Objectives

- Outline the determinants of oxygen balance
- Recognize disorders of oxygen delivery
- Identify principles and limitations of techniques for monitoring oxygen balance
- Explain the use of acid-base status in monitoring the seriously ill patient

Case Study 1

- 67-year-old woman status post cholecystectomy 1 day ago
- Develops shortness of breath and altered mental status
- Vital signs: HR 136 beats/min, BP 106/55 mm Hg, RR 28 breaths/min, SpO_2 91% (room air)
- Benign abdominal examination

What monitoring should be immediately implemented?

What monitoring should be immediately implemented? (Select all that apply)

A. Blood pressure
B. Heart rate
C. Respiratory rate
D. Oxyhemoglobin saturation
E. Temperature
F. Intra-abdominal pressure

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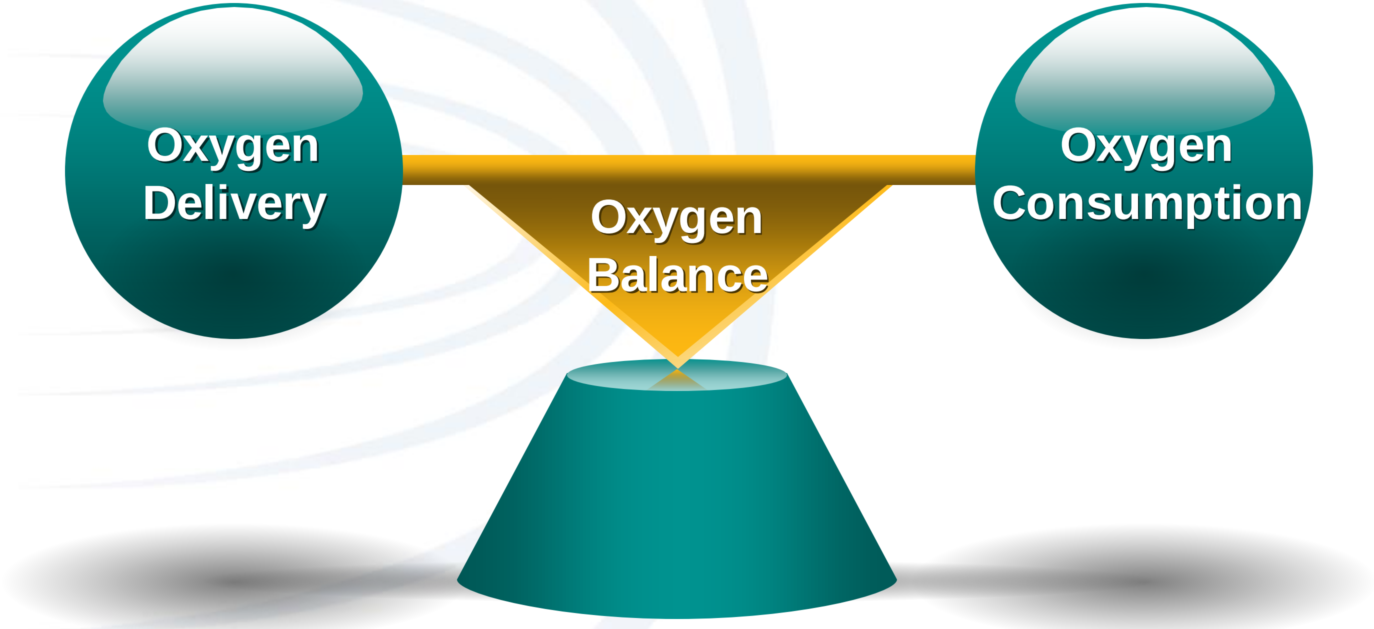
- Benign abdominal examination

What monitoring should be immediately implemented?

What are the goals of monitoring in this patient?

Tissue Oxygenation

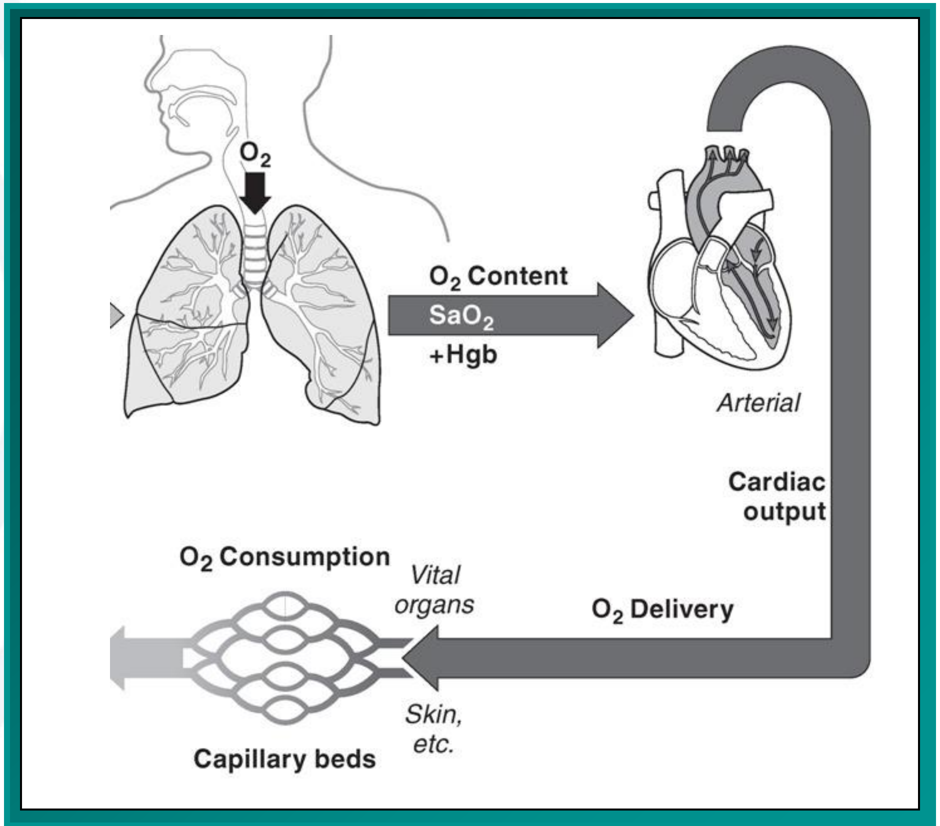
- Cannot be directly measured or monitored



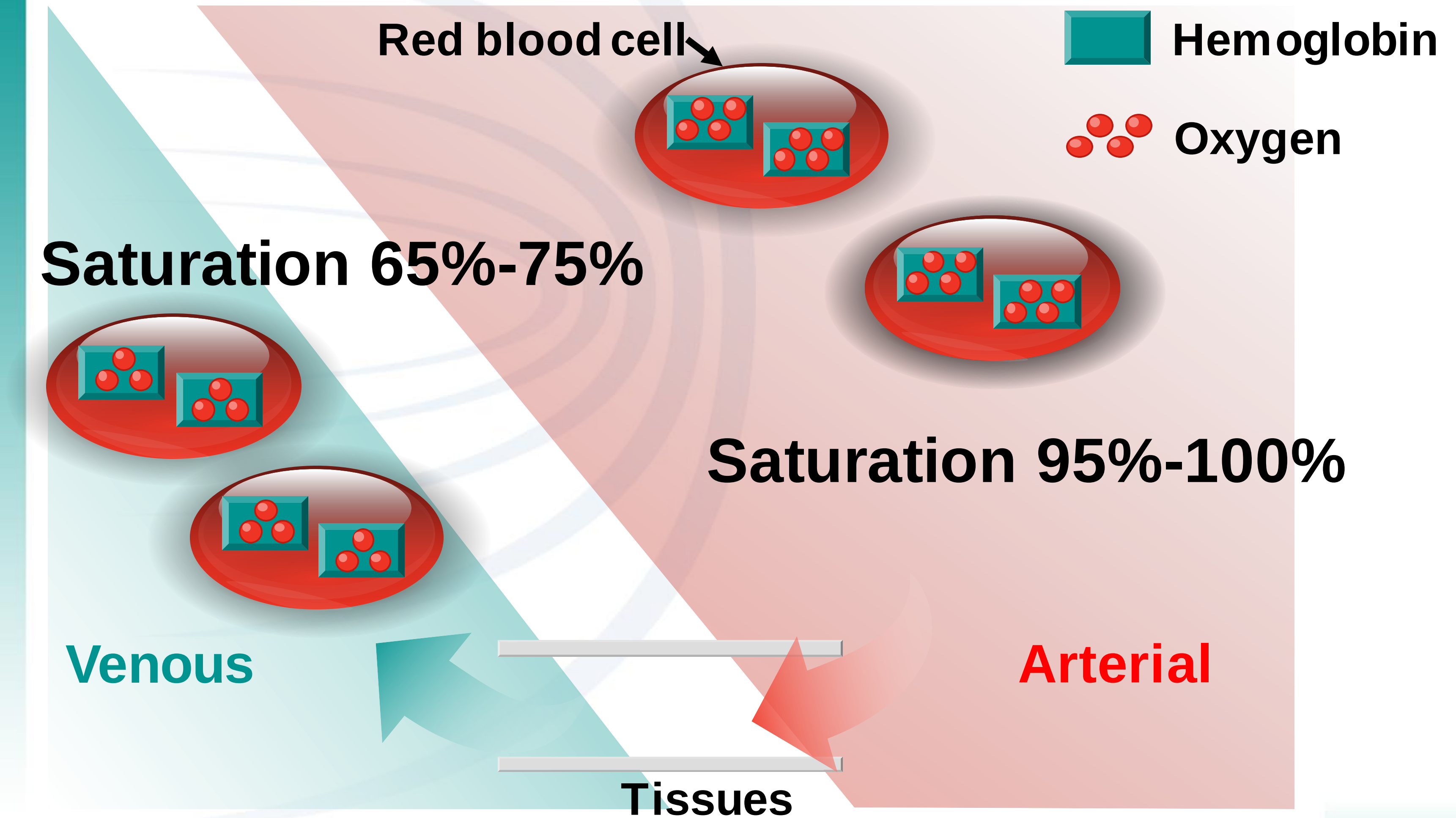
Which component of oxygen balance is more likely to be modified by clinical interventions?

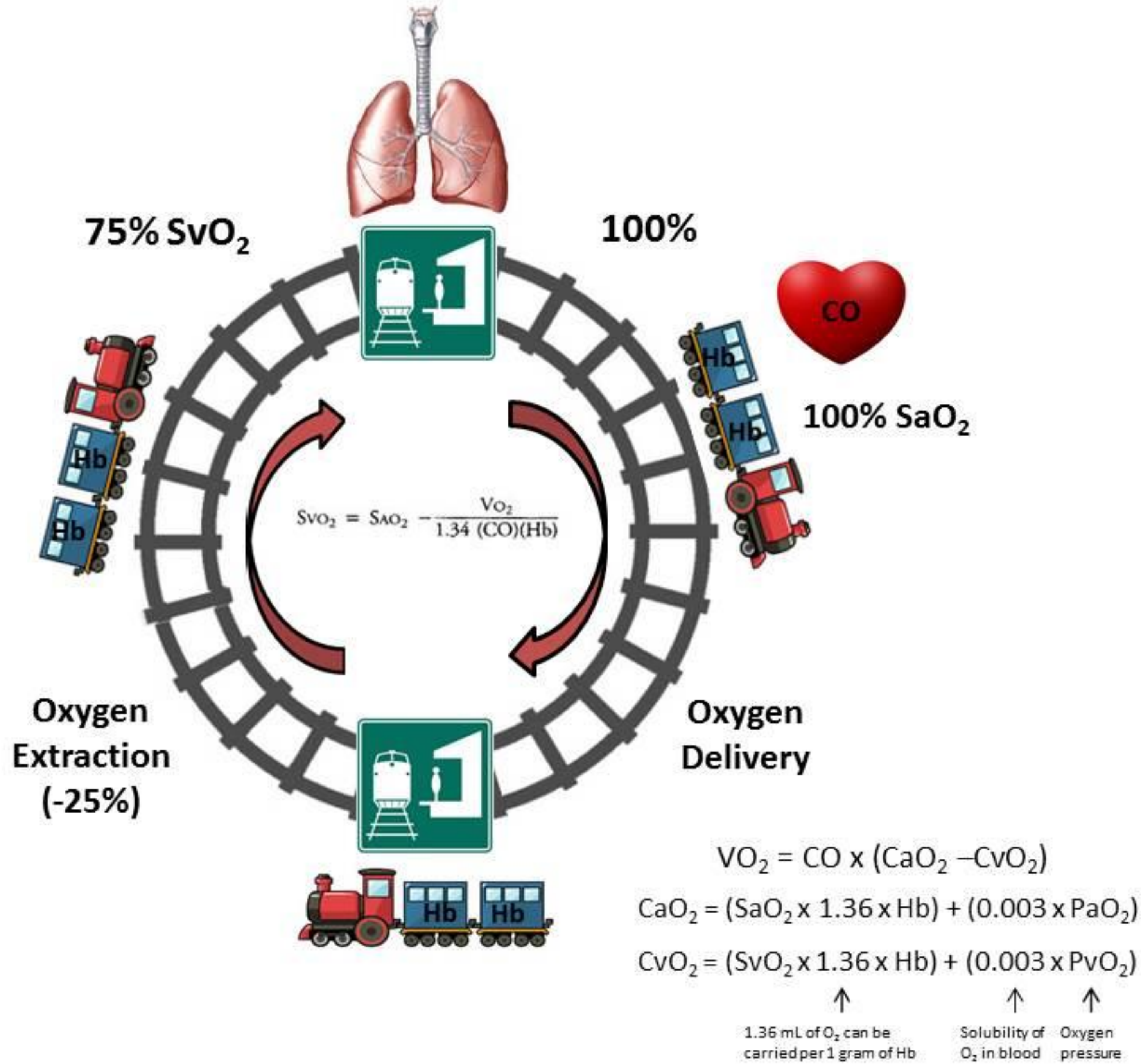
Determinants of O_2 Delivery

- **Cardiac output (blood flow)**
- **O_2 content of arterial blood**
  - **Hemoglobin**
  - **Oxyhemoglobin saturation**
  - **PaO_2**



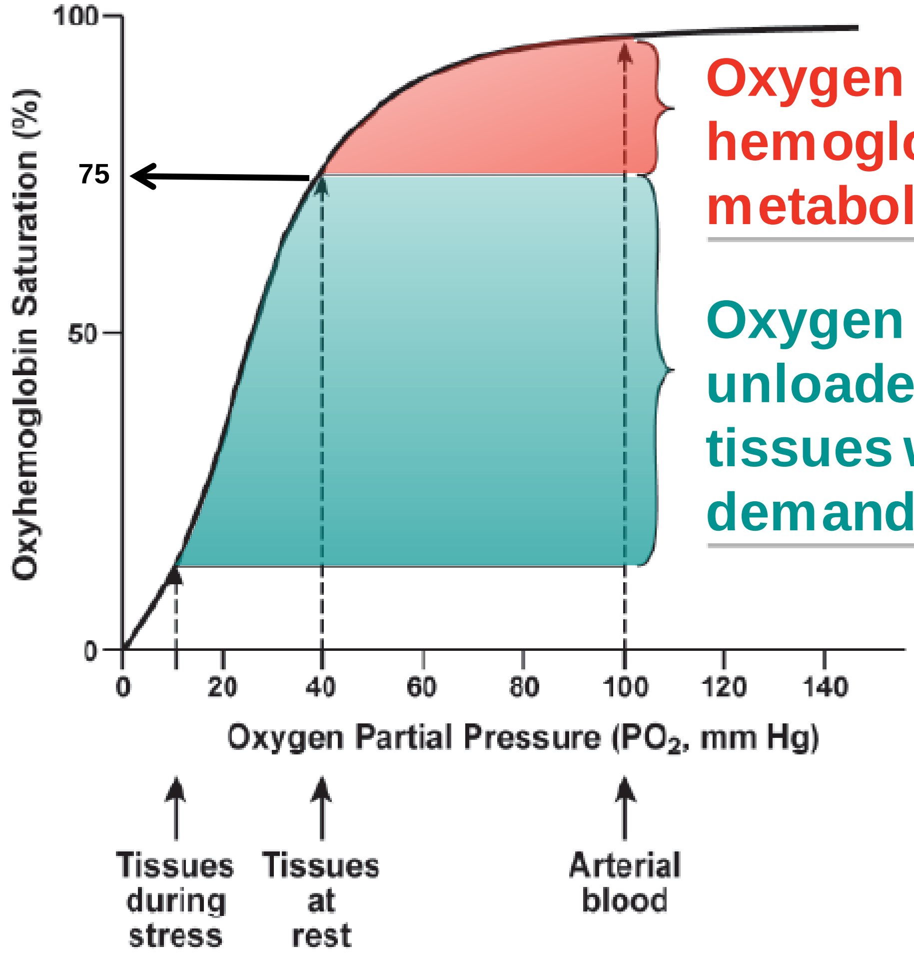
Arterial O_2 Content





75% SvO_2
100%
CO
100% SaO_2
Hb
Hb
Hb
Hb
Hb
Hb
$SvO_2 = SaO_2 - \frac{VO_2}{1.34\,(CO)(Hb)}$
Oxygen Extraction (-25%)
Oxygen Delivery
$VO_2 = CO \times (CaO_2 - CvO_2)$
$CaO_2 = (SaO_2 \times 1.36 \times Hb) + (0.003 \times PaO_2)$
$CvO_2 = (SvO_2 \times 1.36 \times Hb) + (0.003 \times PvO_2)$
1.36 mL of O_2 can be carried per 1 gram of Hb
Solubility of O_2 in blood
Oxygen pressure

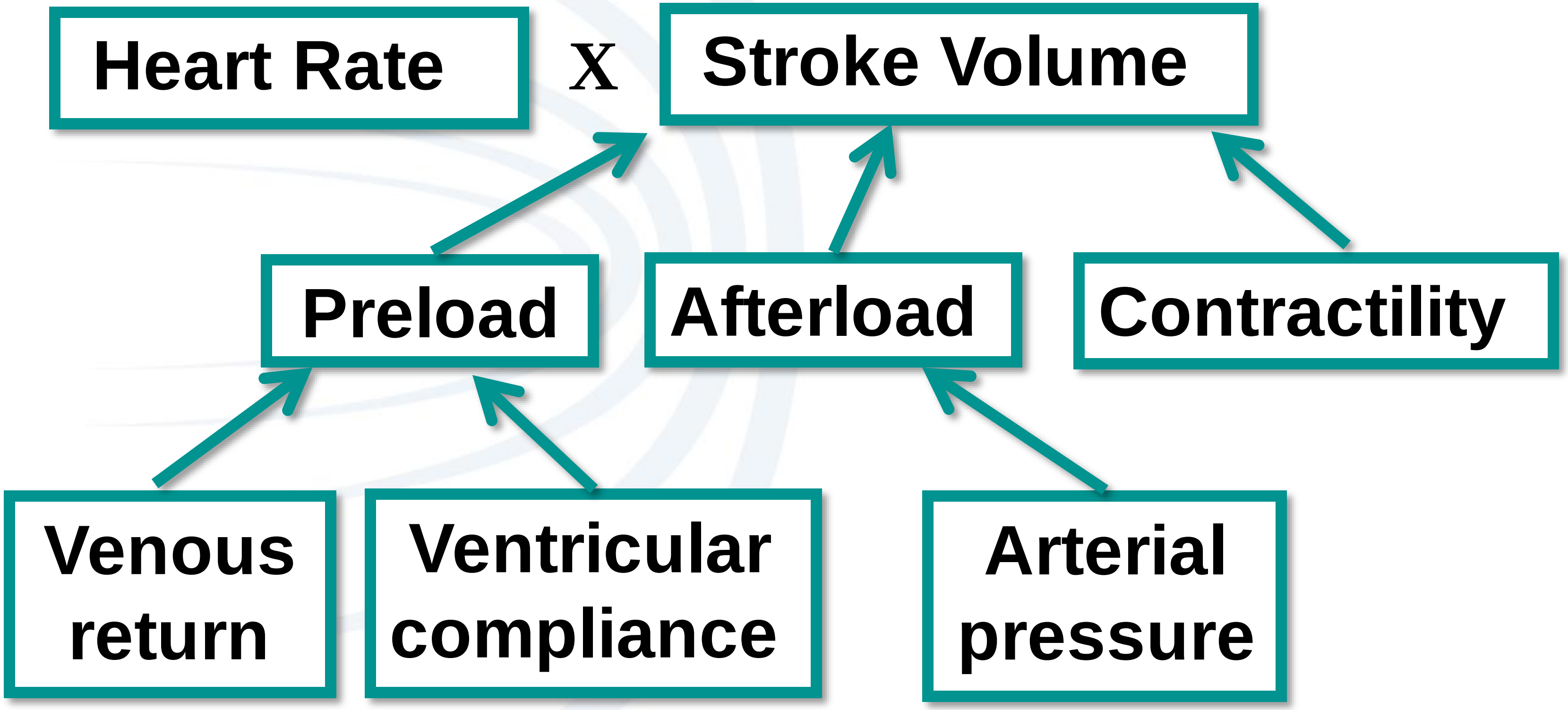
Oxygen Reserve



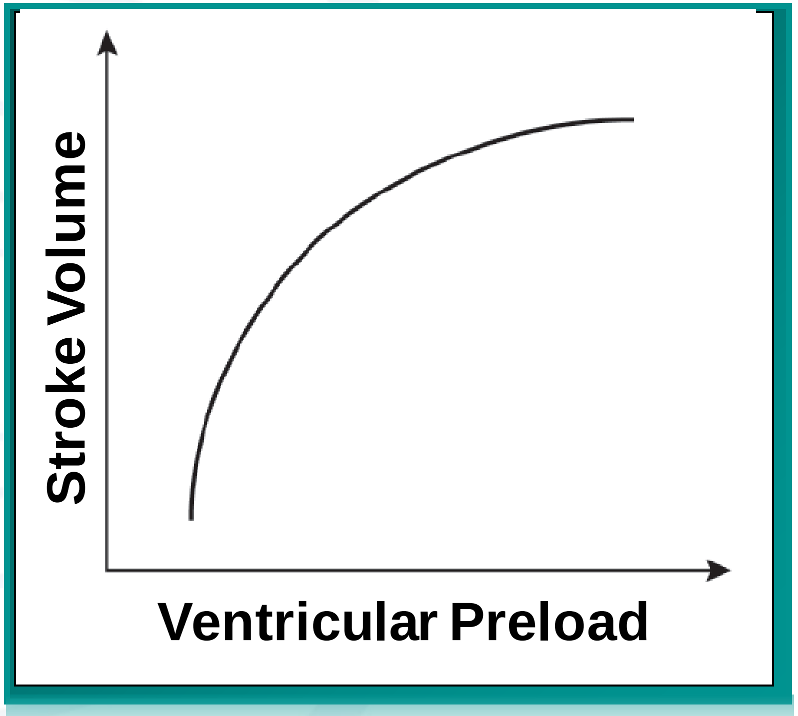
Oxygen unloaded from hemoglobin during normal metabolism

Oxygen reserves that can be unloaded from hemoglobin to tissues with increased demands

Cardiac Output



Importance of Preload



- **Preload also affects contractility**

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How would you evaluate oxygen delivery in this patient?

- How would you evaluate oxygen delivery in this patient? (Select all that apply)

A. Heart rate
B. Mean arterial pressure
C. Venous blood gas analysis
D. Pulse oximetry

Case Study 1

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- Vital signs: HR 136 beats/min, BP 106/55 mm Hg, RR 28 breaths/min, SpO_2 94% (room air)

How would you determine oxygen delivery in this patient?

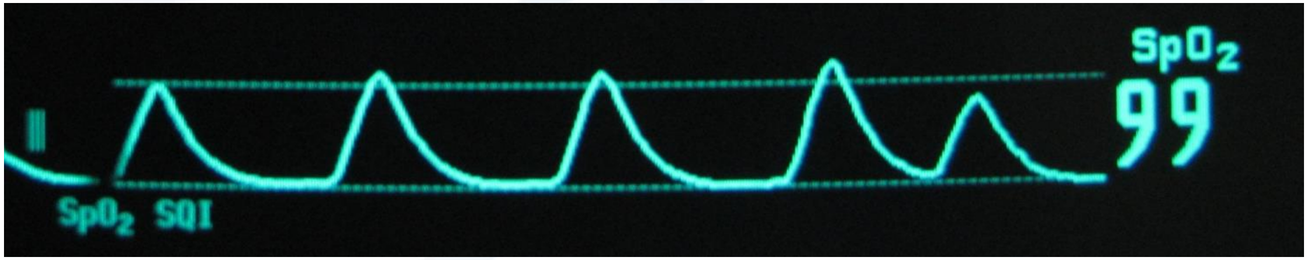
- Cardiac output
- Arterial oxygen content

Pulse Oximetry

What does a pulse oximeter measure?

- **SpO_2 vs SaO_2**

What factors might affect the accuracy of the pulse oximeter measurement?



Blood Pressure Measurement

- Blood pressure = cardiac output x systemic vascular resistance

What options would you consider for monitoring blood pressure in this patient?

- Manual noninvasive device
- Automated noninvasive device
- Arterial cannulation

Case Study 1

- Automated blood pressure device and pulse oximeter applied
- SpO_2 91% (room air), HR 135 beats/min,
  BP 96/50 mm Hg
- Hemoglobin 11.5 g/dL

Is oxygen delivery sufficient to maintain an adequate oxygen balance?

- **Is oxygen delivery sufficient to maintain adequate oxygen balance? (Choose the best answer)**

  A. Yes

  B. No

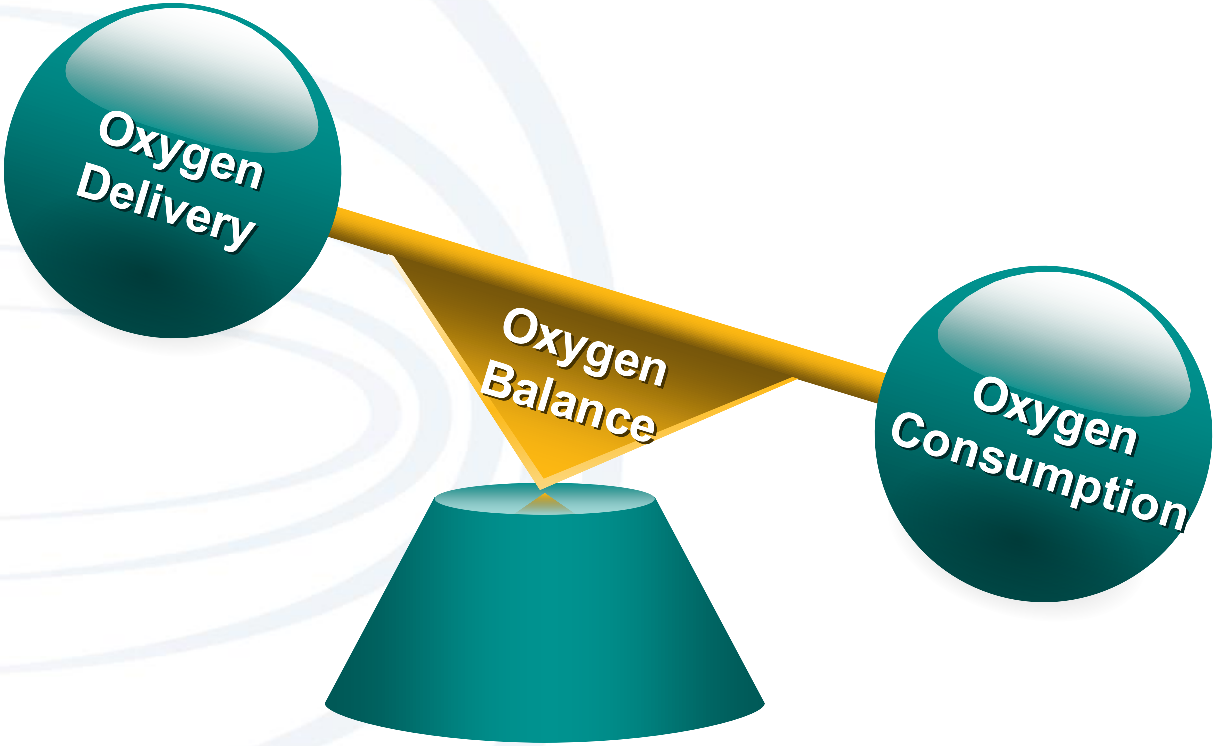
  C. More information is needed

Case Study 1

- Automated blood pressure device and pulse oximeter applied
- SpO_2 91% (room air), HR 135 beats/min, BP 96/50 mm Hg
- Hemoglobin 11.5 g/dL

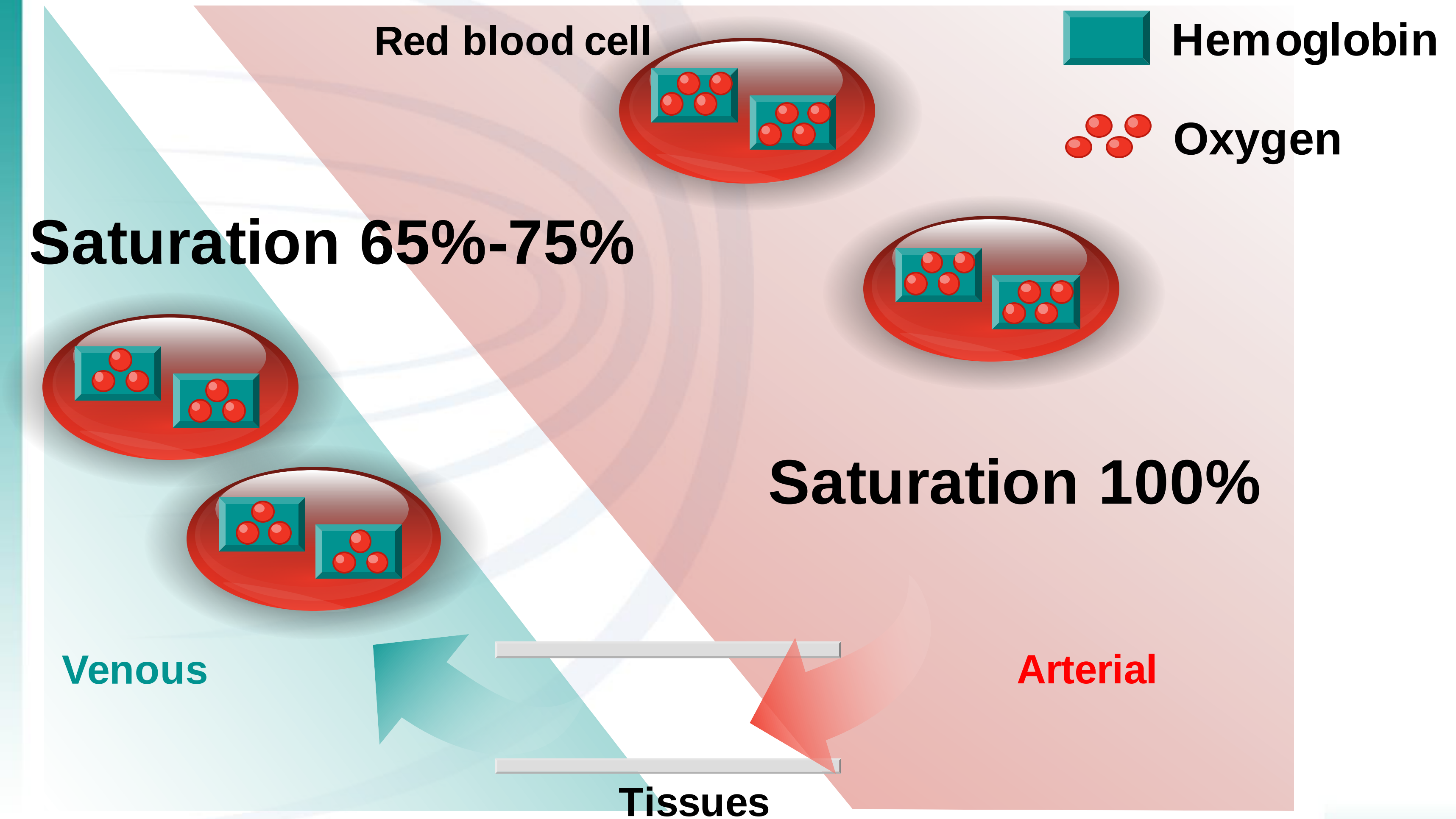
Is oxygen delivery sufficient to maintain an adequate oxygen balance?

Tissue Oxygenation



- **Central venous oxyhemoglobin saturation ($ScvO_2$)**
- **Lactate concentration**

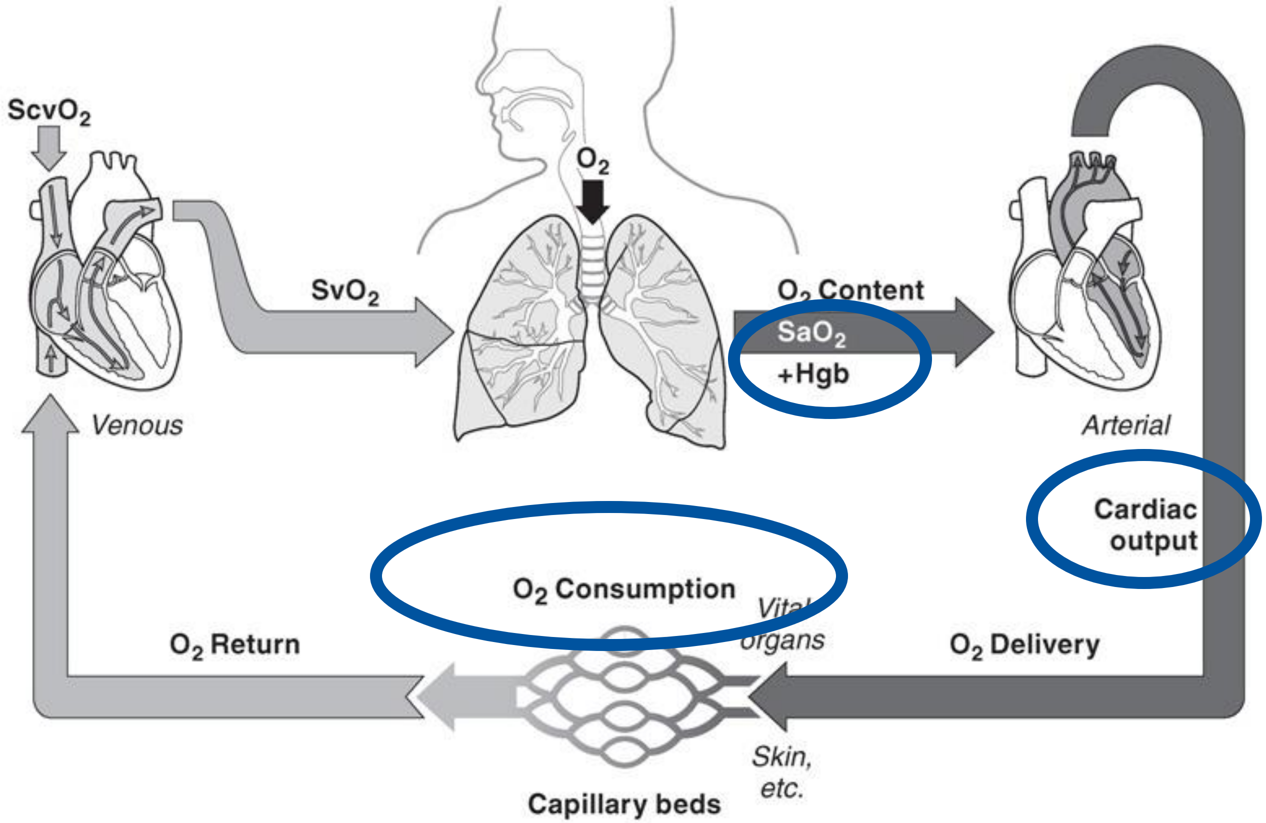
Venous Oxyhemoglobin Saturation



Central Venous Oxyhemoglobin Saturation

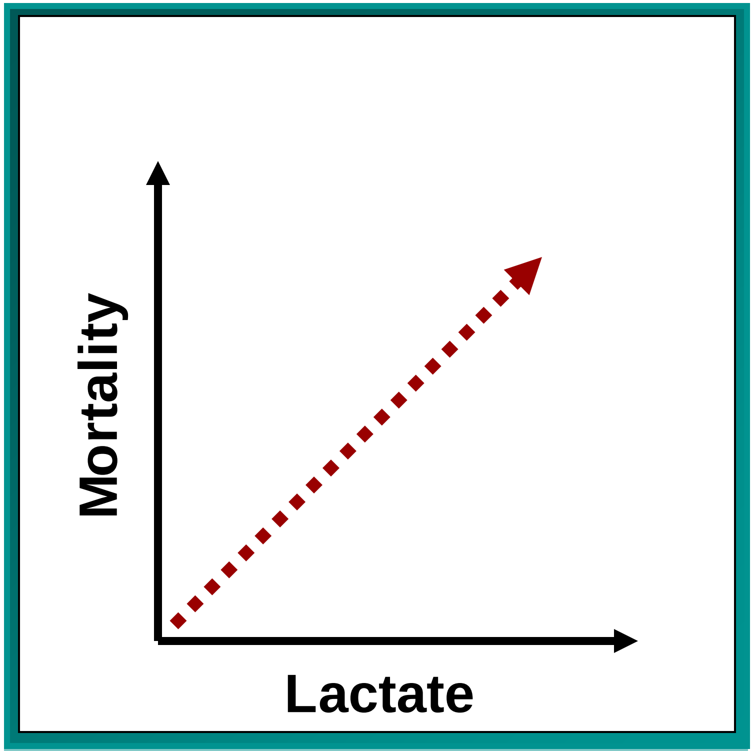
What does a low $ScvO_2$ mean?

What does a normal $ScvO_2$ mean?



Lactate

- Product of anaerobic metabolism with cellular hypoxia
- Elevated concentrations
  - Inadequate oxygen supply
  - Drugs
  - Hepatic dysfunction



Case Study 1

- Repeat vital signs: HR 135 beats/min, BP 96/50 mm Hg, RR 28 breaths/min, T 101°F (38.3°C), Sp_{O_2} 92% (6 L/min nasal cannula)
- Arterial blood gas: pH 7.32, Pa_{CO_2} 32 mm Hg (4.3 kPa), Pa_{O_2} 68 mm Hg (9.1 kPa)
- Na 142 mmol/L, K 4.0 mmol/L, Cl 106 mmol/L, HCO_3 16 mmol/L, BUN 28 mg/dL, creatinine 1.4 mg/dL

Does the acid-base status suggest the patient is seriously ill?

Acid-Base Analysis

- Determine overall acid-base condition (acidemia or alkalemia)
- Determine if primary process is metabolic or respiratory
- Determine if acute or chronic process in respiratory disturbance
- Determine if respiratory compensation adequate in metabolic process
- Calculate anion gap (always)

Acid Base 101

Look at the pH.

Expect an increase in the bicarbonate by 1 meq/L for every 10 mm Hg rise in the $PaCO_2$ in respiratory acidosis.

Calculate the anion gap.

Greater than or equal to 20 → metabolic acidosis no matter what.

The body does not generate a large enough anion gap to compensate for a primary disorder.

Calculate the excess anion gap (∆ gap).

12 (10-14) is the standard, so subtract the anion gap from 12.

Next, add this value to your measured bicarbonate. If this is greater than 30, you have an underlying metabolic alkalosis.

If this is less than 23 (a normal bicarbonate value), you have an underlying NON gap metabolic acidosis.

The reason for this is because 1 mmol of unmeasured acid should titrate 1 mmol of bicarbonate; hence a ∆ anion gap should equal the ∆ bicarb under normal circumstances.

Measured Anion Gap – 12

> 30 → Underlying metabolic ALKalosis

< 23 → Underlying NON gap metabolic ACIDosis

$$AG = [Na^{+} + K^{+}] - [Cl^{-} + HCO3^{-}]$$

Metabolic Acidosis

If you are still second guessing yourself, use Winter's formula for metabolic acidosis to make sure your $PaCO_2$ is what it should be.

$$PaCO_2 = 1.5 \times \text{measured } HCO_3^- + 8\ (\pm 2)$$

One other trick for metabolic acidosis*: the expected $PaCO_2$ should approximate the* last 2 digits of the pH value*. For example, the expected $PaCO_2$ for a primary metabolic acidosis with a pH of 7.25 is 25.*

Stewart Approach

Strong Ion Gap = SID = [strong cations] – [strong anions]

$\approx Na^{+} - Cl^{-}$

$\approx 38\ (140\text{-}102)$

ACIDOSIS usually means extra anions.
The strong ion difference is **DECREASED**.
Seen in disorders where cations are decreased (potassium, sodium) or where anions are increased (hyperchloremia, lactatemia, ketoacids, etc.).

ALKALOSIS usually means extra cations.
The strong ion difference is **INCREASED**.
Seen in disorders where cations are increased (hyperkalemia, hypercalcemia, hypernatremia) or where anions are decreased (hypoalbuminemia, hypochloremia)

insert new data into the acidbase database
please - be careful choosing the units for your measurements!
there are plenty of different units used around the world - preferentially use SI units!

chemical data

required data

pH			
BE (base excess) read more!		mEq/l	required for cross-checking purposes
Na read more! about the influence of serum Na^+ on its ionic activity		mmol/l	
normal value for Na	range 137 - 145 adjust for the values at your institution!	mmol/l	
K		mmol/l	
Cl		mmol/l	may you make an *educated guess* about chloride? NO - why???: read more!
normal value for Cl	range 102 - 108 adjust for the values at your institution!	mmol/l	
PCO2		kPa	be careful choosing the unit! (mmHg or kPa - this is essential!)
albumin the most prominent of the weak acids		g/l	may you make an *educated guess* about albumin? yes - BUT: read more!

optional data

lithium		mmol/l	
Mg		mmol/l	
Ca (total, not free or "ionised") read more!		mmol/l	
phosphate		mmol/l	
lactate		mmol/l	registering this value is strongly recommended!
haemoglobin		mmol/l	only useful for calculating UIX (unknown ion excess) (if not given, a value of 6 mmol/l / 100g/l is assumed.)
osmolality (freezepoint method)		mosmol/l	only required if you want to calculate the osmotic gap, strongly recommended in cases of intoxication or ketoacidosis
glucose		mmol/l	
urea		mmol/l	
ethanol or other osmotically active substances (1 ‰ ethanol is 21 mosmol/l)		mosmol/l	do not register anionic substances like **hydroxybutyrate** (because their osmotic effect is already accounted for by the corresponding kation)
did you "buffer" with **trometamol (THAM)**, e.g.	yes?	mmol/l	

Case Study 1

- pH 7.32, $PaCO_2$ 32 mm Hg (4.3 kPa), PaO_2 68 mm Hg (9.1 kPa)
- Na 142 mmol/L, K 4.0 mmol/L, Cl 106 mmol/L, HCO_3 16 mmol/L

Acidemia or alkalemia? → Acidemia

Respiratory or metabolic? → Metabolic

Adequate respiratory compensation? → Yes

$PaCO_2 = 1.5\,[HCO_3] + 8 \pm 2 \rightarrow 1.5 \times 16 + 8 = 32$

Case Study 1

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- Na 142 mmol/L, K 4.0 mmol/L, Cl 106 mmol/L, HCO_3 16 mmol/L

Anion gap?

AG = [Na] – ([Cl] + [HCO_3])

→142 – 122 = 20

What is the expected AG if albumin = 2.0 g/dL?

- Expected AG decreases by 2.5-3 mmol/L for every 1 g/dL decrease in albumin

Expected AG = 12 – (5-6) = 6-7

Case Study 1

- Patient is intubated for worsening oxygenation, SpO_2 95% (FIO_2 0.60)
- Arterial catheter inserted, BP 92/54 mm Hg
- Central venous catheter inserted
  - Central venous pressure 10 mm Hg
  - $ScvO_2$ 60%
- Lactate concentration 6 mmol/L

Does the CVP measurement indicate the need for more intravenous fluids?

- Does the CVP measurement indicate the need for more intravenous fluids? (Choose the best answer)

A. Yes
B. No
C. Cannot be determined

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- Arterial catheter inserted, BP 92/54 mm Hg
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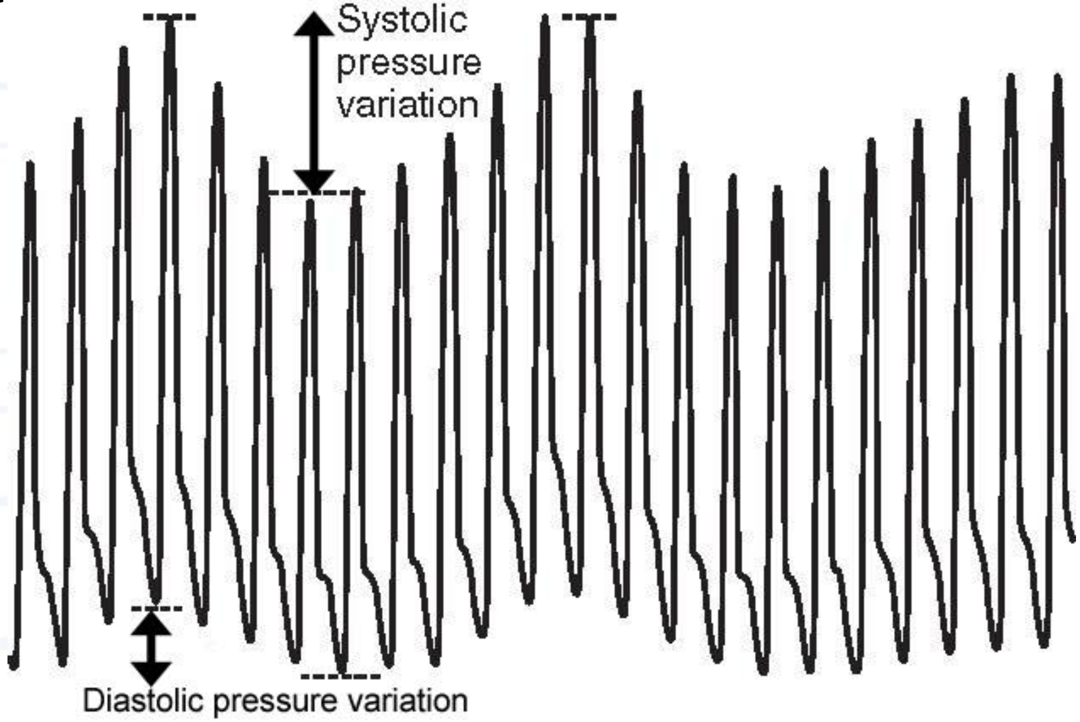
What other monitoring methods can help in determining fluid responsiveness?

Monitoring Fluid Responsiveness

- Variation in systolic blood pressure, pulse pressure, or stroke volume
  - Mechanically ventilated patients
- Response to increased preload
  - Passive leg raising
  - Fluid boluses
  - Assess change in stroke volume, cardiac output, or blood pressure
- Variation/change >10%-15% suggests responsive to additional fluids

Case Study 1

- **Arterial waveform tracing on mechanical ventilation**



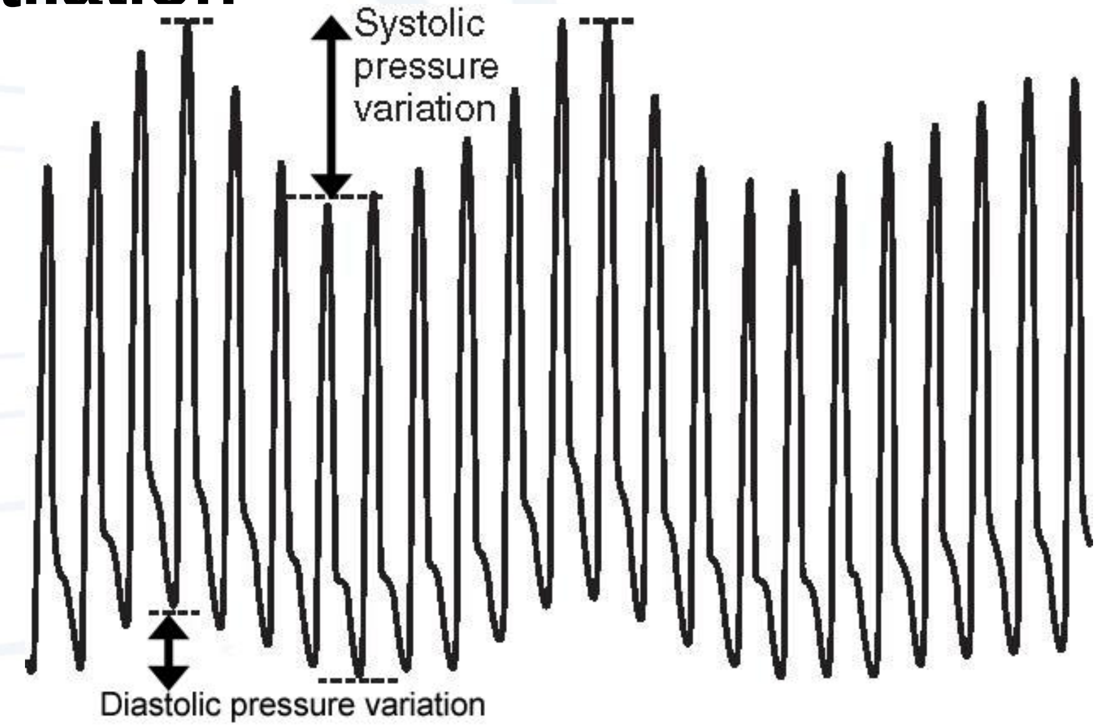
What interventions might be considered?

- What interventions might be considered? (Select the single best answer)

A. Administration of vasopressors
B. Administration of IV fluids
C. Administration of sedation
D. Decrease PEEP or tidal volume

Case Study 1

- Arterial waveform tracing on mechanical ventilation



What interventions might be considered?

Questions

Key Points

- Oxygen delivery is dependent on cardiac output and arterial oxygen content
- Hemoglobin is the major contributor of oxygen for tissue demands
- Normal filling pressures may not indicate adequate preload volume
- $ScvO_2$ and lactate are useful measures of global oxygen balance
- Low $ScvO_2$ values suggest oxygen imbalance

Key Points

- Pulse oximetry values do not reflect adequacy of oxygen delivery
- Arterial cannulation is preferred for blood pressure monitoring in unstable patients
- Systolic blood pressure, pulse pressure, or stroke volume variation and fluid responsiveness may help optimize cardiac output and oxygen delivery
- Assessment of acid-base status may suggest specific diagnoses and/or interventions