CARDIAC OUTPUT MONITORING

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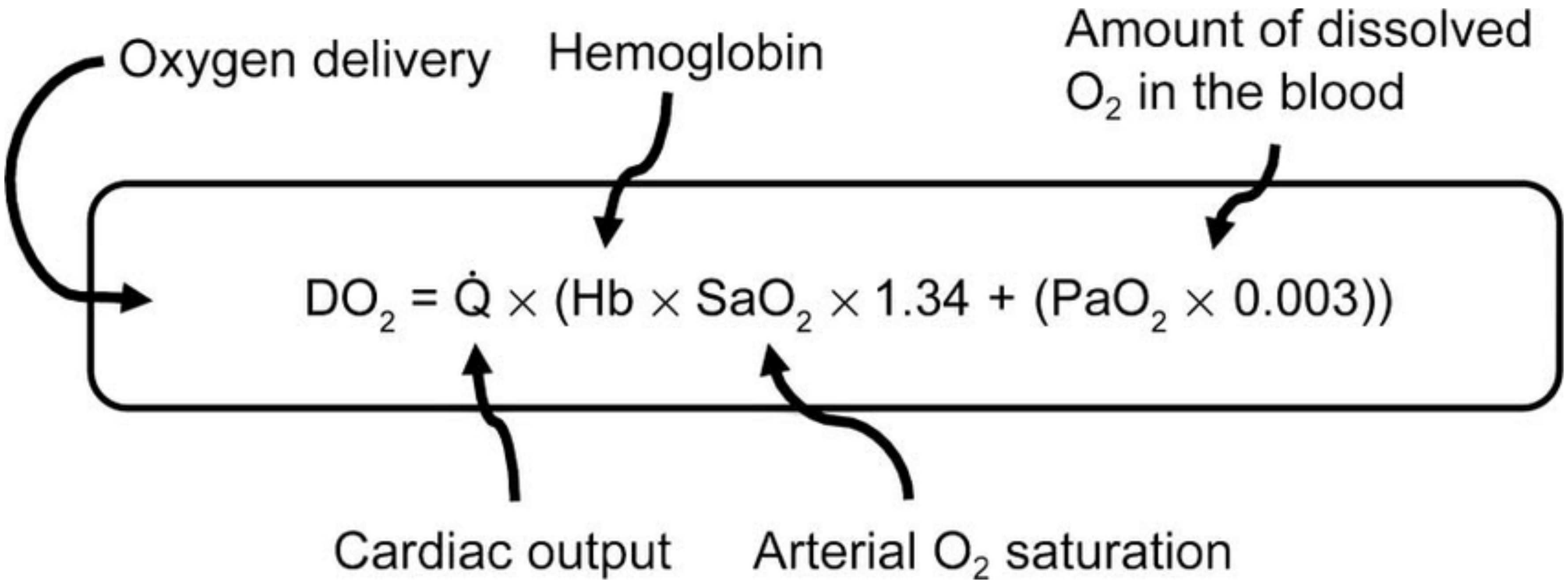
Sept

AGENDA

- Basics of cardiac output
- Arterial measurements
  - Non-invasive
  - Invasive
- Venous measurements

BASICS OF CARDIAC OUTPUT

OXYGEN DELIVERY



OXYGEN DELIVERY

Oxygen delivery

Hemoglobin

Amount of dissolved O_2 in the blood

$$DO_2 = \dot{Q} \times (Hb \times SaO_2 \times 1.34 + (PaO_2 \times 0.003))$$

Cardiac output

Arterial O_2 saturation

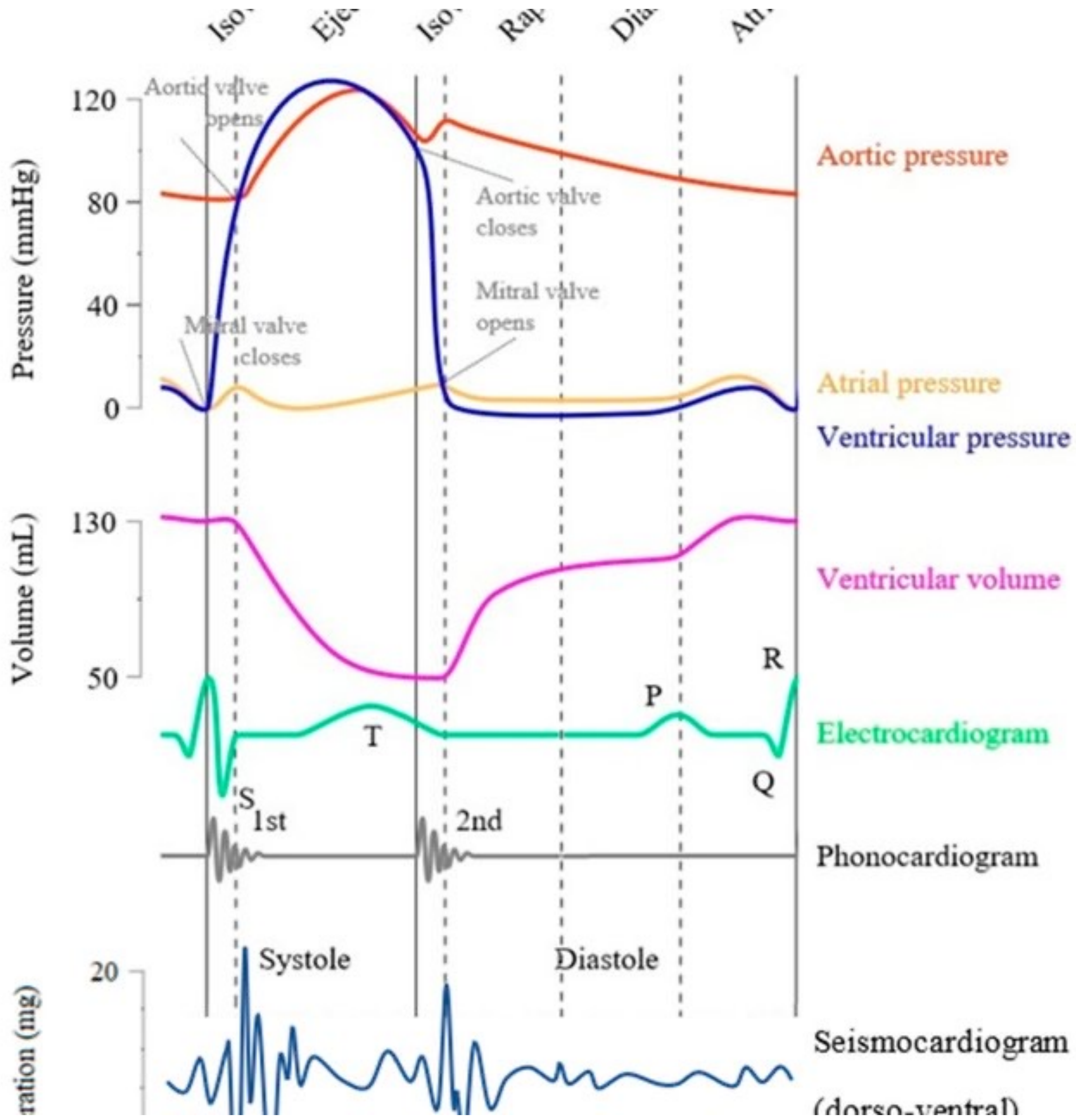
CARDIAC OUTPUT

- Cardiac output (Q)= SV x HR

- Ohm's law:
  - $\Delta P = Q \times R$
  - Arterial blood pressure= CO x SVR

BLOOD PRESSURE

- Mean Arterial Blood Pressure (MAP)
  - MAP= diastolic + $\frac{Pulse\ pressure}{3}$
    - Pulse pressure= systolic- diastolic



NON-INVASIVE MONITORING

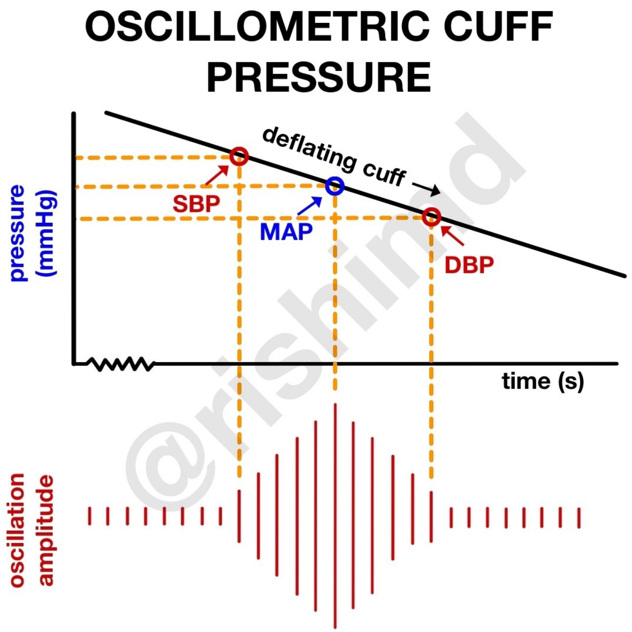
INDIRECT BLOOD PRESSURE MONITORING

Oscillometric

- Measures MAP
  - SBP and DBP are calculated

Doppler

- Measures SBP
  - MAP in cats?



BLOOD PRESSURE CUFF

ACVIM consensus statement: Guidelines for the identification, evaluation, and management of systemic hypertension in dogs and cats

Mark J. Acierno[1] | Scott Brown[2] | Amanda E. Coleman[2] | Rosanne E. Jepson[3] | Mark Papich[4] | Rebecca L. Stepien[5] | Harriet M. Syme[3]

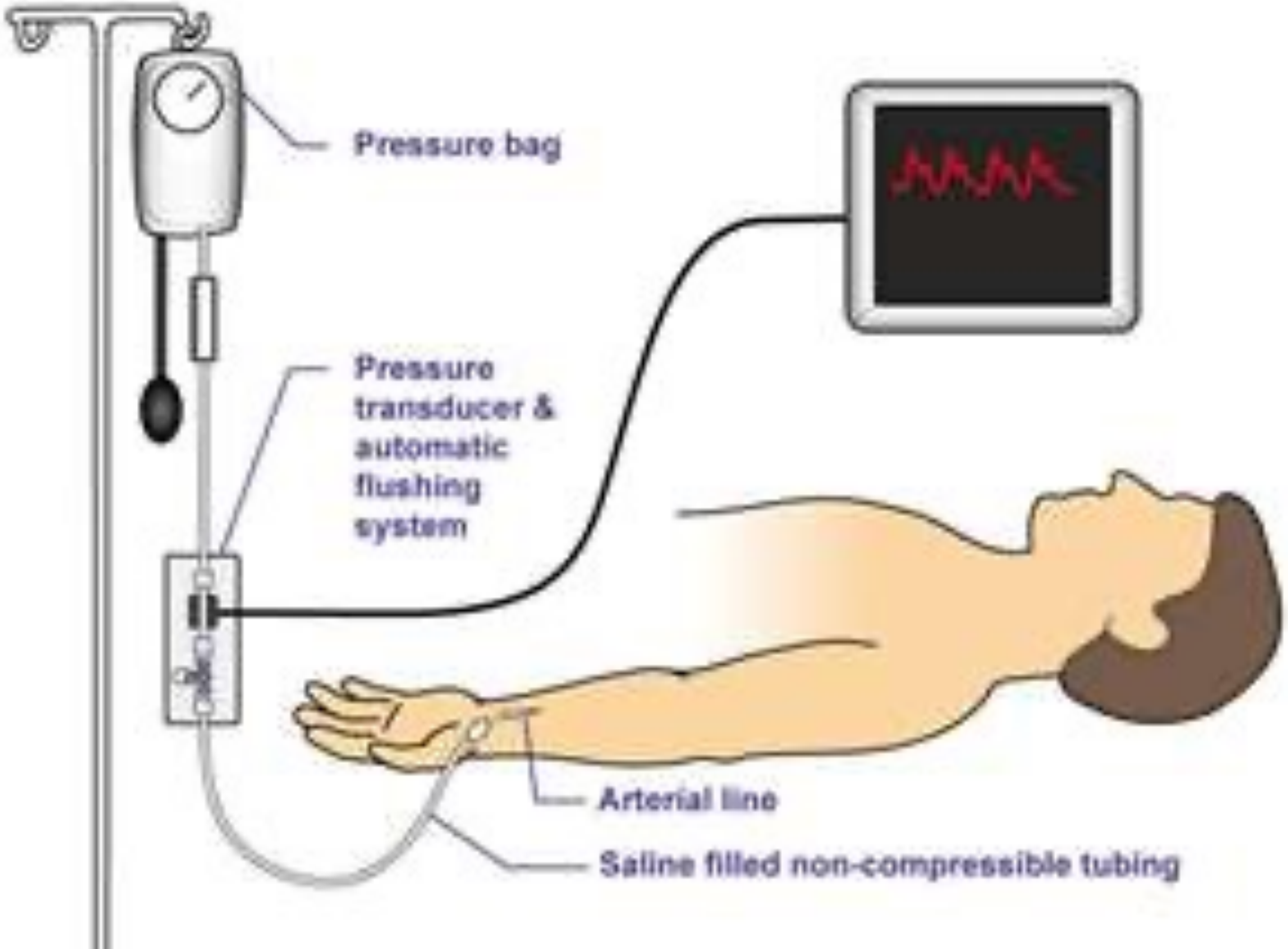
- Cuff width should be 30-40% the circumference of patient's limb
  - Smaller cuff= over-estimation of blood pressure
  - Larger cuff= under-estimation of blood pressure
- Cuff/limb should be at the level of the right atrium

TABLE 1 Protocol for accurate blood pressure (BP) measurement

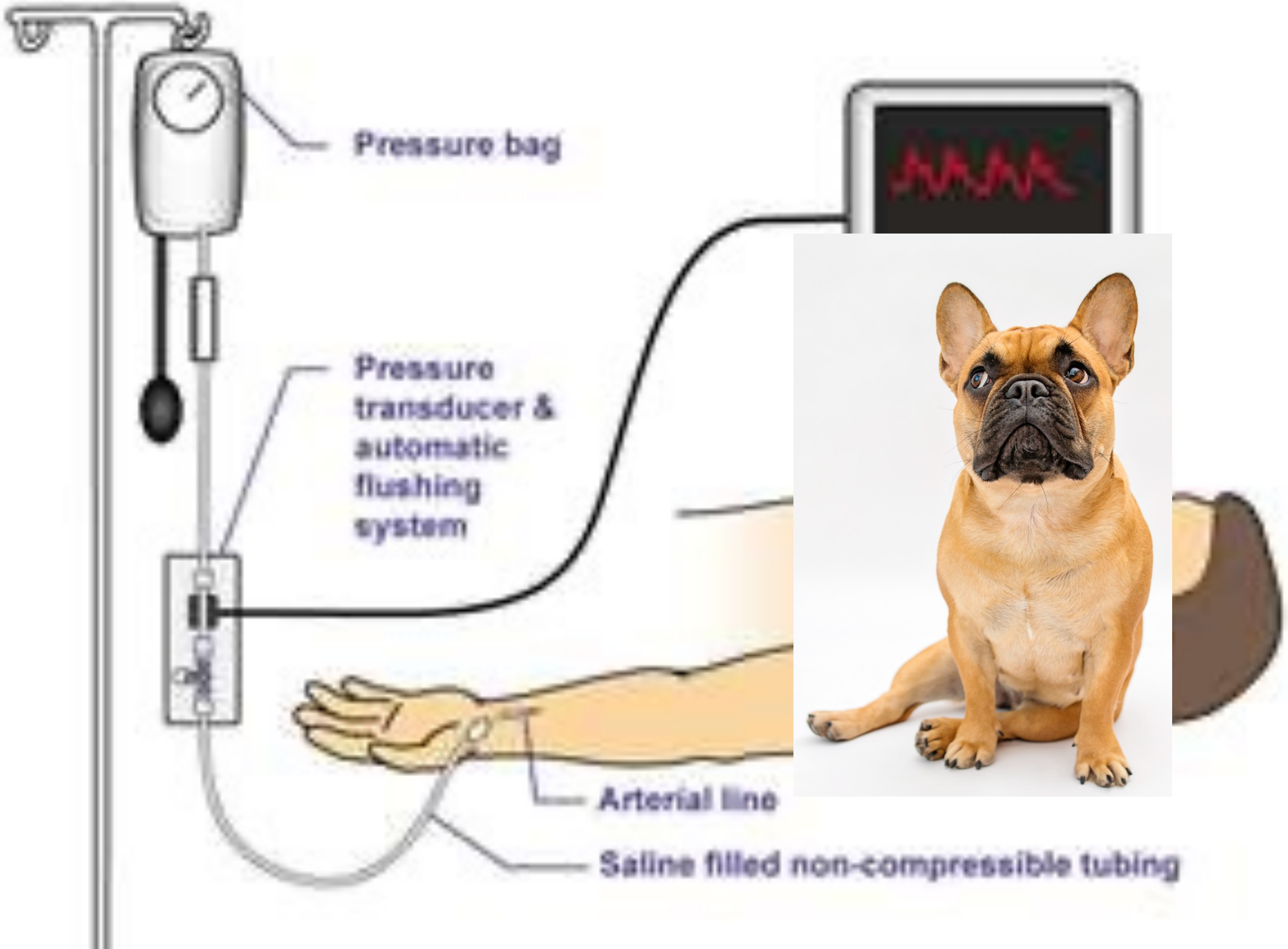
- Calibration of the BP device should be tested semiannually either by the user, when self-test modes are included in the device, or by the manufacturer.
- The procedure must be standardized.
- The environment should be isolated, quiet, and away from other animals. Generally, the owner should be present. The patient should not be sedated and should be allowed to acclimate to the measurement room for 5-10 minutes before BP measurement is attempted.
- The animal should be gently restrained in a comfortable position, ideally in ventral or lateral recumbency to limit the vertical distance from the heart base to the cuff (if more than 10 cm, a correction factor of +0.8 mm Hg/cm below or above the heart base can be applied).
- The cuff width should be approximately 30%-40% of circumference of the cuff site.
- The cuff may be placed on a limb or the tail, taking into account animal conformation and tolerance, and user preference.
- The same individual should perform all BP measurements following a standard protocol. Training of this individual is essential.
- The measurements should be taken only when the patient is calm and motionless.
- The first measurement should be discarded. A total of 5-7 consecutive consistent values should be recorded. In some patients, measured BP trends downward as the process continues. In these animals, measurements should continue until the decrease plateaus and then 5-7 consecutive consistent values should be recorded.
- Repeat as necessary, changing cuff placement as needed to obtain consistent values.
- Average all remaining values to obtain the BP measurement.
- If in doubt, repeat the measurement subsequently.
- Written records should be kept on a standardized form and include person making measurements, cuff size and site, values obtained, rationale for excluding any values, the final (mean) result, and interpretation of the results by a veterinarian.

INVASIVE PRESSURE MONITORING

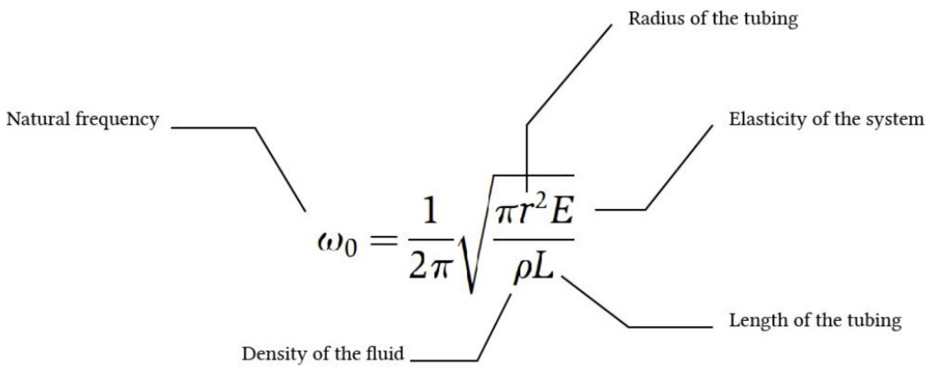
MATERIALS AND SETUP



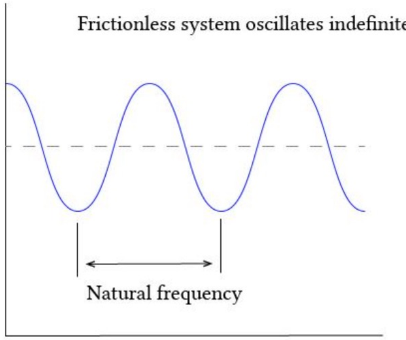
MATERIALS AND SETUP

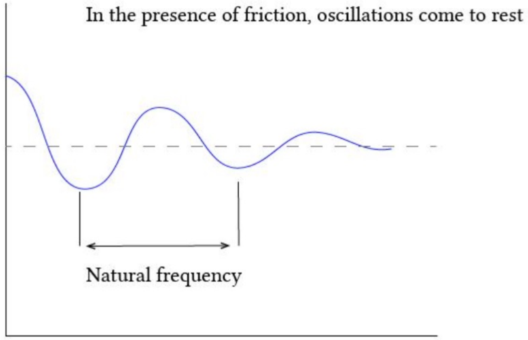


NATURAL FREQUENCY



$$\omega_0 = \frac{1}{2\pi}\sqrt{\frac{\pi r^2 E}{\rho L}}$$

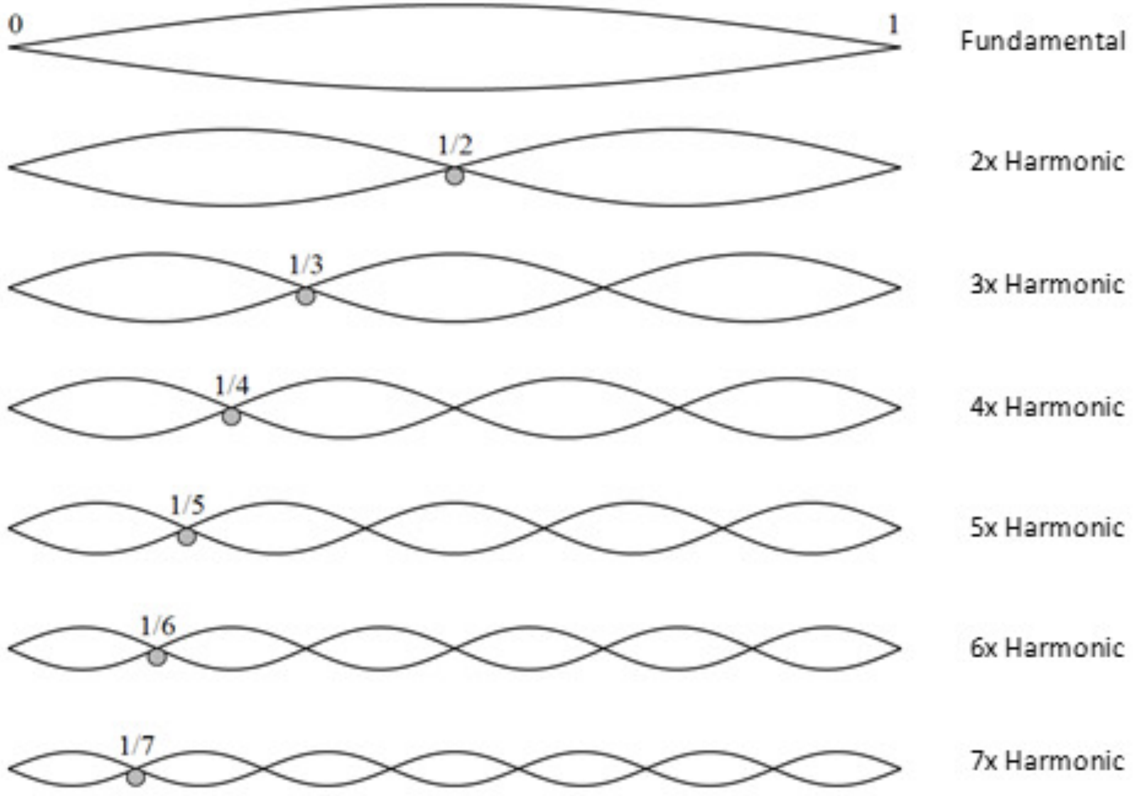




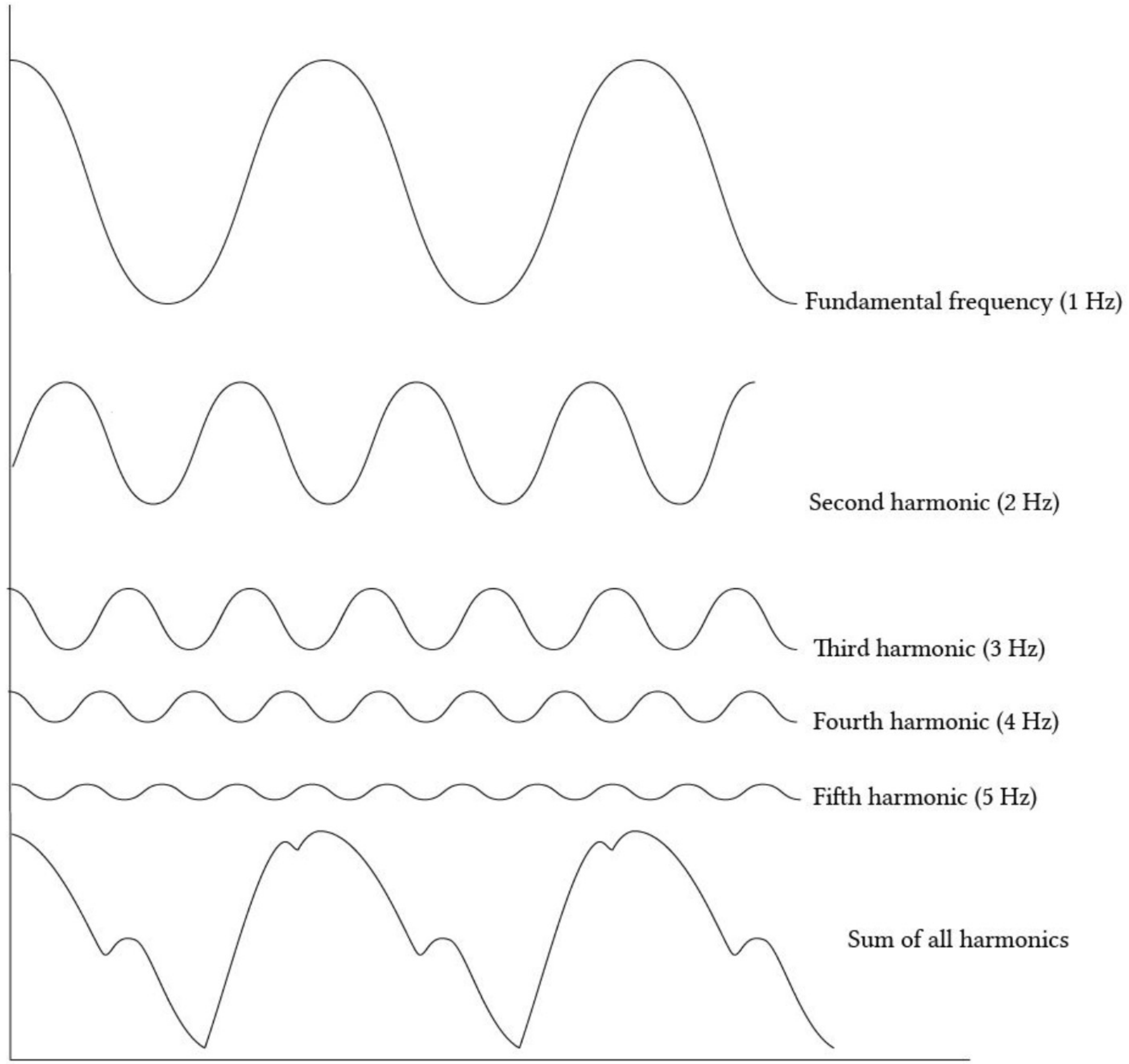
- Natural frequency: Frequency (measured in Hz) that the system oscillates at
  - Energy from the arterial pressure will be lost as it is absorbed by the system

PHYSICS

- The natural frequency of the system needs to be significantly higher than the pulse frequency for accurate readings (usually 6-10x higher than frequency of patient's HR)
  - Most commercially available systems have natural frequencies of ~200Hz
  - Addition of lines, stopcocks, etc decreases the natural frequency
    - Important to minimize the amount of "stuff" attached to the system
  - Most commercially available systems analyze to the 8th harmonic
    - Need at least 6th harmonic for detection of dicrotic notch



ARTERIAL PRESSURE WAVEFORM



ARTERIAL PRESSURE WAVEFORM

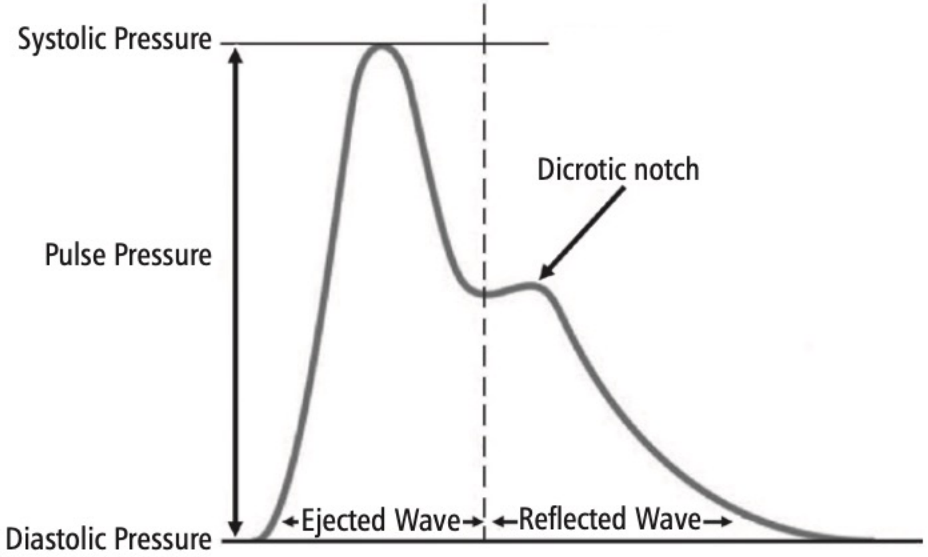
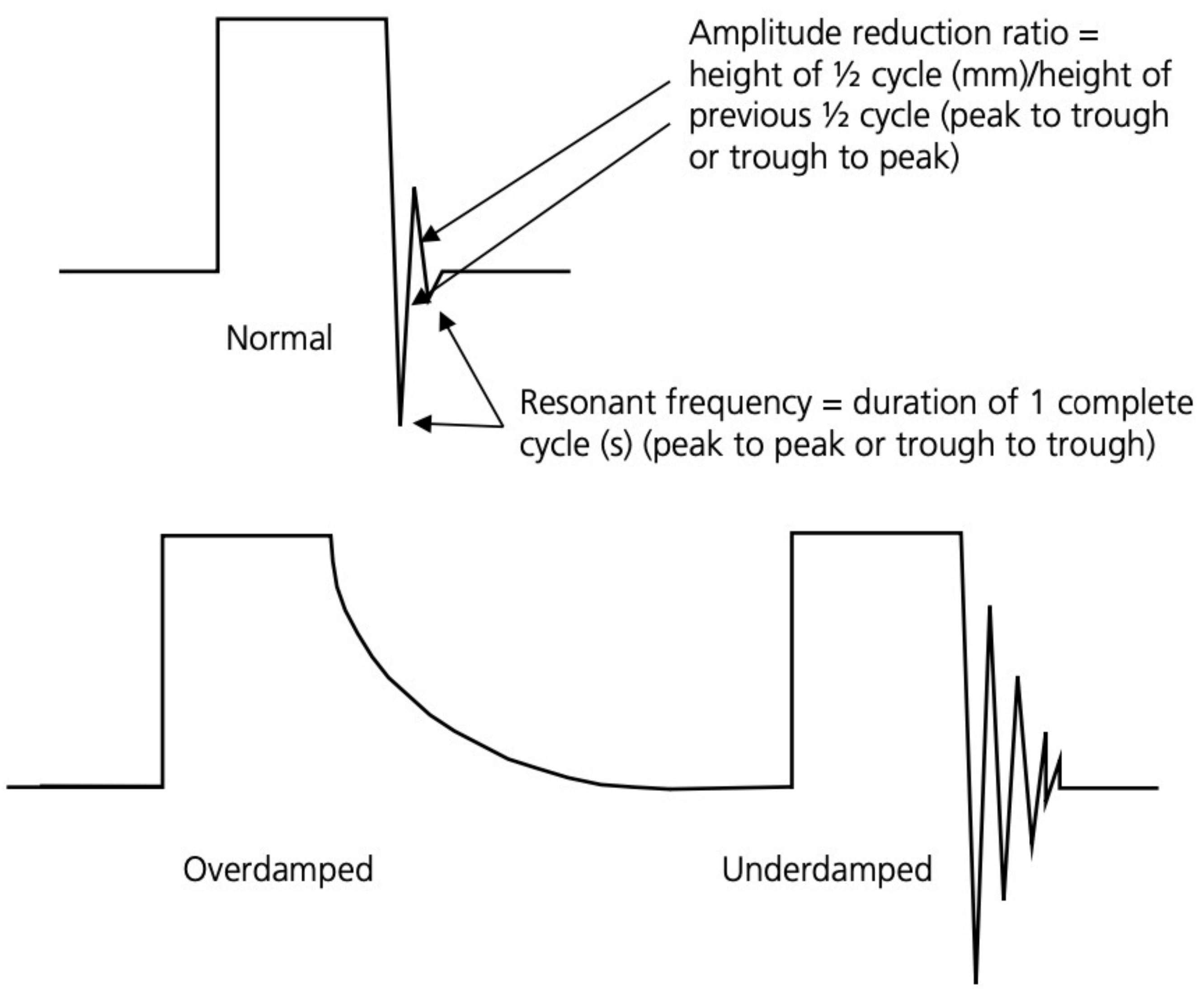


Figure 9.3 Idealized arterial pressure waveform.

- Systolic pressure: pressure following ventricular contraction
- Dicrotic notch: pressure due to elastic recoil of aorta following aortic valve closure (dashed line)

DAMPING

- Damping: absorption of oscillating wave energy
  - Defined as a damping coefficient measured with square wave test
  - Damping coefficient (Y)
    - Y= c/2m
      - c= friction coefficient
      - m= mass
- Optimal damping coefficient= 0.64-0.7
  - Corresponds to 2-3 oscillations following a square wave test


Amplitude reduction ratio = height of ½ cycle (mm)/height of previous ½ cycle (peak to trough or trough to peak)
Normal
Resonant frequency = duration of 1 complete cycle (s) (peak to peak or trough to trough)
Overdamped
Underdamped

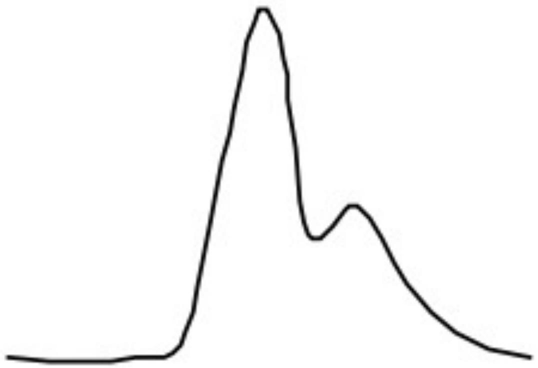
DAMPING

Over-damped system

- Most common
- Decreased SBP, increased DBP
  - **MAP remains accurate**
- Causes
  - Compliant tubing
  - Increased length of tubing system
  - Air in line

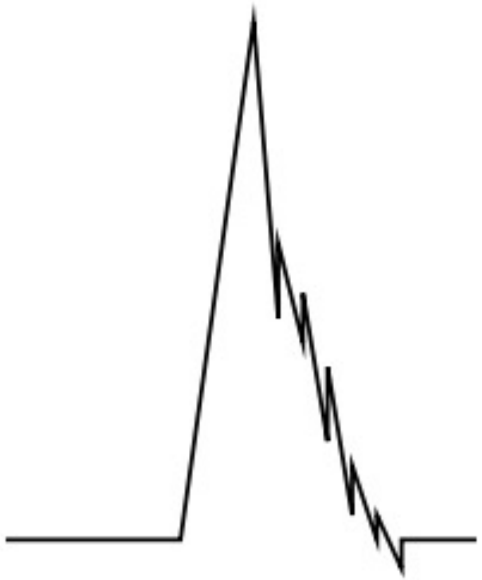
Under-damped system

- Less common
  - Occurs when system frequency approaches patient HR frequency
- Increased SBP, decreased DBP
  - **MAP remains accurate**



Normal
waveform

Overdamped
waveform



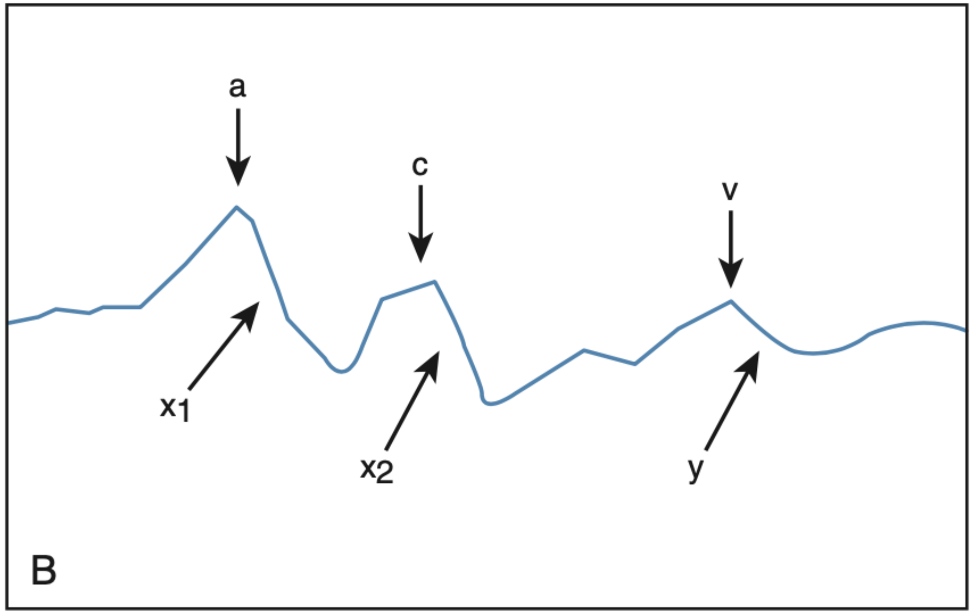
Underdamped
waveform

CENTRAL VENOUS PRESSURES

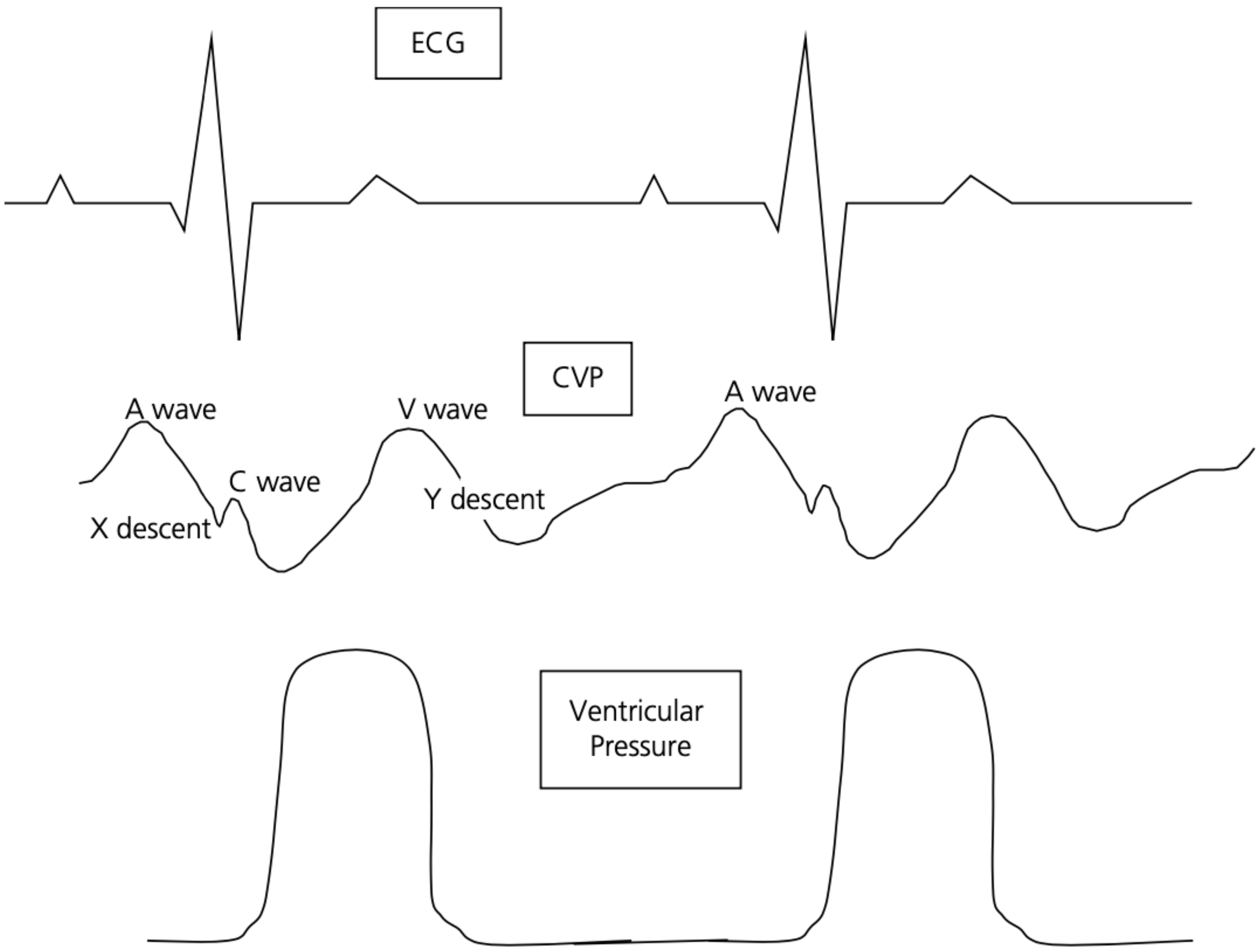
CENTRAL VENOUS PRESSURE MONITORING

- Historically used to monitor volume status/fluid responsiveness
  - Recently fallen out of favor
  - Pulse pressure variation and/or pleth variability index are more accurate
- Normal CVP: 0-5cm H_2O
  - Low CVP: Volume underload?
  - High CVP: Volume overload?

CENTRAL VENOUS PRESSURE

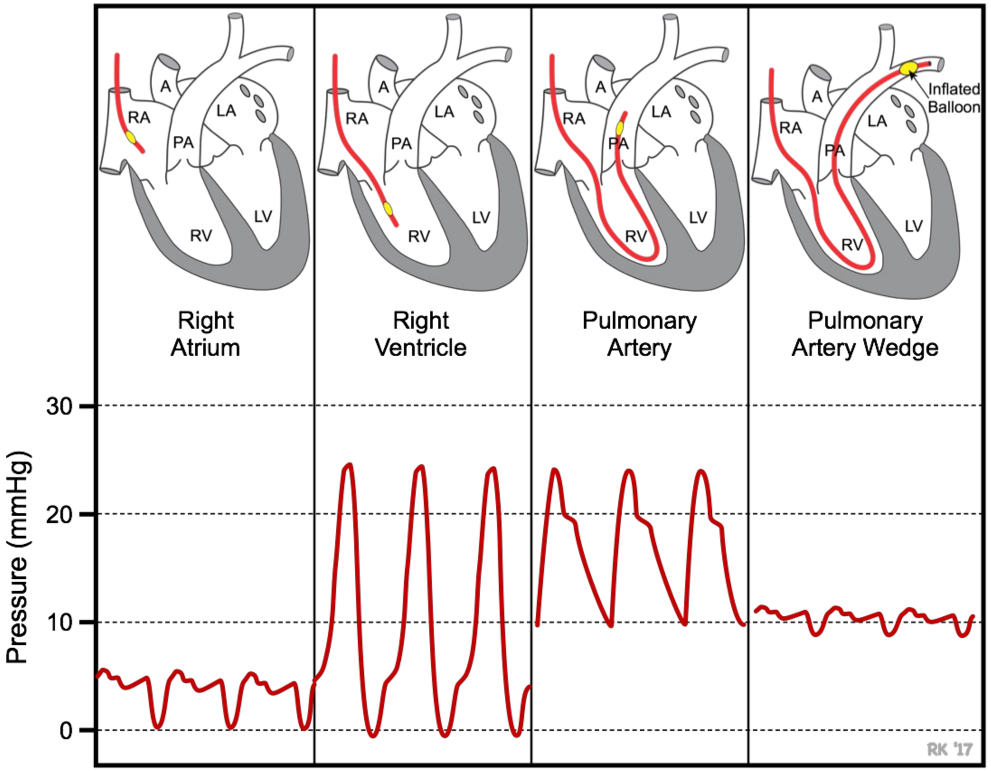


- a: right atrial contraction
- c: closure of tricuspid valve and bowing into RA
- x_1 and x_2 : decreased pressure due to ventricular ejection
- v: Filling of RA prior to opening of tricuspid valve
- y: emptying of RA when tricuspid valve opens


ECG
CVP
A wave
V wave
A wave
C wave
X descent
Y descent
Ventricular Pressure

PULMONARY ARTERIAL WEDGE PRESSURES

SWAN GANZ CATHETER



- Pulmonary artery occlusion/wedge pressure (PAOP): approximates the LEFT ATRIAL pressure
- Normal LAOP: 5-12 mmHg

SWAN GANZ PLACEMENT VIDEO

https://education.edwards.com/swan-ganz-catheter-placement/148895#

CARDIAC OUTPUT MONITORING

NORMAL CARDIAC OUTPUTS

Table 184-1 Normal Cardiopulmonary Values for Dogs and Cats

Parameter (Unit)	Dog	Cat
Heart rate (beats/min)	100-140	110-140
Mean arterial pressure (mm Hg)	80-120	100-150
Cardiac output (ml/kg/min)	125-200	120
Cardiac index (L/min/m^2)	3.5-5.5	—
Stroke volume (ml/beat/kg)	40-60	—
Systemic vascular resistance (mm Hg/ml/kg/min)	0.5-0.8	—
Mean pulmonary artery pressure (mm Hg)	10-20	—
Pulmonary vascular resistance (mm Hg/ml/kg/min)	0.04-0.06	—
Central venous pressure (cm H_2O)	0-10	—
Pulmonary artery wedge pressure (mm Hg)	5-12	—
Oxygen delivery (ml/kg/min)	20-35	—
Oxygen consumption (ml/kg/min)	4-11	3-8
Oxygen extraction (%)	20-30	—

FICK PRINCIPAL

- Amount returned to the venous blood must equal amount delivered in arterial blood minus what was used in the tissues
  - **Absolute amount of substance must be conserved**
- **Can use oxygen consumption or carbon dioxide elimination**
  - (Arterial O_2 blood content- venous O_2 blood content) x CO = O_2 consumption
    - $CO = \frac{O_2 \text{ consumption}}{\text{Arterial } O_2 \text{ blood content} - \text{venous } O_2 \text{ blood content}}$
  - (Arterial CO_2 blood content- venous CO_2 blood content) x CO = CO_2 consumption
    - $CO = \frac{CO_2 \text{ consumption}}{\text{Arterial } CO_2 \text{ blood content} - \text{venous } CO_2 \text{ blood content}}$

SWAN GANZ INDICATOR DILUTION

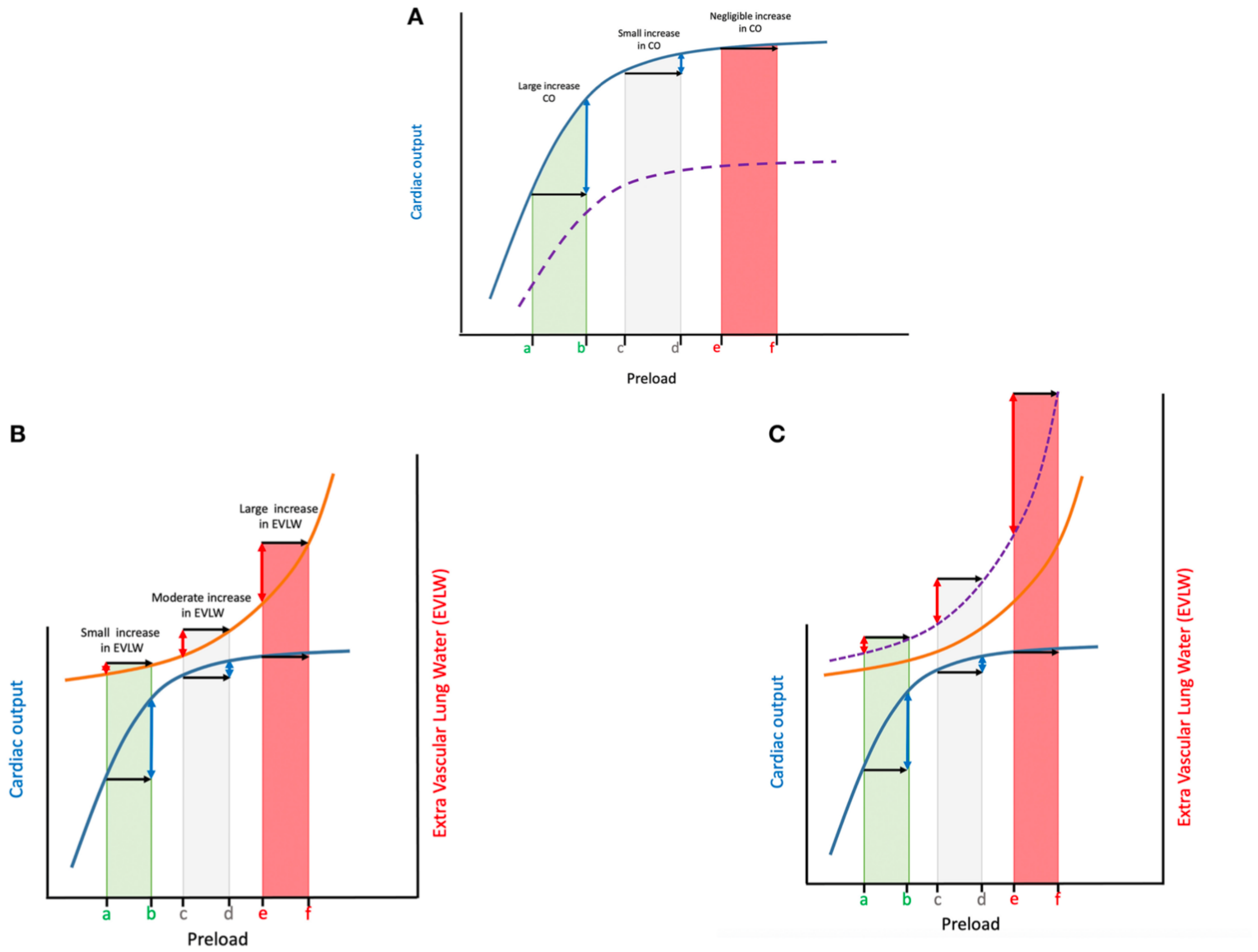
- Uses Fick principle:
  - Saline at known temp injected on right side. Final temp measured at PA
    - Total amount injected divided by area under the curve equal to cardiac output
  - Can also use different dyes

Assessment of Volume Status and Fluid Responsiveness in Small Animals

Søren R. Boysen[1] and Kris Gommeren[2]*

ASSESSING VOLUME RESPONSIVENESS

APPROACH TO FLUID RESPONSIVENESS



PULSE PRESSURE AND STROKE VOLUME VARIATION (PPV AND SVV)

- Differences in preload/stroke volume associated with changes in intrathoracic pressure
- Most commonly used in mechanically ventilated/anesthetized patients
- Variation of 10-15% supportive of fluid responsiveness in dogs
  - No data in cats

Pulse Pressure, Systolic Pressure and Stroke Volume Variation

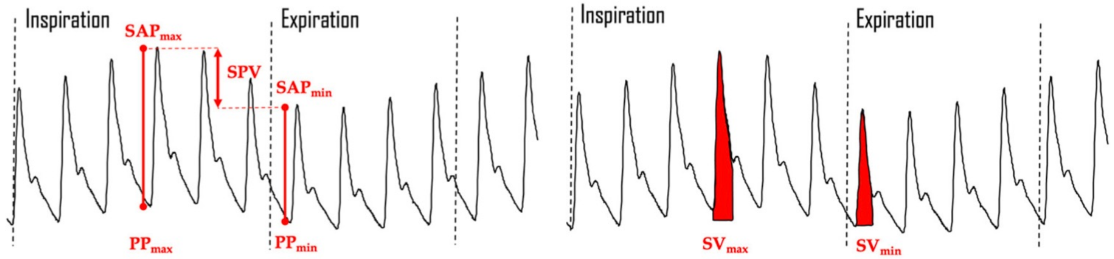


FIGURE 4 | Mechanical ventilation induced variations in the arterial pressure curve showing systolic arterial pressure (SAP) maximum (max) and minimum (min), pulse pressure (PP) maximum and minimum, and stroke volume (SV) maximum and minimum. The greater the degree of hypovolemia, all other variables held constant (e.g., tidal volume, airway pressure, etc.), the greater the change in ventilation induced variations for all parameters. SPV, systolic pressure variation.

PLETHYSMOGRAPHIC VARIABILITY INDEX (PVI)

- Change in perfusion index (measured by pulse ox) associated with respiratory cycle
  - Basically non-invasive surrogate of PPV
- Combined limitations of PPV and pulse oximetry

POCUS

Cardiac

- Ventricular/atrial lumen sizes
- Ventricular pseudohypertrophy
  - Less helpful in cats
- LA:Ao
- Subjective contractility
- Left ventricular end diastolic area (LVEDA) commonly used in humans

Caudal vena cava collapsibility index

- Caudal vena cava measured at:
  - Suprailiac (kidney)
  - Right intercostal (transhepatic)
  - Subxiphoid (diaphragmatic)
- Collapsibility of CVC (>50%) with respiratory cycle corresponds with hypovolemia

- B lines, GB halo, suggest possible fluid overload

ASSESSING FLUID RESPONSIVENESS

TABLE 1 | Formula and reported threshold values to discern fluid responders from non-responders.

Parameter	Abbreviation	Formula	Human threshold	Canine threshold
Systolic pressure variation	ΔSP	$\Delta SP = SP_{max} - SP_{min}$	dDown > 5 mmHg (89)	dUp > 4 mmHg (35)
Pulse pressure variation	PPV	$\frac{(PP_{max} - PP_{min}) \times 100}{(PP_{max} + PP_{min})/2}$	13.7% (90) 6.5–17% (91)	7 (71)–9.3% (17) 13% (18)–15.6% (92)
Stroke volume variation	SVV	$\frac{(SV_{max} - SV_{min}) \times 100}{(SV_{max} + SV_{min})/2}$	10–22% (19)	11% (22)
Plethysmographic variability index	PVi	$\frac{(Pi_{max} - Pi_{min}) \times 100}{Pi_{max}}$	14% (93) 9.5–19.0% (94)	11% (17)–13% (18)
Caudal vena cava collapsibility index	CVC ci	$\frac{CVC_{max} - CVC_{min}}{CVC_{max}}$	50% (95)*	30% (21)**

QUESTIONS?