306e

Disturbances of Respiratory Function

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The primary functions of the respiratory system—to oxygenate blood and eliminate carbon dioxide—require virtual contact between blood and fresh air, which facilitates diffusion of respiratory gases between blood and gas. This process occurs in the lung alveoli, where blood flowing through alveolar wall capillaries is separated from alveolar gas by an extremely thin membrane of flattened endothelial and epithelial cells, across which respiratory gases diffuse and equilibrate. Blood flow through the lung is unidirectional via a continuous vascular path, along which venous blood absorbs oxygen from and loses CO_2 to inspired gas. The path for airflow, in contrast, reaches a dead end at the alveolar walls; thus the alveolar space must be ventilated tidally, with inflow of fresh gas and outflow of alveolar gas alternating periodically at the respiratory rate (RR). To provide an enormous alveolar surface area (typically 70 m^2) for blood-gas diffusion within the modest volume of a thoracic cavity (typically 7 L), nature has distributed both blood flow and ventilation among millions of tiny alveoli through multigenerational branching of both pulmonary arteries and bronchial airways. As a consequence of variations in tube lengths and calibers along these pathways as well as the effects of gravity, tidal pressure fluctuations, and anatomic constraints from the chest wall, the alveoli vary in their relative ventilations and perfusions. Not surprisingly, for the lung to be most efficient in exchanging gas, the fresh gas ventilation of a given alveolus must be matched to its perfusion.

For the respiratory system to succeed in oxygenating blood and eliminating CO_2, it must be able to ventilate the lung tidally and thus to freshen alveolar gas; it must provide for perfusion of the individual alveolus in a manner proportional to its ventilation; and it must allow adequate diffusion of respiratory gases between alveolar gas and capillary blood. Furthermore, it must accommodate severalfold increases in the demand for oxygen uptake or CO_2 elimination imposed by metabolic needs or acid-base derangement. Given these multiple requirements for normal operation, it is not surprising that many diseases disturb respiratory function. This chapter considers in some detail the physiologic determinants of lung ventilation and perfusion, elucidates how the matching distributions of these processes and rapid gas diffusion allow normal gas exchange, and discusses how common diseases derange these normal functions, thereby impairing gas exchange—or at least increasing the work required by the respiratory muscles or heart to maintain adequate respiratory function.

VENTILATION

It is useful to think about the respiratory system as three independently functioning components: the lung, including its airways; the neuromuscular system; and the chest wall, which includes everything that is not lung or active neuromuscular system. Accordingly, the mass of the respiratory muscles is part of the chest wall, while the force these muscles generate is part of the neuromuscular system; the abdomen (especially an obese abdomen) and the heart (especially an enlarged heart) are, for these purposes, part of the chest wall. Each of these three components has mechanical properties that relate to its enclosed volume (or—in the case of the neuromuscular system—the respiratory system volume at which it is operating) and to the rate of change of its volume (i.e., flow).

Volume-Related Mechanical Properties—Statics Figure 306e-1 shows the volume-related properties of each component of the respiratory system. Due both to surface tension at the air-liquid interface between alveolar wall lining fluid and alveolar gas and to elastic recoil of the lung tissue itself, the lung requires a positive transmural pressure difference between alveolar gas and its pleural surface to stay inflated; this difference is called the *elastic recoil pressure* of the lung, and it increases with lung volume. The lung becomes rather stiff at high volumes, so that relatively small volume changes are accompanied by large changes in transpulmonary pressure; in contrast, the lung is compliant at lower volumes, including those at which tidal breathing normally occurs. At zero inflation pressure, even normal lungs retain some air in the alveoli because the small peripheral airways are tethered open by radially outward pull from inflated lung parenchyma attached to adventitia; as the lung deflates during exhalation, those small airways are pulled open progressively less, and eventually they close, trapping some gas in the alveoli. This effect can be exaggerated with age and especially with obstructive airway diseases, resulting in gas trapping at quite large lung volumes.

The elastic behavior of the passive chest wall (i.e., in the absence of neuromuscular activation) differs markedly from that of the lung. Whereas the lung tends toward full deflation with no distending (transmural) pressure, the chest wall encloses a large volume when pleural pressure equals body surface (atmospheric) pressure. Furthermore, the chest wall is compliant at high enclosed volumes, readily expanding even further in response to increases in transmural pressure. The chest wall also remains compliant at small negative transmural pressures (i.e., when pleural pressure falls slightly below atmospheric pressure), but as the volume enclosed by the chest wall becomes quite small in response to large negative transmural pressures, the passive chest wall becomes stiff due to squeezing together of ribs and intercostal muscles, diaphragm stretch, displacement of abdominal contents, and straining of ligaments and bony articulations. Under normal circumstances, the lung and the passive chest wall enclose essentially the same volume, the only difference being the volumes of the pleural fluid and of the lung parenchyma (both quite small). For this reason and because the lung and chest wall function in mechanical series, the pressure required to displace the passive respiratory system (lungs plus chest wall) at any volume is simply the sum of the elastic recoil pressure of the lungs and the transmural pressure across the chest wall. When plotted against respiratory system volume, this relationship assumes a sigmoid shape, exhibiting stiffness at high lung volumes (imparted by the lung), stiffness at low lung volumes (imparted by the chest wall or sometimes by airway closure), and compliance in the middle range of lung volumes.

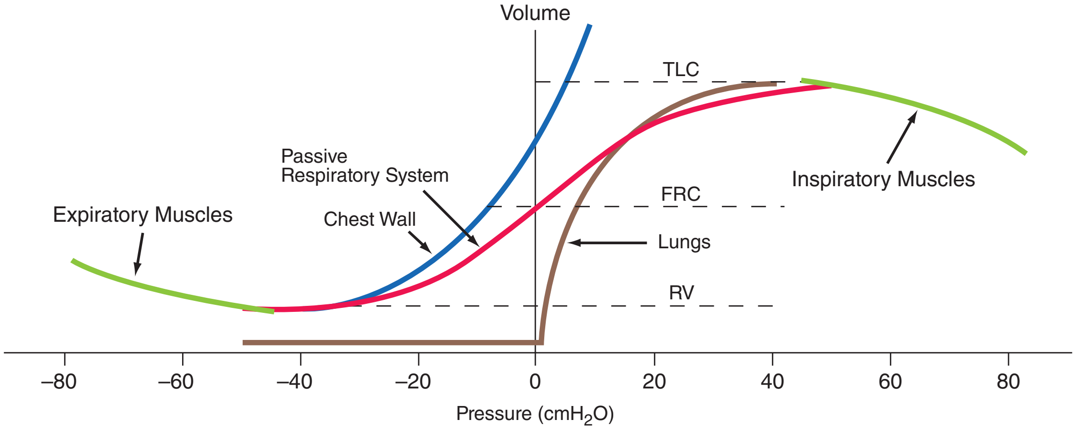

FIGURE 306e-1 **Pressure-volume curves** of the isolated lung, isolated chest wall, combined respiratory system, inspiratory muscles, and expiratory muscles. FRC, functional residual capacity; RV, residual volume; TLC, total lung capacity.