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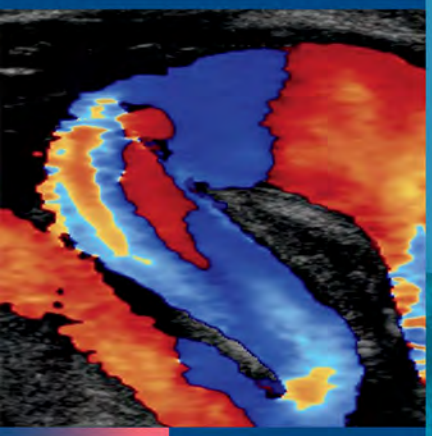

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CLAUDIA RUMWELL | MICHALENE McPHARLIN

Vascular Technology

An Illustrated Review

5th Edition

Claudia Rumwell, RN, RVT, FSVU

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CHAPTER 2

Physiology and Fluid Dynamics

Arterial System

Energy

Blood Flow Characteristics

Poiseuille's Law

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Pressure/Velocity Relationships (Bernoulli Principle)

Steady versus Pulsatile Flow

Peripheral Resistance

Cardiac Effects

Collateral Effects

Effects of Exercise

Effects of Stenosis on Flow

ARTERIAL SYSTEM

The arterial system is a multibranched elastic conduit that carries blood away from the heart and outward to the most distant tissues.

- The arterial tree oscillates with every beat of the heart, each one of which pumps approximately 70 ml of blood into the aorta and causes a blood pressure pulse.
- At the beginning of the cardiac contraction, the pressure in the left ventricle rises rapidly, quickly exceeding that in the aorta so that the aortic valve opens, blood is ejected, and the blood pressure rises. The amount of blood ejected is called the *stroke volume*.
- Increased heart rate delivers an increased blood volume that supplies more nutrients. Conversely, the lower the heart rate, the smaller the volume of pumped blood.
- The patient's cardiac status plays an important role in the movement of blood throughout the vascular system.

The heart pump generates the pressure (*potential energy*) to move the blood. The stroke volume of blood produced by each heartbeat creates a pressure (or *energy*) wave that travels rapidly throughout the arterial system (Figure 2-1):

- The propagation speed, shape, and strength of the pressure wave change as the wave moves through the arterial system.

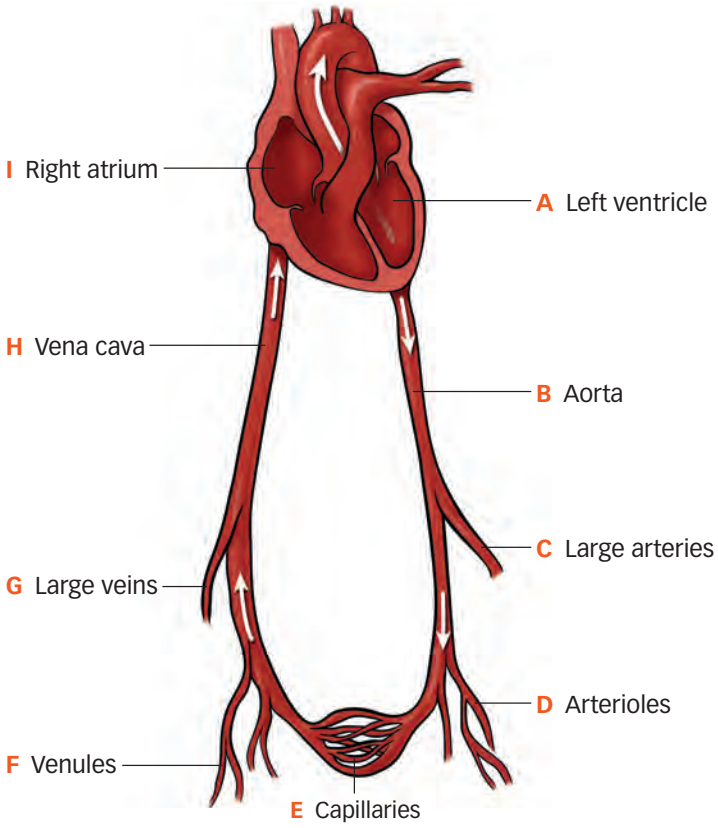


Figure 2-1. Once the heart generates the pressure to move the blood, the energy wave produced travels rapidly throughout the system beginning with the left ventricle (**A**) to the capillary bed (**E**) back to the heart via the venous system (**F–I**).

Example: As the arterial pressure wave moves distally, away from the heart and out toward the periphery, the propagation speed—the pulse wave velocity—increases with the growing stiffness of the arterial walls.

- Variations in the characteristics of the vessels influence these alterations in blood flow. Velocity and flow direction also vary with each heartbeat.
- As the pressure wave moves from the large arteries through the high-resistance vessels, capillaries, and then into the venous side, the mean pressure gradually declines because of losses in total fluid energy.

The pumping action of the heart maintains a high volume of blood in the arterial side of the system that in turn sustains a high pressure gradient between the arterial and venous sides of the circulation. This pressure gradient is necessary to maintain flow.

Cardiac output governs the amount of blood that enters the arterial system, while arterial pressure and total peripheral resistance (which is controlled by the level of vasoconstriction in the microcirculation) determine the volume of blood that leaves it.

A large portion of the energy created with each left ventricular contraction results in distention of the arteries, producing an arterial "reservoir" that stores some of the blood volume and the potential energy supplied to the system.

It is this store of energy and volume that promotes the flow of blood into the tissue during diastole. That is, potential energy is stored in the distended arterial wall and is released when the wall recoils.

Pressure is greatest at the heart and gradually decreases as the blood moves distally. This pressure difference (or *gradient*) is necessary to maintain blood flow.

ENERGY

The movement of any fluid medium between two points requires two things: (1) a route along which the fluid can flow and (2) a difference in energy (pressure) levels between the two points. The volume of flow depends on the net energy difference between these two points, a factor that is affected by losses resulting from the movement of the fluid—i.e., friction—and any resistance within the pathway that opposes such movement.

The greater the energy difference (or the lower the resistance), the greater the flow, as illustrated in Figure 2-2.

The greater the pathway resistance and/or energy losses, the lower the flow.

lower resistance = higher flow rate
higher resistance = lower flow rate

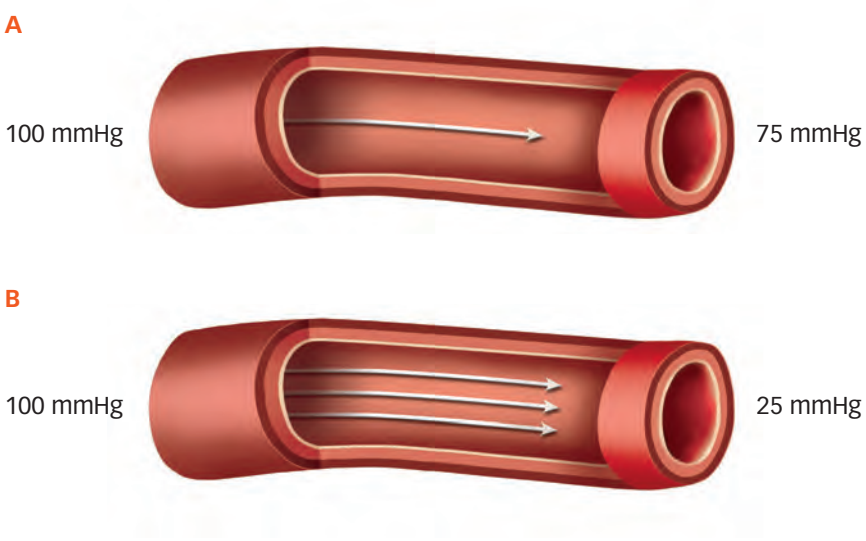
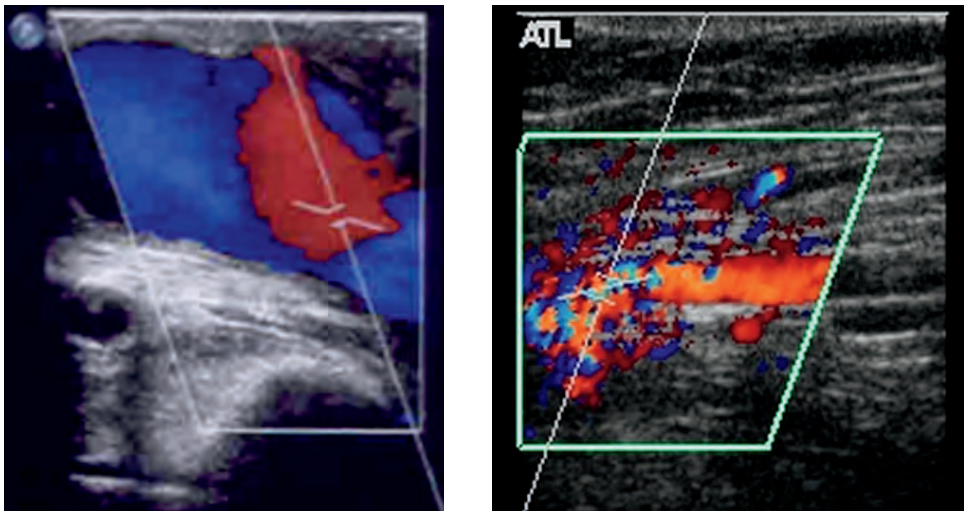


Figure 2-2. The greater the pressure gradient, the greater the flow. Example **A** has less pressure difference and therefore less flow than example **B**, which has a larger pressure gradient and greater flow.

The total energy contained in moving fluid is the sum of pressure (potential) energy, kinetic (movement) energy, and gravitational energy, as explained below:

- *Pressure energy* is the main form of energy present in flowing blood (see Figure 2-3A). It is created by the pumping action of the heart, which subsequently distends the arterial vessels. This distention occurs because of elastin, which allows for a rapid increase in capacity. Arteries are more elastic proximally and less distally as they become smaller. Elastin quickly converts kinetic energy to pressure energy. The pressure energy is then converted back to kinetic energy in diastole. Pressure energy is also referred to as *potential energy*. Potential energy has several components. The dominant source is the pumping action of the heart muscle, as well as distention of the arterial wall.
- *Kinetic energy* is the ability of flowing blood to do work as a result of its velocity; it is the energy of something in motion (see Figure 2-3B). With regard to blood flow, the kinetic energy portion is small compared to the pressure energy. Kinetic energy is also proportional to the density of blood (which is normally stable) and to the square of its velocity. The everyday example of a dam illustrates the difference between potential and kinetic energy: The water behind the dam has *potential* energy (with the height of the dam providing a form of *gravitational* energy), while the water flowing through the dam has *kinetic* energy.
- *Gravitational energy* (*hydrostatic pressure*) is expressed in millimeters of mercury (mmHg). Changes in the height of the fluid column introduce the element of gravitational energy, which is hydrostatic pressure. In the circulatory system, hydrostatic pressure is equivalent to the weight of the column of blood extending from the heart, where the right atrium is considered the 0 pressure reference point (i.e., atmospheric pressure), to the level where the pressure is being measured.



A B

Figure 2-7. **A** In a popliteal artery aneurysm, resistance to flow is reduced due to the larger-than-normal diameter. Although the volume of blood flow through this vessel remains constant, velocities are decreased compared to normal. **B** In this superficial femoral artery (SFA) stenosis, resistance to flow is increased because of the stenotic lumen. Although the volume flow remains constant, velocities are elevated as a result of the stenosis.

POISEUILLE'S LAW

Poiseuille's law defines the relationship between volume flow (Q), pressure (P), and resistance (R) and may be written as $Q = P/R$. It helps to answer the question of how much fluid is moving through a vessel. When combined with the resistance equation (see page 21), Poiseuille's law may be stated as follows:

$$Q = \frac{(P_1 - P_2)\,\pi r^4}{8\eta L}$$

where Q = volume flow, P_1 = pressure at the proximal end of the vessel, P_2 = pressure at the distal end of the vessel, r = radius of the vessel, L = length of the vessel, $\pi = 3.1416$, and η = viscosity of the fluid.

- A change in the diameter (hence, radius) of a vessel affects resistance more dramatically than viscosity or vessel length (see Figures 2-7A and 2-7B).
- The radius of a vessel is directly proportional to the volume flow. Small changes in radius may result in large changes in flow, as demonstrated in Figure 2-8.

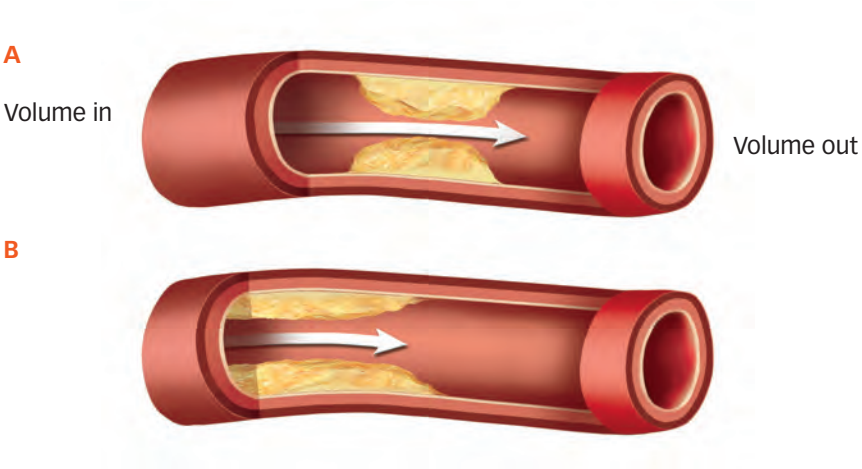


Figure 2-8. Parts **A** and **B** both illustrate narrowed segments. The reduction in volume flow through segment A will be greater than that through segment B, where the radius of the stenotic segment is somewhat larger.

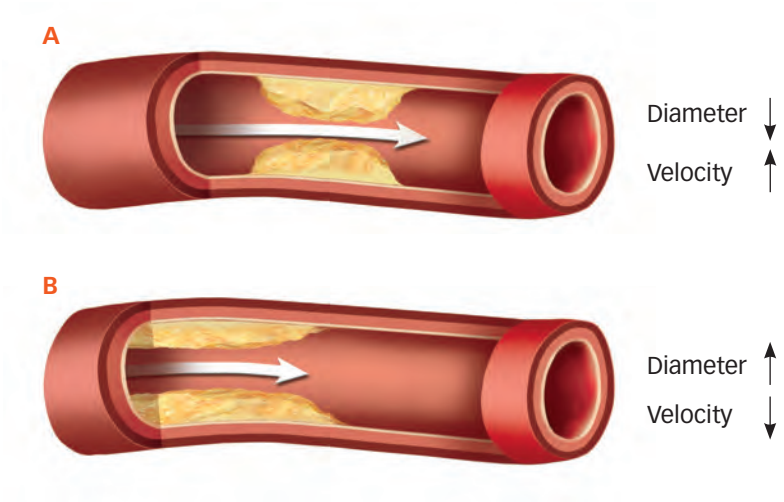


Figure 2-9. A As the diameter decreases, the velocities increase. **B** As the diameter increases, the velocities decrease.

- As vessel radius decreases, resistance increases. The volume of blood flow through the vessel nevertheless remains constant. To maintain volume flow as vessel size decreases, velocity must increase. As illustrated in Figures 2-9 and 2-7A and B, the size of a vessel is inversely proportional to the velocity of blood flow. According to the basic laws of fluid dynamics, most notably the law of conservation of mass (i.e., what goes in must come out), the relationship among velocity, volume flow, and cross-sectional area of the vessel is

$$V = \frac{Q}{A}$$

  where V = velocity (cm/sec), Q = volume flow (cm^3), and A = cross-sectional area (cm^2).
- In the cardiovascular system, the length of the vessels and the viscosity of the blood usually do not change much. This means that changes in blood flow occur mainly as a result of changes in the radius of a vessel and in the pressure energy gradient that makes flow possible.

The abbreviated pressure/volume flow relationship is quite similar to one used in electronics to explain the flow of electricity—Ohm's law—commonly expressed as I (flow of electrons) = E/R. Please note that it may be written as I = V/R in some references. Here is how the two equations compare:

Q = P/R		**I = E/R**
Flow volume (Q)	similar to	Current (I), flow volume of electrons
Pressure (P)	similar to	Voltage (E)
Flow resistance (R)	similar to	Electrical resistance (R)

REYNOLDS NUMBER

After the initial acceleration in systole, blood movement continues and develops into distinct streamline formations. Where P = pressure, note in Figure 2-10A that the streamlines are evenly distributed. When the flow pattern becomes unstable, these continuous streamlines break up and form small circular currents called eddy currents and vortices (swirling patterns of rotational flow) (Figure 2-10B).

Osborne Reynolds sought to determine how viscosity, vessel radius, and the pressure/volume relationship influence the stability of flow through a vessel. Although most of his work applied to straight, rigid tubes, it still provides insight into the physics of blood flow.

Flow volume increases as pressure increases, but only to a point. As flow changes from stable to disturbed, Reynolds found that an increase in pressure no longer increased flow volume. Instead, it increased flow disturbance, contributing to the formation of eddy currents.

The elements that affect the development of turbulent flow are expressed by a "dimensionless" number called the *Reynolds number* (Re). The factors that affect the development of turbulence are expressed by this number according to the following equation:

$$Re = \frac{V\rho 2r}{\eta}$$

where Re = Reynolds number, V = velocity, ρ = the density of the fluid, r = the radius of the tube, and η = the viscosity of the fluid. Because the density and viscosity of the blood are fairly constant, the development of turbulence depends mainly on the size of the vessels and the velocity of flow. When the Reynolds number exceeds 2000, laminar flow tends to become disturbed. Flow disturbances also can occur at lower values because of other factors, such as body movement, pulsatility of blood flow, and irregularities of the vessel wall and plaque.

Turbulent flow may cause vessel walls to vibrate. The harmonics of this vibration produce vascular bruits.

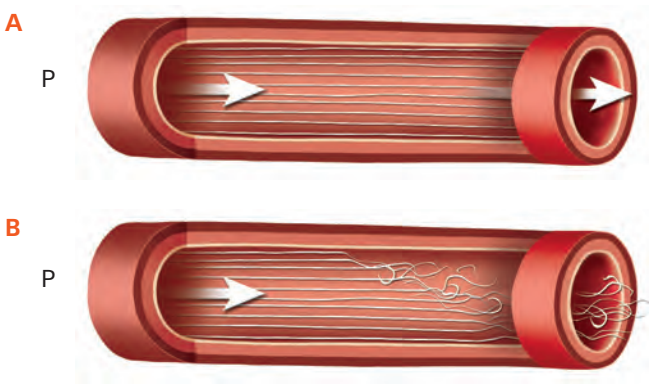


Figure 2-10. Arterial flow streamlines. **A** Evenly distributed. **B** Disrupted (turbulent). P = pressure.

PRESSURE/VELOCITY RELATIONSHIPS (BERNOULLI PRINCIPLE)

As previously described in the section on energy, the total energy contained in moving fluid is the sum of potential (i.e., pressure), kinetic, and gravitational energies. If one of these variables changes, the others also must change to maintain total fluid energy at the same level.

Example: If gravitational energy remains unchanged (that is, there is no change in the height of the fluid) but kinetic energy (velocity) increases, then potential (pressure) energy must decrease to maintain the same total fluid energy.

The Bernoulli equation shows that velocity and pressure are inversely related. Where there is high velocity, there is low pressure; where there is low velocity, there is high pressure. This inverse relationship between pressure and velocity explains why pressure decreases where fluid velocity increases (within the stenotic segment of an artery, for example) and why pressure distal to a stenosis (the region of poststenotic turbulence, where velocity decreases) is higher than that within the lesion itself. (See Figure 2-11.)

In other words, this is the law of conservation of energy:

1. In the region proximal to the stenosis (prestenosis), the pressure energy is higher and the kinetic energy lower. This region has the highest total energy sum.
2. As blood flows into the area of the stenosis, the pressure energy decreases and the kinetic energy increases (higher). However, total energy in this stenotic segment is less than that in the prestenotic segment because energy is lost (i.e., converted into heat) as it moves through the narrowing.
3. Lastly, distal to the stenosis (poststenosis), the kinetic energy decreases and the pressure energy increases. At this point the total energy sum is lowest.

Pressure gradients—the difference in pressure between two points in a vessel—are described as *flow separations*. Flow separations within a vessel may be

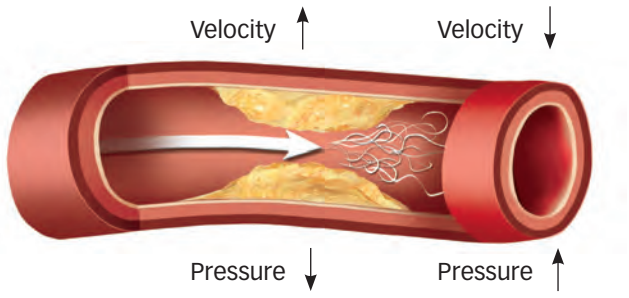


Figure 2-11. Velocity energy is elevated and pressure energy diminished within a stenosis. Relative velocity energy decreases and pressure energy increases distal to a stenosis. However, overall energy decreases.

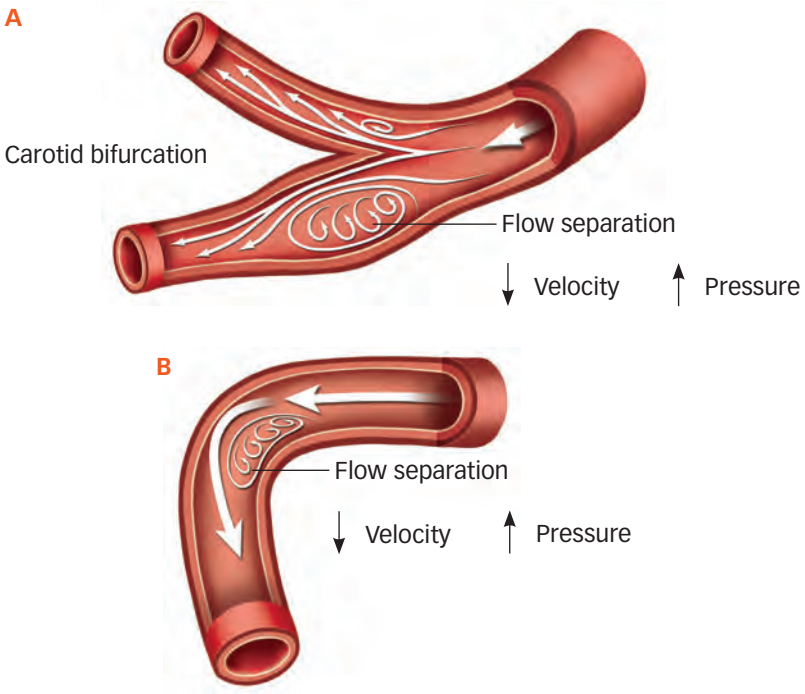


Figure 2-12. Flow separation patterns. In both examples **A** and **B**, pressure energy is higher and velocity energy lower in the area of the pressure gradient (flow separation). This causes flow direction to move to the area of lower pressure energy. **A** Flow separation in the carotid bulb. **B** Flow separation at a curve (note that it is located on the inside of the vessel curve).

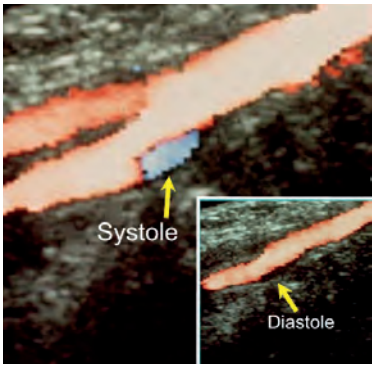


Figure 2-13. Longitudinal image of the carotid bifurcation in systole. The inset shows the same image in diastole. Note that flow separation (blue) is present during systole, absent in diastole.

caused by changes in the geometry of the vessel (with or without intraluminal disease) or the direction of the vessel, as depicted in Figures 2-12A and B. See also Figure 2-13.

Flow separations leave behind regions of flow reversal, stagnant or little movement. Figure 2-14 demonstrates two different regions within a bypass graft where these flow separations can occur.

Because flow moves from high to low pressure (described as a *pressure gradient*), the direction of flow in the region of flow separation (e.g., carotid bulb, bypass graft anastomosis) changes with respect to the transducer, causing a visible color change in the color flow image at systole.

During diastole, when flow at the vessel wall is stagnant, there is no movement of blood and therefore no color in the color flow image. The flow separation pattern is an ideal one to use to help define whether an image is in systole or diastole.

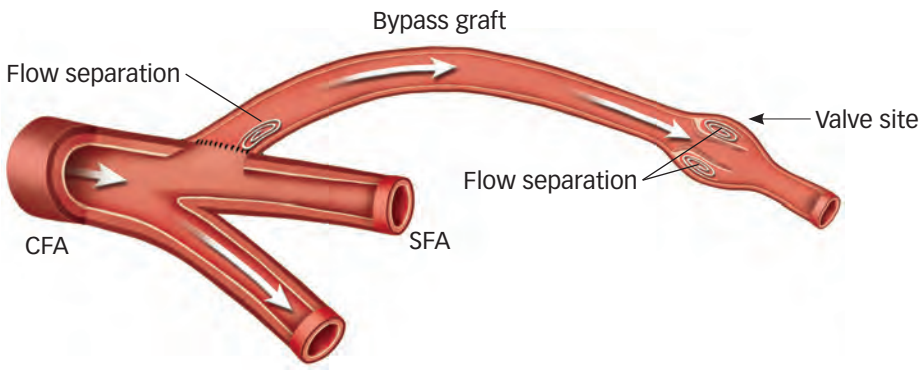


Figure 2-14. In this reversed saphenous vein graft at the end-to-side proximal anastomosis there is an area of flow stagnation (flow separation) on the inside wall. Distally, there are areas of flow separation at the site of a valve cusp. Note the variability of vessel dimension in the bypass graft. CFA = common femoral artery, SFA = superficial femoral artery.

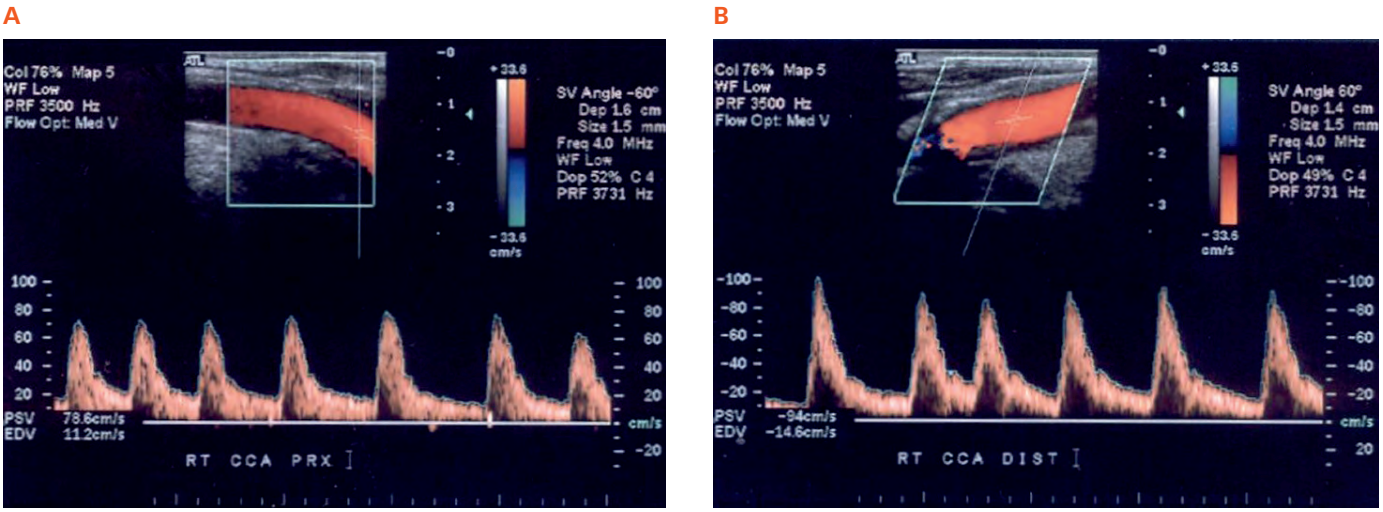


Figure 2-22. An irregular heart rhythm is evident in this spectral analysis of a common carotid artery.

- A severely irregular heart rhythm (Figure 2-23), on the other hand, represents a challenge in obtaining reliable peak systolic velocity (PSV) measurements. Some protocols call for averaging a few cycles to be the most reliable; others consider the averaging of 10 cycles to be the best method. When determining the significance of a stenosis, calculating a velocity ratio may be helpful; e.g., the highest internal carotid artery PSV is divided by the PSV of the more distal common carotid artery.

Stenosis of the Aortic Valve

- A delay in the systolic upstroke is evident (Figure 2-24).
- Decreased peak systolic velocities (PSVs) are also usually seen. Therefore, PSVs may underestimate a stenosis.

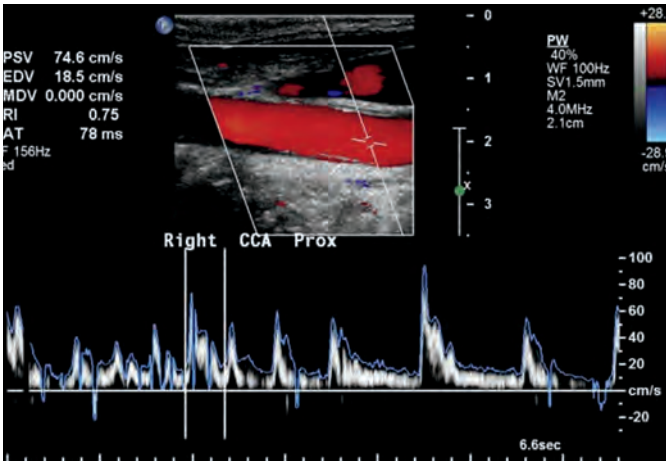


Figure 2-23. Severely irregular heart rhythm provides significant challenges in determining a reliable peak systolic velocity measurement.

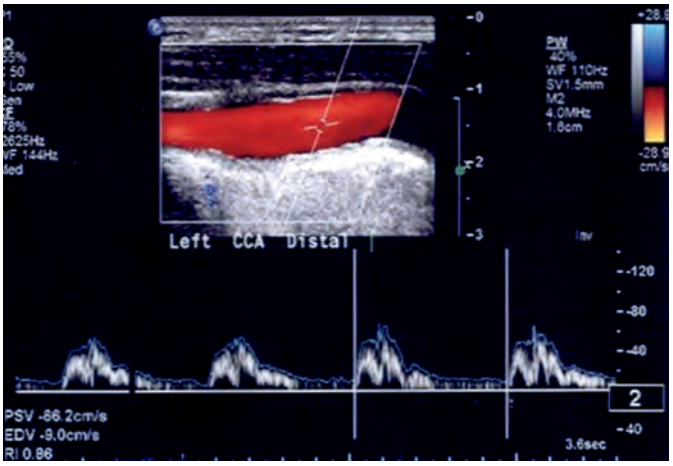


Figure 2-24. A delay in the systolic upstroke is evident with a stenosis of the aortic valve. A decrease in peak systolic velocities is also usually seen.

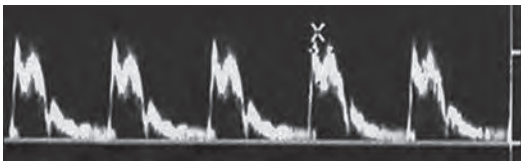


Figure 2-25. Double systolic peak (pulsus bisferiens) in the common carotid artery of a patient with aortic regurgitation/insufficiency.

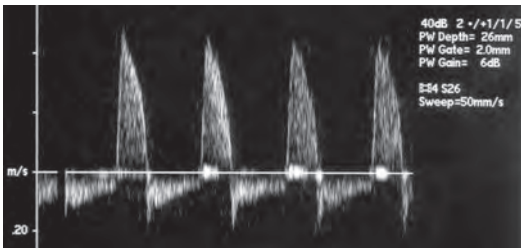


Figure 2-26. Pandiastolic flow reversal in the subclavian artery of a patient with aortic regurgitation/insufficiency.

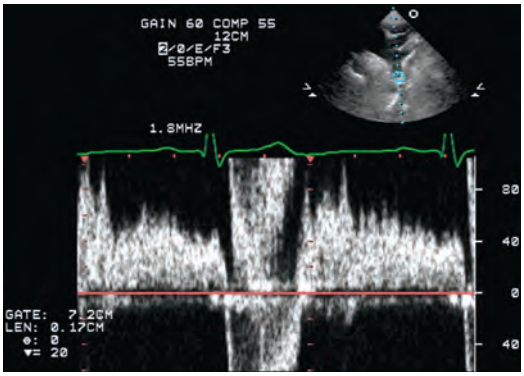


Figure 2-27. Significant flow reversal in the proximal aorta of a patient with severe aortic regurgitation/insufficiency.

Regurgitation/Insufficiency of the Aortic Valve

- A double systolic peak, sometimes referred to as *pulsus bisferiens*, may be evident (Figure 2-25). However, a similar finding, i.e., a second systolic peak, may be a normal finding in a young patient secondary to vessel wall compliance. In addition, one author* suggests that there may be a relationship between a double systolic peak and aortic dissection.
- Diminished diastolic flow or even reversed flow throughout diastole may also be documented on spectral analysis (Figures 2-26 and 2-27).

High Cardiac Output

- A systemic increase in peak systolic velocities may normally be evident in younger, athletic individuals or physically fit adults (Figure 2-28). A decrease in end-diastolic velocities may also be evident in a low-resistance vessel, e.g., the internal carotid artery. As previously mentioned, a double systolic peak may also be a normal finding in a young patient secondary to vessel wall compliance (Figure 2-25).

*Burgess W: Recommended protocol for duplex ultrasound in common carotid artery dissection extending from the aortic arch. Paper presented at the Annual Conference of the Society for Vascular Ultrasound, San Francisco, California, May 2013.

chronic obstructive pulmonary disease, primary pulmonary hypertension, and renal failure. It should be noted that elevated right heart pressure may also be related to a pulmonary embolism. In addition, it may reflect a fluid overload condition not necessarily related to a disease process, such as overhydration.

COLLATERAL EFFECTS

In an extremity at rest, total blood flow may be fairly normal even in the presence of severe stenosis or complete occlusion of the main artery because of the development of a collateral network, as well as the aforementioned compensatory decrease in peripheral resistance.

To evaluate the approximate location of the obstructed artery, Doppler segmental pressures may be helpful.

Arterial obstruction may alter flow in nearby or more distant collateral channels, increasing volume flow, reversing flow direction, increasing velocity, and/or altering the pulsatility of the waveform. Note in Figure 2-38 the low-resistance quality of the spectral waveform.

The location of collateral vessels helps to provide a tentative indication of the obstruction level, as demonstrated in Figure 2-39.

Secondary collateral changes (such as evidence of tissue healing or granulation, increased capillary refill, and decreased symptomatology) also provide some limited information regarding the adequacy of a collateral system that has evolved in response to arterial obstruction.

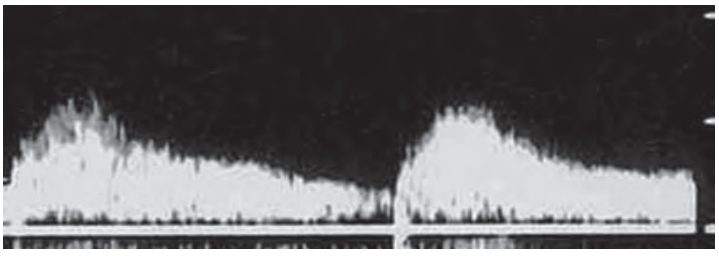


Figure 2-38. With a proximal superficial femoral artery (SFA) occlusion, flow in this popliteal artery is reconstituted via collaterals. Because flow is collateral-based and moving into a vasodilated vascular bed, its quality is of low resistance.

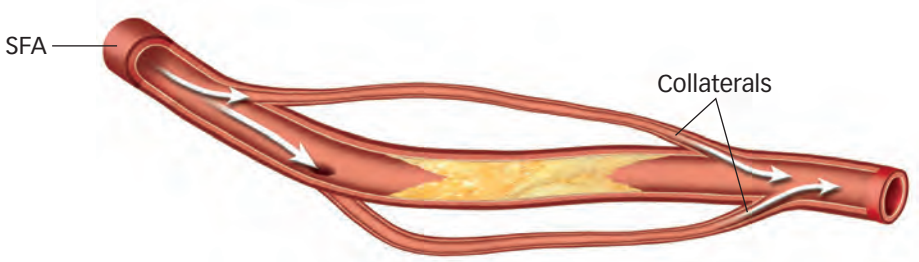


Figure 2-39. Representation of an occluded superficial femoral artery (SFA) with reconstituted flow distally due to collateralization. Arterial branches that were small are now taking a larger portion of the arterial flow, actually bypassing the obstruction in order to provide needed arterial flow to the foot.

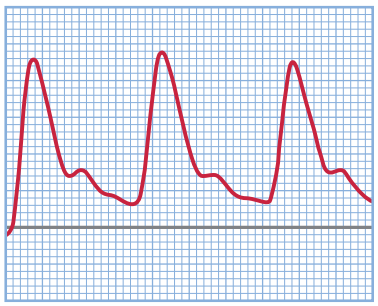


Figure 2-40. Because exercise produces a demand for blood to the muscles, a normally high-resistance arterial Doppler signal becomes low-resistance. In this analog waveform, the usual reversal below the baseline is seen as a forward reflection instead. This finding is quite normal after exercise.

EFFECTS OF EXERCISE

Exercise should induce peripheral vasodilation in the microcirculation so that distal peripheral resistance diminishes and blood flow markedly increases.

Peripheral resistance—the resistance to blood flow caused by the ever-decreasing size of the vessels, especially in the microcirculation—changes in response to a variety of stimuli such as heat, cold, tobacco use, and emotional stress.

Vasoconstriction and vasodilation of the blood vessels within skeletal muscles are also influenced by sympathetic innervation fibers that function primarily to regulate body temperature.

Exercise is probably the best single vasodilator of high-resistance vessels within skeletal muscle.

Autoregulation also controls vasoconstriction and vasodilation. Autoregulation accounts for the ability of most vascular beds to maintain a constant level of blood flow over a wide range of perfusion pressures.

- Autoregulation does not function normally when perfusion pressure drops below a critical level.
- High-resistance vessels constrict in response to increased blood pressure and dilate in response to decreased blood pressure.

By decreasing resistance in the working muscle, exercise normally decreases reflection (flow reversal) of the Doppler flow signal in the exercising extremity. ***Example:*** A low-resistance, monophasic Doppler flow signal (Figure 2-40) may be present normally in an extremity artery after vigorous exercise because the exercise causes peripheral dilatation and reduced flow resistance. This same low-resistance monophasic pattern is also seen pathologically when peripheral dilatation occurs in response to proximal arterial obstruction (see Figure 2-38).

On the other hand, a high-resistance signal (Figure 2-41) may occur from normal (physiologic) vasoconstriction at the arteriolar level or from distal arterial obstruction.

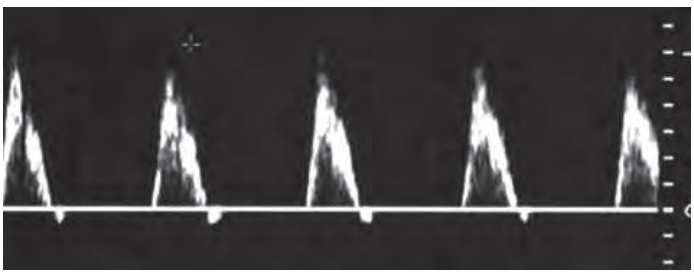


Figure 2-41. This high-resistance Doppler signal can occur with normal vasoconstriction at the arteriolar level. It can also occur proximal to distal arterial obstruction.

Additional notes:

- Proper characterization of velocity waveforms requires an understanding of both the normal flow characteristics of a particular artery and the physiologic status of the circulation supplied by the vessel.
- Questions need to be asked: Was the extremity cooled or warmed? Has it been exercised prior to the exam? Flow to a cool, vasoconstricted extremity will have pulsatile signals. Flow to a warm, vasodilated extremity will have continuous, steady signals.
- Proximal and distal pulsatility changes do not precisely differentiate between occlusion and severe stenosis.
- If good collateralization is present, proximal or distal Doppler velocity waveform qualities may not be altered.
- The distal effects of obstructive disease may be detectable in the presence of exercise or hyperemic evaluation.

EFFECTS OF STENOSIS ON FLOW

Laminar flow review:

- Laminar flow has an even distribution of frequencies at systole, with the lower frequencies distributed at the walls (the boundary layer) and the higher frequencies in center stream.
- Stable flow through a relatively straight vessel is usually laminar, the layers of fluid slipping over one another with minimal friction normally.

A hemodynamically significant stenosis causes a major reduction in volume flow and pressure. A stenosis usually becomes hemodynamically significant when the cross-sectional area of the arterial lumen is reduced 75%, which corresponds to a diameter reduction of 50%.

- Diameter reduction is a one-dimensional measurement (Figure 2-42).
- Area reduction is a two-dimensional measurement (Figure 2-43).
- In hemodynamically significant stenoses, both pressure and flow volume decrease.

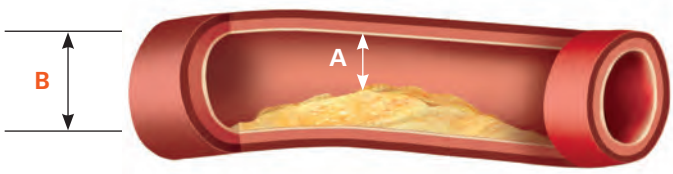


Figure 2-42. The nondiseased arterial segment is measured from wall to wall in a longitudinal approach (**B**) and then compared to the residual flow channel at the area of stenosis (**A**). A percentage diameter reduction is calculated.

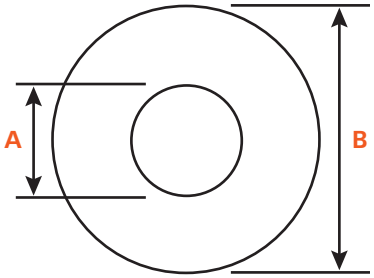


Figure 2-43. The original lumen (**B**) is measured and compared to the residual lumen (**A**) when the vessel is in a transverse approach. A percentage area reduction is calculated.

CHAPTER 12

Duplex Scanning and Color Flow Imaging of the Upper Extremities

Capabilities and Limitations

Physical Principles

Technique

Interpretation

Brachial Artery Reactivity Testing

CAPABILITIES AND LIMITATIONS

Capabilities

- Localizes arterial stenosis or occlusion and evaluates degree of stenosis.
- Determines the presence or absence of aneurysm.
- Evaluates hemodialysis access graft or arterial bypass graft postoperatively.
- Detects arteriovenous fistulas or other unusual abnormalities.
- Evaluates medical treatment or surgery on a follow-up basis.

Limitations

- Cannot be used in the presence of dressings, skin staples, sutures, or open wounds.
- Imaging is difficult around IV site.
- Hemodialysis access grafts:
  - Difficult to assess the anastomotic sites because of graft angulation.
  - Difficult to adequately evaluate the outflow vein secondary to increased collateral development.
- For diagnosis of Raynaud's phenomenon, previously described in Chapter 10 (page 113), physiologic studies combined with the clinical presentation (Chapter 3, pages 52–53) constitute the most useful diagnostic approach.

PHYSICAL PRINCIPLES

- Duplex scanning combines real-time B-mode imaging (gray-scale evaluation) and Doppler spectral analysis (which is an analysis and display of the Doppler-shifted frequencies).
- Color flow imaging continues to provide the duplex information described above and in addition evaluates the Doppler flow information for its *phase* (direction toward or away from the transducer, on which basis color is assigned) and its *frequency content* (which determines the hue or shade of the assigned color).
- More in-depth coverage of this topic should be gleaned from textbooks focusing on physical principles of ultrasound scanning.

TECHNIQUE

- The patient is supine with a small pillow under the head.
- The extremity is positioned close to the examiner.
- The arm to be evaluated is externally rotated and positioned at approximately a 45-degree angle from the body in what has been called the "pledge position."

For the patient with a dialysis graft, auscultate for a bruit and/or palpate for a "thrill" (vibration), bearing in mind that both graft stenosis and the high volume of blood flow through a patent dialysis graft will produce this effect.

- A multifrequency (e.g., 5–7 MHz) linear array transducer is used.
- The neck vessels are identified, with attention given to the innominate artery on the right. The left common carotid artery arises from the aortic arch.
- Duplex scanning (with or without color flow imaging) is performed at the following anatomic sites in this order:
  1. Subclavian artery
  2. Axillary artery

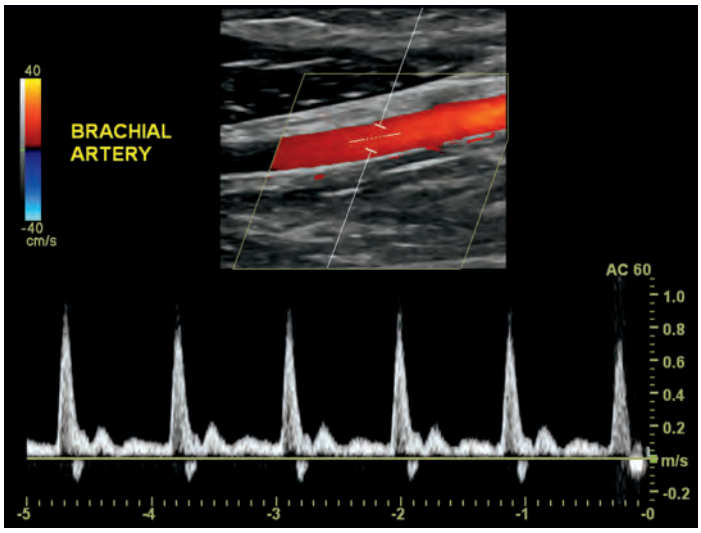


Figure 12-1. Spectral Doppler of the brachial artery, accompanied by color flow. Courtesy of Steve Bernhardt, BS, RDMS, RVT, RPhS.

3. Brachial artery
4. Radial artery
5. Ulnar artery
6. Palmar arch if necessary

Gray-scale imaging is used to observe vessel walls and to identify the presence of plaque and its morphology. Spectral analysis of these vessels, including evaluation of waveforms and measurement of peak systolic velocities, is used to assess blood flow. (See Figure 12-1.)

Color flow imaging is useful to discriminate flow deviations, flow channel narrowing within the vessel, and absence of flow where it should be, as well as assessing whether there is flow where there should not be (e.g., pseudo- or true aneurysm or inflamed lymph node).

- It is rather uncommon for arteries in the upper extremities to become stenotic. The main use for duplex and color flow imaging in the upper extremity is to evaluate hemodialysis access grafts, although other applications exist as well, including vein mapping and evaluation for thrombosis.
- Hemodialysis grafts are evaluated in the following order:
  1. Identify and evaluate inflow artery.
  2. Identify and evaluate arterial anastomosis.
  3. Identify and evaluate body of the graft.
  4. Observe for abnormalities, e.g., aneurysm, puncture site leaks, perigraft fluid collections.
  5. If color flow imaging is available, observe the image for frequency increases, turbulence, flow channel changes, and other deviations from normal.
  6. Identify and evaluate venous anastomoses.
  7. Identify and evaluate outflow vein.

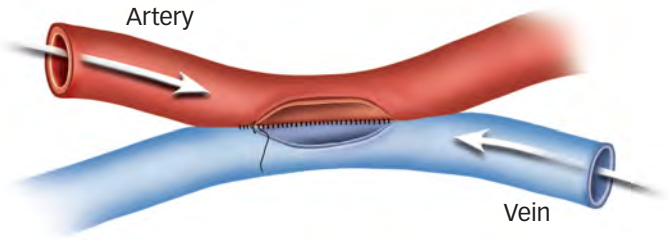


Figure 12-2. Brescia-Cimino fistula being surgically created.

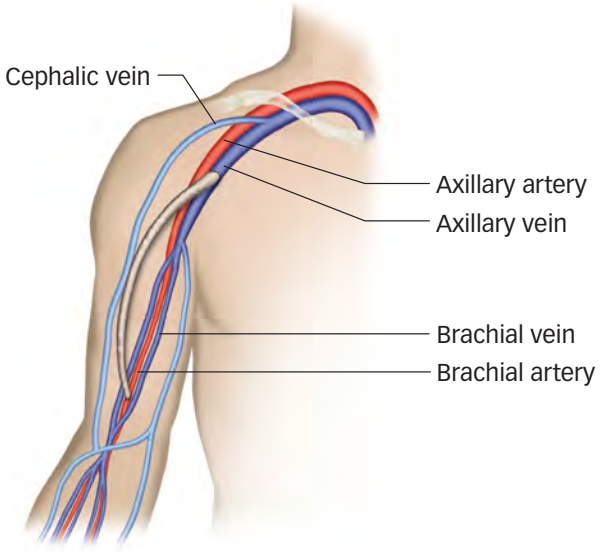


Figure 12-3. Straight arteriovenous dialysis access graft (brachial artery to axillary vein).

- Types of dialysis access include Brescia-Cimino fistulas (i.e., radial artery and cephalic vein) (Figure 12-2), straight synthetic grafts (see Figure 12-3), and looped synthetic grafts.
- Longitudinal and transverse approaches are used to evaluate the gray-scale image for thrombus, wall thickening, and other changes.
- Doppler peak systolic velocities (PSVs) are measured at the aforementioned sites (depending on which study is being performed) and also at other locations of interest (e.g., for stenosis, preocclusion).
- Documentation consists of storing the digital images (e.g., via the Picture Archiving and Communication System [PACS]) or making hard-copy prints.

INTERPRETATION

Stenosis

- Currently, there are no criteria for classifying upper extremity disease as there are for the lower extremities.
- Peak systolic velocities vary widely with changes in skin temperature. The Doppler signal quality is usually triphasic (Figure 12-4A), but when the hand is quite warm or the arm has been exercised, the Doppler signal quality becomes lower-resistance (continuous through diastole). (See Figure 12-4B.) The effects of cooling were previously discussed in Chapter 10, page 111.

CHAPTER 14

Duplex Scanning and Color Flow Imaging of the Abdominal Vessels

Diagnostic Imaging of the Abdominal Vessels

Organ Transplants

DIAGNOSTIC IMAGING OF THE ABDOMINAL VESSELS

Capabilities

- *Aortoiliac vessels*: Determines the presence/absence of significant stenosis, supports follow-up for bypass grafts, and evaluates aneurysms.
- *Renal artery*: Determines if significant stenosis of ≥60% diameter reduction is present.
- *Kidney*: Helps determine presence/absence of nephrosclerotic disease and evaluates and supports follow-up for transplants.
- *Mesenteric arteries*: Determines presence/absence of significant stenosis, which may account for or cause mesenteric bowel ischemia.
- *Liver*: Evaluates for suspected portal hypertension and evaluates pre/post liver transplants.

Limitations

- Depth of ultrasound penetration is limited by size of patient.
- Bowel gas may limit access to some vessels.
- Previous abdominal surgery (scar tissue) may compromise results.
- Shortness of breath and rapid respiration may result in inaccurate results.
- Nonfasting patient may compromise results.

Physical Principles

- See the descriptions of physical principles in Chapter 12 (page 120) and Chapter 13 (page 129).

Technique and Interpretation

Patient Positioning

- Supine, with minimal head elevation (a pillow is acceptable) as the procedure begins.
- Left lateral decubitus (LLD) for access to the right flank and right lateral decubitus (RLD) for access to the left flank. These positions allow the bowel to fall to the other side, providing better access to the renal arteries and kidneys.
- The positions listed above are also useful for accessing the aorta and superior mesenteric artery.
- Evaluation of the abdominal vessels requires creative patient positioning and scanning approaches in order to optimize the study.

General Remarks

- Using a multifrequency linear or phased array transducer, e.g., 3–5 MHz (a higher-frequency transducer, e.g., 7MHz, may be needed for children or thin elderly patients) and duplex ultrasonography with or without color flow imaging, the examiner begins scanning for the vessels of interest.
- Combining longitudinal (sagittal) and transverse (see note below) approaches with other approaches as necessary, the examiner evaluates the gray-scale and color flow patterns, observing for aneurysm, plaque, and other pathologies and findings.

  Note: The transverse approach includes both the orthogonal 90-degree plane relative to the body itself and the short-axis view, which is transverse in relation to the structure under examination.
- Using a longitudinal approach in order to accurately and appropriately set the Doppler angle (≤60 degrees), the examiner also assesses the Doppler waveform qualities, peak systolic velocity, and when appropriate the end-diastolic velocity of the arteries under examination.

Aortoiliac Arteries—Technique

See "General Remarks" above, and examine:

- Proximal, mid, and distal aorta to the bifurcation.
- Common iliac artery bilaterally.
- Proximal, mid, and distal external iliac artery bilaterally.
- Internal iliac artery bilaterally.
- Brief observation is made of the celiac artery, superior mesenteric artery, and renal artery branches.

Note: It is important, especially when evaluating an abdominal aortic aneurysm (AAA), that the measurements are made of the maximum diameter of the aneurysm. These measurements must be made perpendicular to the aorta, *not* transverse to the body. Many patients have an angulated aorta. In order to obtain accurate measurements, the examiner must adjust the transducer so that it is perpendicular or orthogonal to the aorta, even if this means the plane of insonation is oblique. Some authors recommend also measuring the diameter of an AAA in the sagittal and coronal planes for reproducibility and to avoid errors based on oblique transverse measurements.

Aortoiliac Arteries—Interpretation

- Stenosis: The criteria applied to the lower extremities are utilized here as well. See "Interpretation" on pages 132–136 of Chapter 13.
- Aneurysm:
  - For the aorta, a dilatation of >3 cm qualifies for designation as an aneurysm. In general, an increase in diameter of 50% or more qualifies an artery as aneurysmal. See Figure 14-1.
  - The majority of AAAs are atherosclerotic and infrarenal, i.e., below the renal artery branches.

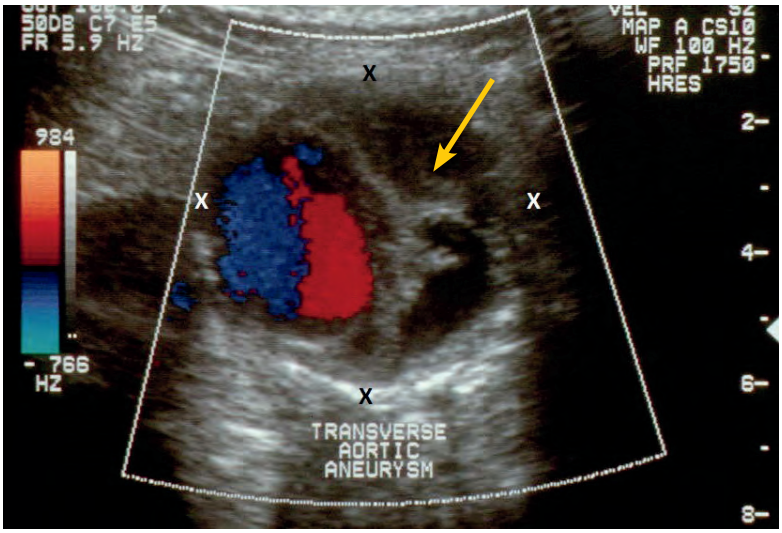


Figure 14-1. In this transverse image, the A/P (black X's) and lateral (also referred to as transverse) measurements (white X's) both meet the criteria for aneurysm. Note also the presence of thrombus (arrow) within the vessel.

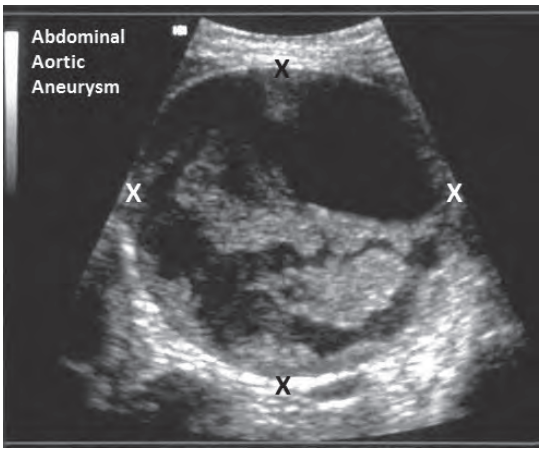


Figure 14-2. In this transverse image of an abdominal aortic aneurysm, at least 7 cm in diameter, the A/P measured distance is depicted with black X's, while the lateral (also referred to as transverse) measured distance is depicted with white X's. It contains a mixture of echoes that are more heterogeneous than homogeneous. Peak systolic velocities vary according to the extent of thrombus. Large lumen (less thrombus) = lower velocities; small lumen (more thrombus) = higher velocities; preocclusive = lower velocities.

- The examiner should note the type of aneurysm—true (i.e., fusiform or saccular), false, or dissecting—and the presence of thrombus, if any. See the example of a thrombotic aneurysm in Figure 14-2.
- The most frequent complication and danger of an AAA is rupture, but it can also embolize. Both thrombosis and embolization are considered primary complications of peripheral arterial aneurysms. It is not uncommon for both abdominal and peripheral aneurysms to contain varying amounts of thrombus.

Renal Artery and Kidney—Technique

See "General Remarks" on page 140. It is helpful to know that many of the patients undergoing this study present with hypertension (controlled or not well controlled) and that many of these hypertensive patients have *renovascular* hypertension. Renovascular hypertension, a secondary form of high blood pressure, is often caused by renal artery stenosis (which can be secondary to atherosclerosis or fibromuscular dysplasia) or occlusion. The narrowing of the artery reduces blood flow to the kidney and, in response, the kidney produces the enzyme renin. Through a series of complicated interactions, there is a conversion of angiotensinogen to angiotensin II, which results in constriction of the blood vessels. Through another process, sodium and fluid retention also occur.

- The examiner begins in the longitudinal plane, acquiring velocity data from the celiac and superior mesenteric arteries.
- The peak systolic velocity of the aorta is obtained just distal to the superior mesenteric artery.
- Using a transverse approach, the examiner locates the renal arteries. The left renal vein is a good landmark for identifying the left renal artery, as depicted in Figure 14-3. See also Figures 14-4, 14-5, and 14-6, which show not only the left renal vein but also the renal artery branches.
- Kidney size and morphology are evaluated bilaterally. Figure 14-7 shows a normal-sized kidney with color flow clearly demonstrating the segmental arteries, as well as the renal artery.

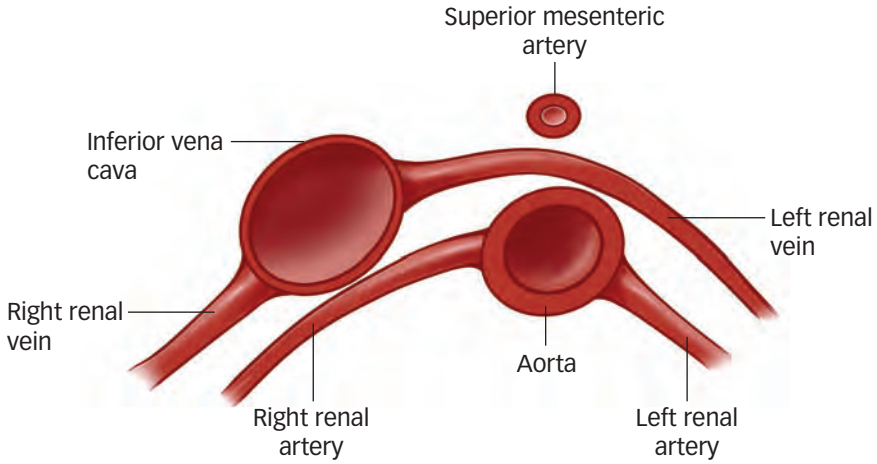


Figure 14-3. Transverse view of the abdomen showing the position of the left renal vein in relation to the left renal artery.

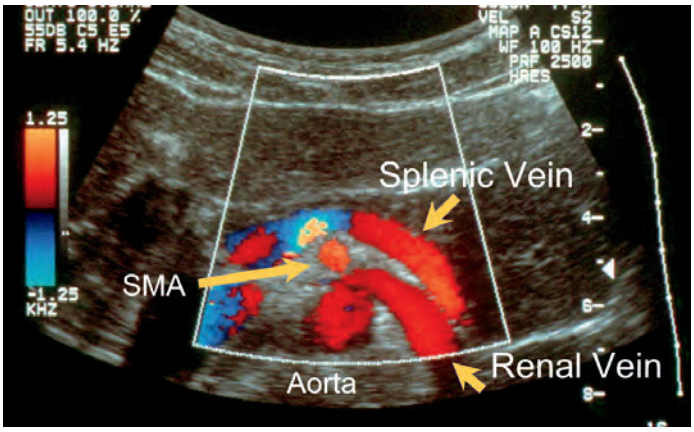


Figure 14-4. Transverse view of the abdominal aorta also showing the superior mesenteric artery (SMA), left renal vein, and splenic vein. This image is a good reminder to watch the color bars for flow direction. The veins, in this example, are not blue.

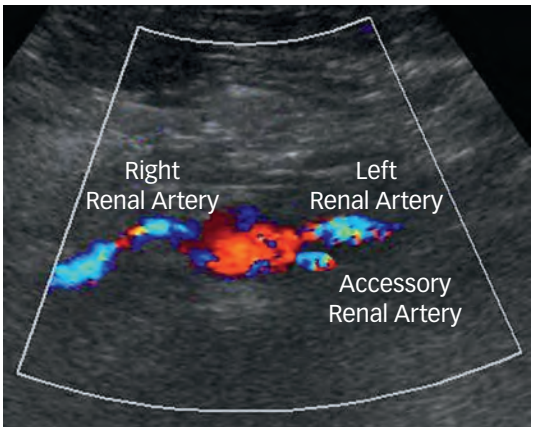


Figure 14-5. Transverse image of the abdominal aorta, showing two left renal arteries and a single right renal artery.

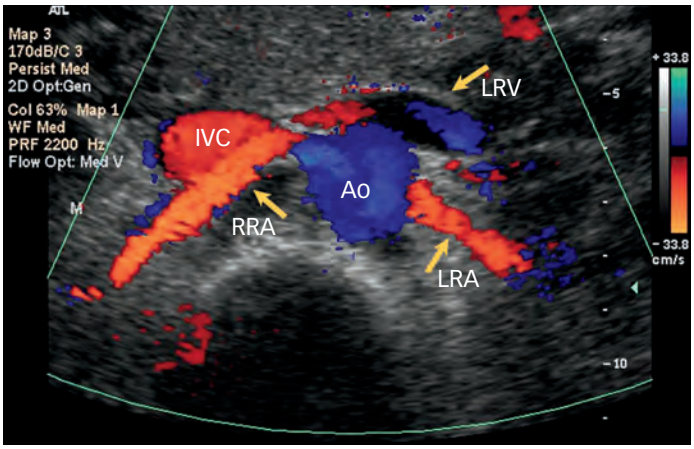


Figure 14-6. Transverse image of the abdominal aorta (Ao), showing the following vessels with an accompanying arrow: right (RRA) and left (LRA) renal arteries and left renal vein (LRV), which can be insonated with an appropriate Doppler angle. Note also the inferior vena cava (IVC), to the left of the aorta and the left renal vein. Courtesy of UC Davis Medical Center.

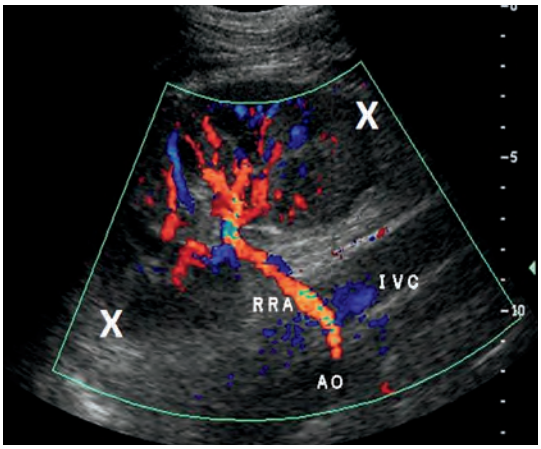


Figure 14-7. Normal-sized kidney with color flow clearly showing the segmental arteries, as well as the right renal artery (RRA) depicted from its origin at the aorta (Ao) into the kidney. The X's shown on the ends of the kidney depict the start and end points for length measurement. Courtesy of UC Davis Medical Center.

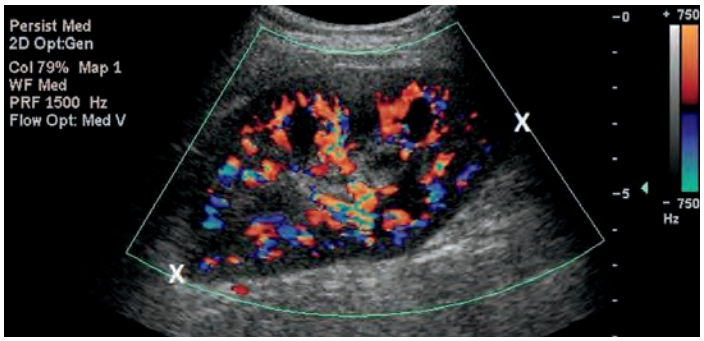


Figure 14-13. Longitudinal view of a normal kidney. The X's located at the ends of the kidney show how the kidney length is measured.

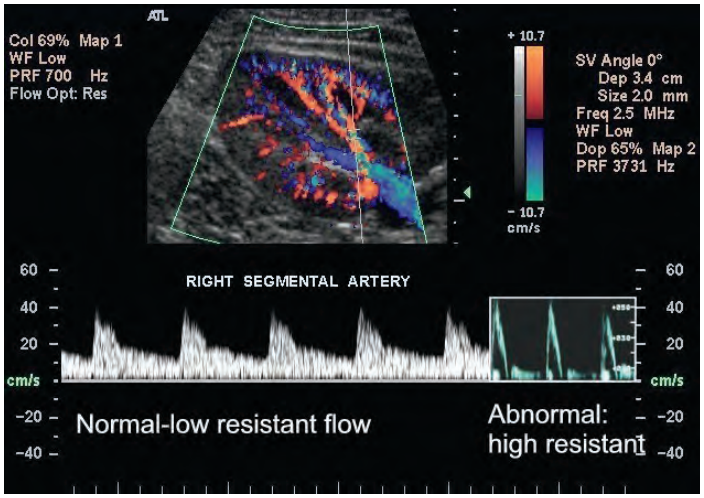


Figure 14-14. Transverse view of the right kidney, using a coronal approach. Doppler signals are obtained from a segmental artery within the kidney. Normally, the signals are low-resistance, as noted on the image with the first set of waveforms. In an abnormal (e.g., nephrosclerotic) kidney, the Doppler signal is high-resistance, as seen to the right.

The results are interpreted as follows:

- *Normal:* ≥0.2
- *Abnormal:* <0.2

An EDR or PRR of <0.2 indicates an increase in resistance within the kidney parenchyma. An example of the type of waveform obtained in this situation appears in Figure 14-14.*

- Another ratio used (to a lesser degree) to determine whether resistance is increasing in the kidney (especially the transplanted kidney) is Pourcelot's ratio/resistivity index (RI), which is calculated as follows:

$$\frac{PSV - EDV}{PSV}$$

- *Normal:* <0.7
- *Abnormal (increased resistance):* ≥0.7**

*Neumyer MM: Native renal artery and kidney parenchymal blood flow duplex evaluation with/without color flow imaging. In Rumwell CB, McPharlin MM, Strandness DE, et al (eds): *Vascular Laboratory Policies & Procedures Manual*. Pasadena, Davies Publishing, 2008.

**Rifkin MD, Needleman L, Pasto ME, et al: Evaluation of renal transplant rejection by duplex Doppler examination: value of the resistive index. Am J Roentgenol 148:759–762, 1987.

Example of velocity findings in a kidney with abnormal arterial flow patterns:

- *Doppler findings:* PSV = 70, EDV = 10
- *End-diastolic ratio (EDR):* 10/70 = 0.14
- *Resistivity index (RI):* $\frac{70 - 10}{70} = 0.86$

- The renal resistive-index value (RRIV)* also uses the peak systolic velocity and the end-diastolic velocity obtained from the kidneys' segmental arteries. The purpose of using this value is to help prospectively identify patients whose renal function or blood pressure will improve after correction of the renal artery stenosis. A lower-resistance RRIV value of <0.75 is associated with improvement in both blood pressure and renal function after the correction of renal artery stenosis. Conversely, an RRIV of ≥0.75 is a strong predictor of worsening renal function and lack of blood pressure improvement, despite the correction of renal artery stenosis. Calculation of the RRIV is as follows: 1 − EDV/PSV. When you compare this to the EDR or PRR, described above, note that the sum of the PRR and the RRIV is 1; that is, subtract the PRR from 1 and you will get the RRIV, and vice versa.
- Proximal high-grade stenosis or occlusion of the renal artery may result in a dampened (prolonged-upstroke) but still low-resistance waveform (see Figure 14-15A). The angiographic result (see Figure 14-15B) is an example of what can cause the poor flow depicted in Figure 14-15A.
- Some references describe the usefulness of evaluating the kidney arterial flow by determining the acceleration time (AT) and acceleration index (AI).
  - The AT is the time interval from the onset of systole to the initial peak and is reported in milliseconds (msec). A proximal stenosis of ≥60% diameter reduction is most likely to produce an AT of ≥100 msec.
  - The AI describes the slope of the Doppler velocity waveform. It is calculated as the change in velocity between the onset of systole and the

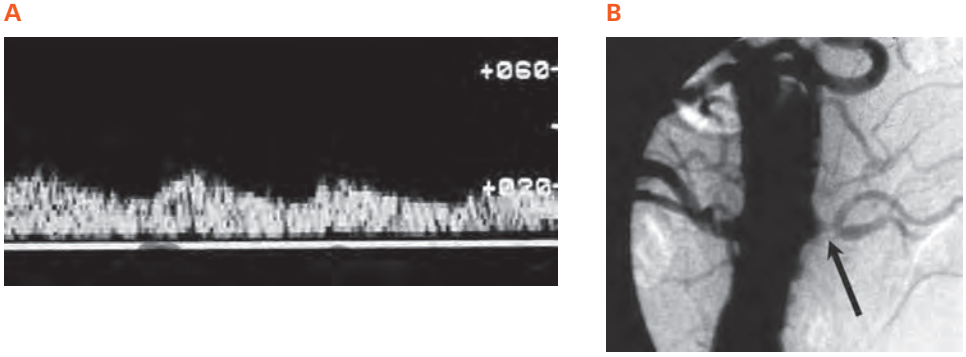


Figure 14-15. A Spectral Doppler arterial signal obtained from the kidney in the presence of a proximal high-grade stenosis or occlusion of the renal artery. This waveform pattern is termed *tardus parvus*. **B** Angiogram showing an occlusion (arrow) of the left renal artery. Collateral vessels are providing poor-quality arterial flow to the kidney.

*Yuksel UC, Anabtawi AG, Cam A, et al: Predictive value of renal resistive index in percutaneous renal interventions for atherosclerotic renal artery stenosis. J Invasive Cardiol 24:504–509, 2012.

systolic peak (cm/sec) divided by the AT. The units of measure for AI are cm/sec^2. A positive result (consistent with a ≥60% diameter reduction) is defined as AI ≤291 cm/sec^2.*, **

Mesenteric Arteries—Technique

- Patient history: Patients who present with a history of dull, achy, or crampy abdominal pain 15–30 minutes after meals may suffer from *mesenteric ischemia*. Mesenteric ischemic pain is also known as *mesenteric angina*. This condition may be caused by a stenosis or occlusion of vessels such as the superior mesenteric, celiac, or inferior mesenteric arteries.
- Mesenteric ischemia may be acute or chronic. Both conditions are difficult to diagnose. The study described here assists with the diagnostic process, but an arteriogram is essential for diagnosis.
- It is essential that this study always be performed on a fasting patient.
- Peak systolic and end-diastolic velocities are obtained in the longitudinal plane from the following arteries:
  - Celiac trunk (artery), hepatic artery, and splenic artery, all of which often require a transverse approach to the aorta (see Figure 14-16)
  - Proximal, mid, and distal superior mesenteric artery (see Figure 14-17)

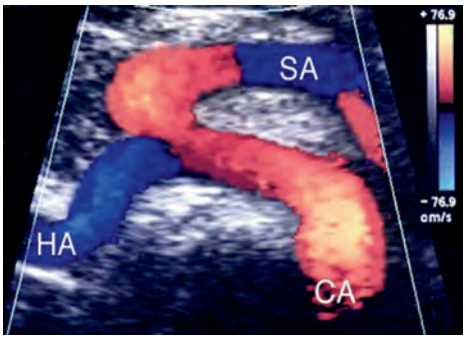


Figure 14-16. Celiac artery (CA)—i.e., celiac trunk—with branches. The hepatic artery (HA) takes blood to the liver; the splenic artery (SA) takes blood to the spleen. All Doppler flow is low-resistance because organs have a constant need for blood supply. Courtesy of Steve Bernhardt, BS, RDMS, RVT, RPhS.

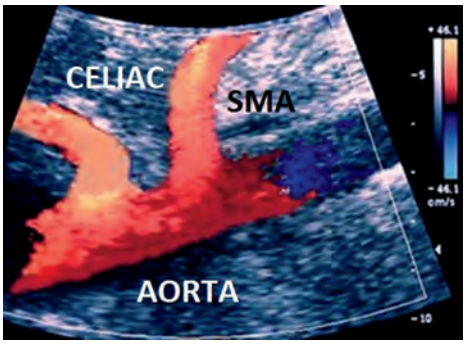


Figure 14-17. Color flow Doppler image using a low-frequency transducer in the longitudinal (sagittal) approach demonstrates the celiac artery followed by the superior mesenteric artery (SMA) branching off the aorta. Courtesty of Steve Bernhardt, BS, RDMS, RVT, RPhS.

*Issacson JA, Zierler RE, Spittell PC, et al: Noninvasive screening for renal artery stenosis: comparison of renal artery and renal hilar duplex scanning. J Vasc Technol 19:105–110, 1995.

**Martin RL, Nanra RS, Wlodarczyk J, et al: Renal hilar Doppler analysis in the detection of renal artery stenosis. J Vasc Technol 15:173–180, 1991.

Table 14-1 Summary criteria for interpreting pre- and postprandial findings in the superior mesenteric and celiac arteries.

Description	SMA	Celiac Artery
Preprandial (fasting):		
PSV	High	High
EDV	Low	High
Flow reversal	Yes	No
Postprandial (food challenge):		
PSV	Marked increase	No change
EDV	Marked increase	No change
Loss of flow reversal	Yes	N/A
Velocity criteria:		
Normal PSV*	110–177 cm/sec	50–160 cm/sec
*Stenosis criteria** (includes poststenotic turbulence)	PSV ≥275 cm/sec predicts ≥70% diameter reduction	PSV ≥200 cm/sec predicts ≥70% diameter reduction

*Criteria and other information from various publications by Gregory L. Moneta, MD, Oregon Health & Science University Hospital, Portland, Oregon.

- Celiac band syndrome, which is an extrinsic compression of the celiac artery origin by the median arcuate ligament of the diaphragm, is a fairly frequent anatomic finding, especially among young, athletic women. A reversible celiac artery stenosis occurs and is rarely the cause of clinical symptoms. In such cases the high-velocity signals indicative of stenosis are substantially improved with deep inspiration and return with expiration. See Figure 14-23. An audible bruit can be auscultated, and during duplex/color flow imaging a "color bruit" may appear during exhalation.
- The celiac artery branches into the hepatic and splenic arteries (see Figure 14-16). The liver and spleen have fixed metabolic requirements and are not likely to be influenced by the postprandial state. Therefore, high peak systolic and end-diastolic velocities are normally evident in these vessels at all times.

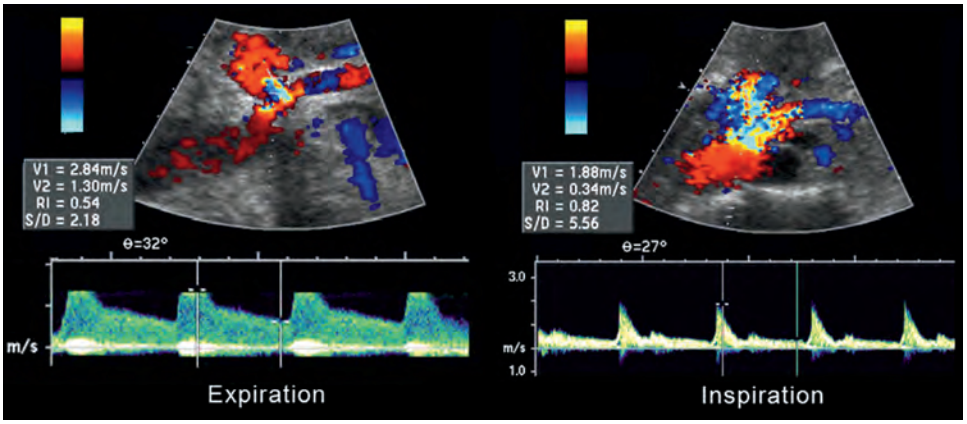


Figure 14-23. Longitudinal image of the abdominal aorta and celiac artery. The Doppler spectral waveforms were recorded at both phases of respiration. Extrinsic compression of the celiac artery during expiration is a frequent finding. In this example, it causes peak systolic velocities and end-diastolic velocities to increase (>284/130 cm/sec) with aliasing noted. During inspiration, velocities decrease to 188/34 cm/sec. Courtesy of Steve Bernhardt, BS, RDMS, RVT, RPhS.

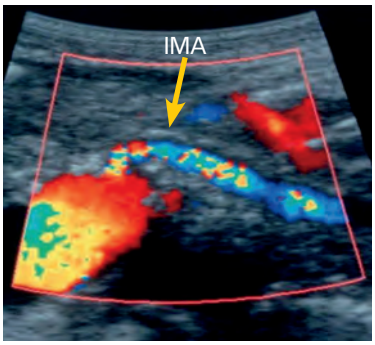


Figure 14-24. Inferior mesenteric artery (IMA) easily observed in this image because of a superior mesenteric artery (SMA) occlusion (not seen on this image).

- The hepatic artery and splenic artery Doppler signals should be low-resistance in quality because each provides arterial inflow to a particular organ. There are no specific peak systolic velocity criteria for what suggests stenosis in either of these vessels (other than the stenosis profile described on pages 40–41), but if the celiac artery is occluded, retrograde flow may occur in the hepatic artery and, if so, should be identified during the duplex evaluation.
- Because of its small caliber, it is quite difficult to locate the inferior mesenteric artery (IMA), which branches off the distal aorta. Easy detection and ultrasonographic dominance of the inferior mesenteric artery (see Figure 14-24) may suggest occlusion of the superior mesenteric artery.
- Of interest is the ability of the IMA to provide collateralization in response to an occlusion of the SMA. Two possible collateral connections between the SMA and IMA include the arc of Riolan and the marginal artery of the colon (also known as the marginal artery of Drummond).
- Chronic mesenteric ischemia is suggested when there are abnormal findings for at least two of the three mesenteric vessels (celiac, superior mesenteric, and inferior mesenteric arteries) in symptomatic patients.

ORGAN TRANSPLANTS

Liver Transplant (Allograft)

- Liver transplantation is becoming a more frequently utilized procedure to treat patients with end-stage liver disease. In the pre- and postoperative assessment of these patients, the examiner uses a multifrequency (e.g., 3–5 MHz) linear or phased array transducer.
- The preoperative duplex evaluation of candidates for liver transplantation includes documenting the patency of the portal vein, splenic vein, superior mesenteric vein, hepatic veins, inferior vena cava, and hepatic artery while observing for abnormalities (i.e., tumors in the liver and surrounding tissue) and/or other vasculature (see Figure 14-25). Doppler waveforms are evaluated according to the appropriate criteria. It is also important to determine the status of the biliary tree. Abnormalities such as thrombosis of the portal vein can make transplantation difficult, if not impossible.
- Postoperatively, duplex ultrasonography is used to document patency of the portal vein (Figure 14-26), splenic vein, superior mesenteric vein, hepatic veins, inferior vena cava, and hepatic artery, as well as portal vein flow direction and vessel size. Normal portal vein size should be $\leq$1 up to 1.5 cm.
- Postoperative complications include allograft rejection, pseudoaneurysm, hepatic infarction, and thrombosis of the portal vein, inferior vena cava, and/or hepatic artery. Obviously, the hepatic artery inflow becomes crucial to the viability of the liver.
  - The location of this artery provides a challenge to obtaining a proper Doppler angle. If the Doppler angle is high (i.e., 80–90 degrees), no flow

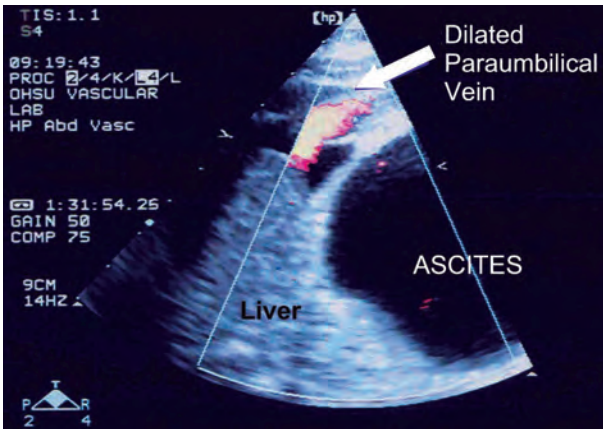


Figure 14-25. Sagittal/oblique view of the liver revealing ascites and a dilated paraumbilical vein. It is not unusual to observe one or both of these findings in patients being evaluated for liver transplantation. A sudden increase of ascites often precedes portal vein thrombosis, especially in cirrhotic patients. Dilatation of the paraumbilical vein is a specific finding for portal hypertension, in which normally hepatopetal flow becomes hepatofugal as blood flow is diverted to the systemic venous circulation through a collateral pathway.

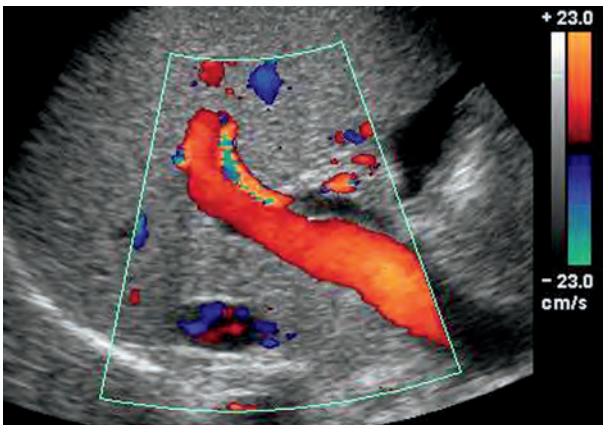


Figure 14-26. Duplex scan of the liver with a patent, normal portal vein. Flow direction (red color) is toward the liver (hepatopetal).

may be detected because of the poor or nonexistent Doppler shift. Before concluding that the hepatic artery is occluded, the examiner must be certain that an appropriate Doppler angle has been used. If possible, the proximal hepatic artery is examined where it branches off the celiac artery to determine the presence or absence of flow.

- Acute rejection will cause liver dysfunction. It has been thought by some that rejection would cause arterial resistance (measured by the resistivity index) to increase. Others, however, suggest that rejection is a cellular process that does not affect the peripheral vessels.

Renal Transplant (Allograft)

- Both living related–donor and cadaveric kidneys are implanted most commonly in the right iliac fossa.
- Postoperative examination is facilitated if the examiner knows what type of anastomosis was used. The transplanted renal artery vessels are anastomosed either end-to-side with the external iliac artery or end-to-end with the internal iliac artery. The venous anastomosis connects the renal vein to the external iliac vein in an end-to-side fashion. Most often, the donor ureter is implanted into the bladder directly.

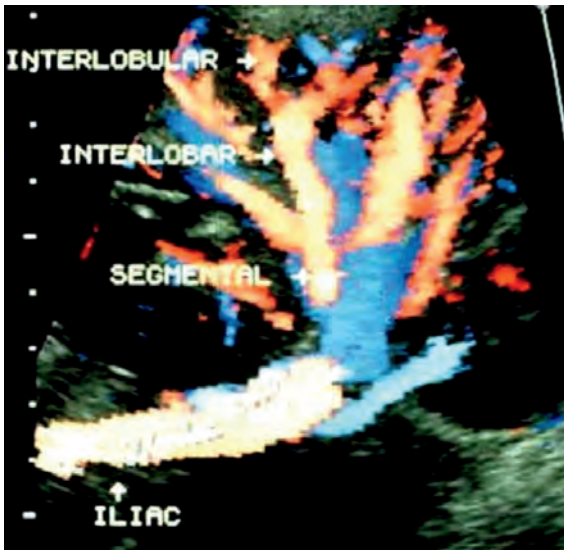


Figure 14-27. Transplanted kidney located in the iliac fossa, which makes scanning easier because of the shallower location of the kidney. The kidney branches are clearly seen in the kidney pelvis (segmental arteries) to the outer region (interlobular arteries). Although not identified, the interlobar arteries branch into the arcuate arteries and the arcuates branch into the interlobular arteries.

Technique

- Duplex evaluation is usually performed with a multifrequency (e.g., 5–7 MHz) linear or phased array transducer. See Figure 14-27.
- Longitudinal and transverse approaches are utilized.
- The length and A/P diameter of the allograft are measured for subsequent follow-up.
- Careful B-mode observation is made of parenchymal echogenicity, including the renal cortex, renal sinus, and pyramids.
- B-mode observation continues for the detection of fluid collections (e.g., hematoma, abscess). If there are regions of hypoechogenicity within the allograft, Doppler ultrasound is used to differentiate between a vascular abnormality and a fluid collection.
- Postoperative follow-up also includes Doppler spectral analysis of the aorta, internal or external iliac artery, donor renal artery, external iliac vein, donor renal vein, and allograft vessels. Peak systolic and end-diastolic velocities are obtained and flow qualities assessed as to whether the flow resistance is normal (i.e., lower-resistance flow) or abnormal (i.e., higher-resistance flow).

Interpretation

- B-mode signs of rejection include:
  - Increased renal transplant size
  - Increased cortical echogenicity
  - Hypoechoic regions in the parenchyma
- The promise of Doppler analysis as a method for diagnosing acute rejection continues to be a source of discussion. There are those groups who have found the resistivity index to be predictive of acute rejection; others, however,

have found that pulsatility abnormalities are not reliable. What is interesting is that conditions other than acute rejection—renal vein thrombosis, infection, cyclosporine toxicity, and tubular necrosis, to name a few—can increase pulsatility.

- According to many sources, biopsy continues to be the most reliable method for rejection diagnosis.
- With respect to other vascular complications, duplex scanning also has diagnostic value. Its applications include:
  - Renal artery stenosis
  - Renal vein thrombosis
  - Arteriovenous fistula
  - Pseudoaneurysm

Vascular Technology

AN ILLUSTRATED REVIEW

5th EDITION

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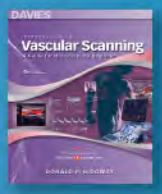

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Claudia Rumwell lectures on registry preparation, provides consulting services, and continues to write. She is a past member of the board of the Society for Vascular Ultrasound, is a recipient of the SVU Distinguished Service Award, and has been honored with the status of SVU Fellow. She previously served in the following roles for the Division of Vascular Surgery at Oregon Health & Science University: Technical Director of the Vascular Lab, Clinic Nurse Coordinator, Research Nurse Coordinator, and Instructor in Surgery.

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0 Enter the number of questions you want.

Total number of questions on the topic you selected.

0 Enter the number of questions you want.

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160 The ultrasound image below shows an internal carotid artery with:

A A calcified plaque

B An ulcerated lesion

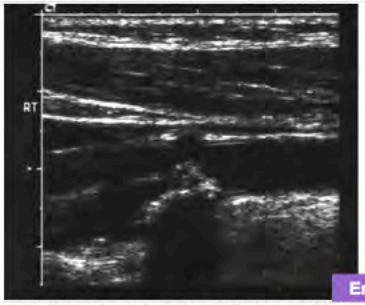
C A normal arterial wall

D An intraplaque hemorrhage

E A homogeneous plaque

Next | 160 of 665 | Prior | Bookmark/Skip | Pause | First | Last | Finish

Question Image 1



Enlarge

Question Image 2

Enlarge

Exam Topic I. Cerebrovascular (25%–35% of ARDMS exam)

160 The ultrasound image below shows an internal carotid artery with:

A A calcified plaque

B An ulcerated lesion

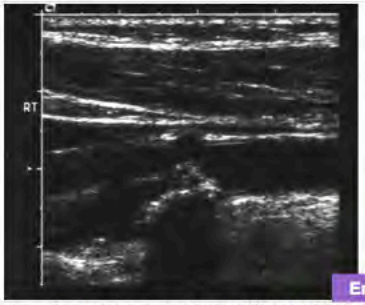
C A normal arterial wall

D An intraplaque hemorrhage

E A homogeneous plaque

Next | 160 of 665 | Prior | Bookmark/Skip | Pause | First | Last | Finish

Explanation Image 1



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Explanation Image 2

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Exam Topic I. Cerebrovascular (25%–35% of ARDMS exam)

RIGHT!

You chose the correct answer, A: A calcified plaque

Note the brightly echogenic plaque and acoustic shadowing.

References

Zwiebel WJ: *Introduction to Vascular Ultrasonography*, 5th edition. Philadelphia, Elsevier Saunders, 2005, pp 157–167.

More Q&A Information

This question belongs to the following ARDMS exam topic:

I. Cerebrovascular [25–35% of ARDMS exam]

To focus only on this or other specific exam topics:

24 The great saphenous vein:

A Originates along the medial dorsum of the foot

B Passes superiorly, anterior to the medial malleolus

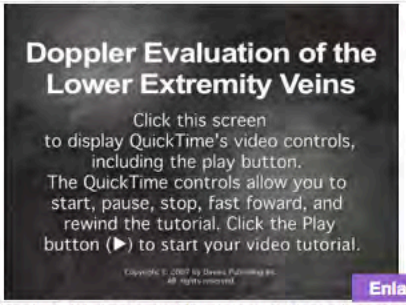
C Is accompanied by the saphenous nerve

D Receives tributaries from all surfaces of the lower extremity

E All are correct

Next | 24 of 665 | Prior | Bookmark/Skip | Pause | First | Last | Finish

Explanation Image 1



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Explanation Image 2

Enlarge

Tutorial

Anatomy of the Lower Extremity Veins

by
David S. Sumner, MD

Unlike their arterial counterparts, the veins of the leg are divided into two systems: the superficial and the deep (Figures 1 and 2). [Click "More Images" on the purple navigation bar below to view figures.] The two principal veins in the superficial system are the greater (or long) saphenous vein and the lesser (or short) saphenous vein. Beginning just anteriorly and laterally to the medial malleolus, the great saphenous vein courses up the medial aspect of the calf and thigh to enter the common femoral vein at the groin (Figure 3–click "More Images"). The small saphenous vein, which is found posterior to the lateral malleolus, runs up the posterior aspect of the calf and terminates

Exam Topic I–IV. Anatomy, Physiology & Hemodynamics (4%–18% of ARDMS exam)

RESULTS FOR CURRENT TEST

Date: 5/12/2014
Time: 2:45:57 PM

Your results appear below in three categories:

(1) Overall results.
(2) Results by exam topic.
(3) Results by individual questions.

This analysis also tells you how many questions (if any) you failed to answer and for which questions you changed your first answer. From this page you can also print your results, review wrong answers in Learn Mode, repeat the same test again, return to the Start Page for another activity, or Quit.

OVERALL RESULTS

Total Questions = 60
Total percentage correct = 18.33% / 11 of 60
Target time / actual time used = 60 minutes / 1.02 minutes
Number of unanswered questions = 0

SUBJECT AREA RESULTS

I–IV. Anatomy, Physiology & Hemodynamics = 33.33% / 1 of 3 (Unanswered 0)
I. Cerebrovascular = 15.38% / 2 of 13 (Unanswered 0)
II. Venous = 15.38% / 2 of 13 (Unanswered 0)
III. Peripheral Arterial = 18.18% / 2 of 11 (Unanswered 0)

SUBJECT AREA RESULTS

I–IV. Anatomy, Physiology & Hemodynamics = 33.33% / 1 of 3 (Unanswered 0)
I. Cerebrovascular = 15.38% / 2 of 13 (Unanswered 0)
II. Venous = 15.38% / 2 of 13 (Unanswered 0)
III. Peripheral Arterial = 18.18% / 2 of 11 (Unanswered 0)
IV. Abdomen and Visceral = 33.33% / 1 of 3 (Unanswered 0)
V. Miscellaneous Conditions & Tests = 33.33% / 1 of 3 (Unanswered 0)
VI. Quality Assurance = 0% / 0 of 2 (Unanswered 0)
VII. Image-Based Questions = 10% / 1 of 10 (Unanswered 0)
VIII. Physiology & Fluid Dynamics = 50% / 1 of 2 (Unanswered 0)

INDIVIDUAL QUESTION RESULTS

For your convenience, the following question numbers correspond to those in the book version of this mock exam. Use the CD and the book together for best results.

Question ID VTR583 = WRONG VII. Image-Based Questions
Question ID VTR426 = WRONG III. Peripheral Arterial (20%–30% of ARDMS exam)
Question ID VTR570 = WRONG VII. Image-Based Questions
Question ID VTR11 = WRONG I–IV. Anatomy, Physiology & Hemodynamics (4%–18% of ARDMS exam)
Question ID VTR446 = WRONG IV. Abdomen and Visceral (5%–15% of ARDMS exam)
Question ID VTR400 = WRONG III. Peripheral Arterial (20%–30% of ARDMS exam)
Question ID VTR403 = WRONG III. Peripheral Arterial (20%–30% of ARDMS exam)
Question ID VTR502 = WRONG VI. Quality Assurance (3%–5% of ARDMS exam)
Question ID VTR615 = WRONG VII. Image-Based Questions
Question ID VTR531 = WRONG VII. Image-Based Questions
Question ID VTR537 = WRONG VII. Image-Based Questions
Question ID VTR137 = WRONG I. Cerebrovascular (25%–35% of ARDMS exam)

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LIFE IS A TEST...

Physics

An Interactive Q&A Review for the ARDMS SPI Exam

CD-ROM Version 3.1

Cindy A. Owen, RT, RVT, RDMS
James A. Zagzebski, PhD

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Registry Reviews & Study Aids

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- Test myself
- Study and learn
- Browse the Image Library
- Earn continuing medical education (CME) credit
- Review test-prep and exam-taking strategies
- Access the Contact Directory

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Create a Standard ARDMS-Style Test

This program automatically randomizes questions on all ARDMS exam topics in the same ratio as on the real exam.

Select the number of questions you want . . .

(●) 60
( ) 120
( ) 180

Create My Test | **Clear My Selection** | **Return To Start**

Need to focus on specific exam topics?

You can create your own test by selecting as many as three ARDMS exam topics and specifying the number of questions you want in each topic area. To do so, click the purple button below.

This is an excellent way to focus on topics you need to work on.

Click here to design your own custom test.

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This is an excellent way to focus on topics you need to work on.

Click below to select one or more exam topics . . .

Total number of questions on the topic you selected.

0 Enter the number of questions you want.

Total number of questions on the topic you selected.

0 Enter the number of questions you want.

Total number of questions on the topic you selected.

0 Enter the number of questions you want.

Create My Test | Clear My Selections | Return To Start

48 Which of the following sound interactions produced the shadows indicated by the arrows on this image?

A Reflection

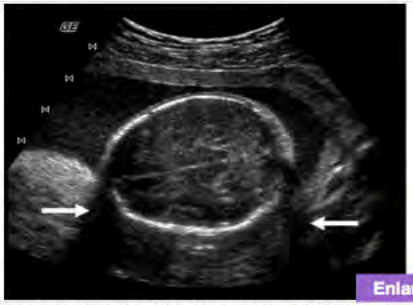
B Diffraction

C Diffusion

D Rayleigh scattering

E Refraction

Question Image 1



Enlarge

Question Image 2

Enlarge

Exam Topic II. Physical Principles (20% of ARDMS exam)

48 Which of the following sound interactions produced the shadows indicated by the arrows on this image?

A Reflection

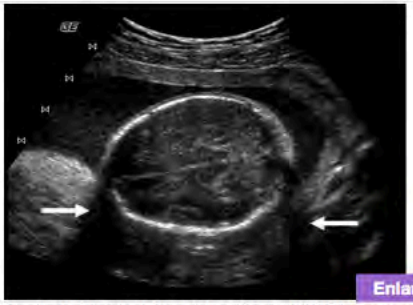
B Diffraction

C Diffusion

D Rayleigh scattering

E Refraction

Explanation Image 1



Enlarge

Explanation Image 2

Enlarge

RIGHT!

You chose the correct answer, E: Refraction

*The **edge shadowing** seen with curved interfaces is caused by refraction of the sound beam. This is the same physical principle that can be observed by placing a pencil in a partially filled glass of water. When viewed from the side, the pencil appears bent.*

More Q&A Information

This question belongs to the following ARDMS exam topic:

II. Physical Principles (20% of ARDMS exam)

To focus only on this or other specific exam topics:

Exam Topic II. Physical Principles (20% of ARDMS exam)

RESULTS FOR CURRENT TEST

Date: 5/12/2014
Time: 3:40:07 PM

Your results appear below in three categories:

(1) Overall results.
(2) Results by exam topic.
(3) Results by individual questions.

This analysis also tells you how many questions (if any) you failed to answer and for which questions you changed your first answer. From this page you can also print your results, review wrong answers in Learn Mode, repeat the same test again, return to the Start Page for another activity, or Quit.

OVERALL RESULTS

Total Questions = 60
Total percentage correct = 13.33% / 8 of 60
Target time / actual time used = 60 minutes / 1.41 minutes
Number of unanswered questions = 0

SUBJECT AREA RESULTS

I. Patient Care, Safety, and Communication = 0% / 0 of 3 (Unanswered 0)
II. Physical Principles = 16.67% / 2 of 12 (Unanswered 0)
III. Ultrasound Transducers = 9.09% / 1 of 11 (Unanswered 0)
IV. Pulse-Echo Instrumentation = 16.67% / 3 of 18 (Unanswered 0)

SUBJECT AREA RESULTS

I. Patient Care, Safety, and Communication = 0% / 0 of 3 (Unanswered 0)
II. Physical Principles = 16.67% / 2 of 12 (Unanswered 0)
III. Ultrasound Transducers = 9.09% / 1 of 11 (Unanswered 0)
IV. Pulse-Echo Instrumentation = 16.67% / 3 of 18 (Unanswered 0)
V. Doppler Instrumentation and Hemodynamics = 8.33% / 1 of 12 (Unanswered 0)
VI. Quality Assurance/Quality Control of Equipment = 25% / 1 of 4 (Unanswered 0)

INDIVIDUAL QUESTION RESULTS

For your convenience, the following question numbers correspond to those in the book version of this mock exam. Use the CD and the book together for best results.

Question ID SPI211 = WRONG III. Ultrasound Transducers (20% of ARDMS exam)
Question ID SPI87 = WRONG II. Physical Principles (20% of ARDMS exam)
Question ID SPI113 = WRONG II. Physical Principles (20% of ARDMS exam)
Question ID SPI110 = WRONG II. Physical Principles (20% of ARDMS exam)
Question ID SPI588 = RIGHT VI. Quality Assurance/Quality Control of Equipment (5% of ARDMS exam)
Question ID SPI250 = WRONG III. Ultrasound Transducers (20% of ARDMS exam)
Question ID SPI121 = WRONG II. Physical Principles (20% of ARDMS exam)
Question ID SPI242 = RIGHT III. Ultrasound Transducers (20% of ARDMS exam)
Question ID SPI590 = WRONG VI. Quality Assurance/Quality Control of Equipment (5% of ARDMS exam)
Question ID SPI463 = WRONG V. Doppler Instrumentation and Hemodynamics (20% of ARDMS exam)
Question ID SPI507 = WRONG V. Doppler Instrumentation and Hemodynamics (20% of ARDMS exam)
Question ID SPI407 = WRONG IV. Pulse-Echo Instrumentation (30% of ARDMS exam)
Question ID SPI553 = RIGHT V. Doppler Instrumentation and Hemodynamics (20% of ARDMS exam)
Question ID SPI539 = WRONG V. Doppler Instrumentation and Hemodynamics (20% of ARDMS exam)
Question ID SPI348 = WRONG IV. Pulse-Echo Instrumentation (30% of ARDMS exam)

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