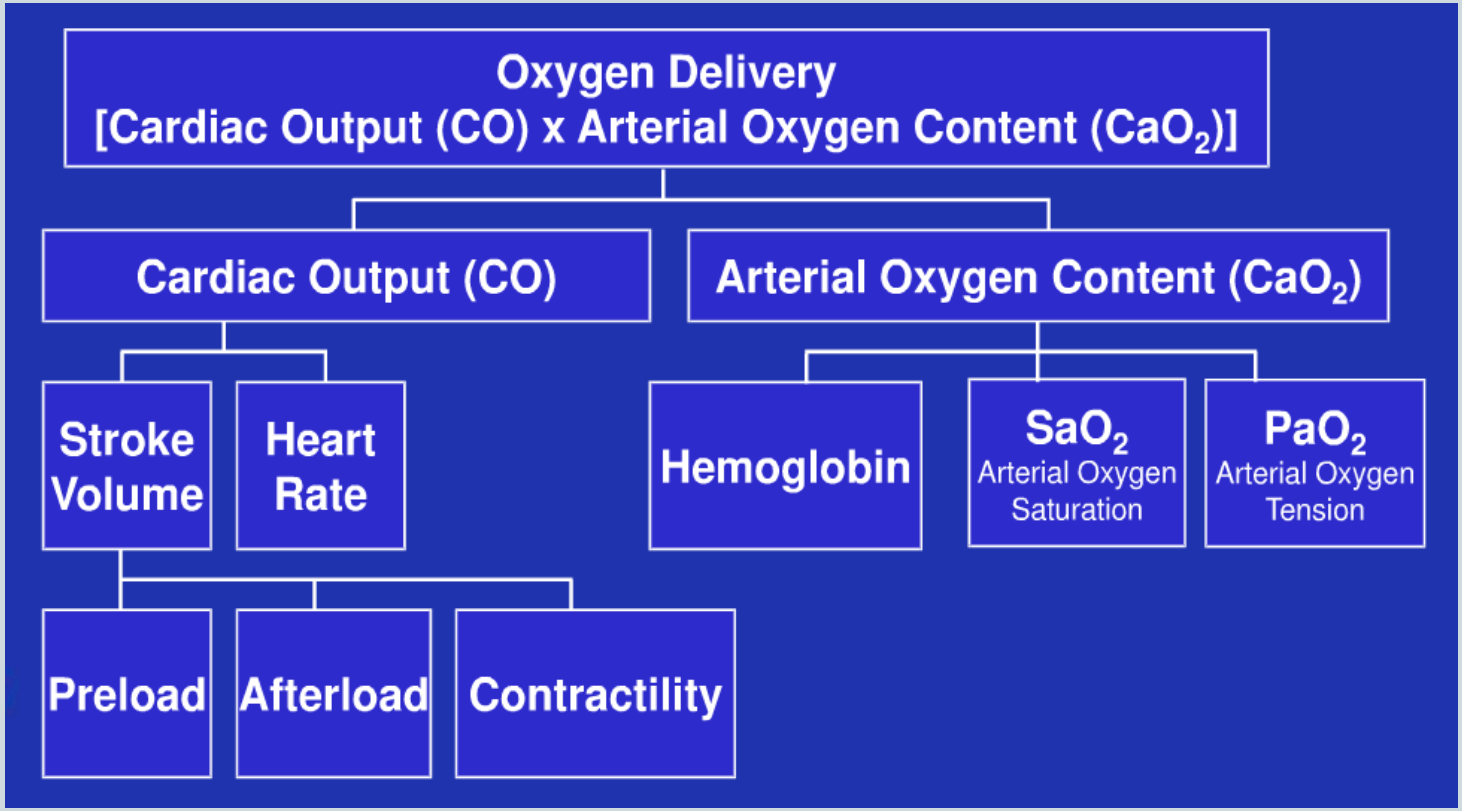
Cardiac Output and SVO_2 Monitoring

RYAN LAUER, M.D.

What are we trying to monitor?

- Oxygen delivery to tissues:

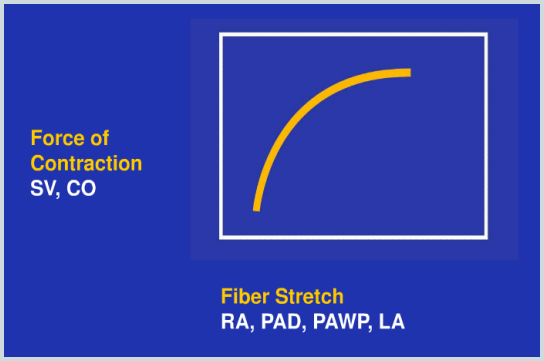


Cardiac Output Determinants

- HR: easiest? to manipulate
- Stroke Volume:

Preload

LV Preload
PAD
Normal: 8 – 15 mmHg
PAWP/LAP
Normal: 6 - 12 mmHg



Afterload

- Systemic vascular resistance (SVR)
- $SVR = \frac{MAP-RAP}{CO} \times 80$
- Normal: 800 – 1200 dynes/sec/cm^{-5}

Contractility

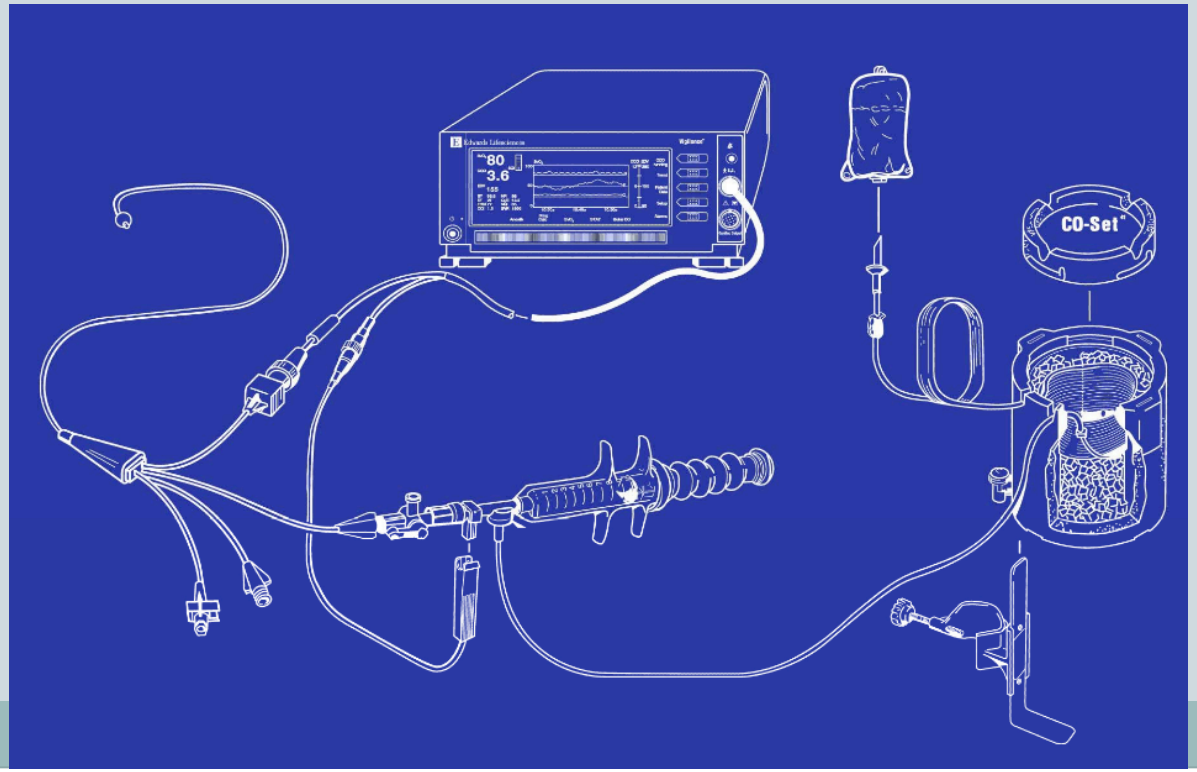
LV
Left Ventricular Stroke Work Index (LVSWI) =
SVI x (MAP-PAWP) x 0.0136
Normal 45-65 gm-m/m^2/beat

Cardiac Output: How do we do it?

- Fick Method: $CO = VO_2 / (Ca_{O2} - Cv_{O2})$
  - Not clinically practical due to difficulty measuring VO_2
  - Attempts have been made to use CO_2 production as a surrogate but still cumbersome and mixed validity
- Dye dilution:
  - Stewart-Hamilton equation: $CO = I \times 60 / (Cm \times t \times K)$
    - Vol. of indicator injected
    - Integral of indicator concentration over time
    - Constant
  - Used indocyanine green dye
    - Injected in to CVL and measured from a-line through a densitometer to get area under concentration decay curve

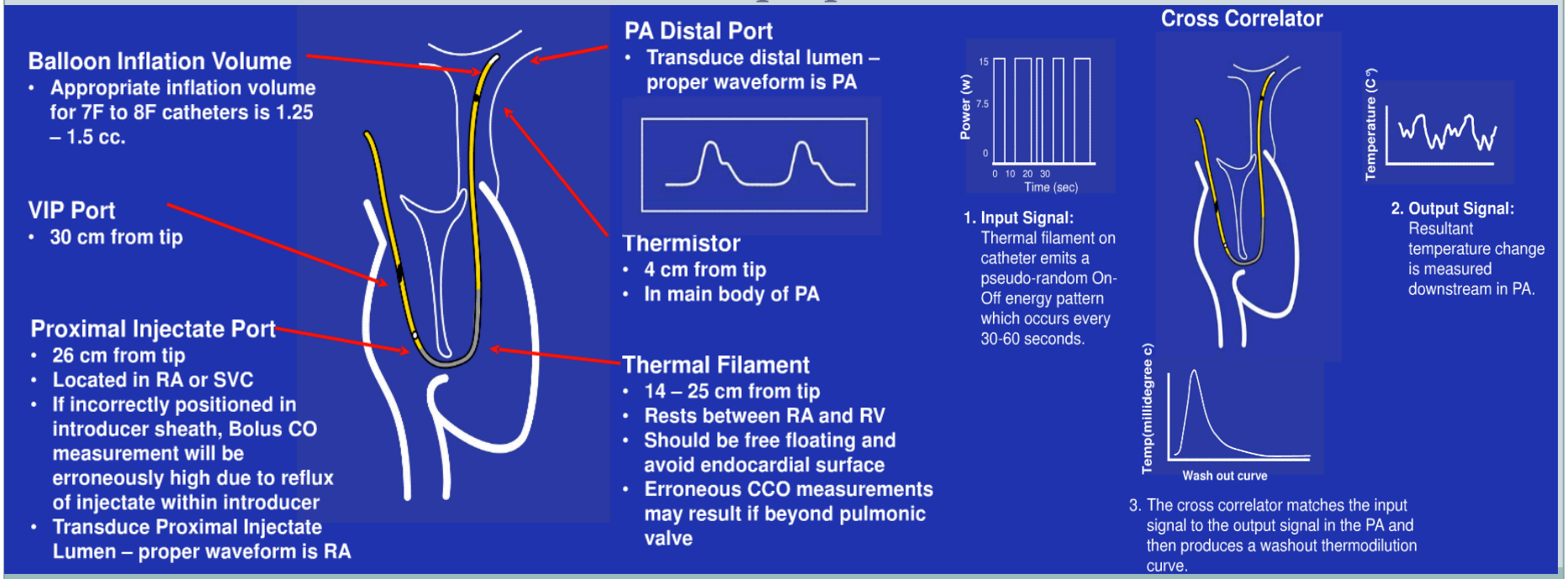
Measuring CO: Thermodilution

- Modification of dye dilution
- A known amount of a known temperature solution is injected proximally in PAC and temperature change is measured downstream



Continuous Cardiac Output

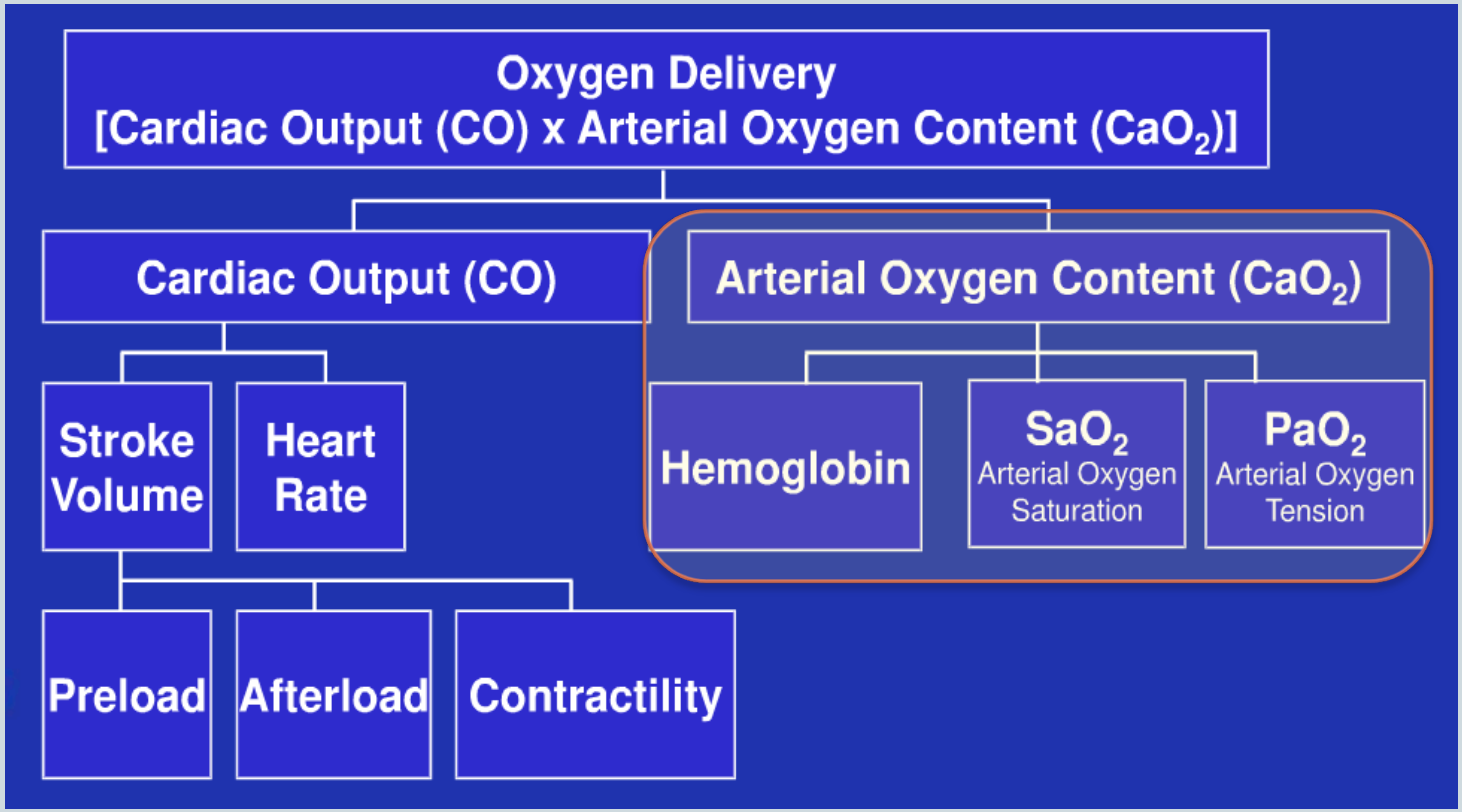
- Same principle as bolus thermodilution
  - Warm bolus instead of cold bolus
  - Multiple varying "sized" boluses given continuously and averaged over a minute then averaged over a 10 minute period
  - Area under washout curve still proportional to CO



“Rules” for Thermodilution CO

- Forward flow
- Adequate mixing of blood and injectate
- A difference between injectate and PA blood temp
- Steady PA temp
  - Take care with concurrent fluid administration
  - Ventilator cycle
  - Movement
  - Changes in venous return
- Limitations:
  - Intracardiac shunts
  - Tricuspid and pulmonic regurgitation

Now to the other side of Oxygen Delivery



Arterial Oxygen Content

- Blood O_2 Content (CO_2)

  = O_2 dissolved + O_2 bound to Hb

  (.0031 x PO2) (1.38 x Hb x SO2)

  2% 98% of oxygen in blood

  O_2 solubility coefficient

  mL of O_2 bound by 1 g of Hb

- CaO_2 = 1.38 x Hb x SaO_2 = 1.38 x 15 x 97% = 20.1 mL / dL
- CvO2 = 1.38 x Hb x SvO_2 = 1.38 x 15 x 75% = 15.5 mL / dL
-

Blood Oxygen Content

- $CaO_2 = 1.38 \times Hb \times SaO_2$

  $= 1.38 \times 15 \times 97\%$

  $= 20.1$ mL / dL

- $CvO2 = 1.38 \times Hb \times SvO_2$

  $= 1.38 \times 15 \times 75\%$

  $= 15.5$ mL / dL

Oxygen Transport

- Arterial O2 Transport = CO x CaO_2 x 10

  = 5 x 20.1 x 10

  = 1005 ml O_2/min

- Venous O2 Transport = CO x CvO_2 x 10

  = 5 x 15.5 x 10

  = 775 ml O_2/min

Oxygen Consumption

- VO_2 = Arterial Oxygen Transport – Venous Oxygen Transport
  = (CO x CaO2 x 10) – (CO x CvO2 x 10)
  = CO (Hb x SaO2 x 13.8) – CO (Hb x SvO2 x 13.8)
  = CO x Hb x 13.8 x (SaO2 – SvO2)

- This is simply a restatement of the Fick Equation for CO
- For a normal person O_2 consumption is 230 ml/min
  - 1005 ml O_2/min – 775 ml O_2/min = 230 ml O_2/min

Compensatory Mechanisms

- Increase in CO
  - Can increase about 3x in healthy adults
  - ~5 L/m to ~15 L/m
- Increase in Oxygen extraction by tissues
  - Normally 25%
  - Can increase to near 70%
- $VO_2 = CO \times Hb \times 13.8 \times (SaO_2 - SvO_2)$

  2050 15 15 .97 .31 (66%)
- What happens when compensatory mechanisms exhausted? *Lactic acid* production.

Specific Insults

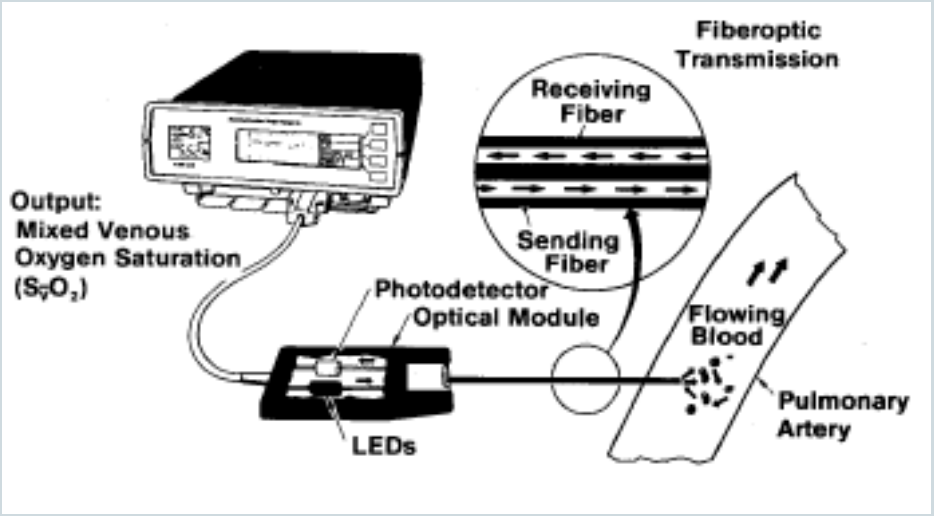
- Increased oxygen demand (VO_2) – fever, shivering, seizure
  - $VO_2 = CO \times Hb \times 13.8 \times (SaO_2 - SvO_2)$
    $= \mathbf{15} \times 15 \times 13.8 \times (.97 - \mathbf{.31}) = 2049$ ml O_2/min
- Decrease in hemoglobin
  - $VO_2 = CO \times Hb \times 13.8 \times (SaO_2 - SvO_2)$
    $= \mathbf{15} \times 1.7 \times 13.8 \times (.97 - \mathbf{.31}) = 232$ ml O_2/min

Specific Insults

- Decrease in SaO_2
  - VO2 = CO x Hb x 13.8 x (SaO2 - SvO2)
    = **15** x 15 x 13.8 x (.38 – **.31**) = 217 ml O2/min
- Decrease in Cardiac Output
  - VO2 = CO x Hb x 13.8 x (SaO2 - SvO2)
    = 1.7 x 15 – x 13.8 x (.97 – **.31**) = 232 ml O2/Min

How do we monitor SVO_2

- Measure in pulmonary artery
  - Ensures adequate mixing
  - Make sure PAC not wedged as this will artificially increase SVO_2
- Technology is similar to pulse oximetry
  - Reflection spectrophotometry
  - 2 wavelengths of light
- Must be calibrated to Hb level



SVO_2 Changes

High SvO_2

↑ Oxygen delivery

↑ FIO_2 Hyperoxia

↓ Oxygen demand Hypothermia

Anesthesia
Pharmacologic paralysis

Low SvO_2

↓ Oxygen delivery

↓ Hb Anemia, hemorrhage
↓ SaO_2 Hypoxia, suctioning
↓ CO Hypovolemia, shock
Arrhythmias

↑ Oxygen demand

Hyperthermia, pain
Shivering, seizures