TITLE: A NEW INDEX OF PULMONARY FUNCTION FROM SINGLE BREATH CO_2 WASHOUT

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INTRODUCTION: The total cross sectional area of the conducting airways expands rapidly as one moves from the trachea toward the alveolar ducts. The large area at the periphery leads to a low value for gas velocity. As a result, the Peclet number in the alveolated region is much less than one, implying that gas transport is predominantly by molecular diffusion rather than convection. This together with Fick's law of diffusion means that longitudinal diffusion gradients of CO_2 must exist in the peripheral airways. When averaged in time over a respiratory cycle these gradients must be large enough to transport 200 ml/min of CO_2 (at rest) across the effective peripheral cross sectional area. Quantitative application of Fick's law allows the computation of this area.

$VCO_2 = A \times dc/dx \times D$ eq. 1

for exponentially increasing area

$dc/dx = A \times dc/dv$ eq. 2

combining

$VCO_2 = A^2 \times D \times dc/dv$ eq. 3

solving for A

$A = (VCO_2/(D \times dc/dv))^{.5}$ eq. 4

where

D = molecular diff of CO_2 in Air = .16 cm^2/sec
A = effective peripheral area (cm^2)
c = CO_2 fractional concentration
x = linear distance from mouth (cm)
v = cumulative volume from mouth (cm^3)

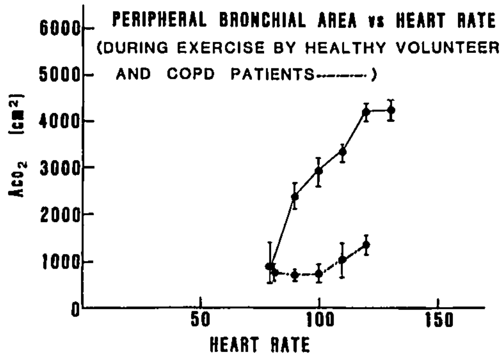
Assuming steady exhaled flow and pure convective mixing of a very large number of gas streams, originating in the alveolar ducts, at bronchial bifurcations, it can be shown that the CO_2 concentration seen at the mouth is very nearly (within 3% of) the spatial average of the CO_2 concentration in alveolar ducts at the beginning of exhalation[1,2]. It should thus be possible to apply equation 4 to single breath, CO_2 vs exhaled volume curves and calculate the effective peripheral area.

METHODS: Six normal adult males and four patients with chronic obstructive pulmonary disease consented to this study, approved by our institutional review board. All of the patients had normal arterial CO_2 tensions at rest. The mouthpiece and nose clips were fitted. A mouthpiece was connected to a valved breathing circuit that permitted inhalation of fresh room air and directed exhaled gases into our measurement apparatus. ECG leads were attached and heart rate was continuously monitored. Measurements were made at rest for 5 minutes then during graded exercise on either a treadmill or a bicycle ergometer. Effort was increased in graded steps until the heart rate reached 160 or the patient became exhausted and requested cessation of the study. The measurement apparatus incorporated either a Fleisch pneumotachograph or a calibrated electronic spirometer as the flow sensor and a Siemens Model 930 infrared CO_2 analyzer or a Perkin Elmer Medspec Mass spectometer as the CO_2 sensor. The outputs of the CO_2 sensor and the flow sensor were carefully time aligned. A plot of CO_2 concentration versus exhaled volume was made for each breath. We calculated CO_2 excretion, mixed exhaled CO_2, end tidal CO_2, VD/VT and the slope of the central 50% of the alveolar portion of the CO_2 concentration versus exhaled volume curve. From these values and D, the effective area was calculated using equation 4. The resulting areas were averaged for the normal and COPD patient groups by heart rates from 80 to 140 in 10 BPM steps.

RESULTS: The mean value ±S.D. for peripheral airway area versus heart rate for normals and COPD patients is shown in the figure. Both groups had similar areas at rest, but during exercise the area increased much more rapidly in normals than in COPD patients.

DISCUSSION: The maximal area in normals of 4218 ± 235 cm^2 agrees well with morphometric data at bronchial generation 16 to 19. The increase in area which occurred during exercise in normals most probably represents recruitment of the superior portion of the lung. The COPD patients may be almost fully recruited at rest.

We conclude that estimation of peripheral airways area from analysis of single breath CO_2 excretion vs. exhaled volume plots has potential as a pulmonary function test. The measurement requires no invasive procedures. It takes into account only those portions of the lung which are both ventilated and perfused. It clearly distinguishes between normals and COPD patients. Further studies to determine the quantitive value of the data are being actively pursued.



1. Scherer PW, Neufeld GR, Aukburg SJ, Hess GD: Measurement of effective peripheral bronchial cross-section from single-breath gas washout. J Biomech Engineering 105:290-293, 1983
2. Solway J, Gavriely, Kamm RD, Drazen JM, Ingram, Jr. RH, Khoo MCK, Brown R, Slutsky AS: Intra-airway gas mixing during high-frequency ventilation. J Appl Physiol 56(2):343-354, 1984