Cardiac Output Measurement

Key Points
Cardiac Output Measurement:
- understand $BP = Q \times VR$
- know the meaning of Ejection Fraction
- what is the healthy range?
- methods of measurement
  - oxygen uptake
  - dye dilution
  - Thermodilution
- know the application of the Swan-Ganz catheter for thermodilution
- understand the path of the P-A catheter (Pulmonary Artery, from heart to lung)
- in thermodilution, understand the relation of injectate volume and flow rate
- history: originally cold injectate, then room temp, now a heated filament
- be familiar with Body Surface Area and the ‘rule of 9s’
- know how BSA is different from BMI
- what are the possible sources of error in CO measurement?
Electronic analog of the vascular system

Ohm’s Law
\[ V = I \times R \]

BP = Q x VR

Ejection Fraction (“EF”):
The proportion of the ventricular volume that is actually pumped out with each systole.

(EDV is the amount of blood in the ventricles just before systole)

\[ F_e = \frac{\text{Stroke Volume}}{\text{End Diastolic Volume}} \]

Example for a resting adult male = \[ \frac{70 \text{ mL}}{120 \text{ mL}} = .58 \text{ or } 58\% \]

<table>
<thead>
<tr>
<th>Ejection Fraction Measurement</th>
<th>What It Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-70%</td>
<td>Normal</td>
</tr>
<tr>
<td>40-50%</td>
<td>Below Normal (borderline)</td>
</tr>
<tr>
<td>Less than 40%</td>
<td>May confirm diagnosis of heart failure</td>
</tr>
<tr>
<td>&lt;35%</td>
<td>Patient may be at risk of life-threatening irregular heartbeats</td>
</tr>
</tbody>
</table>
Factors Influencing Cardiac Output – Heart Rate and Stroke Volume

Factors Affecting Heart Rate (HR)
- Autonomic innervation
- Hormones
- Fitness levels
- Age

Factors Affecting Stroke Volume (SV)
- Heart size
- Fitness levels
- Gender
- Contractility
- Duration of contraction
- Preload (EDV)
- Afterload (resistance)

Heart Rate (HR)

Stroke Volume (SV) = EDV – ESV

Cardiac Output (CO) = HR × SV

http://cnx.org/content/col11496/1.6 Anatomy & Physiology

Cardiac Output Determination by Oxygen Uptake: (The Fick Method)
(slow; good for research)

\[
\text{Oxygen uptake} = \frac{250 \text{ mll/min}}{(20-15 \text{ mll} \ O_2/100 \text{ ml Blood})}
\]

\[
\text{CO} = \frac{250 \text{ mll} \ O_2/\text{min}}{5,000 \text{ mll Blood/\text{min}}}
\]

Determining Cardiac Output by Thermodilution:

The Swan-Ganz Catheter:
A pulmonary artery ("PA") catheter that includes a balloon at its tip and a thermistor 10 cm from the tip.
Access points for insertion of pulmonary artery catheters:

Basic Swan-Ganz Pulmonary Artery Catheter:

Cross-section:
5 lumens:
- Distal port
- Proximal port
- Right Ventricle port
- Balloon
- Thermocouple

Final position of the P-A catheter for monitoring:

Cardiac output by thermodilution:
Cold saline injectate to create a temperature shift
(normal blood temp 37° C)
Bolus of ‘cold’ injectate passes by the temperature sensor, creating a shift in the time-temperature curve:

(Note the inverted temperature scale)

Same action, different injectate volume:

Same action, different injectate volume and different flow rate:
Typical time-temp curve for an ideal cardiac output determination:

Cardiac output is determined as the area under the curve, with corrections for the tail of the curve.

Cardiac output: what does the graph tell us?

Typically, 10 mL of sterile saline is injected at room temperature, into a P-A catheter. The sensor in the catheter detects the temperature shift.

Three measurements are usually taken to get a valid average.

The monitor stores the values and the waveforms in memory for recall.
Sources of error in CO determinations:
- inconsistent injection
- respiratory interference
- motion artifact

Thermodilution Cardiac Output Equation:
\[
V_{\text{inj}} \times (T_{\text{inj}} - T_{\text{blood}}) \times C_{\text{inj}} \times D_{\text{inj}} \times F
\]
\[
\frac{C_{\text{blood}} \times D_{\text{blood}} \times T(\text{dt})}{C_{\text{blood}} \times D_{\text{blood}} \times T(\text{dt})}
\]
where:
- \( V \) = volume
- \( T \) = temperature
- \( C \) = specific heat (J/mL)  (heat to raise this material 1°C)
- \( D \) = density (gm/mL)
- \( F \) = computation constant for this specific S-G cath

Typical output for a resting adult male: ~5.0 l/m
Typical output for a resting adult female: ~4.5 l/m
Body surface area (BSA) :

The total surface area of the body

\[ BSA(m^2) = 0.007184 \times \text{weight (kg)}^{0.425} \times \text{height (cm)}^{0.725} \]

or:

\[ BSA(m^2) = \sqrt{\frac{\text{weight (kg)} \times \text{height (cm)}}{3600}} \]

note 'rule of nines' used to calculate severity of burns.

11 zones of 9% surface area each

disambiguation:

Body surface area (BSA)

- calculated from height and weight
- result is in square meters
- used to calculate cardiac output; severity of burns

Body mass index (BMI)

\[ BMI = \frac{\text{mass}_{\text{kg}}}{\text{height}_{\text{in}}^2} = \frac{\text{mass}_{\text{lb}}}{\text{height}_{\text{in}}^2} \times 703 \]

- calculated from height and weight
- result is in kilograms per square meter
- used to quantify over- and underweight conditions
Cardiac Index:
Cardiac Output divided by Body Surface Area

\[ CI = \frac{CO}{BSA} = \frac{SV \times HR}{BSA} \]

Useful way to reference cardiac output to the patient’s size (not weight).

Normal range of cardiac index = 2.6 to 4.2 L/min per square meter.

Test Equipment for Cardiac Output

Static Cardiac Output simulation:
Edwards ‘CCombo’ P-A cath for Continuous Cardiac Output + SvO₂:

> Creates a constant temperature shift in the pulmonary artery by means of a pulsed heated filament.
> Calculates cardiac output from the area under the averaged curves created by the temperature shifts
> ‘Vigileo’ Proprietary to Edwards Lifesciences Corp.
www.edwards.com/Products/PACatheters/CCOCatheter.htm

Continuous Cardiac Output by Pulse Contour Analysis:

(PICO, or PCCO)
NonInvasive Cardiac Output:
The Cheetah (NICOM) System - Uses impedance sensing during the cardiac cycle to derive cardiac output and fluid changes

An electric current of known frequency is applied across the thorax between the outer pair of sensors.
A signal is recorded between the inner pair of sensors.
The signal ideal is detected, causing a delay in the signal. The delay is proportional to the volume of blood, and the interaction is updated every 40 seconds.
This time delay, called the Phase Shift, is recorded, and the figure is inversely related to flow.

http://www.cheetah-medical.com/products/bioreactance