

Acid-base

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THE STORY IN ONE SENTENCE

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“Acid-base means: pH direction, main troublemaker (CO₂ or bicarbonate), how hard the body is working to fix it, anion gap clues, then find what broke upstream.”

Normal anatomy — the body's job

Three teams keep pH between 7.35 and 7.45: buffers (chemicals that grab or release H⁺ instantly), lungs (control CO₂ by breathing faster or slower), and kidneys (control bicarbonate over days by dumping or saving it). Buffers react in seconds, lungs adjust in minutes to hours, kidneys fine-tune over days. Keep that picture in your head, because every abnormal finding is a change from this normal teamwork.

BODY'S JOB

Normal job: buffers hold pH steady moment to moment, lungs blow off or keep CO₂ to adjust acid fast, kidneys reabsorb or dump bicarbonate and hydrogen ions to fine-tune pH slowly. When one team fails—acid floods in from shock (lactate), diabetes (ketones), poisons (methanol, antifreeze, aspirin), diarrhea or kidney tube disease (bicarbonate loss), weak breathing (CO₂ piles up), or fast breathing (CO₂ drops too low)—pH swings. That upstream break is what we trace and fix.

1. Cell metabolism makes CO₂ and H⁺ every second (like a car engine makes exhaust).
2. Buffers (proteins, hemoglobin, phosphate, bicarbonate) grab H⁺ instantly so pH stays steady.
3. Lungs blow off CO₂ (which carries acid) when you breathe out; hold CO₂ when you breathe slow.

4. Kidneys dump H^+ into urine and save bicarbonate (a base) back into blood over hours to days.
5. Final check: pH stays 7.35 to 7.45, CO_2 stays 35 to 45 mmHg, bicarbonate stays 22 to 28 mEq/L.

What breaks

Usually one broken thing upstream explains all the strange numbers together.

CLINICAL TERM

Acid floods in from lactate (shock, low oxygen), ketones (diabetic ketoacidosis or starvation), toxins (methanol, ethylene glycol, aspirin), or bicarbonate loss (diarrhea, renal tubular too much acid in the blood (acidosis)). Or CO_2 builds up from weak breathing (COPD flare, sedation, weak muscles). Or hyperventilation (pain, panic, low oxygen, infection) blows off too much CO_2 . That break does not stay local. The downstream signal you will see at the bedside is acidemia confuses the brain (H^+ disrupts nerve signals), weakens heart squeeze, and pushes potassium out of cells into blood (trading places with H^+). Read all the weird findings backward from there—they all point to this one upstream break.

How the body compensates

Vital signs can look acceptable while the body is working hard to compensate. The job is to see the crash point coming before the patient collapses.

1. The body keeps vital signs steady for a while through compensation—lungs blow off CO_2 for metabolic acidosis (acid building up in the blood) (Winter formula: expected $CO_2 = 1.5 \times \text{bicarbonate} + 8, \pm 2$), kidneys save bicarbonate for respiratory acidosis (acid building up from trapped carbon dioxide) (acute: bicarbonate rises 1 mEq/L per 10 mmHg CO_2 rise; chronic: 3.5 mEq/L per 10 mmHg rise).
2. That is the dangerous middle, because it hides where the patient really is on the curve toward collapse. Heart rate, blood pressure, and oxygen saturation can look okay even as pH is dropping and lactate is climbing.
3. The crash point to watch for is: missed toxic alcohol (methanol from windshield fluid, ethylene glycol from antifreeze—both cause high anion gap too much acid in the blood (acidosis) and can blind or kill), missed infection with lactate above 4 mmol/L (sepsis, tissue dying), diabetic ketoacidosis (the acid crisis of missing insulin) with pH below 7.0 or potassium swinging dangerously, or respiratory failure with CO_2 above 60 mmHg and confusion (CO_2 narcosis).

4. Watch for the crash point before it happens, because once compensation fails—lungs cannot blow off more CO₂, kidneys cannot save more bicarbonate—pH plummets, heart rhythm destabilizes, brain shuts down, and the window to reverse it closes fast.
5. Look at trends—how things are getting worse or better over repeated blood gases (every 1 to 4 hours depending on severity)—not just one snapshot. Compare bicarbonate, CO₂, pH, lactate, and anion gap side by side.
6. A stable patient on a downhill slope (acidosis deepening, lactate climbing from 2 to 4 to 6 mmol/L, bicarbonate dropping from 18 to 14 to 10 mEq/L) is not really stable—escalate care (ICU, more aggressive resuscitation) before decompensation.

Domino effect

1. Acidemia confuses the brain, weakens heart squeeze, and raises blood potassium. — Acidemia (pH below 7.35) means extra H⁺ ions compete with calcium for spots on troponin (the protein that makes heart muscle squeeze), so the heart pumps weaker and blood pressure can drop. H⁺ also disrupts nerve cell electrical signals (changes sodium and potassium channel function), causing confusion, sleepiness, or coma. H⁺ shifts into cells in exchange for K⁺ (the cell membrane pump trades one for the other to buffer the acid), pushing potassium out into the blood—serum potassium rises about 0.6 mEq/L for every 0.1 pH drop—and risking deadly heart rhythms (peaked T waves, wide QRS, ventricular fibrillation).
2. Alkalemia drops active calcium and causes muscle spasms, seizures, and abnormal heart rhythms. — Alkalemia (pH above 7.45) makes blood proteins (albumin) grab more calcium ions, so free ionized calcium (the active form that nerves and muscles use) drops even though total calcium looks normal. Nerve and muscle cells become hyperexcitable (fire too easily) because calcium normally stabilizes the cell membrane. Result: tetany (muscle spasms, especially hands and feet—Trousseau sign, Chvostek sign), seizures, and heart rhythm problems (prolonged QT interval, torsades de pointes). Alkalemia also shifts the oxygen-hemoglobin curve left, making hemoglobin hold oxygen tighter and deliver less to tissues.

3. Compensation follows predictable formulas: for metabolic acidosis (acid building up in the blood), expected CO_2 equals 1.5 times bicarbonate plus 8 (Winter formula); for respiratory acidosis (acid building up from trapped carbon dioxide), bicarbonate rises 1 mEq/L per 10 mmHg CO_2 rise (acute) or 3.5 mEq/L per 10 mmHg (chronic). If the measured value does not match the expected, a second hidden disorder is present. — The body's three rescue teams—buffers (instant), lungs (minutes to hours), kidneys (days)—work together to hold pH in the narrow zone 7.35 to 7.45 so enzymes work at the right speed, oxygen delivery stays optimal (hemoglobin releases oxygen to tissues), and electrolyte balance holds (potassium, calcium stay in safe ranges). When one system breaks, the other two compensate, creating predictable blood gas patterns. Deviation from formulas signals a mixed disorder—for example, metabolic acidosis (acid building up in the blood) plus hidden metabolic alkalosis (the blood turning too alkaline) (vomiting and septic shock together), or respiratory acidosis (acid building up from trapped carbon dioxide) plus metabolic alkalosis (COPD patient on diuretics).
4. Calculate anion gap (sodium minus the sum of chloride and bicarbonate, normal 8 to 12) for every metabolic acidosis (acid building up in the blood) to see if unmeasured acids are present. — Elevated anion gap (above 12) means unmeasured anions—lactate (from shock, seizures, blood-starved (ischemic) bowel), ketones (diabetic ketoacidosis, alcoholic ketoacidosis, starvation), toxins (methanol, ethylene glycol, aspirin as salicylate), or uremic acids (kidney failure)—are filling the blood. Normal anion gap (8 to 12) metabolic acidosis (acid building up in the blood) means bicarbonate was lost directly (diarrhea loses bicarbonate in stool, renal tubular too much acid in the blood (acidosis) loses it in urine) or chloride was added (normal saline resuscitation, acetazolamide). The gap directs you to the cause: high gap → think GOLD MARK mnemonic (Glycols—ethylene/propylene, Oxoproline, L-lactate, D-lactate, Methanol, Aspirin, Renal failure, Ketoacidosis); normal gap → think diarrhea, RTA, saline.
5. Use delta-delta (change in anion gap divided by change in bicarbonate from normal) to unmask hidden mixed disorders. — Delta-delta compares how much the anion gap rose versus how much bicarbonate dropped. Normally they move together 1:1 (one unmeasured anion replaces one bicarbonate). If delta-delta is above 2, hidden metabolic alkalosis (the blood turning too alkaline) is present (vomiting, diuretics on top of lactic acidosis (acid from oxygen-starved tissues)). If delta-delta is below 1, hidden normal-gap too much acid in the blood (acidosis) is present (diarrhea plus ketoacidosis). If delta-delta is 1 to 2, pure high anion gap too much acid in the blood. This catches coexisting problems that one blood gas snapshot hides—common in ICU patients with multiple organ failures.

6. Each abnormal number you see (high potassium, confusion, weak heart, deep gasping breaths) is not the disease itself—it is the body's response to the real broken thing upstream. — Kussmaul breathing (deep, fast, rhythmic breathing—like a marathon runner but at rest) is the lungs trying to blow off CO₂ to raise pH in metabolic acidosis (acid building up in the blood) (seen in diabetic ketoacidosis (the acid crisis of missing insulin), severe waste buildup in the blood (uremia), severe lactic acidosis (acid from oxygen-starved tissues)). High potassium is the H⁺-K⁺ swap trying to buffer extra acid inside cells. Confusion or coma is the brain failing as pH drops below 7.2 (H⁺ disrupts neurotransmitter release and receptor function). Weak heart contraction is acidemia blocking troponin-calcium binding. Trace every finding backward to the upstream break—shock (lactate), infection (lactate), uncontrolled diabetes (ketones), toxin ingestion, kidney failure, lung failure—and fix that root cause.
7. Trace it back: identify the main disorder (metabolic vs. respiratory, too much acid in the blood (acidosis) vs. too little acid in the blood (alkalosis) from pH and CO₂/bicarbonate direction), check if compensation matches formulas, calculate anion gap, use delta-delta, then fix the cause—resuscitate shock with fluids and pressors, give insulin and fluids for diabetic ketoacidosis (the acid crisis of missing insulin), dialyze toxins and severe waste buildup in the blood (uremia), treat infection, support or take over breathing, stop diarrhea, correct vomiting and volume loss. — Fixing the upstream cause reverses the whole cascade. Fluids and pressors restore blood flow, stopping lactate production. Insulin opens the glucose gate, stopping ketone production. Dialysis pulls out methanol, ethylene glycol, and uremic toxins. Antibiotics clear infection. Ventilator or BiPAP takes over breathing work. Stopping diarrhea or vomiting stops bicarbonate or acid loss. Giving bicarbonate IV (sodium bicarbonate) is reserved only for severe acidemia (pH below 7.1 to 7.2) because it can overshoot into too little acid in the blood (alkalosis), drop ionized calcium, and shift potassium dangerously—treat the cause first, support pH only as a bridge. As the root problem resolves, pH, CO₂, bicarbonate, potassium, and mental status all normalize together.
8. Monitor response with serial blood gases (arterial or venous), lactate, and electrolytes every 1 to 4 hours in severe cases, watching for pH moving toward 7.35 to 7.45, lactate dropping toward normal (below 2 mmol/L), anion gap closing, potassium normalizing, and mental status clearing. — Trends tell you if your treatment is working or if the patient is decompensating despite therapy. A rising pH and falling lactate mean resuscitation is working. A stable or worsening pH, climbing lactate, or rising CO₂ despite treatment means escalate care—more fluids, pressors, higher ventilator support, or emergent dialysis. Serial monitoring catches the turn early, while you still have time to intervene, before the patient crashes into cardiac arrest or refractory shock.

Symptoms · what the patient feels, and why

- **Kussmaul breathing (deep, fast, sighing breaths):** When blood pH drops (metabolic too much acid in the blood (acidosis)), the brain's breathing center sends urgent signals to blow off carbon dioxide fast. The lungs breathe harder and deeper to push out CO₂ — that raises pH back up. It's like opening a window to let heat escape when a room gets too hot.
- **Confusion, drowsiness, or coma:** When blood is too acidic (pH below 7.35) or too alkaline (pH above 7.60), nerve cells can't send electrical signals properly. Brain cells need the right pH to work — when it's off, the brain slows down. Severe pH swings (below 7.20 or above 7.60) can shut the brain down completely.
- **Nausea and vomiting:** Acidic blood irritates the vomiting trigger zone in the brainstem and slows the stomach. It's common in diabetic ketoacidosis (the acid crisis of missing insulin) (ketones spill into blood), kidney failure (waste builds up), and poisonings. The gut just stops moving when pH drops.
- **Muscle weakness or paralysis:** Acidemia pushes potassium out of cells into blood. High potassium (above 6.5 mEq/L) makes muscle cells unable to fire — like a dead battery. Alkalemia does the opposite: potassium drops too low (below 2.5), and muscles also can't contract. Either way, muscles go weak or stop working.
- **Muscle spasms, tingling in fingers and lips, or seizures (tetany):** Alkaline blood (pH above 7.45) makes calcium stick to proteins, so less free calcium floats in the blood. Nerves and muscles need free calcium to stay calm — without it they fire on their own. You see twitches, hand cramps (Trousseau sign), facial twitches (Chvostek sign), or full seizures.
- **Heart racing, fluttering, or dangerous rhythms:** Severe acidemia (pH below 7.20) weakens the heart squeeze and triggers arrhythmias. High potassium from acidemia causes peaked T waves and wide QRS on ECG — the heart can suddenly fibrillate (stop beating). Low potassium and low free calcium from alkalemia also scramble the heart's electrical rhythm.
- **Belly pain:** Seen in diabetic ketoacidosis (the acid crisis of missing insulin) (ketones irritate the gut and stall movement), lactic acidosis (acid from oxygen-starved tissues) (gut not getting enough blood), and poisonings. Acidemia slows gut movement and starves gut tissue, causing cramping pain.
- **Fruity or sweet breath smell:** Acetone is a ketone body made when the body burns fat for fuel. It's a gas and gets breathed out through the lungs — you can smell it. Classic for diabetic ketoacidosis (the acid crisis of missing insulin).
- **Peeing a lot and feeling very thirsty:** High blood sugar spills into urine and drags water with it (osmotic diuresis). The body loses huge amounts of water, so you pee constantly and feel desperately thirsty. This happens in diabetic ketoacidosis (the acid crisis of missing insulin).

- Low blood pressure or shock: Severe acidemia (pH below 7.20) weakens the heart's ability to pump and makes blood vessels go limp. Blood pressure drops, and organs can't get enough blood (shock). Lactic acidosis (acid from oxygen-starved tissues) both causes shock and is caused by shock — a vicious cycle.

Focused exam

- Check how fast and how deep the person is breathing. Is it fast and deep (Kussmaul breathing—big breaths the patient cannot stop), or slow and shallow?: When blood has too much acid, the lungs try to fix it by blowing out carbon dioxide (a gas that acts like acid when dissolved in blood). Fast, deep breathing removes carbon dioxide to push pH back up. When blood has too much base, the lungs try to fix it by keeping carbon dioxide in—breathing slows and gets shallow. The pattern shows whether the lungs are helping correct the problem or whether the lungs themselves are causing it.
- Check mental state. Is the person alert, confused, very sleepy, or twitching?: Too much acid in the blood (pH below 7.35, called acidemia) slows brain cells, making the person confused, sleepy, or unresponsive. Too much base (pH above 7.45, called alkalemia) overexcites nerves, causing muscle twitching, tingling around the mouth, or seizures. Mental changes tell you which direction pH has shifted and how urgently dangerous it is.
- Check heart rate and rhythm. Is it too fast, too slow, or irregular? Listen for the quality of heart sounds.: Too much acid weakens heart muscle contraction and makes dangerous rhythms (like ventricular a fast heart rate (tachycardia) or fibrillation—the heart quivers instead of pumping) more likely. Too much base lowers blood potassium and calcium, which also triggers abnormal rhythms. An irregular or very fast heartbeat in someone with an acid-base disorder signals immediate life threat per AHA emergency cardiovascular care guidelines.
- Ask whether the person has been vomiting, has diarrhea, or recently took water pills (diuretics), aspirin, or diabetes medicines.: Vomiting removes stomach acid (hydrochloric acid), leaving too much bicarbonate (a base) behind—this causes metabolic alkalosis (the blood turning too alkaline) (too much base). Diarrhea removes bicarbonate from the intestines, causing metabolic acidosis (acid building up in the blood) (too much acid). Water pills cause the kidneys to lose acid or base depending on the type. Aspirin directly poisons cells and causes acid buildup. Metformin (a diabetes pill) can cause lactic acidosis (acid from oxygen-starved tissues) in people with kidney disease. The history often points straight to the cause.

- Look at the skin. Is it flushed (red), pale, or mottled (blotchy patches)? Touch it—does it feel warm or cool and clammy?: When acid is very high, the heart cannot pump enough blood (poor cardiac output). Tissues do not get enough oxygen (poor blood flow (perfusion)), so skin looks blotchy and feels cool and sweaty. If skin is warm and flushed but acid is high, suspect life-threatening infection (sepsis) with lactic acidosis (acid from oxygen-starved tissues) (acid from cells starving for oxygen despite high blood flow)—this needs IV antibiotics and fluids immediately per Surviving Sepsis Campaign guidelines.
- Press gently on the belly. Is it tender, rigid (hard like a board), or soft? Ask about belly pain.: Diabetic ketoacidosis (the acid crisis of missing insulin) (acid from the body burning fat when blood sugar is very high and insulin is too low) and certain poisonings cause belly pain. A rigid belly with high acid may mean a surgical emergency like a ruptured organ (perforation) or dead bowel from blocked blood flow (mesenteric starved blood flow (ischemia))—hidden behind the acid-base problem. This needs emergency surgery, not just pH correction.

Diagnostics · every test answers a question

- Arterial blood gas (ABG—blood drawn from an artery in the wrist) or venous blood gas (VBG—blood drawn from a vein) → What is the pH, carbon dioxide (PaCO_2), and bicarbonate (HCO_3^-)? Is the main problem metabolic (bicarbonate too high or too low) or respiratory (carbon dioxide too high or too low)? Is the body compensating correctly?
- Basic metabolic panel (BMP—blood test for sodium, potassium, chloride, bicarbonate, blood urea nitrogen, creatinine, and glucose); calculate anion gap: sodium minus (chloride plus bicarbonate), normal range 8 to 12 mEq/L → Is there metabolic acidosis (acid building up in the blood) from adding unmeasured acids (high anion gap) or from losing bicarbonate (normal anion gap)? Are the kidneys working? Is potassium dangerously high or low?
- Serum lactate (lactic acid level in the blood) → Are tissues starving for oxygen, causing lactic acidosis (acid from oxygen-starved tissues)?
- Serum or urine ketones (beta-hydroxybutyrate is most accurate; urine dipstick detects acetoacetate) → Is there too much acid in the blood (acidosis) from the body burning fat for energy because it cannot use sugar?
- Delta-delta calculation: (measured anion gap minus 12) divided by (24 minus measured bicarbonate) → Is there a second, hidden acid-base problem happening at the same time?
- Serum osmolal gap: measured serum osmolality minus calculated osmolality [$2 \times \text{sodium} + \text{glucose}/18 + \text{BUN}/2.8$]; normal gap is less than 10 mOsm/kg → Is there a toxic alcohol (methanol or ethylene glycol) in the blood causing too much acid in the blood (acidosis)?
- Serum salicylate level (aspirin level); toxic level is above 30 mg/dL, severe toxicity above 100 mg/dL → Is aspirin poisoning causing the too much acid in the blood (acidosis)?

- Arterial or venous blood gas with co-oximetry (measures carboxyhemoglobin and methemoglobin) → Is carbon monoxide or another poison blocking oxygen delivery despite normal oxygen saturation on the pulse oximeter?

Treatment logic

- Identify the primary disorder: Look at pH first. If pH is low (below 7.35), the primary problem is too much acid in the blood (acidosis). If pH is high (above 7.45), it is too little acid in the blood (alkalosis). Then look at PaCO₂ and bicarbonate—whichever one moved in the same direction as pH (both low or both high) is the primary problem. Calculate anion gap if metabolic acidosis (acid building up in the blood) is present. → Shows whether the main problem is metabolic (bicarbonate or unmeasured acid) or respiratory (carbon dioxide). Shows whether compensation is appropriate (use Winter's formula for metabolic acidosis (acid building up in the blood): $\text{expected PaCO}_2 = 1.5 \times \text{bicarbonate} + 8 \pm 2$; if actual PaCO₂ is higher or lower, there is a second respiratory disorder). Uncovers hidden mixed disorders that need different treatments.
- Obtain detailed history and perform targeted physical exam: Ask about vomiting, diarrhea, shortness of breath, chest pain, diabetes, medicines (diuretics, aspirin, metformin), kidney or lung disease, alcohol or drug use, possible toxic ingestion. Examine breathing pattern, mental status, skin blood flow (perfusion), heart rhythm, and abdomen. → Points directly to the root cause: sepsis with lactic acidosis (acid from oxygen-starved tissues), diabetic ketoacidosis (the acid crisis of missing insulin), bicarbonate loss from diarrhea, carbon dioxide retention from COPD, poison ingestion, vomiting with too little acid in the blood (alkalosis). Treating the cause—not just the lab number—stops progression, prevents recurrence, and prevents complications like organ failure.
- Treat the underlying cause: IV regular insulin 0.1 units/kg/hour plus IV 0.9% saline 500–1000 mL/hour initially for diabetic ketoacidosis (the acid crisis of missing insulin) per ADA; IV fluids (crystalloid 30 mL/kg in first 3 hours) plus IV antibiotics within 1 hour plus vasopressors (norepinephrine first-line) to restore blood flow (perfusion) and clear lactate in septic shock per Surviving Sepsis Campaign; oxygen plus non-invasive ventilation (BiPAP) or intubation and mechanical ventilation for COPD with respiratory acidosis (acid building up from trapped carbon dioxide) per ATS/GOLD; stop metformin and give IV fluids for metformin-associated lactic acidosis (acid from oxygen-starved tissues); fomepizole 15 mg/kg IV load plus hemodialysis for methanol or ethylene glycol; IV sodium bicarbonate to alkalinize urine plus hemodialysis for severe aspirin toxicity; hemodialysis for kidney failure (uremic too much acid in the blood (acidosis)) per KDIGO. → Removes or stops the source of acid or carbon dioxide. Restores normal metabolism so the body's own lungs, kidneys, and buffer systems (bicarbonate, proteins, bone) can bring pH back to normal over hours to days. This is the only way to truly fix the problem.

- Give IV sodium bicarbonate (50–100 mEq in 1 liter of D5W over 30–60 minutes) ONLY if pH is below 7.10 AND the cause cannot be corrected quickly, OR in specific situations: tricyclic antidepressant overdose with wide QRS (above 100 ms) or arrhythmia (to overcome sodium-channel blockade), severe high potassium (hyperkalemia) (potassium above 6.5 mEq/L) with ECG changes per AHA, aspirin or methotrexate poisoning (to alkalinize urine and trap drug for faster excretion), or rhabdomyolysis with myoglobinuria (to prevent kidney damage). → Provides exogenous buffer to raise pH quickly, buying time for definitive treatment and endogenous systems to work. In tricyclic overdose, raising serum pH above 7.50 reduces drug binding to cardiac sodium channels and reverses conduction block and arrhythmias per toxicology guidelines.
- Monitor and manage potassium closely: Measure potassium every 2–4 hours during treatment. If potassium is above 5.5 mEq/L with ECG changes (peaked T waves, wide QRS), give IV calcium gluconate 1–2 grams over 5 minutes to protect the heart, then insulin 10 units IV plus dextrose 25 grams IV to shift potassium into cells per AHA. If potassium is normal or low at presentation, start potassium replacement (20–40 mEq/L in IV fluids) before or with insulin in diabetic ketoacidosis (the acid crisis of missing insulin) per ADA. → Acidemia shifts potassium out of cells into blood by exchanging hydrogen ions into cells—raising serum potassium and increasing risk of life-threatening arrhythmias (ventricular fibrillation, asystole). As pH is corrected, potassium moves back into cells and serum potassium can drop dangerously low (hypokalemia below 3.5 mEq/L), also causing arrhythmias (torsades de pointes) and muscle weakness. Close monitoring and early replacement prevent both extremes.
- Provide ventilatory support as needed: Supplemental oxygen by nasal cannula or non-rebreather mask to maintain SpO₂ above 90%; non-invasive positive-pressure ventilation (BiPAP) for COPD flare-up (exacerbation) with respiratory acidosis (acid building up from trapped carbon dioxide) if alert and cooperative; endotracheal intubation and mechanical ventilation if mental status is declining (GCS below 8), respiratory muscles are exhausted (paradoxical breathing, accessory muscle use), or PaCO₂ is rising above 60 mmHg with worsening acidemia per ATS guidelines. Adjust minute ventilation (respiratory rate × tidal volume) to target PaCO₂. → Lowers PaCO₂ and raises pH when the patient cannot breathe effectively due to muscle fatigue, airway obstruction, or central nervous system depression. In metabolic acidosis (acid building up in the blood), augmenting ventilation helps the lungs compensate by blowing off more carbon dioxide. Prevents respiratory arrest and allows time for definitive treatment of the underlying cause.

- Consider renal replacement therapy (hemodialysis or continuous veno-venous hemofiltration): Indications include pH below 7.10 despite maximal therapy, severe kidney failure with too much acid in the blood (acidosis) (creatinine above 4 mg/dL, GFR below 15 mL/min), severe electrolyte disturbances (potassium above 6.5 mEq/L refractory to medical therapy), toxic alcohol ingestion (methanol, ethylene glycol), or salicylate toxicity with level above 100 mg/dL per KDIGO and toxicology guidelines. → Directly removes acids (lactate, ketones, uremic acids), toxins (methanol, ethylene glycol, salicylates, metformin, lithium), and excess potassium from blood. Rapidly corrects severe acidemia and prevents irreversible organ damage (blindness from methanol, kidney failure from ethylene glycol, pulmonary edema (fluid flooding the lungs) from salicylates). Can add bicarbonate to dialysate to raise pH.

Medications

Sodium bicarbonate · Alkalinizing agent (a medicine that makes blood less acidic by adding base)

Sodium bicarbonate is baking soda given through an IV. It dumps bicarbonate (the body's main base, which soaks up extra acid like a sponge) directly into the blood. When bicarbonate meets hydrogen ions (the particles that make blood acidic), they combine to form water and carbon dioxide (the gas you breathe out). This raises the blood pH (makes it less acidic) within minutes. The kidneys then filter out the extra sodium and water over the next few hours.

1. You give sodium bicarbonate through an IV, usually as a slow drip or a careful push over several minutes.
2. Bicarbonate spreads through the blood and reaches every tissue.
3. Each bicarbonate molecule grabs a hydrogen ion (H^+ , the acid particle) and turns into carbonic acid, which instantly breaks into water and CO_2 .
4. The lungs breathe out the extra CO_2 , so the acid leaves the body as gas.
5. Blood pH rises (becomes less acidic) within 10 to 30 minutes.
6. The kidneys filter the extra sodium and any leftover bicarbonate into urine over the next few hours.

SAFETY WATCH

Overcorrection: giving too much can swing blood pH too high (alkalosis), which causes muscles to twitch, seizures, and dangerous heart rhythms. · Sodium overload: each dose dumps a huge amount of sodium into the blood, which can cause fluid buildup in the lungs (pulmonary swelling (edema)) and swelling, especially in people with heart failure or kidney failure. · Low potassium (Hypokalemia) (low potassium): bicarbonate pushes potassium out of the blood and into cells; if potassium drops too low, the heart can stop. Always check potassium before and during treatment and replace it if needed. · Low calcium (Hypocalcemia) (low calcium): too little acid in the blood (alkalosis) makes calcium bind to proteins, so less calcium is free in the blood. Low free calcium can cause muscle spasms and heart problems. · Paradoxical CNS too much acid in the blood (acidosis): bicarbonate cannot cross into the brain quickly, but the CO₂ it creates can. This can make the brain more acidic even though blood pH is rising, leading to confusion or decreased breathing drive. · Tissue injury: if the IV leaks under the skin, sodium bicarbonate burns tissue and causes severe damage (extravasation injury).

Insulin (regular insulin IV drip) · Hormone replacement

In diabetic ketoacidosis (the acid crisis of missing insulin), the body has no insulin, so cells cannot use glucose (sugar) for energy. Instead, the liver breaks down fat and makes ketones (acids that pile up in the blood). Regular insulin given through an IV tells cells to open their doors and let glucose in. Once cells have fuel again, the liver stops making ketones. Ketone production shuts off within 1 to 2 hours, and the acids slowly leave the blood through urine and breathing. Blood pH rises as ketones disappear.

1. Start an IV drip of regular insulin (usually 0.1 units per kilogram per hour for an adult, about 5 to 10 units per hour).
2. Insulin binds to receptors on liver cells and shuts down ketone production within 1 to 2 hours.
3. Insulin opens glucose transporters on muscle and fat cells so glucose moves from blood into cells.
4. As cells get energy from glucose, the body stops burning fat and making acid.
5. Ketones already in the blood are filtered by the kidneys and exhaled as acetone (which is why the breath smells fruity).
6. The anion gap (the count of unmeasured acids) falls, and blood pH rises over 12 to 24 hours.
7. You also give IV fluids and potassium because insulin pushes potassium into cells and can cause dangerous low potassium.

SAFETY WATCH

Low blood sugar (Hypoglycemia) (low blood sugar): once blood glucose drops below 250 mg/dL, add sugar (dextrose) to the IV fluid while continuing insulin, or glucose will crash and cause confusion, seizures, or coma. · Low potassium (Hypokalemia) (low potassium): insulin drives potassium into cells. Potassium can drop fast and cause deadly heart rhythms. Check potassium every 2 to 4 hours and replace it through the IV to keep blood potassium between 4.0 and 5.0 mEq/L. · Cerebral swelling (edema) (brain swelling): in children and young adults with diabetic ketoacidosis (the acid crisis of missing insulin), correcting blood sugar and pH too fast can cause the brain to swell. Give fluids and insulin slowly and watch for headache, confusion, or decreased alertness. · Rebound ketoacidosis: if you stop insulin too early (before the anion gap closes and the patient can eat), ketone production restarts and too much acid in the blood (acidosis) comes back.

Normal saline (0.9% sodium chloride IV fluid) · Isotonic crystalloid (IV fluid that matches blood salt concentration)

Normal saline is salt water given through an IV. In metabolic acidosis (acid building up in the blood) from dehydration, vomiting, or diarrhea, the body loses fluid and bicarbonate. Saline replaces blood volume, which improves kidney blood flow. When kidneys get enough blood, they start making new bicarbonate and filtering out acid. Saline also dilutes the acid already in the blood (like adding water to strong lemon juice). In metabolic alkalosis (the blood turning too alkaline) from vomiting or diuretics, saline gives the kidneys the chloride they need to dump the extra bicarbonate into urine and bring pH back to normal.

1. Give normal saline through an IV, usually 1 to 2 liters fast in the first hour if the patient is very dry, then slower (100 to 250 mL per hour) to match what the body loses.
2. Saline fills blood vessels and raises blood pressure within 15 to 30 minutes.
3. Blood flow to the kidneys improves, and kidney cells turn on the pumps that reabsorb bicarbonate and dump hydrogen ions into urine.
4. In too much acid in the blood (acidosis) from volume loss (like diarrhea or diabetic ketoacidosis (the acid crisis of missing insulin)), kidneys make new bicarbonate and blood pH rises over 12 to 24 hours.
5. In too little acid in the blood (alkalosis) from vomiting or diuretics (water pills that also remove chloride), the chloride in saline lets kidneys excrete the extra bicarbonate, and pH falls back to normal over 24 to 48 hours.

SAFETY WATCH

Fluid overload: giving too much saline, especially in heart failure or kidney failure, causes fluid to back up into the lungs (pulmonary swelling (edema)), making breathing hard. · Hyperchloremic too much acid in the blood (acidosis): large volumes of normal saline (more than 3 to 4 liters) raise blood chloride, which lowers bicarbonate by a chemical balance rule and can make blood slightly acidic (pH 7.30 to 7.35). This is usually mild and fixes itself once you slow the saline. · Low potassium (Hypokalemia) or high potassium (hyperkalemia) (low or high potassium): saline dilutes potassium in the blood. If potassium was already low, dilution makes it dangerously low. If kidneys are failing, extra fluid and sodium can raise potassium to dangerous levels. Check potassium and adjust. · Incorrect use in saline-unresponsive too little acid in the blood (alkalosis): if too little acid in the blood is from high aldosterone (a hormone problem, like Conn syndrome or severe liver disease), giving saline makes it worse because the kidneys hold onto all the sodium and dump more acid. Treat the hormone problem instead.

Oxygen and mechanical ventilation · Respiratory support (not a drug—tools that help the lungs move air and gas)

In respiratory acidosis (acid building up from trapped carbon dioxide), the lungs cannot blow off enough CO₂ (the acid gas made by every cell), so CO₂ builds up in the blood and makes it acidic. Oxygen alone does NOT fix this—you must move more air in and out of the lungs. Mechanical ventilation is a breathing machine that pushes air into the lungs and pulls it out, doing the work the lungs cannot do. By increasing the rate or depth of breaths, the machine blows off extra CO₂, and blood pH rises. In respiratory alkalosis (blowing off too much carbon dioxide), the person is breathing too fast (hyperventilation) and blowing off too much CO₂, making blood too basic. You treat the cause (pain, anxiety, fever, lung disease) so breathing slows down, CO₂ rises, and pH comes back to normal.

1. In respiratory acidosis (acid building up from trapped carbon dioxide): place a breathing tube (endotracheal tube) into the windpipe, or use a tight-fitting mask (non-invasive ventilation) connected to a ventilator.
2. Set the machine to breathe faster (increase respiratory rate, typically 12 to 20 breaths per minute) or take deeper breaths (increase tidal volume, the amount of air per breath, usually 6 to 8 mL per kilogram of body weight).
3. The machine pushes fresh air into the lungs and pulls out air filled with CO₂.
4. CO₂ in the blood drops within minutes. For every 10 mm Hg drop in blood CO₂, pH rises by about 0.08 units.
5. Monitor blood gases (a test that measures pH, CO₂, and oxygen) every 1 to 4 hours and adjust the machine settings until CO₂ and pH are safe.

6. In respiratory alkalosis (blowing off too much carbon dioxide): treat the cause (give pain medicine, calm anxiety, cool a fever, treat the lung infection or clot). As the person breathes slower and more normally, CO₂ rises and pH falls back to normal. You do NOT need a machine unless the underlying problem makes them unable to breathe on their own.

SAFETY WATCH

Barotrauma (lung popping): if the machine pushes air in with too much pressure, it can pop a hole in the lung (pneumothorax), causing the lung to collapse and air to leak into the chest. · Ventilator-associated pneumonia: a breathing tube bypasses the body's natural defenses, so bacteria can reach the lungs and cause infection. Risk goes up the longer the tube stays in. · Over-correction of CO₂: lowering CO₂ too fast or too much causes respiratory alkalosis (blowing off too much carbon dioxide) (blood becomes too basic), which makes blood vessels in the brain tighten, reducing brain blood flow and oxygen. This can cause confusion, seizures, or stroke. · Oxygen toxicity: breathing 100% oxygen for more than 24 to 48 hours damages lung tissue. Use the lowest oxygen level that keeps blood oxygen safe (usually aiming for 90 to 96% saturation). · Hemodynamic compromise (blood pressure drop): positive pressure from the ventilator pushes on the heart and big veins, reducing the amount of blood returning to the heart. This can drop blood pressure, especially in patients who are dehydrated or have weak hearts. · Difficulty weaning: some patients become dependent on the machine and have trouble breathing on their own again, especially if the underlying lung or muscle problem is severe.

Potassium chloride (KCl IV or oral) · Electrolyte replacement

Potassium is a charged particle (electrolyte) that every cell needs to work, especially heart and muscle cells. In metabolic alkalosis (the blood turning too alkaline), the kidneys dump potassium into urine while trying to get rid of extra bicarbonate. Low potassium makes too little acid in the blood (alkalosis) worse because the kidneys hold onto hydrogen ions (acid particles) to save potassium, which keeps blood basic. Giving potassium lets the kidneys release hydrogen ions and dump bicarbonate, so pH comes back to normal. In too much acid in the blood (acidosis) treatment (especially with insulin or bicarbonate), potassium shifts from blood into cells, and blood potassium can drop to dangerous levels. Replacing potassium prevents deadly heart rhythms.

1. Check blood potassium level. If it is low (below 3.5 mEq/L) or falling fast during treatment, give potassium.
2. If the patient can swallow and has a working gut, give potassium chloride pills or liquid by mouth (10 to 40 mEq at a time).

3. If the patient cannot eat or needs potassium fast, give potassium chloride through an IV. Add it to saline or other IV fluid (usual concentration is 20 to 40 mEq per liter) and drip it slowly (no faster than 10 to 20 mEq per hour through a peripheral IV, faster through a central line if needed).
4. Potassium enters cells and blood levels rise within 1 to 2 hours.
5. Recheck blood potassium every 2 to 4 hours during rapid replacement and adjust the dose to keep potassium between 4.0 and 5.0 mEq/L.
6. As potassium normalizes, the kidneys can balance acid and base correctly, and pH moves toward normal.

SAFETY WATCH

High potassium (Hyperkalemia) (high potassium): giving too much potassium, or giving it when kidneys are failing, can raise blood potassium above 5.5 mEq/L. High potassium stops the heart. Watch for muscle weakness, nausea, and abnormal heart rhythm on the EKG (tall peaked T waves, wide QRS). Stop potassium immediately if this happens and treat high potassium urgently. · IV infiltration and tissue injury: potassium burns tissue. If the IV leaks under the skin, it causes severe pain and damage. Always give potassium through a good IV and watch the site. · Too-fast infusion: pushing potassium faster than 10 to 20 mEq per hour through a peripheral IV causes intense burning pain in the vein and can cause dangerous high potassium or heart rhythm problems. High-concentration potassium (more than 40 mEq/L) must go through a central line. · Rebound low potassium (hypokalemia): if you replace potassium but do not fix the cause (like ongoing vomiting, diarrhea, or diuretic use), potassium will drop again as soon as you stop giving it.

Acetazolamide · Carbonic anhydrase inhibitor (a diuretic that makes kidneys dump bicarbonate)

Acetazolamide blocks an enzyme in the kidney called carbonic anhydrase, which normally helps the kidney reabsorb bicarbonate from urine back into blood. When you block that enzyme, bicarbonate spills into urine and leaves the body, lowering blood bicarbonate and bringing down a high pH. This is used to treat metabolic alkalosis (the blood turning too alkaline) (blood too basic) that does not respond to saline, or to treat chronic respiratory acidosis (acid building up from trapped carbon dioxide) (like in severe COPD) by lowering bicarbonate so the body tolerates a higher CO₂ without the blood becoming too basic.

1. Give acetazolamide by mouth or IV (usual dose 250 to 500 mg once or twice a day).
2. The drug reaches the kidney within 1 to 2 hours and blocks carbonic anhydrase in the proximal tubule cells.
3. Without carbonic anhydrase, the kidney cannot convert bicarbonate and hydrogen ions into carbon dioxide and water, so bicarbonate cannot be reabsorbed.

4. Bicarbonate spills into urine, and blood bicarbonate drops by 3 to 5 mEq/L per day.
5. Blood pH falls (becomes less basic) over 24 to 72 hours.
6. The drug also causes mild diuresis (increased urine output) because sodium and water follow bicarbonate into urine.

SAFETY WATCH

Metabolic acidosis (acid building up in the blood): if you give too much or use it in the wrong situation, acetazolamide can make blood too acidic by dumping too much bicarbonate. · Low potassium (Hypokalemia) (low potassium): acetazolamide causes the kidneys to lose potassium along with bicarbonate. Check potassium and replace it. · Kidney stones: acetazolamide makes urine more basic (alkaline), which can cause calcium phosphate stones to form in the kidneys or bladder. · Tingling or numbness (Paresthesias) (tingling): patients often feel tingling in fingers, toes, and around the mouth because the drug changes how nerves handle ions. This is uncomfortable but not dangerous. · Sulfa allergy: acetazolamide is a sulfonamide drug. Do not use it in patients with severe sulfa allergy (risk of rash or more serious reaction).

Fomepizole (4-methylpyrazole) · Alcohol dehydrogenase inhibitor (a drug that blocks the enzyme that turns toxic alcohols into deadly acids)

Methanol (wood alcohol) and ethylene glycol (antifreeze) are poisons that, by themselves, cause mild intoxication. The danger comes when the liver enzyme alcohol dehydrogenase breaks them down into toxic acids—methanol becomes formic acid (which blinds you and makes blood very acidic), and ethylene glycol becomes glycolic and oxalic acids (which destroy kidneys and make blood acidic). Fomepizole blocks alcohol dehydrogenase so the poison cannot turn into acid. The original alcohol then leaves the body slowly through the kidneys and lungs, without causing too much acid in the blood (acidosis) or organ damage.

1. As soon as toxic alcohol poisoning is suspected (history of ingestion, high anion gap too much acid in the blood (acidosis) with high osmol gap, or methanol or ethylene glycol detected in blood), give fomepizole through an IV.
2. Loading dose is 15 mg per kilogram body weight over 30 minutes, then 10 mg/kg every 12 hours.
3. Fomepizole reaches the liver and blocks alcohol dehydrogenase within 1 to 2 hours.
4. No new toxic acid is made. The methanol or ethylene glycol that is already in the body is slowly filtered by the kidneys and exhaled by the lungs over 24 to 48 hours (longer if kidneys are damaged).
5. If the patient already has severe too much acid in the blood (acidosis) or kidney failure, start hemodialysis (a machine that filters the blood) at the same time to remove the poison and acid faster.

6. Continue fomepizole until blood methanol or ethylene glycol is undetectable (below 20 mg/dL) and the patient is no longer acidotic.

SAFETY WATCH

Headache and nausea: common but mild side effects; they usually go away as treatment continues. · Rare allergic reactions: rash or more serious allergy can occur; stop the drug if this happens. · Does not replace hemodialysis in severe cases: if blood methanol or ethylene glycol is very high (above 50 mg/dL), too much acid in the blood (acidosis) is severe (pH below 7.25), or kidneys are failing, fomepizole alone is not enough—dialysis is needed to remove the poison quickly. · Cost and availability: fomepizole is expensive and not available in all hospitals. Ethanol (drinking alcohol) IV can be used as a backup because ethanol also blocks alcohol dehydrogenase, but it is harder to dose and monitor.

Red flags

- pH below 7.20 or above 7.60 — risk of deadly heart rhythms, seizures, or coma
- Potassium above 6.5 mEq/L with peaked T waves or wide QRS on ECG — heart can stop beating any second
- Anion gap above 30 with confusion — think poisoning (methanol, antifreeze) or septic shock with severe lactic acidosis (acid from oxygen-starved tissues)
- Bicarbonate below 10 mEq/L in diabetic ketoacidosis (the acid crisis of missing insulin) — brain can swell if you correct pH too fast; do NOT give bicarbonate unless pH is below 6.9 (ADA 2024)
- Kussmaul breathing with fruity breath and high blood sugar — diabetic ketoacidosis (the acid crisis of missing insulin) until proven otherwise; check blood or urine ketones and start insulin right away

Nursing priorities

1. Place patient on continuous cardiac monitor and watch for peaked T waves, wide QRS, or arrhythmias every 15 minutes if potassium is above 5.5 mEq/L. — Too much acid in the blood (Acidosis) pushes potassium out of cells into blood (hyperkalemia), and high potassium changes how the heart's electrical system works—peaked T waves warn that the heart may stop beating (cardiac arrest) within minutes.
2. Check blood glucose immediately with fingerstick, then obtain full metabolic panel, arterial blood gas, and anion gap calculation before any treatment. — You must know the pH, PaCO₂, bicarbonate, and anion gap to identify the primary problem and whether the body is compensating correctly—treating the wrong disorder (like giving bicarbonate in respiratory acidosis (acid building up from trapped carbon dioxide)) can kill the patient.

3. Start high-flow oxygen or prepare for mechanical ventilation if respiratory rate is below 8 or above 35 breaths per minute, or if patient is drowsy and cannot protect airway. — The lungs are the fastest way to fix acid-base problems by changing CO₂ levels—too little breathing traps CO₂ and causes respiratory acidosis (acid building up from trapped carbon dioxide), while the body uses fast deep breathing to blow off CO₂ and compensate for metabolic acidosis (acid building up in the blood), but the patient can tire out.
4. Establish large-bore IV access (18-gauge or larger) and hang normal saline or lactated Ringer's solution at the rate ordered, preparing to give 1 to 2 liters rapidly if patient is with low blood pressure (hypotensive) or in DKA. — Volume depletion (from vomiting, diarrhea, or DKA) concentrates acids in the blood and drops blood pressure, reducing oxygen delivery to tissues—fluid dilutes the acid and restores circulation, often fixing too much acid in the blood (acidosis) without bicarbonate.
5. Hold all bicarbonate administration until the physician reviews the anion gap and identifies the cause, unless pH is below 7.10 in metabolic acidosis (acid building up in the blood) with shock. — Giving bicarbonate for respiratory acidosis (acid building up from trapped carbon dioxide) makes CO₂ go higher and worsens brain swelling; in DKA, fast correction can cause deadly brain swelling (cerebral swelling (edema)) in children and young adults—treat the cause (insulin, fluids, fix breathing) first.
6. Assess for Chvostek sign (tap cheek, watch for face twitch) and Trousseau sign (inflate blood pressure cuff, watch for hand spasm) every 2 hours if pH is above 7.50. — Too little acid in the blood (Alkalosis) lowers ionized calcium by changing how calcium binds to proteins, making nerves and muscles fire without a signal (tetany)—untreated tetany can cause laryngospasm (throat closes) or seizures.
7. Monitor urine output every hour and report if less than 30 mL per hour, while watching for dark brown or tea-colored urine. — Severe too much acid in the blood (acidosis) and high potassium can damage kidney tubules (acute tubular tissue death (necrosis)), and rhabdomyolysis (muscle breakdown releasing myoglobin, a muscle protein) from seizures or lying down too long causes both too much acid in the blood and kidney failure—needs aggressive fluids.
8. Recheck arterial blood gas 1 hour after any ventilator change, bicarbonate dose, or insulin bolus to verify pH is moving toward 7.35 to 7.45 at a safe speed. — Correcting pH too fast (more than 0.1 per hour) can shift potassium dangerously, cause brain swelling in DKA, or trigger seizures in chronic respiratory acidosis (acid building up from trapped carbon dioxide)—slow steady correction protects the brain and heart.

Sources

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Last reviewed: 2026-07-07