Introduction to airway resistance measurements

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AIMS

- Review physiology of airway resistance
- Survey measures of airway resistance
- Provide examples of clinical applications
- Highlight research applications

SUMMARY

Airway resistance (Raw) is one of the fundamental features of the mechanics of the respiratory system. While the flow-volume loop offers insight into the volume and flow of air, it is limited in terms of specific information regarding lung mechanics. Airway resistance is the ratio of driving pressure divided by flow through the airways. It specifies the pressure required to achieve a flow of air with a velocity of 1L/sec. If the airway is represented by a simple, rigid tube, with laminar flow of air through it, the airway resistance Raw = (8 x L x \( \mu \))/\( \pi r^4 \), where L = length of the tube, \( \mu \) = viscosity of the gas, and r = radius of the tube. It is important to note that the \( r^4 \) relationship demonstrates how sensitive resistance is to the size of the tube, varying inversely with the 4th power of the radius. The inner diameter of the airway is itself determined by many factors, including airway smooth muscle contractile state, airway wall thickness (related to inflammation, edema and remodeling), airway wall buckling and formation of mucosal folds, the interdependence, or linkage, of airway and surrounding lung parenchyma, and the intrinsic elastic recoil of the lung parenchyma, which serves as a load on the airway and variably resists bronchoconstriction. Of course, the airways are not rigid tubes, and in fact flow is a complex process involving both laminar and turbulent conditions, so this calculation of Raw is an approximation only. In particular, with turbulent flow, Raw now varies with the density, not viscosity of gas, and is non-linearly related to the square of flow.

In addition to the non-rigid and non-linear nature of airways and airflow, the airways are arranged in a complex network of both series and parallel pathways. The total cross-sectional area of the airways increases markedly as one moves from the central to the peripheral lung, and the net airway resistance ultimately drops accordingly. However, airway resistance initially rises out to the 5th to 8th generation, where the small number of narrower airways results in a net increase in resistance, but beyond this region the more numerous, albeit smaller, airways contribute to a net increase in cross sectional area and an overall decrease in resistance. Because of the parallel arrangement of the airways, the total airway resistance in the system adds according to the reciprocal of each airway’s resistance. In sum, the total resistance of the respiratory system is approximately 2.0 cm H2O/L/s, with 25% originating in the chest wall and 75% within the lung. Within the lung, at breathing frequencies, 50% of the resistance originates within the large airways, 40% within the lung tissue (due to dissipative frictional losses among the various structural elements), and only 10% within the small airways, again reflecting their enormous cross-sectional area. Because such a small amount of resistance emanates from the small airways, it is very difficult to detect changes in this area using conventional spirometry, and so this region has been dubbed the “Silent” or “Quiet” zone of the lung.
In order to measure Raw, one must know the net flow of air through the lung and the driving pressure for flow, which equals the difference between alveolar pressure and mouth pressure. Alveolar pressure is usually obtained by estimating local pleural pressure, which must be done through an esophageal balloon catheter. Making this measurement non-invasively eluded physiologists for many years until Arthur Dubois realized he could do this through the use of the body plethysmograph. The details of this measurement will be covered by another speaker, but by using a panting technique, the equation of motion of the lung is reduced to the predominant influence of Raw, and by combining a closed shutter and open shutter panting maneuver in the body “box”, the relationship between alveolar pressure and mouth flow could be measured and used to calculate Raw. Since Raw is highly dependent on lung volume, it is better expressed as specific airway conductance, sGaw, where \( sGaw = \left(1/Raw\right)/\text{thoracic gas volume (TGV)} \). sGaw is a measure of intrinsic airway resistance, which is volume independent.

Raw can also be measured by the interrupter technique (Rint), and the forced oscillation technique (R-FOT), both of which are performed during quiet breathing and require no special maneuvers like the FEV1. As such, both Rint and R-FOT are also more sensitive indicators of intrinsic Raw than FEV1. All of these methods of measuring Raw have been used to assist in diagnosing lung disease and to assess bronchodilator and bronchoconstrictor responses. In addition, the FOT offers additional insight into the elastic properties of the respiratory system as well as into the homogeneity of ventilation. These additional features have been used to help assess the differences between asthma and COPD. Because these methods are non-invasive and can be performed during quiet breathing, they have special appeal for patients who cannot perform spirometry or may have difficulty with proper technique, including children, the elderly, patients during sleep, or those with neuromuscular disease. Each of the methods has its own advantages and disadvantages. At the present time, some of the main areas of uncertainty with these tests are standardization of methodology, use of appropriate normative equations, and overall clinical utility.

Measuring Raw has many research applications, including assessing specific and real-time responses to bronchodilators and bronchoconstrictors and deep inhalation, measuring peripheral airway responsiveness, and mapping individual patterns of airway resistance and responses to inhaled therapy. In the future, it may be possible to individually phenotype each patient’s own unique airway resistance pattern to allow for selection of personalized precision medicine.

REFERENCES


