4. Pulmonary function tests and alveolar ventilation

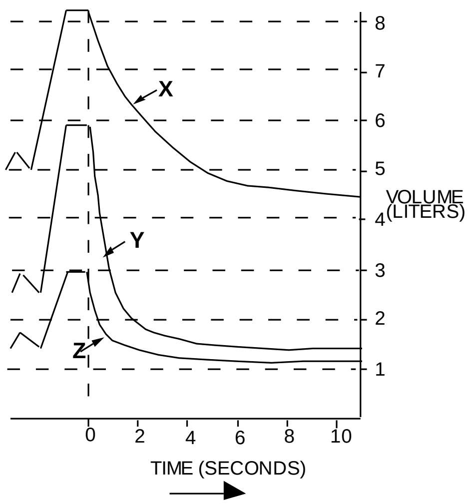

Figure 3. Forced expiratory vital capacity curves generated by individuals X, Y and Z.

FORCED EXPIRATORY VITAL CAPACITY TEST provides an indirect assessment of airway resistance. In this pulmonary function test, the subject inhales to total lung capacity and then exhales into a spirometer as forcefully, rapidly, and as completely as possible. The volume expired under these conditions is called the **forced vital capacity** (FVC) (Fig 3).

The forced expiratory vital capacity test also measures the volume exhaled in 1 second, called the **1-second forced expiratory volume** (FEV1). This value is often expressed as a % of FVC (i.e., FEV1/FVC %). Normally FEV1 is at least **80% of FVC** (curve Y). Patients with restrictive lung disease will have a normal value of 80% (curve Z). In patients such as asthmatics, who have obstructed airways, this value will be reduced (<80%) (curve X).

Exchange of Gases in Alveoli & Tissues
Respiration involves two processes:

(1) Delivery of O_2 to and removal of CO_2 from the cells of the body.
(2) Use of O_2 in oxidative metabolism to generate ATP, water, and CO_2.

In a steady state, the amount of O_2 that is consumed by the cells per unit time is equal to the amount of O_2 added to the blood in the lungs during the same time period. Likewise the rate at which CO_2 is generated by the cells is equal to the rate at which CO_2 leaves the blood in the lungs and is exhaled.

Gases move by diffusion from regions of high concentration to regions of low concentration. Therefore to provide adequate gradients for diffusion, the pulmonary system must increase the amount of oxygen in the alveoli above that found in the mixed venous (MV) blood of the lung. Additionally it must lower the carbon dioxide in the alveoli below that of mixed venous blood.

A second set of gradients must exist at the tissue-blood interface. Here the amount of O_2 consumed by cells and CO_2 produced are not necessarily identical and depend on the fuel source consumed. The ratio of CO_2 produced to O_2 consumed is called the **respiratory quotient (RQ).** For a mixed diet, 8 molecules of CO_2 are produced for every 10 molecules of O_2 consumed (i.e., RQ = 0.8). For a diet composed of carbohydrates, the RQ is 1.0. For a diet of fat, the RQ is 0.7.

Minute & Alveolar Ventilation

Minute ventilation (V_E) is the total volume of gas entering (or leaving) the lung per minute. It is equal to the tidal volume (TV) multiplied by the respiratory rate (*f*).

Minute ventilation = $\mathbf{V_E = TV \times \mathit{f}}$

At rest, a normal person moves ~450 ml/breath x 10 breath/min = 4500 ml/min.

However, because of the anatomical dead space (V_D), not all of this entering air is available for exchange with the blood . Recall that the conducting airway (anatomical dead space) has a volume of ~150 ml. If 450 ml of fresh air is inspired, the first gas to reach the respiratory zone comes from this anatomical dead space (150 ml). Then 300 ml of fresh gas reaches the respiratory zone and the last 150 ml of inspired gas remains in the dead space. Thus, the total amount of fresh air reaching the alveoli during each inspiration equals the tidal volume minus the volume of the anatomical dead space:

$TV – V_D$ = 450 - 150 ml = 300 ml.

Alveolar ventilation (V_A) is the total volume of *fresh air* entering the alveoli per minute. It is calculated as:

Alveolar ventilation = $\mathbf{V_A = (TV – V_D) \times \mathit{f}}$

When evaluating the efficiency of ventilation, one should focus on the alveolar ventilation not minute ventilation.

For example, in the table below, Subjects A and B have the same minute ventilation (V_E = 6 L) but very different alveolar ventilations (V_A). Subject A has no alveolar ventilation and would be become unconscious in a few minutes but Subject B is breathing normally.

Subject	TV	*f*	V_E	V_D	V_A
A	150ml	40	6000ml	150ml	0
B	500ml	12	6000ml	150ml	4200ml

One other important point shown in the table above is that the **depth of breathing** (TV) is far more effective in elevating the alveolar ventilation than an increase in **ventilation rate** (*f*). This is because for each tidal breath a fixed volume is dead space. As tidal volume decreases, the fraction going to dead space increases. The respiratory system will respond to O_2 need (as in exercise) by reflexively increasing ventilation by **increasing the depth of breathing.**

The anatomical dead space is not the only type of dead space in the lung. Some fresh air is not used for gas exchange even though it reaches the alveoli because some alveoli may have little or no blood supply (i.e., blood perfusion). This volume of air is called **alveolar dead space**. In normal individuals this is quite small but may be large in several kinds of lung disease. As we will discuss later, a **mismatch in ventilation and blood perfusion** is minimized by local mechanisms that match air and blood flow. **The sum of the anatomical dead space and alveolar dead space is the physiologic dead space**.

Partial Pressure of Gases
The amount of various gases can be measured by comparing the pressure they exert. Gas molecules behave like individual particles that are in a constant state of motion. When the particles collide with one another or the sides of the container they exert a pressure. The pressure exerted depends on the number of collisions. Two factors affect the number of collisions: the **temperature of the gas** and the **number of gas molecules**. Dalton's law states that in a mixture of gases, the pressure exerted by each gas is the same as it would be if that gas alone occupied the entire container. These individual pressures are called **partial pressures** and are denoted as P in front of the symbol for the gas.

To calculate the partial pressure of gas "X":

$$P_X = P_{atm} \times F_X$$

Where, P_{atm} is the atmospheric pressure (at sea level = 760 mm Hg), and F_X is the fractional concentration of gas X.

Atmospheric air contains mostly nitrogen (79%) and oxygen (21% O_2) with trace amounts of CO_2 and other gases. Air also contains water vapor. At sea level, water vapor is 47 mm Hg. For simplicity, respiratory physiologists and physicians generally assume that room air is **always dry**. Since **21% of dry room air is oxygen**, the fraction of O_2 in inspired air (FiO_2) is:

$$\mathbf{FiO_2 \times P_{atm} = 0.21 \times 760\ mm\ Hg = 160\ mm\ Hg.}$$

The concentration of carbon dioxide in room air is so low (0.04%), it is considered to be 0.

When inspired, the room air is warmed to 37°C and becomes humidified as it passes through the nasal passages. The water vaporizes into the air until the P_{H2O}= 47 mm Hg. What this means is that only 760 - 47 mm Hg or 713mm Hg is available for other gases besides water. Therefore,

$$\mathbf{PO_2 \text{ of inspired gas} = 0.21 \times (760mm\ Hg - 47\ mm\ Hg) = 150\ mmHg.}$$