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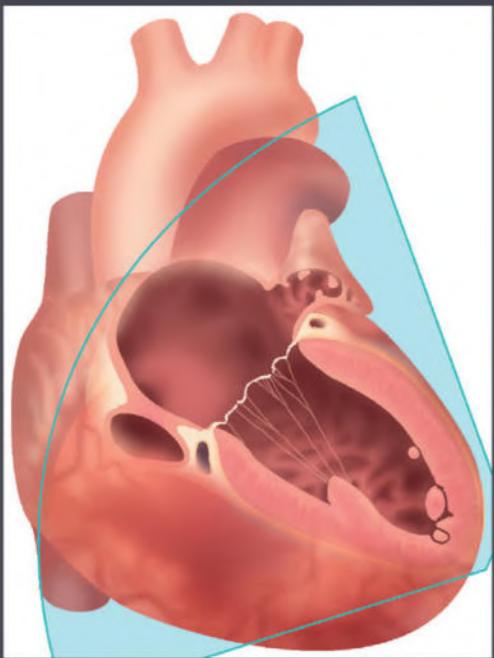

FOURTH EDITION

Companion to *Textbook of Clinical Echocardiography*

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ECHOCARDIOGRAPHY REVIEW GUIDE

Companion to *Textbook of Clinical Echocardiography*

FOURTH EDITION

ECHOCARDIOGRAPHY REVIEW GUIDE

Companion to *Textbook of Clinical Echocardiography*

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Preface

Echocardiography Review Guide, Fourth Edition: Companion to *Textbook of Clinical Echocardiography,* Sixth Edition

The fourth edition of *Echocardiography Review Guide* complements the sixth edition of *Textbook of Clinical Echocardiography*, providing a review of basic principles, additional details of data acquisition and interpretation, and a step-by-step approach to patient examination for each diagnosis. In addition, self-assessment questions, with detailed explanations of the correct answers, allow the reader to be actively involved in the learning process.

This book will be of interest to practicing cardiologists and sonographers as a quick update on echocardiography and will be of value for cardiology fellows and cardiac sonographer students who are mastering the material for the first time. Cardiac anesthesiologists will find helpful information about details of the examination and a chapter dedicated to intraoperative transesophageal echocardiography. In addition, primary care, emergency department, and intensive care physicians using point-of-care ultrasound can refer to this book to get started and to improve their echocardiography skills. Multiple-choice questions provide a review and self-assessment for anyone preparing for an echocardiography examination and can be used in echocardiography laboratories for continuous quality improvement.

The chapters are arranged in the same order as those in the *Textbook of Clinical Echocardiography*, and we recommend that these two books be used in parallel. As in the textbook, there are introductory chapters on basic principles of image acquisition, transthoracic and transesophageal echocardiography, other echocardiographic modalities, and clinical indications. Each of the subsequent chapters focus on a specific clinical diagnosis, including ventricular systolic and diastolic function, ischemic cardiac disease, cardiomyopathies, valve stenosis and regurgitation, prosthetic valves, endocarditis, cardiac masses, aortic disease, adult congenital heart disease, and procedural transesophageal echocardiography.

Every chapter includes the Echo Exam review guide from the *Textbook of Clinical Echocardiography* for quick reference. In addition, there is a detailed step-by-step approach to the echocardiographic examination for each diagnosis. Information is conveyed in bulleted points, with a short list of important basic principles followed by a list of key points. Potential pitfalls are identified and approaches to avoiding errors are provided. Data measurements and calculations are explained with specific examples. Numerous illustrations with detailed figure legends demonstrate each major idea and guide the reader through the teaching points.

Along with a review of basic principles, step-by-step approaches, and clinical examples, carefully structured multiple-choice questions allow the reader to consolidate the information and identify areas where further study is needed. In addition to providing the correct answer for each question, a discussion is provided to explain how the answer was determined and why the other potential answers are not correct. The questions are based on information presented in both the textbook and in the review guide; in effect, this review guide is the "workbook" that accompanies the textbook.

Any book on echocardiography is only a supplement to formal training; no book can replace hands-on training or practical experience. We fully endorse the current requirement for education and training of physicians in clinical cardiac ultrasound as provided by the Accreditation Council for Graduate Medical Education (ACGME), including training programs in Cardiovascular Disease, Critical Care Medicine, Emergency Medicine, Cardiovascular Anesthesiology, and other specialties. We also support the additional recommendations for training, depending on physician specialty and scope of practice, as proposed by the American College of Cardiology, Society for Cardiovascular Anesthesiology, American Society of Echocardiography, and other organizations. In addition, we support sonographer training in accredited programs with formal certification, evaluation of competency, and ongoing continuing education as established by the American Registry of Diagnostic Medical Sonography, Cardiovascular Credentialing International, and other similar organizations.

The material in this book reflects the clinical practice of echocardiography at one point in time. Cardiac imaging is a rapidly changing field, and we encourage our readers to stay up to date by reading journals and other online sources and by attending national meetings and continuing medical education courses.

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Jason P. Linefsky, MD, MS

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Finally, we all sincerely thank our spouses—Steve, Jack, Brooke, and Robert—for their unwavering and continual encouragement, as well as the younger members of our families—Vea, Remy, Brendan, Sarah, Claire, Jack, Anna, Fiona, Micah, and Eric—for their support of and patience with the book-writing process. This book would not have been possible without their helping us find the time to bring this project to fruition.

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Contents

Glossary

Abbreviations Used in Figures, Tables, and Equations

2D = two-dimensional
3D = three-dimensional

A = late diastolic ventricular filling velocity with atrial contraction
A′ = diastolic tissue Doppler velocity with atrial contraction
A2C = apical 2-chamber
A4C = apical 4-chamber
AcT = acceleration time
A_{dur} = transmitral *A*-velocity duration
a_{dur} = pulmonary vein *a*-velocity duration
AF = atrial fibrillation
A-long = apical long-axis
A-mode = amplitude mode (amplitude versus depth)
AMVL = anterior mitral valve leaflet
ant = anterior
Ao = aortic or aorta
AR = aortic regurgitation
AS = aortic stenosis
ASD = atrial septal defect
ATVL = anterior tricuspid valve leaflet
AV = atrioventricular
AVA = aortic valve area
AVR = aortic valve replacement

BAV = bicuspid aortic valve
BP = blood pressure
BSA = body surface area

c = propagation velocity of sound in tissue
CAD = coronary artery disease
cath = cardiac catheterization
CI = cardiac index
C_m = specific heat of tissue
cm/s = centimeters per second
CMR = cardiac magnetic resonance (imaging)
CO = cardiac output
cos = cosine
CS = coronary sinus
CSA = cross-sectional area
CT = computed tomography
CW = continuous-wave (Doppler)
Cx = circumflex coronary artery

D = diameter
DA = descending aorta
dB = decibel
dP/dt = rate of change in pressure over time
DSE = dobutamine stress echocardiography
DT = deceleration time
dT/dt = rate of increase in temperature over time
D-TGA = complete transposition of the great arteries
DTI = Doppler tissue imaging
$dyne \cdot s \cdot cm^{-5}$ = units of resistance

E = early-diastolic peak velocity
E′ = early-diastolic tissue Doppler velocity
ECG = electrocardiogram
echo = echocardiography
EDD = end-diastolic dimension
EDP = end-diastolic pressure
EDV = end-diastolic volume
EF = ejection fraction
endo = endocardium
epi = epicardium
EPSS = E-point septal separation
ESD = end-systolic dimension
ESV = end-systolic volume
ETT = exercise treadmill test

Δf = frequency shift
f = frequency
FL = false lumen
F_n = near field
F_o = resonance frequency
F_s = scattered frequency
FSV = forward stroke volume
F_T = transmitted frequency

HCM = hypertrophic cardiomyopathy
HFpEF = heart failure with preserved ejection fraction
HFrEF = heart failure with reduced ejection fraction
HPRF = high pulse repetition frequency
HR = heart rate
HV = hepatic vein
Hz = Hertz (cycles per second)

I = intensity of ultrasound exposure
IAS = interatrial septum

ICE = intracardiac echocardiography
inf = inferior
IV = intravenous
IVC = inferior vena cava
IVCT = isovolumic contraction time
IVRT = isovolumic relaxation time

LA = left atrium
LAA = left atrial appendage
LAD = left anterior descending coronary artery
LAE = left atrial enlargement
lat = lateral
LCC = left coronary cusp
LMCA = left main coronary artery
LPA = left pulmonary artery
LSPV = left superior pulmonary vein
L-TGA = corrected transposition of the great arteries
LV = left ventricle
LVH = left ventricular hypertrophy
LVID = left ventricular internal dimension
LVOT = left ventricular outflow tract

MAC = mitral annular calcification
MI = myocardial infarction or mechanical index (depends on context)
M-mode = motion display (depth versus time)
MR = mitral regurgitation
MRI = magnetic resonance imaging
MS = mitral stenosis
MV = mitral valve
MVA = mitral valve area
MVL = mitral valve leaflet
MVR = mitral valve replacement

NBTE = nonbacterial thrombotic endocarditis
NCC = noncoronary cusp

ΔP = pressure gradient
P = pressure
PA = pulmonary artery
PAP = pulmonary artery pressure
PCI = percutaneous coronary intervention
PDA = patent ductus arteriosus or posterior descending artery (depends on context)
PE = pericardial effusion
PEP = preejection period
PET = positron emission tomography
PFO = patent foramen ovale
PISA = proximal isovelocity surface area
PLAX = parasternal long-axis
PM = papillary muscle
PMVL = posterior mitral valve leaflet
post = posterior (or inferior-lateral) ventricular wall
PR = pulmonic regurgitation
PRF = pulse repetition frequency
PRFR = peak rapid filling rate
PS = pulmonic stenosis
PSAX = parasternal short-axis (view)
PV = pulmonary vein
PVC = premature ventricular contraction
PV_D = pulmonary vein diastolic velocity
PVR = pulmonary vascular resistance
PW = pulsed wave
PWT = posterior wall thickness

Q = volume flow rate
Q_p = pulmonic volume flow rate
Q_s = systemic volume flow rate

r = correlation coefficient
R = ventricular radius
RA = right atrium
RAE = right atrial enlargement
RAO = right anterior oblique
RAP = right atrial pressure
RCA = right coronary artery
RCC = right coronary cusp
R_e = Reynolds number
RF = regurgitant fraction
R_o = radius of microbubble
ROA = regurgitant orifice area
RPA = right pulmonary artery
RSPV = right superior pulmonary vein
RSV = regurgitant stroke volume
RV = right ventricle
RVE = right ventricular enlargement
RVH = right ventricular hypertrophy
RVol = regurgitation volume
RVOT = right ventricular outflow tract

SAM = systolic anterior motion
SC = subcostal
SEE = standard error of the estimate
SPPA = spatial peak pulse average
SPTA = spatial peak temporal average
SSN = suprasternal notch
STE = speckle tracking echocardiography
STEMI = ST-segment elevation myocardial infarction
STJ = sinotubular junction
STVL = septal tricuspid valve leaflet
SV = stroke volume or sample volume (depends on context)
SVC = superior vena cava

$T\frac{1}{2}$ = pressure half-time
TAPSE = tricuspid annular plane systolic excursion
TAVR = transcatheter aortic valve replacement
TD = thermodilution
TEE = transesophageal echocardiography
TGC = time-gain compensation
Th = wall thickness
TL = true lumen
TN = true negatives
TOF = tetralogy of Fallot

TP = true positives
TPV = time to peak velocity
TR = tricuspid regurgitation (jet)
TS = tricuspid stenosis
TSV = total stroke volume
TTE = transthoracic echocardiography
TV = tricuspid valve

V = volume or velocity (depends on context)
VAS = ventriculo-atrial septum
Veg = vegetation
V_{max} = maximum velocity
VSD = ventricular septal defect
VTI = velocity-time integral

Z = acoustic impedance

Symbols	Greek Name	Used for
α	alpha	Frequency
γ	gamma	Viscosity
Δ	delta	Difference
θ	theta	Angle
λ	lambda	Wavelength
μ	mu	Micro-
π	pi	Mathematical constant (approx. 3.14)
ρ	rho	Tissue density
σ	sigma	Wall stress
τ	tau	Time constant of ventricular relaxation

Units of Measure

Variable	Unit	Definition
Amplitude	dB	Decibels = a logarithmic scale describing the amplitude (“loudness”) of the sound wave
Angle	degrees	Degree = (π/180) radians. Example: intercept angle
Area	cm^2	Square centimeters. A 2D measurement (e.g., end-systolic area) or a calculated value (e.g., continuity equation valve area)
Frequency (*f*)	Hz kHz MHz	Hertz (cycles per second) Kilohertz = 1000 Hz Megahertz = 1,000,000 Hz
Length	cm mm	Centimeter (1/100 m) Millimeter (1/1000 m or 1/10 cm)
Mass	g	Grams (e.g., LV mass)
Pressure	mm Hg	Millimeters of mercury, 1 mm Hg = 1333.2 dyne/cm^2, where dyne measures force in cm · mg · s^{-2}
Resistance	dyne · s · cm^{-5}	Measure of vascular resistance
Time	s ms μs	Second Millisecond (1/1000 s) Microsecond
Ultrasound intensity	W/cm^2 mW/cm^2	Where watt (W) = joule per second and joule = m^2 · kg · s^{-2} (unit of energy)
Velocity (*v*)	m/s cm/s	Meters per second Centimeters per second
Velocity-time integral (VTI)	cm	Integral of the Doppler velocity curve (cm/s) over time (s), in units of cm
Volume	cm^3 mL L	Cubic centimeters Milliliter, 1 mL = 1 cm^3 Liter = 1000 mL
Volume flow rate (*Q*)	 L/min mL/s	Rate of volume flow across a valve or in cardiac output L/min = liters per minute mL/s = milliliters per second
Wall stress	dyne/cm^2 kdyn/cm^2 kPa	Units of meridional or circumferential wall stress Kilodynes per cm^2 Kilopascals where 1 kPa = 10 kdyn/cm^2

Key Equations

ULTRASOUND PHYSICS	
Frequency	f = cycles/s = Hz
Wavelength	$\lambda = c/f = 1.54/f$ (MHz)
Doppler equation	$v = c \times \Delta f / [2F_T(\cos\Theta)]$
Bernoulli equation	$\Delta P = 4V^2$
LV IMAGING	
Stroke volume	SV = EDV − ESV
Ejection fraction	EF(%) = (SV/EDV) × 100%
Wall stress	σ = PR/2Th
DOPPLER VENTRICULAR FUNCTION	
Stroke volume	SV = CSA × VTI
Rate of pressure rise	dP/dt = 32 mm Hg/time from 1 to 3 m/s of MR CW jet (sec)
Myocardial performance index	MPI = (IVRT + IVCT)/SEP
PULMONARY PRESSURES AND RESISTANCE	
Pulmonary systolic pressure	$PAP_{systolic} = 4(V_{TR})^2 + RAP$
PAP (when PS is present)	$PAP_{systolic} = [4(V_{TR})^2 + RAP] - \Delta P_{RV-PA}$
Mean PA pressure	$PAP_{mean} = \text{Mean } \Delta P_{RV-RA} + RAP$
Diastolic PA pressure	$PAP_{diastolic} = 4(V_{PR})^2 + RAP$
Pulmonary vascular resistance	$PVR = 10(V_{TR})/VTI_{RVOT}$
AORTIC STENOSIS	
Maximum pressure gradient (integrate over ejection period for mean gradient)	$\Delta P_{max} = 4(V_{max})^2$
Continuity equation valve area	$AVA(cm^2) = [\pi(LVOT_D/2)^2 \times VTI_{LVOT}]/VTI_{AS\text{-}Jet}$
Simplified continuity equation	$AVA(cm^2) = [\pi(LVOT_D/2)^2 \times V_{LVOT}]/V_{AS\text{-}Jet}$
Velocity ratio	Velocity ratio $= V_{LVOT}/V_{AS\text{-}Jet}$
MITRAL STENOSIS	
Pressure half-time valve area	$MVA_{Doppler} = 220/T½$
AORTIC REGURGITATION	
Total stroke volume	$TSV = SV_{LVOT} = (CSA_{LVOT} \times VTI_{LVOT})$
Forward stroke volume	$FSV = SV_{MA} = (CSA_{MA} \times VTI_{MA})$
Regurgitant volume	RVol = TSV − FSV
Regurgitant orifice area	$ROA = RSV/VTI_{AR}$
MITRAL REGURGITATION	
Total stroke volume (or 2D or 3D LV stroke volume)	$TSV = SV_{MA} = (CSA_{MA} \times VTI_{MA})$
Forward stroke volume	$FSV = SV_{LVOT} = (CSA_{LVOT} \times VTI_{LVOT})$
Regurgitant volume	RVol = TSV − FSV
Regurgitant orifice area	$ROA = RSV/VTI_{AR}$
PISA method	
Regurgitant flow rate	$R_{FR} = 2\pi r^2 \times V_{aliasing}$
Orifice area (maximum)	$ROA_{max} = R_{FR}/V_{MR}$
Regurgitant volume	$RV = ROA \times VTI_{MR}$
AORTIC DILATION	
Predicted sinus diameter	
Children (<18 years): Predicted sinus dimension = 1.02 + (0.98 BSA)	
Adults (18-40 years): Predicted sinus dimension = 0.97 + (1.12 BSA)	
Adults (>40 years): Predicted sinus dimension = 1.92 + (0.74 BSA)	
Ratio = Measured maximum diameter/Predicted maximum diameter	
PULMONARY (Q_P) TO SYSTEMIC (Q_S) SHUNT RATIO	
	$Q_p{:}Q_s = [CSA_{PA} \times VTI_{PA}]/[CSA_{LVOT} \times VTI_{LVOT}]$

1 Principles of Echocardiographic Image Acquisition and Doppler Analysis

BASIC PRINCIPLES

- Knowledge of basic ultrasound principles is needed for interpretation of images and Doppler data.
- Appropriate adjustment of instrument parameters is needed to obtain diagnostic information.

❖ KEY POINTS

- The appropriate ultrasound modality (two-dimensional [2D] or three-dimensional [3D] imaging, pulsed Doppler, color Doppler, etc.) is chosen for each type of needed clinical information.
- Current instrumentation allows modification of many parameters during data acquisition, such as depth, gain, harmonic imaging, wall filters, and so on.
- Artifacts must be distinguished from anatomic findings on ultrasound images.
- Accurate Doppler measurements depend on details of both blood flow interrogation and instrument acquisition parameters.

ULTRASOUND WAVES

- Ultrasound waves (Table 1.1) are mechanical vibrations with basic descriptors including:
  - Frequency (cycles per second = Hz, 1000 cycles/second = MHz)
  - Propagation velocity (about 1540 m/s in blood)
  - Wavelength (equal to the propagation velocity divided by frequency)
  - Amplitude (decibels [dBs])
- Ultrasound waves interact with tissues (Table 1.2) in four different ways:
  - Reflection (used to create ultrasound images)
  - Scattering (the basis of Doppler ultrasound)
  - Refraction (used to focus the ultrasound beam)
  - Attenuation (loss of signal strength in the tissue)

❖ KEY POINTS

- Tissue penetration is greatest with a lower frequency transducer (e.g., 2 to 3 MHz)
- Image resolution is greatest (about 1 mm) with a higher frequency transducer (e.g., 5 to 7.5 MHz) (Fig. 1.1)
- Amplitude ("loudness") is described using the logarithmic dB scale; a 6 dB change represents a doubling or halving of signal amplitude.
- Acoustic impedance depends on tissue density and the propagation velocity of ultrasound in that tissue.
- Ultrasound reflection occurs at smooth tissue boundaries with different acoustic impedances (such as between blood and myocardium). Reflection is greatest when the ultrasound beam is *perpendicular* to the tissue interface.
- Ultrasound scattering that occurs with small structures (such as red blood cells) is used to generate Doppler signals. Doppler velocity recordings are most accurate when the ultrasound beam is *parallel* to the blood flow direction.
- Refraction of ultrasound can result in imaging artifacts due to deflection of the ultrasound beam from a straight path.

TRANSDUCERS

- Ultrasound transducers use a piezoelectric crystal to alternately transmit and receive ultrasound signals (Fig. 1.2).
- Transducers are configured for specific imaging approaches—transthoracic, transesophageal, intracardiac, and intravascular (Table 1.3).

TABLE 1.1 Ultrasound Waves

	Definition	Examples	Clinical Implications
Frequency (*f*)	The number of cycles per second in an ultrasound wave: f = cycles/s = Hz	Transducer frequencies are measured in MHz (1,000,000 cycles/s). Doppler signal frequencies are measured in KHz (1000 cycles/s).	Different transducer frequencies are used for specific clinical applications, because the transmitted frequency affects ultrasound tissue penetration, image resolution, and the Doppler signal.
Velocity of propagation (c)	The speed that ultrasound travels through tissue	The average velocity of ultrasound in soft tissue about 1540 m/s.	The velocity of propagation is similar in different soft tissues (blood, myocardium, liver, fat, etc.) but is much lower in lung and much higher in bone.
Wavelength (λ)	The distance between ultrasound waves: $\lambda = c/f = 1.54/f$ (MHz)	Wavelength is shorter with a higher frequency transducer and longer with a lower frequency transducer.	Image resolution is greatest (about 1 mm) with a shorter wavelength (higher frequency). Depth of tissue penetration is greatest with a longer wavelength (lower frequency).
Amplitude (dB)	Height of the ultrasound wave or “loudness” measured in decibels (dB)	A log scale is used for dB. On the dB scale, 80 dB represents a 10,000-fold and 40 dB indicates a 100-fold increase in amplitude.	A very wide range of amplitudes can be displayed using a gray scale display for both imaging and spectral Doppler.

TABLE 1.2 Ultrasound Tissue Interaction

	Definition	Examples	Clinical Implications
Acoustic impedance (*Z*)	A characteristic of each tissue defined by tissue density (ϱ) and propagation of velocity (c) as: $z = \varrho \times c$	Lung has a low density and slow propagation velocity, whereas bone has a high density and fast propagation velocity. Soft tissues have smaller differences in tissue density and acoustic impedance.	Ultrasound is reflected from boundaries between tissues with differences in acoustic impedance (e.g., blood versus myocardium).
Reflection	Return of ultrasound signal to the transducer from a smooth tissue boundary	Reflection is used to generate 2D cardiac images.	Reflection is greatest when the ultrasound beam is perpendicular to the tissue interface.
Scattering	Radiation of ultrasound in multiple directions from a small structure, such as blood cells	The change in frequency of signals scattered from moving blood cells is the basis of Doppler ultrasound.	The amplitude of scattered signals is 100 to 1000 times less than reflected signals.
Refraction	Deflection of ultrasound waves from a straight path due to differences in acoustic impedance	Refraction is used in transducer design to focus the ultrasound beam.	Refraction in tissues results in double image artifacts.
Attenuation	Loss in signal strength due to absorption of ultrasound energy by tissues	Attenuation is frequency dependent with greater attenuation (less penetration) at higher frequencies.	A lower frequency transducer may be needed for apical views or in larger patients on transthoracic imaging.
Resolution	The smallest resolvable distance between two specular reflectors on an ultrasound image	Resolution has three dimensions—along the length of the beam (axial), lateral across the image (azimuthal), and in the elevational plane.	Axial resolution is most precise (as small as 1 mm), so imaging measurements are best made along the length of the ultrasound beam.

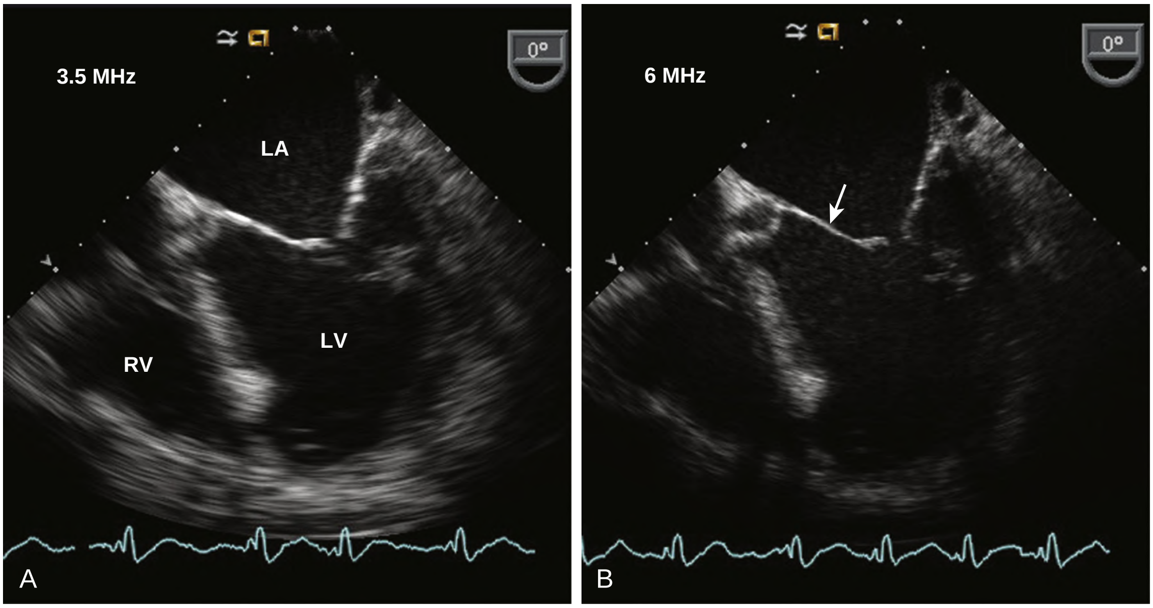

Fig 1.1 The effect of transducer frequency on penetration and resolution. In this transesophageal 4-chamber view recorded at a transmitted frequency of 3.5 MHz (A) and 6 MHz (B), the higher frequency transducer provides better resolution—for example, the mitral leaflets *(arrow)* look thin, but the depth of penetration of the signal is very poor, so the apical half of the LV is not seen. With the lower frequency transducer, improved tissue penetration provides a better image of the LV apex but image resolution is poorer, with the mitral leaflets looking thicker and less well defined.

- The basic characteristics of a transducer are:
  - Transmission frequency (from 2.5 MHz for transthoracic to 20 MHz for intravascular ultrasound)
  - Bandwidth (range of frequencies in the transmitted ultrasound pulse)
  - Pulse repetition frequency (the number of transmission-receive cycles per second)
  - Focal depth (depends on beam shape and focusing)
  - Aperture (size of the transducer face or "footprint")
  - Power output

❖ KEY POINTS

- The time delay between transmission of an ultrasound burst and detection of the reflected wave indicates the depth of the tissue reflector.
- The pulse repetition frequency is an important factor in image resolution and frame rate.
- A shorter transmitted pulse length results in improved depth (or axial) resolution.
- A wider bandwidth provides better resolution of structures distant from the transducer.
- The shape of the ultrasound beam depends on several complex factors. Each type of transducer focuses the beam at a depth appropriate for the clinical application. Some transducers allow adjustment of focal depth.

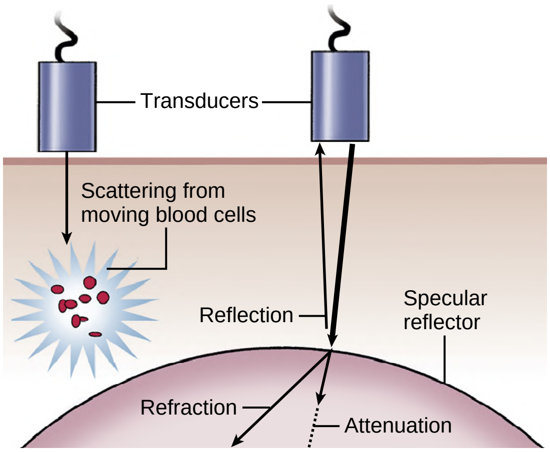

Fig 1.2 Diagram of the interaction between ultrasound and body tissues. Doppler analysis is based on the scattering of ultrasound in all directions from moving blood cells with a resulting change in frequency of the ultrasound received at the transducer. 2D imaging is based on reflection of ultrasound from tissue interfaces (specular reflectors). Attenuation limits the depth of ultrasound penetration. Refraction, a change in direction of the ultrasound wave, results in imaging artifacts. *(From Otto, CM:* Textbook of clinical echocardiography, *ed 6, Elsevier, 2018, Philadelphia.)*

- A smaller aperture is associated with a wider beam width; however, the smaller "footprint" may allow improved angulation of the beam in the intercostal spaces. This is most evident clinically with a dedicated non-imaging continuous-wave (CW) Doppler transducer.

ULTRASOUND IMAGING

Principles

- The basic ultrasound imaging modalities are:
  - M-mode—a graph of depth versus time
  - 2D—a sector scan in a tomographic image plane with real-time motion
  - 3D—a selected cutaway real-time image in a 3D display format or a 3D volume of data (see Chapter 4)
- System controls for 2D imaging typically include:
  - Power output (transmitted ultrasound energy)
  - Gain (amplitude of the received signal)
  - Time gain compensation (differential gain along the ultrasound beam)
  - Depth of the image (affects pulse repetition frequency and frame rate)
  - Gray scale/dynamic range (degree of contrast in the images)

❖ KEY POINTS

- M-mode recordings allow identification of very rapid intracardiac motion, because the sampling rate is about 1800 times per second compared to a 2D frame rate of 30 frames per second (Fig. 1.3).

TABLE 1.3 Ultrasound Transducers

	Definition	Examples	Clinical Implications
Type	Transducer characteristics and configuration Most cardiac transducers use phased array of piezoelectric crystals	Transthoracic (adult and pediatric) Non-imaging CW Doppler 3D echocardiography TEE Intracardiac	Each transducer type is optimized for a specific clinical application. More than one transducer may be needed for a full examination.
Transmission frequency	The central frequency emitted by the transducer	Transducer frequencies vary from 2.5 MHz for transthoracic echo to 20 MHz for intravascular imaging.	A higher frequency transducer provides improved resolution but less penetration. Doppler signals are optimal at a lower transducer frequency than used for imaging.
Power output	The amount of ultrasound energy emitted by the transducer	An increase in transmitted power increases the amplitude of the reflected ultrasound signals.	Excessive power output may result in bioeffects measured by the mechanical and thermal indexes.
Bandwidth	The range of frequencies in the ultrasound pulse	Bandwidth is determined by transducer design.	A wider bandwidth allows improved axial resolution for structures distant from the transducer.
Pulse (or burst) length	The length of the transmitted ultrasound signal	A higher frequency signal can be transmitted in a shorted pulse length compared with a lower frequency signal.	A shorter pulse length improves axial resolution.
Pulse repetition frequency (PRF)	The number of transmission-receive cycles per second	The PRF decreases as imaging (or Doppler) depth increases because of the time needed for the signal to travel from and to the transducer.	Pulse repetition frequency affects image resolution and frame rate (particularly with color Doppler)
Focal depth	Beam shape and focusing are used to optimize ultrasound resolution at a specific distance from the transducer	Structures close to the transducer are best visualized with a short focal depth, distant structures with a long focal depth.	The length and site of a transducer's focal zone is primarily determined by transducer design, but adjustment during the exam may be possible.
Aperture	The surface of the transducer face where ultrasound is transmitted and received	A small non-imaging CW Doppler transducer allows optimal positioning and angulation of the ultrasound beam.	A larger aperture allows a more focused beam. A smaller aperture allows improved transducer angulation on TTE imaging.

- Ultrasound imaging resolution is more precise along the length of the ultrasound beam (axial resolution) compared with lateral (side to side) or elevational ("thickness" of the image plane) resolution.
- Lateral resolution decreases with increasing distance from the transducer (Fig. 1.4).
- Harmonic imaging improves endocardial definition and reduces near-field and side-lobe artifacts (Fig. 1.5).

Imaging Artifacts

- Common imaging artifacts result from:
  - A low signal-to-noise ratio
  - Acoustic shadowing
  - Reverberations
  - Beam width
  - Lateral resolution
  - Refraction
  - Range ambiguity
  - Processing

KEY POINTS

- A shadow occurs distal to a strong ultrasound reflector because the ultrasound wave does not penetrate past the reflector (Fig. 1.6).
- Signals originating from the edges of the ultrasound beam or from side lobes can result in imaging or Doppler artifacts.
- Deviation of the ultrasound beam from a straight pathway due to refraction in the tissue results in the structure appearing in the incorrect location across the sector scan (Fig. 1.7).
- Ultrasound reflected back and forth between two strong reflectors creates a reverberation artifact.
- Reflected ultrasound signals received at the transducer are assumed to originate from the preceding transmitted pulse. Signals from very deep structures or signals that have been re-reflected will be displayed at one-half or twice the actual depth of origin.

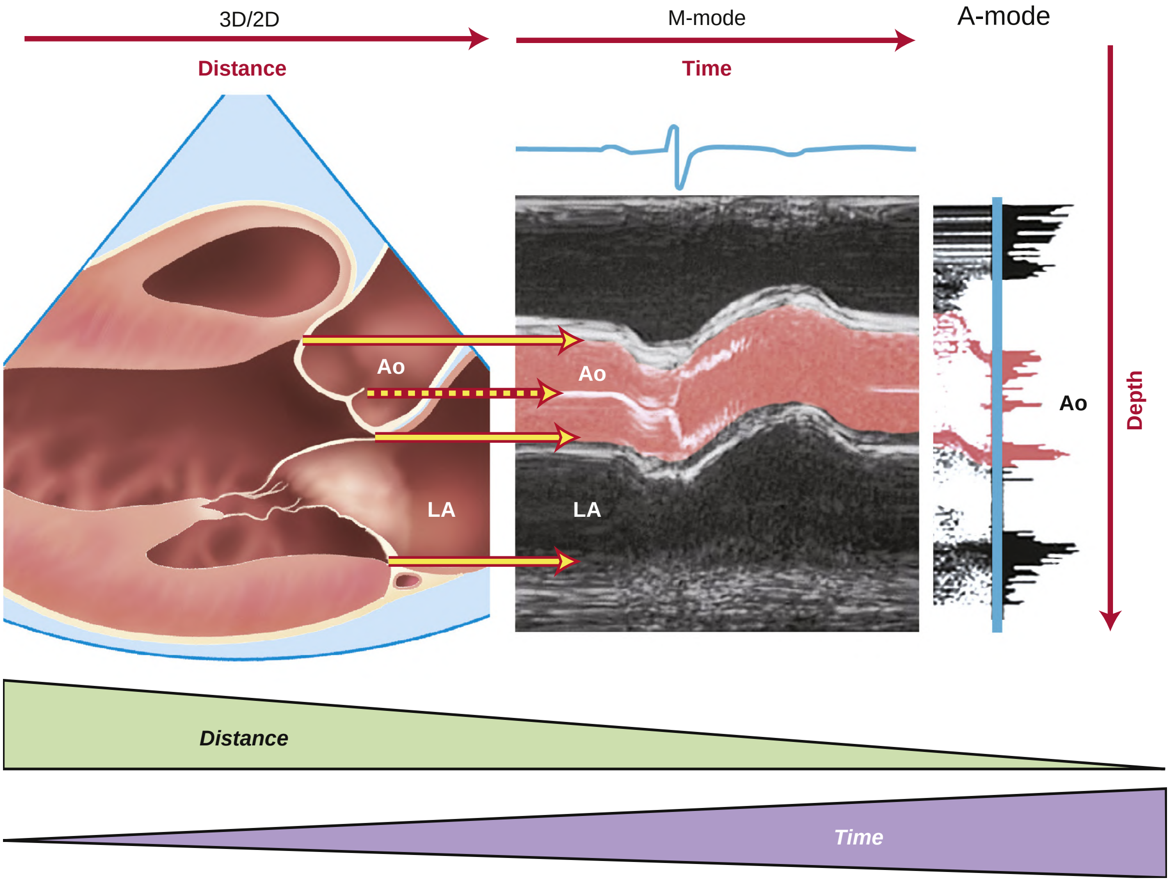

Fig 1.3 3D, 2D, M-mode, and A-mode recordings of aortic valve motion. This illustration shows the relationship between the 3D and 2D long-axis image of the aortic valve *(left)*, which shows distance in both the vertical and horizontal directions, M-mode recording of aortic root *(Ao)*, *LA*, and aortic valve motion, which shows depth versus time *(middle)* and A-mode recording *(right)*, which shows depth only (with motion seen on the video screen). Spatial relationships are best shown with 3D/2D, but temporal resolution is higher with M-mode and A-mode imaging. *(From Otto, CM:* Textbook of clinical echocardiography, *ed 6, Elsevier, 2018, Philadelphia.)*

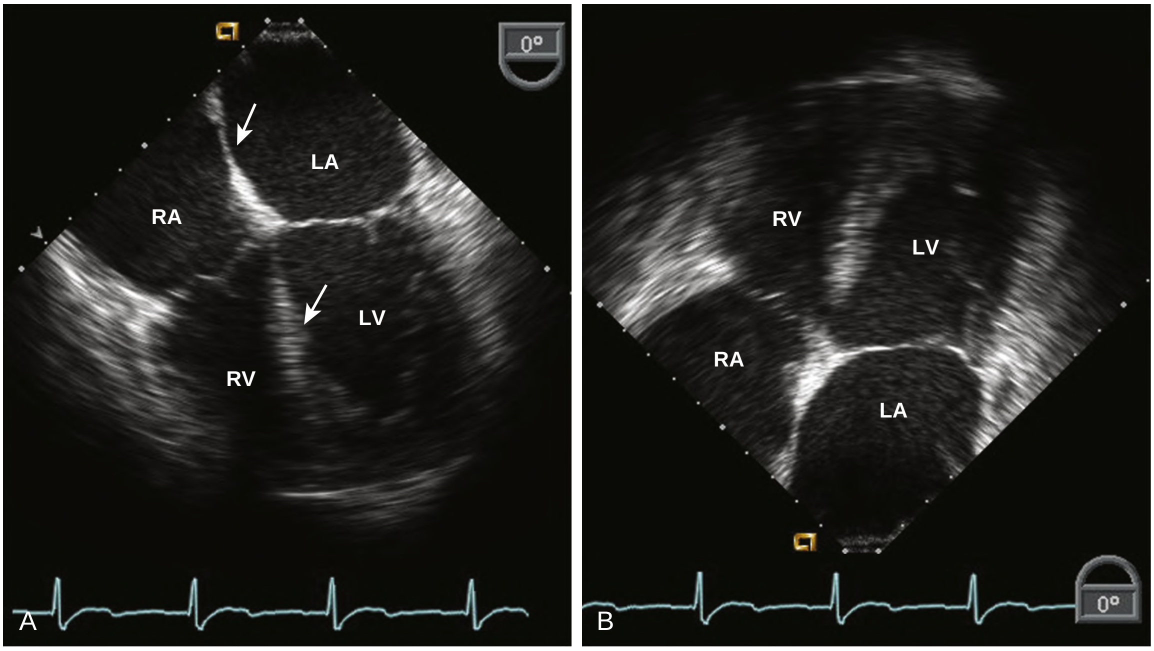

Fig 1.4 **Lateral resolution with ultrasound decreases with the distance of the reflector from the transducer.** (A) In this TEE image oriented with the origin of the ultrasound signal at the top of the image, thin structures close to the transducer, such as the atrial septum *(upper arrow)*, appear as a dot because lateral resolution is optimal at this depth. Reflections from more distant structures, such as the ventricular septum *(lower arrow)*, appear as a broad line due to poor lateral resolution. (B) When the image is oriented with the transducer at the bottom of the image, the effects of depth on lateral resolution are more visually apparent. The standard orientation for echocardiography with the transducer as the top of the image is based on considerations of ultrasound physics, not on cardiac anatomy.

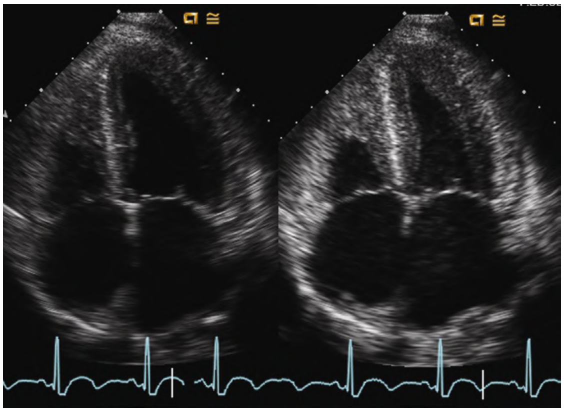

Fig 1.5 **Harmonic imaging compared with fundamental frequency imaging.** Harmonic imaging improves identification of the LV endocardial border, as seen in this apical 4-chamber view recorded with a 4-MHz transducer using *(left)* fundamental frequency imaging and *(right)* harmonic imaging.

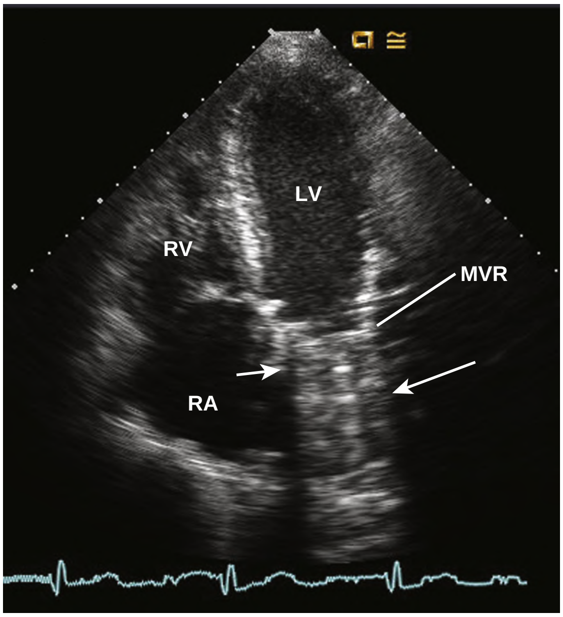

Fig 1.6 **Acoustic shadowing and reverberations.** This apical 4-chamber view in a patient with a mechanical mitral valve replacement *(MVR)* illustrates the shadowing (dark area, *small arrow*) and reverberations (white band of echoes, *large arrow*) that obscure structures (in this case, the left atrium) distal to the valve.

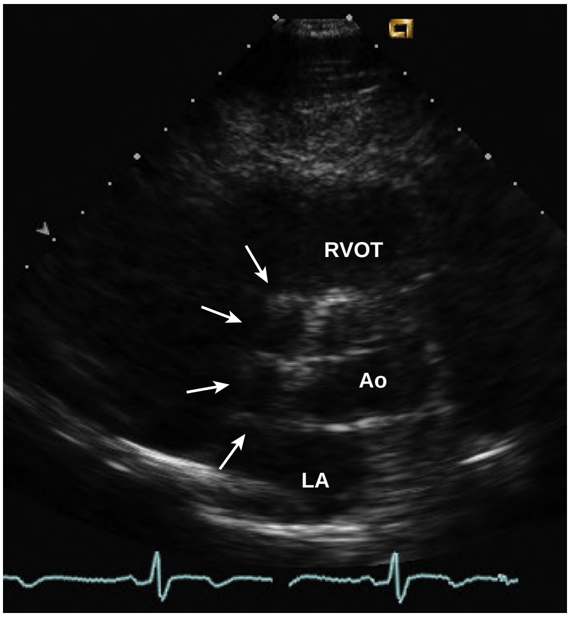

Fig 1.7 **Refraction artifact.** In this parasternal short-axis image of the aortic valve *(Ao)*, a refraction artifact results in the appearance of a "second" aortic valve *(arrows)*, partly overlapping with the actual position of the aortic valve. *RVOT,* Right ventricular outflow tract.

DOPPLER

- Doppler ultrasound is based on the principle that ultrasound backscattered (F_s) from moving red blood cells will appear higher or lower in frequency than the transmitted frequency (F_T) depending on the speed and direction of blood flow (v), the speed of sound in blood (c), and the cosine (cos) of the angle between the ultrasound beam and direction of blood flow (θ). (Table 1.4).
- The Doppler equation is:

$$v = c\,(F_S - F_T)/[2F_T\,(\cos\ \theta)]$$

- Accurate blood flow measurements depend on a parallel intercept angle θ (a cosine of 1.0). between the ultrasound beam and direction of blood flow.
- There are three basic Doppler modalities: pulsed Doppler, color flow imaging, and CW Doppler ultrasound.

❖ KEY POINTS

- The speed (c) of ultrasound in blood is about 1540 m/s.
- Blood flow velocity will be underestimated with a nonparallel intercept angle; the error is only 6% with an angle of 20 degrees but increases to 50% at a 60-degree angle.
- When the ultrasound beam is perpendicular to flow, there is no Doppler shift, and blood flow is not detected, even when present.
- The standard Doppler velocity display (or spectral recording) shows time on the horizontal axis and velocity on the vertical axis with signal amplitude displayed using a dB gray scale (Fig. 1.8).
- Standard Doppler instrument controls are:
  - Power output
  - Receiver gain (Fig. 1.9)
  - High-pass ("wall") filters (Fig. 1.10)
  - Velocity range and baseline shift
  - Post-processing options

Pulsed Doppler

- Pulsed Doppler allows measurement of blood flow velocity at a specific intracardiac site.
- The depth of interrogation (or sample volume) is determined by the time interval between transmission and sampling of the backscattered signal.
- Signal aliasing limits the maximum velocity measurable with pulsed Doppler.

❖ KEY POINTS

- A pulse of ultrasound is transmitted and then the backscattered signal is analyzed at a time interval corresponding to the transit time from the depth of interest.
- The pulsed Doppler interrogation line and sample volume are displayed on the 2D image, with the transducer switched to Doppler only during data recording.
- Pulse repetition frequency is the number of transmission/receive cycles per second, which is determined by the depth of the sample volume.
- The maximum frequency detectable with intermittent sampling is one-half the pulse repetition frequency (or Nyquist limit).
- The direction of blood flow for frequencies in excess of the Nyquist limit is ambiguous, a phenomenon called *signal aliasing* (Fig. 1.11)
- The effective velocity range for pulsed Doppler can be doubled by moving the baseline to the edge of the spectral display.
- The sample volume length can be adjusted to localize the signal (short length) or improve signal strength (long length).
- Pulsed Doppler is used to measure normal intracardiac transvalvular flow velocities.
- Variations of the pulsed Doppler principle are used to generate color Doppler flow images and tissue Doppler recordings.

TABLE 1.4 Doppler Physics

	Definition	Examples	Clinical Implications
Doppler effect	The change in frequency of ultrasound scattered from a moving target: $v = c \times \Delta F/[2F_T\ (\cos\theta)]$	A higher velocity corresponds to a higher Doppler frequency shift, ranging from 1 to 20 kHz for intracardiac flow velocities.	Ultrasound systems display velocity, which is calculated using the Doppler equation, based on transducer frequency and the Doppler shift, assuming cos θ equals 1.
Intercept angle	The angle (θ) between the direction of blood flow and the ultrasound beam	When the ultrasound beam is parallel to the direction of blood flow (0° or 180°), cos θ is 1 and can be ignored in the Doppler equation.	Velocity is underestimated when the intercept angle is not parallel. This can lead to errors in hemodynamic measurements.
CW Doppler	Continuous ultrasound transmission with reception of Doppler signals from the entire length of the ultrasound beam	CW Doppler allows measurements of high velocity signals but does not localize the depth of origin of the signal.	CW Doppler is used to measure high velocities in valve stenosis and regurgitation.
Pulsed Doppler	Pulsed ultrasound transmission with timing of reception determining depth of the backscattered signal	Pulsed Doppler samples velocities from a specific site but can only measure velocity over a limited range.	Pulsed Doppler is used to record low velocity signals at a specific site, such as LV outflow velocity or LV inflow velocity.
Pulse repetition frequency (PRF)	The number of pulses transmitted per second	PRF is limited by the time needed for ultrasound to reach and return from the depth of interest. PRF determines the maximum velocity that can be unambiguously measured.	The maximum velocity measurable with pulsed Doppler is about 1 m/s at 6 cm depth.
Nyquist limit	The maximum frequency shift (or velocity) measurable with pulsed Doppler equal to ½ PRF	The Nyquist limit is displayed as the top and bottom of the velocity range with the baseline centered.	The greater the depth, the lower the maximum velocity measurable with pulsed Doppler.
Signal aliasing	The phenomenon that the direction of flow for frequency shifts greater than the Nyquist limit cannot be determined	With aliasing of the LV outflow signal, the peak of the velocity curve is "cut off" and appears as flow in the opposite direction.	Aliasing can result in inaccurate velocity measurements if not recognized.
Sample volume	The intracardiac location where the pulsed Doppler signal originated	Sample volume depth is determined by the time interval between transmission and reception. Sample volume length is determined by the duration of the receive cycle.	Sample volume depth and length are adjusted to record the flow of interest.
Spectral analysis	Method used to display Doppler velocity data versus time, with gray scale indicating amplitude	Spectral analysis is used for both pulsed and CW Doppler.	The velocity scale, baseline position, and time scale of the spectral display are adjusted for each Doppler velocity signal.

Color Doppler

- Color Doppler uses the pulsed Doppler principle to generate a 2D image or "map" of blood flow velocity superimposed on the 2D real-time image (Table 1.5).
- Color Doppler signals, like all pulsed Doppler velocity data, are angle dependent and subject to signal aliasing.
- The frame rate for color Doppler imaging depends on:
  - Pulse repetition frequency (depth of color sector)
  - Number of scan lines (width of color sector and scan line density)
  - Number of pulses per scan line (affects accuracy of mean velocity calculation)

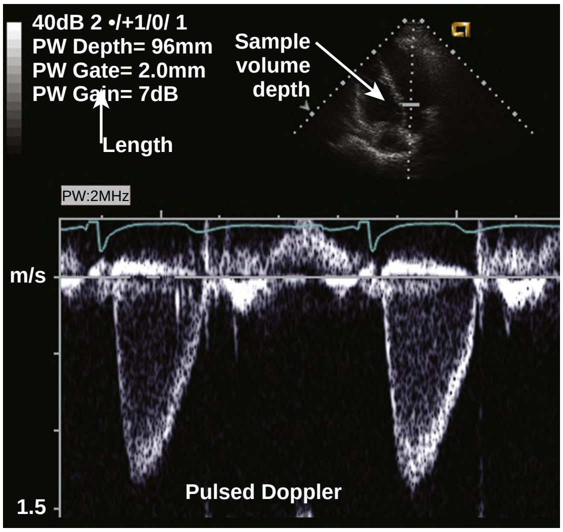

Fig 1.8 Doppler spectral tracing. LV outflow velocity was recorded with pulsed Doppler ultrasound from the apex. The sample volume depth (time for transmission and reception of the signal) is shown on a small 2D image with the length (sampling duration) indicated by the pulsed wave *(PW)* gate size. The spectral tracing shows time *(horizontal axis)*, velocity *(vertical axis)*, and signal strength *(gray scale)*. The baseline has been shifted upward to show the entire velocity curve directed away from the transducer. Some diastolic LV inflow is seen above the baseline, directed toward the transducer.

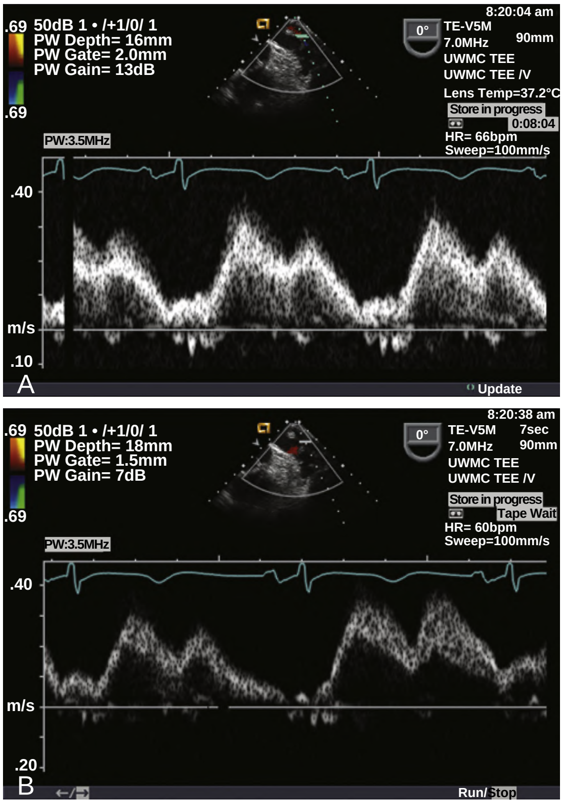

Fig 1.9 Pulsed Doppler gain setting. The effect of Doppler gain settings are shown for a TEE recording of pulmonary vein inflow. Excess noise is eliminated; then the gain is decreased from 13 dB (A) to 7 dB (B).

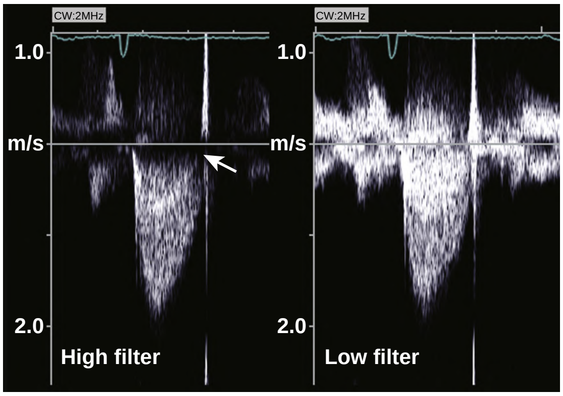

Fig 1.10 Wall filter settings. An aortic outflow signal is recorded with CW Doppler with the high pass ("wall") filter set at a high and low level. With the higher filter, low velocity signals are eliminated as shown by the blank space adjacent to the baseline *(arrow)*. This tracing enhances identification of the maximum velocity and recognition of the valve closing click. At the lower filter setting, the velocity signals extend to the baseline, making measurement of time intervals more accurate, but there also is more low velocity noise in the signal, related to motion of cardiac structures.

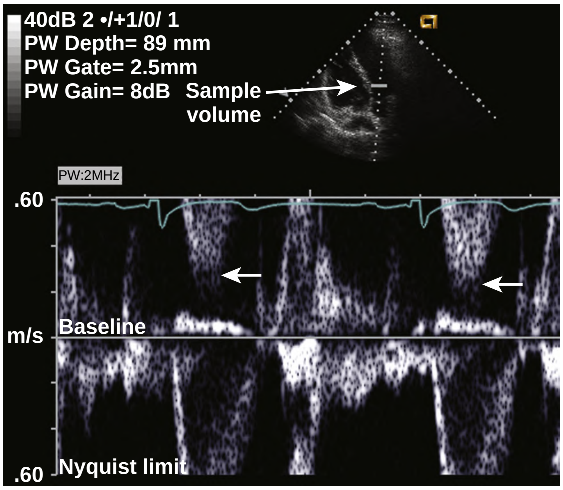

Fig 1.11 Signal aliasing. LV outflow velocity recorded from the apical approach with the sample volume on the LV side of the aortic valve. The spectral tracing is shown in the standard format with the baseline in the center of the scale and the Nyquist limit at the top and bottom of the scale. Signal aliasing is present with the top of the LV outflow signal seen in the reverse channel *(arrows)*. This degree of aliasing is easily resolved by shifting the baseline, as seen in Fig. 1.8. Aliasing with higher velocity flow is best resolved using CW Doppler ultrasound.

❖ KEY POINTS

- Color Doppler is recorded in real time simultaneous with 2D imaging.
- Flow toward the transducer typically is shown in red, with flow directed away from the transducer in blue (Fig. 1.12).
- When velocity exceeds the Nyquist limit, signal aliasing occurs so that faster flows toward the transducer alias from red to blue and vice versa for flow away from the transducer.
- The amount of variation in the velocity signal from each site can be coded on the color scale as variance.

TABLE 1.5 Color Doppler Flow Imaging

	Definition	Examples	Clinical Implications
Sampling line	Doppler data is displayed from multiple sampling lines across the 2D image	Instead of sampling backscattered signals from one depth (as in pulsed Doppler), signals from multiple depths along the beam are analyzed.	A greater number of sampling lines results in denser Doppler data but a slower frame rate.
Burst length	The number of ultrasound bursts along each sampling line	Mean velocity is estimated from the average of the backscattered signals from each burst.	A greater number of bursts results in more accurate mean velocity estimates but a slower frame rate.
Sector scan width	The width of the displayed 2D and color image	A greater sector width requires more sampling lines or less dense velocity data.	A narrower sector scan allows a greater sampling line density and faster frame rate.
Sector scan depth	The depth of the displayed color Doppler image	The maximum depth of the sector scan determines PRF (as with pulsed Doppler) and the Nyquist limit.	The minimum depth needed to display the flow of interest provides the optimal color display.
Color scale	Color display of Doppler velocity and flow direction	Most systems use shades of red for flow toward the transducer and blue for flow away from the transducer.	The color scale can be adjusted by shifting the baseline and adjusted the maximum velocity displayed (within the Nyquist limit).
Variance	The degree of variability in the mean velocity estimate at each depth along a sampling line	Variance typically is displayed as a green scale superimposed on the red–blue velocity scale. Variance can be turned on or off.	A variance display highlights flow disturbances and high velocity flow, but even normal flows will be displayed as showing variance if velocity exceeds the Nyquist limit.

PRF, Pulse repetition frequency.

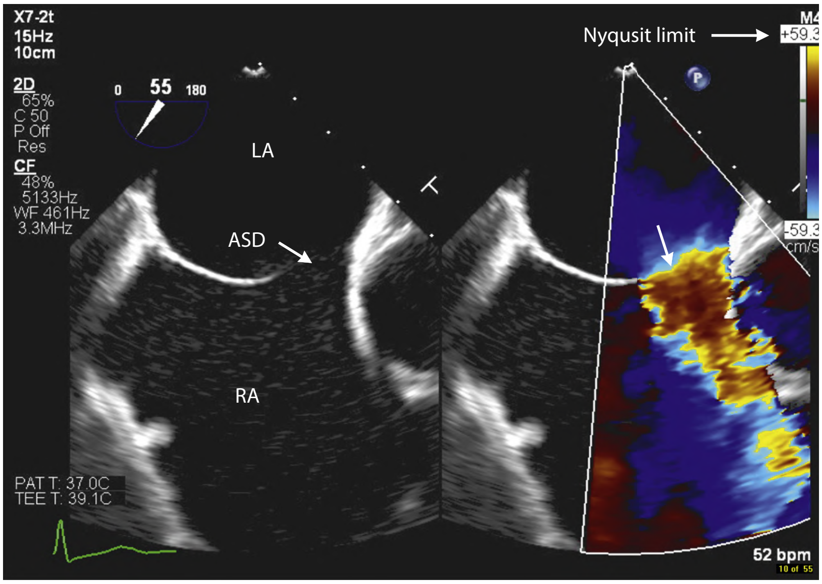

Fig 1.12 Color Doppler flow mapping. In this transesophageal view of the interatrial septum, flow across the atrial septal defect *(ASD)* is directed away from the transducer from the *LA* to *RA* but aliases from blue to orange because the velocity exceeds the Nyquist limit of 59 cm/s.

- Variance reflects either signal aliasing (high velocity flow) or the presence of multiple flow velocities or directions (flow disturbance).
- Color Doppler is most useful for visualization of spatial flow patterns; for this purpose, examiner preference determines the most appropriate color scale.
- For color Doppler measurements, such as vena contracta width or proximal isovelocity surface area (PISA) measurements, a color scale without variance is optimal.

- The maximum velocity measurable with color Doppler is determined by the Nyquist limit, but the baseline can be shifted or the velocity scale can be reduced.

Continuous-Wave Doppler

- CW Doppler uses two ultrasound crystals to continuously transmit and receive ultrasound signals.
- CW Doppler allows accurate measurement of high flow velocities without signal aliasing.
- Signals from the entire length of the ultrasound beam are included in the spectral CW Doppler recording.

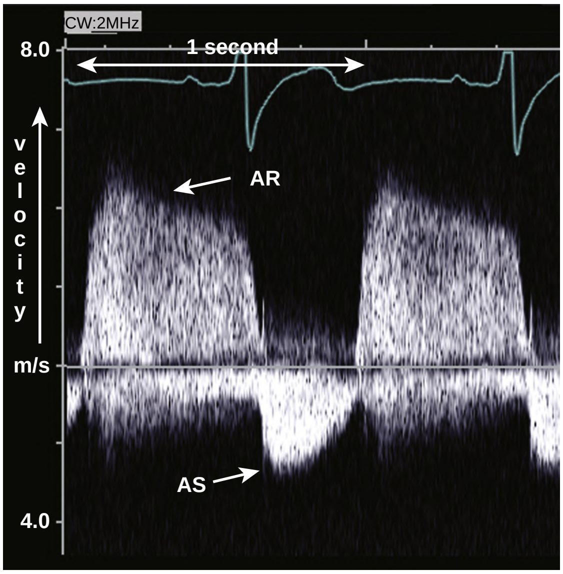

Fig 1.13 CW Doppler recording. The spectral recording of antegrade (aortic stenosis, *AS*) and retrograde flow (aortic regurgitation, *AR*) across the aortic valve shows time *(horizontal axis in seconds)*, velocity *(vertical axis in m/s)*, and signal strength *(gray scale)*. High velocity flow can be measured without aliasing using CW Doppler, as shown in the aortic regurgitant velocity over 4 m/s in this example.

KEY POINTS

- CW Doppler is used to measure high velocity flows, for example, across stenotic and regurgitant valves (Fig. 1.13).
- The CW Doppler signal is recorded as a spectral tracing with the scale and baseline adjusted as needed to display the signal of interest.
- CW Doppler can be recorded with a standard transducer with the CW interrogation line shown on the 2D image; however, a dedicated non-imaging CW transducer is optimal due to a higher signal-to-noise ratio and better angulation with a smaller transducer.
- The lack of range resolution means that the origin of the CW signal must be inferred from:
  - Characteristics of the signal itself (timing, shape, and associated flow signals)
  - Associated 2D imaging and pulsed or color Doppler findings
- Underestimation of blood flow velocity occurs when the CW Doppler beam is not parallel to the flow of interest.

Doppler Artifacts

- Artifacts with pulsed or CW Doppler spectral recordings include:
  - Underestimation of velocity because of a nonparallel intercept angle
  - Signal aliasing (with pulsed Doppler)
  - Range ambiguity
  - Beam width artifacts with superimposition of multiple flow signals
  - Mirror image artifact (Fig. 1.14)
  - Transit time effect
  - Electronic interference

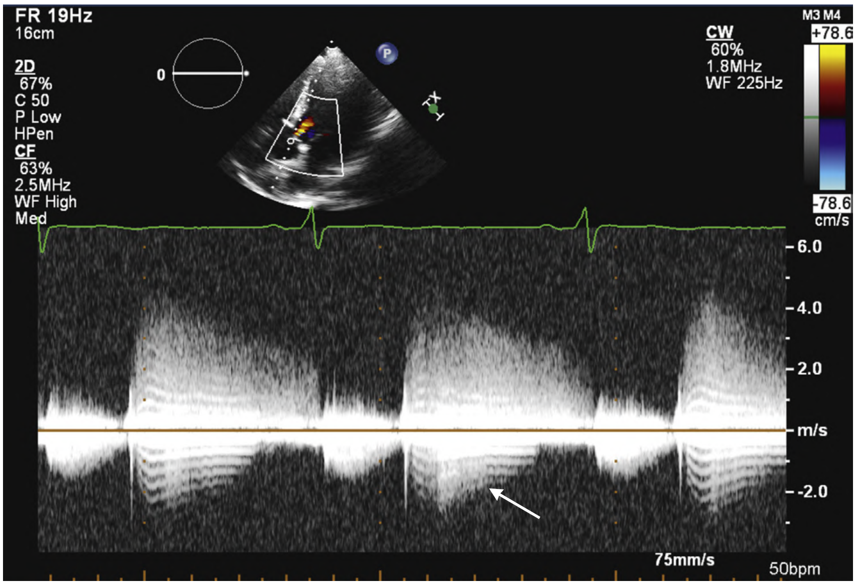

Fig 1.14 Doppler artifacts. Appropriate use of instrumentation allows minimization of many ultrasound artifacts. This recording of an aortic regurgitation velocity signal shows marked channel cross-talk (signal below the baseline that does not correlate with an actual intracardiac flow) due to high signal intensity with coarse fluttering of the incompetent valve leaflet. This recording would be improved by a higher wall filter and lower gain setting.

- Artifacts with color Doppler flow imaging (Table 1.6) include:
  - Shadowing resulting in inability to detect flow abnormalities
  - Ghosting from strong reflectors leading to flashes of color across the image plane
  - Gain too low (loss of true signal) or gain too high (speckle pattern across the image)
  - Intercept angle, including absence of detectable flow at a 90° angle
  - Signal aliasing (Fig. 1.15)
  - Electronic interference

KEY POINTS

- The potential for underestimation of velocity is the most important clinical limitation of Doppler ultrasound.
- Signal aliasing limits measurement of high velocities with pulsed Doppler and may confuse interpretation of color Doppler images.
- Range ambiguity with CW Doppler is obvious. With pulsed Doppler, range ambiguity occurs when signals from two times, three times or more the sample volume depth return to the transducer during a receive cycle.
- A mirror image artifact is common on spectral tracings and may be reduced by lowering power output and gain.
- As ultrasound propagates through moving blood, there is a slight change in ultrasound frequency, called the *transit time effect*. The transit time effect results in slight blurring of the edge of the CW Doppler spectral display, particularly for high velocity flows.
- Acoustic shadowing can be avoided by using an alternate transducer position; for example, transesophageal imaging of a mitral prosthetic valve.
- Color ghosting is seen in only one or two frames of the cardiac cycle, whereas blood flow signals demonstrate physiologic timing.

BIOEFFECTS AND SAFETY

- A simple measure of ultrasound exposure is the "duty factor," defined as percent of time ultrasound is being transmitted.
- Two types of ultrasound bioeffects are important with diagnostic imaging:
  - Thermal (heating of tissue due to the interaction of ultrasound energy with tissue)
  - Cavitation (the creation or vibration of small gas-filled bodies)
- Ultrasound exposure is measured by the:
  - Thermal index (TI; the ratio of transmitted acoustic power to the power needed to increase temperature by 1°C)
  - Mechanical index (MI; the ratio of peak rarefactional pressure to the square root of transducer frequency)

TABLE 1.6 Ultrasound Terminology: Ultrasound Safety

	Definition	Examples	Clinical Implications
Exposure Intensity (I)	Ultrasound exposure depends on power and area: I = power/area = watt/cm^2	Common measures of intensity are the SPTA or the SPPA.	Transducer output and tissue exposure affect the total ultrasound exposure of the patient.
Thermal bioeffects	Heating of tissue due to absorption of ultrasound energy described by the thermal index (TI)	The degree of tissue heating is affected by tissue density and blood flow. TI is the ratio of transmitted acoustic power to the power needed to increase temperature by 1°C. TI is most important with Doppler and color flow imaging.	Total ultrasound exposure depends on transducer frequency, power output, focus, depth, and exam duration. When the TI exceeds 1, the benefits of the study should be balanced against potential biologic effects.
Cavitation	Creation or vibration of small gas-filled bodies by the ultrasound wave	Mechanical index (MI) is the ratio of peak rarefactional pressure to the square root of the transducer frequency. MI is most important with 2D imaging.	Cavitation or vibration of microbubbles occurs with higher intensity exposure. Power output and exposure time should be monitored.

SPPA, Spatial peak pulse average; *SPTA*, spatial peak temporal average.

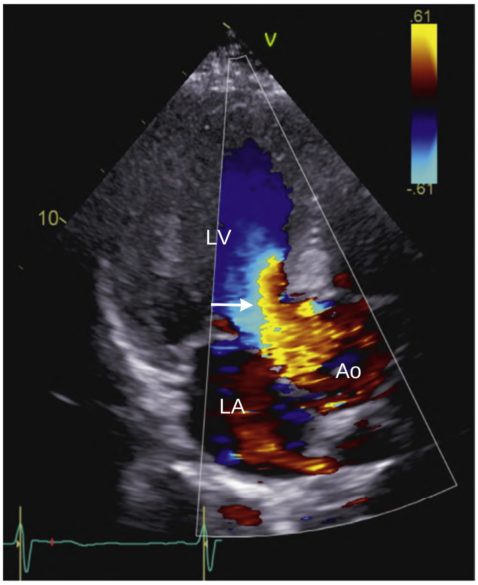

Fig 1.15 **Color Doppler signal aliasing.** In this apical long-axis view, the antegrade flow in the LV outflow tract, away from the transducer, aliases from blue to red because velocity exceeds the Nyquist limit of 61 cm/s. The shape of the aliasing transition across the outflow tract also depends in the exact angle between the ultrasound beam and blood flow stream; a nonparallel intercept angle underestimates velocity, so aliasing occurs closer to the aortic valve even when velocities are uniform across the outflow tract. Ao, Aorta.

❖ KEY POINTS

- The degree of tissue heating depends on the ultrasound energy imparted to the tissue and on characteristics of the tissue, including tissue density and blood flow.
- The total ultrasound exposure depends on transducer frequency, focus, power output, and depth, as well as the duration of the examination.
- Cavitation or vibration of microbubbles occurs with higher intensity ultrasound exposure.
- When the TI or MI exceeds 1, the benefit of the ultrasound examination should be balanced against potential biologic effects.
- Power output and exposure time should be monitored during the echocardiographic examination.
- Duty factor ranges from <1% for pulsed Doppler or imaging to 100% for CW Doppler.

THE ECHO EXAM

Basic Principles

Optimization of Echocardiographic Images

Instrument Control	Data Optimization	Clinical Issues
Transducer	• Different transducer types and transmission frequencies are needed for specific clinical applications. • Transmission frequency is adjusted for tissue penetration in each patient and for ultrasound modality (Doppler versus imaging).	• A higher transducer frequency provides improved resolution but less penetration. • A larger aperture provides a more focused beam.
Power output	• Power output reflects the amount of ultrasound energy transmitted to the tissue. • Higher power output results in greater tissue penetration.	• Potential bioeffects must be considered. • Exam time and mechanical and thermal indexes should be monitored.
Imaging mode	• 2D imaging is the clinical standard for most indications. • M-mode provides high time resolution along a single scan line. • 3D imaging provides improved appreciation of spatial relationships.	• Optimal measurement of cardiac chambers and vessels requires a combination of imaging modes.
Transducer position	• Acoustic windows allow ultrasound tissue penetration without intervening lung or bone tissue. • Transthoracic acoustic windows include parasternal, apical subcostal, and suprasternal. • TEE acoustic windows include high esophageal and transgastric.	• Optimal patient positioning is essential for acoustic access to the heart. • Imaging resolution is optimal when the ultrasound beam is reflected perpendicular to the tissue interface. • Doppler signals are optimal with the ultrasound beam is aligned parallel to flow.
Depth	• Depth is adjusted to show the structure of interest. • PRF depends on maximum image depth.	• PRF is higher at shallow depths, which contributes to improved image resolution. • Axial resolution is the same along the entire length of the ultrasound beam. • Lateral and elevations resolution depend on the 3D shape of the ultrasound beam at each depth.
Sector width	• Standard sector width is 60°, but a narrower sector allows a higher scan line density and faster frame rate.	• Sector width should be adjusted as needed to optimize the image. • Too narrow a sector might miss important anatomic or Doppler findings.
Gain	• Overall gain affects the display of the reflected ultrasound signals.	• Excessive gain obscures border identification. • Inadequate gain results failure to display reflections from tissue interfaces.
TGC	• TGC adjusts gain differentially along the length of the ultrasound bean to compensate for the effects of attenuation.	• An appropriate TGC curve results in an image with similar brightness proximally and distally in the sector image.
Grey scale or Dynamic range	• Ultrasound amplitude is displayed using a dB scale in shades of grey.	• The range of displayed amplitudes is adjusted to optimize the image using the dynamic range or compression controls.

Optimization of Echocardiographic Images—Cont'd

Instrument Control	Data Optimization	Clinical Issues
Harmonic imaging	• Harmonic frequencies are proportional to the strength of the fundament frequency but increase with depth of propagation.	• Harmonic imaging improves endocardial definition and decreased near field and side lobe artifacts. • Flat structures, such as valves, appear thicker with harmonic than with fundamental imaging. • Axial resolution is reduced.
Focal depth	• Transducer design parameters that affect focal depth include array pattern, aperture size, and acoustic focusing.	• The ultrasound beam is most focused at the junction between the near zone and far field of the beam pattern. • Transducer design allows a longer focal zone. In some cases, focal zone can be adjusted during the examination.
Zoom mode	• The ultrasound image can be restricted to a smaller depth range and narrow section. The maximum depth still determines PRF, but scan line density and frame rate can be optimized in the region of interest.	• Zoom mode is used to examine areas on interest identified on standard views.
ECG	• The ECG signal is essential for triggering digital cine loop acquisition.	• A noisy signal or low amplitude ECG results in incorrect triggering or inadvertent recording of an incomplete cardiac cycle.

dB, Decibel; *ECG,* electrocardiogram; *PRF,* pulse repetition frequency; *TGC,* time gain compensation.

Optimization of Doppler Recordings

Modality	Data Optimization	Common Artifacts
Pulsed	• 2D guided with "frozen" image • Parallel to flow • Small sample volume • Velocity scale at Nyquist limit • Adjust baseline for aliasing • Use low wall filters • Adjust gain and dynamic range	• Non-parallel angle with underestimation of velocity • Signal aliasing. Nyquist limit = ½ pulse repetition frequency (PRF) • Signal strength/noise
Continuous wave	• Dedicated non-imaging transducer • Parallel to flow • Adjust velocity scale so flow fits and fills displayed range • Use high wall filters • Adjust gain and dynamic range	• Nonparallel angle with underestimation of velocity • Range ambiguity • Beam width • Transit time effect
Color flow	• Use minimal depth and sector width for flow of interest (best frame rate) • Adjust gain just below random noise • Color scale at Nyquist limit • Decrease 2D gain to optimize Doppler signal • 3D color imaging allows better visualization of the size and shape of jet geometry proximal to a restrictive orifice (e.g., valve regurgitation)	• Shadowing • Ghosting • Electronic interference

SELF-ASSESSMENT QUESTIONS

Questions 1-5

Which ultrasound imaging interaction best describes the findings in each of the following images:

A. Reverberation
B. Ring-down
C. Scattering
D. Refraction
E. Attenuation

Question 1:

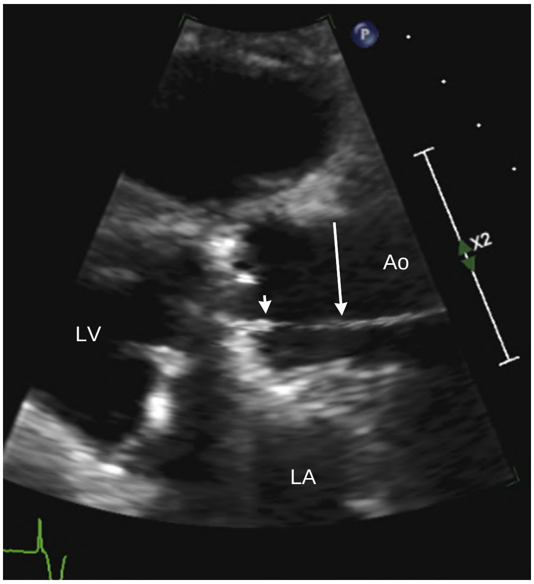

Fig 1.16 Parasternal long-axis view.

Question 2:

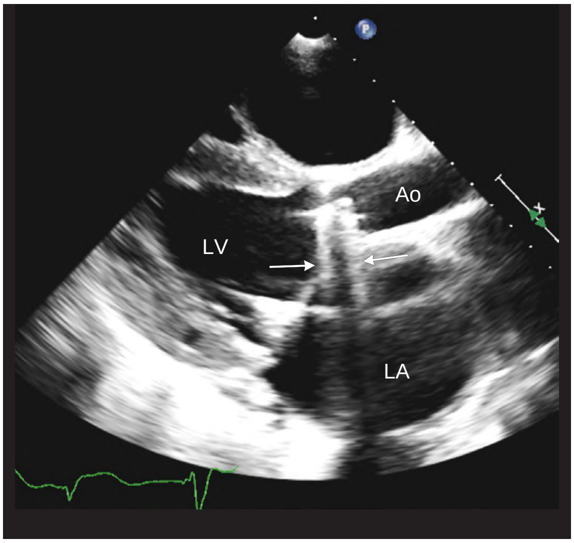

Fig 1.17 High esophageal window, TEE imaging. *Ao,* Aortic valve.

Question 3:

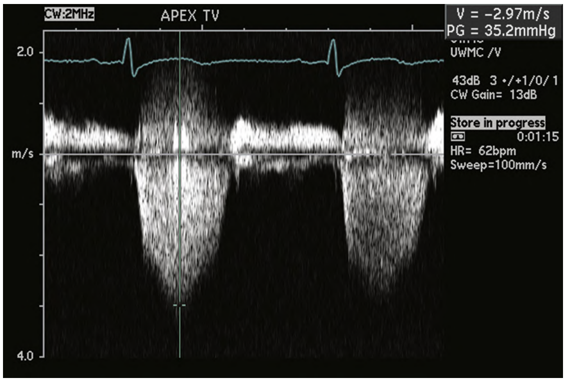

Fig 1.18 Tricuspid regurgitant jet.

Question 4:

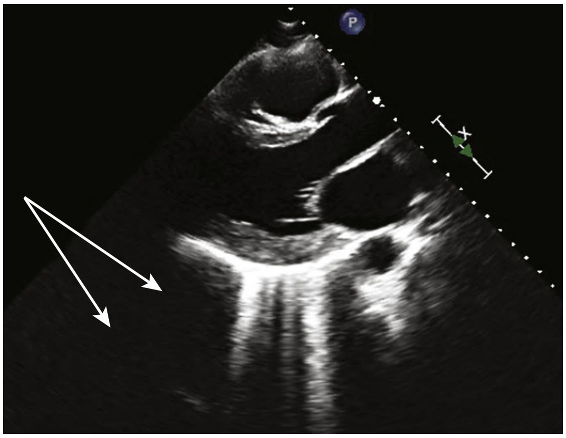

Fig 1.19 Parasternal long-axis view.

Question 5:

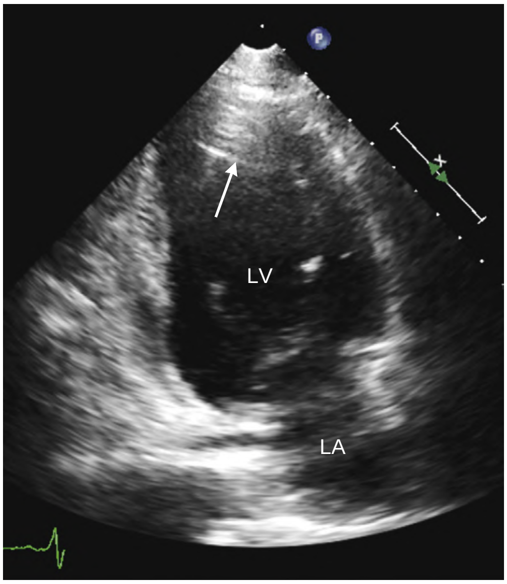

Fig 1.20 Apical 4-chamber view.

Question 6

Which of the following would reduce echocardiographic attenuation of an ultrasound signal?

A. Increase the sector depth
B. Apply water-soluble gel to the transducer
C. Move the transducer laterally over the left lung
D. Decrease the power output
E. Raising the transducer frequency

Question 7

Compared to pulsed-wave Doppler, CW Doppler:

A. Has a duty factor of 1
B. Is more susceptible to nonparallel alignment
C. Has a lower Nyquist limit
D. Has less range ambiguity
E. Has a larger aperture when using a dedicated transducer

Question 8

Which of the following most affects frame rate during color Doppler imaging?

A. Burst length
B. Color scale
C. Electronic interference
D. Variance setting
E. Intercept angle

Question 9

In this TEE color Doppler long axis image of the descending thoracic aorta (Fig. 1.21), the interposed black region between the red and blue color Doppler shift is the result of:

A. Acoustic shadowing
B. Intercept angle
C. Electronic interference
D. Signal aliasing
E. Flow disruption

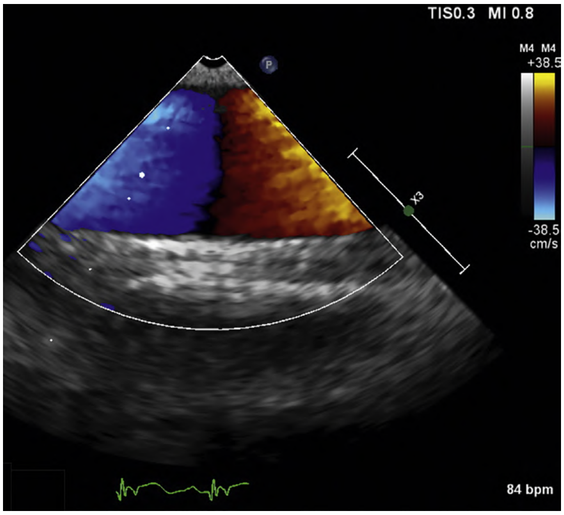

Fig 1.21

Question 10

Which of the following allows measurement of higher velocities with pulsed Doppler ultrasound?

A. Shifting the baseline
B. Decreasing the pulse repetition frequency
C. Increasing depth
D. Decreasing the Nyquist limit

Question 11

The black signal seen on the parasternal long-axis view shown (Fig. 1.22) is best explained by:

A. Acoustic shadowing
B. Intercept angle
C. Electronic interference
D. Reverberations
E. Refraction of the ultrasound beam

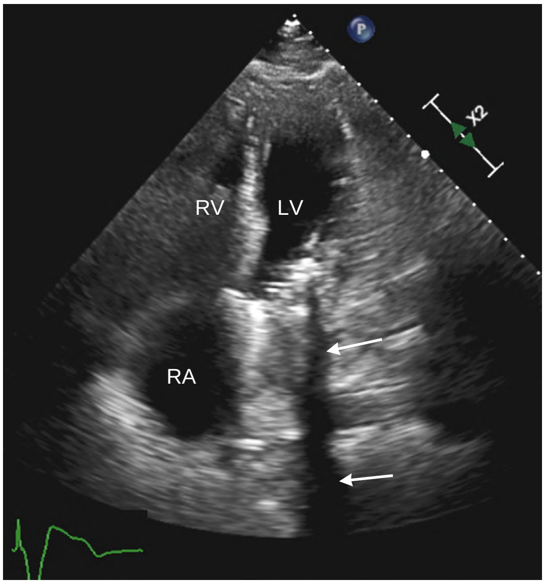

Fig 1.22

Question 12

Which of the following is least affected by increasing width of the 2D scanning sector?

A. Temporal resolution
B. Spatial resolution
C. Axial resolution

Questions 13-17

Select the Doppler modality that offers the best diagnostic data for Questions 13 to 17:

A. Color Doppler imaging
B. Pulsed Doppler imaging
C. CW Doppler imaging

Question 13: Myocardial velocity for evaluation of LV diastolic function

Question 14: Vena contracta for mitral valve regurgitation severity assessment

Question 15: Pulmonary venous flow reversal for mitral regurgitation severity assessment

Question 16: Velocity of the aortic jet in a patient with severe aortic stenosis

Question 17: Tricuspid regurgitation velocity in a patient with pulmonary hypertension

ANSWERS

Answer 1: D

In this parasternal long-axis image of a patient with a bileaflet mechanical aortic valve, strong reflections from one of the valve occludes *(short arrow)* appears as a linear echo in the aorta due to refraction of the strong reflector being displayed as a line across the width of the image *(long arrow)*.

Answer 2: A

This parasternal long axis image of a patient with a bileaflet mechanical aortic valve (and a mitral valve clip) shows reverberations from the aortic valve obscuring the left atrium. Reverberation occurs if strong specular reflectors result in the ultrasound signal going back and forth between the two reflectors before returning to the transducer. The received delayed signal is assigned to expected depth based on the time interval from transmission, leading to display of multiple echodensities in a line distal to the actual structure. In this case, reverberation between the two valve leaflets result in linear artifacts distal to the valve. There also is an acoustic shadow from the mechanical aortic valve between the two reverberation artifacts.

Answer 3: C

Doppler ultrasound sends a signal that is reflected and backscattered off of small structures, such as red blood cells. The reflected backscatter frequencies will be dependent on the speed and direction of blood flow. Based on the Doppler equation, higher Doppler frequency shifts are associated with a higher velocity recording. Peak tricuspid regurgitant jet velocity is the highest recorded velocity from the Doppler envelope. The highest velocity is recorded when the ultrasound beam is parallel with flow.

Answer 4: E

Attenuation describes the loss in ultrasound signal strength due to tissue absorption of ultrasound energy, resulting in poor image quality in the far field. Use of a lower frequency transducer aids tissue penetration, improving image quality, but will relatively lower image resolution in the near field.

Answer 5: B

High amplitude oscillations of the piezoelectric crystal elements may create an acoustic noise artifact, termed *ring-down artifact,* or *near field clutter,* which limits image resolution within 1 to 2 cm of the transducer. This is commonly seen in apical view images of the LV, with an artifact in the LV apex. Multiple views of the LV are needed to correctly identify the artifact.

Answer 6: B

Attenuation is the loss of signal intensity as the ultrasound wave travels through the tissue and back to the transducer. Attenuation is dependent on acoustic properties of the tissue, transducer frequency, acoustic pressure (power), and travel distance. Air produces significant attenuation that is minimized by applying gel to a transducer and avoiding lung tissue. Lowering the transducer frequency improves tissue penetration by increasing the ultrasound wavelength and thus reduces attenuation. Increasing the ultrasound power results in a stronger signal reflected back to the transducer. Increasing sector depth leads to more attenuation by increasing the distance the ultrasound signal travels.

Answer 7: A

The duty factor is the percent of time between ultrasound pulses used for transmitting the ultrasound signal. A CW Doppler continuously sends and receives ultrasound signal and thus has a duty factor of 100% (or 1), whereas a pulsed Doppler typically has a duty factor of 5%. Continuous sampling of the ultrasound signal leads to range ambiguity but allows for measuring higher velocities by eliminating the Nyquist limit. A dedicated CW Doppler transducer has a smaller surface footprint (aperture), allowing for optimal positioning and angulation of the ultrasound beam. All forms of Doppler are equally susceptible to nonparallel alignment, leading to underestimation of frequency shifts.

Answer 8: A

Burst length represents the number of ultrasound bursts transmitted along each sample line in the imaging sector. A higher number of bursts increases the accuracy of mean velocity assessment, but, because of increased data acquisition, results in a slower frame rate. Color scale shows the direction and velocity of flow. Shifting the color scale increases identification of lower velocity flow as long as the maximum velocity is within the Nyquist limit. Beyond the Nyquist limit, there is aliasing of the signal. Electronic interference affects image quality and therefore resolution of velocities within the color sector, but it does not affect frame rate. Variance displays flow turbulence in the color sector and is superimposed on the standard color velocity scale. Although variance can be toggled on/off and affects the display of flow turbulence, the color frame rate is not affected. With Doppler imaging, the signal is optimized when the ultrasound beam is parallel with flow. If flow is perpendicular to the ultrasound beam (90° intercept angle), this is displayed as absence of color, or no detectable flow, but does not affect imaging frame rate.

Answer 9: B

Color Doppler imaging samples blood velocity moving toward (displayed as red) or away (displayed as blue) from the transducer. Maximal velocities are obtained when flow is parallel to the ultrasound beam. In this TEE long-axis view of the descending thoracic aorta, systolic blood flow is from right to left across the image; thus flow toward the transducer on the right is displayed in red and flow away from the transducer is displayed in blue. Flow perpendicular to the transducer, in this case the interposed black region, is recorded as an absent signal. Thus, this black region is due to a perpendicular intercept angle in this image. Acoustic shadowing occurs when a strong specular reflector, such as prosthetic valves or calcium, blocks ultrasound penetration distal to the reflector. Electronic interference is displayed as an overlaying artifact, which is not associated with the image and may extend beyond tissue borders. Signal aliasing results in flow being displayed as if it were due to flow opposite in direction to actual flow. So, flow toward the transducer, by convention shown in red, would be displayed as blue, and vice versa. Signal aliasing often is seen on subcostal images of the proximal abdominal aorta. Disruption of flow would be accompanied by turbulent and disarrayed flow with aliasing of the color Doppler signal at the point of disruption, which is not seen on this image of a normal descending thoracic aorta.

Answer 10: A

To accurately measure the velocity of a sound wave, the signal must be sampled at least twice per wavelength. Aliasing occurs from under-sampling of the backscattered signal, resulting in ambiguity in measuring the Doppler frequency shift with higher frequency shifts appearing as lower velocities in the opposite direction. The maximum pulse repetition frequency, or Nyquist limit, is the sampling rate at a given depth of interrogation for a given transmitted frequency. Thus, the highest velocity measurable without aliasing is limited to one-half of the pulse repetition frequency (Nyquist limit). Decreasing the pulse repetition frequency (and hence Nyquist limit) will decrease the measurable velocity and lead to more aliasing. The pulse repetition frequency decreases with increasing depth as more time is required to transmit and receive the backscattered signals. Shifting the baseline does not change the Nyquist limit but acts as an electronic "cut and paste" moving the signal in the opposite channel to show the physiologic velocity curve, in effect looking like less aliasing in one direction of flow.

Answer 11: A

This 2D image in an apical four-chamber view shows severe mitral leaflet and annular calcification resulting in an acoustic shadow. Calcium is a strong specular reflector, which blocks ultrasound penetration distally. Most of the transmitted ultrasound beam reflects from the calcium back to the transducer. This is shown on the generated image as a bright echodensity at the site of calcium with shadowing of the signal in the distal field. On 2D imaging, a parallel intercept angle between the structure of interest and the ultrasound beam results in image "drop out," as few signals are reflected from the anatomic structure. Electronic interference typically has a geometric pattern and affects the entire 2D image. Reverberations appear as multiple bright echo-densities distal to the anatomic structure, whereas refraction results in the structure of interest appearing lateral to the actual location.

Answer 12: C

With scanned (2D) imaging, the image sector is formed by multiple adjacent scan lines where the transducer sweeps the ultrasound beam across the imaging field. Rapid image processing allows for real-time imaging. Widening the scanning sector allows for improved spatial resolution across the imaging field. Because time is incurred sweeping the ultrasound beam across the imaging field with 2D imaging, temporal resolution is optimal with M-mode imaging, which images only along a single scan line. A wider 2D scanning sector decreases imaging frame rate and decreases temporal resolution. Axial resolution (longitudinal resolution) is resolution in the direction parallel to the ultrasound beam. Because resolution is the same at any point along an ultrasound beam, axial resolution is not affected by scanning sector width.

Answers 13-17

Answer 13: **B**
Answer 14: **A**
Answer 15: **B**
Answer 16: **C**
Answer 17: **C**

CW Doppler imaging allows accurate measurement of high velocity flow without aliasing of the signal. Clinically, CW Doppler is used whenever a high velocity signal is present—for example, with aortic stenosis, tricuspid regurgitation, mitral regurgitation, or a ventricular septal defect. However, with CW Doppler, sampling occurs along the line of interrogation without localization of the point of maximum velocity along that line (lack of range resolution). The origin of the high velocity signal is inferred from imaging data or localized using pulsed Doppler or color flow imaging.

Color Doppler imaging is useful for evaluating the spatial distribution of flow, which is especially helpful in determining the severity and mechanism of regurgitant flow. The width of the color Doppler regurgitant jet, the vena contracta, is a reliable measure of regurgitation severity.

Pulsed-wave Doppler imaging allows spatial localization of a velocity signal but is best used for low velocity signals with a maximum velocity that is below the Nyquist level. Clinical examples of the use of pulsed Doppler include LV inflow across the mitral valve, pulmonary venous flow, and LV outflow velocity proximal to the aortic valve (even when aortic stenosis is present). With velocities that exceed the Nyquist limit, aliasing of the pulsed-wave Doppler signal occurs, which precludes accurate velocity measurements. Conventional Doppler imaging assesses blood flow velocity by measuring signals from moving blood cells. With myocardial tissue Doppler imaging, as is used for LV diastolic function assessment, pulsed Doppler is used to quantify the lower velocity signals of myocardial tissue motion.

2 The Transthoracic Echocardiogram

STEP-BY-STEP APPROACH

Step 1: Clinical Data

- The indication for the study determines the focus of the examination.
- Key clinical history and physical examination findings and results of any previous cardiac imaging studies are noted.

❖ KEY POINTS

- The goal of the echo study is to answer the specific question asked by the referring provider.
- Blood pressure is recorded at the time of the echo, because many measurements vary with loading conditions.
- Knowledge of clinical data ensures that the echo study includes all the pertinent images and Doppler data. For example, when a systolic murmur is present, the echo study includes data addressing all the possible causes for this finding.
- Data from previous imaging studies may identify specific areas of concern, such as a pericardial effusion noted on chest computed tomography (CT) imaging.
- Detailed information about previous cardiac procedures assists in interpretation of postoperative findings, evaluation of implanted devices (such as prosthetic valves or percutaneous closure devices), and detection of complications.
- Use of precise anatomic terminology facilitates accurate communication of imaging results (Table 2.1).

Step 2: Patient Positioning

- A steep left lateral position provides acoustic access for parasternal and apical views (Fig. 2.1).
- The subcostal views are obtained when the patient is supine; if needed, the legs are bent to relax the abdominal wall.
- Suprasternal notch views are obtained when the patient is supine with the head turned toward either side.

❖ KEY POINTS

- Images may be improved with suspended respiration, typically at end-expiration but sometimes at other phases of the respiratory cycle.
- An examination bed with an apical cutout allows a steeper left lateral position, often providing improved acoustic access for apical views.
- Imaging can be performed with either hand holding the transducer and with the examiner on either side of the patient. However, imaging from the patient's left side avoids reaching over the patient and is essential for apical views when the patient's girth is larger than the arm span of the examiner.
- Prolonged or repetitive imaging requires the examiner to learn ergonomic approaches to minimize mechanical stress and avoid injury.

Step 3: Instrumentation Principles

- A higher transducer frequency provides improved resolution but less penetration of the ultrasound signal.
- Harmonic imaging is frequently used to improve image quality, particularly recognition of endothelial borders.
- Depth, zoom mode, and sector width are adjusted to optimize the image and frame rate, depending on the structure or flow of interest (Fig. 2.2).
- Gain settings are adjusted to optimize the data recording while avoiding artifacts.

TABLE 2.1 Terminology for Normal Echocardiographic Anatomy

Aorta*	Sinuses of Valsalva Sinotubular junction Coronary ostia Ascending aorta Descending thoracic aorta Proximal abdominal aorta
Aortic valve	Right, left, and non-coronary cusps Nodules of Arantius Lambl excrescence
Mitral valve	Anterior and posterior leaflets Posterior leaflet scallops (lateral, central, medial) Chordae (primary, secondary, tertiary; basal, and marginal) Commissures (medial and lateral)
Left ventricle	Wall segments (see Chapter 8) Septum, free wall Base, apex Medial and lateral papillary muscles
Right ventricle	Inflow segment Moderator band Outflow tract (conus) Supraventricular crest Anterior, posterior, and conus papillary muscles
Tricuspid value	Anterior, septal, and posterior leaflets Chordae Commissures
Right atrium	RA appendage SVC and IVC junctions Valve of IVC (Chiari network) Coronary sinus ostium Crista terminalis Fossa ovalis Patent foramen ovale
Left atrium	LA appendage Superior and inferior left pulmonary veins Superior and inferior right pulmonary veins Ridge at junction of LA appendage and left superior pulmonary vein
Pericardium	Oblique sinus Transverse sinus

IVC, Inferior vena cava; *SVC,* superior vena cava.

*The term *aortic root* is used inconsistently, sometimes meaning the aortic sinuses and sometimes meaning the entire segment of the aorta from the annulus to the arch (including sinuses and ascending aorta).

❖ KEY POINTS

- Although the control panel varies for each instrument, the basic functions are similar for all ultrasound systems.
- The highest frequency that penetrates adequately to the depth of interest is used for optimal imaging.

Fig. 2.1 **Patient positioning for transthoracic echocardiography.** The patient is positioned in a steep left lateral decubitus position on an examination bed with a removable section cut out of the mattress to allow placement of the transducer on the apex by the sonographer as shown. Ultrasound gel is used to enhance coupling between the transducer face and the patient's skin. The sonographer sits on an adjustable chair and uses the left hand for scanning and the right hand to adjust the instrument panel. The room is darkened to improve visualization on the ultrasound instrument display screen.

- With harmonic imaging, flat structures (such as valve leaflets) appear thicker than with fundamental imaging.
- Frame rate is higher for a shorter depth or a narrower sector; a fast frame rate is especially important with Doppler color flow imaging.
- Too narrow a sector may miss important anatomic or physiologic findings.
- Excessive gain results in artifacts with both imaging and Doppler, whereas inadequate gain results in data loss.

Step 4: Data Recording

- Representative digital images from the echo study are saved to document the findings and for later review and measurement.
- Echo images include an electrocardiogram (ECG) tracing for timing purposes.
- A 2-beat cine loop is adequate for sinus rhythm; longer timed cycles are used when atrial fibrillation or other arrhythmia is present.

❖ KEY POINTS

- Two-dimensional (2D) echo images in each view are recorded first with a depth and sector width that encompasses all the structures in the image plane and then at a depth and sector width optimized for the structures of interest (Fig. 2.3).

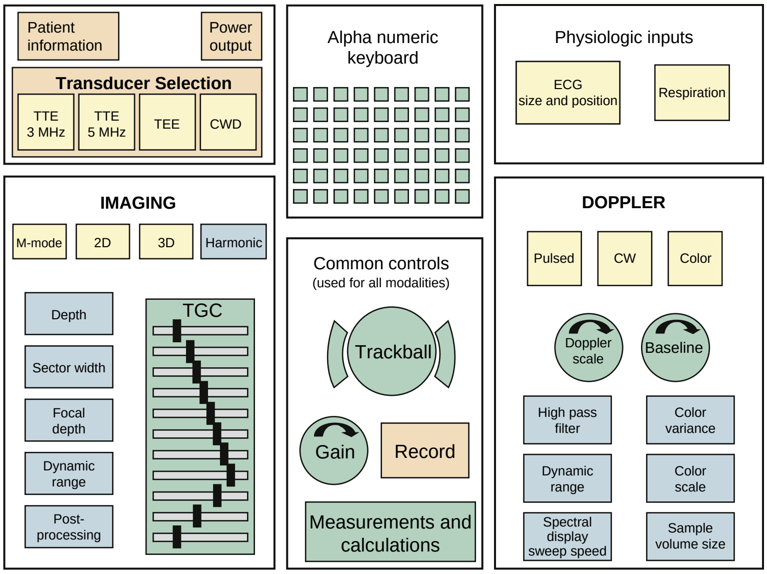

Fig. 2.2 Schematic diagram illustrating the typical features of a simplified echocardiographic instrument panel. Each ultrasound system has a unique instrument panel, ranging from simple to complex, often now integrated into an interactive screen rather than physical buttons. However, the functions controlled by the instrument panel fall into several basic categories as shown schematically here. Understanding the basic principles of ultrasound physics, imaging and Doppler parameters allow the operator to quickly master the interface for any given ultrasound system. Additional options are provided as needed for advanced imaging modalities, such as 3D imaging or speckle tracking strain.

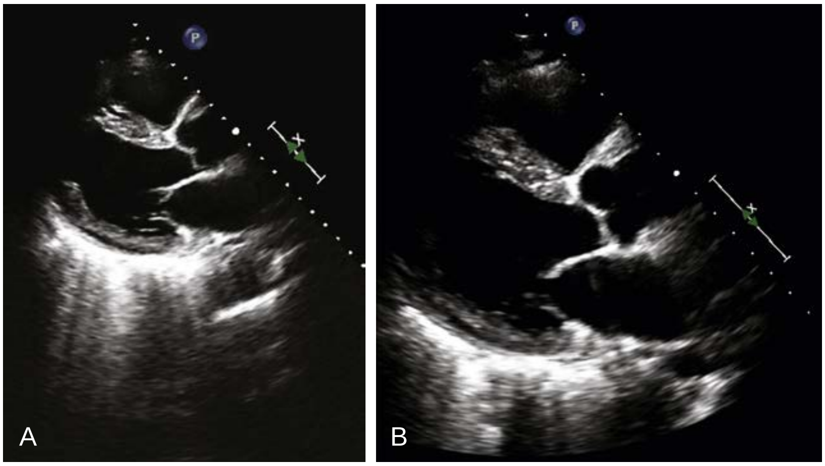

Fig. 2.3 Parasternal long-axis view. (A) Initially images are recorded at a depth of 18 cm to show the structures posterior to the heart *(top)*. (B) Next, images are recorded with the depth decreased to 13 cm and the resolution mode used (note that the top of the displayed image now is 2 cm from the skin) to focus on the aortic and mitral valves.

- Additional zoom mode images of normal and abnormal findings are recorded as needed.
- Three-dimensional (3D) imaging is used routinely for measurement of ventricular volumes and as needed for other cardiac structures (see Chapters 4 and 6).
- Spectral pulsed and continuous-wave (CW) Doppler data are recorded with the baseline and velocity range adjusted so that the flow signal fits but fills the vertical axis. The time scale is adjusted to maximize the accuracy of measurements (usually an x-axis of 100 mm/s) (Fig. 2.4).
- Color Doppler is recorded after sector width and depth are adjusted to optimize frame rate and gain is set just below the level that results in background speckle.
- The variance mode on the color scale is preferred by many examiners (including the authors) to enhance recognition of abnormal flows.
- Some normal flows result in a variance display—for example, when left ventricular (LV) outflow velocity exceeds the Nyquist limit and signal aliasing occurs (Fig. 2.5).

Step 5: Examination Sequence

- Subsequent chapters provide details on the elements of the examination for each clinical condition needed for a final diagnosis.
- These examination elements are incorporated into a systemic patient study sequence.

❖ KEY POINTS

- There are several approaches to an examination sequence; any of these are appropriate if a complete systemic examination is performed.
- In some clinical situations, a limited examination may be appropriate, with the study components selected by the referring or performing physician.

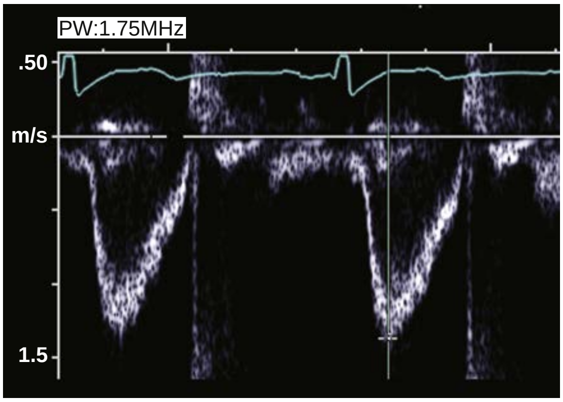

Fig. 2.4 **Pulsed Doppler velocity recording.** The spectral display of the pulsed wave *(PW)* Doppler signal is shown with the baseline shifted and velocity scale adjusted to avoid aliasing and to use the full vertical axis to improve measurement accuracy; for example, the signal fits but fills the graphical display. The horizontal time scale is 100 mm/s, which is standard for most Doppler recordings.

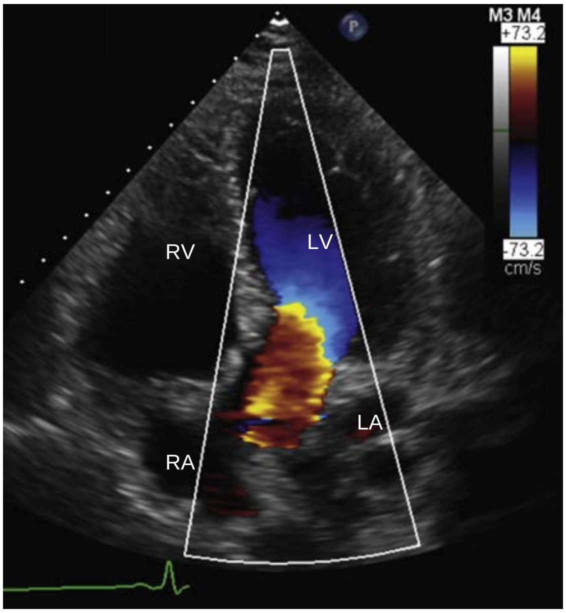

Fig. 2.5 **Color Doppler with signal aliasing.** This color Doppler image of LV outflow in an anteriorly angulated apical 4-chamber view shows signal aliasing adjacent to the septum in the subaortic region. Although this appearance may be due to an asymmetric flow profile, the effects of intercept angle also may be important. Even if the velocity is identical across the outflow tract, compared with the region along the anterior mitral valve leaflet, the region adjacent to the septum the Doppler beam is more parallel to the flow direction. The higher Doppler shift results in signal aliasing. Aliasing at the aortic valve level is expected because the aortic velocity typically exceeds the Nyquist limit at this depth (0.73 m/s in this example).

- The approach suggested here is based on obtaining all data (imaging and Doppler) for each acoustic window (parasternal, apical, subcostal, and suprasternal) before moving to the next acoustic window; this approach minimizes the time needed to reposition the patient between acoustic windows (Fig. 2.6).

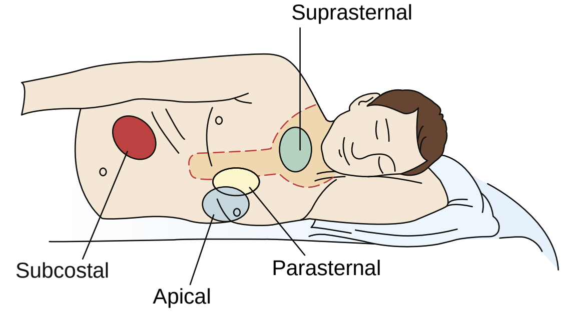

Fig. 2.6 **Standard acoustic windows.** The positions on the chest wall where ultrasound can reach the cardiac structures without intervening lung or bone include the parasternal, apical, subcostal, and suprasternal notch windows. The parasternal and apical windows typically are optimal with the patient in a steep left lateral position. For the subcostal window, the patient is supine with the knees flexed to relax the abdominal vasculature. For the suprasternal notch window, the patient is supine with the head tilted back and to one side.

- Some examiners prefer to obtain all the imaging data and then obtain all the Doppler data; this approach allows the Doppler data recording to be tailored to the imaging findings.
- With any approach, the examiner may need to go back to previous acoustic windows at the end of the examination if additional views or measurements are needed based on abnormal findings.
- The examination sequence also may need to be modified depending on patient factors (inability to move, bandages, etc.) or the urgency of the examination.
- Basic measurements are made as the examination is performed (Table 2.2) or during review of images at completion of the study. Normal values for chamber sizes are provided in Chapter 6 (Tables 6.2 and 6.3) and for the aorta in Chapter 16 (Tables 16.1 and 16.2).

Step 6: Parasternal Window

Long-Axis View

- Many echocardiographers start with the parasternal long-axis view with:
  - Imaging to show the aortic and mitral valves, left atrium, aortic sinuses and ascending aorta, LV basal segments, and the right ventricular (RV) outflow tract
  - Color Doppler to screen for aortic and mitral regurgitation
- Standard measurements include:
  - LV end-diastolic and end-systolic diameters; diastolic thickness of the septum and LV inferior-lateral wall just apical from the mitral leaflet tips (Fig. 2.7)
  - Aortic diameter at end-diastole (Fig. 2.8)
  - Left atrial anterior–posterior dimension
  - Vena contracta width for aortic and mitral regurgitation

TABLE 2.2 Basic Echo Imaging Measurements

Cardiac Structure	Basic Measurements	Additional Measurements	Technical Details
Left ventricle	• ED dimension • ES dimension • Wall thickness • ED volume • ES volume • Ejection fraction	• Stroke volume • LV mass • Global longitudinal strain	• 2D imaging is used to ensure measurements are centered and perpendicular to the long axis of the LV. • M-mode provides superior time resolution and more accurate identification of endocardial borders. • LV volumes and ejection fraction are measured by 2D and 3D imaging. • LV volumes and stroke volume often are indexed to body size.
Left atrium	• AP diameter	• LA area • LA volume	• Left atrial anterior–posterior dimension provides a quick screen but may underestimate LA size. • When LA size is important for clinical decision making, measurement of LA volume is helpful.
Right ventricle	• Visual estimate of size • TAPSE	• ED RV outflow tract diameter • ED RV length and diameter	• Quantitation of RV size by echo is challenging due to the complex 3D shape of the chamber. • TAPSE via M-mode is a quantitative measure of RV systolic function.
Right atrium	• Visual estimate of size		• RA size is usually compared to the LA in the apical 4-chamber view.
Aorta	• ED diameter at sinuses	• Maximum diameter indexed to expected dimension • Diameter at multiple sites in aorta	• With 2D echo, inner edge to inner edge measurements are more reproducible. • Measurements are made at end-diastole by convention, but end-systolic measurements also may be helpful.
Pulmonary artery		• Diameter	

AP, Anterior–posterior; *ED,* end-diastole (onset of the QRS); *ES,* end-systole (minimum LV volume); *TAPSE,* tricuspid annular plane systolic excursion.

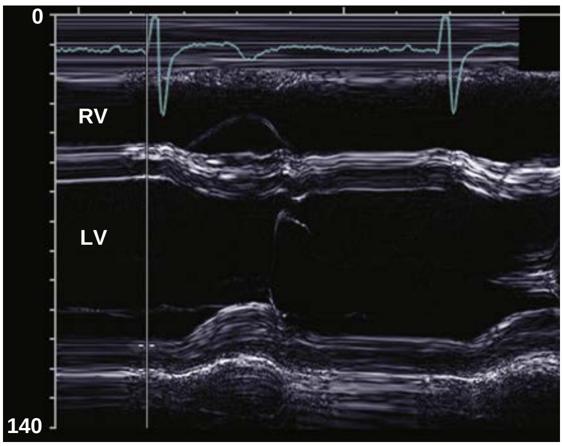

Fig. 2.7 LV M-mode tracing. 2D-guided M-mode recording of the LV at the mitral chordal level. End-diastolic measurements of wall thickness and cavity dimension are made at the onset of the QRS, as shown. End-systolic measurements are made at the maximum posterior motion of the septum (when septal motion is normal) or at minimal LV size. The rapid sampling rate with M-mode allows more accurate identification of the endocardial border, which is distinguished from chordae or trabeculations as being a continuous line in diastole, with the steepest slope during systole.

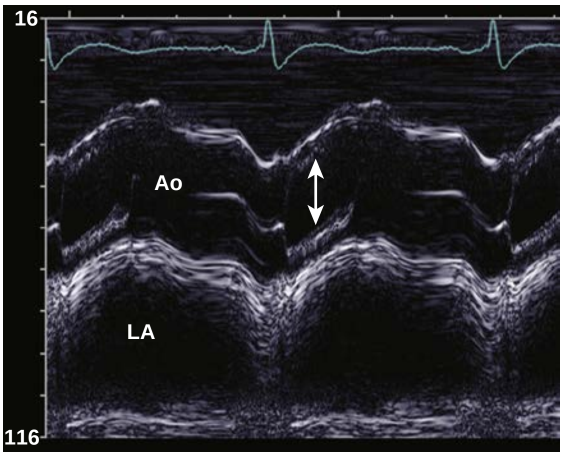

Fig. 2.8 Aortic valve M-mode tracing. 2D guided M-mode recording of the aortic valve *(Ao)* and LA allows measurement of aortic root dimension at end-diastole using a leading-edge to leading-edge approach; the aortic leaflet separation *(arrows);* and the left atrial maximum anterior–posterior dimension in early diastole. The fine fluttering of the aortic valve leaflets is normal.

❖ KEY POINTS

- Images are initially recorded at a depth that includes the descending thoracic aorta to detect pleural and pericardial effusions.
- Next, depth is reduced to the level of the posterior wall for assessment of the size and function of the base of the LV basal segments and the RV outflow tract.
- The aortic and mitral valves are examined with zoom mode sweeping through the valve planes from medial to lateral to assess valve anatomy and motion (Fig. 2.9).
- M-mode tracings of the mitral valve can aid in timing of leaflet motion, such as systolic anterior motion in hypertrophic cardiomyopathy or posterior buckling in mitral valve prolapse.
- Left atrium (LA) anterior–posterior dimension may underestimate LA enlargement; LA volume is measured from apical views.
- The aortic sinuses of Valsalva and sinotubular junction are visualized first from the standard window and then with the transducer moved up one or more interspaces to visualize the proximal and mid-ascending aorta (Fig. 2.10).
- Color Doppler of aortic and mitral valves is used to screen for valve regurgitation. If more than physiologic regurgitation is present, further evaluation is needed as discussed in Chapter 12.

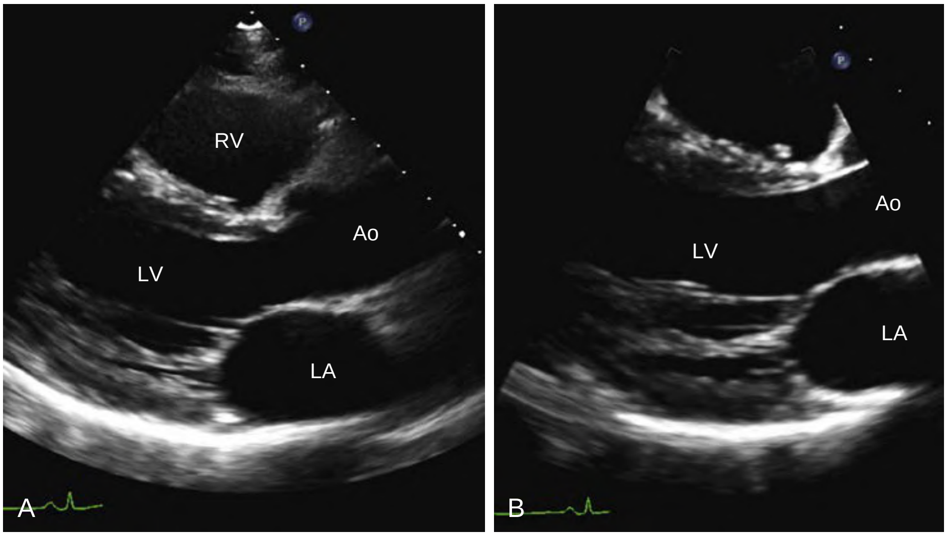

Fig. 2.9 Mitral valve imaging. (A) First the mitral valve is examined at a standard depth in the parasternal long-axis view. (B) Then zoom mode (ZOOM) is used to optimize visualization of the aortic and mitral valves. The image plane is angled slightly medial and lateral to encompass the medial and lateral aspects of the valve. Some normal thin mitral chords are well seen in this slightly laterally angulated view, extending from the mitral closure plane to the papillary muscle.

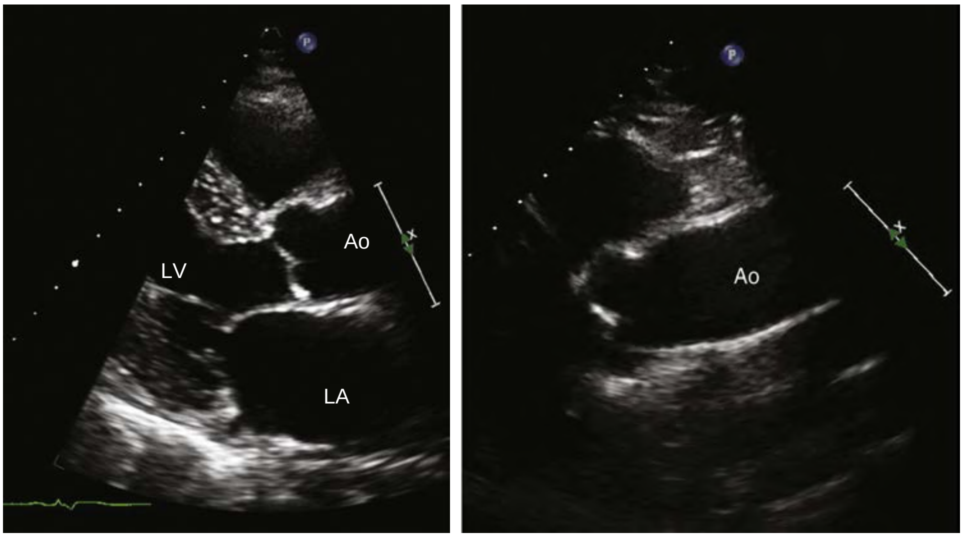

Fig. 2.10 Ascending aorta. The ascending aorta is visualized by moving the transducer up an interspace from the parasternal long-axis view. *Ao,* Aorta.

Right Ventricular Inflow View

- From the long-axis view, the image plane is angled medially to show the RV inflow view (Fig. 2.11) with:
  - Imaging of the right atrium (RA), tricuspid valve, and RV
  - Color Doppler evaluation of tricuspid regurgitation (vena contracta width)
  - CW Doppler recording of tricuspid regurgitant (TR) jet velocity
- Standard measurements include:
  - Maximum tricuspid regurgitant velocity (Fig. 2.12)

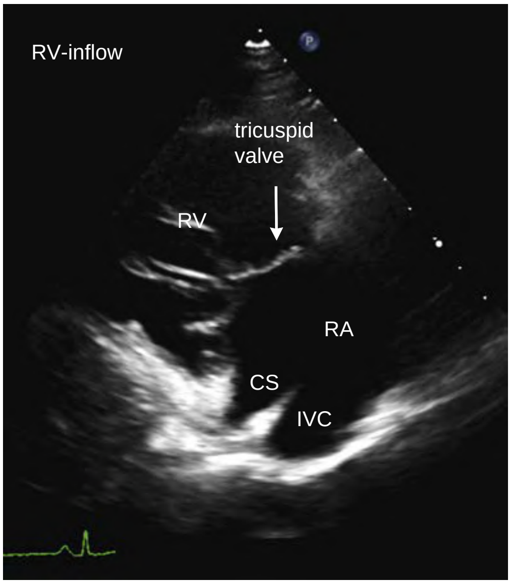

Fig. 2.11 **RV inflow view.** From the parasternal long-axis view, the image plane is angulated medially to visualize the RV inflow view with the RV, RA, coronary sinus *(CS),* inferior vena cava *(IVC),* and tricuspid valve.

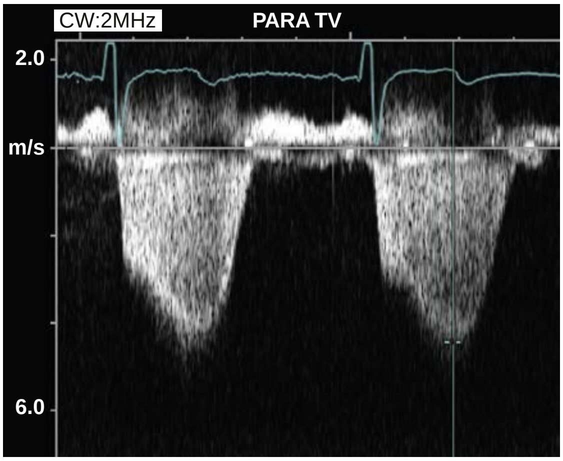

Fig. 2.12 **Tricuspid regurgitant (TR) jet velocity.** The tricuspid regurgitation jet is recorded with CW Doppler from both the parasternal RV inflow view and from the LV apex. Only the highest velocity is reported, in normal sinus rhythm, because the apparent lower velocity signal is due to a nonparallel intercept angle between the ultrasound beam and regurgitant jet. This example shows a high velocity jet consistent with severe pulmonary hypertension. The maximum velocity is measured at the edge of the dense "envelope" of flow, avoiding the faint signals due to gain and transit time effects.

❖ KEY POINTS

- Slide the transducer apically one interspace if views are not obtained from the standard window.
- Adjust depth to include the RA, RV, and tricuspid valve.
- The entrance of the coronary sinus and the inferior vena cava (IVC) into the RA are seen in this view.
- A small amount of tricuspid regurgitation on color Doppler is seen in most (>80%) normal individuals and sometimes is referred to as *physiologic.*
- The CW Doppler TR jet is recorded from multiple views; the highest velocity represents the most parallel intercept angle with flow and is used to estimate pulmonary pressure; lower velocity recordings are ignored.

Right Ventricular Outflow View

- From the long-axis view, the image plane is angled laterally to show the RV outflow view (Fig. 2.13) with:
  - Imaging of the RV outflow tract, pulmonic valve, and main pulmonary artery
  - Color Doppler evaluation of pulmonic regurgitation (Fig. 2.14)
  - Pulsed Doppler recording of pulmonary artery flow (Fig. 2.15)
- Standard measurements include:
  - Antegrade velocity in the pulmonary artery

❖ KEY POINTS

- Slide the transducer cephalad one interspace if views are not obtained from the standard window.
- Adjust depth to include the RV outflow tract, main pulmonary artery, and pulmonary artery bifurcation.
- The pulmonic valve often is difficult to visualize in adults, but a small amount of pulmonic regurgitation typically is present with a normally functioning valve.
- The pulsed Doppler recording of flow in the main pulmonary artery is helpful for assessment of pulmonary pressures and to exclude pulmonic stenosis or a patent ductus arteriosus.

Short-Axis View

- From the long-axis view, the image plane is rotated 90 degrees to show the short-axis plane with:
  - Imaging and color Doppler at the level of the aortic valve to evaluate the aortic, tricuspid, and pulmonic valves (Fig. 2.16)
  - 2D imaging and color Doppler evaluation of the interatrial septum; imaging at the level of the mitral valve for evaluation of mitral leaflet anatomy and motion and LV size and function (Fig. 2.17)
  - Imaging at the mid-papillary muscle level to evaluate global and regional LV size and function (Fig. 2.18)

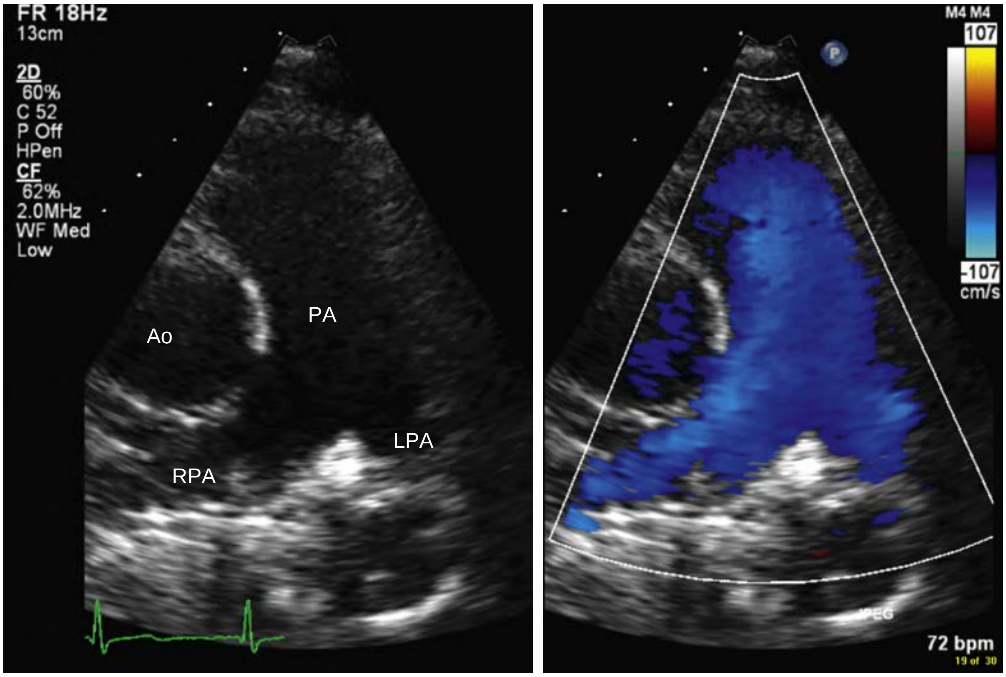

Fig. 2.13 **RV outflow view.** The 2D and color Doppler RV outflow view, obtained by angulating the transducer laterally from the parasternal long-axis view, shows the RV outflow tract, pulmonic valve, main pulmonary artery *(PA)*, and left and right branch pulmonary arteries *(LPA* and *RPA). Ao,* Aorta.

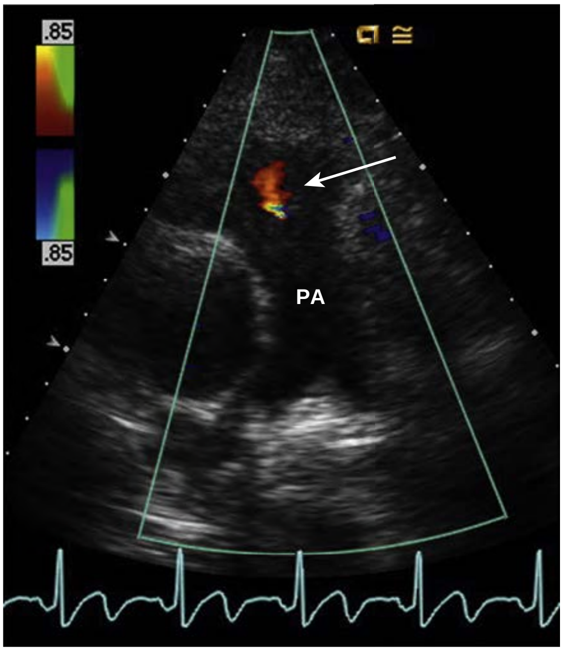

Fig. 2.14 **Color Doppler of pulmonic valve regurgitation.** Color Doppler in a RV outflow view showing a narrow jet of pulmonic regurgitation *(arrow)* in diastole. Mild pulmonic regurgitation is seen in about 80% of normal adults. *PA,* Pulmonary artery.

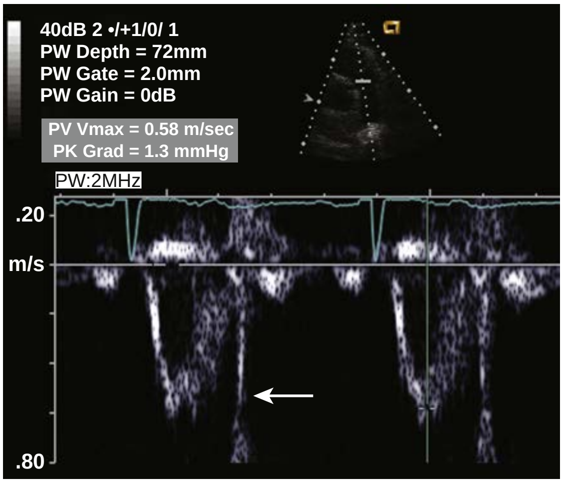

Fig. 2.15 **Pulsed Doppler recording of normal flow in the RV outflow tract.** The pulmonic valve closure click indicates that the sample volume is on the RV side of the valve. Normal flow shows a smooth velocity curve that peaks in mid-systole with a velocity less than 1 m/s.

- Standard measurements include:
  - M-mode or 2D measurements of the aorta, LA, and LV using the combination of long and short-axis view to ensure the dimensions are measured in the minor axis of each chamber or vessel (see Table 2.1)

❖ KEY POINTS

- The aortic and pulmonic valves normally are perpendicular to each other (when the aortic valve is seen in short axis, the pulmonic valve is seen in long axis).
- Zoom mode is used to identify the number of aortic valve leaflets, taking care to visualize the leaflets in systole.
- A bicuspid aortic valve is a common abnormality with a prevalence of about 1% of the total

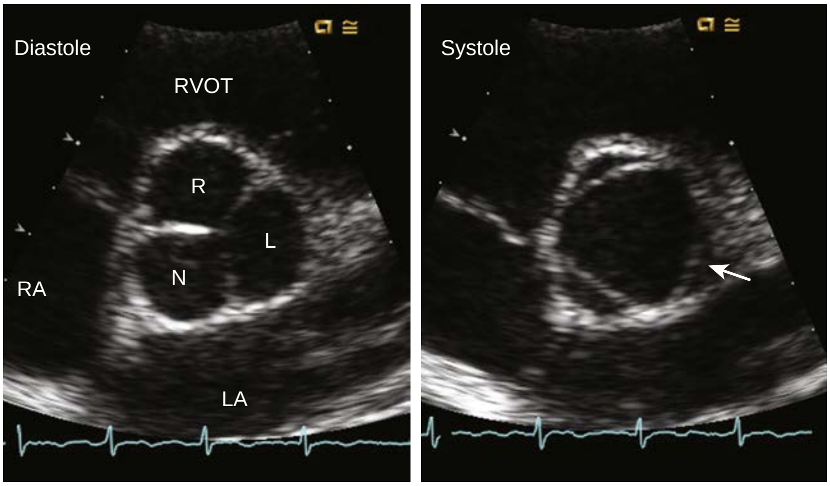

Fig. 2.16 Aortic valve imaging. Parasternal short-axis view of a normal trileaflet aortic valve in diastole *(left)* and in systole *(right)*. The normal positions of the right *(R)*, left *(L)*, and noncoronary *(N)* cusps are seen in diastole. In systole, the open left coronary cusp often is difficult to see *(arrow)*, because the leaflet edge is parallel to the ultrasound beam. However, the three commissures of the open valve are clearly visualized. *RVOT,* Right ventricular outflow tract.

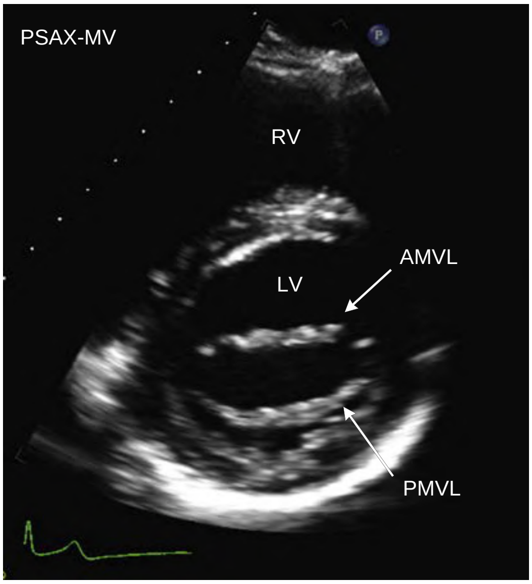

Fig. 2.17 Mitral valve imaging. Parasternal short-axis view of the left ventricle at the level of the mitral valve showing both anterior and posterior valve leaflets. *AMVL,* Anterior mitral valve leaflet; *PMVL,* posterior mitral valve leaflet; *PSAX-MV,* parasternal short-axis–mitral valve.

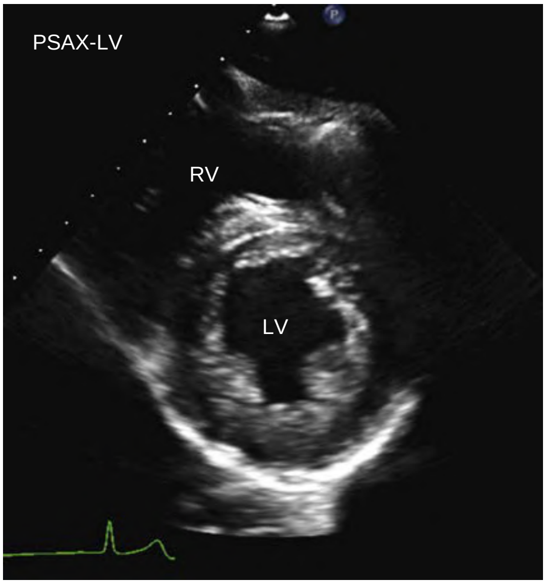

Fig. 2.18 LV short-axis view. Parasternal short-axis *(PSAX)* view of the LV at the papillary muscle level. The LV cavity should appear circular in this view, and an elliptical shape suggests an oblique intercept angle. This view sometimes requires the transducer be moved slightly apically from the short-axis view of the aortic valve, instead of just tilting the transducer toward the apex from a fixed position on the chest wall.

population and often is diagnosed on echocardiography requested for other indications.
- 3D imaging is useful for better definition of aortic or mitral valve anatomy in selected cases.
- The coronary artery ostia may be seen originating in expected positions from the right and left coronary sinuses.
- The atrial septum is seen in the short-axis view at the aortic valve level. Color flow imaging may help detect a patent foramen ovale but must be distinguished from normal flow in the RA (inflow from the superior and IVC and regurgitation across the tricuspid valve), all of which are adjacent to the atrial septum.
- Parasternal views of the LV at the papillary muscle level provide optimal endocardial definition and are used in conjunction with apical views for detection of regional wall motion abnormalities.

Step 7: Apical Window

Imaging Four-Chamber, Two-Chamber, and Long-Axis Views

- The apical window usually corresponds to the point of maximal impulse and is optimized with the patient in a steep left lateral position.

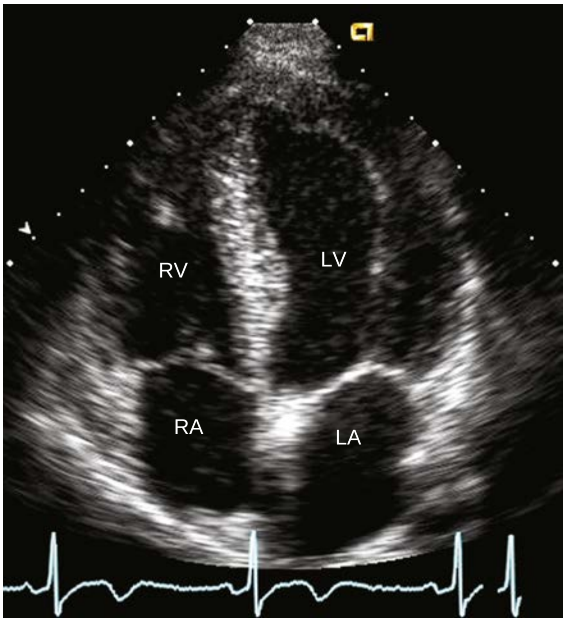

Fig. 2.19 Apical 4-chamber view. The transducer is correctly positioned over the LV apex as shown by the longer LV length than width and ellipsoid shape of the chamber. Foreshortening of this view results in a more spherical appearance of the LV. This older adult has both enlargement of atrium and some benign thickening (lipomatous hypertrophy) of the atrial septum. The loss of signal in the mid-segment of the atrial septum is an artifact, because the thin fossa ovalis is parallel to the ultrasound beam at this point resulting in echo "dropout."

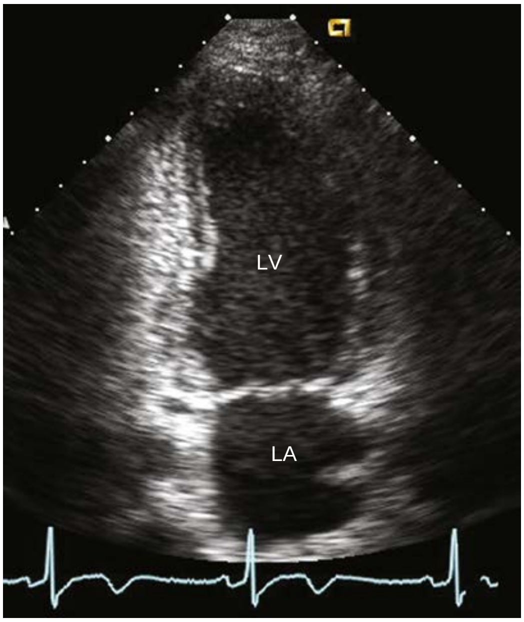

Fig. 2.20 Apical 2-chamber view. This view is obtained by rotating the transducer about 60° counterclockwise from the 4-chamber view.

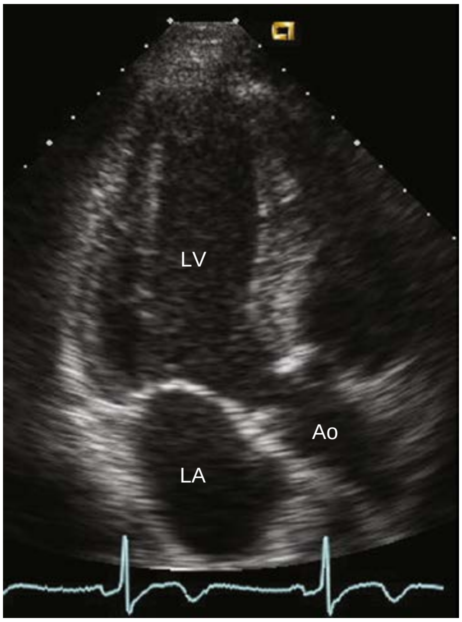

Fig. 2.21 Apical long-axis view. This view is obtained by rotating an additional 60° counterclockwise to obtain an image similar to the parasternal long-axis view. *Ao,* Aortic.

- Images are obtained in 4-chamber (Fig. 2.19), 2-chamber (Fig. 2.20), and long-axis (Fig. 2.21) views to evaluate:
  - 2D images for LV size, wall thickness, global and regional systolic function, and longitudinal strain measurements
  - 3D full volume imaging for measurement of ventricular volumes and ejection fraction
  - RV size, wall thickness, and systolic function
  - Anatomy and motion of the mitral and tricuspid valves
  - LA and RA size and coronary sinus anatomy
  - The amount of pericardial fluid, if present
- Standard measurements include:
  - 2D apical biplane ejection fraction (see Chapter 5)
  - Global longitudinal strain
  - 3D LV ejection fraction
  - Measurement of LA area or volume when clinically indicated (Fig. 2.22)
  - Tricuspid annular plane systolic excursion (TAPSE) and other quantitative measures of RV systolic function (see Chapter 6)

❖ KEY POINTS

- The three apical views are at approximately 60 degrees of rotation from each other; however, image planes are based on cardiac anatomy, not external reference points, so that slight adjustment of transducer position and angulation often is needed to optimize the image.
- Initial views are recorded at the maximum depth to see all the cardiac chambers and surrounding pericardium.

- Evaluation of the LV and RV are based on images with the depth adjusted to just beyond the valve annular plane. The RV is best visualized using zoom mode (Fig. 2.23).
- Left-sided echo contrast should be used to improve identification of LV endocardial borders when needed.
- Visual estimates of LV ejection fraction are appropriate only if quantitative measurements are not possible.
- From the 4-chamber view, the image plane is angled anteriorly to visualize the aortic valve (sometimes called the *5-chamber view*); this view is useful for Doppler recordings, but image quality is suboptimal at the depth of the aortic valve from the apical window (Fig. 2.24).
- The image plane is angled posteriorly to visualize the length of the coronary sinus and its entrance into the RA (Fig. 2.25).
- The LA appendage is not well visualized on transthoracic imaging, and the sensitivity for detection of LA thrombus is low. Transesophageal imaging is needed when atrial thrombus is suspected.
- The descending thoracic aorta is seen in cross section behind the left atrium in the long-axis view and in a longitudinal plane from the 2-chamber view with lateral angulation.

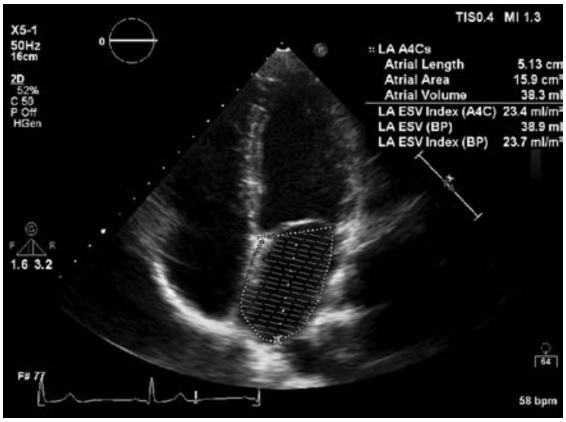

Fig. 2.22 **Left atrial volume measurement.** Left ventricle volume is measured in the apical 4-chamber view by tracing the inner edge of the atrial border at end-systole. At the mitral annulus, a straight line from leaflet insertion to leaflet insertion is used for this calculation. The area is also traced in the 2-chamber view for a biplane volume calculation.

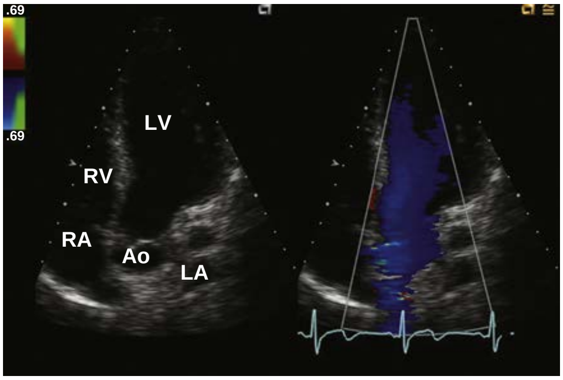

Fig. 2.24 **Anteriorly angulated apical 4-chamber view (or 5-chamber view).** Anterior angulation from the 4-chamber view allows visualization of the LV outflow tract and an oblique view of the aortic *(Ao)* valve. Laminar flow in the LV outflow tract is demonstrated with color Doppler.

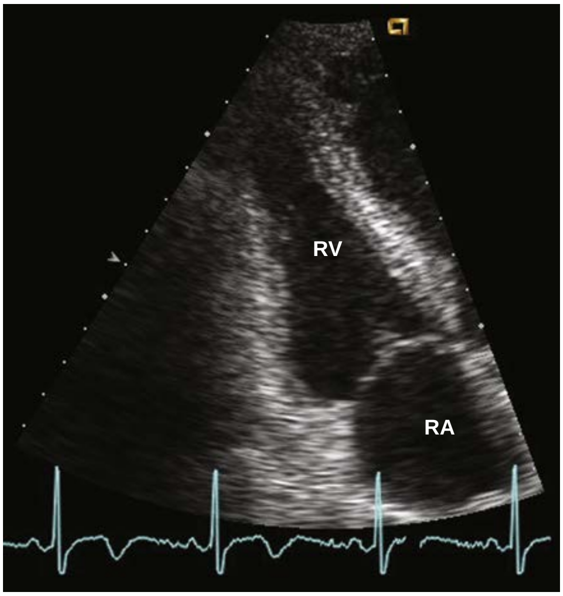

Fig. 2.23 **Apical view focusing on the RV.** RV size and function are best estimated by centering the RV in the image plane and adjusting depth and zoom appropriately.

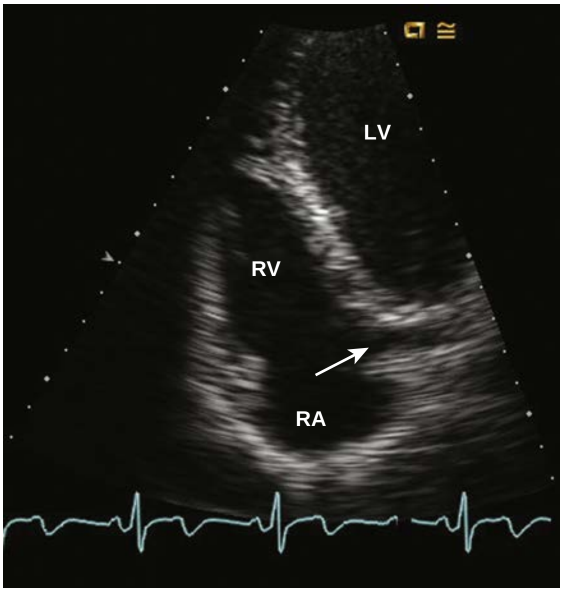

Fig. 2.25 **Coronary sinus.** The entrance of the coronary sinus *(arrow)* into the RA is visualized by posterior angulation from the apical 4-chamber view.

- With active adjustment of the imaging plane, pacemaker leads can be "tracked" visually at the entry into the heart along the course of the lead (RA, RV, coronary sinus).

Doppler Data

- The apical window provides an intercept angle that is relatively parallel to flow for the aortic, mitral, and tricuspid valves. Standard data recording includes:
  - Pulsed Doppler recordings of transmitral flow, pulmonary vein inflow, and LV outflow (Fig. 2.26)
  - Color Doppler evaluation of mitral and tricuspid regurgitation
  - CW Doppler recordings of mitral, tricuspid, and aortic antegrade flow and regurgitation (Fig. 2.27)
- Standard measurements include:
  - Pulsed Doppler antegrade mitral early (E) diastolic filling and atrial (A) filling velocities
  - Pulsed Doppler LV outflow and CW Doppler aortic flow velocities
  - Maximum velocity of the TR jet
  - Additional measurements as clinically indicated (see specific chapters for each clinical condition)

❖ KEY POINTS

- Transmitral and pulmonary venous inflow velocities are helpful for evaluation of LV diastolic dysfunction (see Chapter 7). Pulsed Doppler tissue velocities of the myocardial septal or lateral wall also are helpful for evaluation of diastolic function.
- There is only a small increase in velocity from the LV outflow tract to the ascending aorta in normal individuals (see Chapter 11).

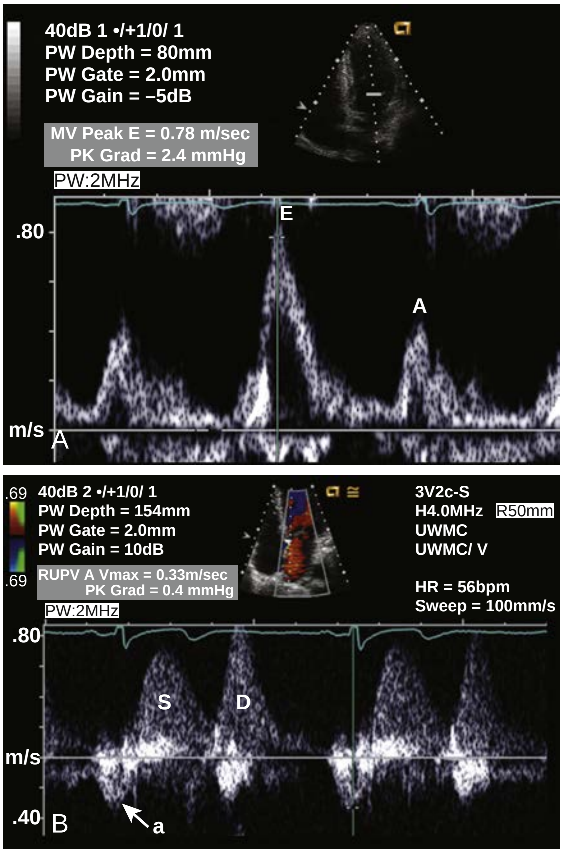

Fig. 2.26 **LV diastolic function.** (A) LV inflow is recorded using pulsed Doppler with the sample volume positioned at the mitral leaflet tips in diastole. The typical early *(E)* diastolic filling velocity and atrial *(A)* velocity are seen. (B) Left atrial inflow is recorded with the pulsed Doppler sample volume in the right superior pulmonary vein in an apical 4-chamber view. The normal pattern of systolic *(S)* and diastolic *(D)* inflow with a small atrial *(a)* flow reversal are seen.

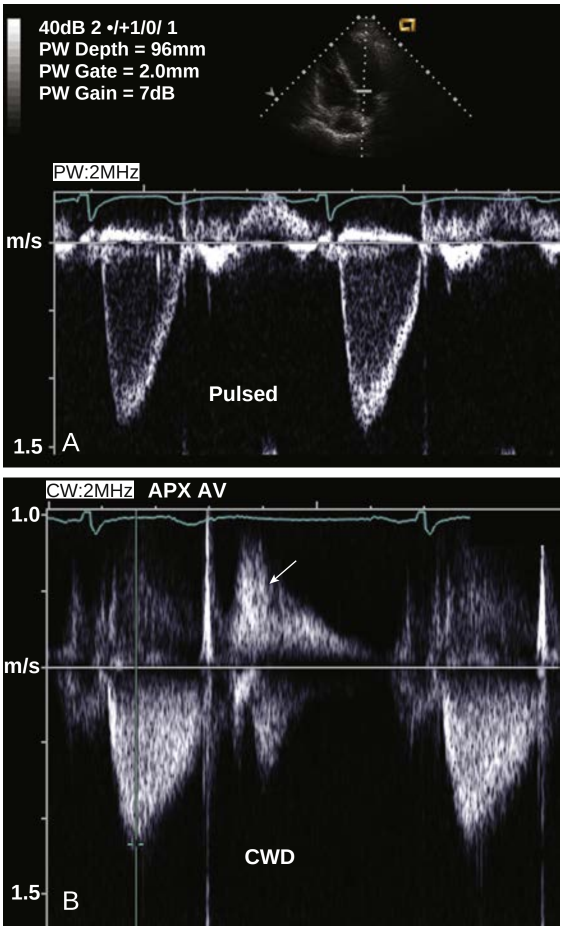

Fig. 2.27 **LV outflow.** (A) LV outflow is recorded with the Doppler sample volume on the LV side of the aortic valve either in an anteriorly angulated 4-chamber view or in an apical long-axis view. The normal smooth "envelope" of flow with dense signals along the outer edge and few velocity signals within the curve are seen. Again, the baseline and scale are adjusted to prevent aliasing and allow accurate measurements. (B) Aortic flow velocity is recorded from an apical approach using CW Doppler (CWD). This velocity tracing includes signals from the entire length of the ultrasound beam so that the velocity curve is filled in by lower velocities proximal to the valve. The aortic closing click is seen. In diastole, the relatively broad CW beam intersects the LV inflow curve *(arrow)*.

- The CW Doppler recordings of aortic, mitral, and tricuspid regurgitation provide data on the severity of regurgitation (based on the density of the signal) and the transvalvular hemodynamics (based on the shape and density of the time velocity curve).
- Color flow Doppler from the apical approach is helpful for evaluation of jet direction and for visualization of proximal jet geometry (vena contracta) and the proximal isovelocity surface area (PISA).
- Apical color Doppler is less helpful for aortic regurgitation, because beam width is greater at the depth of the aortic valve than at the mitral valve.

Step 8: Subcostal Window

- The subcostal window provides:
  - An alternate acoustic window for evaluation of LV and RV systolic function (Fig. 2.28)
  - An optimal angle to evaluate the interatrial septum
  - Estimation of RA pressure based on the size and respiratory variation in the IVC (Fig. 2.29)
  - Pulsed Doppler evaluation of hepatic vein flow (right atrial inflow) and proximal abdominal aortic flow, when clinically indicated (Fig. 2.30)
  - An alternate acoustic window for evaluation of pericardial effusion and detection of abdominal ascites

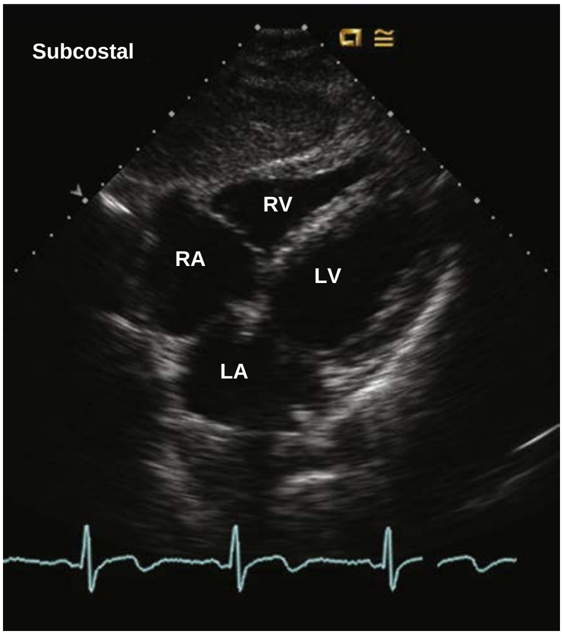

Fig. 2.28 Subcostal 4-chamber view. This view is useful for evaluation of RV and LV function. This view also is best for evaluation of the atrial septum because the ultrasound beam is perpendicular to the septum from this transducer position.

❖ KEY POINTS

- Estimation of RA pressure is a standard part of the examination used to calculate pulmonary systolic pressure.
- Atrial septal defects often are best visualized on imaging and with color Doppler using a low Nyquist setting from the subcostal window.
- Hepatic vein flow patterns are helpful for detection of severe tricuspid regurgitation and for evaluation of pericardial disease.
- Descending aortic holodiastolic flow reversal is seen with severe aortic regurgitation; persistent holodiastolic antegrade flow is seen with aortic coarctation.

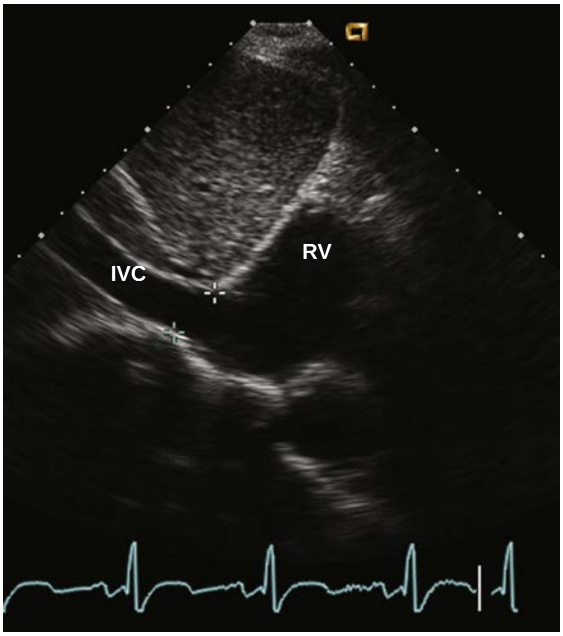

Fig. 2.29 Inferior vena cava *(IVC).* The IVC is examined from the subcostal view with the size and respiratory variation used to estimate right atrial pressure, as discussed in Chapter 6.

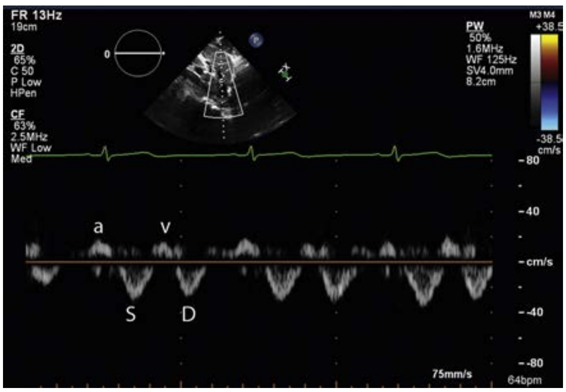

Fig. 2.30 Hepatic vein flow. Pulsed Doppler velocities are recorded from the subcostal view to evaluate right atrial filling when tricuspid regurgitation or pericardial disease is of concern. *a,* Atrial; *D,* diastolic wave; *S,* systolic wave; *v,* ventricular.

Step 9: Suprasternal Window

- The suprasternal window is a standard part of the examination of patients with diseases of the aortic valve or aorta.
- The suprasternal window provides:
  - Images of the aortic arch and proximal descending thoracic aorta (Fig. 2.31)
  - Pulsed and CW Doppler evaluation of descending aortic flow, when clinically indicated (Fig. 2.32)

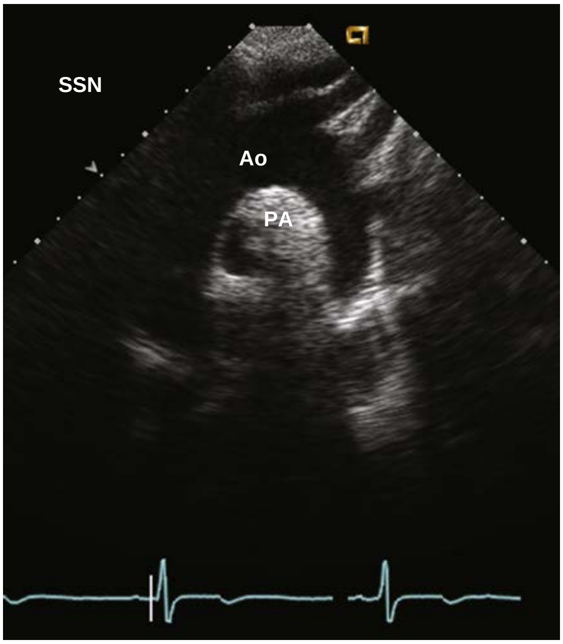

Fig. 2.31 Suprasternal notch *(SSN)* view. This view shows the ascending aorta *(Ao),* arch, and descending thoracic aorta. A small segment of the right pulmonary artery *(PA)* is seen in cross section.

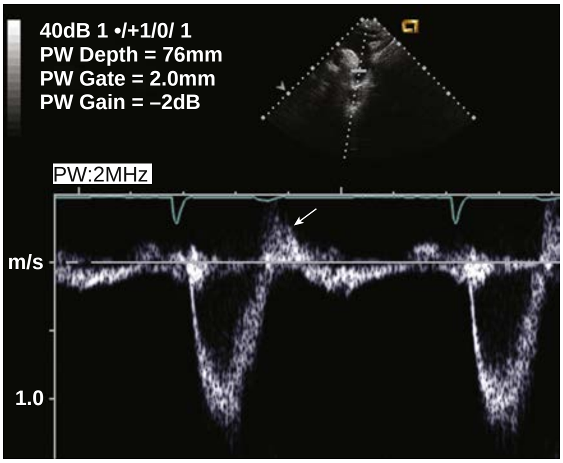

Fig. 2.32 Normal pattern of flow in the descending thoracic aorta. There is antegrade flow in systole, brief diastolic flow reversal as a result of aortic recoil and coronary blood flow, a small amount of antegrade flow in mid-diastole, and slight reversal just before the next cardiac cycle.

  - A parallel intercept angle with the aortic velocity in some patients with native or prosthetic aortic valve disease

❖ KEY POINTS

- Aortic disease, such as aortic dissection, may be visualized from this window.
- An increased systolic velocity with persistent antegrade flow (“runoff”) in diastole is seen with an aortic coarctation.
- Holodiastolic flow reversal in the descending aorta suggests significant aortic valve regurgitation.

Step 10: The Echo Report

- The echo report consists of four sections:
  - Clinical Data
  - Measurements
  - Echo Findings
  - Conclusions (with recommendations)

❖ KEY POINTS

- The Clinical Data section includes the reason for the study, pertinent history and physical examination findings, cardiac medications, and blood pressure.
- Standard measurements are indicated in the example (Table 2.3) with additional measurements as clinically indicated.
- The Echo Findings section documents what views and flow were recorded and describes any abnormal and key normal findings.
- The Conclusions section indicates the major diagnosis, associated findings, and pertinent negative findings (depending on the indication for the study).
- Image stills taken from the echo study addressing important findings may be incorporated into the final report.
- When clinically appropriate, specific recommendations are made. These include:
  - The clinical significance of the findings
  - Recommendations for cardiology evaluation and periodic follow-up
- Serious unexpected findings are communicated promptly directly to the referring physician.
- When data are not definitive, the findings are described along with a differential diagnosis to explain these findings.
- Additional diagnostic approaches are recommended as appropriate.

TABLE 2.3 Sample Echo Report

Name________________________ Date of Study_____________________
Age: 45 years Sex: M
Indication: Systolic murmur on auscultation
Cardiac medications: None
Clinical history: Chest pain on exertion, systolic murmur, no prior cardiac procedures
Blood pressure: 118/68 mm Hg Heart rate: 60 bpm Rhythm: NSR
Sonographer: BKS Image quality: Excellent

Measurements

	Dimensions (cm)	Normal Values (Men)
LV chamber		
End-systole	3.2	2.1–4.0 cm
End-diastole	5.4	4.2–5.9 cm
Wall thickness (diastole)	0.8	0.6–1.0 cm
2D ejection fraction	65%	≥55 %
3D ejection fraction	64%	≥55 %
Left atrium	3.6	3.0–4.0 cm
Aortic sinus	2.9	<4.0 (<2.1 cm/m^2)

Doppler Flows

	Regurgitation	Velocity (m/s)	
Aortic valve	None	LV outflow tract Aorta	1.0 1.4
Mitral valve	Trace	E A	1.0 0.4
Pulmonary valve	Trace		
Tricuspid valve	Mild	TR jet	2.3
			Normal Values
RA pressure estimate (mm Hg)		5	0–5
PA pressure estimate (mm Hg)		26	20–30

Findings

Left ventricle	Wall thickness, internal dimension and systolic function are normal with an estimated ejection fraction of 65%. There are no resting regional wall motion abnormalities.
Left atrium	Size is normal.
Aortic valve	Trileaflet with normal systolic opening and no regurgitation.
Aortic root	Normal dimensions with normal contours of the sinuses of Valsalva.
Mitral valve	Normal anatomy and motion with no stenosis and only physiologic regurgitation.
PA pressures	Estimated pulmonary systolic pressure is normal at 21-26 mm Hg, based on the velocity in the TR jet and the size and respiratory variation of the inferior vena cava.
Right heart	Right ventricular size and systolic function are normal. Tricuspid and pulmonic valves show normal anatomy and Doppler flows. Right atrial size is normal.
Pericardium	No effusion.

Conclusions

1. Normal valve anatomy and function.
2. Normal left ventricle with an estimated ejection fraction of 65%.
3. Normal pulmonary pressures and right heart.

Given these findings, the murmur appreciated on physical examination most likely is a benign flow murmur. Although resting left ventricular regional function is normal, coronary disease cannot be excluded on a resting study. If there is concern that chest pain may be due to coronary disease, a stress study should be considered.

Signed: __________________MD

THE ECHO EXAM

A Complete Echo Exam = Core Elements + Additional Components

Diagnostic TTE: Core Elements

Modality	Window	View/Signal	Basic Measurements
Clinical data		Indication for echo Key history and PE findings Previous cardiac imaging data	Blood pressure at time of Echo Exam
2D imaging	Parasternal	Long axis Short-axis aortic valve Short-axis mitral valve Short-axis LV (papillary muscle level) RV inflow	LV end-diastole and end-systole dimensions LV end-diastole wall thickness Aortic end-diastole sinus dimension LA dimension
	Apical	4-chamber Anteriorly angulated 4-chamber 2-chamber Long axis	Visual estimate or biplane ejection fraction
	Subcostal	4-chamber IVC with respiration Proximal abdominal aorta	
	Suprasternal	Aortic arch	
Pulsed Doppler	Parasternal	PA flow	PA velocity
	Apical	LV inflow LV outflow	E velocity A velocity LV outflow velocity
Color flow	Parasternal	Long axis: Aortic and mitral valves Short axis: Aortic and pulmonic valves RV inflow: Tricuspid valve	Color flow to identify regurgitation of all four valves. If more than mild, measure vena contracta
	Apical	4-chamber: Mitral and tricuspid valves Long axis: Aortic and mitral valves	
CW Doppler	Parasternal	Tricuspid valve Pulmonic valve	TR-jet velocity
	Apical	Aortic valve Mitral valve Tricuspid valve	Aortic velocity TR jet (pulmonary pressures)

A-velocity, Late diastolic ventricular filling velocity with atrial contraction; *E-velocity,* early-diastolic peak velocity; *IVC,* Inferior vena cava; *PA,* pulmonary artery; *PE,* pericardial effusion; *TR,* tricuspid regurgitation.

Diagnostic TTE: Additional Components	
Abnormality on Core Elements	**Additional Echo Exam Components (Chapter)**
Reason for Echo	**Additional Components to Address Specific Clinical Question***
Left Ventricle	
Decreased ejection fraction	See Systolic Function (6)
Abnormal LV filling velocities	See Diastolic Function (7)
Regional wall motion abnormality	See Ischemic Heart Disease (8)
Increased wall thickness	See Hypertrophic Cardiomyopathy, Restrictive Cardiomyopathy and Hypertensive Heart Disease (9)
Valves	
Imaging evidence for stenosis or an increased antegrade transvalvular velocity	See Valve Stenosis (11)
Regurgitation greater than mild on color flow imaging or CW Doppler	See Valve Regurgitation (12)
Prosthetic valve	See Prosthetic Valves (13)
Valve mass or suspected endocarditis	See Endocarditis and Masses (14,15)
Right Heart	
Enlarged RV	See Pulmonary Heart Disease and Congenital Heart Disease (9,17)
Elevated TR-jet velocity	See Pulmonary Pressures (6)
Pericardium	
Pericardial effusion	See Pericardial Effusion (10)
Pericardial thickening	See Constrictive Pericarditis (10)
Great Vessels	
Enlarged aorta	See Aortic Disease (16)

TR, Tricuspid regurgitation.

*The echo exam should always include additional components to address the clinical indication. For example, if the indication is "heart failure," additional components to evaluate systolic and diastolic function are needed even if the core elements do not show obvious abnormalities. If the indication is "cardiac source of embolus," the additional components for that diagnosis are needed.

Principles of Doppler Quantitation		
Method	**Assumptions/Characteristics**	**Examples of Clinical Applications**
Volume flow Stroke volume (SV) = CSA × VTI	• Laminar flow • Flat flow profile • Cross-sectional area (CSA) and velocity time integral (VTI) measured at same site	• Cardiac output • Continuity equation for valve area • Regurgitant volume calculations • Intracardiac shunts, pulmonary to systemic flow ratio
Velocity–pressure relationship $\Delta P = 4v^2$	• Flow limiting orifice • CW Doppler velocity (v) signal recorded parallel to flow	• Stenotic valve gradients • Calculation of pulmonary pressures • LV dP/dt
Spatial flow patterns	• Proximal flow convergence region • Narrow flow stream in orifice (vena contracta) • Downstream flow disturbance	• Detection of valve regurgitation and intracardiac shunts • Level of obstruction • Quantitation of regurgitant severity