

Airway Resistance Measurements in the Evaluation of Obstructive Lung Disease

by Michael Snow, RPFT

Chronic obstructive pulmonary disease (COPD) and asthma are growing health problems and are expected to be among the leading causes of mortality worldwide as we enter the next century. Recent studies evaluating the role of quality of life indicators with educational interventions in asthma, as well as a growing understanding of the role of inflammatory processes in the progression of COPD, have highlighted the importance of early diagnosis and treatment of airway obstruction.¹⁻⁴ The primary cause of airway obstruction, regardless of etiology, is increased airway resistance (R_{aw}). Unfortunately, the relationship of airway resistance to determinants of airflow is less well understood and, as a result, underutilized.

Measuring maximal airflow

Most commonly, the diagnosis of airway obstruction is based on changes in airflow as assessed by maximal, forced expiratory maneuvers (FEV_1 and PEF). Although these maneuvers reflect changes in airway resistance, forced expiratory maneuvers reflect a complex, dynamic relationship between patient effort, muscle strength, compliance, and elastic recoil, as well as airway resistance. As a result, using forced expiratory maneuvers to assess changes in airway resistance can frequently be misleading or create uncertainty about the diagnosis or the therapeutic value of treatments.

In a simple model of a single rigid airway, airflow results from driving pressure overcoming the resistance of the airway. Maximal

airflow is determined by the size of the airway. Once maximal airflow has been achieved, continuing to increase driving pressure will not increase airflow. In a patient model, the expiratory airflow proceeds from small, non-rigid, peripheral airways, combining into larger, more rigid, central airways. The cumulative cross-sectional area of the larger airways determines the maximal airflow.

The magnitude of the inspired volume is determined by the elastic properties of the lung combined with muscle strength required to overcome these forces. The shape of the maximal expiratory flow-volume curve is a result of decreased R_{aw} and increased elastic recoil due to lung expansion combining with patient effort to produce higher expiratory flows near total lung

capacity, which progressively decrease as residual volume is approached.

Since patients frequently have the ability to generate greater driving pressure than is required to achieve maximal airflow, significant increases in R_{aw} can be missed when forced expiratory volume in one second (FEV_1) or peak expiratory flow (PEF) are the only measured parameters. This can be easily demonstrated by performing forced expiratory maneuvers with and without an external, fixed resistance (see Table 1). Even with as much as 4.0 cm/H₂O/L/sec added, the FEV_1 and PEF do not change in clinically meaningful ways.

During quiet, non-forced breathing, the influence of elastic recoil and compliance are minimized except in the case of airway collapse. Increased airway resistance is predominantly due to airway occlusion, bronchoconstriction,

or airway collapse. Bronchoconstriction can occur as a result of mucosal buildup with the airway, as in bronchitis. Bronchoconstriction can result from bronchospasm or inflammatory processes that compress the airway, as seen in asthma or COPD. Airway collapse can result from increased compliance or a combination of occlusion and compression, as seen in emphysema and cystic fibrosis. Typically, collapse patterns are seen on the expiratory phase rather than during inspiration.

Airway resistance measurement methods

Documented correlation between R_{aw} and FEV_1 only shows that both variables share a common causative factor.⁵⁻⁸ The greater sensitivity of airway resistance should be intuitively obvious when other influences, such as effort and muscle strength, are

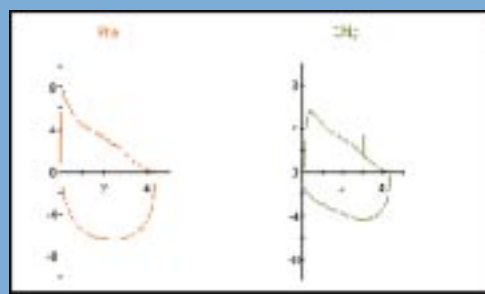
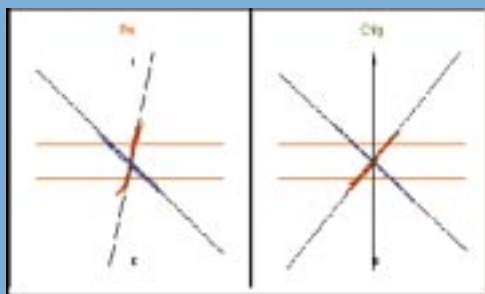
excluded. It is usually more effective to monitor the parameter directly rather than infer change from an indirect measurement.^{9,10} Multiple approaches to clinical measurement of R_{aw} are available. Interrupter, forced oscillations, and body plethysmography are the primary options, each of which offer relative advantages and disadvantages.

The interrupter technique is simple to implement and only requires that airway pressure and flow be monitored while flow is abruptly interrupted. Resistance is obtained by dividing the pressure change after interruption by the flow obtained immediately before the interruption. The interruption may be repeated rapidly to permit multiple measurements over a single breath. This method is easy to use and requires minimal equipment.

Resistance measured by interrupter protocols provides a rea-

Table 1: Effect of Fixed Resistance on Forced Expiratory Maneuvers

	<u>Baseline</u>	<u>+ 4.0 cm H₂O Resistance</u>	<u>Percent Change</u>
FVC	4.33	4.36	1
FEV_1	3.20	3.12	-2
$FEF_{25-75\%}$	2.54	2.32	-9
FEF_{max}	7.90	5.55	-30
R_{aw}	2.96	7.04	138
sG_{aw}	0.40	0.14	-64



sonably good indication of R_{aw} as long as proper methodology is followed for supporting the cheeks during measurement and negligible compliance differences exist within the airways. Significant compliance differences would cause more compliant airways to buffer less compliant compartments, resulting in the measurement of proximal airways resistance only. This frequency-dependent effect is the result of insufficient time to permit pressure equilibration within the airways and can make interpretation of the results more complex. A good analysis of the interrupter technique is presented by Bates et al.¹¹

Forced oscillation technique (FOT) measures resistance by imposing flow oscillations on the airways during spontaneous breathing. This can be accomplished in several ways, but most commonly an external loudspeaker is used to generate cyclical waves that are applied to the airway. These waves are, in fact, slight changes in airflow. Airway pressure changes occur in response to the changes in airflow. Since the frequency of the airflow changes is known, it is possible to compare the pressure changes with the flow changes and calculate airway resistance and other parameters. The analysis of the resulting pressure responses can provide useful information not only regarding R_{aw} , but also can potentially help evaluate central versus peripheral resistances.^{12,13}

Numerous studies have evaluated various approaches to FOT.¹⁴⁻¹⁶ Current research is focused on the dynamic information that can be obtained by scanning a range of frequencies. Other advantages of FOT relate to minimal patient cooperation requirements — essentially only quiet breathing — that extend the use-

fulness of the measurement for young children and older patients. The approach is widely used in Europe but has been slow to achieve acceptance in the United States. This is probably primarily due to lack of familiarity with the measurement. This also creates difficulty in interpreting the results. One of the drawbacks is the lack of standardization between the various commercially available systems, although this should change with the adoption of standards.

Body plethysmographic measurement of R_{aw} is similar to the interrupter method but with an important difference. As in the interrupter technique, flow and airway pressure are continuously measured. A shutter is closed during breathing efforts, and the pressure changes are measured. The pressure changes are compared with the flow changes immediately prior to interruption. Unlike the interrupter method, however, the occlusion is complete and sustained, permitting pressure equilibration to take place within the respiratory circuit. The flow can be measured during quiet breathing or with gentle panting. The panting technique tends to minimize oropharyngeal components and minimize the effects of temperature and humidity differences between inspired and expired gas. Descriptions of plethysmographic techniques are available.¹⁷⁻¹⁹

Lung volume and R_{aw} relations

R_{aw} is strongly correlated with lung volume because as the lungs expand, the airways also dilate. As you approach total lung capacity (TLC), the airway resistance is minimized by lung expansion and the resulting airway dilation. If lung volume decreases, R_{aw} increases, reflecting the effect of

decreasing lung volumes on airway caliber.

A common compensatory mechanism to chronic increases in airway obstruction is to increase the functional residual capacity (FRC), and ultimately TLC, in order to expand the airways and maintain R_{aw} within acceptable ranges. This adjustment of FRC is one reason why some patients with significant reduction in FEV_1 may have relatively normal R_{aw} . After bronchodilation, the reduced airway obstruction allows the overinflation to decrease, in turn causing the resistance to settle back into a level appropriate for the reduced lung volume. In this case, there is a significant bronchodilation effect despite the lack of an apparent change in R_{aw} . It is this dynamic interaction between airway resistance and lung volume that makes R_{aw} difficult to evaluate as an isolated parameter.

One of the primary advantages of body plethysmography, compared to other techniques for assessing R_{aw} , is the ability to correlate the lung volume with the measured R_{aw} . Compensatory changes in lung volume can be observed by measuring specific conductance (sG_{aw}) or specific resistance (sR_{aw}). Essentially, sG_{aw} and sR_{aw} evaluate resistance and conductance at the lung volume at which they were measured. For sG_{aw} , this means dividing the measured airway conductance (G_{aw}) by the observed thoracic gas volume (TGV). For sR_{aw} , the measured R_{aw} is multiplied by the observed TGV. This, in effect, volume adjusts the resistance and conductance and makes the response to bronchodilators or the underlying airway obstruction apparent.

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Another advantage of the plethysmographic method is that the shape of the resistance loop can be diagnostic.

In summary, resistance measurements by any method can be extremely useful in evaluating bronchodilator response as well as detecting airway obstruction. Used in conjunction with sG_{aw}

and FEV_1 , R_{aw} measurements can increase sensitivity, significantly aid in the differentiation of concurrent processes, and offer the possibility of developing patient-specific treatment programs.

Carefully selecting the measurement methodology can permit objective measurements in a much wider patient population. 🧠

Michael Snow is vice president of research and development at Medical Graphics Corp in St. Paul, MN.

See the "Tools of the Trade" column on the "Table of Contents" in this issue for additional resources on this topic.