Tfy-99.269 Current methods and issues in monitoring physiological systems

<u>Problems for examination on January 9, 2004</u>

1. Assume a patient with 30% of venous admixture (shunt) when breathing room air. How much the inspired oxygen level should be increased to restore the normal oxygenation level of the arterial blood?

2. Cardiac output is measured by an esophageal ultrasonic Doppler device aiming to the descending aorta at a nominal angle of 45°. Analyze how much relative error is typically generated by inaccuracy of a) the sound beam angle related to flow and b) inaccuracy in the estimated diameter of the aorta.

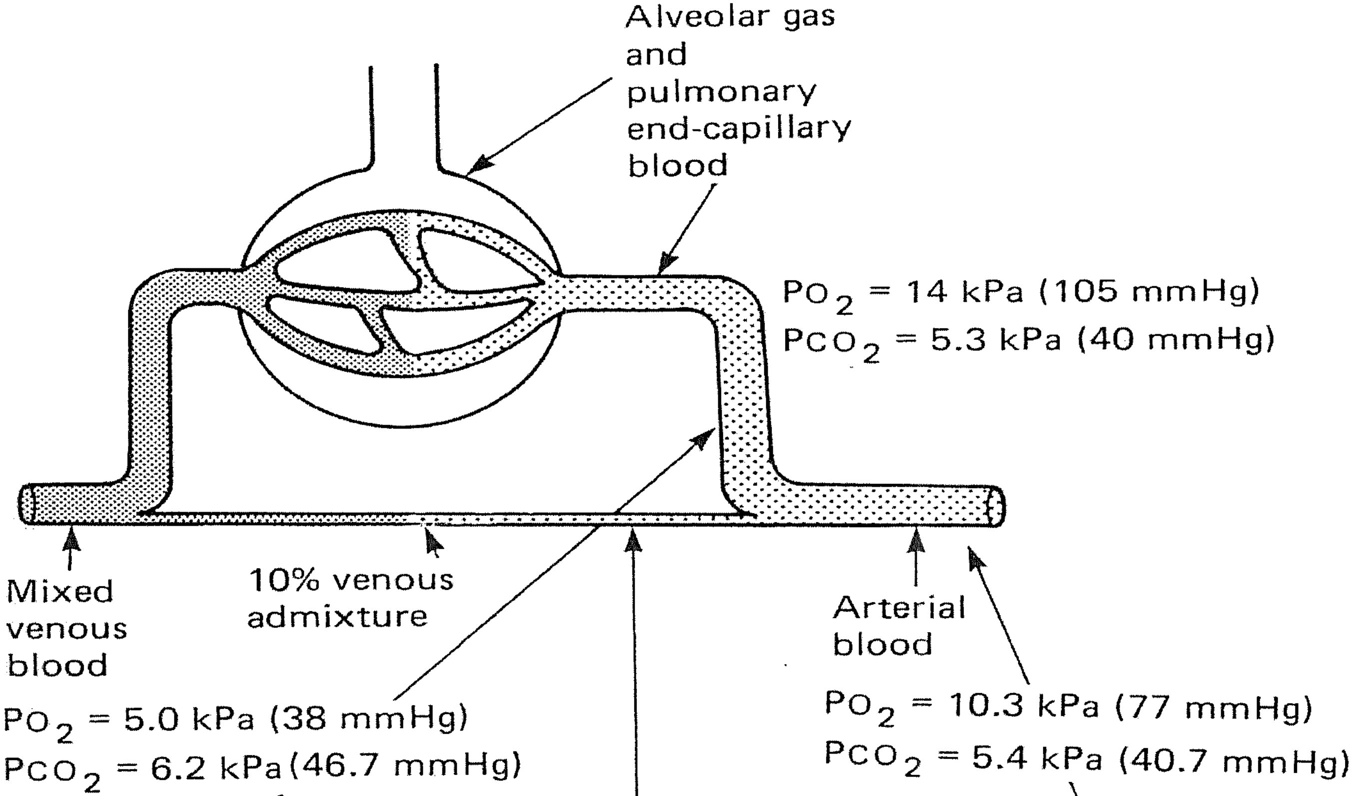
3. Analyze how much the oxygen concentration of the inhaled gas affects on the accuracy of oxygen consumpion measurement when utilizing the Haldane transformation. Let the FIO2 be increased from the room air level to 70% and assume that there is a relative error of 2% in the measurement of mixed exhaled CO2, and 4% in the difference between FIO2 and mixed expired O2.

4. A lung with compliance of 50 ml/cmH_2O is ventilated through an endotracheal tube with an inner diameter of D = 12 mm at a constant inhalation flow of 0,5 liters/s, inhalation time of 2 s and exhalation time of 4 s. Draw the standard pressure-volume loop under these circumstances.

5. Derive the basic pulse oximeter equation for SpO2 as a function of R. Calculate the value of R at SpO2 = 100% when the wavelengths used are 660 and 940 nm.

-The attached selected lecture material is at your disposal

-You may answer either in English or Finnish

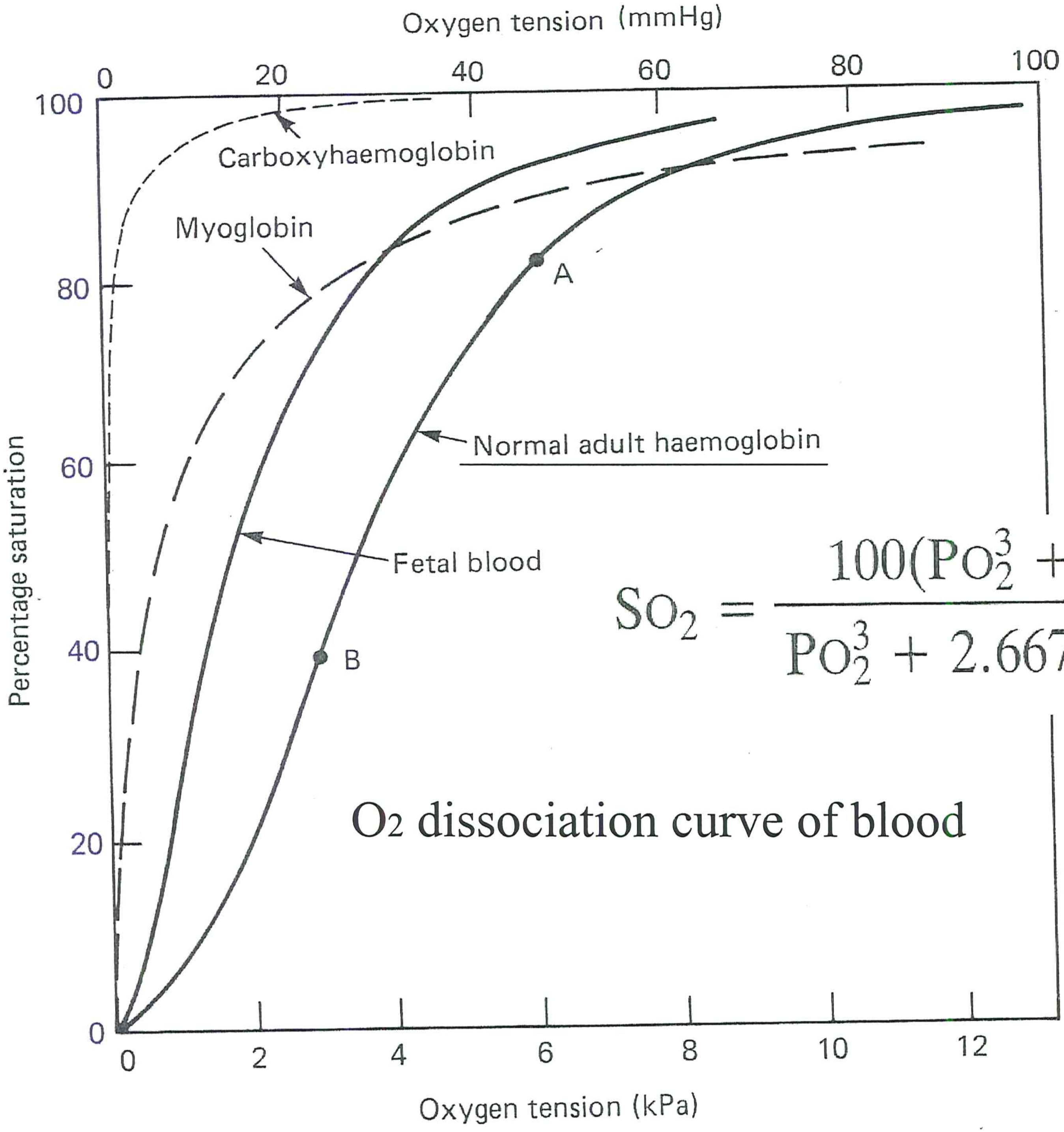


Pulmonary capillary blood flow + Venous admixture = Cardiac output

$$\dot{Q}c + \dot{Q}s = \dot{Q}t$$

$$Cc'_{O_2} \times \dot{Q}c + C\bar{v}_{O_2} \times \dot{Q}s = Ca_{O_2} \times \dot{Q}t$$

$$\therefore \frac{\dot{Q}s}{\dot{Q}t} = \frac{Cc'_{O_2} - Ca_{O_2}}{Cc'_{O_2} - C\bar{v}_{O_2}}$$



$$SO_2 = \frac{100(PO_2^3 + 2.667 \times PO_2)}{PO_2^3 + 2.667 \times PO_2 + 55.47}$$

O2 dissociation curve of blood

Ultrasonic flow meters: Doppler principle

When a target recedes from a fixed source that transmits sound, the frequency of the received sound is lowered because of the Doppler effect. For small changes, the fractional change in frequency equals the fractional change in velocity.

$$\frac{f_d}{f_0} = \frac{u}{c} \tag{8.13}$$

where

f_d = Doppler frequency shift

f_0 = source frequency

u = target velocity

c = velocity of sound

The Doppler-shifted signal is not at a single frequency, as implied by (8.15), for several reasons.

1. Velocity profiles are rarely blunt, with all cells moving at the same velocity. Rather, cells move at different velocities, producing different shifts of the Doppler frequency.
2. A given cell remains within the beam-intersection volume for a short time. Thus the signal received from one cell is a pure frequency multiplied by some time-gate function, yielding a band of frequencies.
3. Acoustic energy traveling within the main beam, but at angles to the beam axis, plus energy in the side lobes, causes different Doppler-frequency shifts due to an effective change in θ.
4. Tumbling of cells and local velocities resulting from turbulence cause different Doppler-frequency shifts.

Haldane transformation

Assuming no nitrogen exchange in the lungs:

$$F_{IN2} \cdot \dot{V}_I = F_{EN2} \cdot \dot{V}_E \quad (26)$$

Mixed expired gas values!

$$(1 - F_{IO2}) \cdot \dot{V}_I = (1 - F_{EO2} - F_{ECO2}) \cdot \dot{V}_E \quad (27)$$

Here, for simplicity, F_{ICO2} was assumed to be zero. Then by substituting V_I from (27) into (25) we obtain:

$$\dot{V}_{O2} = (F_{IO2} (\frac{1 - F_{EO2} - F_{ECO2}}{1 - F_{IO2}}) - F_{EO2}) \cdot \dot{V}_E \quad (28)$$

Manipulating further, this can be written as:

$$\dot{v}_{O2} = \left(\frac{(F_{IO2} - F_{EO2}) - F_{IO2}F_{ECO2}}{1 - F_{IO2}}\right) \cdot \dot{v}_E \tag{29}$$

The CO_2 production can be obtained by starting from:

$$\dot{v}_{CO2} = F_{ECO2} \cdot \dot{v}_E - F_{ICO2} \cdot \dot{v}_I \tag{30}$$

Again by substituting $\dot{v}_I$ from (27) into (30), we obtain:

$$\dot{v}_{CO2} = \left[F_{ECO2} - F_{ICO2}\left(\frac{1 - F_{EO2} - F_{ECO2}}{1 - F_{IO2}}\right)\right] \cdot \dot{v}_E \tag{31}$$

Using Haldane transformation we have

$$\dot{V}_{O2} = \frac{\dot{V}_E}{1 - F_{IO2}} \cdot ((F_{IO2} - F_{EO2}) - F_{IO2}F_{ECO2})$$

Let

$$F_{IO2} - F_{EO2} = F_{DO2}$$

and

$$\frac{F_{ECO2}}{F_{DO2}} = r$$

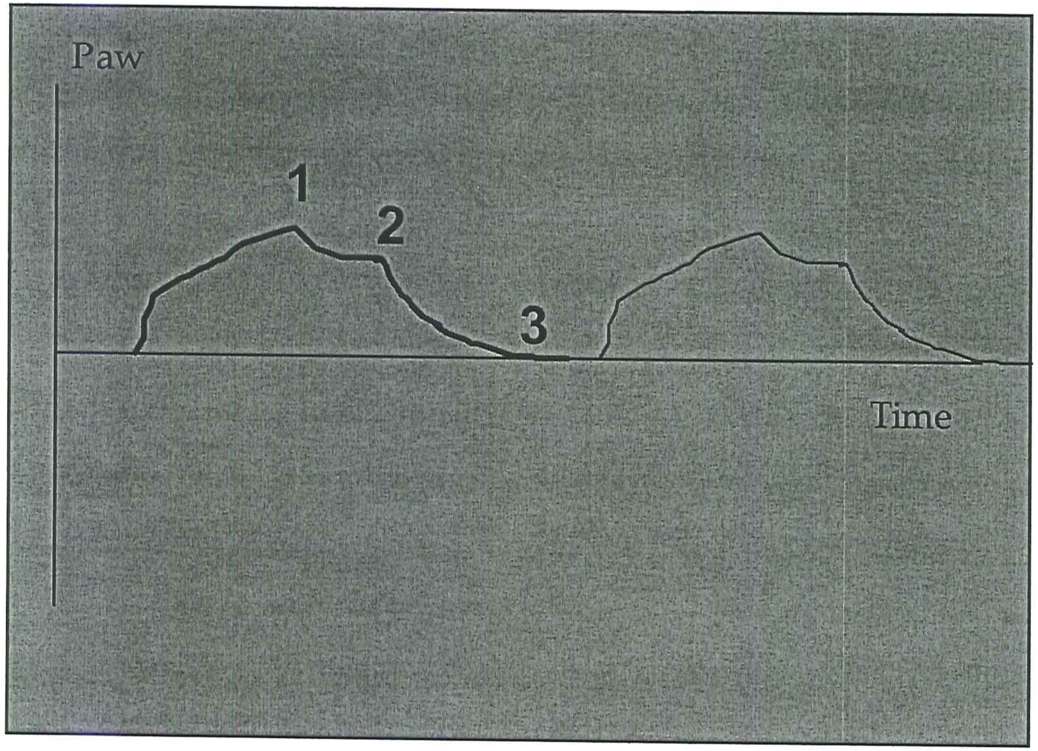
Then (b2) can be rewritten as

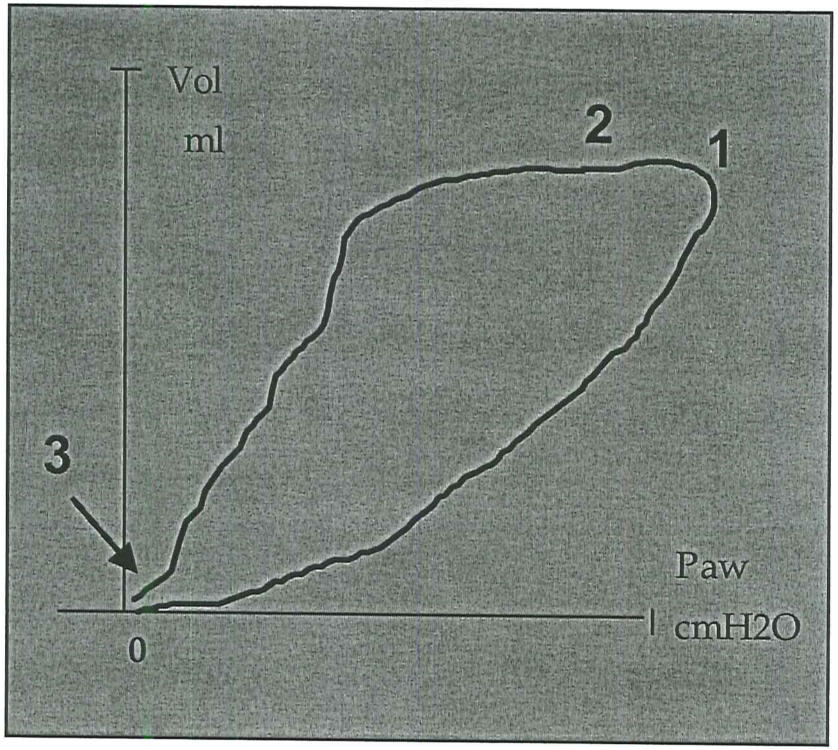
$$\dot{V}_{O2} = F_{DO2} \cdot \dot{V}_E \cdot \frac{1 - rF_{IO2}}{1 - F_{IO2}}$$

Simplified form for oxygen consumption

Think what happens when F_{IO2} approaches 1 (100%)

Pressure/Volume Loop

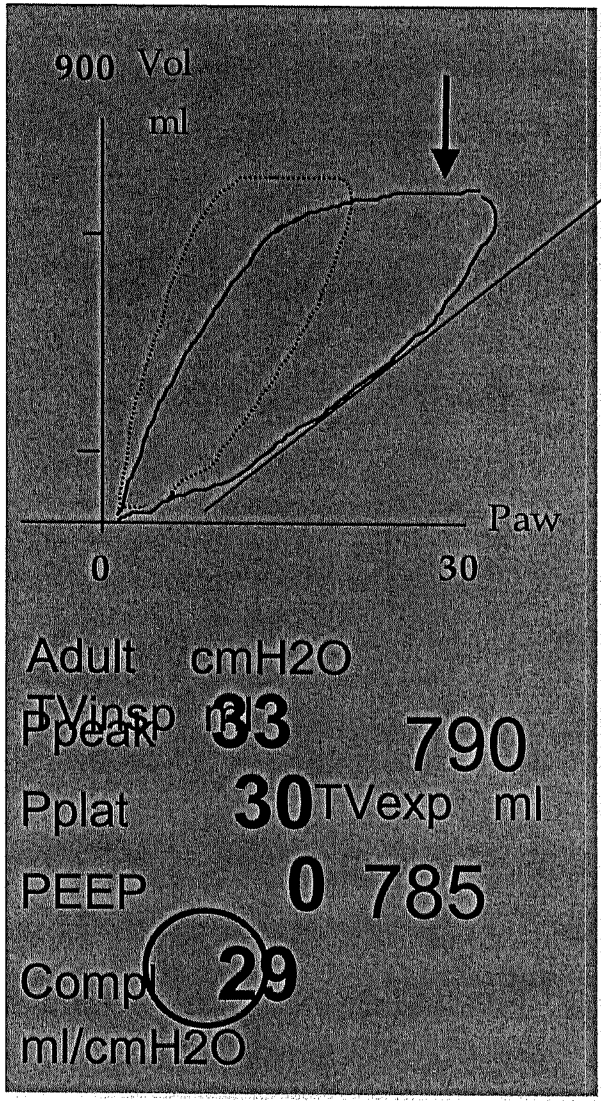




- Start of inspiration
- Inspiration
- Inspiratory pause
- Expiration

1. PEAK pressure
2. Plateau pressure
3. PEEP pressure

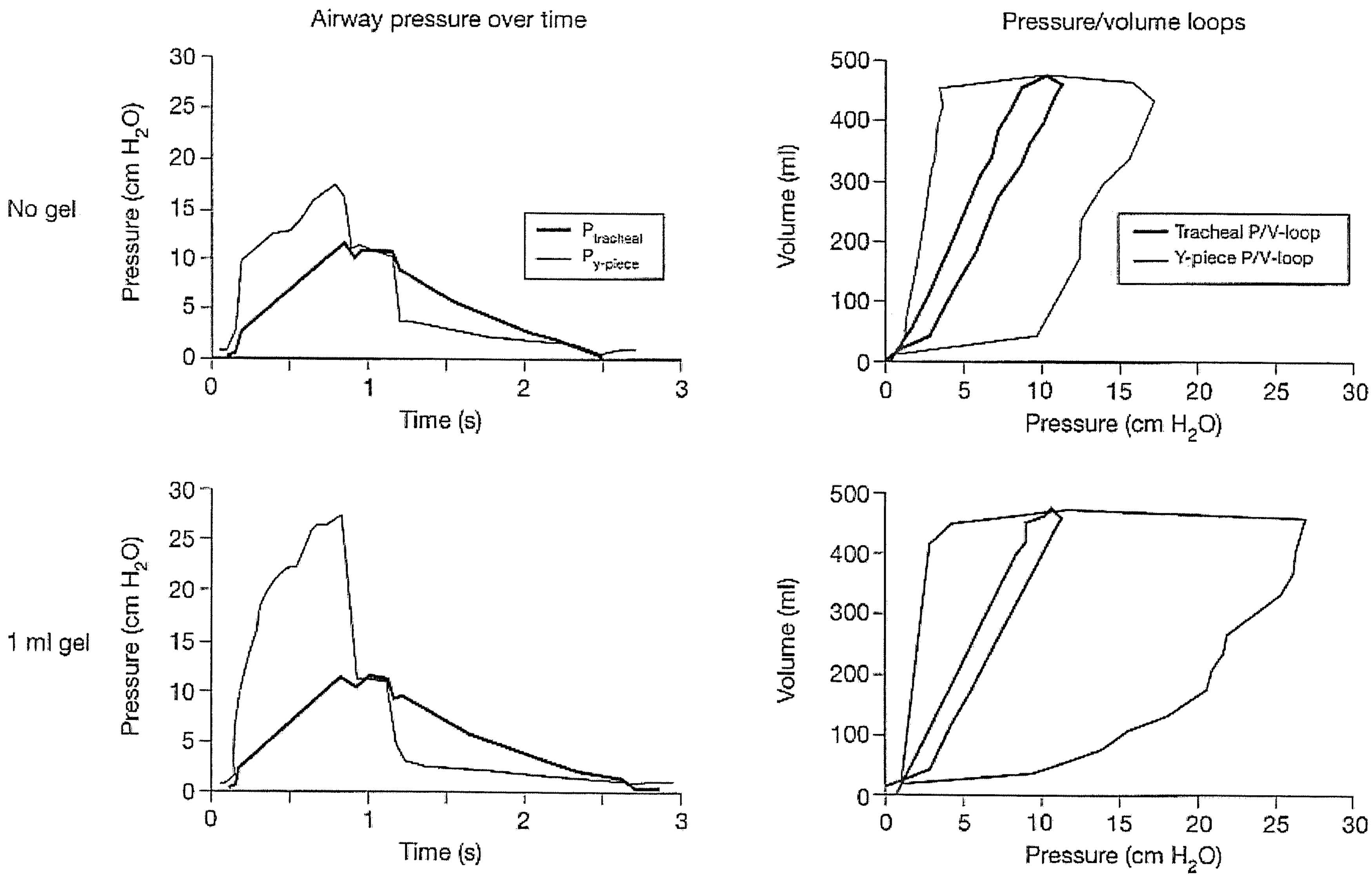
Lung Compliance



$C = \Delta V / \Delta p$ (slope)

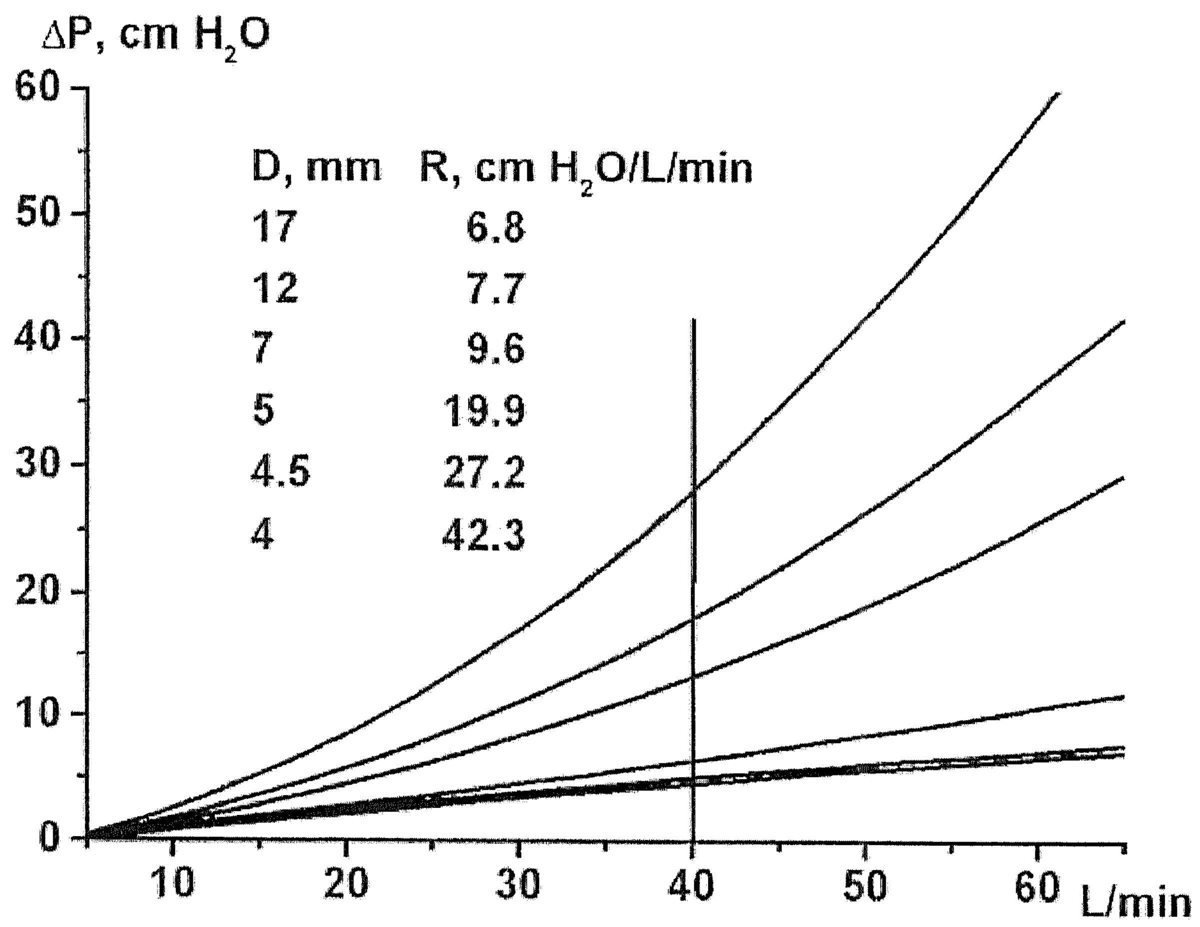
Possible causes for decreased compliance

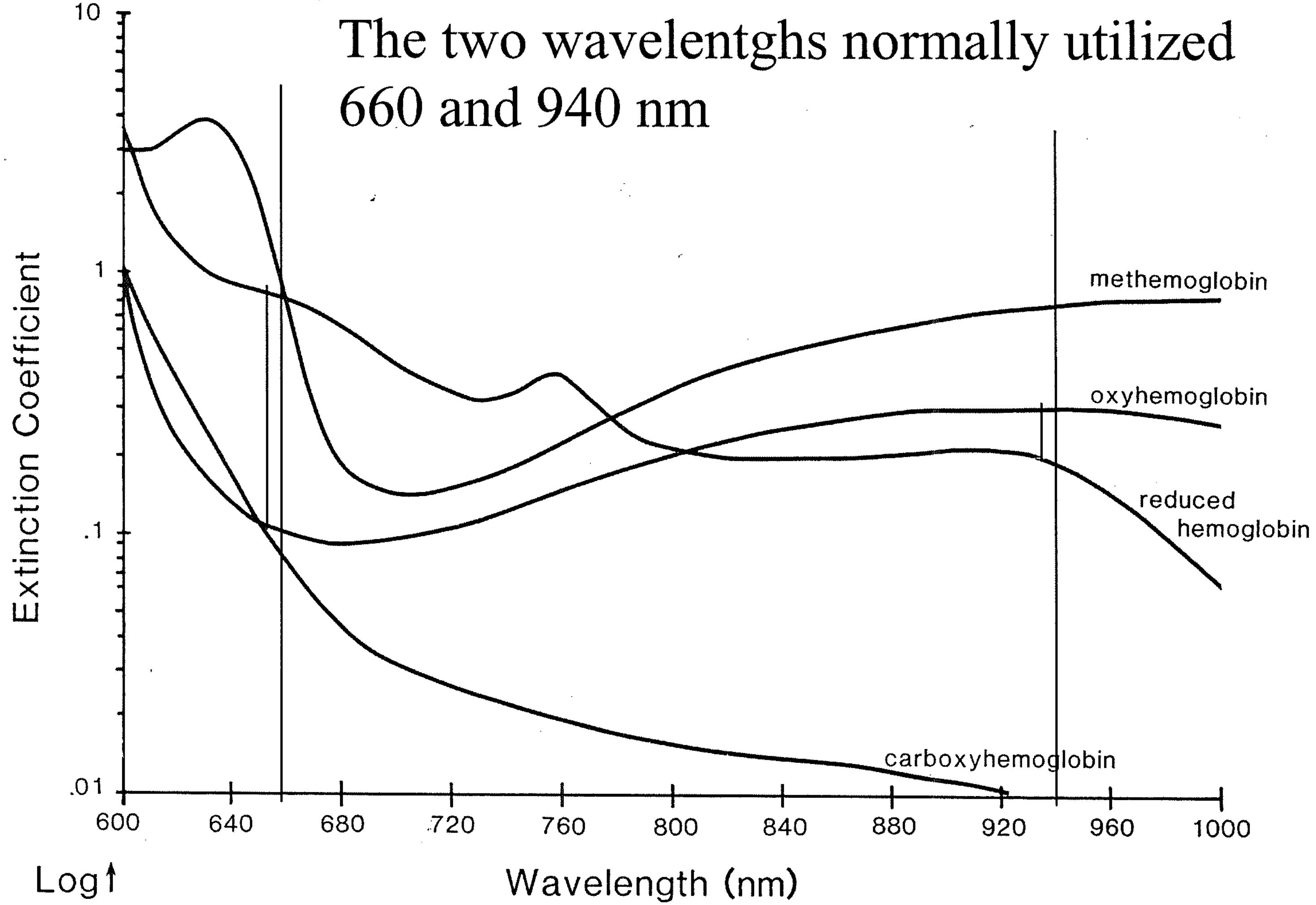
- Surgical position
- Obesity
- CO_2 insufflation in laparoscopy
- Broncospasm



Airway pressure over time
Pressure/volume loops
No gel
1 ml gel
Pressure (cm H_2O)
Time (s)
$P_{tracheal}$
$P_{y\text{-}piece}$
Volume (ml)
Pressure (cm H_2O)
Tracheal P/V-loop
Y-piece P/V-loop

Pressure loss vs. flow for different sizes of endotracheal tubes





Extinction curves of different haemoglobins.

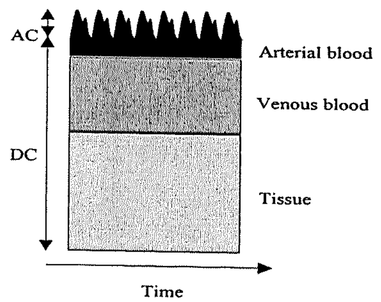
Unfortunately, light traveling through biologic tissue such as the finger or earlobe is absorbed by more than two substances. Primary absorbers are the skin pigmentation, bones, and the arterial and venous blood. The light is also attenuated by light scattering, geometric factors, and characteristics of the light emitter and detector elements. Using two wavelengths, the total absorbance can be written as

$$A_t(\lambda_1) = \varepsilon_o(\lambda_1)c_o l_o + \varepsilon_d(\lambda_1)c_d l_d + \varepsilon_x(\lambda_1)c_x l_x + A_y(\lambda_1) \tag{4.8}$$

$$A_t(\lambda_2) = \varepsilon_o(\lambda_2)c_o l_o + \varepsilon_d(\lambda_2)c_d l_d + \varepsilon_x(\lambda_2)c_x l_x + A_y(\lambda_2) \tag{4.9}$$

where the subscript o refers to arterial oxyhemoglobin, d refers to arterial deoxyhemoglobin, x refers to variable absorbances not from arterial blood, and y refers to nonspecific sources of optical attenuation. It is assumed that dysfunctional forms of hemoglobin (i.e., MetHb and COHb) are not present.

To isolate the contributions of arterial blood, only the pulsating absorbances are analyzed, thus leading to "pulse" oximetry. By taking the time derivative of the absorbances, the last two constant terms in Eqs. (4.8) and (4.9) go to zero. Additionally, an assumption is made that the blood path length changes, dl_o/dt and dl_d/dt, are equivalent. Thus, the ratio, R, of the two absorbance derivatives remains constant:



$$R = \frac{\frac{dA_t(\lambda_1)}{dt}}{\frac{dA_t(\lambda_2)}{dt}} = \frac{\varepsilon_o(\lambda_1)c_o\frac{dl_o}{dt} + \varepsilon_d(\lambda_1)c_d\frac{dl_d}{dt}}{\varepsilon_o(\lambda_2)c_o\frac{dl_o}{dt} + \varepsilon_d(\lambda_2)c_d\frac{dl_d}{dt}} \tag{4.10}$$

$$R = \frac{\varepsilon_o(\lambda_1)c_o + \varepsilon_d(\lambda_1)c_d}{\varepsilon_o(\lambda_2)c_o + \varepsilon_d(\lambda_2)c_d} \tag{4.11}$$

Recalling from Eq. (4.4) that functional arterial oxygen saturation is calculated from c_o = [HbO_2] and c_d = [Hb] leads to $S_{pO2} = c_o/(c_d + c_o)$ -->

$$S_pO_2 = \frac{\varepsilon_d(\lambda_1) - \varepsilon_d(\lambda_2)R}{[\varepsilon_d(\lambda_1) - \varepsilon_o(\lambda_1)] - [\varepsilon_d(\lambda_2) - \varepsilon_o(\lambda_2)]R} \tag{4.12}$$

where S_pO_2 denotes S_aO_2 measurements made by pulse oximetry.