KSA Kantonsspital Aarau

USZ Universitäts Spital Zürich

luzerner kantonsspital LUZERN SURSEE WOLHUSEN

Pocket Guidelines
Echocardiography/Doppler

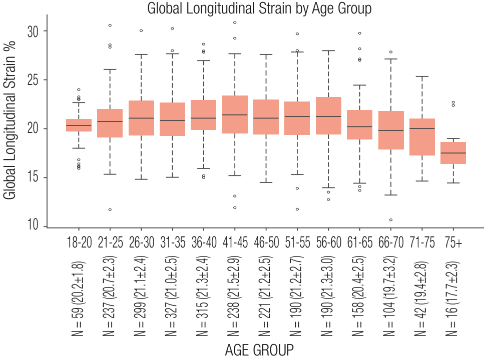
Prof. Dr. med. Michel Zuber
PD Dr. med. Simon Stämpfli
Prof. Dr. med. Felix Tanner
PD Dr. med. Tobias Fuchs

we acknowledge Dr. med. Shehab Anwer
for his help to generate the App
Edition June 2025

2D-LVEF and LA volume[1]

	Male				Female			
	Normal range	Mildly abnormal	Moderately abnormal	Severely abnormal	Normal range	Mildly abnormal	Moderately abnormal	Severely abnormal
LV EF (%)	52–72	41–51	30–40	<30	54–74	41–53	30–40	<30
Max. LA volume/BSA (mL/m²)	16–**34**	35–41	42–48	>48	16–**34**	35–41	42–48	>48

Variations of GLS in Normal Values[32]



The normal range for GLS varied between the vendors:
TomTec with highest values (n= 644; 22.1% [20.1,23.8], LLN 18.0%]
General Electric (n= 1,013; 21.%2 [19.9, 22.8], LLN 18.2%)
Toshiba (n= 278; 19.9% [18.3, 21.5], LLN 15.8%)
Philips (n= 379; 19.6% [18.1, 21.3], LLN 15.5%)
Siemens (n= 82; 16.9% [16.0, 18.8], LLN 14.0%)

Regardless of vendor or clinical covariate, a GLS <16% likely indicates significant myocardial dysfunction.

Advanced echocardiographic parameters[2]

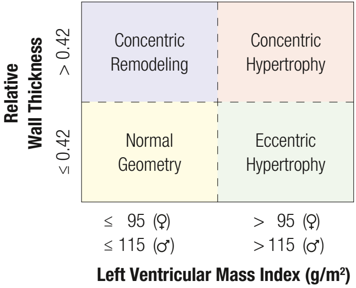
Chamber	Parameter	Normal values
Left ventricle	LV GLS (%)	>20%[a]
	3D EDV index (mL/m^2)	<80 (M), <72 (F)
	3D ESV index (mL/m^2)	<33 (M), <29 (F)
	3D LVEF (%)	>54 (M), >57 (F)
Right ventricle	Free wall GLS	>23%[a]

[a] Expressed in absolute value despite of negative sign.
EDV, end-diastolic volume; *EF,* ejection fraction; *ESV,* end-systolic volume; *GLS,* global longitudinal strain; *LV,* left ventricular; *RV,* right ventricular.

LV mass indices[1]

	Women	Men
LV mass/BSA (g/m^2)	***43–95***	***49–115***
Septal thickness (cm)	***0.6–0.9***	***0.6–1.0***
Posterior wall thickness (cm)	***0.6–0.9***	***0.6–1.0***

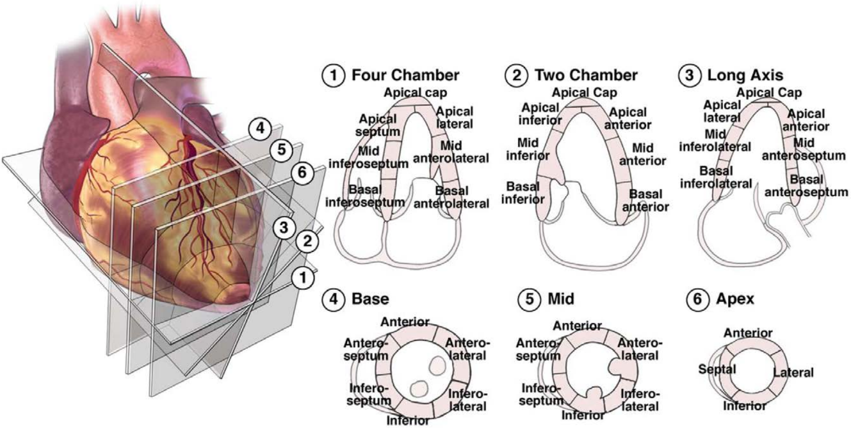
Bold italic values: recommended and best validated.



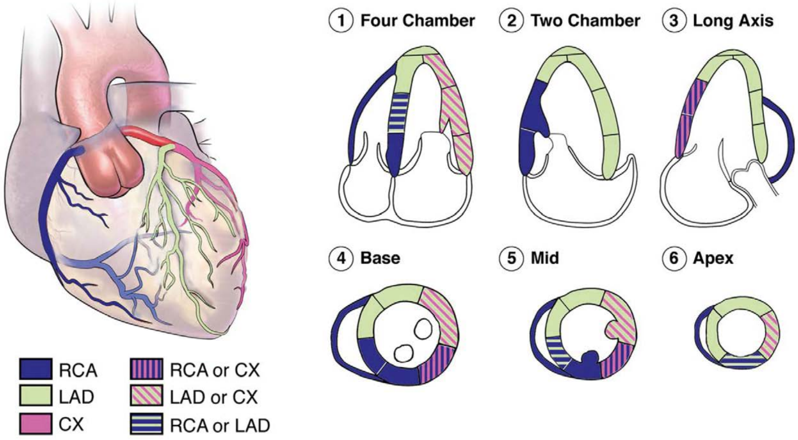
Severity ranges for 2D LV-size, function and mass[1]

	Male				Female			
	Normal range	Mildly abnormal	Moderately abnormal	Severely abnormal	Normal range	Mildly abnormal	Moderately abnormal	Severely abnormal
LV dimension								
LV diastolic diameter (cm)	**4.2–5.8**	**5.9–6.3**	**6.4–6.8**	**> 6.8**	**3.8–5.2**	**5.3–5.6**	**5.7–6.1**	**> 6.1**
LV diastolic diameter/BSA (cm/m²)	**2.2–3.0**	**3.1–3.3**	**3.4–3.6**	**> 3.6**	**2.3–3.1**	**3.2–3.4**	**3.5–3.7**	**> 3.7**
LV systolic diameter (cm)	2.5–4.0	4.1–4.3	4.4–4.5	> 4.5	2.2–3.5	3.6–3.8	3.9–4.1	> 4.1
LV systolic diameter/BSA (cm/m²)	1.3–2.1	2.2–2.3	2.4–2.5	> 2.5	1.3–2.1	2.2–2.3	2.4–2.6	> 2.6
LV volume								
LV diastolic volume (mL)	62–150	151–174	175–200	> 200	46–106	107–120	121–130	> 130
LV diastolic volume/BSA (mL/m²)	**34–74**	**75–89**	**90–100**	**> 100**	**29–61**	**62–70**	**71–80**	**> 80**
LV systolic volume (mL)	21–61	62–73	74–85	> 85	14–42	43–55	56–67	> 67
LV systolic volume/BSA (mL/m²)	11–31	32–38	39–45	> 45	8–24	25–32	33–40	> 40
LV function								
LV EF (%)	**52–72**	**41–51**	**30–40**	**< 30**	**54–74**	**41–53**	**30–40**	**< 30**
LV mass by linear method								
Septal wall thickness (cm)	0.6–1.0	1.1–1.3	1.4–1.6	> 1.6	0.6–0.9	1.0–1.2	1.3–1.5	> 1.5
Posterior wall thickness (cm)	0.6–1.0	1.1–1.3	1.4–1.6	> 1.6	0.6–0.9	1.0–1.2	1.3–1.5	> 1.5
LV mass (g)	88–224	225–258	259–292	> 292	67–162	163–186	187–210	> 210
LV mass/BSA (g/m²)	**49–115**	**116–131**	**132–148**	**> 148**	**43–95**	**96–108**	**109–121**	**> 121**
LV mass by 2D method								
LV mass (g)	96–200	201–227	228–254	> 254	66–150	151–171	172–193	> 193
LV mass/BSA (g/m²)	50–102	103–116	117–130	> 130	44–88	89–100	101–112	> 112

Segmental analysis of LV walls[1]



Segmental distribution and coronary attribution[1]

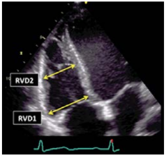


RV size and function[1]

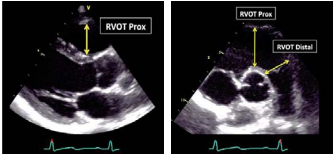
Parameter	Mean ± SD	Abnormality threshold
TAPSE (mm)	24 ± 3.5	<17
Pulsed Doppler S wave (cm/sec)	14.1 ± 2.3	<9.5
Color Doppler S wave (cm/sec)	9.7 ± 1.85	<6.0
RV fractional area change (%)	49 ± 7	<35
RV free wall 2D strain* (%)	–29 ± 4.5	>–20**
RV 3D EF (%)	58 ± 6.5	<45
Pulsed Doppler MPI	0.26 ± 0.085	>0.43
Tissue Doppler MPI	0.38 ± 0.08	>0.54
E wave deceleration time (msec)	180 ± 31	<119 or >242
E/A	1.4 ± 0.3	<0.8 or >2.0
e'/a'	1.18 ± 0.33	<0.52
e'	14.0 ± 3.1	<7.8
E/e'	4.0 ± 1.0	>6.0

MPI, Myocardial performance index. *Limited data; values may vary depending on vendor and software version. **<20 in magnitude with the negative sign.

RV linear dimensions (inflow)*

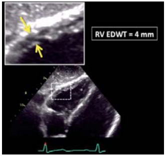


RV linear dimensions (outflow)*



RV areas (inflow)

RV wall thickness



Recommended measures of right heart structure and function[33]

Variable	Normal	Mild	Moderate	Severe
RA area (cm²)	<19	≥19 — <22	≥22 — <24	≥24
RAV index (method of disks) (mL/m²)	<30	≥30 — <36	≥36 — <41	≥41
RAV index (area-length method) (mL/m	<33	≥33 — <38	≥39 — <44	≥44
RV end-systolic area (cm²)	<14	≥14 — <16	≥16 — <19	≥19
RV end-systolic area index (cm²)	<8	≥8 — <9	≥9 — <11	≥11
RV end-diastolic area (cm²)	<25	≥25 — <28	≥28 — <32	≥32
RV end-diastolic area index (cm²)	<14	≥14 — <15	≥15 — <17	≥17
3D end-systolic volume (mL)	<66	≥66 — <77	≥77 — <89	≥89
3D end-systolic volume index (mL/m²)	<41	≥41 — <48	≥48 — <55	≥55
3D end-diastolic volume (mL)	<130	≥130 — <150	≥150 — <170	≥170
3D end-diastolic volume index (mL/m²)	<90	≥90 — <103	≥103 — <115	≥115
PA (cm)	<2.5	≥2.5 — <3.0	≥3.0 — <3.5	≥3.5
TAPSE (cm)	>1.7	≤1.7 — >1.3	≤1.3 — >1.0	≤1.0
TDI S' velocity (cm/sec)	>9.5	≤9.5 — >7.2	≤7.2 — >5.0	≤5.0
RV FAC (%)	>35	≤35 — >29	≤29 — >22	≤22
3D RVEF (%)	>45	≤45 — >39	≤39 — >32	≤32
RV long. FWS (three segment) (%) *	>20	≤20 — >15	≤15 — >11	≤11
RV GLS (six segment) (%) *	>17	≤17 — >13	≤13 — >9	≤9
RV E/A ratio	≥0.8 — <2.0	<0.8	0.8 — 2.1	>2.1
Relaxation pattern	Preserved	Impaired	Pseudonormal	Restrictive
RV E/e' ratio	<6.0	≥6.0 — <7.3	≥7.3 — <8.4	≥8.5
Deceleration time (msec)	≥120 — ≤230	≥87 — <120	≥57 — <87	<57
TRV max. (m/s) †	<2.8	≥2.8† — <3.1	≥3.2 — <3.5	≥3.6
RVSP (mmHg)	≤34	≥35 — <49	≥50 — <69	≥70
RAP (mmHg)	≤0 — <5	≥5 — <10	≥10 — <15	≥15
RVOT AccT (msec)	>105	≥80 — ≤105	≥60 — <80	<60

† Resting peak TRV of ≥ 2.9 or ≥ 2.8 m/s with at least two adjunctive echocardiographic signs suggests **Pulmonary Hypertension.**

*** Absolute values and ranges for strain**

3D, three-dimensional **AccT**, acceleration time **FAC**, fractional area change; **PA**, pulmonary artery; **RA**, right atrium; **RAP**, right atrial pressure; **RAV**, right atrial volume; **RV**, right ventricle; **RVEF**, right ventricular ejection fraction; **RVOT**, right ventricular outflow tract; **RVSP**, right ventricular systolic pressure; **RVWT**, right ventricular wall thickness; **TAPSE**, tricuspid annular plane systolic excursion; **TRV**, tricuspid regurgitant velocity.

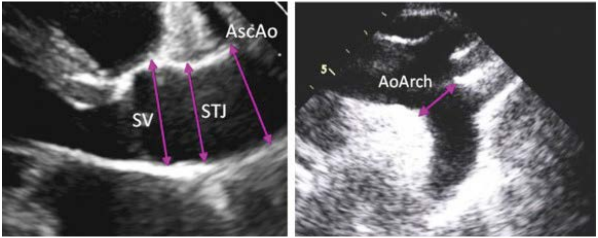
Right atrial size[1,3]

	Women	Men
RA minor axis dimension (cm/m²)	1.9 ± 0.3	1.9 ± 0.3
RA major axis dimension (cm/m²)	2.5 ± 0.3	2.4 ± 0.3
2D echocardiographic RA volume (mL/m²)	21 ± 6	25 ± 7
	< 28 ml/m²	**< 33 ml/m²**

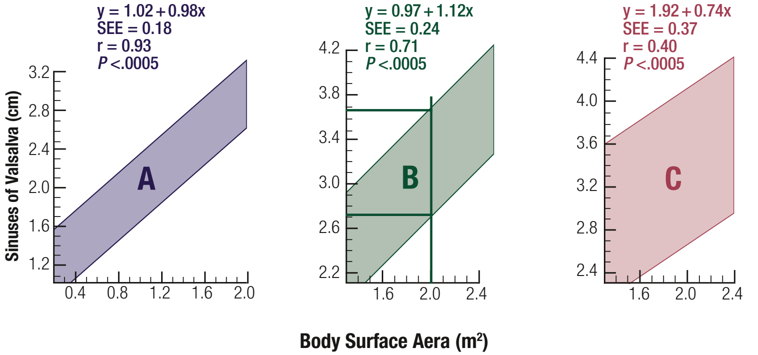
Data are expressed as mean ±SD.

	Women	Men
RA area cm² in 4CHV	13 ± 2	17 ± 3

A zoomed parasternal long-axis view for aortic diameters in the proximal region and aortic arch from suprasternal long axis view[4]



Aortic root diameter[5]



Aortic root diameter *(vertical axis)* in relation to BSA *(horizontal axis)* in apparently normal individuals aged 1 to 15 *(left panel, blue)*, 20 to 39 *(center panel, green)*, and ≥40 *(right panel, pink)* years. For example, an individual between the ages of 20 and 39 years *(center panel, green)* who has a BSA of 2.0 m^2 *(vertical green line)* has a normal root diameter range (2 SDs) between 2.75 and 3.65 cm, as indicated by the intersections of the *two horizontal green lines* with the *green-shaded* parallelogram.

Aortic root diameter[5]

Normal aortic root diameter by age for men with BSA of 2.0 m²

	Age (y)					
	15–29	30–39	40–49	50–59	60–69	≥70
Mean normal (cm)	3.3	3.4	3.5	3.6	3.7	3.8
Upper limit of normal (cm) (95% CI)	3.7	3.8	3.9	4.0	4.1	4.2

Add 0.5 mm per 0.1 m^2 BSA above 2.0 m^2 or subtract 0.5 mm per 0.1 m^2 BSA below 2.0 m^2.[6]
CI, Confidence interval.

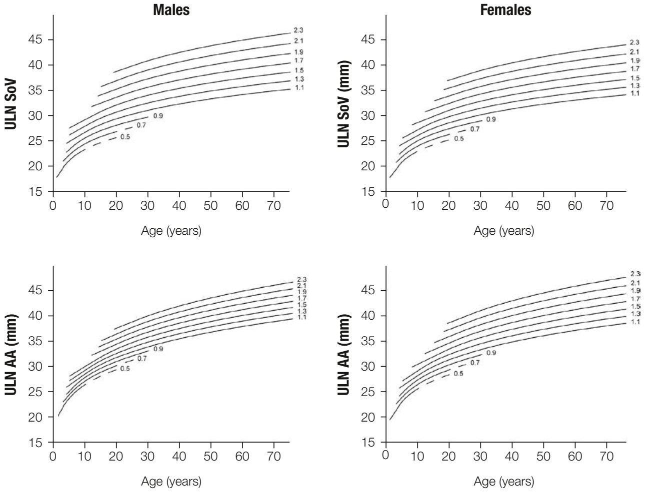
Normal aortic root diameter by age for women with BSA of 1.7 m²

	Age (y)					
	15–29	30–39	40–49	50–59	60–69	≥70
Mean normal (cm)	2.9	3.0	3.2	3.2	3.3	3.4
Upper limit of normal (cm)	3.3	3.4	3.6	3.6	3.7	3.9

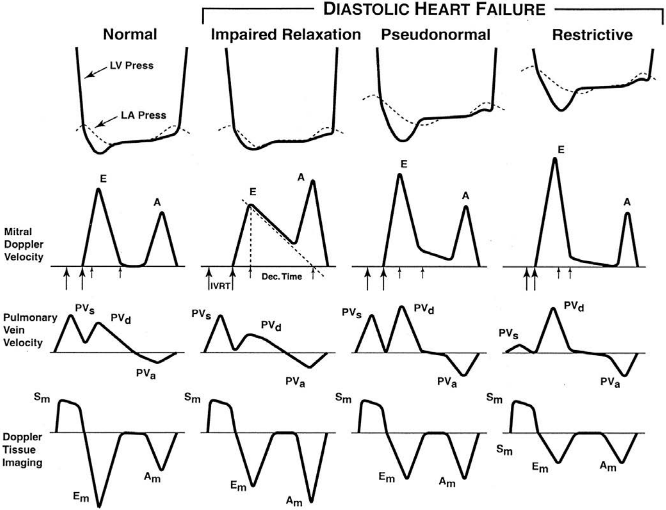
Add 0.5 mm per 0.1 m^2 BSA above 1.7 m^2 or subtract 0.5 mm per 0.1 m^2 BSA below 1.7 m^2.[6]

Nomograms for sinus of Valsalva and ascending aorta diameters[7]

as a function of BSA_{DB} and age for both genders



Classification of diastolic function[8]



LV relaxation, filling pressures and 2D and Doppler findings according to LV diastolic function[9]

	Normal	Grade I	Grade II	Grade III
LV relaxation	Normal	Impaired	Impaired	Impaired
LAP	Normal	Low or normal	Elevated	Elevated
Mitral E/A ratio	≥0.8	≤0.8	>0.8 to <2	>2
Average E/e' ratio	<10	<10	10–14	>14
Peak TR velocity (m/sec)	<2.8	<2.8	>2.8	>2.8
LA volume index	Normal	Normal or increased	Increased	Increased

Diastolic stress test: Indications and criteria for response[25]

Do not need the diastolic stress test:	• Preserved e' at rest: mitral annulus septal e' >7 cm/s and lateral e' >10 cm/s. Unlikely to develop elevated LV filling pressures with exercise. • Elevated LV filling pressure at rest, by echocardiography.
Candidates for the test:	• Grade 1 LV diastolic dysfunction with normal LV filling pressure at rest and signs of delayed myocardial relaxation.
Diastolic stress test is positive when all of the following three conditions are met:	• Average E/e' > 14 or septal E/e' ratio >15 with exercise. • Peak TR velocity >2.8 m/s with exercise. • Septal e' < 7 cm/s or if only lateral velocity is acquired, lateral e' < 10 cm/s at baseline.
Normal response to diastolic stress test if both of the following two conditions are met:	• Average or septal E/e' < 10 with exercise. • Peak TR velocity <2.8 m/s with exercise.

Normal diastole (according to the age group)[10]

Normal values for Doppler-derived diastolic measurements

Measurement	Age group (y)			
	16–20	21–40	41–60	>60
IVRT (ms)	50±9 (32–68)	67±8(51–83)	74±7(60–88)	87±7(73–101)
E/A ratio	1.88±0.45(0.98–2.78)	1.53±0.40(0.73–2.33)	1.28±0.25(0.78–1.78)	0.96±0.18(0.6–1.32)
DT (ms)	142±19(104–180)	166±14(138–194)	181±19(143–219)	200±29(142–258)
A duration (ms)	113±17(79–147)	127±13(101–153)	133±13(107–159)	138±19(100–176)
PV S/D ratio	0.82±0.18(0.46–1.18)	0.98±0.32(0.34–1.62)	1.21±0.2(0.81–1.61)	1.39±0.47(0.45–2.33)
PV Ar (cm/s)	16±10(1–36)	21±8(5–37)	23±3(17–29)	25±9(11–39)
PV Ar duration (ms)	66±.39(1–144)	96±33(30–162)	112±15(82–142)	113±30(53–173)
Septal e’ (cm/s)	14.9±2.4(10.1–19.7)	15.5±2.7(10.1–20.9)	12.2±2.3(7.6–16.8)	10.4±2.1(6.2–14.6)
Septal e’/a’ ratio	2.4*	1.6±0.5(0.6–2.6)	1.1±0.3(0.5–1.7)	0.85±0.2(0.45–1.25)
Lateral e’ (cm/s)	20.6±3.8(13–28.2)	19.8±2.9(14–25.6)	16.1±2.3(11.5–20.7)	12.9±3.5(5.9–19.9)
Lateral e’/a’ ratio	3.1*	1.9±0.6(0.7–3.1)	1.5±0.5(0.5–2.5)	0.9±0.4(0.1–1.7)

Data are expressed as mean ±SD (95 % confidence interval). Note that for e’ velocity in subjects aged 16 to 20 years, values overlap with those for subjects aged 21 to 40 years. This is because e’ increases progressively with age in children and adolescents. Therefore, the e’ velocity is higher in a normal 20-year-old than in a normal 16-year-old, which results in a somewhat lower average e’ value when subjects aged 16 to 20 years are considered.

* Standard deviations are not included because these data were computed, not directly provided in the original articles from which they were derived.

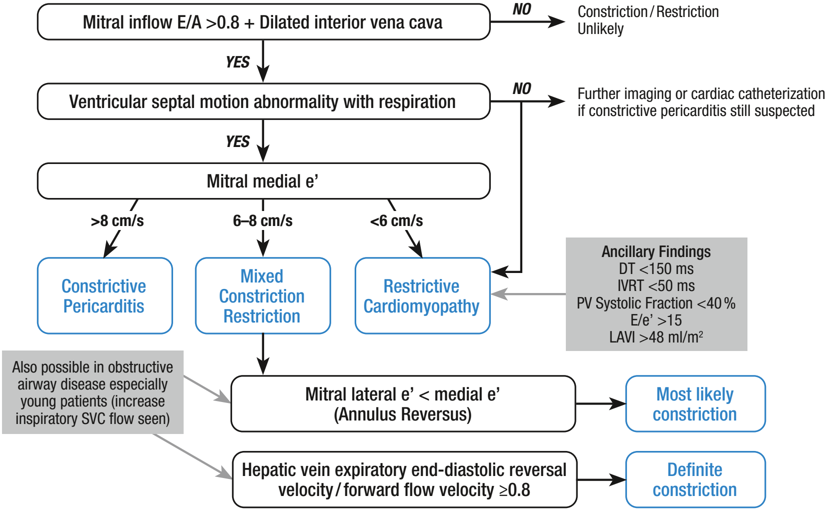
Diastolic function in special populations[10]

Assessment of LV filling pressures in special populations

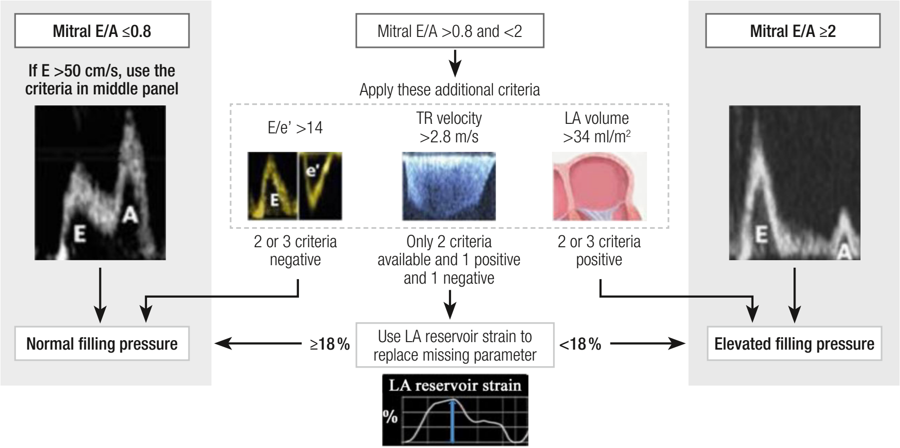
Disease	Echocardiographic measurements and cutoff values
Atrial fibrillation	Peak acceleration rate of mitral E velocity (≥1,900 cm/s^2), IVRT (≤65 ms), DT of pulmonary venous diastolic velocity (≤220 ms), E/Vp ratio (≥1.4), and septal E/e’ ratio (≥11)
Sinus tachycardia	Mitral inflow pattern with predominant early LV filling in patients with EFs <50 %, IVRT ≤70 ms is specific (79 %), systolic filling fraction ≤40 % is specific (88 %), lateral E/e’ >10 (a ratio >12 has highest the specificity of 96 %)
Hypertrophic cardiomyopathy	Lateral E/e’ (≥10), Ar – A (≥30 ms), PA pressure (>35 mmHg), and LA volume (≥34 mL/m^2)
Restrictive cardiomyopathy	DT (<140 ms), mitral E/A (>2.5), IVRT (<50 ms has high specificity), and septal E/e’ (>15)
Noncardiac pulmonary hypertension	Lateral E/e’ can be applied to determine whether a cardiac etiology is the underlying reason for the increased PA pressures (cardiac etiology: E/e’ >10; noncardiac etiology: E/e’ <8)
Mitral stenosis	IVRT (<60 ms has high specificity), IVRT/TE-e’ (<4.2), mitral A velocity (>1.5 m/s)
MR	Ar – A (≥30 ms), IVRT (<60 ms has high specificity), and IVRT/$T_{E\text{-}e'}$ (<3) may be applied for the prediction of LV filling pressures in patients with MR and normal EFs, whereas average E/e’ (>15) is applicable only in the presence of a depressed EF

A comprehensive approach is recommended in all of the above settings, and conclusions should not be based on single measurements. Specificity comments refer to predicting filling pressures >15 mmHg.

DD Restriction vs. Constriction[9]



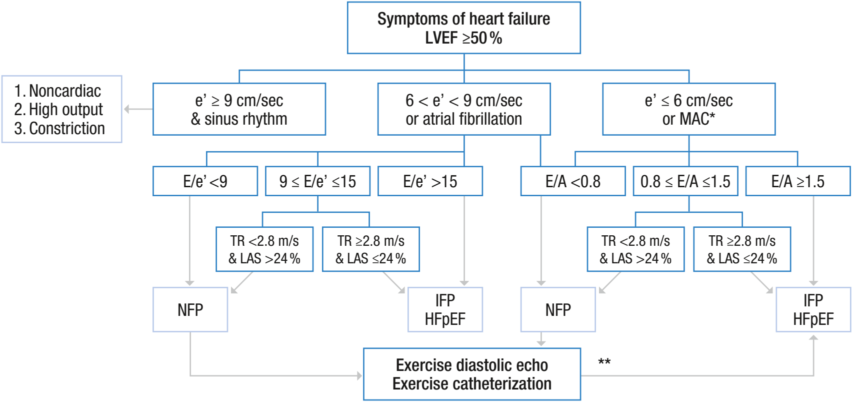
Estimation of left ventricular filling pressure[25]



Caveat-Algorithm not to be applied in any of the following conditions: No suspicion of heart disease; Atrial fibrillation; LBBB/CRT/RV pacing; HCM; Severe MR/MS/MAC; MV prosthesis or repair; High output HF; LV assist device

Figure: Algorithm for estimation of LV filling pressure.

HFpEF: new algorithm to detect increased mean LV diastolic pressure[31]



A proposed new algorithm to detect increased mean LV diastolic pressure and diagnose HFpEF. Almost all patients with HFpEF have diastolic dysfunction, that is, reduced mitral annulus e' velocity. Therefore, diagnostic algorithms start with e' velocity.

* Mitral annulus calcification (MAC) represents patients in whom velocity is not reliable with very high probability of diastolic dysfunction.

** When E/e >15 with exercise, PCWP ≥15 mm Hg at rest, or ≥25 mm Hg with exercise, then the diagnosis of HFpEF can be established. HFpEF indicates heart failure with preserved ejection fraction; IFP, increased filling pressure; LAS, left atrial reservoir strain; LVEF, left ventricular ejection fraction; NFP, normal filling pressure; PAWP, pulmonary artery wedge pressure; and TR, tricuspid regurgitation.

Right Atrial Pressure[24,*]

Estimation of RA pressure on the basis of IVC diameter and collapse

Variable	Normal (0–5 [3] mmHg)	Intermediate (5–10 [8] mmHg)		High (15 mmHg)
IVC diameter	≤2.1 cm	≤2.1 cm	>2.1 cm	>2.1 cm
Collapse with sniff	>50 %	<50 %	>50 %	<50 %
Secondary indices of elevated RA pressure				– Restrictive filling – Tricuspid E/E' >6 – Diastolic flow predominance in hepatic veins (systolic filling fraction <55 %)

RV Diastolic Function[24]

	E:A	E:E'	Deceleration Time	Additional Findings
Normal	0.8–2.1	< 6	> 120 ms	–
Impaired Relaxation	< 0.8	< 6	> 120 ms	–
Pseudonormal	0.8–2.1	> 6	> 120 ms	Diastolic flow predominance in HV
Restrictive	> 2.1	> 6	< 120 ms	Late diastolic antegrade flow in PA

* Ranges are provided for low and intermediate categories, but for simplicity, midrange values of 3 mmHg for normal and 8 mmHg for intermediate are suggested. Intermediate (8 mmHg) RA pressures may be downgraded to normal (3 mmHg) if no secondary indices of elevated RA pressure are present, upgraded to high if minimal collapse with sniff (<35 %) and secondary indices of elevated RA pressure are present, or left at 8 mmHg if uncertain. IVC, Inferior vena cava; RA, right atrial.

Grading of aortic stenosis[11]

	Aortic sclerosis	Mild	Moderate	Severe
Aortic jet velocity (m/s)	≤2.5 m/s	2.6–2.9	3.0–4.0	>4.0
Mean gradient (mmHg)	–	<20 (<30[a])	20–40[b] (30–50[a])	**>40[b] (>50[a])**
AVA (cm^2)	–	>1.5	1.0–1.5	**<1.0**
Indexed AVA (cm^2/m^2)		>0.85	0.60–0.85	**<0.6**
Velocity ratio		>0.50	0.25–0.50	<0.25

Prothesis-patient mismatch (aortic valve)[12]

The effective orifice area (EOA in cm^2/m^2) of the prosthetic aortic valve is 0.85 x BSA (m^2)

- EOA >0.85: no mismatch.
- EOA between 0.85–0.66: slight mismatch.
- EOA <0.65: severe mismatch.

[a] ESC Guidelines.
[b] AHA/ACC Guidelines.

Relationship between energy loss index (ELI) and indexed aortic valve area (AVAI) for different aorta sizes[13]

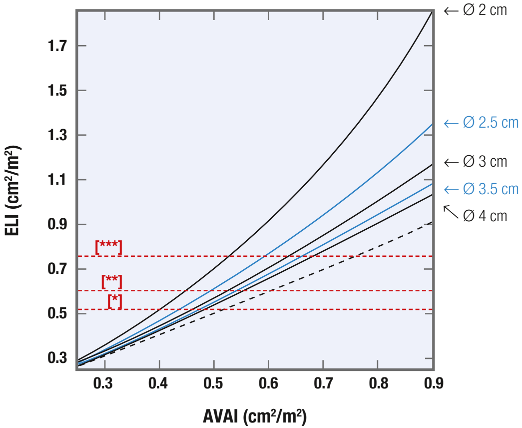


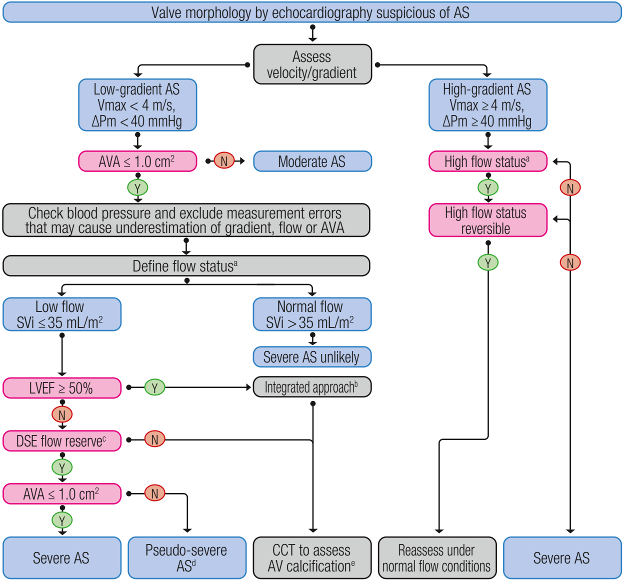
Figure 2. Relationship between energy loss index (ELI) and indexed aortic valve area (AVAI) for different aorta sizes. The calculation of ELI becomes more relevant in patients with an ascending aorta diameter (Ø) <3.0 cm and/or with an AVAI >0.5 cm^2/m^2.

* Best cut point of ELI to predict outcomes over an 8-month follow-up in the study by Garcia et al.[14]

** Cut point of ELI used for reclassification of stenosis severity in the previous study by Bahlmann et al.[15]

*** Best cut point of ELI to predict outcomes over a 4-year follow-up in the present study.[16] The black dashed line is the identity line.

Integrated imaging assessement of aortic stenosis[26]



Integrated imaging assessment of aortic stenosis. AS= aortic stenosis; AV= aortic valve; AVA= aortic valve area; CT= computed tomography; ΔPm= mean pressure gradient; DSE= dobutamine stress echocardiography; LV= left ventricle/left ventricular; LVEF= left ventricular ejection fraction; SVi= stroke volume index; V_{max} = peak transvalvular velocity. [a]High flow may be reversible in patients with anaemia, hyperthyroidism or arterio-venous fistulae, and may also be present in patients with hypertrophic obstructive cardiomyopathy. Upper limit of normal flow using pulsed Doppler echocardiography: cardiac index 4.1 L/min/m^2 in men and women, SVi 54 mL/m^2 in men, 51 mL/m^2 in women).[155] [b]Consider also: typical symptoms (with no other explanation), LV hypertrophy (in the absence of coexistent hypertension) or reduced LV longitudinal function (with no other cause). [c]DSE flow reserve= >20% increase in stroke volume in response to low-dose dobutamine. [d]Pseudo-severe aortic stenosis= AVA >1.0 cm^2 with increased flow. [e]Thresholds for severe aortic stenosis assessed by means of CT measurement of aortic valve calcification (Agatston units): men >3000, women >1600= highly likely; men >2000, women >1200= likely; men <1600, women <800= unlikely.

Cave Durchmesser des sinu-tubulären Überganges unter 30 mm wegen energy loss.

Criteria that increase the likelihood of severe aortic stenosis in patients with AVA <1.0 cm^2 and mean gradient <40 mmHg in the presence of preserved ejection fraction (modified from Baumgartner et al.[27])

Criteria	
Clinical criteria	• Typical symptoms without other explanation • Elderly patient (>70 years)
Qualitative imaging data	• LV hypertrophy (additional history of hypertension to be considered) • Reduced LV longitudinal function without other explanation
Quantitative imaging data	• Mean gradient 30-40 mmHg[2]
	• AVA ≤0.8 cm^2
	• Low flow (SVi <35 mL/m^2) confirmed by techniques other than standard Doppler technique (LVOT measurement by 3D TOE or MSCT; CMR, invasive data)
	• Calcium score by MSCT[b] Severe aortic stenosis very likely: men ≥3000; women ≥1600 Severe aortic stenosis likely: men ≥2000; women ≥1200 Severe aortic stenosis unlikely: men <1600; women <800

3D = three-dimensional; AVA = aortic valve area; CMR = cardiovascular magnetic resonance; LV = left ventricular; LVOT = left ventricular outflow tract; MSCT = multislice computed tomography; SVi = stroke volume index; TOE = transoesophageal echocardiography.

[a] Haemodynamics measured when the patient is normotensive.

[b] Values are given in arbitrary units using Agatston method for quantification of valve calcification.

Grading of aortic regurgitation[18]

Parameters	Mild	Moderate	Severe
Qualitative			
Aortic valve morphology	Normal/Abnormal	Normal/Abnormal	Abnormal/flail/large coaptation defect
Colour flow AR jet width[a]	Small in central jets	Intermediate	Large in central jet, variable in eccentric jets
CW signal of AR jet	Incomplete/faint	Dense	Dense
Diastolic flow reversal in descending aorta	Brief, protodiastolic flow reversal	Intermediate	**Holodiastolic flow reversal** (end-diastolic velocity >20 cm/s)
Semi-quantitative			
VC width (mm)	<3	Intermediate	>6
Pressure half-time (ms)[b]	>500	Intermediate	<200
Quantitative			
EROA (mm^2)	<10	10–19; 20–29[c]	≥30
R Vol (mL)	<30	30–44; 45–59[c]	≥60
+LV size[d]			

AR, aortic regurgitation; CW, continuous-wave; LA, left atrium; EROA, effective regurgitant orifice area; LV, left ventricle; R Vol, regurgitant volume; VC, vena contracta.

[a] At a Nyquist limit of 50–60 cm/s.

[b] PHT is shortened with increasing LV diastolic pressure, vasodilator therapy, and in patients with a dilated compliant aorta or lengthened in chronic AR.

[c] Grading of the severity of AR classifies regurgitation as mild, moderate or severe and subclassifies the moderate regurgitation group into 'mild-to-moderate' (EROA of 10–19 mm or an R Vol of 30–44 mL) and 'moderate-to-severe' (EROA of 20–29 mm^2 or an R Vol of 45–59 mL).

[d] Unless for other reasons, the LV size is usually normal in patients with mild AR. In acute severe AR, the LV size is often normal. In chronic severe AR, the LV is classically dilated. Accepted cut-off values for non-significant LV enlargement: LV end-diastolic diameter <56 mm, LV end-diastolic volume <82 mL/m^2, LV end-systolic diameter <40 mm, LV end-systolic volume <30 mL/m^2.

Evaluation of severity of prosthetic

PVR severity	Mild	Moderate	Severe
Aortography	Contrast does not fill entire LV and clears with each cycle	Intermediate	Contrast fills LV on first beat, ending with greater density than in ascending aorta
Invasive Hemodynamic Parameters			
AR index*	≥25	<25	<25
Dicrotic notch	Present	Present	Effaced or absent
Echocardiography: TTE and/or TEE			
Structural parameters			
Position of prosthesis	Usually normal	Variable	Frequently abnormal
Stent and leaflet morphology	Usually normal	Variable	Frequently abnormal
Doppler Parameters			
Qualitative			
Proximal flow convergence (CD)	Absent	May be present	Often present
AR velocity waveform density (CWD)	Soft	Dense	Dense
Diastolic flow reversal (PWD) in – Proximal descending aorta[†,‡] – Abdominal aorta	 – Brief, early diastolic – Absent	 – May be holodiastolic – Absent	 – Holodiastolic (enddiastolic velocity ≥20 cm/s) – Present

2D, Two-dimensional; *3D,* three dimensional; *AR,* aortic regurgitation; *CD,* color flow Doppler; *CWD,* continuous-wave Doppler; *EROA,* effective regurgitant orifice area; *LVOT,* left ventricular outflow tract; *PVR,* paravalvular regurgitation; *PHT,* pressure half-time; *PWD,* pulsed wave Doppler; *TTE,* transthoracic echocardiography; *TEE,* transesophageal echocardiography.

aortic regurgitation after TAVR[20]

PVR severity	Mild	Moderate	Severe
Semi-quantitative			
Vena contracta width (cm) (CD)	<0.3	0.3-0.6	>0.6
Vena contracta area (cm^2)[§] (2D/3D CD)[§]	<0.10	0.10-0.29	≥0.30
Circumferential extent of PVR (%) (CD)[‖,◊]	<10	10-29	≥30
Jet deceleration rate (PHT, ms)[#] (CWD)	Variable Usually >500	Variable 200-500	Steep Usually <200**
Quantitative			
Regurgitant volume (mL)	<30	30-59[††]	>60[††] (May be lower in low flow states)
Regurgitant fraction (%)	<30	30-49	≥50
EROA (cm^2)[‡‡]	<0.10	0.10-0.29[††]	≥0.30[††]

* One of the hemodynamic parameters (Table 1) used in the catheterization laboratory after TAVR.

† More specific in peri-procedural or early post-procedural assessment. Holodiastolic flow reversal may not be seen in severe bradycardia.

‡ Dependent on aortic compliance; limits its utility in the elderly population; influenced by heart rate.

§ The vena contracta area is measured by planimetry of the vena contracta of the jet(s) on 2D or 3D color Doppler images in the short-axis view.

‖ Measured as the sum of the circumferential lengths of each regurgitant jet vena contracta (not including the non-regurgitant space between the separate jets) divided by the circumference of the outer edge of the valve.

◊ Circumferential extent of PVR best not to be used alone, but in combination with vena contracta width and/or area.

Influenced by LV and aortic compliance, particularly in this population.

** May not be specific for severe aortic regurgitation in the setting of abnormal aortic or ventricular compliance.

†† May be functionally important at lower values depending on the acuteness of PVR, and size and function of the LV. When total stroke volume is calculated from LV volumes, use of 3D echocardiography and preferably contrast echocardiography is recommended to avoid underestimation of LV volumes, RVol, and RF.

‡‡ EROA is infrequently used in AR. It is derived using the volumetric approach, not PISA.

Grading of prosthetic aortic valve stenosis in mechanical and stented biological valves[23,*]

	Normal	Possible Stenosis	Suggests Significant Stenosis
Peak velocity[Ψ]	<3 m/s	3–4 m/s	>4 m/s
Mean gradient[Ψ]	<20 mmHg	20–35 mmHg	>35 mmHg
Doppler velocity index	≥0.30	0.29–0.25	**<0.25**
Effective orifice area	>1.2 cm^2	1.2–0.8 cm^2	**<0.8 cm^2**
Contour of the jet velocity	Triangular, Early peaking	Triangular to Intermediate	Rounded, symmetrical contour
Acceleration time	<80 ms	80–100 ms	>100 ms

Reference website for prosthetic heart valves and annuloplasty rings: www.valveguide.ch

* In conditions of normal or near normal stroke volume (50–70 ml).

Ψ These parameters are more affected by flow, including concomitant aortic regurgitation.

Grading of prosthetic aortic valve regurgitation[23]

Parameters	Mild	Moderate	Severe
Valve structure and motion	Usually normal	Abnormal Ψ	Abnormal Ψ
Mechanical or Bioprosthetic			
Structural parameters			
LV size	Normal Φ	Normal or mildly dilated Φ	Dilated Φ
Doppler Parameters (Qualitative or Semi-Quantitative)			
Jet width in central jets (% LVO diameter): Color*	Narrow (≤ 25 %)	Intermediate 26 %–64 %)	Large (≥65 %)
Jet density: CW	Incomplete or faint	Dense	Dense
Jet deceleration rate (PHT, ms): CW §	Slow (>500)	Variable (200–500)	Steep (<200)
LVO flow compared to pulmonary flow: PW	Slightly increased	Intermediate	Greatly increased
Diastolic flow reversal in the descending aorta: PW	Absent or brief early diastolic	Intermediate	**Prominent, holodiastolic**
Doppler Parameters (Quantitative)			
Regurgitant Volume	<30 ml/beat	30–59 ml/beat	≥60 ml/beat
Regurgitant Fraction (%)	<30 %	30–50 %	≥50 %

Ψ Abnormal mechanical valves: eg. Immobile occluder (valvular regurgitation), dehiscence or rocking (paravalvular regurgitation); Abnormal biologic valves: eg. Leaflet thickening or prolapse (valvular), dehiscence or rocking (paravalvular regurgitation).

* Parameter applicable to central jets and is less accurate in eccentric jets; Nyquist limit of 50–60 cm/s.

§ Influenced by LV compliance.

Φ Applies to chronic, late post operative AR in the absence of other etiologies.

Grading of mitral stenosis[11]
Mitral annular calcification (MAC)

	Mild	Moderate	Severe
Specific findings			
Valve area (cm^2)	>1.5	1.0–1.5	**<1.0**
Supportive findings			
Mean gradient (mmHg)[a]	<5	5–10	>10
Pulmonary artery pressure (mmHg)	<30	30–50	>50

In the absence of > 1+ mitral or aortic regurgitation, the continuity equation (VTI MV and LVOT) is the preferred method for measuring mitral valve area (MVA).[30]
A mitral valve dimensionless index of 0.35-0.50 is consistent with a severe calcific mitral stenosis (MVA ≤ 1.5 cm^2) an an index < 0.35 suggests very calcific mitral stenosis of MVA ≤1.0 cm^2.[30]

[a] At heart rates between 60 and 80 bpm and in sinus rhythm.

Grading of prosthetic mitral valve stenosis[23]

	Normal*	Possible Stenosis	Suggests Significant Stenosis*
Peak velocity $^{\Phi\Psi}$	<1.9 m/s	1.9–2.5 m/s	≥2.5 m/s
Mean gradient $^{\Psi}$	≤5 mmHg	6–10 mmHg	**>10 mmHg**
VTI_{PrMV}/VTI_{LVO} $^{\Psi}$	<2.2	2.2–2.5	>2.5
EOA	≥2.0 cm^2	1–2 cm^2	<1 cm^2
Pressure half-time	<130 ms	130–200 ms	>200 ms

* Best specificity for normality or abnormality is seen if the majority of the parameters listed are normal or abnormal, respectively.

Ψ Slightly higher cut-offs are seen in some bioprosthetic valves, these parameters are also abnormal in the presence of significant prosthetic mitral regurgitation.

Grading of mitral regurgitation[21]

Parameters	Mild	Moderate	Severe
Qualitative			
MV morphology	Normal/Abnormal	Normal/Abnormal	Flail lefleat/Ruptured PMs
Colour flow MR jet	Small, central	Intermediate	**Very large central jet or eccentric jet adhering, swirling and reaching the posterior wall of the LA**
Flow convergence zone[a]	No or small	Intermediate	**Large**
CW signal of MR jet	Faint/Parabolic	Dense/Parabolic	Dense/Triangular
Semi-quantitative			
VC width (mm)	<3	Intermediate	≥7 (>8 for biplane)[b]
Pulmonary vein flow	Systolic dominance	Systolic blunting	**Systolic flow reversal[c]**
Mitral inflow	A wave dominant[d]	Variable	E wave dominant (>1.5 cm/s)[e]
TVI mit /TVI Ao	<1	Intermediate	>1.4
Quantitative			
EROA (mm^2)	<20	20–29; 30–39[f]	≥40
R Vol (mL)	<30	30–44; 45–59[f]	≥60
+ LV and LA size and the systolic pulmonary pressure[g]			

CW, continuous-wave; LA, left atrium; EROA, effective regurgitant orifice area; LV, left ventricle; MR, mitral regurgitation; R Vol, regurgitant volume; VC, vena contracta.

[a] At a Nyquist limit of 50–60 cm/s

[b] For average between apical four- and two-chamber views.

[c] Unless other reasons of systolic blunting (atrial fibrillation, elevated LA pressure).

[d] Usually after 50 years of age;

[e] in the absence of other causes of elevated LA pressure and of mitral stenosis.

[f] Grading of severity of organic MR classifies regurgitation as mild, moderate or severe, and sub-classifies the moderate regurgitation group into 'mild-to-moderate' (EROA of 20–29 mm or a R Vol of 30–44 mL) and 'moderate-to-severe' (EROA of 30–39 mm^2 or a R Vol of 45–59 mL).

[g] Unless for other reasons, the LA and LV size and the pulmonary pressure are usually normal in patients with mild MR. In acute severe MR, the pulmonary pressures are usually elevated while the LV size is still often normal. In chronic severe MR, the LV is classically dilated. Accepted cut-off values for non significant left-sided chambers enlargement: LA volume <36 mL/m^2, LV end-diastolic diameter <56 mm, LV end-diastolic volume <82 mL/m^2, LV end-systolic diameter <40 mm, LV end-systolic volume <30 mL/m^2, LA diameter <39 mm, LA volume <29 mL/m^2.

Grading of mitral regurgitation after

Echocardiographic and Doppler

Parameter	Mild	Moderate	Severe
Structural			
Morphology	Device appropriately positioned/expected or normal valve motion	No specific criteria	Abnormal device position/flail valve (single leaflet detachment, dehiscence, incomplete TMVR expansion etc.)
LA and LV volumes	Reduction in size from baseline or normalization	Minimal change	Enlarged with no change/worsening from baseline, particularly in primary MR
Qualitative			
Color Doppler jet (size, number, eccentricity)	One or two small, narrow jets	More than mild but does not meet severe criteria	Large central jet/multiple jets/eccentric jet(s) of any size wrapping around LA
Flow convergence size†	None or small	Intermediate	Large
Mitral inflow pattern	A-wave dominant	No specific criteria	No specific criteria
Pulmonary vein flow pattern‡	Normal	Blunted systolic flow	Systolic flow reversal
CW Doppler of MR jet (density, contour)	Faint, parabolic contour	No specific criteria	Dense, triangular contour

CW, continuous-wave; *EROA,* effective regurgitant orifice area; *LA,* left atrium; *LV,* left ventricle; *MR,* mitral regurgitation; *PISA,* proximal isovelocity surface area; *PVR,* paravalvular regurgitation; *TMVR,* transcatheter mitral valve replacement; *VCA,* vena contracta area; *VCW,* vena contracta width.

transcatheter interventions[20]

parameters for grading MR severity by TEE or TTE after transcatheter MV interventions*

Parameter	Mild	Moderate	Severe
Semi-quantitative			
Vena contracta width (cm)	Single jet with VCW ≤0.3	Single jet with VCW 0.4–0.6	Any jet with VCW ≥0.7 or ≥2 moderate jets
Quantitative			
Vena contracta area by 3D planimetry (cm^2)§	Single jet with VCA <0.2	Single jet with VCA 0.2–0.39	Any jet with VCA ≥0.4 or ≥2 moderate jets
EROA by PISA (cm^2)	<0.2 Not recommended after edge-to-edge repair or in PVR	0.2–0.39 Not recommended after edge-to-edge repair or in PVR	≥0.4 Not recommended after edge-to-edge repair or in PVR
Regurgitant volume (mL)	<30	30–59‖	≥60‖ (May be lower in low flow states)
Regurgitant fraction (%)	<30	30–49	≥50

* All parameters have limitations and an integrated approach must be used that weighs the strength of each echocardiographic measurement. All signs andmeasures should be interpreted in an individualized manner that accounts for body size, hemodynamics, and other patient characteristics.

† Flow convergence is usually small with a PISA radius ≤0.3 cm and large with a radius ≥1 cm at a Nyquist limit 25–40 cm/s.

‡ Influenced by many other factors (LV diastolic function, atrial fibrillation, LA pressure).

§ by Color Doppler; further validation is needed.

‖ Total stroke volume (inclusive of the RVol) is calculated from LV volumes. Use of 3D echocardiography and preferably contrast echocardiography is recommended to avoid underestimation of LV volumes, RVol, and RF.

Grading of mitral regurgitation by 3D vena contracta[29]

	FMR group		DMR group		*P*-value (ANOVA)
	Moderate MR (*n*=113)	Severe MR (*n*=146)	Moderate MR (*n*=125)	Severe MR (*n*=116)	
VCA_{3D} (cm^2)	0.30 ± 0.07	0.52 ± 0.11°	0.29 ± 0.08	0.62 ± 0.21*°	<0.001

Values are mean ± SD;

* $P < 0.05$ vs. FMR.

° $P < 0.05$ vs. moderate MR.

DMR, degenerative mitral regurgitation; EF, ejection fraction; $EROA_{PISA}$, effective regurgitation orifice area according to PISA method; FMR, functional mitral regurgitation; FNR, functional mitral insufficiency; LAVi, left atrial volume index; LVVDi/LVVSi, left ventricular end-diastolic/end-systolic volume; MR, mitral regurgitation; RR, blood pressure; RV_{3D}, regurgitation volume using 3D volumes; RV_{PISA}, regurgitation volume according to $EROA_{PISA}$; RV_{VCA}, regurgitation volume according to VCA_{3D}; SV_{3D}, stroke volume; VC, vena contracta width; VCA_{3D}, vena contracta area by 3D colour Doppler.

Grading of prosthetic mitral valve regurgitation[23]

Parameters	Mild	Moderate	Severe
Structural Parameters			
LV size	Normal*	Normal or dilated	Usually dilated**
Prosthetic valve [Φ]	Usually normal	Abnormal [Y]	Abnormal [Y]
Doppler Parameters			
Color flow jet area [ΨΦ]	Small, central jet (usually <4 cm^2 or <20 % of LA area)	Variable	Large central jet (usually >8 cm^2 or >40 % of LA area) or variable size wall-impinging jet swirling in LA
Flow convergence [ς]	No or minimal	Intermediate	**Large**
Jet density: CW [Φ]	Incomplete or faint	Dense	Dense
Jet contour: CW [Φ]	Parabolic	Usually parabolic	Early peaking – triangular
Pulmonary venous flow	Systolic dominance [§]	Systolic blunting [§]	Systolic flow reversal [†]
Quantitative Parameters			
VC width (cm) [Φ]	<0.3	0.3–0.59	≥0.6
R Vol (ml/beat)	<30	30–59	≥60
RF (%)	<30	30–49	≥50
EROA (cm^2)	<0.20	0.20–0.49	≥0.50

Φ Parameter may be best evaluated or obtained with TEE, particularly in mechanical valves. * LV size applied only to chronic lesions. ** In the absence of other etiologies of LV enlargement and acute MR. Y Abnormal mechanical valves: e.g. Immobile occluder (valvular regurgitation), dehiscence or rocking (paravalvular regurgitation); abnormal biologic valves: e.g. Leaflet thickening or prolapse (valvular), dehiscence or rocking (paravalvular regurgitation). Ψ At a Nyquist limit of 50–60 cm/s. ς Minimal and large flow convergence defined as a flow convergence radius <0.4 cm and ≥0.9 cm for central jets, respectively, with a baseline shift at a Nyquist of 40 cm/s; cut-offs for eccentric jets may be higher. § Unless other reasons for systolic blunting (e.g. atrial fibrillation, elevated left atrial pressure). † Pulmonary venous systolic flow reversal is specific but not sensitive for severe MR. φ These quantitative parameters are less well validated than in native MR.

Findings indicative of haemodynamically significant tricuspid stenosis[11]

Specific findings	
Mean pressure gradient	≥5 mmHg
Inflow time: velocity integral	>60 cm
$T_{1/2}$	≥190 ms
Valve area by continuity equation[a]	≤1 cm^2[a]
Supportive findings	
Enlarged right atrium ≥moderate	
Dilated inferior vena cava	

[a] Stroke volume derived from left or right ventricular outflow. In the presence of more than mild TR, the derived valve area will be underestimated. Nevertheless, a value ≤1 cm^2 implies a significant haemodynamic burden imposed by the combined lesion.

Grading of tricuspid regurgitation[21]

Parameters	Mild	Moderate	Severe
Qualitative			
Tricuspid valve morphology	Normal/abnormal	Normal/abnormal	Abnormal/flail/large coaptation defect
Colour flow TR jet[a]	Small, central	Intermediate	Very large central jet or eccentric wall impinging jet
CW signal of TR jet	Faint/Parabolic	Dense/Parabolic	Dense/Triangular with early peaking (peak <2 m/s in massive TR)
Semi-quantitative			
VC width (mm)[a]	Not defined	<7	≥7
PISA radius (mm)[b]	≤5	6–9	>9
Hepatic vein flow[c]	Systolic dominance	Systolic blunting	**Systolic flow reversal**
Tricuspid inflow	Normal	Normal	E wave dominant (≥1 cm/s)[d]
Quantitative			
EROA (mm^2)	Not defined	Not defined	≥40
R Vol (mL)	Not defined	Not defined	≥45
+ RA/RV/IVC dimension[e]			

CW, continuous-wave; EROA, effective regurgitant orifice area; RA, right atrium; RV, right ventricle; R Vol, regurgitant volume; TR, tricuspid regurgitation; VC, vena contracta.

[a] At a Nyquist limit of 50–60 cm/s.

[b] Baseline Nyquist limit shift of 28 cm/s.

[c] Unless other reasons of systolic blunting (atrial fibrillation, elevated RA pressure).

[d] In the absence of other causes of elevated RA pressure.

[e] Unless for other reasons, the RA and RV size and IVC are usually normal in patients with mild TR. An end-systolic RV eccentricity index >2 is in favour of severe TR. In acute severe TR, the RV size is often normal. In chronic severe TR, the RV is classically dilated. Accepted cut-off values for non significant right-sided chambers enlargement (measurements obtained from the apical four-chamber view): Mid RV dimension ≤33 mm, RV end-diastolic area ≤28 cm^2, RV end-systolic area ≤16 cm^2, RV fractional area change >32 %, maximal RA volume ≤33 mL/m^2. An IVC diameter <1.5 cm is considered normal.

Expansion grading scheme for severe tricuspid regurgitation[22]

Proposed expansion of the «Severe» grade

Variable	Mild	Moderate	Severe	Massive	Torrential
VC (biplane)	< 3 mm	3–6.9 mm	7–13 mm	14–20 mm	≥ 21 mm
EROA (PISA)	<20 mm^2	20–39 mm^2	40–59 mm^2	60–79 mm^2	≥ 80 mm^2
3D VCA or quantitative EROA[a]			75–94 mm^2	95–114 mm^2	≥ 115 mm^2

VC, vena contracta; EROA, effective regurgitant orifice area; 3D VCA, three-dimensional vena contracta area.
[a] 3D VCA and quantitative Doppler EROA cut-offs may be larger than PISA EROA.

Grading of prosthetic tricuspid valve stenosis[23]

Prosthetic Valve	Consider Valve Stenosis*
Peak velocity $^{\Phi}$	>1.7 m/s
Mean gradient $^{\Phi}$	≥6 mmHg
Pressure half-time	≥230 ms

* Because of respiratory variation, average at least 5 cycles.
Φ May be increased also with concomitant valvular regurgitation.

Grading of residual regurgitation after tricuspid valve interventions

Proposed grading of the severity of residual tricuspid regurgitation by echocardiography after tricuspid valve interventions

Parameters	Mild	Moderate	Severe
Qualitative			
Color jet area*	Small, narrow, central	Moderate central	Large central jet or eccentric wallimpinging jet(s) of variable size swirling in RA
Flow-convergence zone†	Not visible or small	Intermediate in size	Large
TR CW Doppler velocity waveform (density and shape)	Faint/partial/parabolic	Dense, parabolic or triangular	Dense, often triangular
Tricuspid inflow	A-wave dominant	Variable	E-wave dominant‡,§
Semi-quantitative			
VC width (cm)*	<0.3	0.3–0.69	≥0.7 or ≥2 moderate jets
PISA radius (cm)†	≤0.5	0.6–0.9	>0.9
Hepatic vein flow‡	Systolic dominance	Systolic blunting	Systolic flow reversal
Quantitative			
EROA (cm^2)#	<0.20	0.20–0.39	≥0.40
RVol (mL)#	<30	30–44	≥45

CW, Continuous-wave; EROA, effective regurgitant orifice area; RA, right atrium; RVol, regurgitant volume; TR, tricuspid regurgitation; VC, vena contracta.

* With Nyquist limit >50–60 cm/s.

† Not well-validated for quantitation; best used after interventions that leave the valve intact; baseline Nyquist limit shift to 25–35 cm/s.

‡ Non-specific, influenced by other factors (RV diastolic function, atrial fibrillation, RA pressure).

§ Not suitable in procedures intervening with valve leaflets (e.g., edge-to-edge repair).

\# EROA from 2D PISA is not suitable in patients with edge-to-edge valve repair because of multiplicity of jets and non-hemispheric shape of flow convergence. Needs further validation of cut-offs by either PISA or volumetric methods.

Grading of pulmonary stenosis[11]

	Mild	Moderate	Severe
Peak velocity (m/s)	<3	3–4	>4
Peak gradient (mmHg)	<36	36–64	>64

Grading of prosthetic pulmonary valve stenosis[23]

Cusp or leaflet thickening or immobility
Narrowing of forward color map
Peak velocity through the prosthesis >3 m/s, or >2 m/s through a homograft
Increase in peak velocity on serial studies
Impaired RV function or elevated RV systolic pressure

Grading of pulmonary regurgitation[18]

Parameters	Mild	Moderate	Severe
Qualitative			
Pulmonic valve morphology	Normal	Normal/abnormal	Abnormal
Colour flow PR jet width[a]	Small, usually <10 mm in length with a narrow origin	Intermediate	Large, with a wide origin; may be brief in duration
CW signal of PR jet[b]	Faint/slow deceleration	Dense/variable	Dense/steep deceleration, **early termination of diastolic flow**
Pulmonic vs. Aortic flow by PW	Normal or slightly increased	Intermediate	Greatly increased
Semi-quantitative			
VC width (mm)	Not defined	Not defined	Not defined
Quantitative			
EROA (mm^2)	Not defined	Not defined	Not defined
R Vol (mL)	Not defined	Not defined	Not defined
+RV size[c]			

PR, pulmonic regurgitation; CW, continuous wave; EROA, effective regurgitant orifice area; PW, pulse wave; RV, right ventricle; R Vol, regurgitant volume; VC, vena contracta.

[a] At a Nyquist limit of 50–60 cm/s.

[b] Steep deceleration is not specific for severe PR.

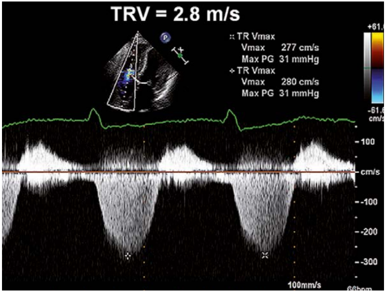
[c] Unless for other reasons, the RV size is usually normal in patients with mild PR. In acute severe PR, the RV size is often normal. Accepted cut-off values for non-significant RV enlargement (measurements obtained from the apical four-chamber view): Mid RV dimension ≤33 mm, RV end-diastolic area ≤28 cm^2, RV end-systolic area ≤16 cm^2, RV fractional area change >32 %, maximal.

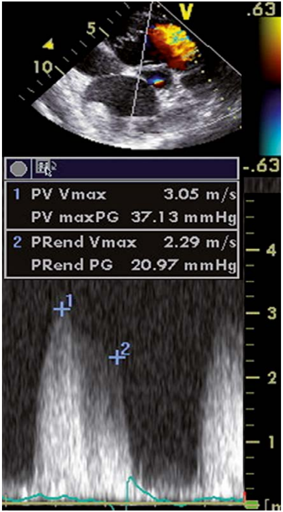
Grading of prosthetic pulmonary valve regurgitation[23]

Parameters	Mild	Moderate	Severe
Valve structure	Usually normal	Abnormal or valve dehiscence	Abnormal or valve dehiscence
RV Size	Normal*	Normal or dilated	Dilated #
Jet size by color Doppler (Central jets) **	Thin with a narrow origin; Jet width ≤25 % of pulmonic annulus	Intermediate; Jet width 26 %–50 % of pulmonic annulus	Usually large, with a wide origin; Jet width >50 % of pulmonic annulus; may be brief in duration
Jet density by CW Doppler	Incomplete or faint	Dense	Dense
Jet deceleration rate by CW Doppler	Slow deceleration	Variable deceleration	Steep deceleration §, **early termination of diastolic flow**
Pulmonic systolic flow compared to systemic flow by PW Doppler †	Slightly increased	Intermediate	Greatly increased
Diastolic flow reversal in the pulmonary artery	None	Present	Present

* Unless other cause of RV dilatation exists, including residual post-surgical dilatation.
** At a Nyquist limit of 50–60 cm/s; parameter applies to central jets and not eccentric jets.
§ Steep deceleration is not specific for severe PR.
† Cut-off values for regurgitant volume and fraction are not well validated.
# Unless there are other reasons for RV enlargement. Acute PR is an exception. RV volume overload is usually accompanied with typical paradoxical septal motion.

Pulmonary Hemodynamics[24]





sPAP	$= 4\ (TRV_{max})^2 + RAP$ Abnormal >35–40 mmHg
mPAP	$= 4$ (Early PI velocity)^2 + RAP
mPAP	= 1/3 sPAP + 2/3 dPAP
mPAP	= 79 – 0.45 x Acceleration Time Abnormal ≥25 mmHg
dPAP	$= 4$ (End PI velocity)^2 + RAP

sPAP	= Systolic pulmonary artery pressure
mPAP	= Mean pulmonary artery pressure
dPAP	= Diastolic pulmonary artery pressure
RAP	= Right atrial pressure

Echocardiographic signs suggesting pulmonary hypertension[25]

A: The ventricles[a]	B: Pulmonary artery[a]	C: Inferior vena cava and right atrium[a]
Right ventricle/ left ventricle basal diameter ratio >1.0	Right ventricular outflow Doppler acceleration time <105 msec and/or midsystolic notching	Inferior cava diameter >21 mm with decreased inspiratory collapse (<50% with a sniff or <20% with quiet inspiration)
Flattening of the interventricular septum (left ventricular eccentricity index >1.1 in systole and/or diastole)	Early diastolic pulmonary regurgitation velocity >2.2 m/sec	Right atrial area (end-systole) >18 cm^2
	PA diameter >25 mm	

PA = pulmonary artery.
[a] Echocardiographic signs from at least two different categories (A/B/C) from the list should be present to alter the level of echocardiographic probability of pulmonary hypertension.

Pulmonary artery systolic pressure at rest and exercise[26]

Level of pulmonary artery systolic pressure at rest, at first workload step (25 W), at peak exercise, and peak exercise-induced increase in pulmonary artery systolic pressure within each range of age

	All (n = 70)	Age 20–30 (n = 13)	Age 30–40 (n=10)	Age 40–50 (n = 14)	Age 50–60 (n = 12)	Age 60–70 (n = 11)	Age 70–80 (n = 10)
PASP at rest (mmHg)	27 ± 4	27 ± 4	29 ± 3	28 ± 3	26 ± 4	27 ± 4	28 ± 6
PASP at first workload step (mmHg)	34 ± 6	31 ± 4	33 ± 5	34 ± 4	31 ± 6	37 ± 9	37 ± 5
PASP at peak exercise (mmHg)	51 ± 9	45 ± 7	51 ± 6	52 ± 9	53 ± 4	54 ± 12*	58 ± 7*
Increase in PASP (mmHg)	27 ± 8	22 ± 8	24 ± 7	27 ± 10	29 ± 5	29 ± 9	30 ± 8

* No significant differences between strata except for PASP at peak exercise: $P = 0.01$.

Echocardiographic probability of PAHT of pat with suspicion of PAHT[25, Table 8A]

Echocardiographic probability of pulmonary hypertension in symptomatic patients with a suspicion of pulmonary hypertension

Peak tricuspid regurgitation velocity (m/s)	Presence of other echo ‘PH signs’	Echocardiographic probability of pulmonary hypertension
≤2.8 or not measurable	No	Low
≤2.8 or not measurable	Yes	Intermediate
2.9–3.4	No	
2.9–3.4	Yes	High
>3.4	Not required	

PH = pulmonary hypertension.

The charts are adapted from:

[1] Lang RM et al. Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of cardiovascular Imaging. J Am Soc Echocardiogr. 2015;28:1-39. DOI: 10.1016/j.echo.2014.10.003

[2] Galderisi M et al. Standardization of adult transthoracic echocardiography reporting in agreement with recent chamber quantification, diastolic function, and heart valve disease recommendations: an expert consensus document of the European Association of Cardiovascular Imaging. Eur Heart J Cardiovasc Imaging. 2017;18:1301-1310. DOI: 10.1093/ehjci/jex244

[3] Peluso D et al. Right atrial size and function assessed with three-dimensional and speckle-tracking echocardiography in 200 healthy volunteers. Eur Heart J Cardiovasc Imaging. 2013;14:1106-14. DOI: 10.1093/ehjci/jet024

[4] Vizzardi E et al., Ascending Aortic Dimensions in Hypertensive Subjects: Reference Values for Two-Dimensional Echocardiography. Journal of the American Society of Echocardiography. 2016; 29(9): 827-837. DOI: 10.1016/j.echo.2016.03.016

[5] Goldstein SA et al. Multimodality imaging of diseases of the thoracic aorta in adults: from the American Society of Echocardiography and the European Association of Cardiovascular Imaging: endorsed by the Society of Cardiovascular Computed Tomography and Society for Cardiovascular Magnetic Resonance. J Am Soc Echocardiogr. 2015;28:119-82. DOI: 10.1016/j.echo.2014.11.015

[6] Devereux RB et al. Normal limits in relation to age, body size and gender of two-dimensional echocardiographic aortic root dimensions in persons >/=15 years of age. Am J Cardiol 2012;110:1189-94. DOI: 10.1016/j.amjcard.2012.05.063

[7] Campens L et al. Reference values for echocardiographic assessment of the diameter of the aortic root and ascending aorta spanning all age categories. Am J Cardiol. 2014;114:914-20. DOI: 10.1016/j.amjcard.2014.06.024

[8] Zile MR et al., New concepts in diastolic dysfunction and diastolic heart failure: Part I: Diagnosis, prognosis, and measurements of diastolic function. Circulation 2002; 105: 1387-1393. DOI: 10.1161/hc1102.105289

[9] Nagueh SF et al., Recommendations for the Evaluation of Left Ventricular Diastolic Function by Echocardiography: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr. 2016;29: 277-314. DOI: 10.1016/j.echo.2016.01.011

[10] Nagueh SF et al., Recommendations for the evaluation of left ventricular diastolic function by echocardiography. J Am Soc Echocardiogr 2009; 22:107-33. DOI: 10.1016/j.echo.2008.11.023

[11] Baumgartner H et al. Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. Eur J Echocardiogr 2009; 10: 1-25. DOI: 10.1093/ejechocard/jen303

[12] David TE. Is prosthesis-patient mismatch a clinically relevant entity? Circulation 2005; 111: 3186-3187. DOI: 10.1161/CIRCULATIONAHA.105.545657

[13] Pibarot P, Garcia D, Dumesnil JG. Energy loss index in aortic stenosis: from fluid mechanics concepts to clinical application. Circulation. 2013; 127: 1101-1104. DOI: 10.1161/CIRCULATIONAHA.113.001130

[14] Garcia D, Pibarot P, Dumesnil JG, Sakr F, Durand LG. Assessment of aortic valve stenosis severity: a new index based on the energy loss concept. Circulation. 2000; 101: 765-771. DOI: 10.1161/01.cir.101.7.765

[15] Bahlmann E, Cramariuc D, Gerdts E, Gohlke-Baerwolf C, Nienaber CA, Eriksen E, Wachtell K, Chambers J, Kuck KH, Ray S. Impact of pressure recovery on echocardiographic assessment of asymptomatic aortic stenosis: a SEAS substudy. JACC Cardiovasc Imaging. 2010; 3: 555-562. DOI: 10.1016/j.jcmg.2009.11.019

[16] Bahlmann E, Gerdts E, Cramariuc D, Gohlke-Baerwolf C, Nienaber CA, Wachtell K, Seifert R, Chambers JB, Kuck KH, Ray S. Prognostic value of energy loss index in asymptomatic aortic stenosis. Circulation. 2013; 127: 1149-1156. DOI: 10.1161/CIRCULATIONAHA.112.078857

[17] 2021 ESC/EACTS Guidelines for the management of valvular heart disease. European Heart Journal (2022) 43, 561-632. DOI: 10.1093/eurheartj/ehab395

[18] Lancellotti P et al., European Association of Echo-cardiography recommendations for the assessment of valvular regurgitation. Part 1: aortic and pulmonary regurgitation (native valve disease). Eur J Echo-cardiogr 2010; 11: 223-244. DOI: 10.1093/ejechocard/jeq030

[19] European Heart Journal - Cardiovascular Imaging (2022) 23, e34-e61. DOI: 10.1093/ehjci/jeab154

[20] Zoghbi WA et al. Guidelines for the Evaluation of Valvular Regurgitation After Percutaneous Valve Repair or Replacement: A Report from the American Society of Echocardiography Developed in Collaboration with the Society for Cardiovascular Angiography and Interventions, Japanese Society of Echocardiography, and Society for Cardiovascular Magnetic Resonance. J Am Soc Echocardiogr. 2019;32:431-475. DOI: 10.1016/j.echo.2019.01.003

[21] Lancellotti P et al. European Association of Echo-cardiography recommendations for the assessment of valvular regurgitation. Part 2: mitral and tricuspid regurgitation (native valve disease). Eur J Echocardiogr 2010;11: 307-332. DOI: 10.1093/ejechocard/jeq031

[22] Rodes-Cabau J, Hahn RT, Latib A, Laule M, Lauten A, Maisano F et al. Transcatheter therapies for treating tricuspid regurgitation. J Am Coll Cardiol 2016;67:1829-45. DOI: 10.1016/j.jacc.2016.01.063

[23] Zoghbi WA et al. Recommendations for evaluation of prosthetic valves with echocardiography and doppler ultrasound J Am Soc Echocardiogr. 2009; 22(9): 975-1014. DOI: 10.1016/j.echo.2009.07.013

[24] Rudski LG et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography. J Am Soc Echocardiogr. 2010; 23: 685-713. DOI: 10.1016/j.echo.2010.05.010

[25] Galiè N et al. 2015 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension: The Joint Task Force for the Diagnosis and Treatment of Pulmonary Hypertension of the European Society of Cardiology (ESC) and the European Respiratory Society (ERS): Endorsed by: Association for European Paediatric and Congenital Cardiology (AEPC), International Society for Heart and Lung Transplantation (ISHLT). Eur Heart J. 2016;37:67-119. DOI: 10.1093/eurheartj/ehv317

[26] Mahjoub H et al. Effects of age on pulmonary artery systolic pressure at rest and during exercise in normal adults. Eur J Echocardiogr. 2009; 10(5): 635-40. DOI: 10.1093/ejechocard/jep024

[27] Baumgartner H, Hung J, Bermejo J, Chambers JB, Edvardsen T, Goldstein S, Lancellotti P, LeFevre M, Miller F, Otto CM. Focus update on the echocardiographic assessment of aortic valve stenosis: EAE/ASE recommendations for clinical practice. Eur Heart J Cardiovasc Imaging 017;18:254-275. DOI: 10.1093/ehjci/jew335

[28] Otto CM et al. 2020 ACC/AHA Guideline for the Management of Patients With Valvular Heart Disease: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation. 2021;143:e72-e227. DOI: 10.1161/CIR.0000000000000923

[29] Goebel B et al. Vena contracta area for severity grading in functional and degenerative mitral regurgitation: a transoesophageal 3D colour Doppler analysis in 500 patients. Eur Heart J Cardiovasc Imaging. 2018. 19, 639-646. DOI: 10.1093/ehjci/jex056

[30] Jeffrey J.SilbigerMD: Mitral Annular Calcification and Calci fic Mitral Stenosis: Role of Echocardiography in Hemodynamic Assessment and Management. J Am Soc Echocardiogr 2021;34:923-31. DOI: 10.1016/j.echo.2021.04.007

[31] Choi KH, Yang JH, Seo JH, Hong D, Youn TH, Joh HS, Lee SH, Kim D, Park TK, Lee JM, et al. Role of invasive LVEDP measurement in HFpEF. J Am Heart Assoc. 2023. doi: 10.1161/JAHA.122.027581. DOI: 10.1161/JAHA.122.027581

[32] Niclas D'Elia et al: Normal Global longitudinal Strain- An Individual Patient Meta-Analysis. JACC: Cardiovascular Imaging Vol 13, No1, 167-168, 2020. DOI: 10.1016/j.jcmg.2019.07.020

[33] Mukherjee M. et al., Guidelines for the Echocardiographic Assessment of the Right Heart in Adults and Special Considerations in Pulmonary Hypertension: Recommendations from the American Society of Echocardiography. Guidelines and standards, Volume 38, Issue 3, P141-186, March 2025. https://doi.org/10.1016/j.echo.2025.01.006

Table of content

We thank A.Menarini for the unrestricted grant
to summarize these guidelines

A. MENARINI
Pharma