

RESISTANCE TO VENTILATION – PART II

by Bill Wojciechowski, MS, RRT



This article is the second portion of a two-part review concerning resistance to ventilation. Part I provided (1) an overview of the total resistance to ventilation, (2) a summary of the three types of resistance (inertial, elastic, and airway) to breathing, and (3) an outline of how airway resistance is divided between the small and large airways. Part II will discuss series and parallel circuits, airway resistance through large and small airways, and clinical implications of airway resistance partitioning.

Series & Parallel Resistances

Fluids flow through three types of circuits. These circuits are series, parallel, and series-parallel combination.

Series Circuit

A series circuit is comprised of a single pathway wherein all the resistances are arranged in chain form through which every molecule of the volume of the flowing gas or liquid passes. The entire volume travels through each component of the series circuit, and encounters each resistance within the circuit. The total airway resistance through a series circuit is the sum of the individual resistances experienced by the fluid flowing through that single pathway.

In the context of the lung, consider the pharynx, larynx, and trachea as one long tube or conduit, constituting a series circuit. Essentially, every molecule of the tidal volume passes through these upper airway structures during inspiration. The only portion

of the tidal volume that does not flow through the pharynx, larynx, and trachea is that which resides in the mouth and nose at the end of inspiration. The inhaled tidal volume must first flow through the pharynx, then the larynx, and finally through the trachea. In the process the flowing air encounters a certain airway resistance through each component of the circuit.

Consider air flowing through these upper airway components in a patient who has a partial pharyngeal obstruction caused by an edematous pharynx. The air flow encounters three resistances as it passes through the pharynx, larynx, and trachea. The first resistance occurs in the pharynx where the flowing air encounters airway resistance caused by the edema. The second resistance is met when the flowing gas moves through the larynx where the air collides with the narrowing caused by the presence of the vocal cords. The third resistance is encountered as the air flows through the trachea. The total resistance through this series circuit is the sum of (1) the airway resistance generated through the edematous pharynx, (2) the airway resistance created when the flowing air interacts with the narrowing caused by the vocal cords, and (3) the airway resistance developed by the flow of air through the trachea.

To make this concept more tangible, arbitrary values will be assigned to the resistances encountered by the air flowing through the hypothetical airway described above. Assume that the resistance through the edematous pharynx is 2 cm H₂O /L/sec, through the larynx 4 cm H₂O/L/sec, and through the trachea 1 cm H₂O/L/sec. Because the pharynx, larynx, and trachea are in series, the total airway resistance through these structures is the sum of the individual resistances in the circuit, i.e., 7 cm H₂O/L/sec. The general formula for calculating the total airway resistance through a series circuit is as follows:

$$R_1 + R_2 + R_3 + \dots R_n = RT$$

The total airway resistance in a series circuit will always be greater than any of the individual components.

Parallel Circuit

A parallel circuit consists of multiple pathways or branches. In a parallel circuit, only a portion of the flowing fluid travels through each branch. For example, the inspired tidal volume splits at the carina where the right and left mainstem bronchi branch off the trachea. A portion of the tidal volume flows through the right mainstem bronchus, and a part of it flows through the left. Diverting the air flow at the carina through the right and left mainstem bronchi represents a parallel circuit.

To calculate the total airway resistance in a parallel circuit, the reciprocals of the constituent resistances are added. That is,

$$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \frac{1}{R_n} = \frac{1}{R_T}$$

Assume that the airway resistance through the trachea is 1 cm H₂O/L/sec, and that the airway resistance through each mainstem bronchus is 3 cm H₂O/L/sec. The total airway resistance through this parallel circuit would be:

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$$\frac{1}{3 \text{ cm H}_2\text{O} / \text{L} / \text{sec}} + \frac{1}{3 \text{ cm H}_2\text{O} / \text{L} / \text{sec}} = \frac{1}{R_T}$$

$$0.66 \text{ L/sec/cm H}_2\text{O} = \frac{1}{R_T}$$

$$R_T = \frac{1}{0.66 \text{ L} / \text{sec} / \text{cm H}_2\text{O}} = 1.5 \text{ cm H}_2\text{O} / \text{L} / \text{sec}$$

The total resistance in a parallel circuit will always be less than the resistance of any of that circuit's components. The airway resistance through the right and left mainstem bronchi individually is greater than that of the trachea. However, because the total cross-sectional area of right and left mainstem bronchi exceeds that of the trachea, the total airway resistance through the right and left mainstem bronchi is less than that through the trachea.

Partitioning of Airway Resistance

The lung contains a sequence of dichotomous branches. Each airway ("parent") bifurcates into two shorter and more narrow "daughter" airways. Each bifurcation produces a new generation of airways. This complex branching increases the cross-sectional area of the airways within the tracheobronchial tree significantly, and is responsible for reducing the velocity of the air flow toward the alveoli.

Dichotomous branching begins with the trachea splitting into the right and left mainstem bronchi, and continues for 23 airway generations. Dichotomous branching is more extensive throughout the small airways (≤ 2 mm diameter) than in the large airways (> 2 mm diameter).

The massive increase in total cross-sectional area at each generation produces a drastic decrease in airway resistance at each generation. Interestingly, the resistance of each "daughter" is greater than that of the "parent." However, the total cross-sectional area of all the "daughters" at a given generation exceeds that of all the preceding "parents." Therefore, the airway resistance across any given airway generation is less than that of the preceding generation.

Airway resistance varies throughout the tracheobronchial tree, and is partitioned according to airway generations. Ninety percent (90%) of the total airway resistance is attributable to air flowing through the large airways, and 10% is generated as air flows through the small airways.

Clinical Implications of Airway Resistance Partitioning

The partitioning of airway resistance throughout the tracheobronchial tree has significant clinical implications. Consider the large airways for example. An aspirated foreign object partially obstructing the right mainstem bronchus will produce considerable respiratory distress within seconds of the event. Similarly, when a child enters the emergency department having epiglottitis, the situation is generally a medical emergency because the inflamed epiglottis significantly interferes with the passage of air through the upper airways, and ultimately to the alveoli. Post-extubation laryngeal edema poses a similar problem hampering the flow of air through the tracheobronchial tree, and representing a threat to complete airway obstruction.

What do these three clinical conditions have in common? Each causes significant and immediate respiratory distress. Each represents some degree of obstruction to a large airway. Large air-

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way obstruction manifests itself abruptly because the vast majority (90%) of the total airway resistance is encountered by air flowing through the large airways.

On the other hand, a reduction of the caliber of the small airways can occur without producing an appreciable increase in the total airway resistance, thereby remaining sub-clinical for an extended time. Consider a patient with cystic fibrosis becoming discouraged, and deciding to suspend all forms of bronchial hygiene. Mucus would continue to accumulate and gravitate to the person's small airways, and interfere with gas exchange. This patient would not experience the ill effects of the buildup of pulmonary secretions immediately. Time, weeks, perhaps months, would elapse before the clinical manifestations of retained secretions became evident.

Furthermore, imagine a patient with asthma who is asymptomatic at a particular time. Spirometry often reveals that asymptomatic asthmatics have below normal FEF25%-75% values. Despite this spirometric abnormality reflecting narrowed small and mid-sized airways, these patients appear fine, and do not exhibit respiratory distress. Because the small airways contribute such a small percentage (10%) to the total airway resistance, small airway obstruction must be considerable before the impaired flow of air produces symptoms. The same reasoning applies to the development of pulmonary emphysema. This disease has a decades-long preclinical period because destruction to the alveoli must be extensive before the damage is perceived clinically. Ultimately, the location of airway obstruction directly influences the clinical presentation.

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