Appendix A
Basic General Formulas in Echocardiography

The formulas below are listed to provide an understanding of basic echocardiographic calculations. They are included in the echocardiographic machine software, so the operator does not need to actually use them but an understanding of the principles involved is necessary to be aware of the indications and limitations of their use.

STROKE VOLUME (SV)[1]

$$\mathrm{SV} = \pi\left(\frac{\mathrm{LVOTd}^2}{2}\right) \times \mathrm{VTI}$$

The stroke volume is calculated as the product of the velocity time integral (VTI) of the flow signal obtained with pulsed wave (PW) Doppler at a given site and the cross-sectional area (CSA) of the same site obtained from the diameter measured by in mid-systole two-dimensional echocardiography. Usually, the CSA is measured at left ventricular outflow tract (LVOT) site in parasternal long-axis view and the Doppler interrogation is performed in the LVOT in apical 5-chamber view. The calculations are performed by the built-in software of the echocardiographic machine.

DOPPLER SHIFT[1]

$$v = \frac{c}{2f_0} \times \frac{f_\mathrm{d}}{\cos\theta}$$

where f_0 = emitted frequency, f_d = Doppler shift, c = ultrasound velocity, v = blood flow velocity, θ = angle between the ultrasound beam and the direction of blood flow.

The difference (f_d) between the emitted US frequency and the frequency of the US reflected by the red blood cells is used to obtain the blood flow velocity. Though angle correction is possible, Doppler measurements are not considered reliable at θ>20°.

CONTINUITY EQUATION[2]

This approach assumes that flow at two cardiac sites must be the same in the absence of regurgitation or shunt. Accordingly, the measurable flow at one site, using CSA and VTI can be used to calculate the effective area at a different site where only the VTI is measurable. The continuity equation can be used for any valve, but most frequently the flow at LVOT level is used to calculate the effective area of a stenotic aortic valve:

$$\text{AVA} = \frac{\pi \times (\text{LVOT}/2)^2 \times V_1}{V_2}$$

where V_1 = subvalvular (LVOT) velocity, V_2 = valvular (aortic) velocity.

The use of LVOT and aortic VTIs rather than peak velocities is theoretically more accurate, but peak velocities are frequently used with good results. The software of most machines will generate results by both methods.

THE SIMPLIFIED BERNOULLI EQUATION[1]

Flow velocities measured by Doppler proximally to- and at the site of an obstruction are used to calculate the pressure gradient across the obstruction. The gradients are part of the evaluation of stenotic valves. A simplified formula, which takes into account convective acceleration only and ignores small drops related to friction, is used for clinical echocardiographic applications.

$$\Delta P(\text{mmHg}) = 4(V_2^2 - V_1^2)$$

where V_2 = distal velocity (m/s), V_1 = proximal velocity (m/s). V_1 can be ignored at values < 1 m/s.

PRESSURE HALF TIME

$P_{½}T$ represents the time needed for the pressure gradient of the flow across a relatively stenotic orifice to decrease to half of its initial value. It is determined directly by the echocardiography machine from the tracing of the deceleration slope, starting from its beginning. An empirically derived constant relates the $P_{½}T$ of the diastolic mitral flow to effective area of the valve in mitral stenosis.

$$MVA\,(cm^2) = \frac{220}{P_{1/2}T(ms)}$$

where MVA = mitral valve area.

The concept of $P_{½}T$ is also used as a measure of deceleration slope of the aortic diastolic flow. Short $P_{½}T$ (<200 ms) is associated with severe aortic regurgitation.

PEAK RIGHT VENTRICULAR SYSTOLIC PRESSURE ESTIMATION

Based on Bernoulli equation, in the presence of tricuspid regurgitation, the peak right ventricular systolic pressure (RVSP) can be calculated as

$$RVSP\,(mmHg) = 4(V_{TR\,max})^2 + \text{estimated right atrial pressure (RAP).}$$

RAP can be estimated using the degree of inspiratory changes of the interior vena cava (IVC) (Table A.1).

In the absence of pulmonary valve stenosis the right ventricular systolic pressure (RVSP) equals the pulmonary artery pressure and is widely used to assess pulmonary hypertension. However, the method may not be reliable in the presence of most severe TR.

NONINVASIVE DETERMINATION OF LEFT VENTRICULAR END-DIASTOLIC PRESSURE USING MITRAL FLOW AND TISSUE DOPPLER[3]

$$PCWP = 1.24\left[\frac{E}{E'}\right] + 1.9$$

where E' is measured at the lateral aspect of the annulus (see Sect. 3.3).

PCWP: pulmonary capillary wedged pressure (used as surrogate for LVEDP)

TABLE A.1. Use of degree of IVC inspiratory collapse to estimate the RA pressure.

IVC collapse in inspiration (%)	Estimated RA pressure (mmHg)
>50	0–10
25–50	10–15
<25	15–20

RA right atrium

References

1. Rimington L, Angelsen B. *Doppler Ultrasound in Cardiology: Physical Principles and Clinical Applications*. 2nd ed. 1985, Philadelphia: Lea & Febiger; Beckenham: Quest [distributor]. xiii, 331pp.
2. Otto CM, Pearlman AS, Gardner CL, Kraft CD, Fujioka MC. Simplification of the Doppler continuity equation for calculating stenotic aortic valve area. J Am Soc Echocardiogr 1988;1:155–157.
3. Nagueh SF, Middleton KJ, Kopelen HA, Zoghbi WA, Quinones MA. Doppler tissue imaging: a noninvasive technique for evaluation of left ventricular relaxation and estimation of filling pressures. J Am Coll Cardiol 1997;30:1527–1533.

Appendix B
Quantitative Assessment of Left Ventricular Systolic Function

Qualitative assessment of the left ventricular (LV) contractility by an experienced echocardiographer is generally satisfactory for most usual clinical scenarios. Quantification of systolic function using ejection fraction may be required in follow-up studies or if needed to decide whether the patient qualifies for a given therapy or to be included in a trial. Cardiac output may be used for hemodynamic monitoring in an intensive care unit (ICU) setting. Other indexes, such as the myocardial performance index or the estimation of d*p*/d*t*, though theoretically attractive, are not of widespread use in clinical practice.

LEFT VENTRICULAR EJECTION FRACTION (LVEF)

Defined as:

- LVEF = (EDV − ESV)/EDV, where EDV = end-diastolic volume and ESV = end-systolic volume

Normal values and accepted values for decreased ejection fraction:[1]

- Normal: ≥55%
- Mildly ↓ : 45%–54%
- Moderately ↓ : 30%–44%
- Severely ↓ : <30%

The use of either M-mode or two-dimensional linear dimensions (end-diastolic and end-systolic diameters) of LV to calculate left ventricular ejection fraction is reasonable in the absence of regional wall motion abnormalities but is still subjected to errors due to geometrical assumptions about the shape of the LV.

Accordingly, the use of these methods is discouraged and the currently recommended method of choice is the biplane method of disks (modified Simpson's method), where the LV cavity is traced at end-systole and end-diastole in apical 4- and 2-chamber views (Fig. B.1) and the machine built-in software provides the calculated LVEF.[1] This method is not based on geometrical assumptions but treats the LV cavity as a stack of elliptical disks. It requires good endocardial-blood interface demarcation, so it is not always practical.

CARDIAC OUTPUT (CO)

Defined as:

- SV × HR where SV = EDV – ESV. Cardiac output is generally indexed to body surface area (BSA) to obtain the cardiac index (CI)

Normal values:

- CI: 2.5–4.2 L/min/m^2

Allowing for some geometrical and hemodynamic assumptions, the stroke volume (see also Appendix A) is calculated as the product of the velocity time integral of the flow signal obtained with PW Doppler at a given site and the cross-sectional area of the same site obtained from the diameter measured by two-dimensional echocardiography (Fig. B.2).

MYOCARDIAL PERFORMANCE (TEI) INDEX

This measurement combines systolic and diastolic assessment in a dimensionless index of global LV performance. PW Doppler in the

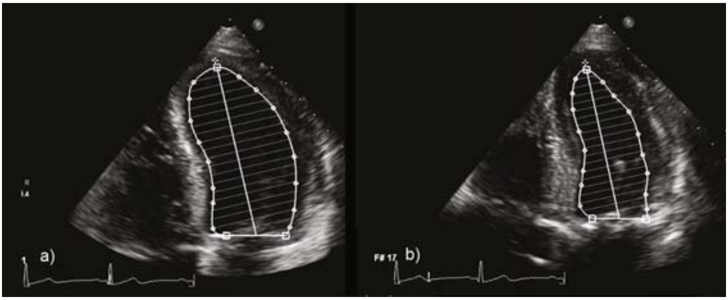

FIG. B.1: Traced LV cavity area in apical 4-chamber view for volumes and ejection fraction calculations by the echocardiographic machine incorporated software, using Simpson's method. a): end-diastolic frame. b): end-systolic frame.

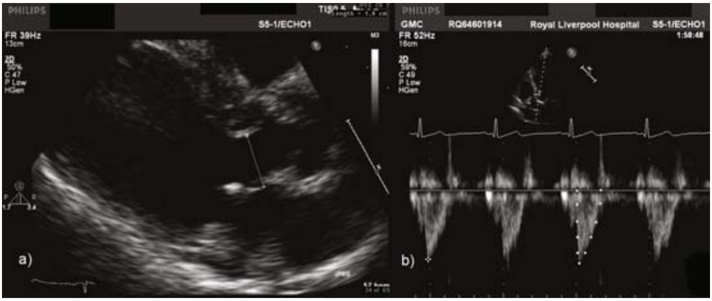

FIG. B.2: Two-dimensional and Doppler measurements for cardiac output.
a): LVOT diameter is measured in mid-systole in parasternal long-axis view between the proximal base of the septum and the anterior mitral leaflet (white thin line).
b): LVOT velocity is traced (white dots) in apical-5-chamber view using PW Doppler, with the volume sample placed at above 1.5 cm below the valve, to match the location of the 2D measurement.
LVOT: left ventricular outflow tract

apical 4-chamber view is used to obtain LV isovolumic contraction and (IVCT) relaxation (IVRT) time and aortic ejection time.

Defined as:
- Tei index = (IVCT + IVRT)/ET

Normal values:
- <0.4

REMODELING AND REVERSE REMODELING

Severe LV systolic dysfunction is frequently accompanied by remodeling, defined as increase in ventricular diastolic and systolic volumes, a more spherical shape, with a ratio >0.5 between the short and long axis of the LV and mitral valve (MV) apparatus distortion with apical tethering of the leaflets.

A reduction of ≥15% in the end-systolic volume (ESV) which can occur as result of therapy represents reverse remodeling.

LV d*p*/dt

The rise in the intraventricular pressure during preejection is an index of myocardial contractility, which, theoretically, is less afterload dependent. Generally measured during left heart catheterization, it can be calculated with Doppler echocardiography as well, provided that a good mitral regurgitation (MR) signal is obtained.

Using a sweep speed of 100 mm/s to improve measurements accuracy, the points of 1 and 3 m/s velocities (corresponding to a rise in pressure from 4 to 36 mmHg) are marked on the CW Doppler signal of MR in apical 4-chamber view and the time (t) between the two is measured.

LV dp/dt is calculated as

- dp/dt= 32/ Δt

Diagnostic values:

- Normal contractility: >1,200 mmHg/s

References

1. Lang RM, Bierig M, Devereux RB, et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 2005;18:1440–1463.

Appendix C
Echocardiographic Assessment and Reporting of Left Ventricular Diastolic function

The echocardiographic assessment of diastolic dysfunction is similar to that of the filling status as detailed in Sect. 3.3. The difference is that the former is presumed to reflect the way in which the left ventricular (LV) copes with diastolic filling under steady, normovolemic conditions, while the latter is a hemodynamic assessment of filling status at the time of hemodynamic instability. If in doubt, the finding of an enlarged left atrium supports a long-standing diastolic dysfunction rather than an acute condition (Table C.1 Fig. C.1).

TABLE C.1. Echocardiographic findings in diastolic dysfunction.

		Diastolic Dysfunction		
	Normal DF	Mild (Grade 1)[a]	Moderate (Grade 2)[b]	Severe (Grade 3)[b]
E/A	>1	<1	≥1	>>1
E′	≥8 cm/s	<8 cm/s	<8 cm/s	<8 cm/s
E/E′	<8–10		>10–15	>15
Echocardiographic pattern	Normal	Abnormal relaxation	Pseudonormal	Restrictive
<u>Hemodynamic significance</u>				
• Relaxation	Normal	↓	↓	↓
• Ventricular compliance	Normal	Normal	↓	↓↓
• Filling pressures	Normal	Normal	↑	↑↑

[a]May be normal for age as isolated finding in an elderly subject
[b]PW Doppler assessment not reliable with severe MR

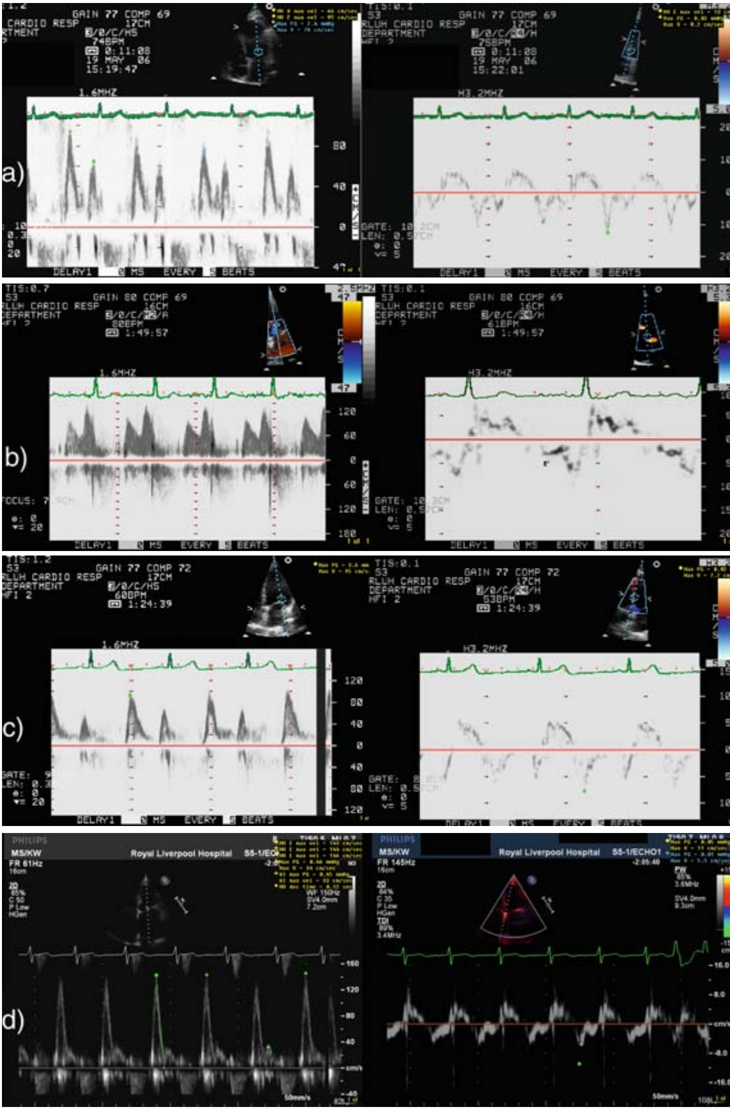

FIG. C.1. Flow and tissue Doppler imaging in the assessment of diastolic function. **a** Normal subject: E/A = 1.43, E' = 13 cm/s, E/E' = 7.3. **b** Elderly patient with mild (grade 1) diastolic dysfunction: E/A = 0.8, E' = 3. **c** Hypertensive patient with exertional dyspnea, normal coronary arteries, and LVEDP = 17 mm at catheterization. Echocardiography shows moderate (grade 2) diastolic dysfunction consistent with elevated diastolic pressures: E = 95 cm/s, E' = 7.7 cm/s, E/E' = 12. **d** Patient with severely decreased systolic function and dyspnea at rest. Echocardiography shows severe, restrictive (grade 3) diastolic dysfunction: E/A = 4.6, DT = 120 ms, E' = 5.5, E/E' = 26.

Appendix D
Valvular Regurgitation Quantification Principles

The true hemodynamic significance of valvular regurgitation is ideally given by the *regurgitant volume* and the *regurgitant fraction* (RF = regurgitant volume/EDV - ESV). Severe regurgitation is defined as:

- regurgitant volume ≥ 60 ml/beat
- RF ≥ 50%

These volumetric calculations are available by Doppler echocardiography, but in practice regurgitation is assessed using either surrogates related to *jet size* by color Doppler or a calculated *effective regurgitant orifice area* (EROA). The main approaches for valvular regurgitation assessment are presented below and the generally accepted cut-off values are summarized in Tables D.1 and D.2.[1] For a more detailed and in-depth discussion of this topic, the reader should consult the relevant chapters in general echocardiography textbooks and valvular heart diseases management guidelines.

- Jet size versus receiving chamber size measurements
  - For mitral regurgitation (MR)
    - Maximal regurgitant jet area/left atrium (LA) area ratio in any parasternal or apical view
  - For aortic regurgitation (AR)
    - Regurgitant jet width (RJW)/left ventricular out-flow tract (LVOT) diameter ratio (RJW/LVOT diameter) in parasternal long axis view

- Jet size at its emergence from the regurgitant orifice, *vena contracta* (VC)
    - For both MR (in parasternal long-axis view or apical views except apical two-chamber view) and AR (in parasternal or apical long-axis view)
- EROA using the proximal isovelocity surface area (PISA) (Fig. D.1)

This is a volumetric approach based on the assumption that the flow converging toward the valve on its ventricular side equals the amount going through the regurgitant orifice. The amount of blood converging toward the valve is the volume of a hemisphere defined by the plane of the valve and the aliasing boundary and which moves with a velocity equal to the Nyquist limit for that study. The EROA is given by the built-in software of the echocardiographic machine or it can be calculated as

EROA (cm^2) = $2\pi r^2 \times V_a/V_{max}$ where r is the radius of the sphere from the valve plane to the aliasing zone, V_a is the Nyquist limit, and V_{max} is the peak velocity of the regurgitant flow by CW Doppler.

Besides the methods described above, ancillary findings have to be actively sought when significant regurgitation is suspected. These are not absolute criteria but are helpful in borderline cases.

For MR:
- LV and LA enlargement
- Hyperdynamic LV
- $E/A > 1$ with $E > 1.2$ m/s in the absence of mitral stenosis

For AR:
- LV and LA enlargement
- Short pressure half-time
- Flow reversal in descending aorta

TABLE D.1. Cut-off values for MR severity.

	MR jet area/ LA area	Vena contracta	EROA[a]	Ancillary findings
Mild	<20%	<0.3 cm	<0.2 cm^2	
Severe	>40%	>0.7 cm	>0.4 cm^2	$E > 1.2$ m/s

[a]A PISA radius of ≥0.9 cm at a Nyquist limit of 40 cm/s is indicative of severe MR. *EROA* effective regurgitant orifice area, *LA* left atrium

Table D.2. Cut-off values for AR severity.

	AR jet width/ LVOT width	Vena contracta	EROA[a]	Ancillary findings
Mild	<20%	<0.3 cm	<0.2 cm^2	P½T > 500 ms
Severe	>65%	>0.6 cm	>0.3 cm^2	P½T < 200 ms[a] Holodiastolic flow reversal in descending aorta

[a]A short P½T is reliable only if there are no other causes of increased LV stiffness such as ischemic damage

LVOT left ventricular outflow tract, *P½T* pressure half time

The overall assessment of regurgitant lesions should take into account more than one technique and ancillary and supportive findings as well. Jet size criteria are not accurate for very eccentric, "against the wall" jets which are assumed to be more severe than they look. Regurgitations with indices falling between the "mild" and "severe" qualifications are considered moderate

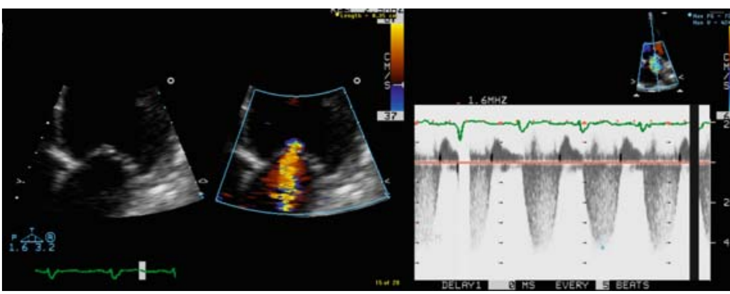

Fig. D.1 Use of PISA method in a patient with mitral regurgitation. a): The aliasing (Nyquist) limit for velocities away from the transducer is lowered to expand the convergence area and the mitral valve and the proximal regurgitant jet are zoomed-in using the apical 4-chamber view. The radius of the convergence hemisphere is measured (green dots) from the leaflets level to the aliasing boundary (bright yellow-blue interface). b): The peak velocity of the regurgitant jet is obtained with CW Doppler. (See text for calculations) PISA: proximal isovelocity surface area

CAVEATS IN THE ECHOCARDIOGRAPHIC ASSESSMENT OF VALVULAR REGURGITATION

- The color-flow display of the regurgitant jet is sensitive to the imaging settings. High gains or a low Nyquist limit can significantly increase the jet area and its turbulence pattern.

  - Use standard settings with a Nyquist limit of 50–60 cm/s (except for PISA calculation when it should be lowered to 40 cm/s).
  - When comparing two studies for follow-up purposes, ensure that both studies were performed using same or similar settings.
- Regurgitations can vary significantly with hemodynamic changes such as blood pressure, volemic status, and ventricular contractility. This may become an issue during acute or follow-up studies in the following circumstances:
  - Successful diuresis and achieving normovolemic status
  - Patients on dialysis who have significant volume shifts
  - With improving ventricular contractility
  - During transesophageal echocardiography (TEE) when blood pressure (BP) can either significantly increase due to anxiety or decrease with use of intravenous sedation (record BP during the study)

References

1. Vahanian A, Baumgartner H, Bax J et al. Guidelines on the management of valvular heart disease: The Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology. *Eur Heart J.* 2007;28(2):230-268.

Appendix E
Valvular Stenosis Quantification Principles[1]

The severity of a valvular stenosis is assessed by:

- *Mean transvalvular gradient (mmHg)*
  - Obtained with:
    - Spectral CW Doppler
  - Advantages:
    - Easy to obtain
    - Generally good correlation with stenosis severity
  - Disadvantages/precautions:
    - Influenced by the hemodynamics at the time of the study
      - Volume status
      - Heart rate
      - Left ventricular (LV) contractility
- *Stenotic orifice area (cm^2)*
  - Obtained with:
    - Direct planimetry
    - Doppler calculations*
      - For aortic stenosis (AS): continuity equation
      - For mitral stenosis (MS): pressure half-time method

*For the scope of this book, only widely used methods are mentioned.

Table E.1. Cut-off values for MS severity.

	Mean gradient (mmHg)[a]	MVA (cm2)[b]
Mild	2–4	>2
Moderate	4–9	1–2
Severe	>10–15	<1

[a]In the absence of tachycardia or bradycardia, which can significantly increase or decrease, respectively, the measured gradient
[b]MVA is either measured by direct planimetry or derived using the pressure half-time method. The two methods are complimentary but planimetry, if feasible is preferable. Pressure half-time is not accurate with:
- mild MS
- >mild AR
- altered LV compliance, for example, LVH
- recent mitral valvotomy

MS: mitral stenosis
MVA: mitral valve area

Table E.2. Cut-off values for AS severity.

	Mean gradient (mmHg)	AVA (cm^2)[a]
Mild		>1.5
Moderate		1–1.5
Severe	>50[b]	<1

[a]Assuming average body-size. For large- or small-bodied individuals, the AVA should be indexed to BSA, with a cut-off value of 0.6 cm^2/m^2 BSA for severe AS
[b]Assuming normal LV contractility and cardiac output
AS: aortic stenosis
AVA: aortic valve area

Formally, valvular stenosis severity is graded using the valve area (Tables E.1 and E.2)[1].

References

1. Vahanian A., Baumgartner H, Bax J et al. Guidelines on the management of valvular heart disease: The Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology. *Eur Heart J* 2007;28(2):230–268

Appendix F
Normal Ranges for Usual Echocardiographic Measurements in Adults

The values given in Table F.1 below represent a consensus of the American and European associations of echocardiography.[1] Different national bodies may adopt slightly different values.[2] Each echocardiography service needs to adopt its own standards, based on national or international recommendations and local practice.

TABLE F.1. Standard dimensions and flow velocity measurements and normal values.[1,2]

	2D/M mode	Measurements[a]
	Not-indexed	BSA indexed (/m^2 BSA)[b]
LVDd (cm)	3.9–5.9	2.4–3.1
Fractional shortening (%)	27–45	
IVSd (cm)	0.6–1	
LVPWd (cm)	0.6–1	
RVOT (cm)	2.5–2.9	
RV free wall thickness (cm)	0.5	
LA diameter (cm)	2.7–4	1.5–2.3
LA area (cm2)	<20	
LA volume (ml)	22–58	<29

(continued)

TABLE F.1. (continued)

	2D/M mode	Measurements[a]
	Not-indexed	BSA indexed (/m^2 BSA)[b]
Aortic root (sinuses level) (cm)	<4	Age and BSA nomograms needed to identify dilatation
	Doppler	Peak velocities
Mitral diastolic flow (m/s)	0.6–1.3	
Tricuspid diastolic flow (m/s)	0.3–0.7	
Pulmonary flow (m/s)	0.6–0.9	
LVOT (m/s)	0.7–1.1	
Aorta (m/s)	1–1.7	

[a]Linear dimensions can be obtained by either M mode or M-mode guided two-dimensional measurements, depending on image quality and orientation. Because of technological advances, the use of the actual blood-tissue interface rather than the original leading edge-to leading edge requirement is suggested now for linear measurements

[b]For clinical use, some measurements need indexing to body surface area as emphasized above. This may be critical especially for borderline values and individuals with body size significantly below or above the average

RVOT right ventricular outflow tract, *LVOT* left ventricular outflow tract, *LA* left atrium, *RV* right ventricular, *LVD*d left ventricular diastolic dysfunction, *IVSd* interventricular septal wall thickness in diastole, *LVPWd* left ventricular posterior wall dimensions, *BSA* body surface area

References

1. Lang RM, Bierig M, Devereux RB, et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 2005;18:1440–1463.
2. http://www.bsecho.org/Guidelines%20for%20Chamber%20Quantification.pdf

Appendix G
Echocardiographic Assessment of Prosthetic Valves

Prosthetic valve assessment may be a challenging task. Ideally, the sonographer should know the type and size of the imaged valve and be familiar with its echocardiographic appearance and normal flow characteristics (Fig. G.1). Each echocardiography service should have reference values and images of typical regurgitant flow patterns for commonly used prosthetic valves.

Besides the overall appearance and motion, the echocardiographic evaluation of a prosthetic valve will address:

REGURGITANT JETS

A trivial and up to mild degree of regurgitation is accepted for an otherwise normally functioning valve. It is seen in virtually all mechanical valves and occasionally in bioprosthetic valves. This "physiologic" regurgitation in mechanical valves is due to two mechanisms:

- a built-in-leakage which allows the valve to be "washed" by the flowing blood and
- a small amount of blood which is moved by the occluder on its way to a closing position (closure volume).

Clues for the "normal" character of regurgitation noted with a mechanical valve include:

- Low velocity, "smooth," and short (<2–3 cm) jets, though exceptions exist:
  - Some Medtronic-Hall valves may have a long, impressive jet

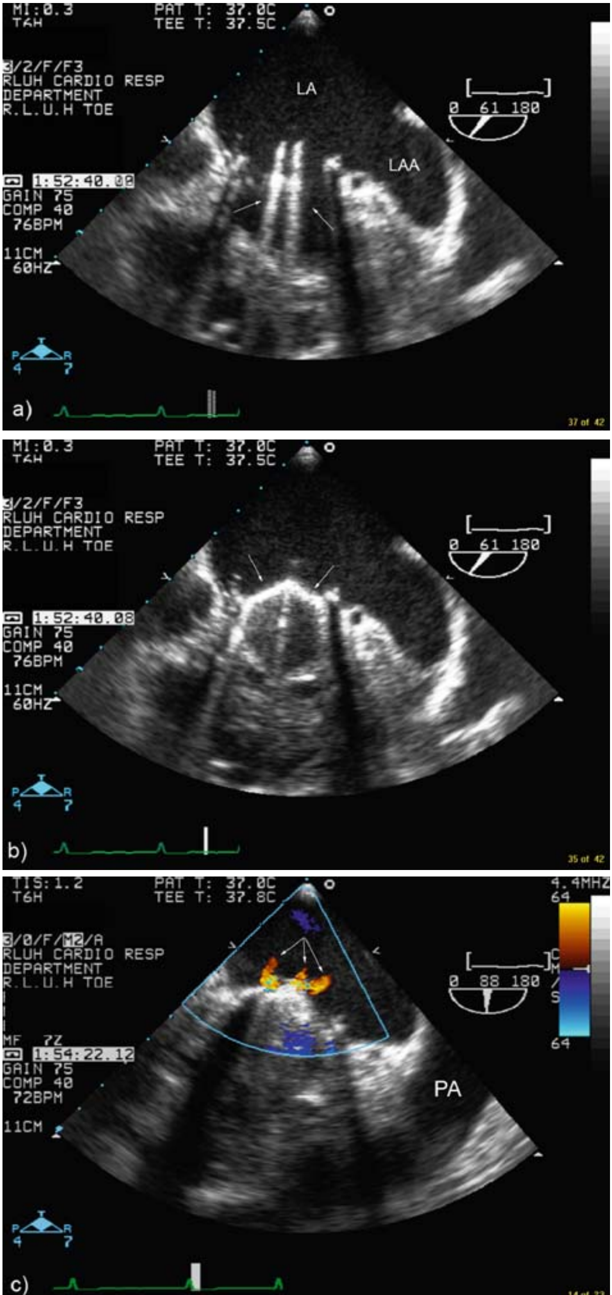

FIG. G.1. Transesophageal echocardiography (*TEE*) imaging of a normally functioning St. Jude valve in mitral position. **a** Diastolic frame showing

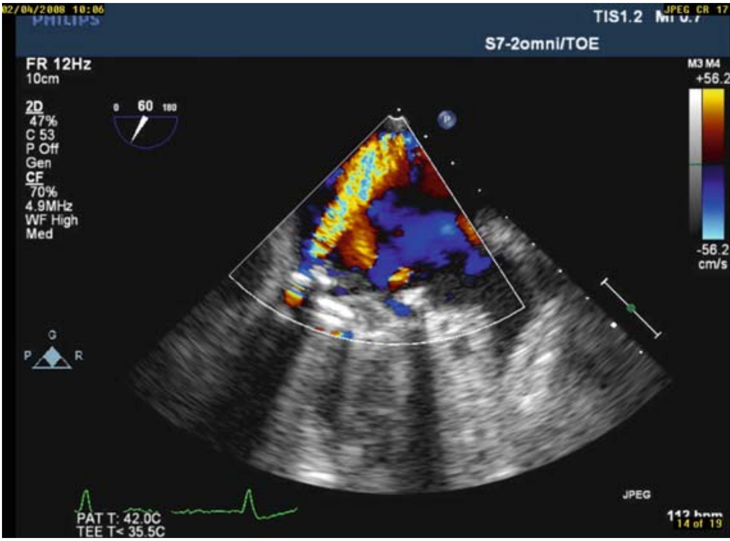

FIG. G.2. Transesophageal echocardiography (*TEE*) findings in a patient with a bileaflet mechanical valve in mitral position, admitted with cardiac failure and hemolytic anemia. A high velocity, turbulent regurgitant jet is seen, originating at the suture line level consistent with significant paravalvular regurgitation.

- Jets origin is "within the valve" as opposed to paravalvular leaks (Fig. G.2)
- The appearance of one or multiple jets with a pattern that fits the description for a particular kind of valve
  - Bileaflet valves may have up to three to four jets at the periphery of the valve (Fig. G.1c)
- Overall severity is no more than mild

PRESSURE GRADIENTS, PRESSURE HALF-TIMES AND EFFECTIVE AREAS

Pressure gradients across prosthetic valves are obtained with Doppler interrogation as for native valves and should be interpreted against published normal values.[1] Increased gradients may

FIG. G.1. (continued) symmetrical and almost parallel leaflets ensuring full opening of the valve. **b** Systolic frame confirming symmetrical and simultaneous closure of the leaflets. **c** Color-Doppler systolic frame showing three short, low-velocity jets, typical for this valve.

suggest obstruction, but some caveats are to be observed before making the diagnosis of stuck valve, especially if this is an incidental finding in an asymptomatic patient:

- Gradients may be high with small diameter valves if valve-patient mismatch exists. Ideally, a study performed in steady conditions after surgery (but not immediately postoperatively) should be available for comparison.
- Gradients may significantly increase with high output states such as acute febrile disease, dialysis patients with shunts, and hyperthyroidism. Also, mitral gradients can increase markedly with high heart rates.
- A disproportionately high-peak gradient with a minimally elevated mean gradient in a prosthetic valve in mitral position is highly suggestive of regurgitation rather than obstruction.

Dimensionless Velocity Index (DVI). Peak velocities and gradients are highly dependent on flow and their use as isolated findings to diagnose valve obstruction may be limited. With changing flows, aortic valvular and subvalvular velocities are expected to maintain their relative ratio. The left ventricular outflow tract (LVOT) peak velocity/aortic valve peak velocity ratio is referred to as the DVI. A DVI 0.25–0.3 suggests valvular stenosis.

Effective areas for prosthetic aortic valves can be calculated using continuity equation and compared with published references. For prosthetic valves in mitral position a prolonged pressure half-time value can indicate obstruction. The pressure half-time ($P_{1/2}T$) has not been thoroughly validated for prosthetic valves areas and its value should be reported as such, but resulting areas are frequently reported for practical reasons.

REFERENCE VALUES

There is a multitude of data on normal Doppler values for prosthetic valves, however, they represent a mixture of in-vitro and in-vivo, manufacturer-provided, clinical and experimental studies, some of which use only velocities or only gradients and report mean and standard deviation (SD) only or range of values as well. Also, areas and gradients vary greatly with valve size and flow state at the time of the study. As such, it is difficult to summarize the existent information.[1-2] A compilation of orientative range of accepted maximal values is provided below, to “flag” a possible pathology and to be used with detailed published data on specific prosthetic valves.

Low valvular areas and gradients at the upper limit of the range are associated with small size valves and do not necessarily mean that the valve is malfunctioning. Some valves, such as

TABLE G.1. Acceptable values for biological and mechanic porsthetic valves over available sizes range.

AORTIC POSITION		
Peak velocity range (m/s)	Mean gradient range (mm Hg)	AVA (cm^2)
1.4-4	5-30	1-3
MITRAL POSITION		
Peak velocity range (m/s)	Mean gradient range (mm Hg)	P ½T (ms)
1.2-2	1-8	60-160

AVA: aortic valve area, P ½T: pressure half-times

the ball-cage Starr-Edwards have gradients at the upper limit of normal range.

SUSPECT REGURGITATION IF FINDING:

- High peak gradient with minimally increased mean gradient and no other evidence of obstruction
- High velocity, turbulent regurgitant jets, not typical for the valve (Fig. F.2)

SUSPECT STENOSIS IF FINDING:

- Both peak and mean gradient are elevated above normal range
- For aortic position
  - AVA < 1 cm^2 (by continuity equation)
  - DVI < 0.3
- For mitral position
  - Pressure half-time > 200 ms

Use reference values and previous studies for comparison (Table G.1).

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Appendix H
General References and Recommended Reading

TEXTBOOKS

1. Hatle L, Angelsen B. *Doppler Ultrasound in Cardiology: Physical Principles and Clinical Applications*. 2nd ed. Philadelphia: Lea and Febiger; 1985.
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7. Rimington H, Chambers JMD. *Echocardiography: A Practical Guide for Reporting*. 2nd ed. London: Informa Healthcare; 2007. vi, 148 pp.

GUIDELINES, STATEMENTS, POSITION PAPERS

1. Stewart WJ, Douglas PS, Sagar K, et al. Echocardiography in emergency medicine: a policy statement by the American Society of Echocardiography and the American College of Cardiology. Task Force on Echocardiography in Emergency Medicine of the American Society of Echocardiography and the Echocardiography and Technology and Practice Executive Committees of the American College of Cardiology. J Am Coll Cardiol 1999;33:586–588.

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10. British Society of Echocardiography 2005: Minimum Dataset for TTE (on BSE website)

Websites

Organizations

1. American Society of Echocardiography (ASE). www.asecho.org
2. British Society of Echocardiography (BSE).www.bsecho.org
3. European Association of Echocardiography (EAE). www.escardio.org/communities/EAE/pages/welcome.aspx

Free Domain Webcasts, Images, Guides

1. ASE University. www.aseuniversity.org
2. Echo by Web. www.echobyweb.com
3. Echo in Context. www.echoincontext.mc.duke.edu
4. E-chocardiography Journal. www.2.umdnj.edu/~shindler/index.htm

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