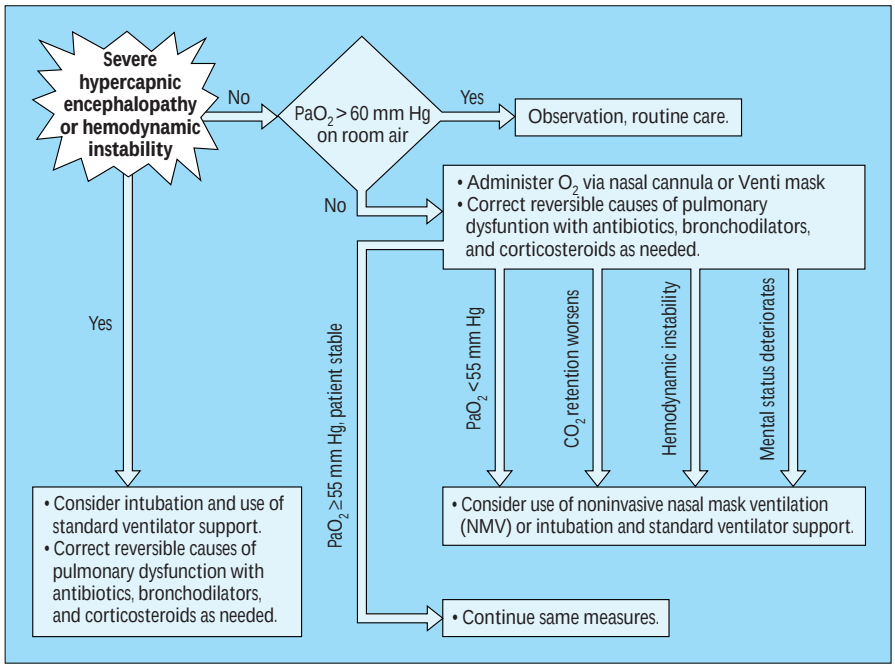
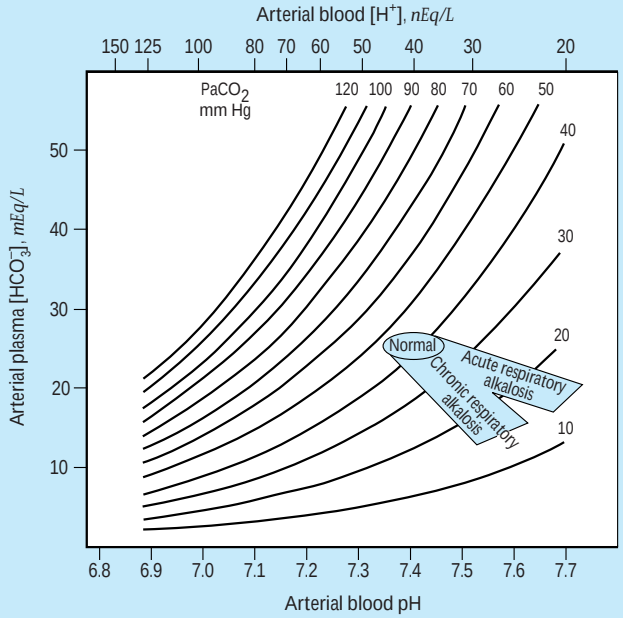


FIGURE 6-8

Chronic respiratory acidosis management. Therapeutic measures are guided by the presence or absence of severe hypercapnic encephalopathy or hemodynamic instability. An aggressive approach that favors the early use of ventilator assistance is most appropriate for patients with acute respiratory acidosis. In contrast, a more conservative approach is advisable in patients with chronic hypercapnia because of the great difficulty often encountered in weaning these patients from ventilators. As a rule, the lowest possible inspired fraction of oxygen that achieves adequate oxygenation (PaO_2 on the order of 60 mm Hg) is used. Contrary to acute respiratory acidosis, the underlying cause of chronic respiratory acidosis only rarely can be resolved [1,9].

Respiratory Alkalosis



Steady-state relationships in respiratory alkalosis: average decrease per mm Hg fall in $PaCO_2$

	$[HCO_3^-]$ mEq/L	$[H^+]$ nEq/L
Acute adaptation	0.2	0.75
Chronic adaptation	0.4	0.4

FIGURE 6-9

Adaptation to respiratory alkalosis. Respiratory alkalosis, or primary hypocapnia, is the acid-base disturbance initiated by a decrease in arterial carbon dioxide tension ($PaCO_2$) and entails alkalinization of body fluids. Hypocapnia elicits adaptive decrements in plasma bicarbonate concentration that should be viewed as an integral part of respiratory alkalosis. An immediate decrement in plasma bicarbonate occurs in response to hypocapnia. This acute adaptation is complete within 5 to 10 minutes from the onset of hypocapnia and is accounted for principally by alkaline titration of the nonbicarbonate buffers of the body. To a lesser extent, this acute adaptation reflects increased production of organic acids, notably lactic acid. When hypocapnia is sustained, renal adjustments cause an additional decrease in plasma bicarbonate, further ameliorating the resulting alkalemia. This chronic adaptation requires 2 to 3 days for completion and reflects retention of hydrogen ions by the kidneys as a result of downregulation of renal acidification [2,10]. Shown are the average decreases in plasma bicarbonate and hydrogen ion concentrations per mm Hg decrease in $PaCO_2$after completion of the acute or chronic adaptation to respiratory alkalosis. Empiric observations on these adaptations have been used for constructing 95% confidence intervals for graded degrees of acute or chronic respiratory alkalosis, which are represented by the areas in color in the acid-base template. The black ellipse near the center of the figure indicates the normal range for the acid-base parameters. Note that for the same level of $PaCO_2$, the degree of alkalemia is considerably lower in chronic than it is in acute respiratory alkalosis. Assuming that a steady state is present, values falling within the areas in color are consistent with but not diagnostic of the corresponding simple disorders. Acid-base values falling outside the areas in color denote the presence of a mixed acid-base disturbance [4].

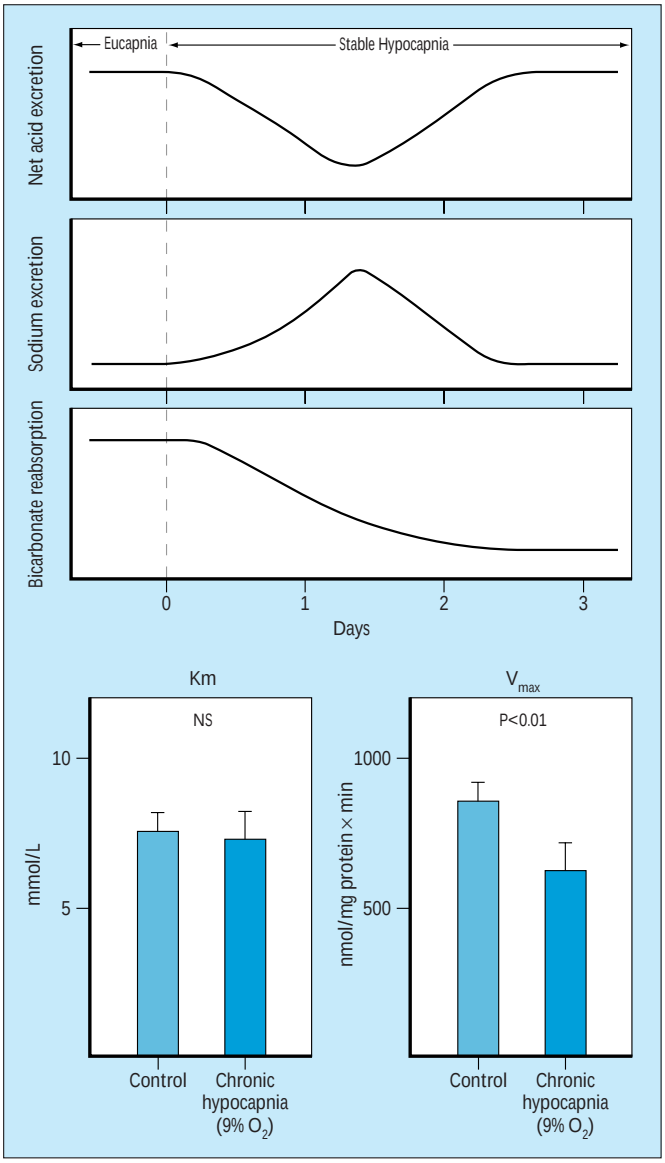


FIGURE 6-10

Renal acidification response to chronic hypocapnia. **A**, Sustained hypocapnia entails a persistent decrease in the renal tubular secretory rate of hydrogen ions and a persistent increase in the chloride reabsorption rate. As a result, transient suppression of net acid excretion occurs. This suppression is largely manifested by a decrease in ammonium excretion and, early on, by an increase in bicarbonate excretion. The transient discrepancy between net acid excretion and endogenous acid production, in turn, leads to positive hydrogen ion balance and a reduction in the bicarbonate stores of the body. Maintenance of the resulting hypobicarbonatemia is ensured by the gradual suppression in the rate of renal bicarbonate reabsorption. This suppression itself is a reflection of the hypocapnia-induced decrease in the hydrogen ion secretory rate. A new steady state emerges when two things occur: the reduced filtered load of bicarbonate is precisely balanced by the dampened rate of bicarbonate reabsorption and net acid excretion returns to the level required to offset daily endogenous acid production. The transient retention of acid during sustained hypocapnia is normally accompanied by a loss of sodium in the urine (and *not* by a retention of chloride as analogy with chronic respiratory acidosis would dictate). The resulting extracellular fluid loss is responsible for the hyperchloremia that typically accompanies chronic respiratory alkalosis. Hyperchloremia is sustained by the persistently enhanced chloride reabsorption rate. If dietary sodium is restricted, acid retention is achieved in the company of increased potassium excretion. The specific cellular mechanisms mediating the renal acidification response to chronic hypocapnia are under investigation. Available evidence indicates a parallel decrease in the rates of the luminal sodium ion–hydrogen ion (Na^+-H^+) exchanger and the basolateral sodium ion–3 bicarbonate ion (Na^+-$3HCO_3^-$) cotransporter in the proximal tubule. This parallel decrease reflects a decrease in the maximum velocity (V_{max}) of each transporter but no change in the substrate concentration at half-maximal velocity (K_m) for sodium (as shown in **B** for the Na^+-H^+ exchanger in rabbit renal cortical brush-border membrane vesicles) [11]. Moreover, hypocapnia induces endocytotic retrieval of H^+-adenosine triphosphatase (ATPase) pumps from the luminal membrane of the proximal tubule cells as well as type A intercalated cells of the cortical and medullary collecting ducts. It remains unknown whether chronic hypocapnia alters the quantity of the H^+-ATPase pumps as well as the kinetics or quantity of other acidification transporters in the renal cortex or medulla [6]. NS—not significant. (**B**, *From* Hilden and coworkers [11]; with permission.)

SIGNS AND SYMPTOMS OF RESPIRATORY ALKALOSIS

Central Nervous System	Cardiovascular System	Neuromuscular System
Cerebral vasoconstriction	Chest oppression	Numbness and paresthesias of the extremities
Reduction in intracranial pressure	Angina pectoris	Circumoral numbness
Light-headedness	Ischemic electrocardiographic changes	Laryngeal spasm
Confusion	Normal or decreased blood pressure	Manifestations of tetany
Increased deep tendon reflexes	Cardiac arrhythmias	Muscle cramps
Generalized seizures	Peripheral vasoconstriction	Carpopedal spasm
		Trousseau's sign
		Chvostek's sign

FIGURE 6-11

Signs and symptoms of respiratory alkalosis. The manifestations of primary hypocapnia frequently occur in the acute phase, but seldom are evident in chronic respiratory alkalosis. Several mechanisms mediate these clinical manifestations, including cerebral hypoperfusion, alkalemia, hypocalcemia, hypokalemia, and decreased release of oxygen to the tissues by hemoglobin. The cardiovascular effects of respiratory alkalosis are more prominent in patients undergoing mechanical ventilation and those with ischemic heart disease [2].

CAUSES OF RESPIRATORY ALKALOSIS

Hypoxemia or Tissue Hypoxia	Central Nervous System Stimulation	Drugs or Hormones	Stimulation of Chest Receptors	Miscellaneous
Decreased inspired oxygen tension	Voluntary	Nikethamide, ethamivan	Pneumonia	Pregnancy
High altitude	Pain	Doxapram	Asthma	Gram-positive septicemia
Bacterial or viral pneumonia	Anxiety syndrome-hyperventilation syndrome	Xanthines	Pneumothorax	Gram-negative septicemia
Aspiration of food, foreign object, or vomitus	Psychosis	Salicylates	Hemothorax	Hepatic failure
Laryngospasm	Fever	Catecholamines	Flail chest	Mechanical hyperventilation
Drowning	Subarachnoid hemorrhage	Angiotensin II	Acute respiratory distress syndrome	Heat exposure
Cyanotic heart disease	Cerebrovascular accident	Vasopressor agents	Cardiogenic and noncardiogenic pulmonary edema	Recovery from metabolic acidosis
Severe anemia	Meningoencephalitis	Progesterone	Pulmonary embolism	
Left shift deviation of oxyhemoglobin curve	Tumor	Medroxyprogesterone	Pulmonary fibrosis	
Hypotension	Trauma	Dinitrophenol		
Severe circulatory failure		Nicotine		
Pulmonary edema				

FIGURE 6-12

Respiratory alkalosis is the most frequent acid-base disorder encountered because it occurs in normal pregnancy and high-altitude residence. Pathologic causes of respiratory alkalosis include various hypoxemic conditions, pulmonary disorders, central nervous system diseases, pharmacologic or hormonal stimulation of ventilation, hepatic failure, sepsis, the anxiety-hyperventilation syndrome, and other entities. Most of these causes are associated with the abrupt occurrence of hypocapnia; however, in many instances, the process might be sufficiently prolonged to permit full chronic adaptation to occur. Consequently, no attempt has been made to separate these conditions into acute and chronic categories. Some of the major causes of respiratory alkalosis are benign, whereas others are life-threatening. Primary hypocapnia is particularly common among the critically ill, occurring either as the simple disorder or as a component of mixed disturbances. Its presence constitutes an ominous prognostic sign, with mortality increasing in direct proportion to the severity of the hypocapnia [2].

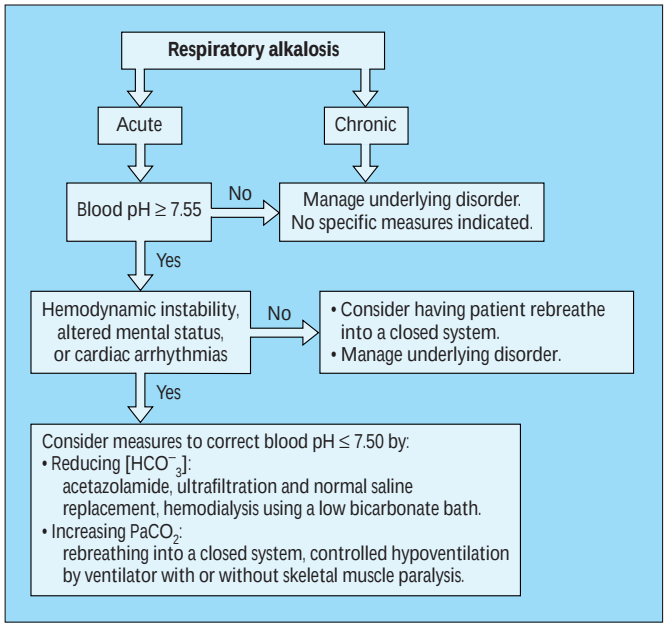


FIGURE 6-13

Respiratory alkalosis management. Because chronic respiratory alkalosis poses a low risk to health and produces few or no symptoms, measures for treating the acid-base disorder itself are not required. In contrast, severe alkalemia caused by acute primary hypocapnia requires corrective measures that depend on whether serious clinical manifestations are present. Such measures can be directed at reducing plasma bicarbonate concentration ($[HCO_3^-]$), increasing the arterial carbon dioxide tension ($PaCO_2$), or both. Even if the baseline plasma bicarbonate is moderately decreased, reducing it further can be particularly rewarding in this setting. In addition, this maneuver combines effectiveness with relatively little risk [1,2].