WATER, ELECTROLYTES AND ACID-BASE BALANCE

1) Hypokalemia.

Answer. Physiology of K^+:

- K^+ is the major intracellular cation, with only 2% of total body K^+ located in the extracellular space.
- The normal serum concentration is 3.3 to 4.9 mmol/L (12.9 to19.1 mg/dL).
- Approximately 50 to 100 mmol (195 to 390 mg/dL) K^+ is ingested and absorbed daily.
- Ninety percent of K^+ is renally excreted, with the remainder eliminated in stools.

Hypokalemia

Causes: K^+ depletion from inadequate intake alone is rare.

Common causes of K^+ depletion in the surgical patient include:

- GI losses (e.g., diarrhea, persistent vomiting, nasogastric suctioning),
- Renal losses (e.g., diuretics, fluid mobilization, amphotericin B), and
- Cutaneous losses (e.g., burns).

Other causes of hypokalemia include:

- Acute intracellular K^+ uptake (associated with insulin excess, metabolic alkalosis, myocardial infarction, delirium tremens, hypothermia, and theophylline toxicity).
- Hypokalemia may also occur in the malnourished patient after initiation of total parenteral nutrition (refeeding syndrome), caused by the incorporation of K^+ into rapidly dividing cells.

Clinical manifestations:

- Mild hypokalemia [K^+ >3 mmol/L is generally asymptomatic.
- The symptoms present with severe K^+ deficiency [K^+ <3 mmol/L (11.7 mg/dL)] and are primarily cardiovascular.
- Early electroencephalogram (ECG) manifestations include ectopy, T-wave depression, and prominent U waves.
- Severe depletion increases susceptibility to reentrant arrhythmias.

Treatment:

- In mild hypokalemia, oral replacement is suitable. Typical daily therapy for the treatment of mild hypokalemia in the patient with intact renal function is 40 to 100 mmol KCl orally in single or divided doses.
- Parenteral therapy is indicated in the presence of severe depletion, significant symptoms, or oral intolerance. K^+ concentrations (administered as chloride, acetate, or phosphate) in peripherally administered intravenous fluids should

not exceed 40 mmol/), and the rate of administration should not exceed 20 mmol (78 mg)/hour.

- However, higher K^+ concentrations [60 to 80 mmol/L (234 to 312 mg/dL)] administered more rapidly (with cardiac monitoring) are indicated in cases of severe hypokalemia, for cardiac arrhythmias, and in the management of diabetic ketoacidosis.
- Administration of high K^+ concentrations via subclavian, jugular, or right atrial catheters should be avoided because local K^+ concentrations may be cardiotoxic.
- Hypomagnesemia frequently accompanies hypokalemia and generally must be corrected to successfully replenish K^+.

2) Hyperkalemia.

Answer. Causes and diagnosis:

- Hyperkalemia may occur with normal or elevated stores of total body K^+. Pseudohyperkalemia is a laboratory abnormality that reflects K^+ release from leukocytes and platelets during coagulation.
- Spurious elevation in K^+ may result from hemolysis or phlebotomy from a strangulated arm.
- Abnormal redistribution of K^+ from the intracellular to the extracellular compartment may occur as a result of insulin deficiency, β-adrenergic receptor blockade, acute acidemia, rhabdomyolysis, cell lysis (after chemotherapy), digitalis intoxication, reperfusion of ischemic limbs, and succinylcholine administration.

Clinical manifestations:

- Mild hyperkalemia [K^+ = 5 to 6 mmol/L] is generally asymptomatic.
- Signs of significant hyperkalemia [K^+ >6.5 mmol/L] are, most notably, ECG abnormalities: symmetric peaking of T waves, reduced P-wave voltage, and widening of the QRS complex. If untreated, severe hyperkalemia ultimately may cause a sinusoidal ECG pattern.

Treatment:

- Mild hyperkalemia [K^+ = 5 to 6 mmol/L] can be treated conservatively by the reduction of daily K^+ intake and the possible addition of a loop diuretic (e.g., furosemide) to promote renal elimination.
- Any medication that is capable of impairing K^+ homeostasis (e.g., nonselective β-adrenergic antagonists, angiotensin-converting enzyme inhibitors, K^+-sparing diuretics, nonsteroidal anti-inflammatory drugs) should be discontinued, if possible.
- Severe hyperkalemia [K^+ >6.5 mmol/L (25.4 mg/dL)]

- Temporizing measures produce shifts of potassium from the extracellular to the intracellular space.
  - $NaHCO_3$ [1 mmol/kg or 1 to 2 ampules (50 mL each) of 8.4% $NaHCO_3$] can be infused intravenously over a 3- to 5-minute period. This dose can be repeated after 10 to 15 minutes if ECG abnormalities persist.
  - Dextrose (0.5 g/kg body weight) infused with insulin (0.3 unit of regular insulin/g of dextrose) transiently lowers serum K^+ (the usual dose is 25 g dextrose, with 6 to 10 units of regular insulin given simultaneously as an intravenous bolus).
  - Inhaled β-agonists [e.g., albuterol sulfate] have been shown to lower plasma K^+, with a duration of action of up to 2 hours.
  - Calcium gluconate 10% (5 to 10 mL intravenously over 2 minutes) should be administered to patients with profound ECG changes who are not receiving digitalis preparations. Calcium functions to stabilize the myocardium.

- Therapeutic measures to definitively decrease total body potassium by increasing potassium excretion.

  - Sodium polystyrene sulfonate (Kayexalate), a Na^+-K^+ exchange resin, can be administered orally or rectally to promote K^+ elimination. A decrease in serum K^+ level typically occurs 2 to 4 hours after administration.
  - Hydration with 0.9% NaCl in combination with a loop diuretic (e.g., furosemide, 20 to 100 mg intravenously) should be administered to patients with adequate renal function to promote renal K^+ excretion.
  - Dialysis is definitive therapy in severe, refractory, or life-threatening hyperkalemia.

3) Hyponatremia.

Answer. Physiology. The normal individual consumes 3 to 5 g of NaCl (130 to 217 mmol Na^+)/day. Balance is maintained primarily by the kidneys.

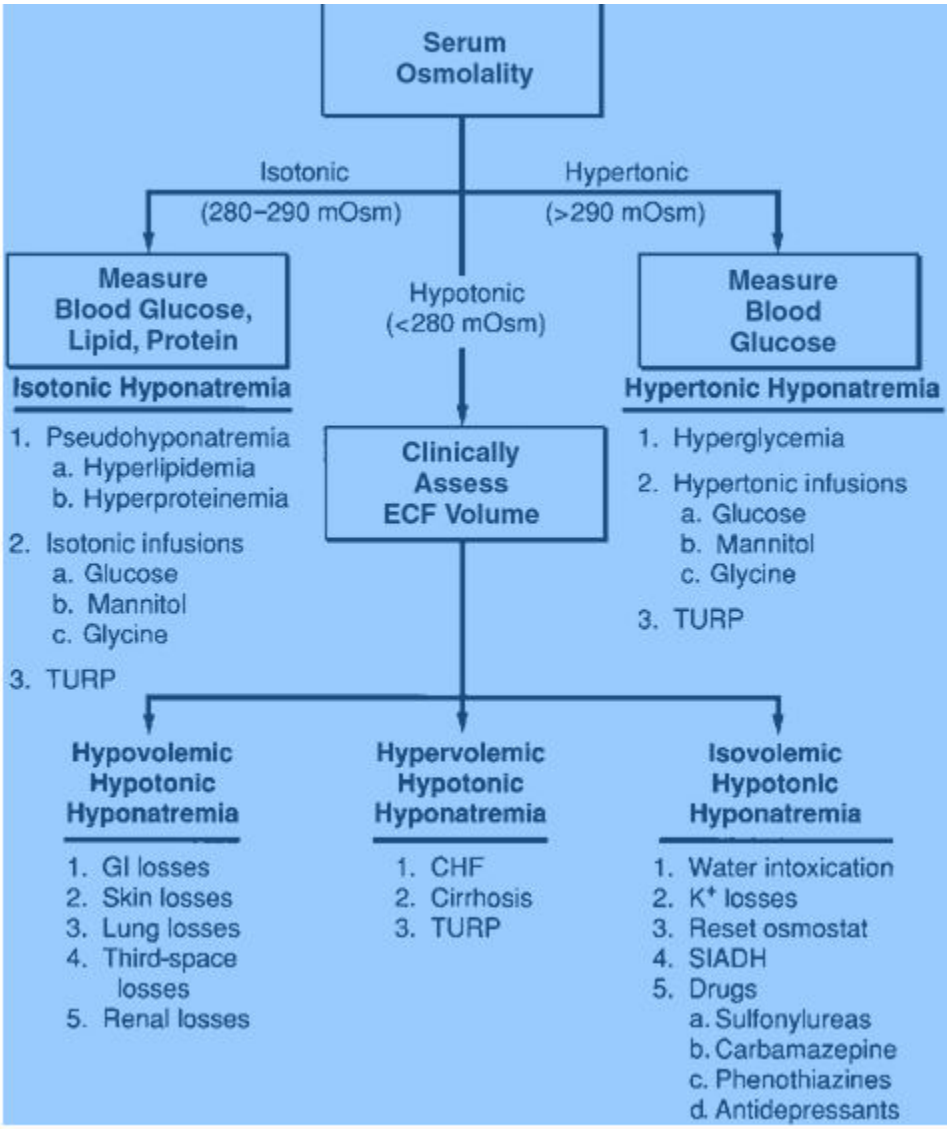
- Normal Na^+ concentration is 135 to 145 mmol/L (310 to 333 mg/dL).
- Potential sources of significant Na^+ loss include sweat, urine, and gastrointestinal (GI) secretions.
- The Na^+ concentration largely determines the plasma osmolality (P_{osm}), which can be approximated by the following equation:

- $\boldsymbol{P_{osm}}$***(mOsm/L)=2Xserum [****Na^+*** *(mMol/L)+* ***K^+*** *(mMol/L)****] + [Glucose(mg/dl)]/18 + [BUN(mg/dl)]/2.8***

Where BUN is blood urea nitrogen. Normal P_{osm} is 290 to 310 mOsm/L.

Hyponatremia:

Causes and diagnosis. The diagnostic approach to hyponatremia is illustrated in Figure below. Hyponatremia may occur in conjunction with hypertonicity, isotonicity, or hypotonicity. Consequently, it is necessary to measure the serum osmolality to evaluate patients with hyponatremia.



Clinical manifestations.

- Symptoms associated with hyponatremia are predominantly neurologic and result from hypoosmolality.
- A decrease in P_{osm} causes intracellular water influx, increased intracellular volume, and cerebral edema.

- Symptoms include lethargy, confusion, nausea, vomiting, seizures, and coma. The likelihood that symptoms will occur is related to the degree of hyponatremia and to the rapidity with which it develops.
- Chronic hyponatremia is often asymptomatic until the serum Na^+ concentration falls below 110 to 120 mEq/L.
- An acute drop in the serum Na^+ concentration to 120 to130 mEq/L conversely, may produce symptoms.

- **Treatment:**

  - Isotonic and hypertonic hyponatremia correct with resolution of the underlying disorder.
  - Hypovolemic hyponatremia can be managed with administration of 0.9% NaCl to correct volume deficits and replace ongoing losses.
  - Water intoxication responds to fluid restriction (1,000 mL/day).
  - For SIADH, water restriction (1,000 mL/day) should be attempted initially. The addition of a loop diuretic (furosemide) or an osmotic diuretic (mannitol) may be necessary in refractory cases.
  - Hypervolemic hyponatremia may respond to water restriction (1,000 mL/day) to return Na^+ to greater than 130 mmol/L.

Administration of synthetic brain natriuretic peptide (BNP) is also useful therapeutically in the setting of acute heart failure. (because it inhibits Na^+ reabsorption at the cortical collecting duct and inhibits the action of vasopressin on water permeability at the inner medullary collecting duct.)

  - {In the presence of symptoms or extreme hyponatremia [Na^+ <110 mmol/L] hypertonic saline (3% NaCl) is indicated. Serum Na^+ should be corrected to approximately 120 mmol/L . The quantity of 3% NaCl that is required to increase serum Na^+ to 120 mmol/L can be estimated by calculating the Na^+ deficit:

Na^+ deficit (mmol) = 0.60 × lean body weight (kg) × [120 - measured serum Na^+ (mmol/L)].

Central pontine demyelination occurs in the setting of correction of hyponatremia. The risk factors for demyelination are controversial but appear to be related to the chronicity of hyponatremia (>48 hours) and the rate of correction. The serum Na^+ should be increased by no more than 12 mmol/L in 24 hours of treatment.

For acute hyponatremia (<48 hours), the serum Na^+ may be corrected more rapidly [i.e., Na^+ = 1 to 2 mmol / hour]. The patient's volume status should be carefully monitored over this time, and the serum Na^+ should be determined frequently (every 1 to 2 hours). Once the serum Na^+ concentration reaches 120 mmol/L and symptoms have resolved, administration of hypertonic saline can be discontinued.}

4) Hypernatremia.

Answer.

- Physiology. The normal individual consumes 3 to 5 g of NaCl (130 to 217 mmol Na^+)/day. Balance is maintained primarily by the kidneys.
- Normal Na^+ concentration is 135 to 145 mmol/L (310 to 333 mg/dL).
- Potential sources of significant Na^+ loss include sweat, urine, and gastrointestinal (GI) secretions.
- The Na^+ concentration largely determines the plasma osmolality (P_{osm}), which can be approximated by the following equation:

- $P_{osm}(mOsm/L)=2Xserum\ [Na^+(mMol/L)+K^+\ (mMol/L)]\ +\ [Glucose(mg/dl)]/18\ +\ [\ BUN(mg/dl)\ ]/2.8$

  where BUN is blood urea nitrogen. Normal P_{osm} is 290 to 310 mOsm/L.

  In general, hypotonicity and hypertonicity coincide with hyponatremia and hypernatremia, respectively.

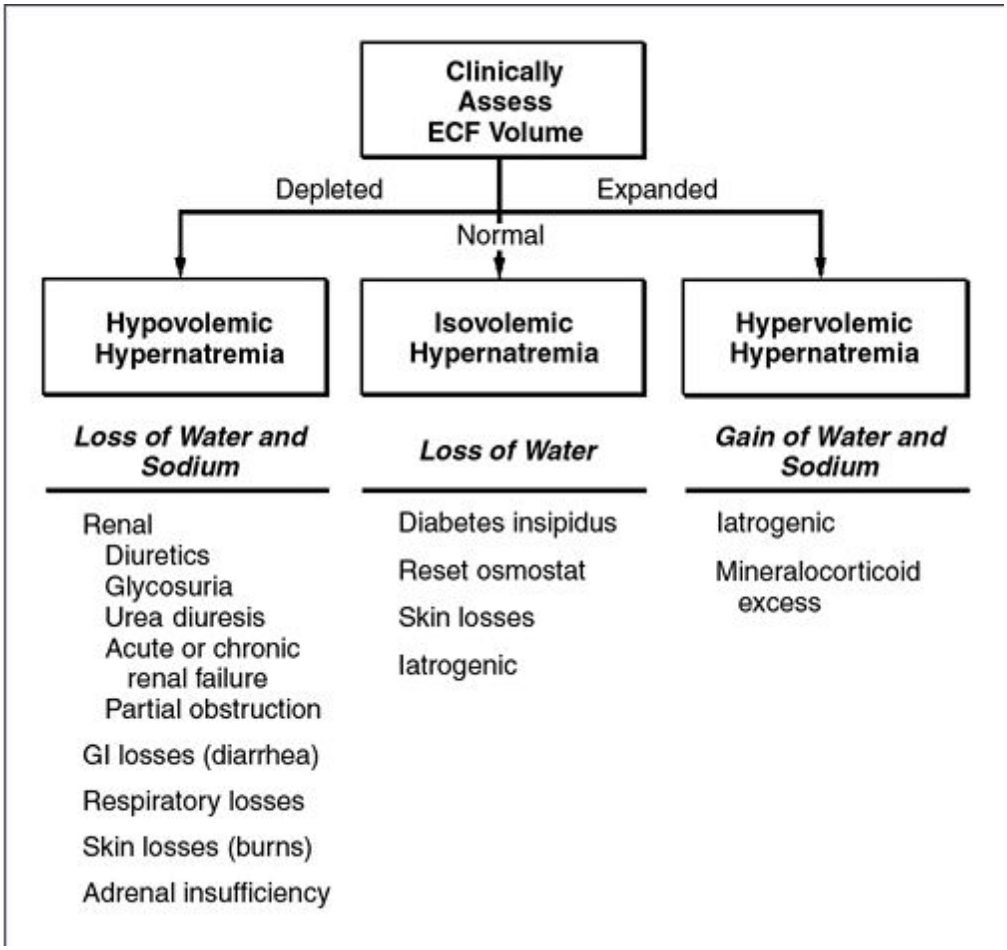
  However, Na^+ concentration and total body water are controlled by independent mechanisms. As a consequence, hyponatremia or hypernatremia may occur in conjunction with hypovolemia, hypervolemia, or euvolemia.

Hypernatremia

Diagnosis:

Hypernatremia is uniformly hypertonic and typically the result of water loss in excess of solute. Patients are categorized on the basis of their extracellular fluid volume status.

Classification and causes of hypernatremia:



Clinical manifestations: Symptoms of hypernatremia that are related to the hyperosmolar state are primarily neurologic. These initially include lethargy, weakness, and irritability and may progress to fasciculations, seizures, coma, and irreversible neurologic damage.

Treatment:

- Water deficit associated with hypernatremia can be estimated using the following equation: Water deficit (L) = 0.60 × total body weight (kg) × [(serum Na^+ in mmol/L/140) = 1].
- Rapid correction of hypernatremia can result in cerebral edema and permanent neurologic damage.
- Consequently, only one half of the water deficit should be corrected over the first 24 hours, with the remainder being corrected over the following 2 to 3 days.
- Serial Na^+ determinations are necessary to ensure that the rate of correction is adequate but not excessive.
- Oral fluid intake is acceptable for replacing water deficits. If oral intake is not possible, D5W or D5/0.45% NaCl can be substituted.

- In addition to the actual water deficit, insensible losses and urinary output must be replaced.

Diabetes insipidus:

- Central diabetes insipidus can be treated with desmopressin acetate administered intranasally [0.1 to 0.4 mL (10 to 40 μg) daily] or subcutaneously or intravenously [0.5 to 1 mL (2 to 4 μg) daily]
- Nephrogenic diabetes insipidus treatment requires removal of any potentially offending drug and correction of electrolyte abnormalities. If these measures are ineffective, dietary sodium restriction in conjunction with a thiazide diuretic may be useful (hydrochlorothiazide, 50 to 100 mg/day orally).

5) Metabolic acidosis.

Answer. Expected Compensation for Simple Acid-base Disorders

Primary disorder	**Initial change**	**Compensatory response**	**Expected compensation**
Metabolic Acidosis	HCO_3^- decrease	PCO_2 decrease	PCO_2 decrease = 1.2 × ΔHCO_3^-
Metabolic Alkalosis	HCO_3^- increase	PCO_2 increase	PCO_2 increase = 0.7 × ΔHCO_3^-
Respiratory acidosis	PCO_2 increase	HCO_3^- increase	Acute: HCO_3^- increase = 0.1 × ΔPCO_2 Chronic: HCO_3^- increase = 0.35 × ΔPCO_2
Respiratory alkalosis	PCO_2 decrease	HCO_3^- decrease	Acute: HCO_3^- decrease = 0.2 × ΔPCO_2 Chronic: HCO_3^- decrease = 0.5 × ΔPCO_2

- Metabolic acidosis results from the accumulation of nonvolatile acids, reduction of renal acid excretion, or loss of alkali. The most common causes of metabolic acidosis are listed in Table 4-6. Metabolic acidosis has few specific signs. The appropriate diagnosis depends on the clinical setting and laboratory tests.
  - The anion gap (AG; normal = 12 ± 2 mmol/L) represents the anions, other than Cl^- and HCO_3^-, that are necessary to counterbalance Na^+ electrically:

AG (mmol/L) = Na^+ (mmol/L) + [Cl (mmol/L) + HCO_3^- (mmol/L)]

It is useful diagnostically to classify metabolic acidosis into increased or normal AG metabolic acidosis.

Causes of Metabolic Acidosis

- Increased anion gap
  - a. Increased acid production
    - 1. Ketoacidosis
      - Diabetic
      - Alcoholic
      - Starvation
    - 2. Lactic acidosis
    - 3.Toxic ingestion (salicylates, ethylene glycol, methanol)
  - b. Renal failure

- Normal anion gap (hyperchloremic)
  - a. Renal tubular dysfunction
    1. Renal tubular acidosis
    2. Hypoaldosteronism
    3. Potassium-sparing diuretics
  - b. Loss of alkali
    1. Diarrhea
    2. Ureterosigmoidostomy
    3. Carbonic anhydrase inhibitors
  - c. Administration of HCl (ammonium chloride, cationic amino acids)

- **Treatment of metabolic acidosis** must be directed primarily at the underlying cause of the acid-base disturbance. Bicarbonate therapy should be considered in patients with moderate to severe metabolic acidosis only after the primary cause has been addressed. The HCO_3^- deficit (mmol/L) can be estimated using the following equation:

HCO_3^- deficit (mmol/L) = body weight (kg) × 0.4 × [(desired HCO_3^- [mmol/L]) - (measured HCO_3^- [mmol/L])]

This equation serves to provide only a rough estimate of the deficit because the volume of HCO_3^- distribution and the rate of ongoing H^+ production are variable.

6) Metabolic alkalosis.

Answer. Metabolic alkalosis is a **metabolic** condition in which the pH of tissue is elevated beyond the normal range (7.35-7.45). This is the result of decreased hydrogen ion concentration, leading to increased bicarbonate, or alternatively a direct result of increased bicarbonate concentrations.

Causes of Metabolic Alkalosis

Associated with extracellular fluid volume (chloride) depletion

Vomiting or gastric drainage
Diuretic therapy
Posthypercapnic alkalosis

Associated with mineralocorticoid excess

Cushing syndrome
Primary aldosteronism
Bartter syndrome

Severe K^+ depletion

Excessive alkali intake

- **Diagnosis.** Although the cause of metabolic alkalosis is usually apparent in the surgical patient, measurement of the urinary chloride concentration may be useful for differentiating these disorders. A urine Cl^- concentration of less than 15 mmol/L suggests inadequate fluid resuscitation, ongoing GI loss from emesis or nasogastric suctioning, diuretic administration, or posthypercapnia as the cause of the metabolic alkalosis. A urine Cl^- concentration of greater than 20 mmol/L suggests mineralocorticoid excess, alkali loading, concurrent diuretic administration, or the presence of severe hypokalemia.
- **Treatment principles** in metabolic alkalosis include identifying and removing underlying causes, discontinuing exogenous alkali, and repairing Cl^-, K^+, and volume deficits. Because metabolic alkalosis generally is well tolerated, rapid correction of this disorder usually is not necessary.
  - Initial therapy should include the correction of volume deficits (with 0.9% NaCl) and hypokalemia. Patients with vomiting or nasogastric suctioning also may benefit from H_2-receptor antagonists or other acid-suppressing medications.
  - Edematous patients. Chloride administration does not enhance HCO_3^- excretion because it does not correct the reduced effective arterial blood volume. Acetazolamide (5 mg/kg/day intravenously or orally) facilitates fluid mobilization while decreasing renal HCO_3^- reabsorption. However, tolerance to this diuretic may develop after 2 to 3 days.
  - Severe alkalemia (HCO_3^- >40 mmol/L), especially in the presence of symptoms, may require more aggressive correction. The infusion of acidic solutions is occasionally indicated in the patient with severe refractory metabolic alkalosis and chloride loss, typically due to massive nasogastric drainage or complete prepyloric obstruction. Ammonium chloride (NH_4Cl) is hepatically converted to urea and HCl. The amount of NH_4Cl that is required can be estimated using the following equation:

    NH_4Cl (mmol) = 0.2 × weight (kg) × [103 - serum Cl^- (mmol)].

    NH_4Cl is contraindicated in hepatic failure.

  - HCl [0.1 N (normal), administered intravenously] corrects metabolic alkalosis more rapidly. The amount of H^+ to administer can be estimated using the following equation:

    H^+ (mmol) = 0.5 × weight (kg) × [103 - serum Cl^- (mmol/L)].

  - Dialysis can be considered in the volume-overloaded patient with renal failure and intractable metabolic alkalosis.

7) Respiratory acidosis.

Answer.

- Respiratory acidosis occurs when alveolar ventilation is insufficient to excrete metabolically produced CO_2.
- Common causes in the surgical patient include
    - Respiratory center depression (e.g., drugs, organic disease),
    - Neuromuscular disorders, and
    - Cardiopulmonary arrest.
- Chronic respiratory acidosis may occur
    - In pulmonary diseases, such as chronic emphysema and bronchitis.
    - Chronic hypercapnia may also result from primary alveolar hypoventilation or alveolar hypoventilation related to extreme obesity (e.g., pickwickian syndrome) or from thoracic skeletal abnormalities.
    - The diagnosis of acute respiratory acidosis usually is evident from the clinical situation, especially if respiration is obviously depressed.
    - Appropriate therapy is correction of the underlying disorder. In cases of acute respiratory acidosis, there is no indication for $NaHCO_3$ administration.

8) Respiratory alkalosis.

Answer.

Metabolic acidosis and respiratory acidosis	**Metabolic acidosis and respiratory alkalosis**	**Metabolic alkalosis and respiratory acidosis**	**Metabolic alkalosis and respiratory alkalosis**	**Metabolic acidosis and alkalosis**
1.Cardiopulmonary arrest 2.Severe pulmonary edema 3.Salicylate and sedative overdose 4.Pulmonary disease with superimposed renal failure or sepsis	1.Salicylate overdose 2.Sepsis 3.Combined hepatic and renal insufficiency	1.Chronic pulmonary disease, with superimposed: Diuretic therapy 2.Steroid therapy 3.Vomiting 4.Reduction of hypercapnia by mechanical ventilation	1.Pregnancy with vomiting 2.Chronic liver disease treated with diuretic therapy 3.Cardiopulmonary arrest treated with bicarbonate therapy and 4.Mechanical ventilation	1. Vomiting superimposed on Renal failure 2.Diabetic ketoacidosis 3. Alcoholic ketoacidosis

- **Respiratory alkalosis** is the result of acute or chronic hyperventilation.

The causes of respiratory alkalosis include

- Acute hypoxia (e.g., pneumonia, pneumothorax, pulmonary edema, bronchospasm),
- Chronic hypoxia (e.g., cyanotic heart disease, anemia), and
- Respiratory center stimulation (e.g., anxiety, fever, Gram-negative sepsis, salicylate intoxication, central nervous system disease, cirrhosis, pregnancy).

  - Excessive ventilation may also cause respiratory alkalosis in the mechanically ventilated patient.
  - Depending on its severity and acuteness, hyperventilation may or may not be clinically apparent.
  - Clinical findings are nonspecific.
  - As in respiratory acidosis, the only effective treatment is correction of the underlying disorder.