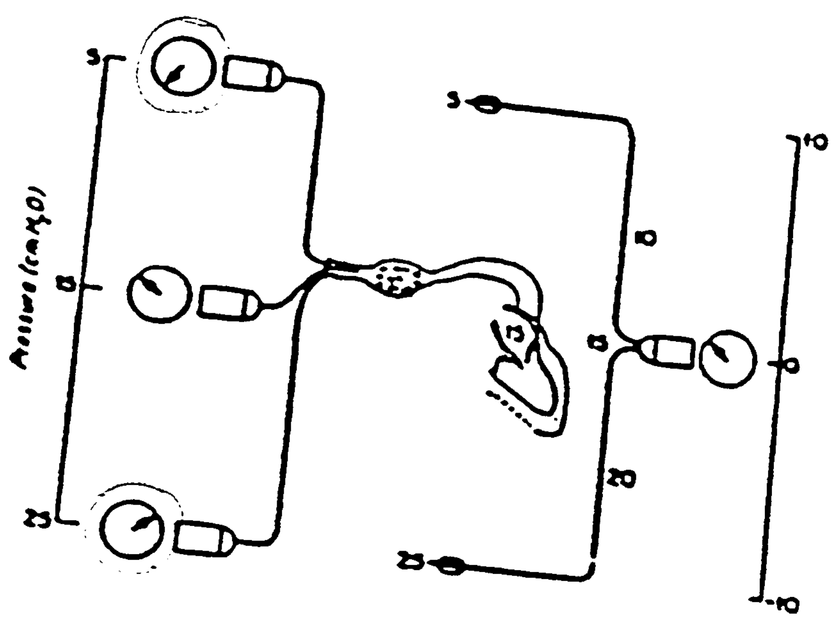
Rationale: Elimination of atmospheric pressure on PA measurement.

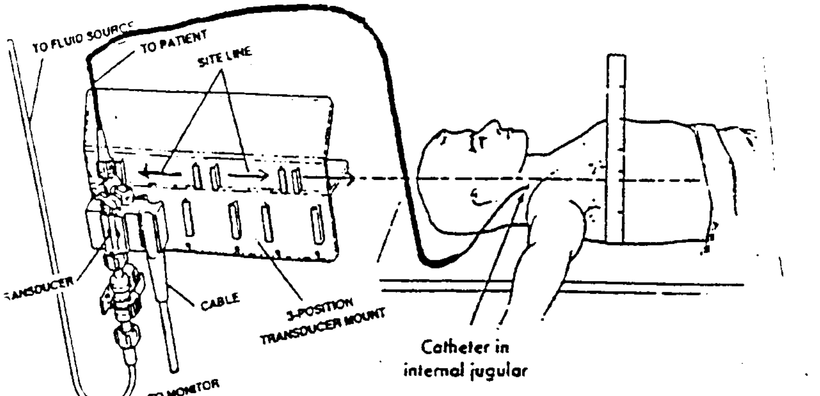
a. Turn transducer off to patient

b. Open air reference stopcock to air

c. Zero and calibrate monitor as per monitor manufacturer's instructions

5. LEVEL TRANSDUCER TO PATIENT REFERENCE POINT WITH EVERY POSITION





The patient's midchest position is measured, marked, and used as an anatomic reference point for placement of the transducer.

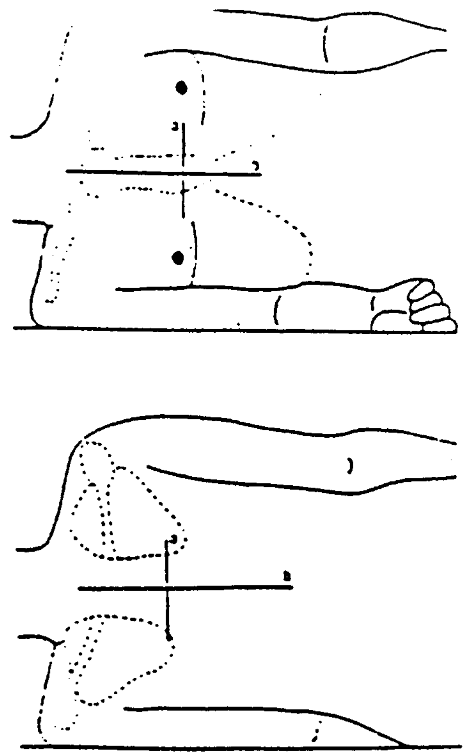


Fig. 2. Determination of anterior and posterior measuri points for lateral decubitus positions. Top, Line *a* represer the fourth intercostal space and line *b* is the midsternal lin Bottom, Line *a* represents the fourth intercostal space (T4 level) and line *b* is the midline of the spinal column.

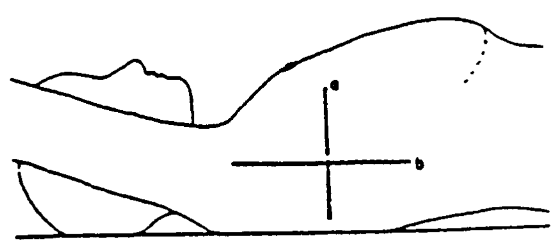


Fig. 3. Determination of the supine measuring point by us of the phlebostatic axis. Line *a* represents the fourth intercostal space and line *b* is the midaxillary line.

Leveling Eliminates of hydrostatic pressure on PAmeasurement.

a. Patient supine - midaxillary line, 4th intercostal space

b. Patient lateral or semi-lateral - midsternal line 4th intercostal space. (The semi-lateral position point is not defined in the literature although this is a common patient position).

c. Mark reference point on patient with pen. Keep same reference points throughout patient stay

d. Use carpenter's level to ensure reference point equality.

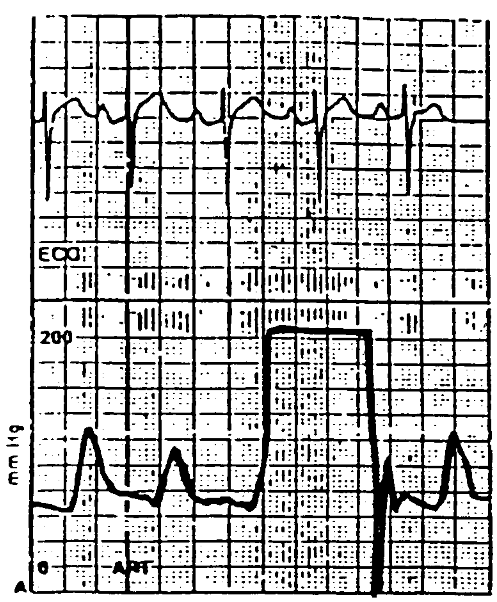
<u>NOTE</u>: The important point is that the two reference points are always the same. A 1 cm difference in reference point causes a 1.34 mm difference in the pressure reading. These two reference points should be marked with an X on every patient with a Swan Ganz catheter to insure consistency in measurement technique and eliminate reference point differences as a cause of PAWP measurement discrepancy.

6. CONDUCT "SQUARE WAVE" TEST BEFORE EVERY READING

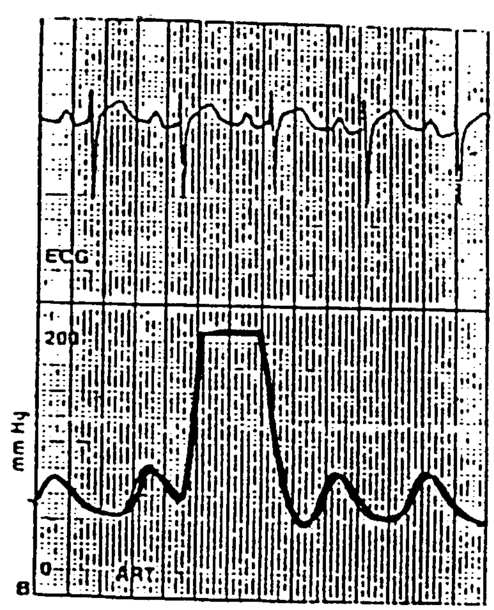
Rationale: Elimination of artifactual influences on PA pressure measurements (air bubbles, blood clots, kinks in catheter)

a. Power flush the catheter after PA waveform confirmation with every measurement - also done during set-up before patient is connected

b. Observe the flush waveform for number of oscillations and sharpness ("squareness") of the flush waveform. Flush waveform should have no more than 2-6 oscillations and should be sharp.



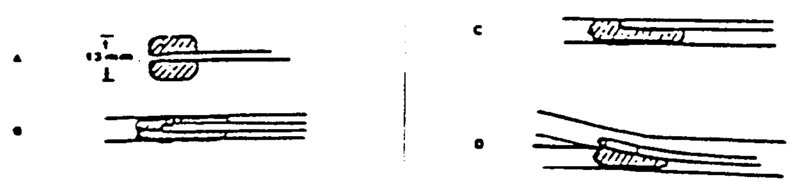
— Normal arterial waveform (ART) with normal square wave response during rapid flushing with continuous flush system.



— Damped arterial waveform (ART) with damped square wave response.

NOTE: Flush waveforms which slope or have greater than 6 oscillations indicate technical problems within the catheter-flush tubing-monitor system which need to be corrected before PA and PAWP measurements can be obtained with that system. Sloped flush waveforms signal air bubbles, loose connections, or a partially clotted catheter tip; PA and PAWP measurements obtained on a system with this response will overestimate diastolic pressures and underestimate systolic pressures. Flush waveforms with greater than 6 oscillations indicate frequency discrepancy problems between the monitor and the patient; PA and PAWP measurement obtained on a system with this response will underestimate diastolic pressures and overestimate systolic pressures. It has been recommended by catheter manufacturers that measurements should not be obtained on catheter systems which fail the "square wave" test.

7. BALLOON INFLATION:



Rationale: Elimination of potential for overwedge/eccentric balloon inflation or non-wedge.

Inflate balloon slowly in .2 cc increments, continuously observing waveform, and ceasing balloon inflation immediately on observing "flattening" or change in observed waveform.

a. <u>Balloon inflation volume should be between .8 and 1.5 cc of air</u>

(1) <u>Balloon inflation volume < .8 cc</u>: With balloon inflation volumes less than .8 cc of air there has been migration of the catheter to peripheral PA. With peripheral migration there are increased chances of overwedge and eccentric balloon inflation causing erroneously high PAWP measurements. Measurements of PAWP obtained with balloon inflation volumes less than .8 cc should not be recorded. The Swan should be pulled back by the physician. Repeated inflation of a peripherally migrated catheter balloon cannot only cause an increased potential of pulmonary infarct and PA rupture.

(2) Balloon inflation volume > 1.5 cc: with balloon inflation volumes greater than 1.5 cc of air, the balloon is probably in main PA instead of a branch of the PA causing increased chance of eccentric balloon inflation. The physician should refloat the Swan.

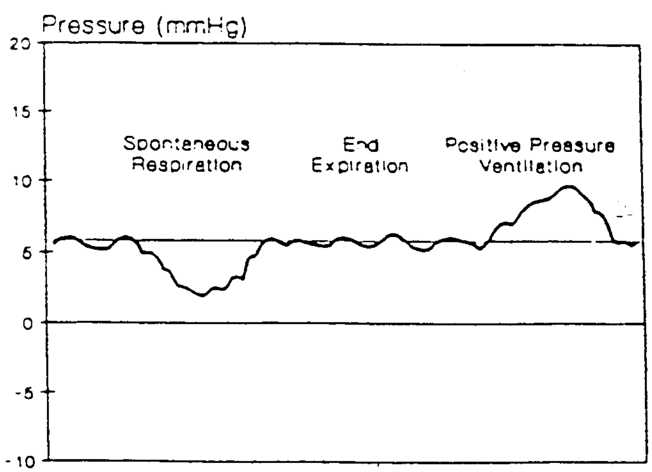
b. Slower balloon inflation is warranted when the patient has high pulmonary vascular resistance (PVR): In circumstances causing increased PVR, such as hypoxia, ARDS, PEEP, it takes longer for blood to flow from the point of balloon occlusion - the catheter tip-to the left atrium.

Faster rates of balloon inflation under conditions of increased PVR can cause increased potential of overwedge and eccentric balloon inflation.

8. RECORD PA PRESSURES AT END EXPIRATION:

Rationale: Elimination of effects of respiratory variation.

End expiration is identified as the most stable portion of the respiratory cycle, PAWP measurements at end expiration most closely parallel left atrial (LA) pressures.



Pulmonary Capillary Wedge Pressure Waveform. Pulmonary capillary wedge pressure decreases during spontaneous inspiration and increases during positive pressure mechanical ventilation. Pulmonary capillary wedge pressure measurements should be obtained during the end-expiratory phase of respiration.

a. Patient spontaneously breathing: When the patient is spontaneously breathing, end expiration causes the PA/PAWP waveform to rise due to the effect of intrapleural pressure on central intravascular pressures.

b. Patient on positive pressure ventilation: When the patient is on positive pressure ventilation, the intrathoracic pressure changes are reversed: inspiration causes central intravascular pressures to rise and expiration causes these pressures to fall.

c. Patient on IMV: When patient is in intermittent mandatoryventilation, the principles on a. an b. still apply. The nurse must be able to differentiate the spontaneous from the ventilated breaths.

d. PEEP: Do not take the patient off the ventilator to obtain hemodynamic measurements. PEEP decreases venous return to the heart related to the increasing intrathoracic pressure. Taking the patient off PEEP can cause bradycardia and asystole related to baroreceptor response cause by the "flooding" of the heart.

e. Patient on inverse ratio ventilation and pressure support: Patients on inverse ratio ventilation or pressure support ventilation will have PA and PAWP readings taken or exhalation also.

9. DEFLATE BALLOON BY ALLOWING PASSIVE BALLOON DEFLATION

Decreased potential of balloon rupture.

10. EVALUATE PA DIASTOLIC (PAD) - PAWP RELATIONSHIP:

PAd MUST BE › PAWP

IF PAWP › PAd ONE OF FOLLOWING PROBLEMS EXISTS

OVERWEDGE

ECCENTRIC BALLOON INFLATION

UNRECOGNIZED END-EXHALATION

DAMPED WAVEFORM

WAVEFORM WITH WHIP OR FLING

UNRECOGNIZED A AND/OR V WAVES

11. PLACE THE PA STRIP IN THE PATIENT'S CHART.

12. NOTIFY THE MD for the following

a. PAWP > 18 or PAWP < 8-12 or have MD set notification parameters

b. Inability to obtain PAWP

c. Abnormal PAWP waveform (A, V, and A and V waves)

d. PAWP >PAd

HEMODYNAMIC CHECKLIST

1. APPROPRIATE WAVEFORM
2. ZERO
3. LEVEL
4. SQUARE WAVE
5. BALLOON INFLATION
   - BALLOON VOLUME
   - WAVEFORM
6. END EXPIRATION
7. EVALUATE PAD - PAWP RELATIONSHIP
8. PA STRIP IN CHART
9. NOTIFY MD

F. Standard of Practice: Hemodynamic Monitoring: Cardiac Output

Outcome: Accurate assessment of patient's cardiovascular status so that appropriate diagnoses and intervention can be instituted by the physician.

1. SET UP IN LINE OR BATH PROBE CARDIAC OUTPUT INJECTATE SYSTEM:

2. SETS MONITOR PARAMETERS APPROPRIATELY:

Rationale: Ensures validity of cardiac output measurements. Indicates on monitor

a. In line vs bath probe

b. Volume of injectate 3 cc, 5 cc, or 10 cc

c. French of PA catheter

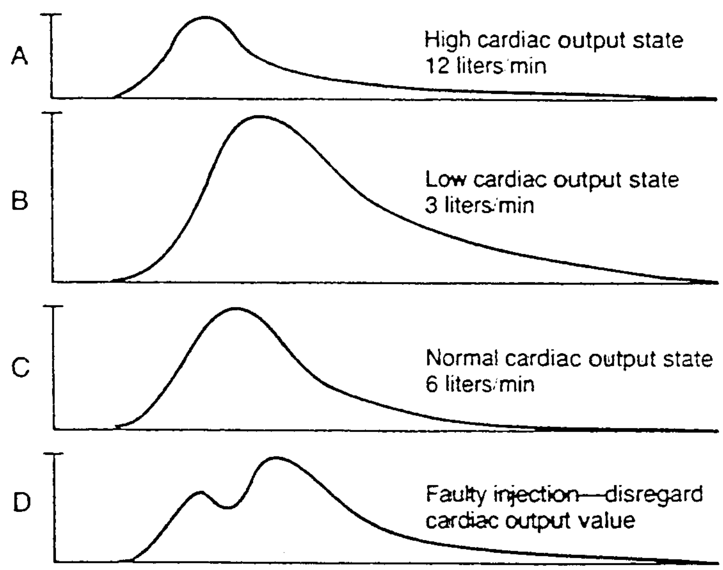
d. Height and dry body weight of patient

3. DRAW UP VOLUME OF INJECTATE INDICATED AND ENSURE NO AIR BUBBLE PRESENT:

4. INJECTS SOLUTION SMOOTHLY AND QUICKLY OVER A MAXIMUM OF FOUR SECONDS:

Rationale: Ensures validity and reliability of cardiac output measurements

5. ASSESSES CARDIAC OUTPUT WAVEFORMS AND DISCARDS MEASUREMENTS OBTAINED WITH UNACCEPTABLE WAVEFORMS:



6. PERFORMS A MINIMUM OF 3 CARDIAC OUTPUT MEASUREMENTS:

7. AVERAGES 3 CARDIAC OUTPUT MEASUREMENTS THAT ARE WITHIN 10% OF EACH OTHER:

Rationale: Ensures reliability of cardiac output measurements

NOTE: Cardiac output should not be obtained during periods of increased ectopy or hemodialysis related to their known effects (decreases and increases) or cardiac output measurements.

8. PERFORMS CARDIOVASCULAR CALCULATIONS:

9 COMPARE CURRENT HEMODYNAMIC PROFILE WITH PATIENT'S PREVIOUS PROFILES:

10. NOTIFIES MD OF ABNORMALS:

a. CI <2.5 or >4.5 or CI outside MD notification parameters

b. SVR <800 or >1200 or SVR outside MD notification parameters

c. Significant changes from previous hemodynamic profile

CARDIAC OUTPUT CHECKLIST

1. IN-LINE SET-UP
2. SET PARAMETERS
3. NO AIR BUBBLES
4. SMOOTH, QUICK INJECTIONS
5. ASSESS CO WAVEFORM
6. 3 CO INJECTIONS
7. CO MEASUREMENTS WITHIN 10%
8. CV CALCULATIONS
9. COMPARE
10. NOTIFY MD

G. SVO_2

1. Mixed Venous Oxygen Saturation (SVO_2)

a. Reflects the amount of oxyhemoglobin returning to the heart after oxygen extraction by the tissues

b. Measured in the pulmonary artery; a reflection of overall tissue utilization of oxygen

c. Normal 60-80%

d. Continuous or single sample measurement

e. Measures adequacy of four factors which influence tissue perfusion

(1) SaO_2 - arterial oxygen saturation or the adequacy of ventilation

(2) CO - cardiac output or the adequacy of the heart to bring oxygenated blood to the tissues

(3) Hgb - the amount of hemoglobin in the vascular system or the capacity of the vascular system to carry oxygenated blood to the tissues

(4) VO_2 - the amount of oxygen being consumed by the tissues

f. SVO_2 is a measure of the supply and demand of oxygen in the body

(1) Dysfunction in any one of the supply factors causes the body to rely on its compensatory mechanisms to increase oxygen delivery to the tissues

(2) Any time there is an increased tissue consumption, there is a decrease in SVO_2

(3) A patient with a small cardiac reserve will not be able to increase his cardiac output to meet either increased demand or decreased supply

2. Oxygen supply/demand dynamics

a. Factors which alter the O_2 delivery/consumption

(1) ↓ supply

(2) ↑ demand

b. Compensatory mechanisms

(1) ↑ cardiac output

(2) ↑ oxygen extraction-->SVO_2 (use of venous oxygen reserve)

c. Changes in oxygen supply/demand balance are reflected in SVO_2 and can be measured clinically at the bedside

(1) $SVO_2 < 60\%$

(a) ↓ SaO_2

(b) ↓ CO

(c) ↓ Hb

(d) ↑ O_2 consumption

(2) $SVO_2 > 80\%$

(a) ↑ oxygen delivery

(b) ↓ oxygen demand (consumption)

(c) Other

1) Wedged PA catheter

2) Cell poisoning

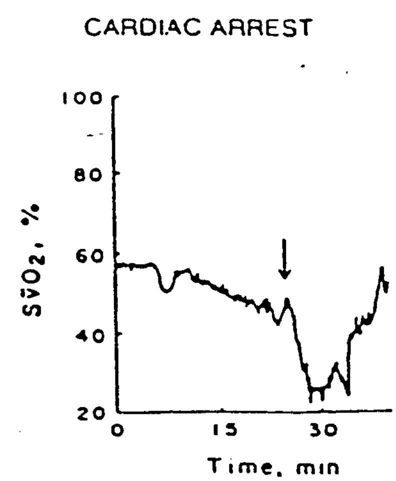
3) Paget's disease

3. Indications for continuous SVO2 measurement

a. As a monitor

(1) Early warning of alterations in hemodynamic status that may warrant therapeutic intervention

(2) Continuous monitoring of changes in cardiorespiratorystatus that may warrant therapeutic intervention



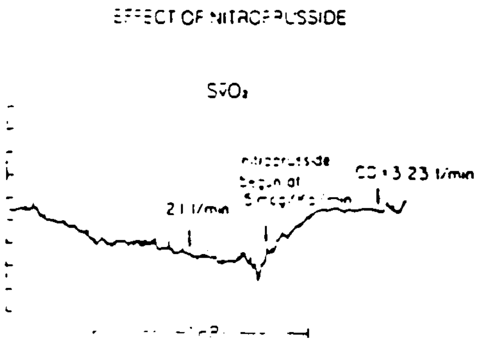
b. At a patient management device

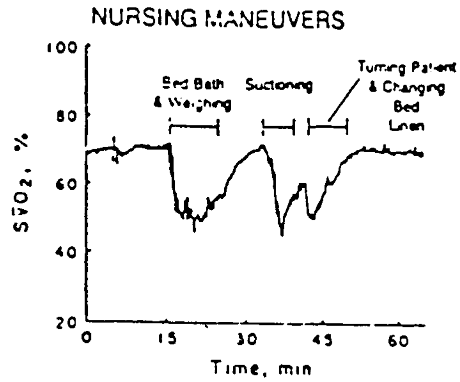
(1) Titration of vasoactive drugs

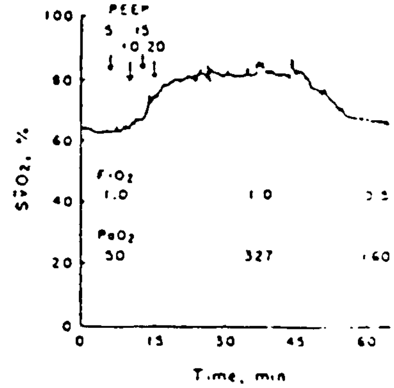
(2) Volumeloading

(3) Effects of routine patient care such as turning, suctioning, weighing, etc.

(4) Ventilator adjustments







4. Clinical Applications

a. Clinical ranges

	Clinical $S\bar{v}O_2$ Range	Probable Physiologic State	Probable Clinical State
		↑ O_2 Delivery	↑FiO_2 Hyperoxia
HIGH $S\bar{v}O_2$	80–95%		
		↓ O_2 Demand	Hypothermia, Sepsis Anesthesia Pharmacologic Paralysis
NORMAL $S\bar{v}O_2$	60–80%	O_2 Delivery O_2 Demand Normal	Adequate tissue perfusion
		Hgb	Anemia, Bleeding
		↓ O_2 Delivery — SaO_2	Hypoxia, Suctioning
		CO	Cardiogenic Shock Hypovolemia Arrhythmia ↓B/P
LOW $S\bar{v}O_2$	< 60%		
		↑ O_2 Demand	Hyperthermia Shivering Seizures Pain

While the above table is an approximate guideline to the interpretation of the absolute $S\bar{v}O_2$ value, equally important is the trend of changes in $S\bar{v}O_2$. Recommended guidelines include:

1. If $S\bar{v}O_2$ falls below 60%, reassess the patient.

2. If $S\bar{v}O_2$ varies by ± 10% for 3 minutes or longer reassess the patient.

[illegible]
form as Actual Measurement of Left Ventricular End Diastolic [illegible]
and Left Ventricular End Diastolic Volume (LVEDV)

STEP I Are technical criteria for reliable and accurate measurement of LVEDP and LVEDV met?

- Appropriate Waveform
- Electrical and Mechanical Calibration Performed
- Air Reference Stopcock Leveled to Phlebostatic Axis
- Square Wave Test Passed (No air bubbles, clots, kinks, or fling)
- Patient in Supine Position HOB 0-45°
- Consistent Evaluation in Relation to Respiratory Cycle (End-expiration)
- Balloon Inflation Volume Between .8 and 1.5 cc

NO → Measurement obtained with wedge waveform is not a measure of LVEDP or LVEDV. (See Remedies)

YES → Measurement obtained with wedge waveform is potentially a measure of LVEDP and LVEDV

STEP II Is the PAd ≥ PAWP

NO → Measurement obtained with wedge waveform is not a measure of LVEDP or LVEDV but is the result of:
MECHANICAL OBSTRUCTION
MITRAL VALVE DYSFUNCTION
IATROGENIC INFLUENCE
(See Remedies)

YES → Measurement obtained with wedge waveform is potentially a measure of LVEDP and LVEDV.

STEP III Is there normal lung compliance?

NO → Measurement obtained with wedge waveform is higher than actual LVEDP, use a wave as best estimate.

YES → Measurement obtained with wedge waveform is potentially a measure of LVEDP and LVEDV.

STEP IV Is there normal left ventricular compliance?

NO → Measurement obtained with wedge waveform is an accurate measurement of LVEDP but does not accurately reflect LVEDV. Increased compliance will yield no change in LVEDP for relatively large LVEDV changes. Decreased compliance will yield increased LVEDP for the same or smaller LVEDV.

YES → Measurement obtained with wedge waveform is a measure of LVEDP and LVEDV.

NORMAL VALUES OF HEMODYNAMICALLY SIGNIFICANT VARIABLES
MEASURED AT BEDSIDE

PARAMETER	HOW MEASUREMENT OBTAINED	NORMAL VALUES
RAm - mean right atrial pressure or CVP	Direct measurement	0 - 8 mm Hg
RV - right ventricular pressure (systolic/diastolic)	Direct measurement, or systolic inferred from PA systolic and diastolic inferred from RAm	$\frac{20-30}{0-8}$ mm HG
PA - pulmonary artery (systolic/ end-diastolic	Direct measurement	$\frac{15-30}{5-12}$ mm Hg
PCWP - pulmonary capillary wedge pressure	Direct measurement, or inferred from PAedp under appropriate conditions	15 - 12 mm Hg
CO - cardiac ouput	Direct measurement	5 - 6 L/min
BSA - body surface area	Calculated after direct measurement of height and weight from Dubois chart	
CI - cardiac index	CO/BSA	2.5 - 3.5 L/min/M^2
MAP - mean arterial pressure	Direct measurement, or $\frac{2(\text{arterial diastolic pressure})+\text{systolic pressure}}{3}$	85 - 95 mm Hg
SVR - systemic vascular resistance	$\frac{MAP - RAm}{60}$ X 80	900 - 1200 dynes • sec • cm^{-5}
PVR - pulmonary vascular resistance	$\frac{PAm - PCWP}{CO}$ X 80	150 - 250 dynes • sec • cm^{-5}
HR - heart rate	Direct measurement	60 - 90 beats/min
O_2 transport - amount oxygen transported to tissues per minute in ml	CO X arterial O_2 content, or CI X arterial O_2 content X 10	——— 520 - 720 ml/min • M^2
O_2 consumption - oxygen consumed by tissues in ml/min	CO X (arterial-mixed venous O_2 content), or CI X (arterial-mixed venous O_2 content) X 10	——— 100 - 180 ml/min • M^2
$P\bar{v}O_2$ - mixed venous pO_2	Direct measurement	35 - 40 mm Hg
Lactate	Direct measurement	2 mEq/L
SI - stroke index	CI ÷ HR	30 - 50 ml/M^2
LVSWI - left ventricular stroke work index	SI X MAP X .0144	44 - 68 g • M/M^2
RVSWI - right ventricular stroke work index	SI X PAm X .0144	4 - 8 g • M/M^2
CPP - coronary perfusion pressure	Arterial diastolic pressure - PCWP	60 - 70 mm Hg
RPP - rate pressure product	Systolic arterial pressure X HR	< 12000 units

EFFECTS OF VARIOUS PATHOLOGIES ON RIGHT ATRIAL MEAN (RAm), PULMONARY ARTERY (PA) AND PULMONARY CAPILLARY WEDGE PRESSURE (PCWP)

PATHOLOGIC OR ABNORMAL CONDITION	RAm (normal value 0 - 8 mm Hg)	PA systolic/diastolic normal value: 15 - 30 / 5 - 12 mm Hg	PCWP (normal value 5 - 12 mm Hg)	ASSOCIATED WAVEFORM PATTERN CHANGES
iock Hypovolemic (H) Neurogenic (N) Septic (S)	↓	↓/↓ ↔/↔ ↑/↑	↓	Differentiated on basis of oxygen consu tion, oxygen transport, SVR, PVRC, CO, H - ↓ CO, ↓ O_2 transport, ↓ O_2 consumpti N - ↓ SVR, ↔ PVR, ↔ ↑ CO, ↔ O_2 consumption S —early: ↑ CO, ↑ O_2 transport ↔ O_2 consumption ↓SVR ↑PVR —late: ↓ CO, ↓ O_2 transport ↓ O_2 consumption, ↑ SVR ↔ PVR
ypervolemia	↑	↑/↑ or ↔/↔	↑	
ight ventricular failure	↑	↔/↔	↔	
ricuspid disease	↑	↔/↔	↔	Regurgitation: prominent V wave Stenosis: prominent A wave
ericardial tamponade	↑	↑/↑	↑	1. PAWP = RAm 2. Diastolic plateau with paradoxical respiratory rise 3. ↓ pulse pressure in PA 4. Prominent A and V waves and X descent
ericar''al disease	↑	↑/↑	↑	Same as tamponade, except A
ncreased pulmonary esistance— Acute: Hypoxemia, PE, Pneumothorax	↔	↑/↑ (dramatic)	↔ or ↑	1. ↑ Discrepancy between PA diastolic pressure and PCWP 2. ↑ Potential for Starling effect with ↑ alveolar pressures with PEEP and PP therapies 3. Marked respiratory variation in COPD
Chronic: COPD, positive pressure ventilation (PPV), PEEP	↑	↑/↑	↔ or ↑	
'entricular septal defect	↔	↑/↔	↔	Wide pulse pressure in PA
4itral valve disease	↔	↔/↑	↑	Regurgitation: prominent V wave Stenosis: prominent A wave
.eft ventricular failure: Acute	↔	↔/↑	↑	
Chronic	↑	↑/↑	↑	
Left ventricular compliance	↔	↔/↑	↑	