| | Restriction due to increased lung elastic recoil (pulmonary fibrosis) | Restriction due to chest wall abnormality (moderate obesity) | Restriction due to respiratory muscle weakness (myasthenia gravis) | Obstruction due to airway narrowing (acute asthma) | Obstruction due to decreased elastic recoil (severe emphysema) |
|---|---|---|---|---|---|
| TLC | 60% | 95% | 75% | 100% | 130% |
| FRC | 60% | 65% | 100% | 104% | 220% |
| RV | 60% | 100% | 120% | 120% | 310% |
| FVC | 60% | 92% | 60% | 90% | 60% |
| $FEV_1$ | 75% | 92% | 60% | 35% pre-b.d.<br>75% post-b.d. | 35% pre-b.d.<br>38% post-b.d. |
| $R_{aw}$ | 1.0 | 1.0 | 1.0 | 2.5 | 1.5 |
| $DL_{CO}$ | 60% | 95% | 80% | 120% | 40% |

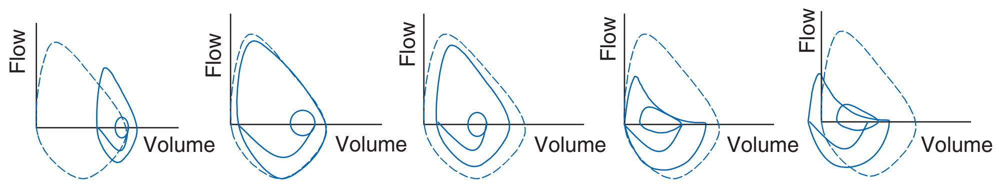


**FIGURE 306e-6 Common abnormalities of pulmonary function** (see text). Pulmonary function values are expressed as a percentage of normal predicted values, except for $R_{aw}$, which is expressed as $cmH_2O/L$ per sec (normal, <2 $cmH_2O/L$ per second). The figures at the bottom of each column show the typical configuration of flow-volume loops in each condition, including the flow-volume relationship during tidal breathing. b.d., bronchodilator; $DL_{co}$, diffusion capacity of lung for carbon monoxide; $FEV_1$, forced expiratory volume in 1 sec; FRC, functional residual capacity; FVC, forced vital capacity; $R_{aw}$, airways resistance; RV, residual volume; TLC, total lung capacity.

physiologic abnormalities may or may not provide sufficient information by which to discriminate among conditions.

Figure 306e-6 lists abnormalities in pulmonary function testing that are typically found in a number of common respiratory disorders and highlights the simultaneous occurrence of multiple physiologic abnormalities. The coexistence of some of these respiratory disorders results in more complex superposition of these abnormalities. Methods to measure respiratory system function clinically are described later in this chapter.

**Ventilatory Restriction Due to Increased Elastic Recoil—Example: Idiopathic Pulmonary Fibrosis** Idiopathic pulmonary fibrosis raises lung recoil at all lung volumes, thereby lowering TLC, FRC, and RV as well as forced vital capacity (FVC). Maximal expiratory flows are also reduced from normal values but are elevated when considered in relation to lung volumes. Increased flow occurs both because the increased lung recoil drives greater maximal flow at any lung volume and because airway diameters are relatively increased due to greater radially outward traction exerted on bronchi by the stiff lung parenchyma. For the same reason, airway resistance is also normal. Destruction of the pulmonary capillaries by the fibrotic process results in a marked reduction in diffusing capacity (see below). Oxygenation is often severely reduced by persistent perfusion of alveolar units that are relatively underventilated due to fibrosis of nearby (and mechanically linked) lung. The flow-volume loop (see below) looks like a miniature version of a normal loop but is shifted toward lower absolute lung volumes and displays maximal expiratory flows that are increased for any given volume over the normal tracing.

**Ventilatory Restriction Due to Chest Wall Abnormality—Example: Moderate Obesity** As the size of the average American continues to increase, this pattern may become the most common of pulmonary function abnormalities. In moderate obesity, the outward recoil of the chest wall is blunted by the weight of chest wall fat and the space occupied by intraabdominal fat. In this situation, preserved inward recoil of the lung overbalances the reduced outward recoil of the chest wall, and FRC falls. Because respiratory muscle strength and lung recoil remain normal, TLC is typically unchanged (although it may fall in massive obesity) and RV is normal (but may be reduced in massive obesity). Mild hypoxemia may be present due to perfusion of alveolar units that are poorly ventilated because of airway closure in dependent portions of the lung during breathing near the reduced FRC. Flows remain normal, as does the diffusion capacity of the lung for carbon monoxide ($DL_{CO}$), unless obstructive sleep apnea (which often accompanies obesity) and associated chronic intermittent hypoxemia have induced pulmonary arterial hypertension, in which case $DL_{CO}$ may be low.

**Ventilatory Restriction Due to Reduced Muscle Strength—Example: Myasthenia Gravis** In this circumstance, FRC remains normal, as both lung recoil and passive chest wall recoil are normal. However, TLC is low and RV is elevated because respiratory muscle strength is insufficient to push the passive respiratory system fully toward either volume extreme. Caught between the low TLC and the elevated RV, FVC and $FEV_1$ are reduced as "innocent bystanders." As airway size and lung vasculature are unaffected, both $R_{aw}$ and $DL_{CO}$ are normal. Oxygenation is normal unless weakness becomes so severe that the patient has insufficient strength to reopen collapsed alveoli during sighs, with resulting atelectasis.

**Airflow Obstruction Due to Decreased Airway Diameter—Example: Acute Asthma** During an episode of acute asthma, luminal narrowing due to smooth muscle constriction as well as inflammation and thickening within the small- and medium-sized bronchi raise frictional resistance and reduce airflow. "Scooping" of the flow-volume loop is caused by reduction of airflow, especially at lower lung volumes. Often, airflow obstruction can be reversed by inhalation of $\beta_2$-adrenergic agonists acutely or by treatment with inhaled steroids chronically. TLC usually remains normal (although elevated TLC is sometimes seen in long-standing asthma), but FRC may be dynamically elevated. RV is often increased due to exaggerated airway closure at low lung volumes, and this elevation of RV reduces FVC. Because central airways are narrowed, $R_{aw}$ is usually elevated. Mild arterial hypoxemia is often present due to perfusion of relatively underventilated alveoli distal to obstructed airways (and is responsive to oxygen supplementation), but $DL_{CO}$ is normal or mildly elevated.

**Airflow Obstruction Due to Decreased Elastic Recoil—Example: Severe Emphysema** Loss of lung elastic recoil in severe emphysema results in