

ARDS · Acute Respiratory Distress Syndrome

The wall between air sacs and blood vessels breaks and leaks fluid into the air sacs, drowning the lung from the inside.

THE ONE-LINE TRUTH

Something—infection, breathing in stomach contents, major injury, bad blood transfusion, or other insult—damages the paper-thin wall between air sacs and blood vessels, so protein-rich fluid floods the air sacs and oxygen cannot cross into the blood.

The chain — how it unfolds

1. An insult damages the alveolar-capillary barrier. — why: A direct hit (pneumonia, aspiration of gastric contents, lung contusion, inhalation of smoke or toxins) or an indirect wave of inflammation (sepsis from bloodstream infection, severe trauma, acute pancreatitis, massive transfusion) triggers release of pro-inflammatory cytokines (TNF- α , IL-1, IL-6, IL-8) and recruits neutrophils (white blood cells) to the lung. These cells release reactive oxygen species and proteases (enzymes that break down proteins), which injure both the capillary endothelium (blood vessel lining) and the alveolar epithelium (air sac lining), disrupting tight junctions and creating gaps in the barrier.
2. Protein-rich fluid floods the alveoli. — why: The damaged barrier becomes permeable (leaky). Plasma proteins—albumin, fibrinogen, immunoglobulins—and fluid leak from the capillaries into the interstitium (the space around the alveoli) and then into the alveolar space itself. This non-cardiogenic pulmonary edema (fluid flooding the lungs) (fluid in the lungs not caused by heart failure) has high protein content (edema fluid-to-plasma protein ratio > 0.65), unlike the watery swelling (edema) of heart failure.
3. Surfactant is inactivated and alveoli collapse. — why: Surfactant—a mix of phospholipids (dipalmitoylphosphatidylcholine) and proteins (SP-A, SP-B, SP-C, SP-D) secreted by type II alveolar cells—normally lowers surface tension, keeping alveoli open at end-exhalation. Swelling (Edema) fluid dilutes surfactant, and plasma proteins (especially fibrinogen and albumin) bind to and inactivate surfactant phospholipids. Surface tension rises, and alveoli collapse (atelectasis) at low lung volumes, especially in dependent (gravity-dependent, back or bottom) regions. The functional residual capacity (the volume of air left in the lungs after a normal breath) drops from roughly 2.5–3.0 liters to less than 1.5 liters.

4. Intrapulmonary shunt develops and low oxygen in the blood (hypoxemia) worsens. — why: Blood flowing through capillaries next to flooded or collapsed alveoli cannot pick up oxygen because there is no air-blood interface for gas exchange. This shunted blood (venous blood with oxygen saturation around 75 percent) mixes with oxygenated blood from the remaining functional 'baby lung,' diluting arterial oxygen. A shunt fraction above 20 percent (normal < 5 percent) causes severe low oxygen in the blood (hypoxemia). Because the shunted blood never contacts ventilated alveoli, increasing inspired oxygen (FiO_2) has limited effect— PaO_2 remains low even at FiO_2 1.0 (100 percent oxygen). This refractory low oxygen in the blood ($\text{PaO}_2/\text{FiO}_2$ ratio ≤ 300 mmHg) is the hallmark of ARDS and meets the Berlin definition when bilateral infiltrates are present on chest imaging, PEEP ≥ 5 cmH₂O is applied, and the swelling (edema) is not fully explained by heart failure or fluid overload.
5. The patient develops fast breathing (tachypnea) and increased work of breathing. — why: Peripheral chemoreceptors in the carotid bodies detect falling PaO_2 (hypoxemia) and central chemoreceptors in the brainstem detect rising PaCO_2 (hypercapnia) and falling pH (acidosis). These sensors signal the respiratory center in the medulla to increase respiratory rate (often 25–40 breaths per minute) and tidal volume, raising minute ventilation. At the same time, lung compliance (stretchiness) falls from normal 50–100 mL/cmH₂O to 20–40 mL/cmH₂O because flooded and collapsed alveoli resist inflation. The pressure needed to move a given volume of air (airway resistance) also rises because small airways collapse. The diaphragm and intercostal muscles must generate much higher force, and accessory muscles (sternocleidomastoid, scalenes, abdominal muscles) recruit. You see suprasternal, supraclavicular, and intercostal retractions (skin sucking inward with each breath), nasal flaring, and tripod positioning (leaning forward, hands on knees).
6. Respiratory muscles fatigue and hypercapnic respiratory failure begins. — why: The diaphragm and intercostals are skeletal muscles with limited endurance at near-maximal workload. After hours to days of extreme effort, they fatigue—force generation drops, tidal volume falls (often below 5 mL/kg), and carbon dioxide (CO_2) production exceeds CO_2 elimination. PaCO_2 climbs above 45 mmHg, then 55, then 65 mmHg. Rising CO_2 lowers blood pH (respiratory too much acid in the blood (acidosis), pH < 7.35, then < 7.25, then < 7.20). Too much acid in the blood impairs cardiac contractility, causes arrhythmias (abnormal heart rhythms), and depresses mental status (confusion, somnolence, coma). Paradoxical abdominal breathing appears: the belly sucks inward during inspiration instead of expanding, a sign of diaphragm fatigue. Without mechanical ventilation to take over the work of breathing, the patient will develop respiratory arrest (cessation of breathing) and cardiac arrest.

7. Right heart strain (acute cor pulmonale) and pulmonary high blood pressure (hypertension) develop. — why: Alveolar low oxygen (hypoxia) (low oxygen in the air sacs) triggers oxygen-starved (hypoxic) pulmonary vasoconstriction: smooth muscle in the walls of small pulmonary arteries contracts to shunt blood away from poorly ventilated regions. When ARDS is widespread, vasoconstriction is diffuse, raising mean pulmonary artery pressure from normal 10–15 mmHg to 25–35 mmHg or higher. High airway pressures from mechanical ventilation (especially if tidal volume is too large or PEEP is excessive) compress alveolar capillaries, further increasing pulmonary vascular resistance (afterload on the right ventricle). The right ventricle, a thin-walled chamber designed to pump against low resistance, dilates and its wall thins (eccentric hypertrophy). Right ventricular stroke volume falls, causing jugular venous distension (JVD), an enlarged liver (hepatomegaly) (enlarged, tender liver), fluid buildup in the belly (ascites) (abdominal fluid), and peripheral swelling (edema) (swollen legs). The interventricular septum bows leftward (seen on echocardiography), impairing left ventricular filling and dropping cardiac output, which worsens low blood pressure (hypotension) and tissue blood flow (perfusion).
8. Multi-organ failure and death occur without effective treatment. — why: Prolonged low oxygen in the blood (hypoxemia) ($\text{PaO}_2 < 55\text{--}60$ mmHg, $\text{SpO}_2 < 88$ percent for hours to days) deprives vital organs of oxygen. The kidneys suffer acute tubular tissue death (necrosis); serum creatinine rises above 1.5–2.0 mg/dL, urine output drops below 0.5 mL/kg/hour (oliguria), and dialysis may be required. The liver shows blood-starved (ischemic) hepatitis; AST and ALT climb into the hundreds or thousands. The brain develops oxygen-starved (hypoxic) encephalopathy; altered mental status, agitation, or coma appear. The heart suffers demand starved blood flow (ischemia) (oxygen supply does not meet need), and troponin may rise; arrhythmias (atrial fibrillation, ventricular a fast heart rate (tachycardia)) become common. Lactic acid accumulates (lactate $> 2\text{--}4$ mmol/L) as cells switch from aerobic to anaerobic metabolism, causing metabolic acidosis (acid building up in the blood). Impaired blood clotting (Coagulopathy) (abnormal clotting) develops from liver dysfunction and consumptive impaired blood clotting. Despite lung-protective ventilation (tidal volume 6 mL/kg predicted body weight, plateau pressure ≤ 30 cmH₂O), prone positioning (16 hours per day face-down to recruit dorsal alveoli), conservative fluid management (CVP target 4–8 mmHg, avoiding fluid overload), and treatment of the underlying cause (antibiotics for pneumonia or sepsis, source control for intra-abdominal infection), mortality in severe ARDS ($\text{P/F} \leq 100$) remains 40–46 percent. Rescue therapies—inhaled pulmonary vasodilators (nitric oxide, epoprostenol), neuromuscular blockade (cisatracurium for 48 hours), recruitment maneuvers, and extracorporeal membrane oxygenation (ECMO)—are reserved for refractory cases and may reduce mortality by 10–15 percent in carefully selected patients.

Spot it — what you see, and why

- Severe shortness of breath (dyspnea) that starts suddenly: The tiny air sacs in the lungs (alveoli) fill with fluid and collapse, so oxygen cannot pass from the air into the blood. The brain senses low oxygen and triggers a desperate feeling of 'I need more air,' making the person breathe harder and harder.
- Very fast breathing (tachypnea), often more than 30 breaths every minute: The breathing control center in the brainstem detects dangerously low oxygen and rising carbon dioxide in the blood. It speeds up breathing to try to pull in more oxygen and blow off carbon dioxide.
- Oxygen level stays dangerously low even when breathing 100% oxygen (refractory low oxygen in the blood (hypoxemia)): Blood flows past flooded or collapsed air sacs without picking up oxygen—like water flowing past a blocked sponge. Giving more oxygen does not help because the air sacs are not open to let the oxygen in.
- Neck and chest muscles working visibly hard with every breath (use of accessory muscles): The lungs are so stiff and heavy with fluid that the normal breathing muscles (the diaphragm and ribs) cannot inflate them alone. The body recruits extra muscles in the neck and between the ribs to help pull air in.
- Fast heart rate (tachycardia): The heart pumps faster to circulate the small amount of oxygen-rich blood to the brain, heart, and kidneys. It is trying to make up for the fact that each liter of blood is carrying less oxygen than normal.
- Blue or gray color of the lips, fingertips, or skin (cyanosis): When the oxygen level in the blood drops very low, hemoglobin (the red protein in red blood cells that carries oxygen) turns dark purple. This dark blood shows through thin skin as a blue or gray color.

Red flags — act now

- Oxygen saturation stays below 88% even on a non-rebreather mask or high-flow nasal cannula (means the lungs are so damaged that oxygen cannot get into the blood)
- Breathing rate climbs above 35 breaths per minute, or suddenly slows down while the person becomes less alert (muscle exhaustion—respiratory arrest is imminent)
- New confusion, extreme drowsiness, or no response to voice or touch (the brain is starving for oxygen)
- Blood pressure drops below 90 systolic or signs of shock appear—cold, sweaty skin, weak pulse, no urine output (multiple organs are failing from low oxygen and widespread inflammation)
- Visible use of neck and chest muscles with every breath, tripod posture, or inability to speak more than a few words (severe respiratory distress—intubation needed urgently)

Treat it — in this order

1. Low tidal volume ventilation: deliver 4 to 8 mL per kilogram of ideal body weight (usually 6 mL/kg), keep plateau pressure below 30 cm H₂O, and keep driving pressure below 15 cm H₂O → This prevents the ventilator from overstretching fragile air sacs and causing more injury (ventilator-induced lung injury or VILI). Smaller, gentler breaths allow the damaged barrier to heal without adding mechanical trauma. The landmark ARDSNet trial showed this strategy cuts the risk of death by 9 percentage points compared to larger breaths.
2. Positive end-expiratory pressure (PEEP): apply 8 to 15 cm H₂O (or higher if needed) to keep air sacs open at the end of each breath, adjusted based on oxygen levels, lung stiffness, and blood pressure tolerance → PEEP stops air sacs from collapsing completely when you breathe out (end-expiratory collapse or atelectasis). It reopens (recruits) collapsed air sacs and matches air flow with blood flow so oxygen can cross into the bloodstream more efficiently. Higher PEEP may let you lower the oxygen percentage (FiO₂) and reduce oxygen toxicity.
3. Find and treat the root cause: give antibiotics for pneumonia (following local resistance patterns and IDSA/ATS pneumonia guidelines), drain infected fluid or remove infected tissue for sepsis (source control), prevent aspiration by elevating the head of the bed and using feeding tubes carefully, and stop any drug causing lung injury → Stopping the trigger halts ongoing damage to the air-blood barrier. Without eliminating the cause—whether it is bacteria, inhaled vomit, or inflammatory chemicals from pancreatitis—the barrier keeps leaking and ARDS gets worse no matter what the ventilator does.
4. Prone positioning (flip the patient face-down) for 16 hours per day when ARDS is moderate to severe (P/F ratio below 150 mmHg) → Lying face-down takes weight off the back parts of the lungs (which collapse under the heart and belly when lying face-up) and reopens those air sacs. It balances air flow and blood flow better and improves oxygen levels. The PROSEVA trial showed that prone positioning cuts the risk of death in half in severe ARDS.
5. Conservative fluid strategy once blood pressure and organ blood flow are stable: give only enough IV fluid to keep organs working, avoid overloading the patient, and use diuretics (water pills) cautiously if the patient is fluid-overloaded → Less fluid in the bloodstream lowers the pressure inside capillaries (hydrostatic pressure) that pushes fluid into air sacs. It helps the body reabsorb fluid from the lungs and shortens the time on the ventilator. The FACTT trial showed fewer ventilator days without causing more shock or kidney failure.

Your top priorities at the bedside

1. Monitor oxygen saturation continuously with pulse oximetry and keep SpO₂ above 88%; escalate immediately if saturation stays below 88% despite oxygen therapy — why: The damaged alveolar-capillary membrane (the wall between air sacs and blood vessels) blocks oxygen transfer, so even small drops in saturation mean the brain and heart are not getting enough oxygen to survive.
2. Position the patient prone (lying on the stomach) for 12 to 16 hours daily if the physician orders it and the patient tolerates the position — why: Gravity redistributes blood flow to healthier parts of the lungs when prone, and the weight of the heart no longer compresses the back lung tissue, which improves oxygen levels by 60 to 80% in many ARDS patients.
3. Limit IV fluid boluses and daily intake to the smallest amount needed to keep blood pressure safe; measure urine output, daily weight, and central venous pressure if available — why: Extra fluid leaks through the damaged alveolar-capillary barrier into the air sacs, worsening low oxygen in the blood (hypoxemia) (low blood oxygen) and making the lungs stiffer and harder to ventilate.