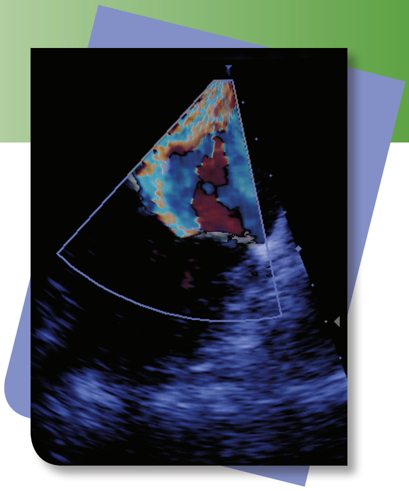
Chapter **21**



Doppler Parameters of Ventricular Function

Louai Razzouk and Muhamed Saric

1. A 45-year-old female is being evaluated for progressive shortness of breath over the past 6 weeks. Transthoracic echocardiography (TTE) was performed, and the following continuous-wave spectral Doppler tracing of the mitral regurgitant (MR) jet was obtained from the apical four-chamber view (FIG. 21.1). Letters A through D represent Doppler velocities; corresponding time points are labeled Ta through Td.

Fig 21.1

Which is the correct formula for calculating left ventricular dP/dT, a measure of systolic function?

A. $(4C^2 - 4A^2)/(Tc - Ta)$
B. $(4B^2 - 4A^2)/(Tb - Ta)$
C. $(4D^2 - 4C^2)/(Td - Tc)$
D. $(4D^2 - 4B^2)/(Td - Tb)$
E. $(4D^2 - 4A^2)/(Td - Ta)$

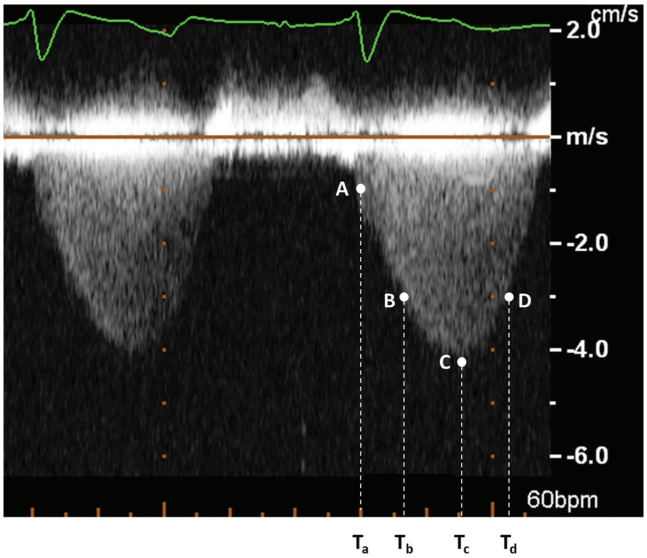


FIGURE 21.1

2. The pulsed-wave Doppler tracing of the left ventricular outflow tract (LVOT) in FIGURE 21.2 was obtained on TTE. The LVOT velocity time integral (VTI) was measured at 20 cm.

Which of the following patients (labeled A through E) with the above LVOT VTI would have the highest effective systemic cardiac output (CO)?

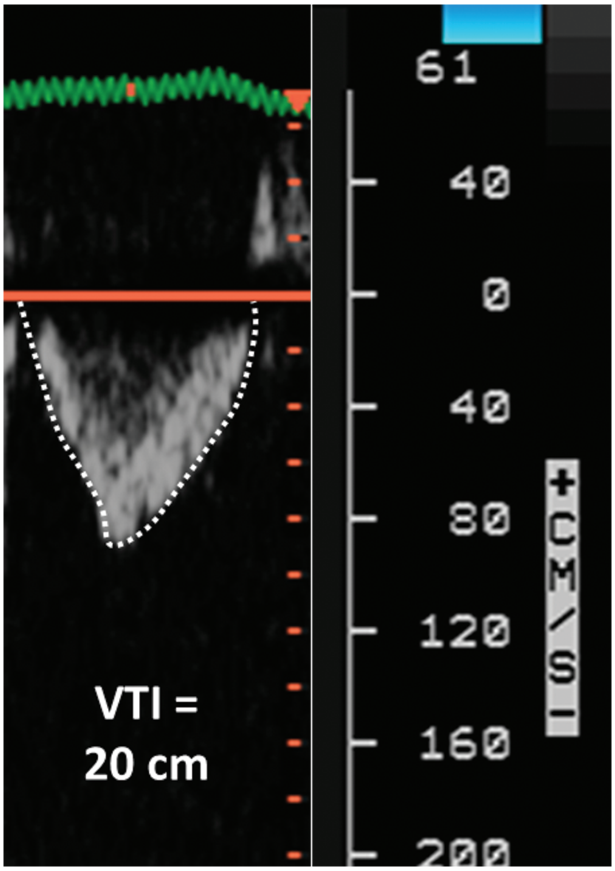


FIGURE 21.2

	A	B	C	D	E
Blood pressure (mm Hg)	90/50	120/80	150/60	100/60	110/70
Heart rate (beats per minute)	60	60	80	70	85
LVOT diameter (cm)	2.0	2.1	2.1	1.8	1.7
Other findings	Mitral stenosis; mitral valve area 1.2 cm^2	Mitral regurgitation; regurgitant volume 30 mL	Aortic regurgitation; regurgitant volume 20 mL	Atrial septal defect with left-to-right shunt; shunt volume 25 mL	Aortic stenosis; aortic valve area 1.8 cm^2

3. A 67-year-old male undergoes TTE for evaluation of a murmur. The flow across the mitral valve is evaluated using pulsed-wave spectral Doppler (left panel in FIG. 21.3) as well as by measuring the mitral annular diameter in the apical four-chamber (A4C) view (middle panel) and the apical two-chamber (A2C) view (right panel). At the time of TTE, blood pressure = 120/70 mm Hg and heart rate 80 beats per minute.

Which is the correct statement regarding the assessment of antegrade flow across the mitral valve?

A. To calculate the stroke volume (SV), pulsed-wave spectral Doppler sample volume is placed at mitral leaflet tips.
B. Mitral annular diameters are measured at peak systole as a distance between inner edges of the annulus.
C. In normal individuals, the SV across the mitral valve is always greater than the SV across the LVOT.
D. Patients with severe mitral regurgitation have a lower diastolic SV at the mitral orifice compared to patients with no regurgitation.
E. In patients with patent ductus arteriosus, the mitral SV multiplied by the heart rate represents the pulmonic flow (Qp).

4. An 82-year-old female undergoes TTE for follow-up of aortic stenosis. Her aortic valve area is calculated at 1.2 cm^2, and the mean aortic valve gradient is 32 mm Hg. The pulsed-wave spectral Doppler tracings of the mitral inflow and the right upper pulmonary vein are shown in FIGURE 21.4.

Which is the correct statement regarding the Doppler assessment of her left ventricular function?

A. The ratio of peak systolic (S) to peak diastolic (D) velocity of pulmonary vein inflow in this patient is indicative of elevated left atrial pressure (LAP).
B. In normal individuals, the atrial reversal (AR) wave lasts at least 30 ms longer than the mitral A wave.
C. In atrial fibrillation, the pulmonary vein diastolic (D) wave disappears.
D. The patient has elevated left ventricular end-diastolic pressure.
E. The peak velocity of the pulmonary vein AR wave is abnormally low.

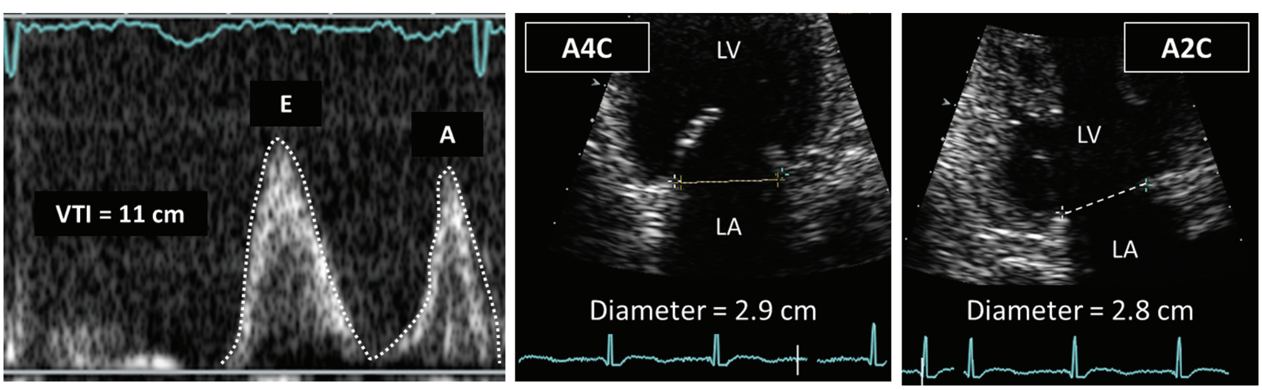


FIGURE 21.3

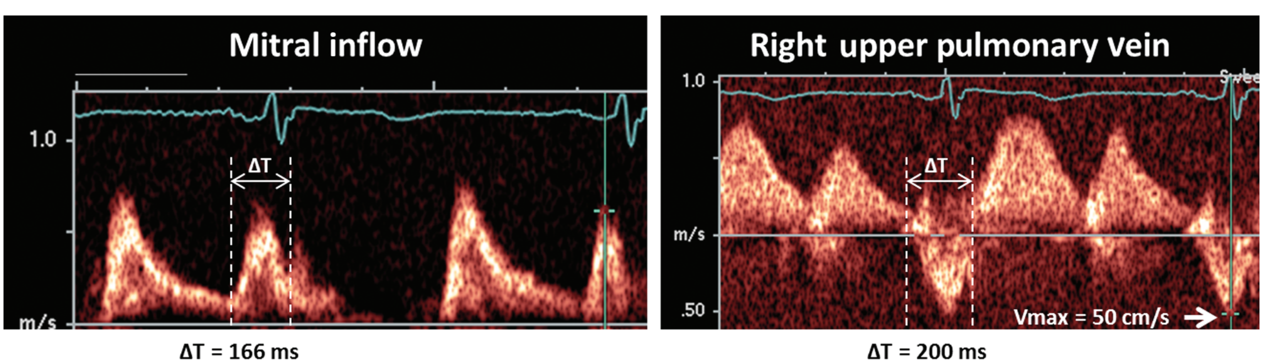


FIGURE 21.4

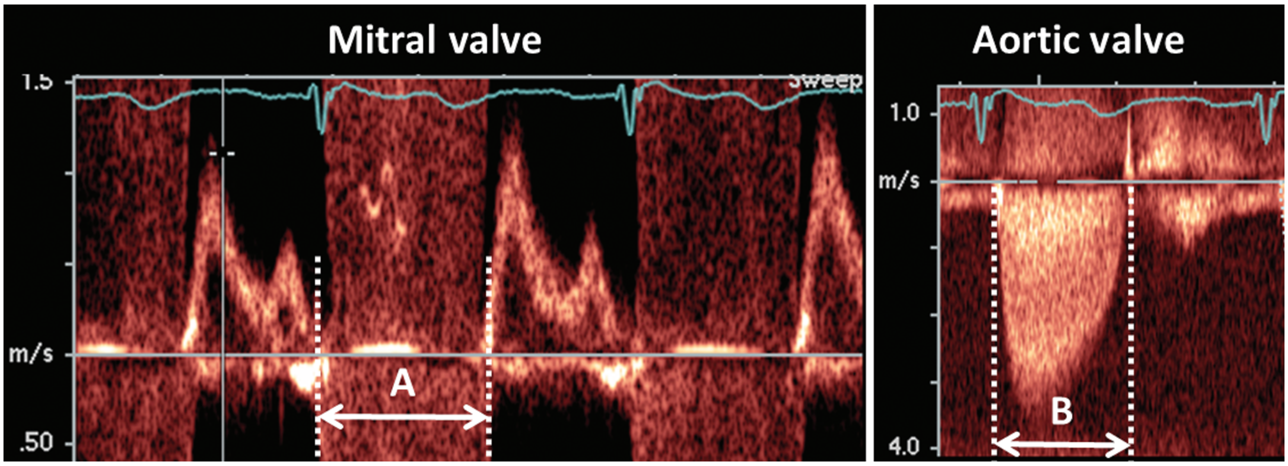


FIGURE 21.5

5. A 68-year-old male presents with new-onset dyspnea on exertion. TTE revealed moderate aortic stenosis and mild to moderate mitral regurgitation. Spectral Doppler tracings of the mitral and aortic valve are shown in FIGURE 21.5.

Q2 Which of the following is the correct formula for calculating the myocardial performance index (MPI), also known as the Tei index?

A. (A – B)/A
B. A/(A + B)
C. (A – B)/B
D. (A + B)/A
E. B/(A + B)

6. A 45-year-old female presented with chronic lower extremity edema. TTE revealed a left ventricular ejection fraction of 35% and no significant valvular disease. The left ventricular tracings in FIGURE 21.6 were obtained on this patient.

Which of the following is a correct statement?

A. Pulmonary artery wedge pressure (PAWP) is elevated.
B. Flow propagation tracing was obtained by color B-mode technique.
C. Flow propagation velocity (Vp) is normal.
D. There is a pseudonormal mitral inflow pattern.
E. The patient is in atrial fibrillation.

7. A 67-year-old male underwent intraoperative transesophageal echocardiography (TEE) prior to ventricular septal defect (VSD) repair. There was no significant valvular disease. A month earlier, he presented with an acute myocardial infarction. At the time of this TEE, his blood pressure was 110/50 mm Hg, and the right atrial pressure was invasively measured at 10 mm Hg (FIG. 21.7).

The panel on the left demonstrates the VSD on color Doppler in a transgastric view. The panel on the right shows the spectral Doppler tracing across the VSD in the same transgastric view.

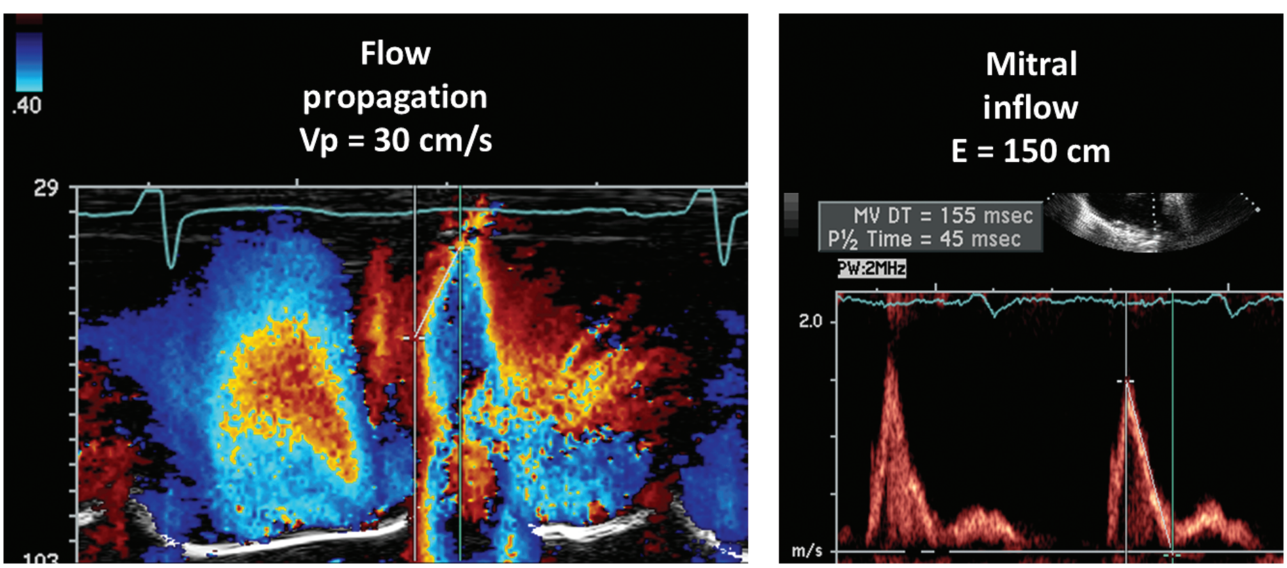


FIGURE 21.6

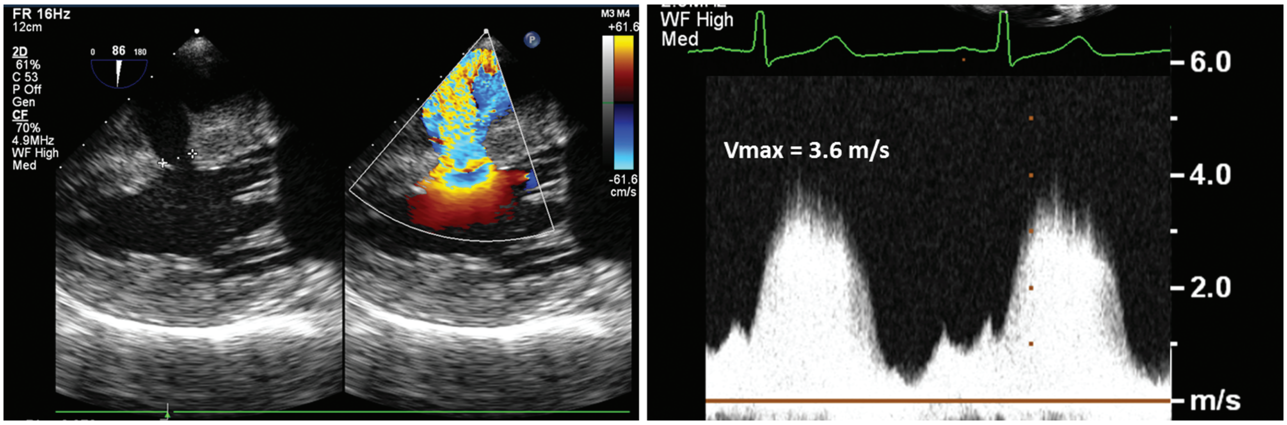


FIGURE 21.7

Which of the following is a correct statement?

A. Findings are consistent with a supracristal VSD.
B. The patient has a very loud diastolic murmur.
C. Pulmonary artery systolic pressure (PASP) is 68 mm Hg.
D. There is a predominant right-to-left shunt.
E. Peak left ventricular systolic pressure (LVSP) is normal.

Q1

8. A 73-year-old female was referred for evaluation of progressive dyspnea on exertion and lower extremity edema over the preceding 3 months. Her exercise tolerance is significantly reduced, and she gets tired after walking only a short distance.

FIGURE 21.8 represents the Doppler-based strain curve of the left ventricle (LV) obtained from the apical four-chamber view.

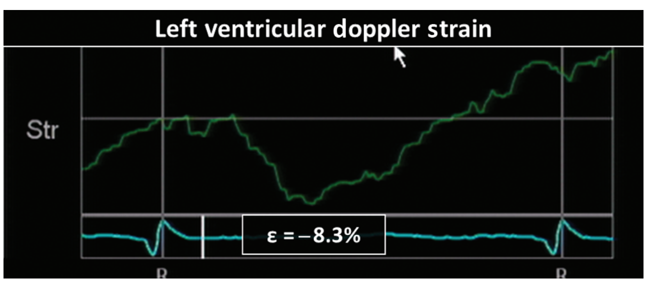


FIGURE 21.8

Which of the following is a correct statement?

A. The curve represents the radial strain of the LV.
B. The peak strain value in this patient is normal.
C. All LV segments can be analyzed by Doppler-based strain imaging.
D. Subendocardial fibers are primarily responsible for longitudinal strain.
E. LV ejection fraction in this patient is definitely abnormal.

9. A 55-year-old obese female presents with shortness of breath after undergoing right knee replacement. Transthoracic echocardiogram revealed normal left ventricular systolic function, no significant valvular disease, and the right heart findings depicted in FIGURE 21.9.

The left panel represents tissue Doppler recordings of the tricuspid annulus. The right panel shows M-mode recording of the tricuspid annulus. In addition, spectral Doppler of the tricuspid inflow was obtained (not shown); it revealed a peak E-wave velocity of 45 cm/s, a peak A-wave velocity of 28 cm/sec, and a deceleration time (DT) of the tricuspid E wave 145 ms.

Which of the following is a correct statement?

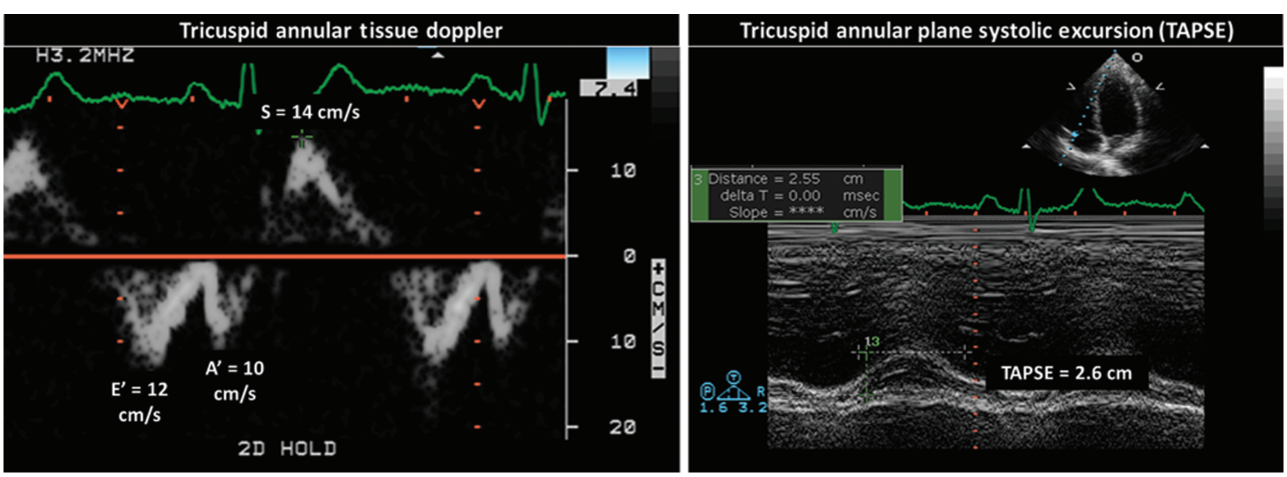


FIGURE 21.9

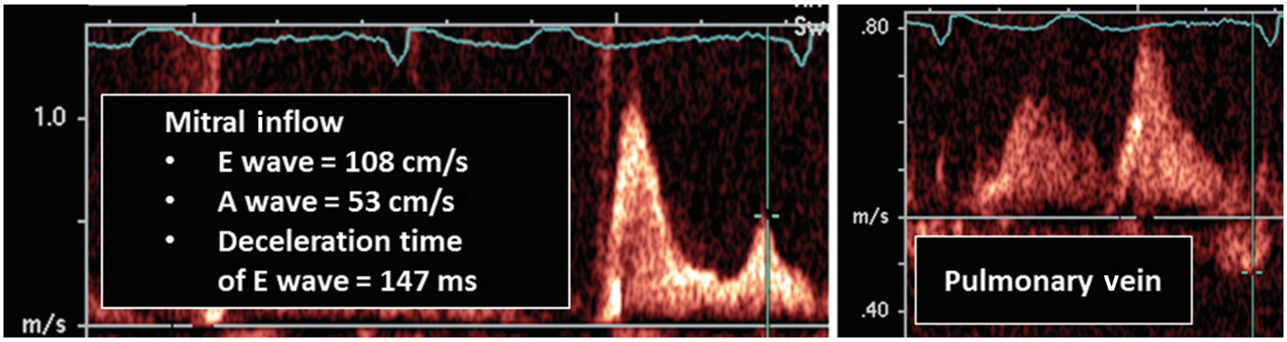


FIGURE 21.10

A. The findings confirm the diagnosis of massive pulmonary embolism.
B. Tricuspid filling pattern demonstrates abnormal relaxation.
C. There is normal longitudinal RV systolic function.
D. Tricuspid annular tissue peak velocity of S wave is diminished.
E. Tricuspid E-wave DT is abnormally short.

10. A 62-year-old male with no known past medical history was admitted because of exertional shortness of breath over the preceding 6 weeks. Recently, he also noted he could no longer put on his shoes because of ankle and foot swelling. Transthoracic echocardiogram was performed on admission. VIDEOS 1 AND 2 and FIGURE 21.10 are from that study.

The left panel represents spectral Doppler recordings of the mitral inflow, and the right panel shows spectral Doppler tracings from the right upper pulmonary vein obtained on the apical four-chamber view.

Which of the following is a correct statement?

A. DT of the mitral E wave is prolonged.
B. Mitral tissue Doppler recordings are not required to estimate LA pressure in this patient.
C. After completion of diuresis, the mitral E/A ratio is expected to increase.
D. A decrease of <50% in the E/A after the Valsalva maneuver would confirm that LA pressure is elevated.
E. Recordings are diagnostic of a pseudonormal filling pattern.

***Answer 1:* B.** The rate of left ventricular pressure rise during early systole (dP/dT) is a measure of left ventricular systolic function. dP/dT can be calculated using the continuous-wave Doppler tracing of the MR jet.

dP/dT represents the slope of a MR jet Doppler tracing between two time points in early systole. By convention, the first time point is when the MR jet velocity reaches 1 m/s (point A in Figure). The second one when the MR jet velocity reaches 3 m/s (point B in Figure).

One can increase accuracy of these measurements by increasing the sweep speed to make the mitral regurgitant jet Doppler envelope as wide as possible and by decreasing the velocity scale to just above 3 m/s.

Using the simplified Bernoulli equation ($dP = 4V^2$), the pressure difference between points A and B can be calculated as follows:

$$dP = 4A^2 - 4B^2$$

$$dP = 4 \times (3\ m/s)^2 - 4 \times (1\ m/s)^2$$

$$dP = 36 - 4 = 32\ mm\,Hg$$

Thus, to calculate the left ventricular dP/dT, one only needs to measure the time interval (in seconds) between points A and B.

$$dP/dT = 32\ mm\,Hg / dT\ (\text{in seconds})$$

$$\text{In the patient above, } dT = Tb - Ta = 0.12\ \text{seconds.}$$

$$dP/dT = 32\ mm\,Hg / 0.12\ \text{seconds}$$

$$dP/dT = 267\ mm\,Hg/s$$

This patient has markedly diminished left ventricular systolic function (flat slope). Normal dP/dT is typically >1000 mm Hg/s (steep slope).

References

Bargiggia GS, Bertucci C, Recusani F, et al. A new method for estimating left ventricular dP/dt by continuous wave Doppler-echocardiography. Validation studies at cardiac catheterization. *Circulation* 1989;80(5):1287–1292.

Mason DT, Braunwald E, Covell JW, et al. Assessment of cardiac contractility. The relation between the rate of pressure rise and ventricular pressure during isovolumic systole. *Circulation* 1971;44(1):47–58.

***Answer 2:* B.** The stroke volume (SV) leaving the left ventricle through the left ventricular outflow tract (LVOT) can be calculated as follows:

$$SV\ (\text{in mL}) = \text{LVOT cross-sectional area (in cm}^2) \times \text{LVOT VTI (in cm)}$$

Assuming a circular shape of the LVOT, the formula becomes

$$SV = \pi \times (\tfrac{1}{2} \times \text{LVOT diameter})^2 \times \text{LVOT VTI}$$

Cardiac output (CO) is then calculated as

$$CO\ (\text{in mL/min}) = SV\ (\text{in mL}) \times \text{heart rate (in beats/min)}.$$

The effective CO is defined as the CO seen by the peripheral systemic circulation and may be the same or lower than the left ventricular CO.

Regarding individual answers:

A. Incorrect answer. Effective CO in this patient is 3800 mL/min; LVOT stroke volume is 63 mL. Mitral stenosis does not impact calculation of CO at the level of the LVOT.

B. Correct answer. Effective CO in this patient is 4200 mL/min; LVOT stroke volume is 69 mL. Mitral regurgitation does not impact calculation of stroke volume at the level of the LVOT. One has to bear in mind that in mitral regurgitation, the total left ventricular stroke volume is larger than the effective stroke volume across the LVOT and is equal to the sum of the mitral regurgitant volume and the effective stroke volume across the LVOT.

C. Incorrect answer. Effective CO in this patient is 3900 mL/min; effective LVOT stroke volume is 49 mL. In aortic regurgitation, the stroke volume calculated at the level of the LVOT is the sum of the effective stroke volume and the aortic regurgitant volume:

SV at LVOT = Effective SV + Aortic regurgitant volume

By rearranging the above equation,

Effective SV = SV at LVOT–Aortic regurgitant volume.

In this patient,

$$\text{Effective SV} = 69 - 20 = 49 \text{ mL}$$
$$\text{Effective CO} = 49 \text{ mL} \times 80 \text{ bpm} = 3900 \text{ mL/min.}$$

D. Incorrect answer. Effective CO in this patient is 3600 mL/min; LVOT stroke volume is 51 mL. Atrial septal defect does not impact calculation of CO at the level of the LVOT.

E. Incorrect answer. Effective CO in this patient is 3900 mL/min; LVOT stroke volume is 45 mL. Aortic stenosis does not impact calculation of CO at the level of the LVOT.

References

Lewis, JF, Kuo, LC, Nelson, JG, et al. Pulsed Doppler echocardiographic determination of stroke volume and cardiac output: clinical validation of two new methods using the apical window. *Circulation* 1984;70:425–431.

Zoghbi WA, Quinones MA. Determination of cardiac output by Doppler echocardiography: a critical appraisal. *Herz* 1986;11: 258–268.

***Answer 3:* E.** Diastolic stroke volume (SV) can be calculated at the level of the mitral valve using the following formula:

$$\text{SV (in mL)} = \text{mitral orifice cross-sectional area (in cm}^2) \times \text{mitral velocity time integral (VTI)}$$

Mitral orifice cross-sectional area can be estimated by one of the following two methods depending on the assumption of the geometric shape of the mitral orifice:

1. Circular mitral orifice—diastolic mitral annular diameter (D) is measured typically in the apical four-chamber view, and the mitral cross-sectional orifice area (MOCSA) is calculated as

$$\text{MOCSA} = \pi \cdot (\tfrac{1}{2}\,\text{D})^2$$

In this patient,

$$\text{MOCSA} = 3.14 \cdot (\tfrac{1}{2} \cdot 2.9 \text{ cm})^2 = 6.6 \text{ cm}^2$$

2. Ellipsoid mitral orifice—diastolic mitral annular diameters are measured in the apical four-chamber view (D1) and apical two-chamber view (D2). Using the formula for surface area of an ellipse, MOCSA can be calculated as follows:

$$\text{MOCSA} = 3.14 \cdot (\tfrac{1}{2} \times \text{D1}) \cdot (\tfrac{1}{2} \times \text{D2})$$

In this patient,

$$\text{MOCSA} = 3.14 \cdot (\tfrac{1}{2} \times 2.9 \text{ cm}) \cdot (\tfrac{1}{2} \times 2.8 \text{ cm})$$
$$\text{MOCSA} = 6.4 \text{ cm}^2$$

Once MOCSA is known, we can then calculate the stroke volume and the cardiac output across the mitral valve:

$$\text{SV (in mL)} = \text{MOCSA (in cm}^2) \cdot \text{Mitral VTI (in cm)}$$
$$\text{CO (in mL/min)} = \text{SV (in mL)} \cdot \text{Heart rate (in beats per minute)}$$

In this patient using the ellipsoid approach,

$$\text{SV} = 6.4 \text{ cm}^2 \cdot 11 \text{ cm} = 70 \text{ mL}$$
$$\text{CO} = 70 \text{ mL} \cdot 80 \text{ bpm} = 5600 \text{ mL/min.}$$

Regarding individual answers:

A. Incorrect answer. When calculating the stroke volume at the mitral level, the pulsed-wave Doppler sample volume is placed at the level of the mitral annulus (the same level at which the mitral annular diameter is measured). This is in contrast to measurements of mitral inflow for the assessment of left ventricular diastolic function when the sample volume is placed at mitral leaflet tips.

B. Incorrect answer. The diameter of the mitral annulus was measured (inner edge to inner edge) at the base of the leaflets at the time of maximal valvular opening during diastole.

C. Incorrect answer. In the absence of significant mitral or aortic regurgitation, the diastolic stroke volume across the mitral valve is the same as the systolic stroke volume at the level of the left ventricular outflow tract.

D. Incorrect answer. The more severe the mitral regurgitation, the larger the diastolic stroke volume across the mitral valve is. In mitral regurgitation, the diastolic flow across the mitral valve is the sum of the effective stroke volume (as measured at the level of the left ventricular outflow tract) and the mitral regurgitant volume.

E. Correct answer. In patients with patent ductus arteriosus, the cardiac output measured at the mitral valve level represents the pulmonicflow (Qp,) while the flow across the right ventricular outflow tract represents the systemic flow (Qs).

References

Enriquez-Sarano M, Bailey KR, Seward JB, et al. Quantitative Doppler assessment of valvular regurgitation. *Circulation* 1993;87(3):841–848.
Lewis JF, Kuo LC, Nelson JG, et al. Pulsed Doppler echocardiographic determination of stroke volume and cardiac output: clinical validation of two new methods using the apical window. *Circulation* 1984;70:425–431.

***Answer 4:* D.**

Regarding individual answers:

A. Incorrect answer. In this patient, the ratio of systolic (S) to diastolic (D) pulmonary vein peak velocity is >1. This is indicative of normal mean left atrial pressure.
B. Incorrect answer. An atrial reversal wave (AR) that lasts 30 ms longer than the mitral A wave is indicative of elevated left ventricular end-diastolic pressure.
C. Incorrect answer. It is the atrial reversal wave (AR) and not the diastolic (D) wave that disappears in atrial fibrillation. In addition, the peak velocity of the systolic (S) wave decreases, and the S/D ratio becomes <1.
D. Correct answer. An atrial reversal wave (AR) that lasts 30 ms longer than the mitral A wave is indicative of elevated left ventricular end-diastolic pressure. In this patient, AR duration − A duration = 200 − 166 = 34 ms.
E. Incorrect answer. Pulmonary vein atrial reversal (AR) velocities may increase with age but usually do not exceed 35 cm/s. Higher AR peak velocities are indicative of increased left ventricular end-diastolic pressure as is the case in this patient (AR = 50 cm/s).

References

Nagueh SF, Appleton CP, Gillebert TC, et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *J Am SocEchocardiogr* 2009;22(2):107–133.
Rossvoll O, Hatle LK. Pulmonary venous flow velocities recorded by transthoracic Doppler ultrasound: relation to left ventricular diastolic pressures. *J Am Coll Cardiol* 1993;21(7):1687–1696.

***Answer 5:* C.** Myocardial performance index (MPI), proposed in 1995 and also known as the Tei index, is a measure of both systolic and diastolic left ventricular function. Conceptually, MPI is the following ratio:

$$\mathbf{MPI = (IVCT + IVRT) / EP}$$

Where IVCT is isovolumic contraction time, IVRT is isovolumic relaxation time, and EP is ejection period. In normal hearts, the sum of the two isovolumic ratios is roughly 1/3 of the ejection period. Normal values of left ventricular MPI are reported as 0.39 +/− 0.05. With systolic and/or diastolic dysfunction, this ratio increases.

Because calculating IVCT and IVRT is technically challenging using mitral and aortic blood flow velocity tracings, one can calculate MPI as follows:

$$\mathbf{MPI = (A - B) / B}$$

where A is the time duration between the end of mitral flow in one cardiac cycle to the beginning of mitral flow in the next cardiac cycle and B is the ejection period as measured by the duration of aortic flow.

It is important to emphasize that MPI is preload and afterload dependent. Left ventricular afterload increase and preload reduction are associated with significant increases in the MPI values. In contrast, changes in left ventricular contractility do not seem to alter MPI values significantly.

Regarding individual answers:

A. Incorrect answer. See General Discussion above.
B. Incorrect answer. See General Discussion above.
C. Correct answer. Indeed, the MPI (Tei index) is calculated as (A–B)/B.

In this patient, MPI = (410–300)/300 = 0.37, which is a normal value.

D. Incorrect answer. See General Discussion above.
E. Incorrect answer. See General Discussion above.

References

Cheung MM, Smallhorn JF, Redington AN, et al. The effects of changes in loading conditions and modulation of inotropic state on the MPI: comparison with conductance catheter measurements. *Eur Heart J* 2004;25(24):2238–2242
Harada K, Tamura M, Toyono M, et al. Comparison of the right ventricular Tei index by tissue Doppler imaging to that obtained by pulsed Doppler in children without heart disease. *Am J Cardiol* 2002;90(5):566–569.
Pellett AA, Tolar WG, Merwin DG, et al. The Tei index: methodology and disease state values. *Echocardiography* 2004;21(7):669–672.
Tei C, Ling LH, Hodge DO, et al. New index of combined systolic and diastolic myocardial performance: a simple and reproducible measure of cardiac function—a study in normals and dilated cardiomyopathy. *J Cardiol* 1995;26(6):357–366.

***Answer 6:* A**

Regarding individual answers:

A. Correct answer. In this patient with reduced left ventricular systolic function, the pulmonary artery wedge pressure (PAWP) is elevated as judged by the markedly increased E/Vp ratio (the ratio of the peak velocity of the mitral E wave to the flow propagation velocity, Vp). The full regression equation for calculating PAWP is as follows:

$$\mathbf{PAWP = 4.6 + 5.27 \times E/Vp}$$

In this patient,

$$\mathbf{E/Vp = 150/30 = 5}$$
$$\mathbf{PAWP = 4.6 + 5.27 \times 5 = 31\ mm\ Hg}$$

It has been shown that in patients with depressed left ventricular systolic function, an E/Vp >2.5 predicts a PAWP >15 mm Hg with reasonable accuracy. Patients with normal LV volumes and ejection fraction but elevated left ventricular filling pressures may have a misleadingly normal Vp. Thus, the E/Vp method should be used with caution in individuals without left ventricular systolic dysfunction.

B. Incorrect answer. To obtain Vp, one uses the color M-mode technique. In the apical four-chamber view, a color box is placed over the left ventricle, and the color scale (Nyquist limit) is typically set at 40 cm/s. Then the M-mode interrogation line is placed in the left ventricle and aligned with the mitral inflow. Flow propagation velocity (Vp) is measured as the slope of the first aliasing velocity during early diastole. Vp slope is measured from the mitral valve plane to 4 cm apically into the left ventricular cavity.

C. Incorrect answer. This patient has diminished Vp; normal values are >50 cm/s. The lower the Vp, the slower the left ventricular relaxation rate and the lower the suction force of the left ventricle.

D. Incorrect answer. The patient's mitral inflow is restrictive as judged by an E/A ratio >2 and a very rapid deceleration time of the E wave (<160 ms). In the presence of left ventricular systolic dysfunction, this is also indicative of elevated pulmonary artery wedge pressure.

E. Incorrect answer. The patient is not in atrial fibrillation as the mitral inflow tracing demonstrates the presence of a mitral atrial (A) wave. This correlates with an organized atrial contraction and argues against atrial fibrillation.

References

Garcia MJ, Ares MA, Asher C, et al. An index of early left ventricular filling that combined with pulsed Doppler peak E velocity may estimate capillary wedge pressure. *J Am Coll Cardiol* 1997;29(2):448–454.

Nagueh SF, Appleton CP, Gillebert TC, et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *J Am SocEchocardiogr* 2009;22(2):107–133.

Answer 7: **E.**

Regarding individual answers:

A. Incorrect answer. The recent history of myocardial infarction and the location of the ventricular septal defect are typical of an acquired postinfarction muscular VSD. Supracristal VSD is a type of congenital VSD and is close to the aortic root and the pulmonic valve:

$$\text{PASP} = \text{RVSP}$$

RVSP can be calculated if systolic blood pressure (SBP) and peak systolic gradient across the VSD (ΔP) are known. In the absence of LV outflow obstruction, SBP is equal to the peak left ventricular systolic pressure (LVSP).

AU Response: Agreed.

$$\text{SBP} = \text{LVSP}$$

Therefore,

$$\text{RVSP} = \text{LVSP} - \Delta P$$
$$\text{RVSP} = \text{SBP} - \Delta P$$

In this patient,

$$\text{RVSP} = 110 - 4 \times (3.6\ \text{m/sec})^2$$
$$\text{RVSP} = 58\ \text{mm Hg}$$

It is important to emphasize that this is a direct estimate of RVSP, and there is no need to add right atrial pressure to the pressure gradient. This is in contrast to the RVSP estimate using the tricuspid regurgitant jet.

B. Incorrect answer. Although there is diastolic flow across the VSD on spectral Doppler, this is silent on auscultation. Patients with VSD typically have a holosystolic murmur.

C. Incorrect answer. In the absence of pulmonic stenosis, peak pulmonary artery systolic pressure (PASP) is equal to the peak right ventricular systolic pressure (RVSP).

D. Incorrect answer. Both the color and spectral Doppler are indicative of a predominant left-to-right shunt.

E. Correct answer. Since the patient does not have LVOT or AV obstruction, systolic blood pressure (SBP) is equal to the peak left ventricular systolic pressure (LVSP). Thus, LVSP in this patient is 110 mm Hg, which is a normal value.

References

Hatle L, Rokseth R. Noninvasive diagnosis and assessment of ventricular septal defect by Doppler ultrasound. *Acta Med Scand* 1981;645:47–56.

Murphy DJ, Ludomirsky A, Huhta JC. Continuous wave Doppler in children with ventricular septal defect: noninvasive estimation of interventricular pressure gradient. *Am J Cardiol* 1986;57:428–432.

Answer 8: **D.**

Regarding individual answers:

A. Incorrect answer. There are three major types of myocardial strain: longitudinal, circumferential, and radial. Strain represents a change in myocardial segment length relative to end-diastolic length. Since the myocardium shortens in the longitudinal and circumferential axes, longitudinal and circumferential strain values are negative. In contrast, the myocardium thickens in the radial axis; thus, the radial strain has positive values. In this patient, the peak strain value is −8.3% and thus cannot represent radial strain.

B. Incorrect answer. The Doppler-based strain curve in this patient was obtained from the apical view and represents longitudinal strain. It was obtained from the basal lateral wall but could have been obtained from any nonapical LV segment. Longitudinal strain values of ≤12% are definitely abnormal. Q3

C. Incorrect answer. Doppler-based strain imaging has the same limitation as any other Doppler technique, namely, the inability to image velocities of structures that are perpendicular to the insonation beam. Thus, the LV apex cannot be well visualized using Doppler-based strain imaging.

D. Correct answer. Longitudinal LV mechanics are predominantly governed by the subendocardial fibers, which are the first to be affected in a wide variety of myocardial disorders.

E. Incorrect answer. All forms of myocardial mechanics (such as strain and twist) contribute to global LV function and ejection fraction (LVEF). A loss of longitudinal strain is often compensated by an increase in other forms of strain or twist, which can result in a normal LVEF despite abnormalities in individual strains.

References

Geyer H, Caracciolo G, Abe H, et al. Assessment of myocardial mechanics using speckle tracking echocardiography: fundamentals and clinical applications. *J Am Soc Echocardiogr* 2010;23(4):351–369

Mor-Avi V, Lang RM, Badano LP, et al. Current and evolving echocardiographic techniques for the quantitative evaluation of cardiac mechanics: ASE/EAE consensus statement on methodology and indications endorsed by the Japanese Society of Echocardiography. *J Am Soc Echocardiogr* 2011;24(3): 277–313.

Answer 9: C.

Regarding individual answers:

A. Incorrect answer. Although the clinical scenario may suggest the diagnosis of pulmonary embolism, the echocardiographic findings are not confirmatory. Massive pulmonary embolism is typically associated with reduced right ventricular systolic function. This patient has normal TAPSE (≥1.6 cm) and peak S-wave velocity (≥10 cm/s) values, which argue against right ventricular systolic dysfunction.

B. Incorrect answer. An abnormal relaxation pattern is characterized by a tricuspid E/A ratio of <0.8. In this patient, E/A = 1.6 (normal 0.8 to 2.1). Furthermore, this patient has a normal tricuspid E/E' ratio of 3.8 (normal ≤6); this argues against RV diastolic dysfunction.

C. Correct answer. Tricuspid annular plane systolic excursion (TAPSE) is an M-mode technique that measures systolic displacement of the tricuspid annulus. Normal TAPSE values are ≥1.6 cm and correspond to normal longitudinal right ventricular systolic function.

D. Incorrect answer. The patient has normal S-wave velocity of 12 cm/s (normal ≥10 cm/s). Normal S-wave velocity is indicative of normal RV longitudinal contractility.

E. Incorrect answer. The patient has normal deceleration time (DT) of the tricuspid E wave (145 ms; normal ≥120 ms). Values <120 ms indicate restrictive filling pattern when tricuspid E/A >2.1. Note the different cutoff values for mitral versus tricuspid restrictive filling pattern (mitral restrictive pattern has DT <150 ms; tricuspid restrictive pattern has DT <120 ms).

Reference

Rudski LG, Lai WW, Afilalo J, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. *J Am Soc Echocardiogr* 2010;23(7):685–713.

Answer 10: B.

Regarding individual answers:

A. Incorrect answer. The patient's deceleration time (DT) of the mitral E wave is abnormally short (< 150 ms) and consistent with a restrictive filling pattern since the E/A ratio is >2.

B. Correct answer. This patient presents with acutely decompensated heart failure due to LV systolic dysfunction. When LV ejection fraction is diminished, left atrial pressure (LAP) can often be estimated from the mitral inflow alone. If mitral E/A <1 and E ≤50 cm/s, LAP is normal. In contrast, an E/A >2 and the deceleration time of E wave <150 ms (restrictive filling pattern) as is the case with this patient imply that LAP is elevated. Pulmonary venous flow demonstrating systolic (S) wave less than diastolic (D)-wave peak velocity further indicates that LAP is elevated in this patient. When patients present with heart failure and normal LV ejection fraction, LAP cannot be estimated from the mitral inflow alone and additional parameters (such as the E/E' ratio) are required.

C. Incorrect answer. Diuretic therapy decreases LV preload and typically leads to lower E-wave velocities compared to prediuretic recordings in patients with acutely decompensated heart failure. A lack of significant decrease in E-wave velocity following adequate diuretic therapy in patients who initially present with a restrictive filling pattern may portend worse survival.

D. Incorrect answer. In cardiac patients, a decrease of ≥50% in the mitral E/A ratio is highly specific for elevated LV filling pressures. However, a change in the E/A ratio of <50% does not always indicate that the LV filling pressures are normal.

E. Incorrect answer. A pseudonormal filling pattern is characterized by a mitral E/A ratio between one and two, a deceleration of the mitral E wave of >150 ms, and a pulmonary venous flow pattern demonstrating systolic (S) wave less than the diastolic (D)-wave peak velocity. Although the patient has an S/D ratio of <1, his filling pattern is restrictive since the mitral E/A ratio is >2, and the DT of the mitral E wave is <150 ms.

Reference

Nagueh SF, Appleton CP, Gillebert TC, et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *J Am Soc Echocardiogr* 2009;22(2):107–133.

Queries

[Q1] Please check if edit to sentence starting "A 73-year-old woman..." is okay.
[Q2] Please provide the expansion of "TEI."
[Q3] Please confirm the change made to the sentence "Longitudinal strain values ..." is okay.