Calculations the Cardiac Cath Lab

Thank You to:
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Darren Powell RCIS, FSICP
Wes Todd, RCIS
CardioVillage.com
## Disclosures

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<tr>
<td><strong>Speaker’s Bureau:</strong></td>
<td><strong>Stockholder:</strong></td>
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<td>• None</td>
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<td><strong>Honorarium:</strong></td>
<td><strong>Grant/Research Support:</strong></td>
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Introduction

• Angiography shows a part of the patients picture, but we need to know the **WHOLE** picture
• Calculations and hemodynamic information completes that picture
Who Likes Math???
Hemodynamics/Calculations

Condition 1:

Height: 68.0 in. 172.7 cm. Weight: 177.0 lbs. 80.4 kg. BSA: 1.94

<table>
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<th>Pressure</th>
<th>Rate</th>
<th>dPdT</th>
<th>Avg. SaO2</th>
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<td>UD2:</td>
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Calculations done with: Flick

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<th>Valves</th>
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Consumption: 221.4 ml/min
Capacity: 153.7 ml/L
Hemoglobin value: 11.3 gm/dL
Overview

- Cardiac Outputs / Cardiac Index
- Fick, Thermodilution, Angiographic
- Regurgitant Fraction
- Mean Arterial Pressures
- Vascular Resistance
- Valve Areas
Cardiac Output = CO

- CO is the blood flow out of the heart in L/min

- Normal CO is 5 L/min (CI=2.5-4.0 L/min/ M²)

- Qs is SBF (systemic Blood Flow) = 5 L/min

- Qp is PBF (Pulmonic Blood Flow) = 5 L/min

- Qp:Qs Ratio (5:5) = 1:1
Cardiac Output

- Assuming a heart rate of 80 and a stroke volume of 85cc’s what is the cardiac output?
  - CO = HR x SV
  - CO = 80 x 85cc’s
  - CO = 6,800 cc’s per minute
  - CO = 6.8 liters per minute
- Normal CO = 4.0 – 8.0 liters per minute
Cardiac Index: (CI) Standardizes cardiac output for body size

Both of these people’s hearts pump 3 liters of blood per minute.

Who feels better?

The smaller one! Why?

Less body surface area.
Cardiac Index = CI

- CI = CO/BSA
- BSA Nomogram
- CI = 6.8 lpm/2.0M²
- CI = 3.4 lpm/M²
- Normal CI = 2.5-4.0 lpm/M²
Cardiac Output: (CO) Measurement of how much blood is ejected by the left ventricle \textit{each minute}. There are three methods to calculate cardiac output.

\begin{itemize}
  \item Angiographic
  \item Fick
  \item Thermodilution
\end{itemize}

All three can be determined in the cath lab.
Angiographic Stroke Volume: (SV) Amount of blood ejected by LV during each contraction

- SV can be calculated using the formula, $SV = EDV - ESV$. End Diastolic Volume and End Systolic Volume must be calculated by using quantitative measurements of the LV angiography.

- Average Stroke Volume for adults is 70 ml.
Angiographic Cardiac Output

- SV = LVEDV - LVESV
- SV = 148 – 84
- SV = 64 cc’s

- If HR is 80
- CO = HR x SV
- CO = 80 x 64
- CO = 5,120 cc’s or 5.12 LPM

- EF% = SV/LVEDV
- EF% = 64/148
- EF% = 43%
Fick Cardiac Output

- Fick cardiac output calculation is considered the “gold standard” for determining cardiac output
- Fick CO requires knowing the oxygen consumption or $\text{VO}_2$
- Fick CO is calculated using blood oxygen content $\text{CaO}_2$ and $\text{CvO}_2$
Fick CO

• Draw at least 2 blood samples
• Analyze the blood for O2 content / O2 Sat.
• Measure or estimate O2 consumption…
Oxygen Consumption  \( \text{VO}_2 \)

- Measure resting \( \text{O}_2 \) uptake = (basal metabolic rate)

- Estimate by formula:
  \[- \text{VO}_2 = 125 \times \text{BSA} \]

- Normal \( \text{VO}_2 = 125 \times 2 = 250 \text{ ml O}_2/\text{min} \ldots \]
Cardiac Output (CO)

Arterial O\(_2\) Content

\( \text{CaO}_2 = 20 \text{ Vol } \% \)

Oxygen Consumption

\[
\frac{\text{CaO}_2 - \text{CvO}_2}{10}
\]

20 ml O\(_2\)

100 ml blood

Hgb O\(_2\) Saturation color

100% 90 80 70 60 40 % sat

CS
Venous $O_2$ Content

$CvO_2 = 15 \text{ Vol} \%$

Cardiac Output (CO)

Oxygen Consumption

\[
\frac{(CaO_2 - CvO_2)}{10}
\]

15 ml O2

100 ml blood

Hgb $O_2$ Saturation color

100% 90 80 70 60 40 % sat

CS
Fick CO

- Fick CO = \frac{O_2 \text{ Consumption}}{\text{ml/min}} = \text{L/min}

(CaO_2 - CvO_2 \text{ difference}) \times 10

AO & PA blood is used if no shunt is present. Best mixed...

- Fick CO = \frac{250}{\text{ml/mi}} = \frac{250}{50} = 5 \text{ L/min}
Fick Equation

- Gold standard; developed by Adolph Fick
  \[ CO = \frac{\text{O}_2\text{ consumption (VO}_2\text{)}}{\text{(CaO}_2 - \text{CvO}_2)} \times 10 \]

- \( \text{CaO}_2 = (1.36 \times \text{Hb} \times \text{SaO}_2) + .003 \times \text{PaO}_2 \)
- \( \text{CvO}_2 = (1.36 \times \text{Hb} \times \text{SvO}_2) + .003 \times \text{PvO}_2 \)
- \( \text{VO}_2 = 125 \times \text{BSA} \)
A-V Difference

• a-vDO2 varies inversely with CO b/c the greater the blood flow, less O2 is removed per unit of blood and the smaller the gradient of a-vDO2

• as blood flow decreases, O2 removed by tissues increases so blood returning to the heart is < saturated thus the wider the gradient of a-vDO2
A-V Difference

Lower C(a-v)O2 values
• well oxygenated blood moves rapidly thru the cap. - high CO
• Septic shock - cells extract less oxygen

Higher C(a-v)O2 values
• low CO - slow blood flow
• increased VO2 - tissue extraction
Oxygen Content Volume %

- When calculating the Fick Cardiac Output, you must determine the content (vol %) of oxygen in arterial and mixed venous blood and determine oxygen consumption.

\[
\text{CaO}_2 = 1.36 \times \text{Hgb} \times \text{SaO}_2 + (.003 \times \text{PaO}_2)
\]

\[
\text{CvO}_2 = 1.36 \times \text{Hgb} \times \text{SvO}_2 + (.003 \times \text{PvO}_2)
\]

Calculating Oxygen Content Volume %

\[
\text{CaO}_2 = 1.36 \times \text{Hgb} \times \text{SaO}_2
\]
\[
\text{CaO}_2 = 1.36 \times 13 \times 0.98
\]
\[
\text{CaO}_2 = 17.3 \text{ vols%}
\]

- 17.3 cc’s O\(_2\)/100cc’s blood or
- 173 cc’s O\(_2\)/liter of blood

Patient Information
Hct: 39%
Hgb: 13
SaO\(_2\): 98%
SvO\(_2\): 61%
Fick CO using VO₂
Assumption and O₂ Saturation

Patient Information
Predicted O₂ = 125ml/min/M²
Hgb = 13 Gm.
BSA = 2.0 M²
AO blood = 98% O₂ Sat
PA blood = 61% O₂ Sat

Assumed VO₂ = 125 x 2.0 = 250ml O₂/min
CaO₂ = 1.36 x 13 x 0.98 = 17.3 vols%
CvO₂ = 1.36 x 13 x 0.61 = 10.8 vols%

Fick CO = \( \frac{250}{(17.3 - 10.8) \times 10} = \frac{250}{65} = \)

Fick CO = 3.85 LPM
Cardiac Output

- CO fick = 3.85 LPM (HR=80)
  - SV = 3850/80
  - SV\(_{\text{fick}}\) = 48 cc’s

- CO angio = 5.12 LPM (HR=80)
  - SV = 5120/80
  - SV\(_{\text{angio}}\) = 64 cc’s
Mitral Regurgitation

- Leakage of blood across a closed mitral valve during ventricular systole
Regurgitant Fraction

• Cardiac Output
  – RF % = CO angio – CO fick / CO angio

• Stroke Volume
  – RF % = SV angio – SV fick / SV angio
Regurgitant Fraction using CO

Patient Information
Fick
CO = 3.85 LPM
SV = 48 cc’s

Angio
CO = 5.12 LPM
SV = 64 cc’s

RF % = CO angio – CO fick / CO angio
RF % = 5.12 – 3.85 / 5.12
RF % = 1.27 / 5.12
RF % = 25%
Regurgitant Fraction using SV

Patient Information
Fick
CO = 3.85 LPM
SV = 48 cc’s

Angio
CO = 5.12 LPM
SV = 64 cc’s

RF % = SV angio – SV fick / SV angio
RF % = 64 – 48 / 64
RF % = 16 / 64
RF % = 25%
Green Dye Cardiac Output

• Central line - injecting port
• Densitometer - device that sends a light beam thru blood to photocell in cuvette
• arterial line - simultaneous withdrawal
• 5 mg Cardiogreen dye - injecting dye
Fig. 13-7 Dye-dilution cardiac output measurement.
Green Dye Cardiac Output

• Cardiac Output is inversely proportional to the area under the curve
  • wider curve - lower CO
  • narrower curve - high CO
Thermodilution CO

Iced or room temperature saline is injected into the CVP/RA port.

It flows through the RV and cools the thermistor in the PA.

The rate and degree at which it cools measures CO…
Thermodilution CO Equipment

Swan-Ganz thermodilution catheter

3 TDCO curves averaged...
Calculate TDCO

\[
TDCO = \frac{(\text{Temperature Diff.}) \times C}{\text{Area under TDCO curve}}
\]
Thermodilution Cardiac Output

• Introduced in 1954-became widely accepted in the early 1970’s
• Utilizes known temperature as the indicator
  – PA blood temperature is measured
  – Change in PA blood temperature over time is inversely proportionate to the blood flow
• the detected temp. change is ~= to the flow rate (CO) and the change in indicator temp. over time
• only measures right heart output so its not accurate when an intra-cardiac shunt, tricuspid regurgitation and low output syndrome
Requires a Thermodilution PA catheter

- 10 or 5 cc of fluid is injected into the CVP proximal hub into the right atrium
- temperature change is detected by a thermistor bead at the end of the catheter in the pulmonary artery
- resultant change in blood temperature is plotted, producing a curve
Thermodilution Cardiac Output

- D5W or NSS
- Cold or room air solution
- average of 2 to 3 injections
- Injection must be timed with the respiratory cycle (optimally during expiration)
- essential to have a rapid and even injection technique
- discard any irregular waveforms
Thermodilution Cardiac Output

• Low Cardiac Output
  Slow prolonged down slope, large area under curve

• High Cardiac Output
  rapid, shorter down stroke, small area under the curve
Brain Overload???
Systemic Vascular Resistance

- The measurement of left ventricular afterload
- Normal SVR is between 900 and 1440 dynes/sec/cm$^{-5}$
- SVR may be increased by aortic valve stenosis, elevated blood pressure or polycythemia
- SVR is decreased with the use of vasodilators.
Vascular Resistance

Normal SVR:
900 - 1440 dynes/sec/cm²

Normal PVR:
30 - 180 dynes/sec/cm²
Calculate Systemic Vascular Resistance

$$\text{SVR} = \frac{(\text{AO} - \text{RA})}{\text{CO}} = \frac{80-5 \text{ mmHg}}{5 \text{ L/min}}$$

Normal SVR = 15 mmHg/L/min

Also termed “hybrid” units or “Wood” units…

Normal SVR hybrid units $\times$ 80 = SVR dyne cm sec$^{-5}$

Normal SVR = 1200 dsc$^{-5}$
Systemic Vascular Resistance

- $\text{SVR} = \frac{\text{MAP} - \text{CVP}}{\text{CO}} \times 80$
- Normal = 900-1440 dynes/sec/cm
- BP=120/80, CVP=4 CO=5.0 lpm
- MAP = $\frac{2 \times 80 + 120}{3}$
  - $=280/3$
  - $=93 \text{ mmHg}$
- $\text{SVR} = \left[\frac{93 - 4}{5}\right] \times 80$
  - $=(89/5) \times 80$
  - $17.8 \text{ mmHg/L/min}$
  - $17.8 \times 80$
  - $1424 \text{ dynes.sec/cm}$
Calculate Vascular Resistance

\[ PVR = \frac{\text{PA mean} - \text{PCW mean}}{\text{CO L/min}} \]
Pulmonary Vascular Resistance

- PVR = [(MPA - PCWP)/CO] x 80
- Normal = 30-180 dynes/sec/cm-5
- BP=25/8, PCWP=6 CO=5.0 lpm
- MAP = (2x8 + 25)/3
  - =41/3
  - =14 mmHg
- SVR = [(14-6)/5] x 80
  - =(8/5) 80
  - 1.6 mmHg/L/min
  - 1.6 x 80
  - 128 dynes.sec/cm-5
Vascular Resistance

Normal SVR:
900 and 1440 dynes/sec/cm$^{-5}$

Normal PVR:
30-180 dynes/sec/cm$^{-5}$

$SVR = \frac{AO_{mean} - RA_{mean}}{CO} \times 80$

$PVR = \frac{PA_{mean} - PW_{mean}}{CO} \times 80$
I Know it’s Painful…
Valve Areas

- **Aortic**
  - Normal $2.5-4.0 \text{ cm}^2$
  - Critical $\leq 0.7 \text{ cm}^2$
- **Mitral**
  - Normal $4.0-6.0 \text{ cm}^2$
  - Critical $\leq 1.0 \text{ cm}^2$

**Formulas**

- Gorlin requires constants (gold standard)
- Hakki (quick and easy)
Valve Calculations

- The Gorlin formula is:

\[
AVA = \frac{CO \text{ (in cc's)}}{\text{sep} \times HR} \\
44.3 \times \sqrt{\text{MEAN GRADIENT}}
\]

- sep is calculated by measuring at 100 mm/sec. paper speed
The Hakki Formula

- The Hakki formula is:

$$AVA = \frac{\text{Cardiac Output}}{\sqrt{\text{P}k \text{ to } \text{P}k \ \text{GRADIENT}}}$$

If $CO = 5 \ \text{L/M}$ and gradient is 49 mm Hg then:

$$\text{Hakki} = \frac{5}{7} = 0.7 \ \text{cm}^2$$
What is SEP?

SEP: **Systolic Ejection Period.**
It is measured from the time the semilunar valves open, and ventricular contraction propels blood into the great arteries, to the point of when the semilunar valves close.
\[ \text{CO} \times 1000 \div \left( \text{sep} \times \text{HR} \right) \]

\[ 44.3 \times \sqrt{\text{MEAN GRADIENT}} \]

\[
\begin{align*}
4.3 \times 1000 &= 4300 \\
.22 \times 95 &= 20.9 \text{ sec} \\
\sqrt{40} &= 6.3 \\
44.3 \times 6.3 &= 279.1
\end{align*}
\]

\[ \frac{4300}{20.9} = 205.7 \text{ cc's/sec} \]

\[ 205.7 \div 279.1 = 0.7 \text{ cm}^2 \text{ AVA} \]

\[
\begin{align*}
\text{CO} &= 4.3 \text{ L/min} \\
\text{HR} &= 95 \text{ beats/min} \\
\text{sep} &= .22 \text{ sec/beat} \\
\text{mean gradient} &= 40 \text{ mmHg}
\end{align*}
\]
Patient Information:
CO=4.3 lpm, sep = .22 sec/beat, HR = 95, mean gradient = 40 mmHg

AVA= \[ \frac{CO \times 1000}{sep \times HR} \]
\[ 44.3 \times \text{sq. root pressure gradient} \]

AVA= \[ \frac{4.3 \times 1000}{.22 \times 95} \]
\[ 44.3 \times \text{sq. root of 40} \]

AVA= \[ \frac{4300 \text{cc’s}}{20.9 \text{ sec/min}} \]
\[ 44.3 \times 6.3 \]

AVA= \[ \frac{205.7 \text{ cc’s/sec}}{279.1} \]

AVA = 0.7 cm²
Measurement of SEP

The sep is measured on the EKG paper by marking the time lines. 1 small box = 4mm, counting the number of boxes, multiplying that number by the heart rate, and dividing by paper speed.
AVA = Aortic Valve Flow
44.3 X \sqrt{P1-P2}

- What is P1 and P2?
  - P1 = LV systolic pressure
  - P2 = AO systolic pressure
    - LV systolic = 200
    - AO systolic = 120
    - 200 - 120 = 80
  - 80mmHg is the gradient
Mitral Valve The Gorlin Formula

• The Gorlin formula is:

\[ \text{MVA} = \frac{\text{CO (in cc’s) } \times 1000}{\{\text{dfp x HR}\}} \]
\[ 37.7 \times \sqrt{\text{MEAN GRADIENT}} \]

• 37.7 is a constant
• dfp is calculated by measuring at 100 mm/sec. paper speed
What Is DFP?

DFP: **Diastolic Filling Period.**

The diastolic filling period begins at mitral valve opening and ends at end diastole. It is measured between the initial PCW-LV crossover and the end diastole.

www.healthworksonline.cfm
\[
\frac{\text{CO} \times 1000}{\{\text{dfp} \times \text{HR}\}} = 37.7 \times \sqrt{\text{MEAN GRADIENT}}
\]

\[
\begin{align*}
6.3 \times 1000 &= 6300 \\
\text{6300} / 38.22 &= 164.84 \text{ cc’s/sec} \\
.39 \times 98 &= 38.22 \text{ sec} \\
\sqrt{15} &= 3.872 \\
37.7 \times 3.872 &= 145.97 \\
164.835 / 147.136 &= 1.1 \text{ cm}^2 \text{ MVA}
\end{align*}
\]

CO = 6.3 L/min  \quad \text{HR} = 98 \text{ beats/ min.}

mean gradient = 15 mmHg  \quad \text{dfp} = .39 \text{ sec/beat}
Patient Information:
CO = 6.3 lpm, dfp = .39 sec/beat, HR = 98, mean gradient = 15 mmHg

MVA = \[ \frac{\text{CO} \times 1000}{\text{dfp} \times \text{HR}} \times \text{37.7} \times \text{sq. root pressure gradient} \]

\[ \text{MVA} = \frac{6.3 \times 1000}{.39 \times 98} \times 37.7 \times \text{sqrt}(15) \]

\[ \text{MVA} = \frac{6300 \text{cc's}}{38.2 \text{ sec/min}} \times 37.7 \times 3.87 \]

\[ \text{MVA} = \frac{164.8 \text{ cc's/sec}}{145.9} \]

\[ \text{MVA} = 1.1 \text{ cm}^2 \]
Shunts

- $Q_p$ is PBF (Pulmonic Blood Flow) = 12 L/min
- $Q_s$ is SBF (systemic Blood Flow) = 4L/min
- $Q_p:Q_s$ Ratio (12:4) = 3:1
- Absolute shunt (PBF-SBF) 12-4=8 lpm
- % shunt (PBF-SBF/PBF) 12-4/12 8/12=67%
Shunts

Mixed Venous Blood—normally found in PA.

If shunt use Flamm equation

\[ \text{SvO}_2 = \frac{3(\text{SVC}) + 1(\text{IVC})}{4} \]

\[ \text{SBF or } Q_s = \frac{\text{O}_2 \text{ consumption (VO}_2\text{)}}{(C_a \text{O}_2 - C_{mv} \text{O}_2) \times 10} \]

\[ \text{PBF or } Q_p = \frac{\text{O}_2 \text{ consumption (VO}_2\text{)}}{(C_{pv} \text{O}_2 - C_{pa} \text{O}_2) \times 10} \]
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