas can influence flow measurement and for exact measurements the characteristics of different gases must be taken into consideration.

If the Servo Ventilator flow meters are calibrated with air according to the manual, correction for change of gas is made by the factors given in Table 1. Oxygen flow is overestimated in both inspiratory and expiratory flow meters, while N_2O at normally used settings is overestimated by the inspi-



$$R_{E_{end}} = \frac{P_{E_{end}}}{\dot{V}_{E_{end}}}$$

END EXP. FLOW NOT = 0
·END EXP. PAUSE (ONE INSP. BLOCKED)

Fig. 5

Table 1

	Actual flow / Preset insp. flow	Actual flow / Read exp. flow
Air	1.00	1.00
O_2	0.92	0.92
N_2O	1.06-0.90	1.09
$N_2 : O_2$ (1 : 1)	0.96	0.96
$N_2O : O$ (1 : 1)	0.99-0.91	0.00

ratory flow meter and underestimated by the expiratory one.

The difference between the inspiratory and expiratory flow meters depend on the type of flow. In the expiratory flow sensor flow is mostly laminar, while the inspiratory flow sensor has turbulent flow at high flow rates (Fig. 6).

CO_2 measurement

The Siemens-Elema CO_2-meter[2] has a fast response and provides information on end tidal CO_2 (P_{ECO_2}), elimination of CO_2 per breath (V_{TCO_2}) and per minute ($\dot{V}CO_2$).

The type of gas used for ventilation influences CO_2 measurements and the device should be calibrated with CO_2 dispersed in suitable gas mixtures. If calibration is done with other types of gases, the value may be corrected[3)4)].

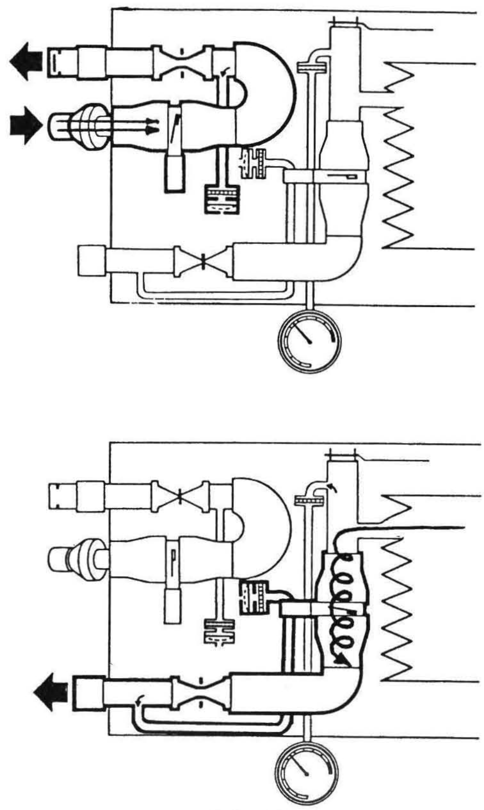


Fig. 6

The monitoring of expired CO_2 gives valuable information about the efficiency of ventilation, and lung perfusion. Sudden changes in lung blood flow, which is normally equivalent to cardiac output, are immediately mirrored by changes in CO_2-elimination. In ventilator treatment for severe bronchial asthma, monitoring of CO_2-elimination simplifies optimum setting of ventilator frequency, tidal volume and ventilatory pattern.

References

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