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OCT-Guided PCI w/ RA in a Heavily Calcified Bifurcation Lesion *page 30*

Kern's Conversations in Cardiology: Is the Cath Lab Just Like the OR? *page 4*

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# Cath Lab Digest®

A Product, News and Clinical Update for the Cardiac Catheterization Laboratory Specialist

## Cath Lab Spotlight

## Durham VA Medical Center

*Sunil V. Rao, MD, Cath Lab Director, Section Chief of Cardiology, Durham VA Medical Center, Associate Professor of Medicine, Duke University Medical Center*

*Marri "Nicki" Fryar, RN, MBA, MHA Nurse Manager, Cardiac Catheterization and Interventional Radiology Laboratories, Durham VA Medical Center*

*Durham, North Carolina*

**Tell us about your cath lab.**

We currently have two procedure rooms, one of which is dedicated to electrophysiology (EP) procedures. Our staff is cross-trained to work both cath and EP procedures. Our lab is staffed with 8 registered nurses (RNs) and 3 cardiovascular technologists. Five RNs hold certifications as CCRN and 1 technologist holds both the registered cardiovascular invasive specialist (RCIS) and registered cardiac electrophysiology specialist (RCES) credentials. Staff longevity ranges from 8 months to over 10 years.

**Tell us about the procedures performed at your lab.**

The average number of procedures performed each week is 30 (we have only one cath procedure room). This number includes

*continued on page 22*

March 2015 vol. 23, no. 3

ECONOMICS & CARE

## Switching From Eptifibatide to Tirofiban Use in ACS: Reducing Cost While Maintaining Quality of Care

*Cath Lab Digest talks with J. Brent Muhlestein, MD, FACC, Co-Director of Cardiology Research, Intermountain Health Care and Intermountain Medical Center, Salt Lake City, Utah; Professor of Medicine, University of Utah, Salt Lake City, Utah.*

**An emphasis on consensus and partnership allows Intermountain Health Care to unite under treatment guidelines, establish protocols, and save money, all while providing quality patient care.**

*continued on page 10*

STRUCTURED REPORTING

## Early Adopters: The Valley Hospital's Structured Reporting Journey With ProVation MD Cardiology

*Cath Lab Digest talks with Janet E. Strain, MD, FACC, FAHA, FSCAI, Director, Cardiac Catheterization Laboratory, Cathy Ilardi, RN, BSN, CNML, Nurse Manager, and Randy Sturm, RT(R), Cardiac Catheterization and Electrophysiology Laboratory, The Valley Hospital, Ridgewood, New Jersey.*

**Could you tell us about your facility and cath lab?**

*Cathy Ilardi, RN, Nurse Manager:* The Valley Hospital is proud to be the hospital of choice for hundreds of thousands of residents of northern New Jersey. Valley is a 451-bed, acute-care, not-for-profit hospital located in Ridgewood, New Jersey. Key services include cardiology, oncology, women's and children's services, emergency care, orthopedics, and neurosciences.

*continued on page 16*

HEMODYNAMICS

## Test Your Hemodynamic Knowledge: Part I

*Richard J. Merschen, EdS, RT(R)(CV), RCIS, Adjunct Assistant Professor, Jefferson School of Health Professions, Senior Staff Technologist, Pennsylvania Hospital Cardiac Catheterization Laboratory, Philadelphia, Pennsylvania*

Accurate interpretation of cardiac hemodynamics is foundational for cath lab practice. Over the past several months, the *Cath Lab Digest* Editorial Board has reached the consensus that reinforcing the basics of cardiac hemodynamics is a priority for all cath lab practitioners. In upcoming issues, there will be a series of initiatives, articles, and case studies presented to improve staff knowledge and reinforce cath lab fundamentals.

*continued on page 36*

*Continued from cover*

# Test Your Hemodynamic Knowledge: Part I

## Case

A 51-year-old white male presented to the cardiac cath lab with a recent, progressive history of shortness of breath, chest pain on exertion, and fatigue. The patient has a history of poorly controlled hypertension, hyperlipidemia, family history of coronary artery disease, and arthritis. Based on the patient history, a left and right heart catheterization and coronary angiography were ordered for the patient. The coronary arteries demonstrated no obstructive lesions. A left ventriculogram (LV gram) demonstrated an ejection fraction of 40%, with global hypokinesis.

*More information:*

1. Weight 234 lbs
2. Height 6'0"
3. Hemoglobin 16.5
4. Heart rate 110
5. Pa Sat 52%
6. Ao Sat 96%
7. Creatinine 1.07
8. Potassium 3.9
9. Platelets 234
10. INR 1.0
11. Blood pressure 160/90mmHg
12. Pulse ox 94%

**Now, test yourself! Based on the hemodynamic study and the information provided, what is the most likely diagnosis for the patient? While you are considering the diagnosis, see if you can answer the 25 questions below.**

## Questions

**1. What is the normal mean pressure range for the right atrium?**
- A. 2-6mmHg
- B. 4-18mmHg
- C. 25/5 mmHg
- D. 12-16mmHg

**2. What is this patient's mean right atrial pressure?**
- A. 25mmHg
- B. 10mmHg
- C. 5mmHg
- D. 100mmHg

**3. What does the atrial A wave mean and which wave of the ECG does it follow?**
- A. Passive filling of the ventricle. Found on the T wave.
- B. The atrial kick, found just after the P wave.
- C. The atrial kick. Found after the QRS complex.
- D. Contraction of the ventricle. Located at the ST segment.

**4. What is the normal pressure for the right ventricle?**
- A. 12/16/14
- B. 25/5
- C. 75/15/15
- D. 40/15

**5. Which portion of the ventricular waveform represents the preload state?**
- A. Systolic peak
- B. Beginning diastole
- C. End diastolic pressure
- D. The ventricular upstroke

**6. What is the normal pressure for the pulmonary artery?**
- A. 45/10/40
- B. 30/30/24
- C. 25/10/15
- D. 50/15/33

**7. What is the patient's pulmonary vascular resistance, in Wood units, based off of the hemodynamics and cardiac output?**
- A. 0.6
- B. 1234
- C. 100H
- D. 70

**8. What is the patient's pulmonary vascular resistance, based off of metric units?**
- A. 48 dynes•sec•cm−5
- B. 1234 dynes-5/cm
- C. 56 grays
- D. 4.8 psi

**9. What is a normal pulmonary capillary wedge pressure?**
- A. 12-16mmHg mean
- B. 2-6mmHg mean
- C. 10-30mmHg mean
- D. 14-45mmHg

**10. What is this patient's mean pulmonary capillary wedge pressure?**
- A. 55mmHg
- B. 10mmHg
- C. 43mmHg
- D. 6mmHg

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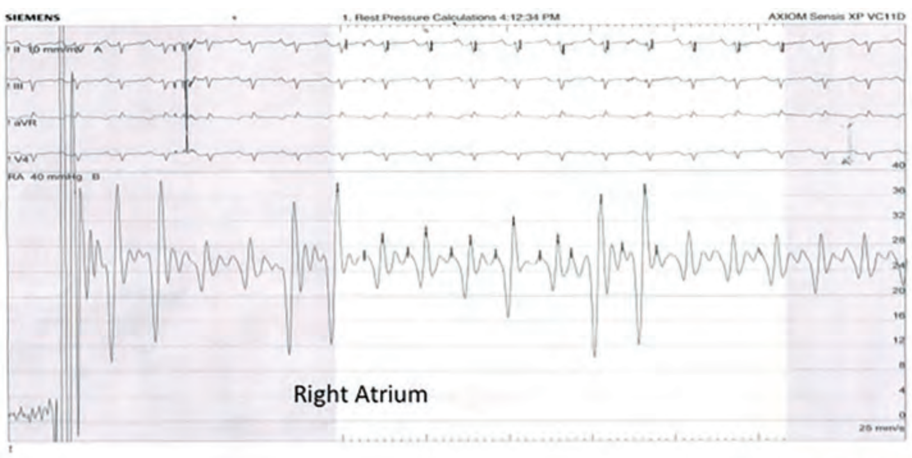



**Figure 1.** Right atrium

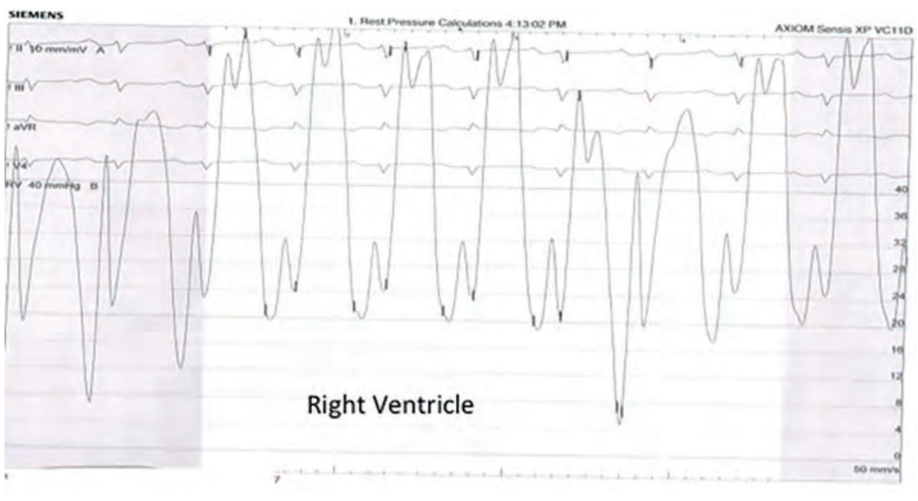



**Figure 2.** Right ventricle

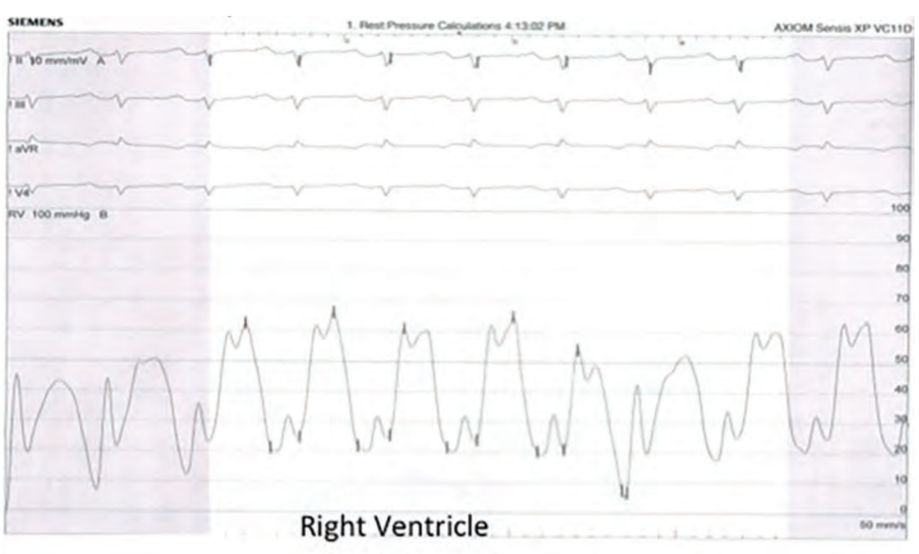



**Figure 3.** Right ventricle


**Figure 4.** Pulmonary artery

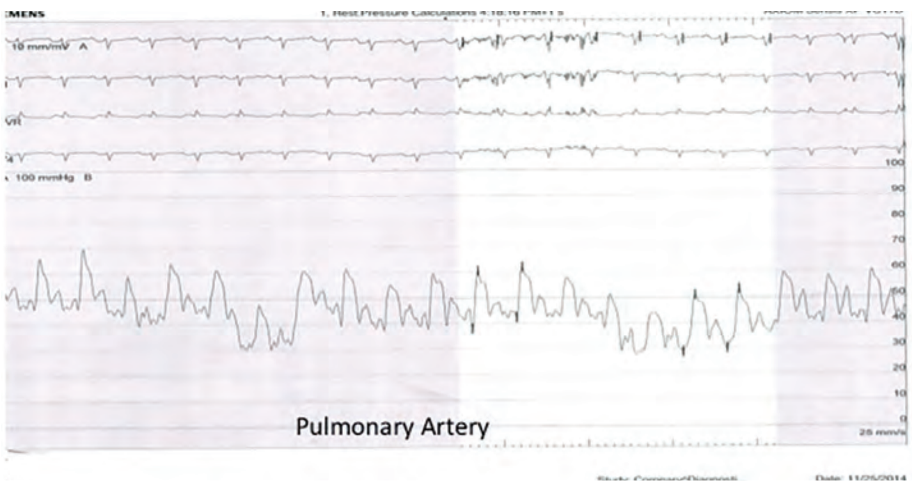



Figure 5. Pulmonary artery

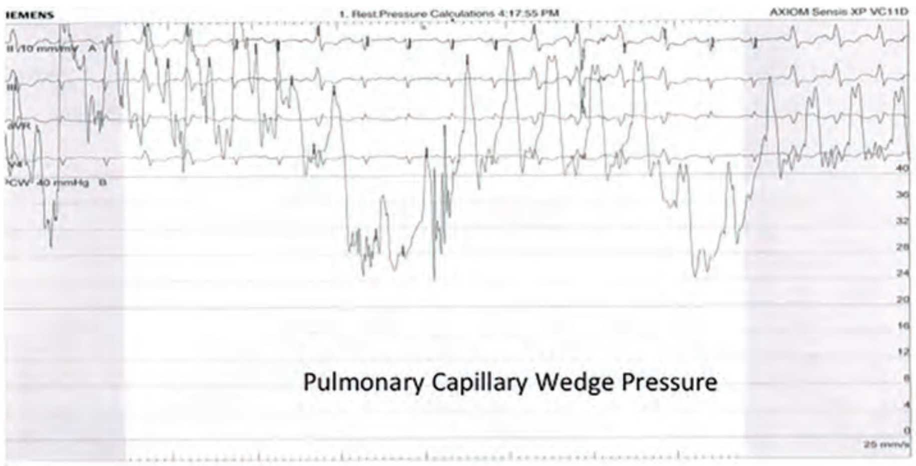



Figure 6. Pulmonary capillary wedge pressure (PCWP)

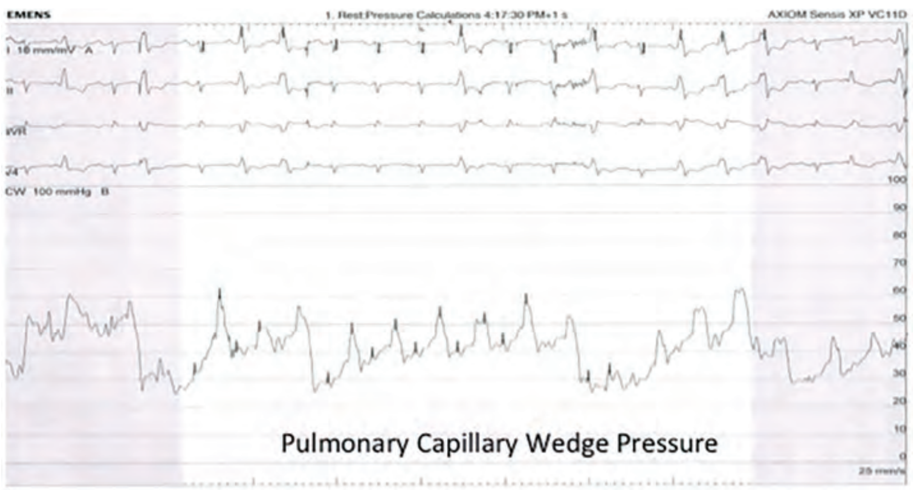



Figure 7. Pulmonary capillary wedge pressure (PCWP)

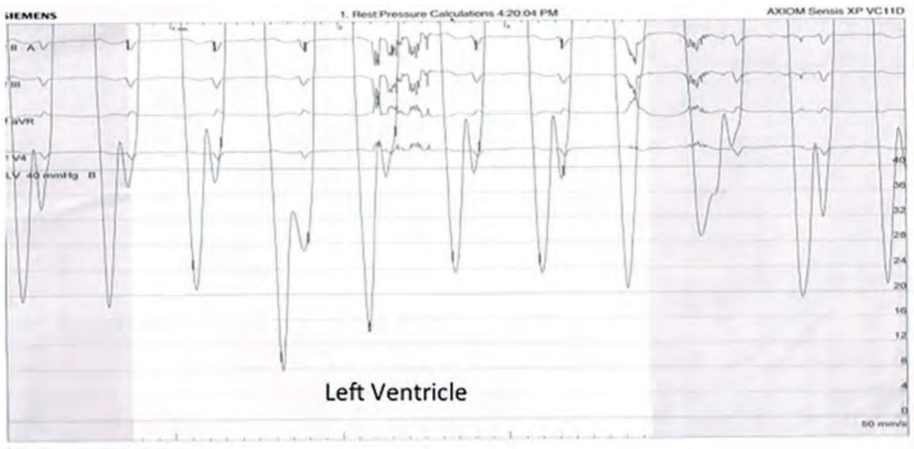



Figure 8. Left ventricle

## Hemodynamics Test

*Continued from page 36*

**11. What does the left ventricular end diastolic pressure (LVEDP) indicate?**

A. Afterload
B. Preload
C. Congestive heart failure
D. The end of the systolic cycle

**12. What is the Fick formula for cardiac output?**

A. Wt (kg) x 3/(Ao Sat – Pa Sat) x 1.36 x hemoglobin x 10
B. Wt (lbs) x 3/Ao Sat x Pa Sat) x 1.36 x 10
C. Height x weight/stroke volume x heart rate + hemoglobin
D. Wt (kg) x body surface area/ (Ao Sat + Pa Sat) x 80

**13. Using the Fick equation and patient data, what is the cardiac output for this patient?**

A. 3.34L/min
B. 5000mL/min
C. 5.0mL/hr
D. 6.0L/min

**14. What is cardiac output?**

A. Weight in kg/heart rate x 1.36
B. Stroke volume x heart rate
C. Stroke volume x cardiac index
D. Cardiac index x heart rate

**15. Based on the heart rate and cardiac output, what is the patient's stroke volume?**

A. 333ml
B. 30.3ml
C. 8.5L/min
D. 200L/min

**16. What is the formula for systemic vascular resistance?**

A. Mean PA pressure – mean RA pressure/cardiac output
B. Mean Ao pressure x mean RA pressure
C. Mean Ao pressure – mean RA pressure/cardiac output
D. Mean Ao pressure x cardiac index/5

**17. What is the metric unit for vascular resistance?**

A. dynes-5 /cm
B. dynes•sec•cm−5
C. mmHg
D. $Cm^2$ x dynes x 5

**18. Where, on the respiratory cycle, is the optimal measurement point for measuring atrial and wedge pressures?**

A. End inspiration.
B. You need inspiration and expiration, and average them.
C. End expiration.
D. Either one is OK, as long as you adjust the measurement scale.

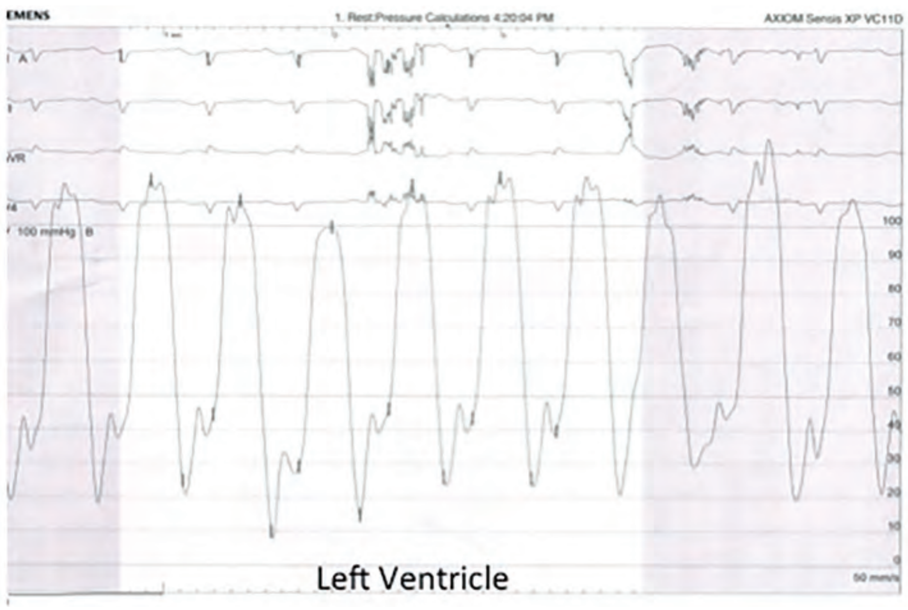



Figure 9. Left ventricle

**19. In which case might a thermodilution cardiac output be superior to a Fick?**

A. Low cardiac output state
B. Tricuspid valve regurgitation
C. Mitral valve stenosis
D. High cardiac output state

**20. In which case would a Fick cardiac output be superior to a thermodilution cardiac output?**

A. Low cardiac output state
B. Tricuspid valve regurgitation
C. Peripheral vascular disease
D. A & B
E. All of the above

**21. What is the formula for calculating mean arterial pressures?**

A. 3 systolic pressure + 1 diastolic/4
B. 2 systolic + 2 diastolic/4
C. 2 systolic + 1 diastolic/3
D. 2 diastolic + 1 systolic/3

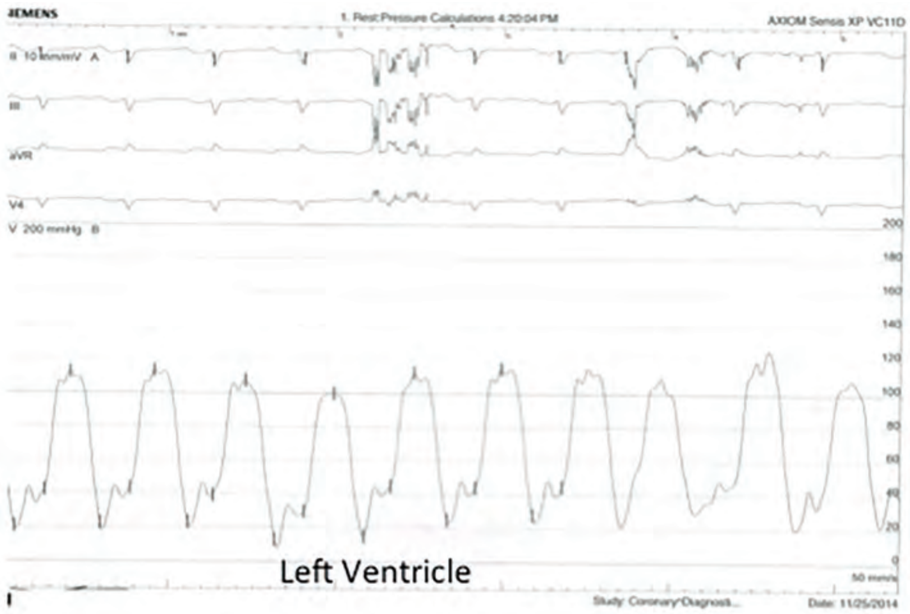



Figure 10. Left ventricle

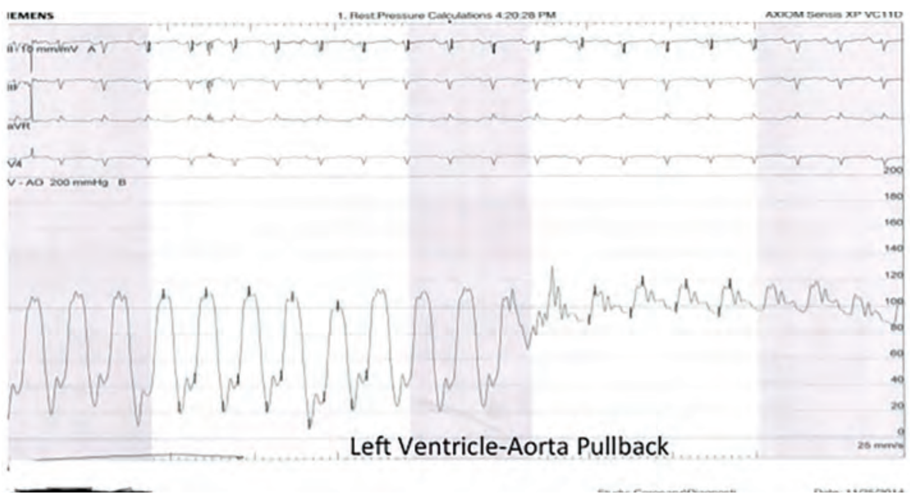



Figure 11. Left ventricle-aorta pullback

## A 51-year-old white male presented to the cardiac cath lab with a recent, progressive history of shortness of breath, chest pain on exertion, and fatigue.

**22. What is the formula for calculating mixed venous saturations?**

A. 3 SVC + 3 IVC/4
B. 3 IVC = 3/IVC
C. 3 SVC + Ao Sat/3
D. 3 SVC + 1 IVC/4

**23. Which hemodynamic pattern aligns with primary pulmonary hypertension?**

A. Elevated right ventricle, large V wave in the right atrium.
B. Elevated wedge pressure, normal pulmonary artery pattern.
C. Elevated LVEDP, normal right-sided measurements.
D. Normal wedge pressure and elevated pulmonary artery, right ventricle, and right atrial pressures.

**24. Which hemodynamic pattern aligns to left heart failure?**

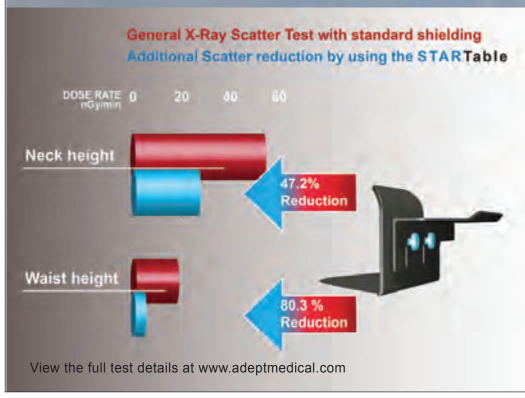
A. Elevated right atrial pressures
B. Normal wedge pressure and elevated pulmonary artery, right ventricle, and right atrial pressures.
C. Elevated A waves on the ventricular pressures.
D. The wedge pressure, pulmonary artery pressure, right ventricular pressure, and right atrial pressure are elevated.

**25. What is the most likely diagnosis for this patient, based off of the hemodynamic assessment?**

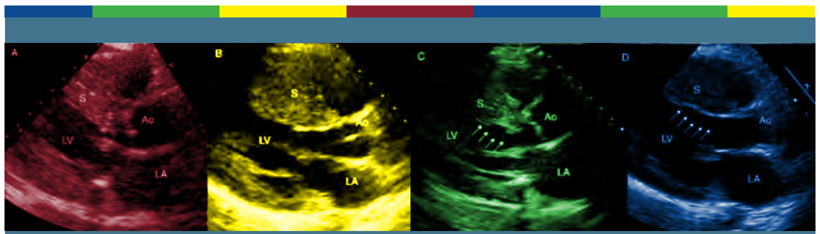
A. Left heart failure
B. Pulmonary hypertension
C. Mitral valve regurgitation
D. Atrial septal defect

Turn to page 42 for the Part II Answer Key and Discussion.







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# Test Your Hemodynamic Knowledge: Part II– The Answer Key

*Richard J. Merschen, EdS, RT(R)(CV), RCIS, Adjunct Assistant Professor, Jefferson School of Health Professions, Senior Staff Technologist, Pennsylvania Hospital Cardiac Catheterization Laboratory, Philadelphia, Pennsylvania*

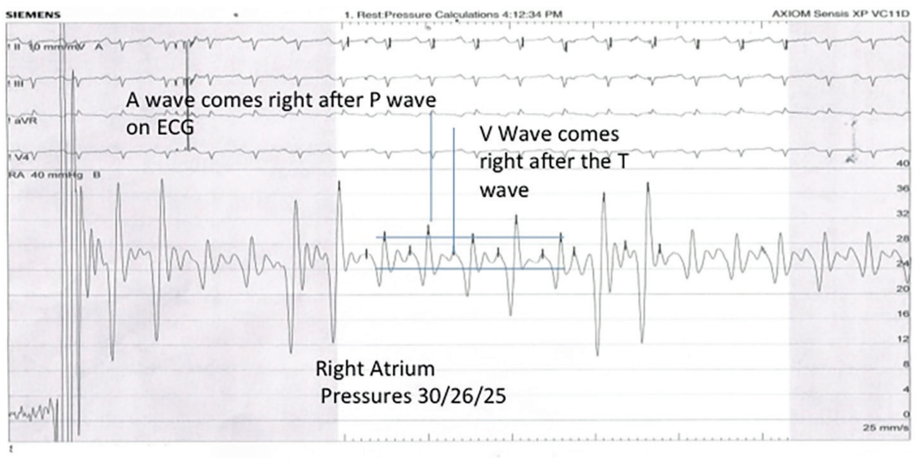


**Figure 1.** Right atrium

## Case

A 51-year-old white male presented to the cardiac cath lab with a recent, progressive history of shortness of breath, chest pain on exertion, and fatigue. The patient has a history of poorly controlled hypertension, hyperlipidemia, family history of coronary artery disease, and arthritis. Based on the patient history, a left and right heart catheterization and coronary angiography were ordered for the patient. The coronary arteries demonstrated no obstructive lesions. A left ventriculogram (LV gram) demonstrated an ejection fraction of 40%, with global hypokinesis.

*More information:*

1. Weight 234 lbs
2. Height 6'0"
3. Hemoglobin 16.5
4. Heart rate 110
5. Pa Sat 52%
6. Ao Sat 96%
7. Creatinine 1.07
8. Potassium 3.9
9. Platelets 234
10. INR 1.0
11. Blood pressure 160/90mmHg
12. Pulse ox 94%

**The diagnosis for this patient is left heart failure.** All of the key hemodynamics, including the left ventricular end diastolic pressure (LVEDP), pulmonary capillary wedge pressure (PCWP), pulmonary artery pressures, right ventricular end diastolic pressure (RVEDP), and right atrial pressures, are all elevated. When assessing pathology, it is important to study the entire collection of hemodynamic data. The PA saturation is also low, and in conjunction with these findings, supports the diagnosis of left heart failure.

The global hypokinesis, without an ischemic component, confirms a diagnosis of non-ischemic heart failure. In patients with heart failure, cardiac catheterization may be extremely important. If there is an ischemic component, revascularization may significantly improve the ejection fraction and reverse some of the damage. In this case, an ejection fraction of 40% is important, because treatment options such as implantable defibrillators, cardiac resynchronization therapy, and medical management strategies will be strongly influenced by the ejection fraction. It will also be important to know whether this is a dilated, hypertrophic, or restrictive disease process, as all of these factors influence long-term treatment. Furthermore, an angiographic ejection fraction may be highly valuable in patients who can tolerate it, as echocardiography is an excellent tool, but not perfect. In practice, there are cases where the angiographic output provides highly useful diagnostic information, and may contradict the non-invasive findings.

When assessing hemodynamics, some of the following questions will maximize the quality of the study and the data that is accumulated:

1. Is your transducer height correct? Measure the phlebostatic axis, as low or high transducer placement will supply false data.
2. Are the left sided pressures normal? If not, are they all abnormal, or is there a gradient?
3. Are the Swan-Ganz pressures normal? Remember that the wedge pressure is really an indirect left-sided measurement. If there is an abnormality, where does the abnormal flow pattern begin?
4. Is there a gradient? If so, where does it occur?
5. Are there elevated V waves? If so, are they associated with the left or right atrium, or both?
6. Are the vascular resistance measurements normal? Vascular resistance is extremely important in diagnosing cardiopulmonary disease, and is especially valuable in diagnosing and treating pulmonary hypertension. Vascular resistance measurements also determine cardiac afterload, the resistance that the ventricles must overcome to eject blood into the arteries.
7. Are the mixed venous and arterial saturation samples normal?
8. Do the mixed venous samples align with the pulmonary artery sample? If not, does a shunt run need to be performed?
9. How high are the mixed venous saturations? Extremely low mixed venous saturations are often associated with critical pathology such as heart failure and cardiac tamponade, because blood is flowing abnormally slowly through the vascular circuit.
10. Are the hemodynamics being recorded on the correct scale? In this case, the initial right-sided pressures and wedge pressures were recorded on 40mmHg scale, but increased to 100 scale. Excellent hemodynamic recording requires using the proper scale, especially when respiratory variances and other factors can make it difficult to accurately measure hemodynamics. Always keep your waveform in the scale so it can be hand calculated and verified by the physician, if necessary.

## Test Your Knowledge: Answers

**1. What is the normal mean pressure range for the right atrium?**

**A. 2-6mmHg**
B. 4-18mmHg
C. 25/5mmHg
D. 12-16mmHg

The normal pressure for the right atrium is around 2-6mmHg. When reviewing right atrial pressures, several tips will help to interpret the waveform. Make sure you have a quality ECG. The A wave, which provides the atrial kick and supplies the ventricle with the final 20-25% of its blood, closely follows the P wave of the ECG. The A wave is the mechanical response to the P wave of the ECG. The decline that occurs immediately after the A wave is known as the x descent and demonstrates atrial emptying. Line up a sheet of paper to the ECG and waveform, and you will see how the atrial A wave follows the electrical activity of the P wave.

The V wave, which represents the end of cardiac systole, aligns to the T wave of the ECG. It is rapidly followed by the Y descent, which reflects the diastolic phase of the cardiac cycle. In this phase, 75-80% of the blood passively spills into the ventricles. Line a sheet of paper up to the T wave and the V wave will align closely to it.

**2. What is this patient's mean right atrial pressure?**

**A. 25mmHg**
B. 10mmHg
C. 5mmHg
D. 100mmHg

This patient's right atrial pressure is approximately 25mmHg, which is significantly elevated. Advance the Swan catheter and determine the source of the pressure elevation. In cases where the pressure is this elevated, causes such as left heart failure, pulmonary hypertension, pulmonic valve disease, and tricuspid regurgitation are among the likely causes. Continue to advance the

**Table 1. Normal Pressure Ranges**

| Chamber measured | Systolic | Diastolic | Mean | End diastolic | A wave | V wave |
|---|---|---|---|---|---|---|
| Right Atrium | | | 2-6 | | 4-6 | 2-4 |
| Right Ventricle | 25 | | | 5 | | |
| Pulmonary Artery | 25 | 10 | 15 | | | |
| Pulmonary Capillary Wedge | | | 12-16 | | 12-16 | 8-12 |
| Left Ventricle | 110-130 | | | 12-16 | | |
| Aorta | 110-130 | 60-80 | 70-90 | | | |

This article received a double-blind peer review from members of the *Cath Lab Digest* editorial board.

Richard J. Merschen, EdS, RT(R)(CV), RCIS, can be contacted at richardmerschen@verizon.net.

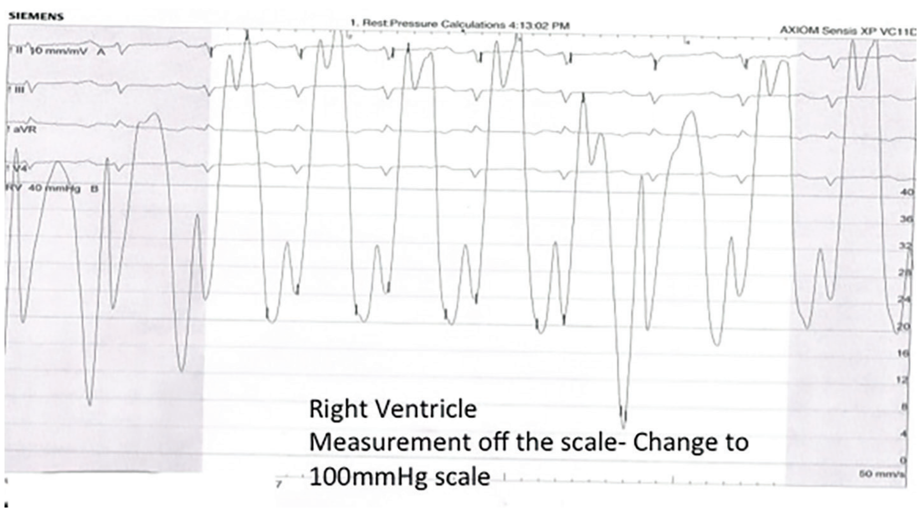


Figure 2. Right ventricle

catheter to determine the source of pressure elevation.

**3. What does the atrial A wave mean and which wave of the ECG does it follow?**

- A. Passive filling of the ventricle. Found on the T wave.
- **B. The atrial kick, found just after the P wave.**
- C. The atrial kick. Found after the QRS complex.
- D. Contraction of the ventricle. Located at the ST segment.

The mechanical activity of the heart always follows the electrical activity of the heart. Since the P wave reflects atrial depolarization or contraction, look for the A wave to come directly after the OP wave. In the case of a wedge pressure, there will be a delay, and the A wave may show up just after the QRS complex. The A wave is important, because it reflects the atrial kick, which drives 20-25% of the atrial blood into the left ventricle and helps establish the preload state (end diastolic pressure, EDP) of the ventricle. Line a piece of paper up to the P wave of the ECG and move the paper to the right. When you see an elevated portion of the waveform, you have found the A wave. In a case like atrial fibrillation where there is no P-wave on the ECG, there is no atrial kick, and therefore, no A wave on the atrial waveform.

**4. What is the normal pressure for the right ventricle?**

- A. 12/16/14
- **B. 25/5**
- C. 75/15/15
- D. 40/15

The normal pressure for the right ventricle is approximately 20 systolic and 5 end diastolic pressure. Mean pressures are not recorded in the ventricles. They are pumps, which have a very high systolic and low diastolic pressure. Elevated end diastolic pressures mean the preload state of the patient is high. This can suggest heart failure and other important pathology such as pulmonary artery hypertension. The ventricles are the critical structures for cardiac systole, and generate the force that is necessary to overcome arterial diastolic pressures. It is important to understand the concept of vascular resistance when discussing the ventricles, and important emergency support equipment such as the intra-aortic balloon pump (IABP) is specifically designed to reduce afterload and the workload that the ventricle has to overcome. In this patient, the right ventricular pressures are elevated, and the catheter should be advanced to find the source of pressure elevation.

**5. Which portion of the ventricular waveform represents the preload state?**

- A. Systolic peak
- B. Beginning diastole
- **C. End diastolic pressure**
- D. The ventricular upstroke

The end diastolic pressure (EDP) is an important measurement for the ventricle. The physicians routinely ask for pressures to be performed on a 40-50mmHg scale, and increase the paper speed to at least 50mm/sec to assess the EDP. It reflects the preload state, and is a highly valuable measurement. It can be used to determine if patients are fluid overloaded, in heart failure, and if they can be aggressively hydrated for conditions like kidney disease. Along with isovolumetric contraction and afterload, preload is a primary determinant of cardiac output.

**6. What is the normal pressure for the pulmonary artery?**

- A. 45/10/40
- B. 30/30/24
- **C. 25/10/15**
- D. 50/15/33

The normal pressure for the pulmonary artery is approximately 25 systolic, 10 diastolic, and a mean pressure of 15. In this patient, the pulmonary artery pressures are extremely elevated. This suggests either pulmonary artery hypertension or left heart failure that is elevating right-sided pressures. It is important to obtain a wedge pressure at this point, to see if the patient has pulmonary hypertension (PHTN) or a left-sided source that is causing the pressure elevation. By

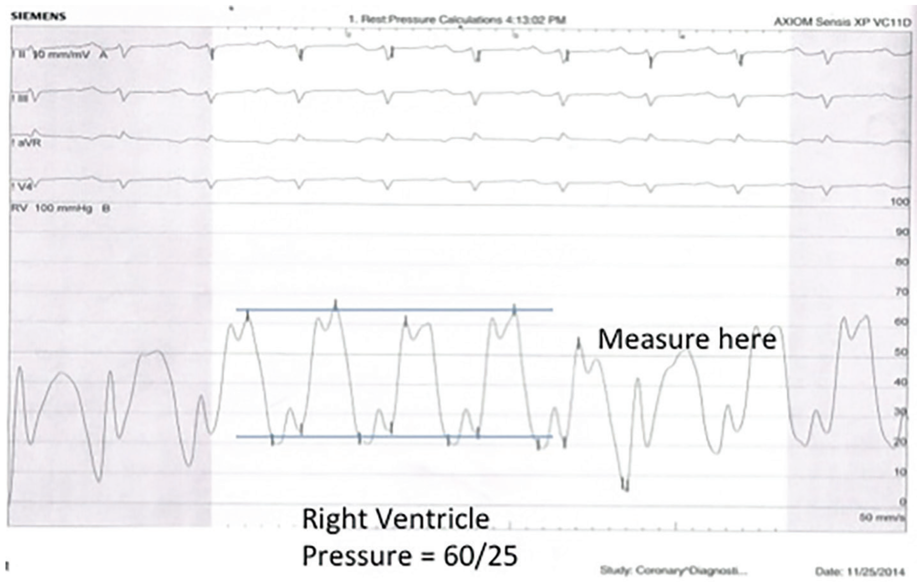


Figure 3. Right ventricle

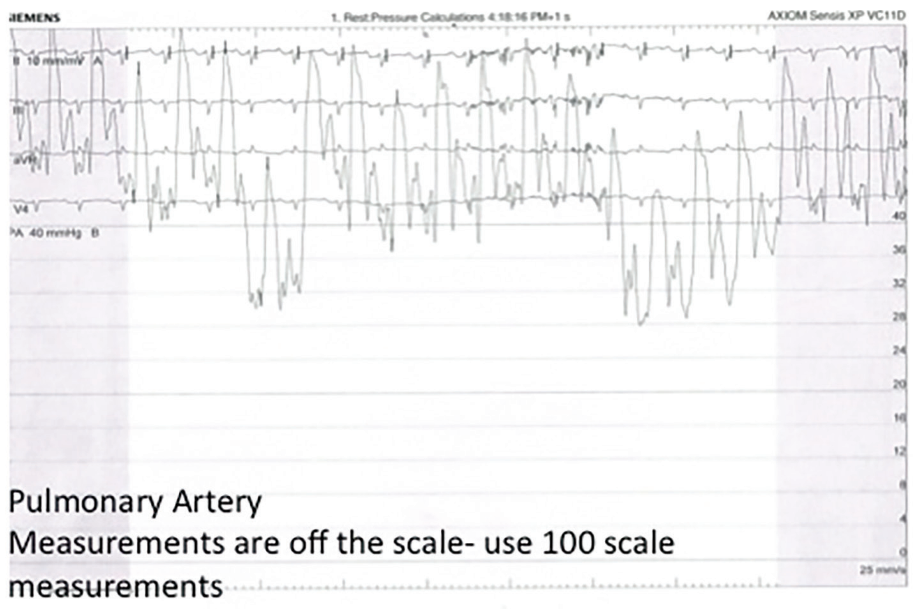


Figure 4. Pulmonary artery

calculating effective mean pulmonary artery pressures and mean wedge pressures, a pulmonary vascular resistance can be calculated to determine if there is pulmonary artery hypertension, and the severity of PHTN, should it exist. Because this pressure is elevated, the catheter should be advanced into the pulmonary capillary beds for left heart analysis.

**7. What is the patient's pulmonary vascular resistance, in wood units, based off of the hemodynamics and cardiac output?**

- **A. 0.6**
- B. 1234
- C. 100H
- D. 70

In this case, the pulmonary vascular resistance is calculated by taking the mean pulmonary artery pressure (47) — the mean wedge pressure (45)/cardiac output (3.34). Pulmonary vascular resistance is extremely valuable in assessing pulmonary artery hypertension, as well as other pathologies. Look at the hemodynamics of this case and assess the mean pressures. This is an important skill, and accuracy is important for diagnosing a variety of pathologies. Vascular resistance is a reflection of cardiac afterload, a primary determinant of cardiac output.

**8. What is the patient's pulmonary vascular resistance, based off of metric units?**

- **A. 48 dynes•sec•cm−5**
- B. 1234 dynes-5/cm
- C. 56 grays
- D. 4.8 psi

Take the answer from question 14 and multiply it by 80 to get the metric answer. The computers in most labs provide vascular resistance and other calculation in metric units. In order to convert metric units to Wood units, divide your answer by 80. Normal pulmonary vascular resistance (PVR) is 20-120 dynes. In this case, the pulmonary vascular resistance is normal, primarily because the pulmonary artery pressures and wedge pressures are both severely elevated. You will find that many physicians like to use Wood units, so being able to convert from metric to

*continued on page 44*

## Hemo Answer Key

*Continued from page 43*

Wood units is a skill that many interventional cardiologists will appreciate.

**9. What is a normal pulmonary capillary wedge pressure?**

- **A. 12-16mmHg mean**
- B. 2-6mmHg mean
- C. 10-30mmHg mean
- D. 14-45mmHg

The normal PCWP pressure is around 12-16mmHg mean pressure. The PCWP is a left-sided pressure, and pathology associated with elevated wedge pressure is usually associated with left heart failure, or mitral valve stenosis. Because the wedge pressure is measured during the "right heart catheterization," it is more accurate to think of a "right heart cath" as a hemodynamic study that looks at both left and right-sided pressures. Elevated wedge pressures are a classic finding for left heart failure. They may also indicate mitral valve stenosis. If the wedge pressure is associated with an elevated V wave, this is often associated with mitral valve regurgitation.

When measuring the wedge pressure, there are a couple of points to remember for practice. The wedge pressure is delayed, in relationship to the right atrial pressure because it is an indirect measurement. Therefore, the A wave will usually arise shortly after the QRS complex, and the V wave will seem to be slightly before the A wave. This is important in making a diagnosis of mitral regurgitation, characterized by a classic, elevated V wave in the wedge pressure measurement. The first positive waveform after the P wave is the A wave, and the second positive waveform is the V wave.

**10. What is this patient's mean pulmonary capillary wedge pressure?**

- A. 55mmHg
- B. 10mmHg
- **C. 43mmHg**
- D. 6mmHg

This patient's mean wedge pressure is around 45mmHg. This is significantly elevated, and is highly suggestive of left heart failure in a patient with progressive shortness of breath. Other conditions such as mitral valve disease can also cause elevated wedge pressures, so it is important to understand the medical history and clinical presentation of the patient. When pressures are elevated to this extent, consider changing the scale for recording. A scale of 100mmHg is better than a scale of 40mmHg to identify the elements of the waveform properly.

**11. What does the left ventricular end diastolic pressure (LVEDP) indicate?**

- A. Afterload
- **B. Preload**
- C. Congestive heart failure
- D. The end of the systolic cycle

The LVEDP shows the preload state of the heart. This is the maximum stretch of the ventricle, right before it ejects blood through the aortic valve into the artery. High preload states are associated with heart failure, and/or fluid overload. Along with isovolumetric contractility and afterload, preload is one of the three determinants of cardiac output. This patient's LVEDP is 40mmHg, which is consistent with heart failure/fluid overload.

**12. What is the Fick formula for cardiac output?**

- **A. Wt (kg) x 3/(Ao Sat – Pa Sat) x 1.36 x hemoglobin x 10**
- B. Wt (lbs) x 3/Ao Sat x Pa Sat) x 1.36 x 10
- C. Height x weight/stroke volume x heart rate + hemoglobin
- D. Wt (kg) x body surface area/(Ao Sat + Pa Sat) x 80

The Fick formula has 2 variants, but both assess the same factors. They take the presumed oxygen content/the difference between arterial and venous saturation.

You can use either (BSA x 125) or (weight in kilograms x 3)/(Ao Sat–Pa Sat) x Hemoglobin x 1.36 x 10. These are presumed values and may not be completely accurate. Many variables can influence the output, including supplemental oxygen, sedation, and septal defects. Therefore, know your patient and consider how the clinical presentation may facilitate the need to calculate a thermodilution (TD) or angiographic output.

**13. Using the Fick equation and patient data, what is the cardiac output for this patient?**

- **A. 3.34L/min**
- B. 5000mL/min
- C. 5.0mL/hr
- D. 6.0L/min

The Fick cardiac output is based off of presumed oxygen consumption divided by the difference between the aortic and mixed venous saturations. Wt (kg) x 3/(Ao Sat - Pa Sat) x 1.36 x Hemoglobin x 10. For this patient, the cardiac output was calculated as follows:

(106kg x 3) = 308/(0.96-0.52) x 16.5 x 1.36 x 10 = 3.34L/min

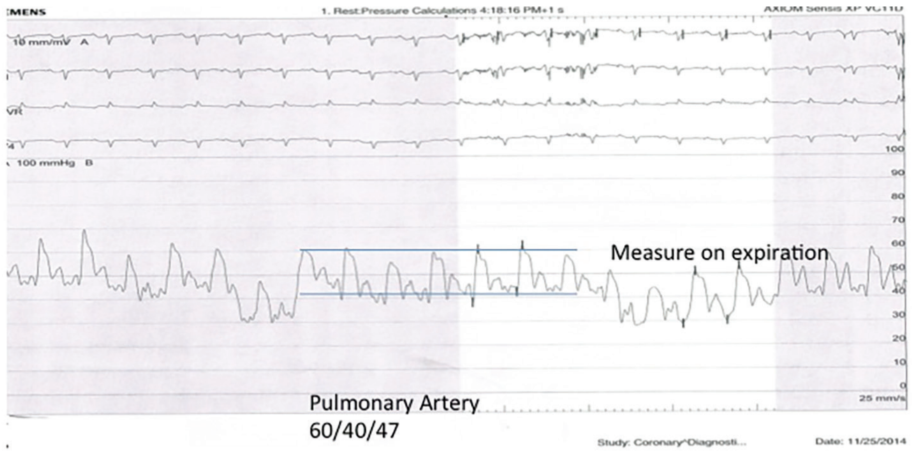


**Figure 5.** Pulmonary artery

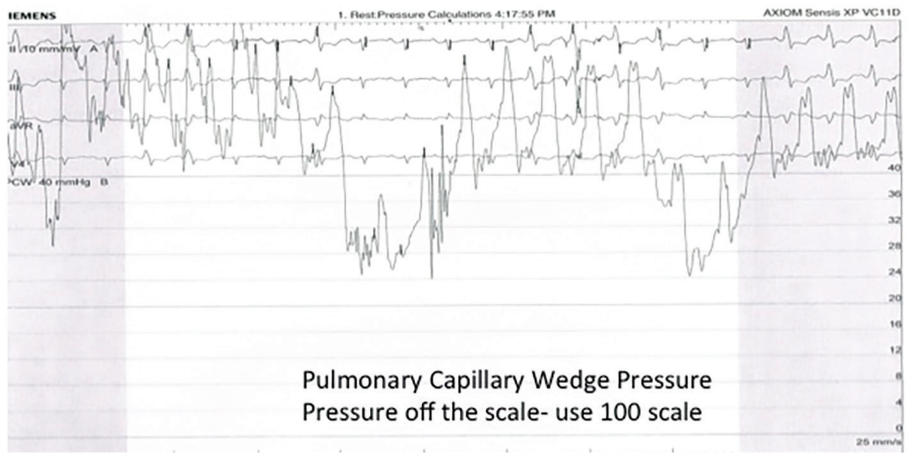


**Figure 6.** Pulmonary capillary wedge pressure (PCWP)

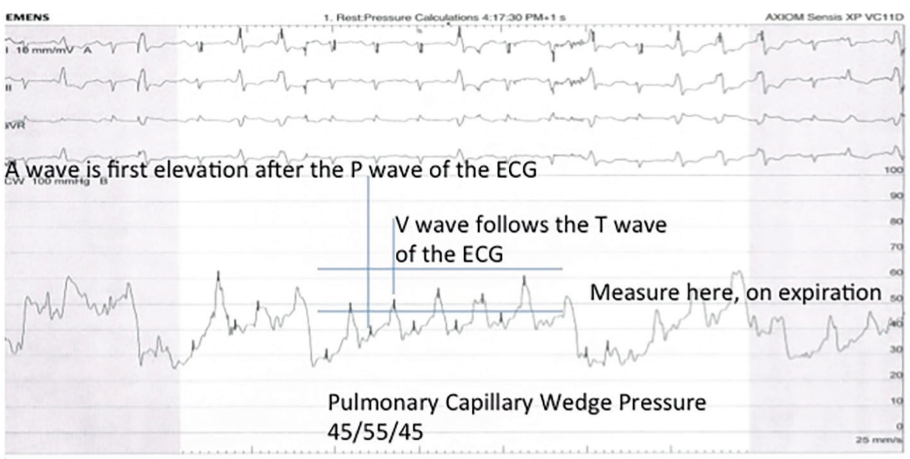


**Figure 7.** Pulmonary capillary wedge pressure (PCWP)

Remember that saturations are percentages and you must place a decimal point in front for an accurate calculation.

**14. What is cardiac output?**

- A. Weight in kg/heart rate x 1.36
- **B. Stroke volume x heart rate**
- C. Stroke volume x cardiac index
- D. Cardiac index x heart rate

Fundamentally, cardiac output equals stroke volume x heart rate. If any two of these variables is known, the third can be easily calculated. In this case, the patient's cardiac output is 3.34L/min and the heart rate is 110. To calculate stroke volume, convert the output to milliliters and divide by the heart rate.

**Table 2. Normal Vascular Resistance**

| Vascular Resistance | Wood units | Wood formula | dyn·s/cm5 | Metric formula |
|---|---|---|---|---|
| Pulmonary Vascular Resistance | 0.25-2 | PA mean–PCWP mean/ Cardiac output | 20-160 | PA mean–PCWP mean/ Cardiac output x 80 |
| Systemic Vascular Resistance | 8-20 | AO mean–RA mean/ Cardiac output | 600-1400 | AO mean–RA mean/ Cardiac output x 80 |

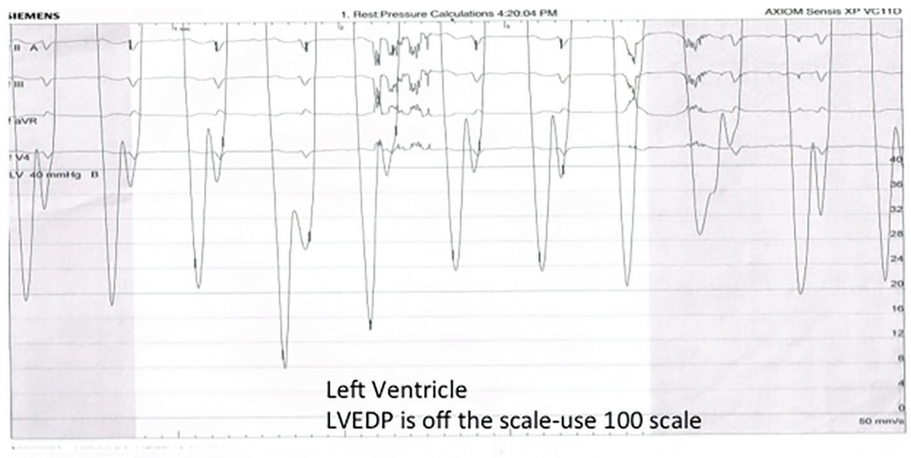


**Figure 8.** Left ventricle

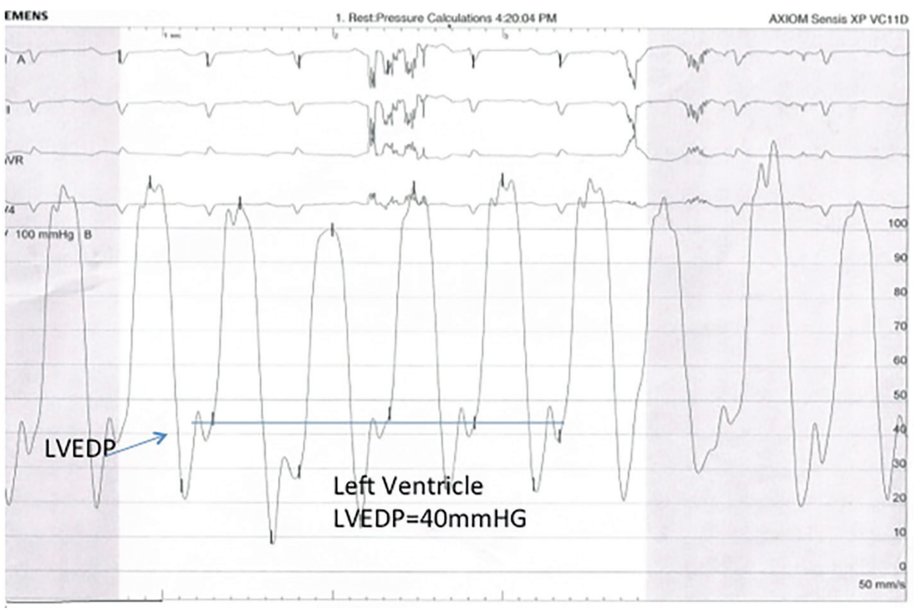


**Figure 9.** Left ventricle

**15. Based on the heart rate and cardiac output, what is the patient's stroke volume?**

A. 333mL
**B. 30.3mL**
C. 8.5L/min
D. 200L/min

Stroke volume (SV) is volume ejected by the ventricle on each beat. When the stroke volume is multiplied by the heart rate (HR), it equals cardiac output (CO) in mL/min. In this case, the cardiac output is 3340mL/min/110 heart rate = 30.3mLs stroke volume. This is abnormally low, and another predictor of left heart failure in this patient.

SV x HR = CO
CO/HR = SV
CO/SV = HR

**16. What is the formula for systemic vascular resistance?**

A. Mean PA pressure – mean RA pressure/cardiac output
B. Mean Ao pressure x mean RA pressure
**C. Mean Ao pressure – mean RA pressure/cardiac output**
D. Mean Ao pressure x cardiac index/5

See Table 2. Systemic vascular resistance is used to help diagnose a wide variety of pathology including hypertension sepsis, and hypovolemic and cardiogenic shock. It is also important in understanding and estimating ventricular afterload, which is a primary determinant of cardiac output.

**17. What is the metric unit for vascular resistance?**

A. dynes-5 /cm
**B. dynes•sec•cm−5**
C. mmHg
D. $Cm^2$ x dynes x 5

Most computers record vascular resistance in metric units of dynes·sec·cm−5. To convert Wood units to metric units, simply multiply the Wood answer by 80. To convert the metric numbers to Wood units, divide the metric answer by 80. If the physician is performing tests on the patient to determine response to pulmonary hypertension, they might want to use Wood units, rather than metric units, to record real-time calculations.

**18. Where, on the respiratory cycle, is the optimal measurement point for measuring atrial and wedge pressures?**

A. End inspiration.
B. You need inspiration and expiration, and average them.
**C. End expiration.**
D. Either one is OK, as long as you adjust the measurement scale.

The best area to assess hemodynamic pressures is at end expiration. This is described as the area where the measurement "falls off the cliff." The extremely low pressures are generated by the negative pressure created by the inspiratory effort. They can grossly distort accurate hemodynamics in patients who have significant respiratory variance. This includes patients who have sleep apnea, chronic obstructive pulmonary disease (COPD), and other lung diseases.

In this patient, there is a sharp respiratory variance on the wedge pressure waveforms. It is important to make sure that the computer aligns with the expiratory measurements, and that the mean pressure is accurate, because it determines pulmonary vascular resistance. A tip to improve practice is to color in the "valleys" that occur during the inspiratory effort and then discard them.

**19. In which case might a thermodilution cardiac output be superior to a Fick?**

A. Low cardiac output state
B. Tricuspid valve regurgitation
C. Mitral valve stenosis
**D. High cardiac output state**

Cardiac output (CO) can also be measured by thermodilution technique. Thermodilution CO involves the use of a catheter with a proximal and distal port, as well as a thermistor, to measure temperature changes. Saline, which may be chilled, is injected into the proximal portion of the catheter, which lies in the right atrium. The injectate mixes with blood and warms up as it passes through the pulmonary arteries. This temperate change is captured by the thermistor and an output is generated. Typically, around 4-5 injections are performed, the outliers are discarded, and an average is taken.

Thermodilution cardiac output is highly useful in patients with very high cardiac outputs, because very slight changes in Ao or Pa saturation can cause large changes in cardiac output via the Fick method.

The TD technique is usually contraindicated in patients with tricuspid regurgitation, because the injectate isn't able to cross the right atrium and reach the pulmonary artery before it becomes too diluted.

**20. In which case would a Fick cardiac output be superior to a thermodilution cardiac output?**

A. Low cardiac output state
B. Tricuspid valve regurgitation
C. Peripheral vascular disease
**D. A & B**
E. All of the above

In the cases of low cardiac output, and especially in tricuspid valve regurgitation, the thermodilution method is not recommended as the best option. The TD method involves injecting saline from the proximal port in the right atrium and calculating the temperature change as the mixed blood and saline reaches the thermistor tip in the pulmonary artery. If the flow is significantly reduced from the right atrium to the pulmonary artery, this can distort the data, and it may even be impossible to get a reading if a patient has severe tricuspid valve regurgitation.

**21. What is the formula for calculating mean arterial pressures?**

A. 3 systolic pressure + 1 diastolic/4
B. 2 systolic + 2 diastolic/4
C. 2 systolic + 1 diastolic/3
**D. 2 diastolic + 1 systolic/3**

Mean arterial pressures reflect effective perfusion. In the systemic circulation, it is an indication of effective perfusion to the vital organs. In this patient, who has a blood pressure of 120/95mmHg (see pullback arterial pressure), 120 + 95 + 95 = 103mmHg

**22. What is the formula for calculating mixed venous saturations?**

A. 3 SVC + 3 IVC/4
B. 3 IVC = 3/IVC
C. 3 SVC + Ao Sat/3
**D. 3 SVC + 1 IVC/4**

Mixed venous saturation is an important calculation in assessing cardiac output and potential septal defects. It is calculated by taking the SVC(3) + IVC(1)/4. If the mixed venous saturations are normal and the pulmonary artery saturation is elevated, a shunt run should be performed to evaluate a patient for atrial or ventricular septal defects. If the mixed venous saturation and the pulmonary artery saturations align, the patient has a high cardiac output state.

**23. Which hemodynamic pattern aligns with primary pulmonary hypertension?**

A. Elevated right ventricle, large V wave in the right atrium.
B. Elevated wedge pressure, normal pulmonary artery pattern.
C. Elevated LVEDP, normal right-sided measurements.
**D. Normal wedge pressure and elevated pulmonary artery, right ventricle, and right atrial pressures.**

In this case, all of the pressures are elevated. If you are only performing a hemodynamic study, avoid using the phrase "right heart catheterization". The wedge is reflective of left ventricular end diastolic pressure, and predicts left-sided heart disease. If this patient had a normal wedge pressure, with the elevations on the right side, pulmonary artery hypertension and right heart failure would be important considerations for diagnosis. Pulmonary vascular resistance would also become a key component of the diagnosis of pulmonary artery hypertension.

*continued on page 46*

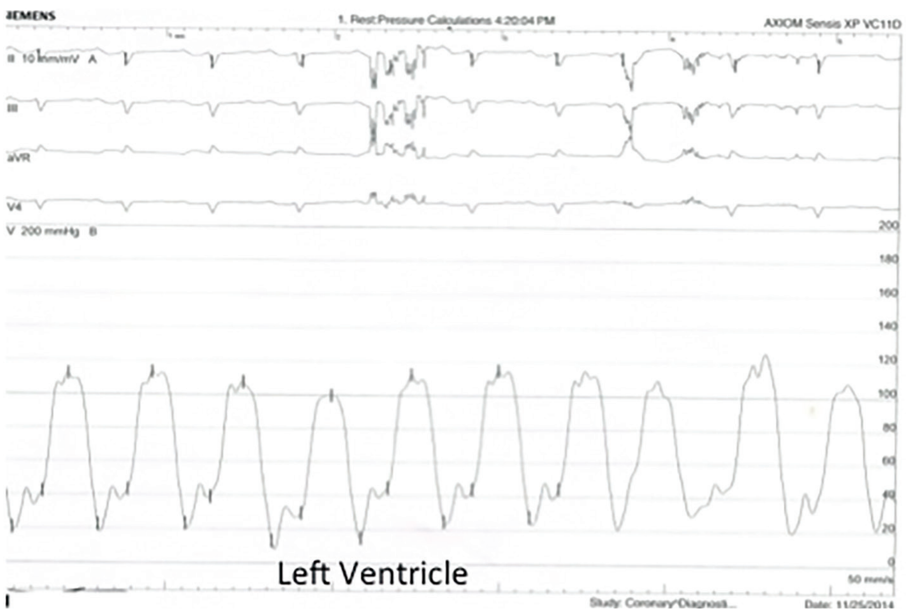


**Figure 10.** Left ventricle

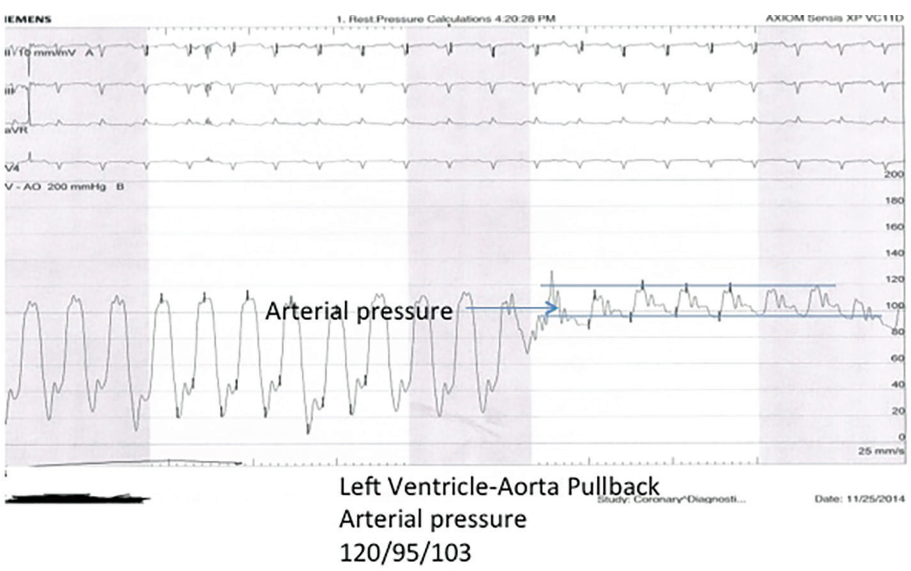


**Figure 11.** Left venticle-aorta pullback

## Hemo Answer Key

*Continued from page 45*

**24. Which hemodynamic pattern aligns to left heart failure?**

A. Elevated right atrial pressures
B. Normal wedge pressure and elevated pulmonary artery, right ventricle, and right atrial pressures.
C. Elevated A waves on the ventricular pressures.
**D. The wedge pressure, pulmonary artery pressure, right ventricular pressure, and right atrial pressure are elevated.**

Remember that the wedge pressure is left sided. Combine this with the elevated left ventricular EDP measurements, as well as all of the right-sided measurements being elevated, and it is highly likely that this patient is in left heart failure.

**25. What is the most likely diagnosis for this patient, based off of the hemodynamic assessment?**

**A. Left heart failure**
B. Pulmonary hypertension
C. Mitral valve regurgitation
D. Atrial septal defect

There is global elevation of all the cardiopulmonary hemodynamics. This is a case demonstrating classic left-sided heart failure. If the left-sided pressures were normal, the possibility of pulmonary hypertension/right heart failure could be considered. It is important to note that as the left ventricle loses its effectiveness as a pump, all of the pressures will rise, and it is not unusual to see patients who have left-sided failure eventually develop right-sided heart failure as well. There is also a very low pulmonary artery (mixed venous) saturation and global hypokinesis on the ventriculogram. At this point, a comprehensive workup should be performed to identify the causes and treatment options for this patient.

Accurate interpretation of cardiac hemodynamics is foundational for cath lab practice. Over the past several months, the *Cath Lab Digest* Editorial Board has reached the consensus that reinforcing the basics of cardiac hemodynamics is a priority for all cath lab practitioners. In upcoming issues, there will be a series of initiatives, articles, and case studies presented to improve staff knowledge and reinforce cath lab fundamentals. ■

### Recommended reading

There is a wealth of material that can offer an increased understanding of cardiac hemodynamics. Some important resources include the following:

Bonow RO, Mann DL, Zipes DP, Libby P, eds. *Braunwald's Heart Disease: A Textbook of Cardiovascular Medicine. 9th ed.* Philadelphia, PA: Saunders Elsevier; 2012.
Kern MJ. *The Cardiac Catheterization Handbook. 5th ed.* Philadelphia: Saunders Elsevier; 2011.
Moscucci M, ed. *Grossman & Baim's Cardiac Catheterization, Angiography, and Intervention. 8th ed.* Philadelphia, PA: Lippincott, Williams and Wilkins; 2014.
Wes Todd's Cardiovascular Review. A Comprehensive Review of CVT Exams. CD-ROM or Flash Drive. Cardiac Self Assessment, Spokane WA. 2012. Available online at http://www.westodd.com. Accessed February 12, 2015.

[A]s the left ventricle loses its effectiveness as a pump, all of the pressures will rise, and it is not unusual to see patients who have left-sided failure eventually develop right-sided heart failure as well. There is also a very low pulmonary artery (mixed venous) saturation and global hypokinesis on the ventriculogram.