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Disclosure Statement of Financial Interest

I, Georgios Bompotis DO NOT have a financial interest/arrangement or affiliation with one or more organizations that could be perceived as a real or apparent conflict of interest in the context of the subject of this presentation.
HEMODYNAMIC COMPONENTS OF CARDIAC CATHETERIZATION PROCEDURES

- Pressure measurements
- Measurement of flow
- Determination of vascular resistances
PRESSURE MEASUREMENTS

• Accurate recording of pressure waveforms and correct interpretation of physiologic data derived from these waveforms

• A pressure wave is a cyclical force generated by cardiac muscle contraction and transmitted through a fluid medium

• A pressure wave pattern, duration and amplitude is influenced by various mechanical and physiologic parameters

• Pressure waveforms from a particular cardiac chamber are influenced by its contracting force, by its surrounding structures (contiguous chambers of the heart, pericardium, lungs, vasculature) and by physiologic variables (heart rate, respiratory cycle)
PRESSURE MEASUREMENTS SYSTEMS

• Typically pressure is measured with use of a fluid-filled catheter that is attached to a pressure transducer

• Micromanometer catheters which have the pressure transducer mounted at the tip can also be used
HEMODYNAMIC ASSESSMENT
COMMON SOURCES OF ERRORS OR INACCURACIES

• Improper transducer leveling, zeroing and calibration balancing

• Defective transducer or inadequately calibrated

• Connection and tubing problems

• Presence of marked tachycardia exceeding the frequency response of the system

• Mechanical ventilation and extreme changes in intrathoracic pressure
POTENTIAL SOURCES OF ERROR

• Catheter whip artifact: motion of the tip of the catheter within the measured chamber
• End-pressure artifact: end-hole catheter measures an artificially elevated pressure because of streaming or high velocity of the pressure wave
• Catheter impact artifact: catheter is struck by the walls or valves of the cardiac chambers
• Catheter tip obstruction: within small vessels or valvular orifices occurring because of the size of the catheter itself
NORMAL PHYSIOLOGY
WAVEFORM CHARACTERISTICS

The three basic waveforms

Atrial

Ventricular

Arterial
mmHg

Normal Cardiac Pressures
Right Atrial Pressure
RIGHT VENTRICULAR WAVEFORM

- Smaller pressure height than the thicker LV pressure waveforms but with characteristic features of ventricular waveforms

- Atrial contraction may cause the appearance of an a wave on the ventricular waveform at end diastole, which is not a normal finding, and is indicative of decreased compliance.
Pulmonary Capillary Wedge Pressure
Breakdown of Pressure

- **LA**
  - a wave
  - c wave
  - v wave

- **LV**
  - Isovolumetric Contraction
  - Rapid Ejection Period
  - Isovolumetric Relaxation
  - Rapid Ventricular Fill

- **AO**
  - Anacrotic notch
  - Rapid ejection period
Left Atrial Pressure Tracings

Waveforms & Meaning

- **a wave**
  - Atrial Systole

- **c wave**
  - Bulge of mitral valve subjected to ventricle in systole

- **v wave**
  - Left atrial fill during ventricular systole. Y descent with rapid ventricular fill
The reasons for tall left vs right atrial v waves

• Left atrium is relatively thick (thickness of RA -2mm, LA -3mm), stiff, less compliant chamber.

• Apart from relative thinness, right atrial volume is more hence it can accommodate more volume without raising its pressure.

• The left atrium is decompressed by the relatively stiff pulmonary veins and can not adequately dampen the refluxing tides of v waves, while the low pressure vena cava of RA dampen the right atrial v waves with ease.
Normal right- and left-heart pressures recorded from fluid-filled catheter systems in a human.

(From Pepine C, Hill JA, Lambert CR [eds]: Diagnostic and Therapeutic Cardiac Catheterization. 3rd ed. Baltimore, Williams & Wilkins, 1998.)
STENOTIC VALVE ORIFICE AREA
FUNDAMENTAL HYDRAULIC FORMULAS

• First hydraulic formula for determining the flow across a “rounded edge” orifice:
  \[ F = AVCc \]
  and by rearranging the terms \[ A = \frac{F}{VCc} \]

• The second hydraulic principle relates pressure gradient and velocity of flow:
  \[ V = k(2g\Delta P)^{1/2} \]

• Substituting for \( V \) in the orifice area equation and combining \( c \) and \( k \) into one constant \( C \):
  \[ A = \frac{F}{44.3C\sqrt{\Delta P}} \]
AORTIC VALVE AREA

• Flow across the aortic valve.

The flow value for calculating cardiac output in milliliters systolic ejection period times the heart rate (HR).
MITRAL VALVE AREA

- Mitral flow occurs only in account the diastolic filling calculated by the following
SIMPLIFIED VERSION OF GORLIN’S FORMULA FOR CALCULATING VALVE AREA

• The formula eliminates period, the diastolic heart rate and is:
DETERMINATION OF PRESSURE GRADIENTS IN AORTIC STENOSIS

Various methods of describing an aortic transvalvular gradient.
Pathophysiology of AS

- Pressure
- $P_{LVOT}$
- $\Delta P_{\text{max}}$
- $\Delta P_{\text{net}}$
- PR
- SBP
- Global Load
- $Z_{\text{va}} = \frac{SBP + \Delta P_{\text{net}}}{SVi}$

Valvular Load
Arterial Load

Catheterization
Doppler-echocardiography
Hemodynamic Differentiation of LVOT Obstruction

3 Differentiating features

a. Aortic upstroke
b. Pulse pressure
c. Contour – spike/dome
Acute DOE and Diastolic murmur
DETERMINATION OF PRESSURE GRADIENT IN MITRAL STENOSIS

Pressure gradient during diastole in mitral stenosis
Figure 5. LA pressure recorded from a patient with mitral regurgitation. Note: The a-waves and the v-waves are both significantly increased; however, the v-waves are predominant.
CARDIAC OUTPUT

- **CARDIAC OUTPUT** is the rate that the heart pumps blood, in the forward direction, to the systemic circulation and is expressed in liters per minute.

- Cardiac output is often corrected for the patient’s size on the basis of the body surface area and expressed as **CARDIAC INDEX** (liters /minute/meter²) for comparison among patients.
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.
MEASUREMENT OF CARDIAC OUTPUT

- Most commonly used methods:
  Fick method
  Thermodilution method

- Less frequently used methods:
  Angiographic Cardiac Output
  Indicator-dilution method

- There is no completely accurate method for determining cardiac output in all patients. It’s estimated on the basis of...
FICK METHOD

• The Fick principle described by Adolph Fick in 1870 states that: the total uptake or release of a substance by an organ is the product of blood flow to the organ and the arteriovenous concentration difference of the substance.

• Fick method uses: a) the lungs as an organ and b) oxygen as the substance released to the blood.
Schematic illustration of flow measurement by the Fick principle.

FICK METHOD

• In the absence of a shunt, pulmonary blood flow equals systemic blood flow.

• Blood flow to the lungs can be calculated by Fick’s relationship:

\[
\text{Fick cardiac output (liter/min)} = \frac{\text{oxygen consumption (mL/min)}}{\text{A-VO}_2 \times 1.36 \times \text{Hgb} \times 10}
\]

A-VO2: arterial-venous oxygen saturation difference
Hgb: hemoglobin concentration (mg/dL)
Constant 1.36: oxygen-carrying capacity of hemoglobin (expressed in mL O2/g Hgb).
Oxygen consumption measurement

• The greatest source of measurement variability is in oxygen consumption
• In the original Fick Method expiratory gas samples were collected in a large bag during a specified period and so the quantity of oxygen consumed over time could be determined
• Currently oxygen consumption is quantified by use of a polarograph
• “Assumed” Fick Method is used in many laboratories in which the oxygen consumption index is assumed on the basis of the patient’s
Sources of error in the Fick Method

- Measurement not done at a steady state
- Assumed rather than the directly measured O2 consumption
- Improper collection of the mixed venous or arterial blood samples
- Migration of the pulmonary artery catheter to a “wedge” position
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
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 $\sim$ to the flow rate (CO) and the change in indicator temp. over time
- Only measures right heart output so it's not accurate when an intra-cardiac shunt, tricuspid regurgitation and low output syndrome
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...
Thermodilution cardiac output curves. A normal curve has a sharp upstroke after an injection of saline. A smooth curve with a mildly prolonged downslope occurs until it is back to baseline. The area under the curve is inversely related to the cardiac output. At low cardiac output, a prolonged period is required to return to baseline. Therefore, there is a larger area under the curve. In a high cardiac output state, the cooler saline injectate moves faster through the right side of the heart, and temperature returns to baseline more quickly. The area under the curve is smaller and the output is higher.
Calculate TDCO

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

• CO fick = 3.85 LPM (HR=80)
  – SV = 3850/80
  – SV_{fick} = 48 cc’s

• CO angio = 5.12 LPM (HR=80)
  – SV = 5120/80
  – SV_{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 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%
Indicator-Dilution Method for Cardiac Output Determination

- The disparity between the Fick Method and indicator-dilution measurements is greater than the disparity between Fick and thermodilution measurements.

- This technique has essentially been abandoned by clinicians and is primarily of historical interest.
Vascular Resistance Definitions

Systemic vascular resistance

\[
SVR = \frac{Ao - RA}{Qs}
\]

Pulmonary vascular resistance

\[
PVR = \frac{PA - LA}{Qp}
\]

Normal reference values

<table>
<thead>
<tr>
<th>Woods Units</th>
<th>Metric Units</th>
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<tr>
<td>10 – 20</td>
<td>770 – 1500</td>
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<tr>
<td>0.25 – 1.5</td>
<td>20 – 120</td>
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</tbody>
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Woods Units x 80 = Metric Units

Vascular resistance Units and conversion

1. Vascular resistance \((R)\) in units (dyne-sec \(\cdot\) cm\(^{-5}\))

2. Hybrid resistance units in mmHg/Lt/min

3. There is no particular advantage
Vascular impedance

- Vascular impedance has been defined as the instantaneous ratio of pulsatile pressure to pulsatile flow.
- Vascular impedance measurements account for blood viscosity, pulsatile flow, reflected waves, and arterial compliance.
- Because the simultaneous pressure and flow data required for the calculation of impedance are complex and difficult to obtain, the concept of impedance has failed to gain widespread acceptance, and vascular impedance has not been adopted as a routine clinical index.
Interventions for the assessment of reversibility of vascular resistances

Elevated resistances in the systemic and pulmonary circuits may represent reversible abnormalities or may be permanent because of irreversible anatomic changes.

Interventions that may be used in the laboratory for this purpose include administration of vasodilating drugs (e.g., sodium nitroprusside), exercise, and (in patients with pulmonary hypertension) nitric oxide inhalation or intravenous epoprostenol, a pulmonary and systemic vasodilator.
Clinical application of Vascular resistance measurement

The concept of vascular resistance in its pure physical sense is limited in application. In the context of the clinical and physiological setting, however, pulmonary and systemic vascular resistances calculated from the hemodynamic measurements during cardiac catheterization have acquired empiric pathophysiological meaning and are often important factors in clinical decision making.

Grossmans 7th Edition  Chapter 8 William Grossman
Thank you!