

may be associated with infiltrative diseases such as sarcoidosis. Impaired PTH secretion may be secondary to magnesium deficiency or to activating mutations in the CaSR or in the G proteins that mediate CaSR signaling, which suppress PTH, leading to effects that are opposite to those that occur in FHH.

Vitamin D deficiency, impaired 1,25(OH)₂D production (primarily secondary to renal insufficiency), or vitamin D resistance also cause hypocalcemia. However, the degree of hypocalcemia in these disorders is generally not as severe as that seen with hypoparathyroidism because the parathyroids are capable of mounting a compensatory increase in PTH secretion. Hypocalcemia may also occur in conditions associated with severe tissue injury such as burns, rhabdomyolysis, tumor lysis, or pancreatitis. The cause of hypocalcemia in these settings may include a combination of low albumin, hyperphosphatemia, tissue deposition of calcium, and impaired PTH secretion.

CLINICAL MANIFESTATIONS

Patients with hypocalcemia may be asymptomatic if the decreases in serum calcium are relatively mild and chronic, or they may present with life-threatening complications. Moderate to severe hypocalcemia is associated with paresthesias, usually of the fingers, toes, and circumoral regions, and is caused by increased neuromuscular irritability. On physical examination, a Chvostek's sign (twitching of the circumoral muscles in response to gentle tapping of the facial nerve just anterior to the ear) may be elicited, although it is also present in ~10% of normal individuals. Carpal spasm may be induced by inflation of a blood pressure cuff to 20 mmHg above the patient's systolic blood pressure for 3 min (Trousseau's sign). Severe hypocalcemia can induce seizures, carpopedal spasm, bronchospasm, laryngospasm, and prolongation of the QT interval.

DIAGNOSTIC APPROACH

In addition to measuring serum calcium, it is useful to determine albumin, phosphorus, and magnesium levels. As for the evaluation of hypercalcemia, determining the PTH level is central to the evaluation of hypocalcemia. A suppressed (or "inappropriately low") PTH level in the setting of hypocalcemia establishes absent or reduced PTH secretion (hypoparathyroidism) as the cause of the hypocalcemia. Further history will often elicit the underlying cause (i.e., parathyroid agenesis vs. destruction). By contrast, an elevated PTH level (secondary hyperparathyroidism) should direct attention to the vitamin D axis as the cause of the hypocalcemia. Nutritional vitamin D deficiency is best assessed by obtaining serum 25-hydroxyvitamin D levels, which reflect vitamin D stores. In the setting of renal insufficiency or suspected vitamin D resistance, serum 1,25(OH)₂D levels are informative.

TREATMENT HYPOCALCEMIA

The approach to treatment depends on the severity of the hypocalcemia, the rapidity with which it develops, and the accompanying complications (e.g., seizures, laryngospasm). Acute, symptomatic hypocalcemia is initially managed with calcium gluconate, 10 mL 10% wt/vol (90 mg or 2.2 mmol) intravenously, diluted in 50 mL of 5% dextrose or 0.9% sodium chloride, given intravenously over 5 min. Continuing hypocalcemia often requires a constant intravenous infusion (typically 10 ampules of calcium gluconate or 900 mg of calcium in 1 L of 5% dextrose or 0.9% sodium chloride administered over 24 h). Accompanying hypomagnesemia, if present, should be treated with appropriate magnesium supplementation.

Chronic hypocalcemia due to hypoparathyroidism is treated with calcium supplements (1000–1500 mg/d elemental calcium in divided doses) and either vitamin D₂ or D₃ (25,000–100,000 U daily) or calcitriol [1,25(OH)₂D, 0.25–2 µg/d]. Other vitamin D metabolites (dihydroxycholesterol, alfalcidol) are now used less frequently. Vitamin D deficiency, however, is best treated using vitamin D supplementation, with the dose depending on the severity of the deficit and the underlying cause. Thus, nutritional vitamin D deficiency generally responds to relatively low doses of vitamin D (50,000 U, 2–3 times per week for several months), whereas vitamin

D deficiency due to malabsorption may require much higher doses (100,000 U/d or more). The treatment goal is to bring serum calcium into the low normal range and to avoid hypercalciuria, which may lead to nephrolithiasis.

GLOBAL CONSIDERATIONS



In countries with more limited access to health care or screening laboratory testing of serum calcium levels, primary hyperparathyroidism often presents in its severe form with skeletal complications (osteitis fibrosa cystica) in contrast to the asymptomatic form that is common in developed countries. In addition, vitamin D deficiency is paradoxically common in some countries despite extensive sunlight (e.g., India) due to avoidance of sun exposure and poor dietary vitamin D intake.

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Acidosis and Alkalosis

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NORMAL ACID-BASE HOMEOSTASIS

Systemic arterial pH is maintained between 7.35 and 7.45 by extracellular and intracellular chemical buffering together with respiratory and renal regulatory mechanisms. The control of arterial CO₂ tension (Paco₂) by the central nervous system (CNS) and respiratory system and the control of plasma bicarbonate by the kidneys stabilize the arterial pH by excretion or retention of acid or alkali. The metabolic and respiratory components that regulate systemic pH are described by the Henderson-Hasselbalch equation:

$$\text{pH} = 6.1 + \log \frac{[\text{HCO}_3^-]}{\text{Pa}_{\text{CO}_2} \times 0.0301}$$

Under most circumstances, CO₂ production and excretion are matched, and the usual steady-state Paco₂ is maintained at 40 mmHg. Underexcretion of CO₂ produces hypercapnia, and overexcretion causes hypocapnia. Nevertheless, production and excretion are again matched at a new steady-state Paco₂. Therefore, the Paco₂ is regulated primarily by neural respiratory factors and is not subject to regulation by the rate of CO₂ production. Hypercapnia is usually the result of hypoventilation rather than of increased CO₂ production. Increases or decreases in Paco₂ represent derangements of neural respiratory control or are due to compensatory changes in response to a primary alteration in the plasma [HCO₃⁻].

DIAGNOSIS OF GENERAL TYPES OF DISTURBANCES

The most common clinical disturbances are simple acid-base disorders; i.e., metabolic acidosis or alkalosis or respiratory acidosis or alkalosis.

SIMPLE ACID-BASE DISORDERS

Primary respiratory disturbances (primary changes in Paco₂) invoke compensatory metabolic responses (secondary changes in [HCO₃⁻]), and primary metabolic disturbances elicit predictable compensatory respiratory responses (secondary changes in Paco₂). Physiologic compensation can be predicted from the relationships displayed in **Table 66-1**. In general, with one exception, compensatory responses return the pH toward, but not to, the normal value. Chronic respiratory alkalosis when prolonged is an exception to this rule and often returns the pH to a normal value. Metabolic acidosis due to an increase in endogenous acids (e.g., ketoacidosis) lowers extracellular fluid [HCO₃⁻] and decreases extracellular pH. This stimulates the medullary chemoreceptors to increase ventilation and to return