Respiratory Failure:

Definition, Causes, Types, and Management

Forough Soltaninejad
Pulmonologist, Sleep Medicine Specialist
Isfahan University of Medical Sciences

Definition

Failure of the respiratory system to maintain adequate gas exchange Results in:

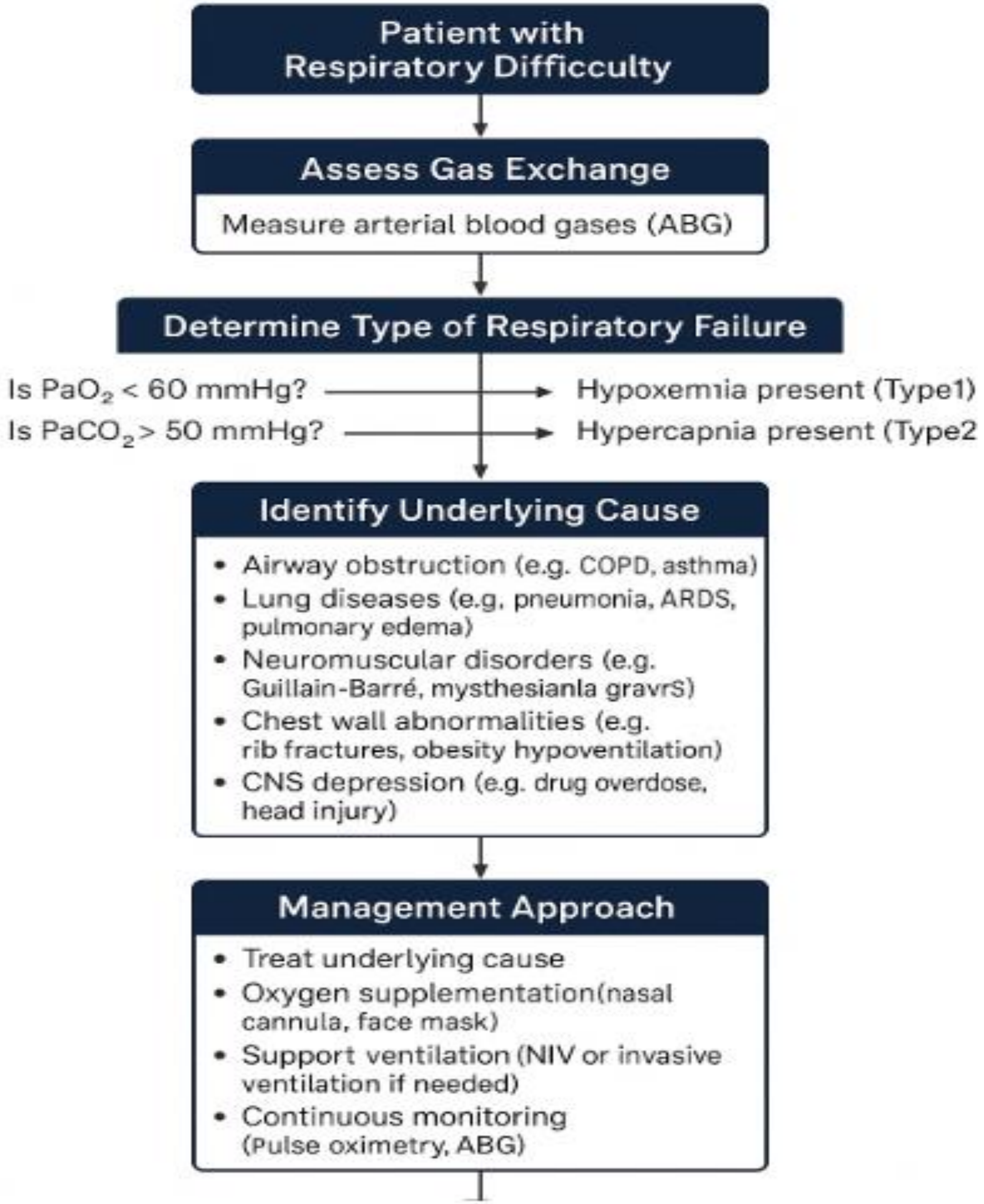
- ✓ Hypoxemia: $PaO_2 < 60$ mmHg on room air
- ✓ Hypercapnia: $PaCO_2 > 50$ mmHg
- ✓ Occurs despite adequate or increased respiratory effort
- ✓ Requires prompt intervention (oxygen therapy, ventilation)

Common Symptoms of Respiratory Failure

- Dyspnea (shortness of breath)
- Tachypnea (rapid breathing)
- Orthopnea (worsening while lying down)
- Fatigue or lethargy
- Confusion or agitation
- Cyanosis (bluish lips or fingertips)

Physical Signs and ABG Findings

Physical Signs	ABG Findings
Use of accessory muscles	Hypoxemia: $PaO_2 < 60$ mmHg
Intercostal/subcostal retractions	Hypercapnia: $PaCO_2 > 50$ mmHg
Cyanosis	Acidosis: pH < 7.35
Restlessness or somnolence	Low oxygen saturation ($SpO_2 < 90\%$)
Tachycardia, hypertension	Elevated A-a gradient in V/Q mismatch


Patient with
Respiratory Difficculty
Assess Gas Exchange
Measure arterial blood gases (ABG)
Determine Type of Respiratory Failure
Is $PaO_2 < 60$ mmHg?
Hypoxemiia present (Type1)
Is $PaCO_2 > 50$ mmHg?
Hypercapnia present (Type2
Identify Underlying Cause
• Airway obstruction (e.g. COPD, asthma)
• Lung diseases (e.g. pneumonia, ARDS, pulmonary edema)
• Neuromuscular disorders (e.g. Guillain-Barré, mysthesianla gravrS)
• Chest wall abnormalities (e.g. rib fractures, obesity hypoventilation)
• CNS depression (e.g. drug overdose, head injury)
Management Approach
• Treat underlying cause
• Oxygen supplementation(nasal cannula, face mask)
• Support ventilation (NIV or invasive ventilation if needed)
• Continuous monitoring (Pulse oximetry, ABG)

Case 1:

A 70-year-old man with COPD and hypertension was brought to the emergency department for severe dyspnoea. His vital signs were as follows: respiratory rate 30 breaths/min, heart rate 110 beats/min, blood pressure 130/80 mmHg and peripheral oxygen saturation 95% in room air.

A chest X-ray showed bilateral consolidation consistent with multi-lobar pneumonia. After an hour of monitoring, you noticed that the patient was getting more tired and breathless. SpO_2 fell to 85% in room air.

Key Points:

- ✓ The patient had acute hypoxaemic respiratory failure (also known as Type I respiratory failure), which is defined as an acute reduction of arterial oxygen partial pressure to <60 mmHg.
- ✓ This level of arterial oxygen is equivalent to arterial oxygen saturation (SaO_2) <90%.
- ✓ This is a potentially life-threatening condition since the oxygen content of blood supplied may be insufficient to satisfy end-organ demand, leading to tissue hypoxia (i.e. low tissue oxygen content).

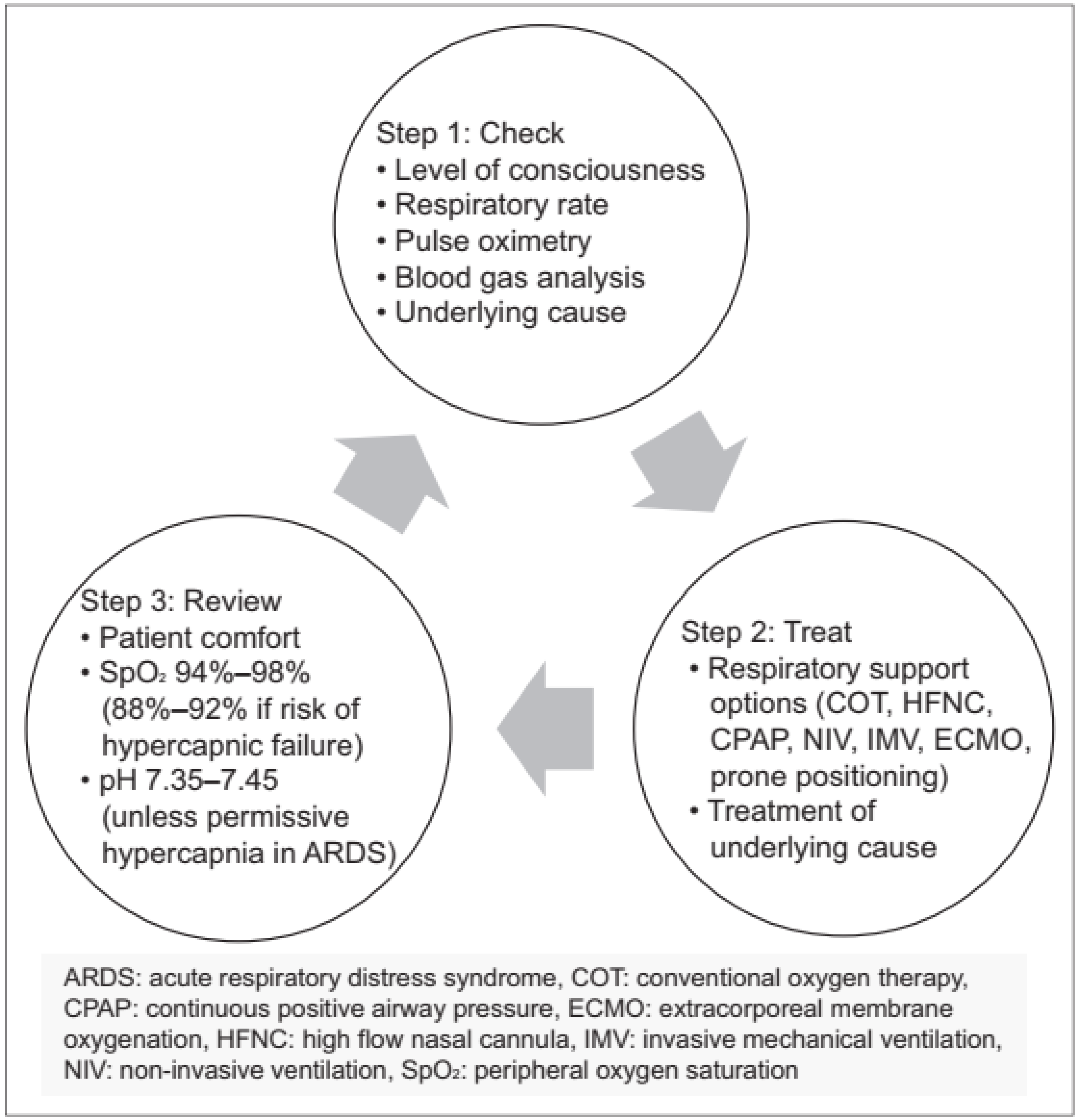


Figure 1: Chart shows the acute respiratory failure management cycle.

Closing Vignette

You recognised that the patient had acute hypoxaemic respiratory failure secondary to multi-lobar pneumonia. Arterial blood gas analysis demonstrated a normal pH and $PaCO_2$. You provided oxygen via a Venturi mask, adjusting the FIO_2 to 35% to keep SpO_2 between 94% and 98%. One hour later, the patient became more tachypneic, desaturated further, and required an FIO_2 of 50%. You transferred the patient to the intensive care unit for high flow nasal cannula, starting at an FIO_2 of 50% and a flow rate of 50 L/min, and achieving an SpO_2 of 94%. Fortunately, over the next 5 days, he improved on high flow oxygen, did not require intubation and was transferred to the general floor ward for rehabilitation.

Table 1. Methods of respiratory support.

Method of respiratory support	Contra-indications	Initiation	Adjustment	Failure criteria
COT	Inability to protect the airway; hypercapnic respiratory failure	Oxygen flow via nasal prongs/face mask 5 L/min or Venturi mask 35%	Titrate the oxygen flow or Venturi mask to achieve the SpO_2 target.*	Severe respiratory distress e.g., respiratory rate >40 breaths per min; cardiovascular decompensation; SpO_2 <90% despite maximum settings; pH <7.35 despite maximum settings†
HFNC	Inability to protect the airway; hypercapnic respiratory failure	Flow 30 L/min; FIO_2 30%	Increase flow by 10 L/min increments and FIO_2 by 10% increments to achieve the SpO_2 target.*	
CPAP	Inability to protect the airway; hypercapnic respiratory failure; inability to tolerate mask interface	PEEP 5 cmH_2O; FIO_2 30%	Increase PEEP by 2 cmH_2O increments and FIO_2 by 10% increments to achieve the SpO_2 target.*	
NIV	Inability to protect the airway; inability to tolerate mask interface	Spontaneous/timed (S/T) mode; IPAP 10 cmH_2O; EPAP 5 cmH_2O; FIO_2 30%; backup rate 12 breaths/min	Increase EPAP by 2 cmH_2O increments and FIO_2 by 10% increments to achieve the SpO_2 target.* Increase IPAP to keep tidal volume 4-8 ml/kg PBW. Adjust respiratory rate to keep pH within the range.	
IMV	None	AC/PC or AC/VC mode; PEEP 5 cmH_2O; FIO_2 30%; respiratory rate 12 breaths/min	Increase FIO_2 by a 10% increment to achieve the SpO_2 target*. Set PEEP according to the PEEP-FIO_2 table [Table 2]. For AC/PC mode, adjust inspiratory pressure above PEEP to keep tidal volume 4-8 ml/kg PBW. For AC/VC mode, adjust tidal volume to 4-8 ml/kg PBW and inspiratory flow to maintain patient comfort. Lower tidal volume to keep plateau pressure <30 cmH_2O. Adjust the respiratory rate to keep the pH within the range.†	
ECMO	None	Use low tidal volume ventilation	Adjust ECMO blood flow, sweep gas flow and FIO_2 as required to maintain target SpO_2, $PaCO_2$ and pH.	

*Target SpO_2 should be 94%-98% for most acutely ill patients, and 88%-92% for patients at risk of hypercapnic respiratory failure. †For patients with acute respiratory distress syndrome, to facilitate low tidal volume ventilation and lung protection during IMV, $PaCO_2$ may be allowed to rise with pH falling as low as 7.15 (i.e. permissive hypercapnia). AC/PC: assist-control pressure-control, AC/VC: assist-control volume-control, COT: conventional oxygen therapy, CPAP: continuous positive airway pressure, ECMO: extracorporeal membrane oxygenation, EPAP: expiratory positive airway pressure, FIO_2: inspired oxygen fraction, HFNC: high flow nasal cannula, IMV: invasive mechanical ventilation, IPAP: inspiratory positive airway pressure, NIV: non-invasive ventilation, $PaCO_2$: partial pressure of arterial carbon dioxide, PBW: predicted body weight. For men, PBW (kg)=50+ (0.91 × [height (cm) − 152.4]). For women, PBW (kg)=45.5+ (0.91 × [height (cm) − 152.4]). PEEP: positive end-expiratory pressure, SpO_2: peripheral oxygen saturation

Table 3. Problem-oriented selection of respiratory support.

Physiological problem	Concurrent conditions	Options for respiratory support
Hypoxaemia	Pneumonia	COT, HFNC, NIV and IMV
	Acute respiratory distress syndrome (P/F ratio ≥150)	COT, HFNC, NIV and IMV
	Acute respiratory distress syndrome (P/F ratio <150)	HFNC and IMV
	Acute cardiogenic pulmonary oedema	COT, CPAP, NIV and IMV
	Severe asthma	COT and IMV
	Multiple organ failure	IMV
	Inability to protect the airway e.g., coma, bulbar and dysfunction	IMV
	Hemodynamic instability	IMV
	Severe refractory hypoxaemia (P/F ratio <80)	ECMO
Hypercapnia	Chronic obstructive pulmonary disease	NIV and IMV
	Severe chest wall restriction e.g., due to kyphoscoliosis or obesity	NIV and IMV
	Neuromuscular weakness without bulbar dysfunction	NIV and IMV
	Inability to protect the airway e.g., coma, bulbar and dysfunction	IMV
	Haemodynamic instability	IMV

COT: conventional oxygen therapy, CPAP: continuous positive airway pressure, ECMO: extracorporeal membrane oxygenation, HFNC: high flow nasal cannula, IMV: invasive mechanical ventilation, NIV: non-invasive ventilation, P/F ratio: ratio of arterial oxygen partial pressure to inspired oxygen fraction

Table 4. Limitations of pulse oximetry.

Limitations	Causes
Inability to detect SpO_2	Incorrect probe application Motion artefact (excessive motion) Nail polish Artificial nails Vasoconstriction Hypotension Hypothermia
$SpO_2 < SaO_2$	All causes for inability to detect SpO_2 Prominent venous pulsation detected by pulse oximeter (e.g. from venous congestion or arteriovenous shunting) Severe anaemia (Hb <5 g/dL) Methaemoglobin (SpO_2 trends towards 85%) Sulfhaemoglobin (SpO_2 trends towards 85%) Methylene blue
$SpO_2 > SaO_2$	Dark skin pigmentation High levels of glycated haemoglobin Carboxyhaemoglobin Methaemoglobin (SpO_2 trends towards 85%) Sulfhaemoglobin (SpO_2 trends towards 85%)

Hb: haemoglobin, SaO_2: oxygen saturation as measured by arterial blood gas, SpO_2: oxygen saturation as measured by pulse oximetry

Table 5. Arterial blood gas interpretation.

pH	Primary problem	Expected compensation	Interpretation
<7.35	Hypercapnia ($PaCO_2$ >45 mmHg)	[HCO_3] increases by 1 mmol/L for every 10 mmHg increase in $PaCO_2$ above 40 mmHg	Acute respiratory acidosis
<7.35	Hypercapnia ($PaCO_2$ >45 mmHg)	[HCO_3] increases by 3.5 mmol/L for every 10 mmHg increase in $PaCO_2$ above 40 mmHg	Chronic respiratory acidosis
<7.35	Metabolic acidosis (HCO_3 <22 mmol/L)	$PaCO_2$ (mmHg) = 8 + (1.5 × [HCO_3 in mmol/L]) ± 2	Metabolic acidosis
>7.45	Hypocapnia ($PaCO_2$ <35 mmHg)	[HCO_3] decreases by 2 mmol/L for every 10 mmHg decrease in $PaCO_2$ below 40 mmHg	Acute respiratory alkalosis
>7.45	Hypocapnia ($PaCO_2$ <35 mmHg)	[HCO_3] decreases by 5 mmol/L for every 10 mmHg decrease in $PaCO_2$ below 40 mmHg	Chronic respiratory alkalosis
>7.45	Metabolic alkalosis (HCO_3 >26 mmol/L)	$PaCO_2$ (mmHg) = 21 + (0.7 × [HCO_3 in mmol/L]) ± 2	Metabolic alkalosis

Note: If more than one acid-base disorder is present, the observed compensation would deviate from the expected compensation. HCO_3: serum bicarbonate, $PaCO_2$: partial pressure of arterial carbon dioxide

Case 2:

Presentation:

65-year-old male with fever, dry cough, and progressive dyspnea for 7 days. No prior lung disease

RR 32, SpO_2 84% on room air

Investigations:

ABG: pH 7.45, $PaCO_2$ 32 mmHg, PaO_2 55 mmHg

Chest CT: bilateral ground-glass opacities

CRP elevated, positive RT-PCR for SARS-CoV-2

Diagnosis:

Type 1 respiratory failure due to viral pneumonia (COVID-19)

Teaching Points:

Hypoxemia with low PaO_2 and normal/low $PaCO_2$ V/Q mismatch and shunting

Need for oxygen therapy or HFNC, possibly escalation to mechanical ventilation

Case 3:

Presentation:

40-year-old woman with sudden-onset dyspnea and pleuritic chest pain. History of recent C-section.
SpO_2 87%, RR 28

Investigations:

ABG: pH 7.47, $PaCO_2$ 30 mmHg, PaO_2 58 mmHgD-dimer elevated, CT pulmonary angiogram: large bilateral PE

Diagnosis:

Type 1 respiratory failure due to acute PE

Teaching Points:

Low PaO_2 with respiratory alkalosis (from hyperventilation)No parenchymal infiltrates; mismatch due to impaired perfusion

Anticoagulation is the cornerstone of treatment

Case 4:

Presentation:

72-year-old male with known COPD, increased sputum and dyspnea, Uses home oxygen, active smoker, RR 24, SpO_2 89% on nasal cannula 2 L/min

Investigations:

ABG: pH 7.28, $PaCO_2$ 68 mmHg, PaO_2 60 mmHg

Chest X-ray: hyperinflated lungs, no consolidation

Diagnosis:

Type 2 respiratory failure due to COPD exacerbation

Teaching Points:

Elevated $PaCO_2$ with respiratory acidosis

Consider non-invasive ventilation (NIV)

Case 5:

Presentation:

35-year-old woman with myasthenia gravis, now with progressive weakness and shallow breathing, RR 12, weak cough, SpO_2 94% on room air

Investigations:

ABG: pH 7.30, $PaCO_2$ 62 mmHg, PaO_2 75 mmHg

No infiltrates on chest X-ray

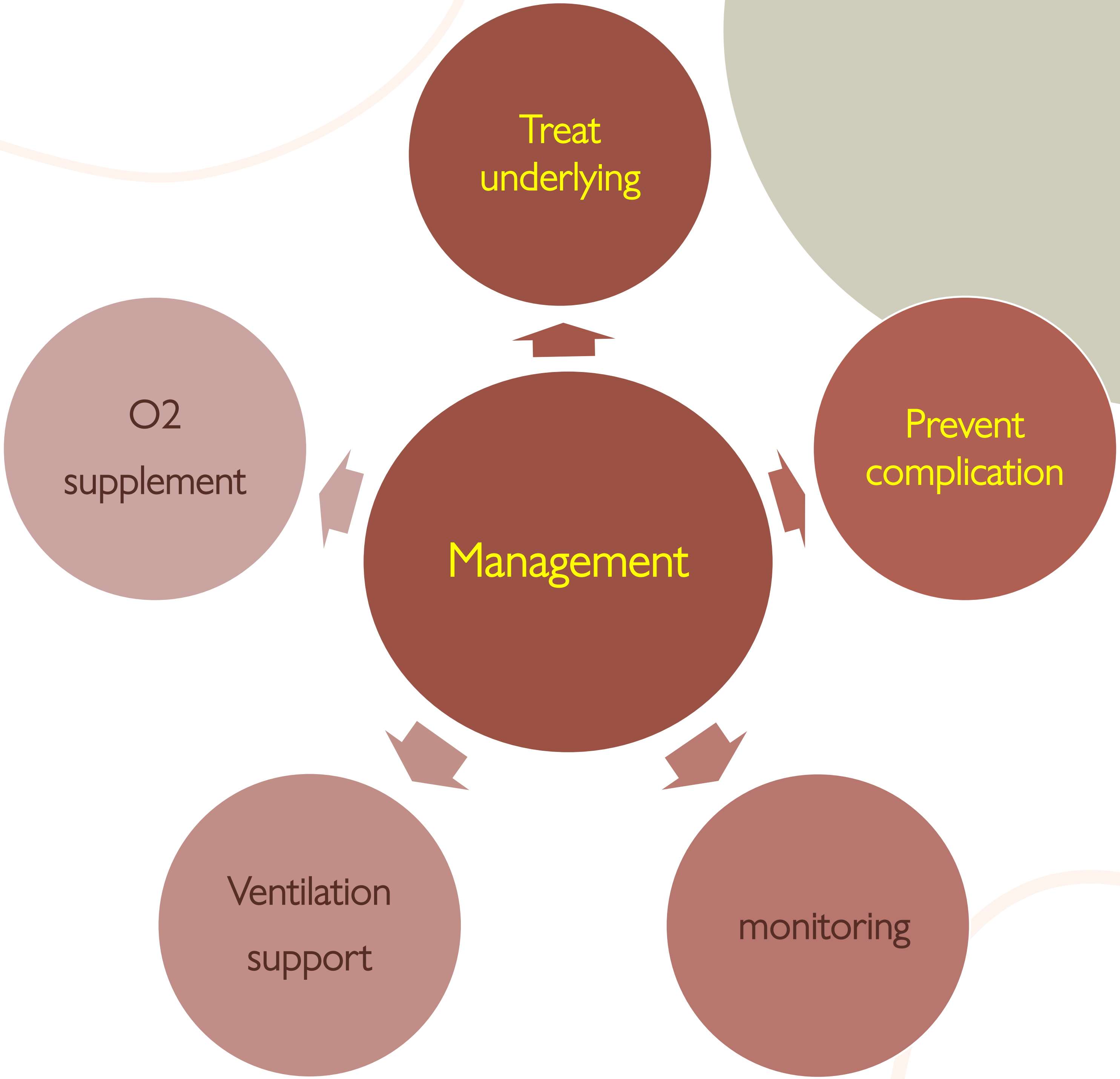
Diagnosis:

Type 2 respiratory failure from neuromuscular hypoventilation

Teaching Points:

Normal O_2 saturation may be misleading

Assess respiratory mechanics in neuromuscular patients, Requires ICU admission and likely intubation


Treat underlying
Prevent complication
O2 supplement
Management
Ventilation support
monitoring

Acute Hypoxemic Respiratory Failure

- NPPV was associated with a lower risk of **mortality** (RR 0.40 [95% CI 0.24–0.63]) and **intubation**(RR 0.26 [95% CI 0.14–0.46])

Timing of intubation when patients are receiving NIV

- The British Thoracic Society recommends evaluating patients 4–6 h after initiating NIV.
- As there are not sufficient data on the optimal timing of intubation for patients receiving NIV, close monitoring of respiratory workload and gas exchange are vital in these patients.

TABLE 1 Monitoring of noninvasive ventilation during acute respiratory failure

Clinical parameters	Comfort Tolerance to interface Respiratory rate Dyspnoea and use of accessory muscles Consciousness-sensorium (GCS, Kelly–Matthay score) Ability to protect the upper airways and presence of an effective cough reflex Gastric distention Disease severity scores (APACHE II) Sedation-delirium scores Monitoring of side-effects
Physiological parameters	Oxygen saturation Arterial blood gas analysis (pH, P_{aCO_2}, P_{aO_2}) Transcutaneous CO_2 End-tidal CO_2
Ventilatory parameters	Respiratory frequency V_{TE}, V'_E Leaks Waveforms (flow–time, pressure–time, capnography) $PEEP_i$ Patient–ventilator interaction
Cardiac parameters	Blood pressure ECG Echocardiography[#]
Other	Radiological evaluation (chest radiography, computed tomography[#]) Lung and diaphragm ultrasonography

Eur Respir Rev 2018

TABLE 2 Levels of monitoring of patients receiving noninvasive ventilation (NIV)

	General ward	HDU	ICU
Degree of severity of respiratory failure	Mild	Moderate	Severe
pH [10, 14, 28]	7.35–7.30	7.30–7.20	<7.20
Respiratory rate breaths·min^{-1}			
Restrictive disorders	<30	30–35	>35
Obstructive disorders	<25	25–35	>35
Level of consciousness			
GCS	15	10–14	<10
Kelly's scale [121]	1	2–4	5–6
Failure of other organs	No	Debatable	Yes
Oxygenation	Corrected with low-flow oxygen (nasal prongs)	Corrected with high-flow oxygen (Venturi mask or nonrebreathing mask)	Not corrected with high-flow oxygen
P_{aO_2}/F_{IO_2} ratio [122–124]	>150	<150	<100
Monitoring			
Medical staff surveillance			
Continuous nurse monitoring	Not necessary	Indicated	Obligatory
Pulmonologist on duty	Preferable	Obligatory	Preferable
Intensivist on duty	Not necessary	Preferable	Obligatory
Clinical assessment			
Blood pressure	Occasional	Occasional	Continuous
Heart rate[#]	Occasional	Continuous	Continuous
Respiratory rate	Occasional	Continuous	Continuous
Level of consciousness	Not necessary	Frequent	Frequent
Gas exchange			
S_{pO_2}	Every 2–4 h	Continuous	Continuous
Arterial blood gas analysis[¶]	Every 8 h	Every 2–4 h	Frequent by arterial line
P_{tcCO_2}	Not necessary	Indicated	Indicated
Ventilator parameters			
Leak, V_{TE}, I:E, V'_E	Every 2–4 h	Every 1 h	Continuous
Patient–ventilator asynchrony	Occasional	Frequent	Frequent
Flow traces	Not necessary	Indicated	Obligatory
Compliance and resistance	Not necessary	Indicated	Obligatory


Thank you!