TITLE: GAS MIXING DURING APNEA AND CONTINUOUS FLOW VENTILATION AT LOW LUNG VOLUME

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Introduction: Continuous flow ventilation (CFV) produces gas exchange without respiratory movements.[1] Absence of collateral airways (CA) impairs CO2 removal during CFV.[2] CFV may have applications in thoracic surgery on adults and children when a motionless field is desirable, when gas exchange is impaired as during one lung ventilation, and with respiratory distress syndrome (RDS). After thoracotomy, or following atelectasis and RDS, lung volume falls below functional residual capacity (FRC). CA and other airways close. Gas mixing at constant lung volume for example, during apnea and CFV, may be impaired. We, therefore, examined gas mixing through CA before and after median sternotomy, during 1 min of apnea and 15 min of CFV, to quantitate differences occurring with the open chest.

Methods: Seven mongrel dogs average 21 kg were anesthetized with 30 mg/kg pentobarbital and pavulonized (0.2 mg/kg). Fluid, neuromuscular and anesthesia maintenance were provided by constant infusion. Two 2.5 mm internal diameter (I.D.) catheters were positioned 3.5 cm beyond the carina in each mainstem bronchus, using fiberoptic bronchoscopy. Dogs were tracheally intubated (9 mmID) and ventilated with conventional mechanical ventilation, FIO2 1.0, rate 12/min to paCO2 35-40 mmHg. Pulmonary (PA) and systemic arterial pressures were monitored. Cardiac output was measured (thermodilution) and arterial and mixed venous blood gas sampled before 1 min of apnea and before and at 5 min intervals for 15 min of CFV using 1 L/kg/min O2 through the endobronchial catheters. To objectively quantitate gas mixing through CA a 3 lumen balloon tipped catheter was placed in a subsegmental bronchus of the left lower lobe and the balloon inflated with water to seal the airway. 1-2 mCi Xenon 133 (Xe) in 4 ml of air was injected into the occluded segment after withdrawl of a similar volume of segmental gas. Xe washout (XeW) was recorded by gamma camera during 1 min of apnea or 6 min CFV. Data was stored on computer (PDP 11/34) for analysis by Gamma 11 software. Rate constants (RC) were determined using non-linear least squares analysis. RC for XeW by CA (Xeca) were calculated from XeW - Xe blood uptake (Xeb). Xeb was obtained from -ln Xeb/Xeo = $\dot{Q}$/8.75 x V x 1.086. Where $\dot{Q}$ = cardiac output, V = lung volume,[3] (estimated from body weight as FRC when chest closed[3] and FRC x 0.5 after thoracotomy). Xe gas/blood partition coeff at BTPS = 8.75/L, t = time, Xeo = initial Xe counts in segment. Values were expressed as mean ± standard deviation. Statistical comparison used repeated measures analysis of variance.

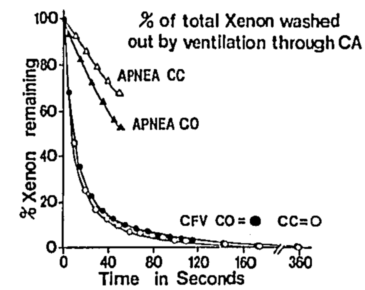
Results: Cardiac index (CI), mean arterial pressure (MAP) and PA pressure, intrapulmonary shunt ($\dot{Q}s/\dot{Q}t$), arterial O_2 (paO_2) and CO_2 ($paCO_2$, $p\bar{v}CO_2$) are shown in Table 1 during CFV and before 1 min apnea. Data is shown during chest closed (cc) and after chest opening (co). $PaCO_2$ and $P\bar{v}CO_2$ rose faster during CFV after CO ($p < 0.02$). There were no other cardiopulmonary differences. The % of total Xe injected that was washed out during apnea and CFV with cc or co is shown in Fig 1. There were no significant differences in Xeca during CFV with cc or co or during apnea with cc or co.

TABLE 1

	CFV						APNEA	
	CC			CO			CC	CO
TIME (min)	0	5	10	0	5	10	0	0
CI L/min/m²	4.3 ±1.6	4.6 ±2.0	4.6 ±2.0	2.8 ±0.8	3.3 ±1.4	3. ±1.2	4.0 ±1.4	3.2 ±1.8
MAP mmHg	128 ±27.0	127 ±24.5	126 ±17.2	108 ±17.2	114 ±24.3	115 ±22.0	122 ±26.1	109 ±16.7
PA mmHg	13 ±3.6	15 ±3.5	15 ±4.3	14 ±4.8	16 ±4.9	16 ±7.2	12 ±1.4	14 ±5.7
$\dot{Q}s/\dot{Q}t$ %	26 ±21.1	25 ±20.7	26 ±21.1	19 ±8.4	21 ±14.0	20 ±12.3	17 ±0.4	25 ±13.6
paO2 mmHg	387 ±109	410 ±106	404 ±107	333 ±108	363 ±108	364 ±113	484 ±37.5	260+ ±95.6
paCO2 mmHg	37 ±1.2	43 ±5.3	44 ±6.8	37 ±3.7	51* ±6.0	55* ±6.8	39 ±1.0	39 ±1.5
pvCO2 mmHg	43 ±3.6	48 ±4.4	48 ±8.9	44 ±4.2	54* ±5.5	59* ±5.3	44 ±2.2	45 ±5.7

*$p < 0.02$ +$p < 0.05$

Fig 1:



Discussion: Ventilation of obstructed lung occurred through CA at lung volumes below FRC during oc apnea and CFV. Forty ± 16.2% of total Xe injected was washed out during 1 min apnea with co and 31 ± 9.3% with cc. In the first 1 min of CFV 92 ± 7.1% XeW occurred with cc and 89 ± 14.0% with co. The failure of ventilatory XeW to be reduced during co when more airways were closed suggests that other factors promoted XeW through open CA after thoracotomy. Possible mechanisms include closer proximity of the lung to the heart causing increased lung parenchymal transmission of cardiogenic oscillations or increased pulmonary vascular pulsatility. The importance of CA in gas exchange at low lung volumes may make CFV less effective in neonates since they lack CA.[4] Similarily, although continuous flow of oxygen may assist gas exchange during extracorporeal membrane CO_2 removal in adult RDS, it may be less effective in children.

Conclusions: (1) CO_2 excretion was less efficient after thoracotomy during CFV, but oxygenation was unchanged. (2) CA take part in gas exchange at lung volumes below FRC during apnea and CFV. (3) CFV increased gas mixing through CA 2.3-3 times compared with apnea.

References:
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2. Mackenzie et al: Amer Rev Respir Dis 131:A313, 1985
3. Attinger EO, Cahill JM: Amer J Physiol 198:346, 1960
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