3. Pressure changes and resistance

Pressure Changes Affect Lung Volumes

In a normal lung, air flows in and out when a pressure gradient is created. Gas always flows from a higher to a lower pressure. During inspiration, expansion of the thorax causes the intrapleural and alveolar pressures to decrease, gas flows into the lung. During exhalation passive recoil of the lung causes the intrapleural pressure and alveolar pressure to increase; gas flows out of the lung. **Note that during inspiration and exhalation the pleural pressure is always less than the pressure in the alveoli.**

The transpulmonary pressure (Fig 1) also increases and decreases with lung volume. By convention, the transpulmonary pressure is always positive ($P_{tp} = P_A – P_{ip}$).

At the end of an unforced exhalation when no air is flowing, then the following conditions exist:

alveolar pressure = 0 mmHg
intrapleural pressure (i.e., pressure in pleural cavity) = -5 mmHg
transpulmonary pressure (P_A- P_{ip}) = +5mmHg.

When there is no airflow in or out of the lungs, the transpulmonary pressure and intrapleural pressure are **equal in magnitude but opposite in sign** (Fig 1).

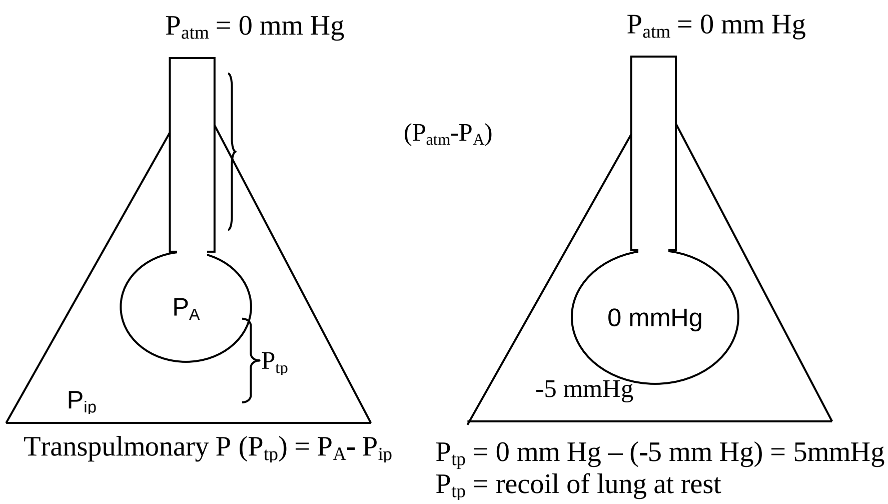

Figure 1. In ventilation, air flow is determined by the difference between atmospheric and alveolar pressures. Lung size is determined by the balance between the transpulmonary pressure and elastic recoil.

At rest, the volume of the lung is a balance between the expansion of the chest wall and the inward elastic recoil of the lungs. The lung at rest is in a partially expanded state (stretched).

A **pneumothorax**, can occur with trauma or surgery. In this instance, the chest wall is pierced without damaging the lung. Atmospheric air enters the intrapleural space raising its pressure to 0 mmHg. This input of air causes the lung to collapse since its elastic recoil is no longer opposed. Concurrently the chest wall moves outward.

Airway Resistance Determined by Driving Pressure & Flow
Thus far we have discussed the changes in pressure that are required to overcome the elastic recoil tendencies of the respiratory system. An additional force that must be overcome during normal breathing is the **resistance to airflow**. Measurement of airway resistance is an extremely useful diagnostic tool because changes in airway resistance accompany aging and many lung diseases.

Air flow (F) will depend upon the driving pressure (P) and the resistance (R) according to the equation:

$$F = (P_{atm} - P_A)/R$$

Factors that influence airway resistance include airway diameter, lung volume, and elastic recoil of the lung.

1. AIRWAY DIAMETER: It is probably intuitive that the more narrow the airway, the higher the resistance in that individual airway. What may not be intuitive is that most of the resistance to air flow is found in the mouth, trachea and large bronchi. The reason for this is that as the airways divide and become narrower, they also become more numerous. The small airways divide more rapidly than their diameter decreases, therefore, the resistance of each individual airway is relatively high, but their total-cross sectional area is so great that their combined resistance is low.

2. LUNG VOLUME: The diameter of the airway lumen is affected by lung volume. The airways are not rigid and are capable of being distended and compressed. At high lung volumes, the airways such as bronchi and bronchioles, are "pulled" open and their resistance is lower than at low lung volumes. Patients with increased airway resistance frequently have high lung volumes in an attempt to compensate.

3. ELASTIC RECOIL: Airway diameter will be affected by the transmural pressure across them (Fig 2). Although the airways are embedded in the lung, the pressure that they are exposed to on their outside wall is close to intrapleural pressure. If elastic recoil is reduced, then intrapleural pressure will be less negative than normal. The transmural pressure across the airways will be reduced, the airway diameter will be smaller than normal, and resistance will be higher than normal. Patients with emphysema often have destruction of lung tissue, decreased elastic recoil (increased compliance), and increased airway resistance.

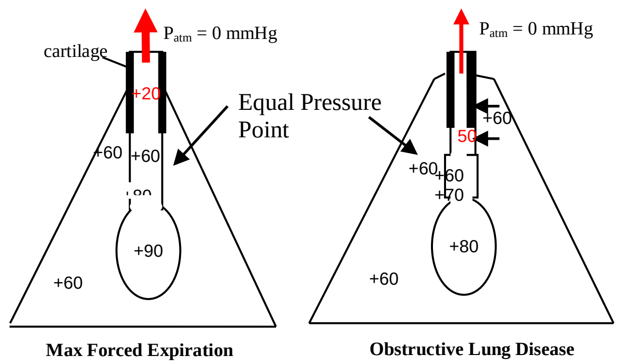

Figure 2. Increased resistance in the airways (bronchi) can lead to airway compression. The movement of air through the narrowed opening causes "wheezing".
At the **equal pressure point,** pressure inside the airway equals that in the pleural space. In normal lungs this occurs in the large airways which are surrounded by cartilage. However, in disease associated with airway obstruction, resistance to flow is increased and the pressure gradient for flow is reduced. Consequently the **equal pressure point** moves into airways that do not contain cartilage causing these airways to close completely (premature airway collapse). This premature airway closure can be heard as **crackles**.

4. MUSCLE TONE Constriction of bronchial smooth muscle will decrease the diameter of the airways and increase airway resistance. **Parasympathetic stimulation causes contraction of bronchial smooth muscle; sympathetic stimulation causes relaxation**. Asthmatics often have hyper-reactive airways and smooth muscle contraction. Drugs which stimulate β-adrenergic receptors (βAR) in the bronchioles cause relaxation and are often used to treat asthmatics.