3DE for cardiac chamber quantification: what do current recommendations suggest?

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Disclaimer

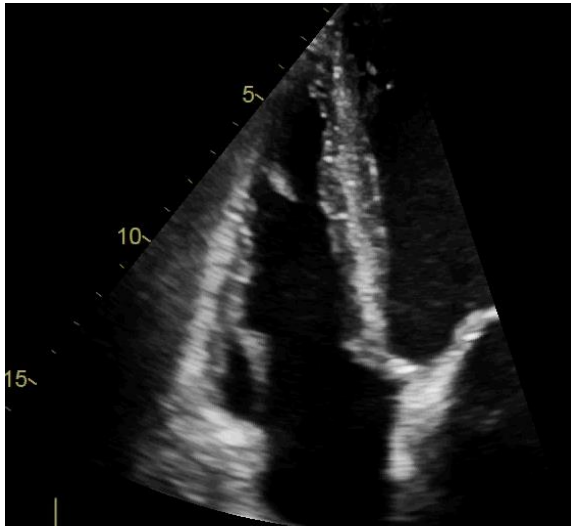
All members of the Faculty have provided a declaration of potential or actual conflict of interest

Why 3D Echocardiography Makes the Difference?

- No geometric assumptions about cardiac chamber’s shape or contraction pattern
- Allows to ***measure***, not ***calculate*** using mathematical formulas
- Volumetric analysis is not affected by foreshortening or off-axis views
- More accurate and reproducible compared to 2D Echocardiography

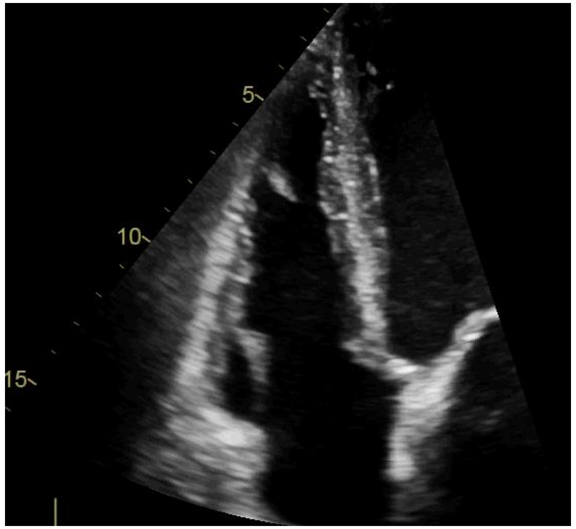
2D versus 4D

One image – One plane

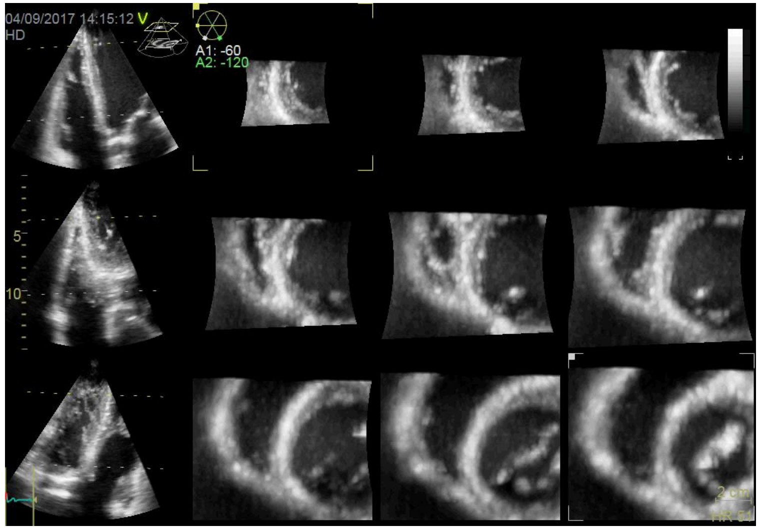


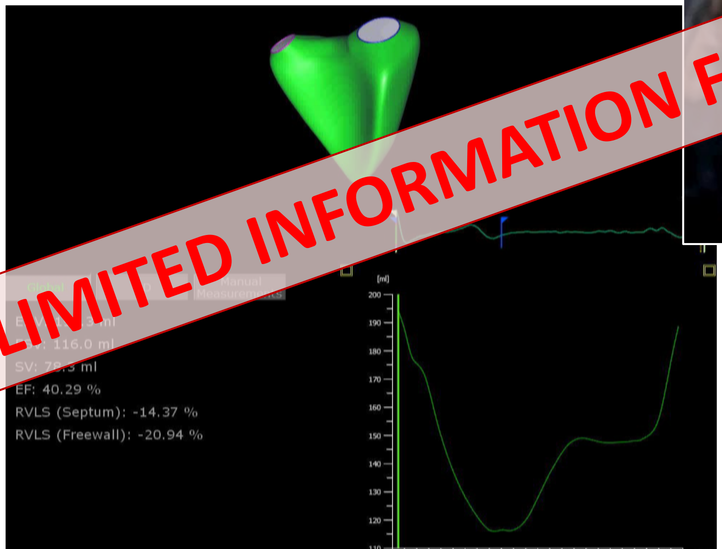
2D versus 4D

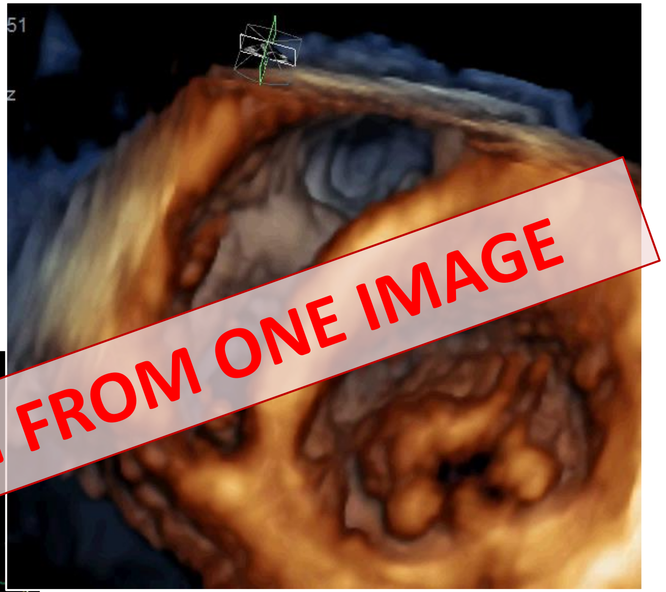
One image – One plane



One image – Multiple planes
Multiple perspectives
Direct measurements







UNLIMITED INFORMATION FROM ONE IMAGE

CARDIAC CHAMBERS QUANTIFICATION

LEFT VENTRICLE

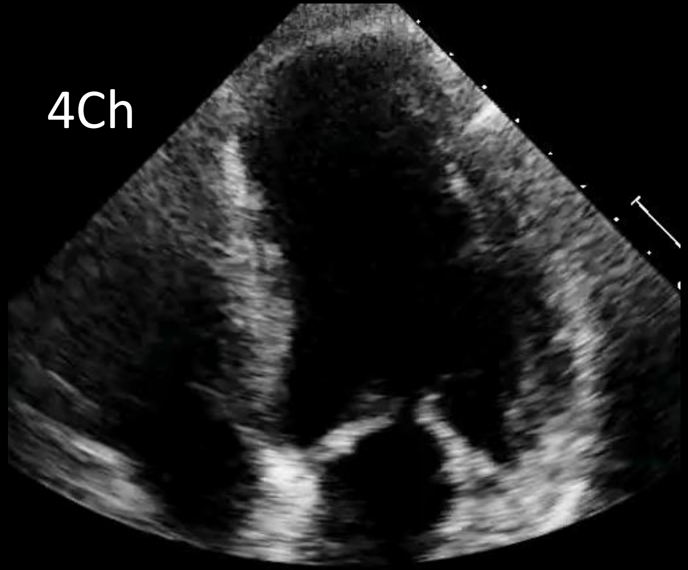
- Feasible and reproducible
- Extensively validated against CMR
- 3DE EF is a better predictor of adverse events than 2DE EF

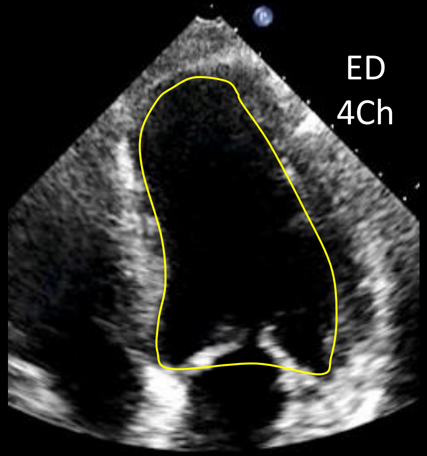
Medvedofsky D, et al. JACC Cardiovasc Imaging, 2021
Rodriguez-Zanella H, et al. JACC Cardiovasc Imaging, 2019

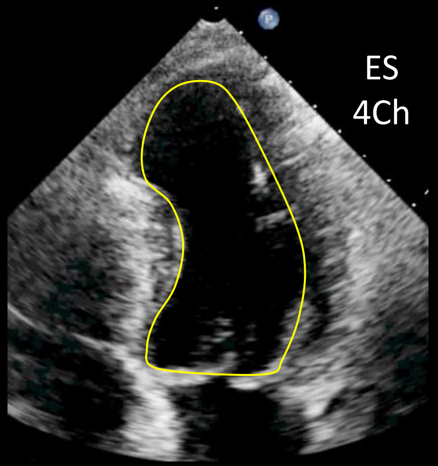
Recommendation. LV size should be routinely assessed on 2DE by calculating volumes using the biplane method of disks summation technique. In laboratories with experience in 3DE, 3D measurement and reporting of LV volumes is recommended when feasible depending on image quality. When reporting LV

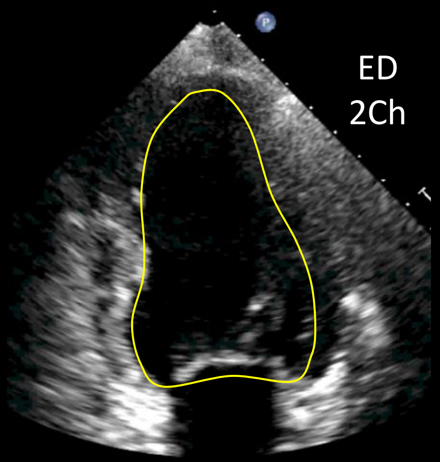
Lang RM, et al. ***Recommendations for cardiac chamber quantification***
EHJ Cardiovasc Imaging, 2015

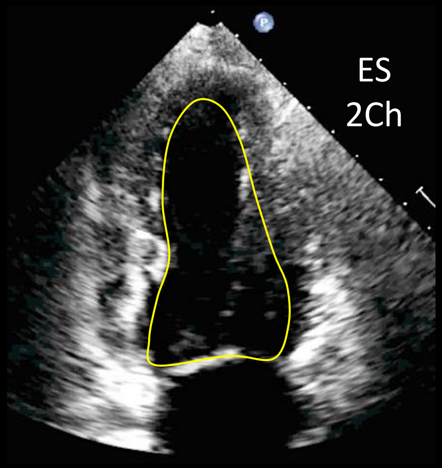
CASE #1 LV systolic function?







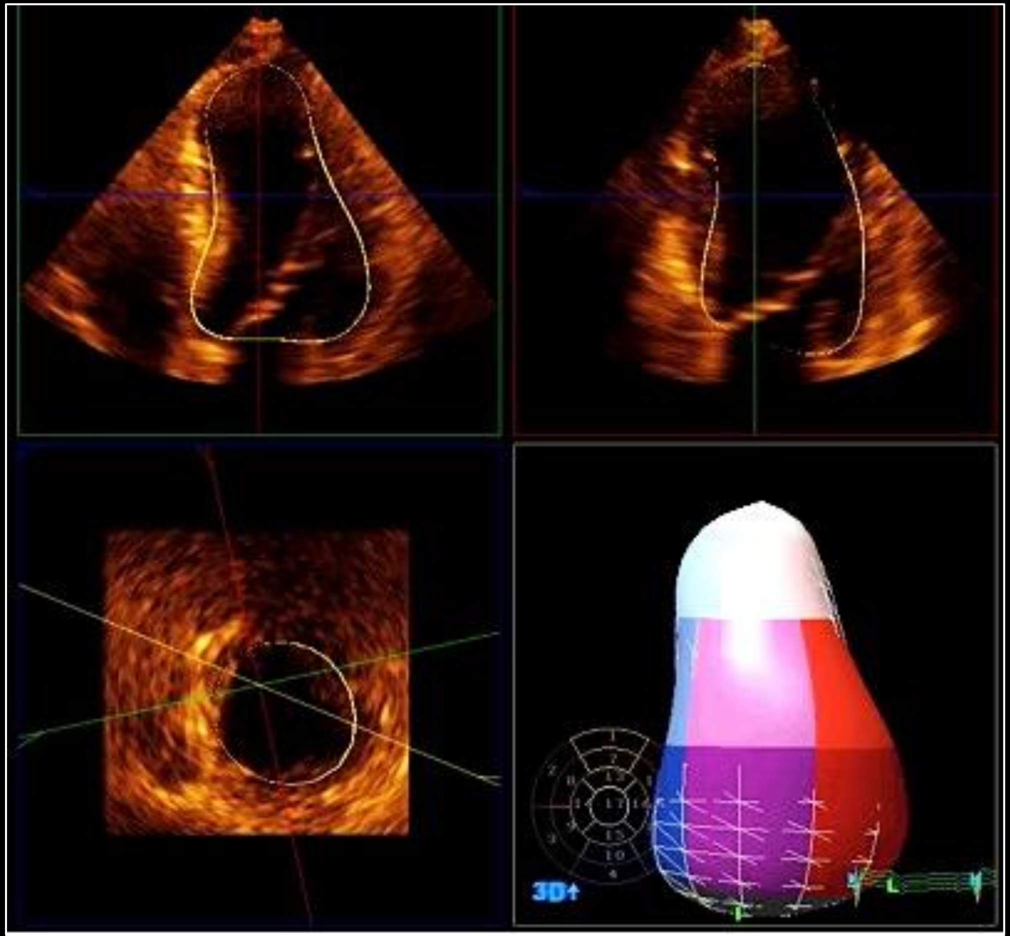




2D Simpson:

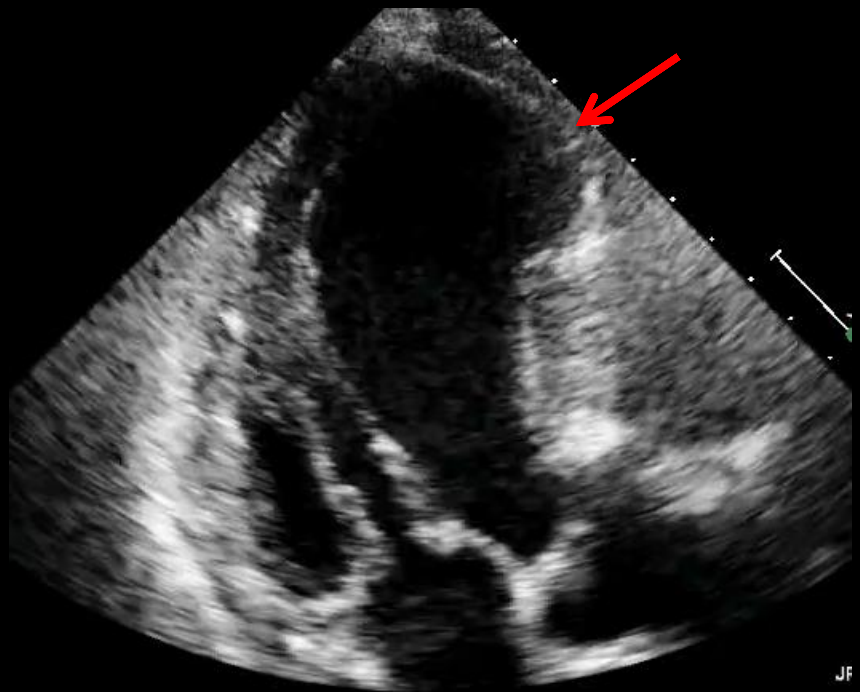
- EDV 112 ml
- ESV 55 ml
- EF 51%

CASE #1 LV systolic function?



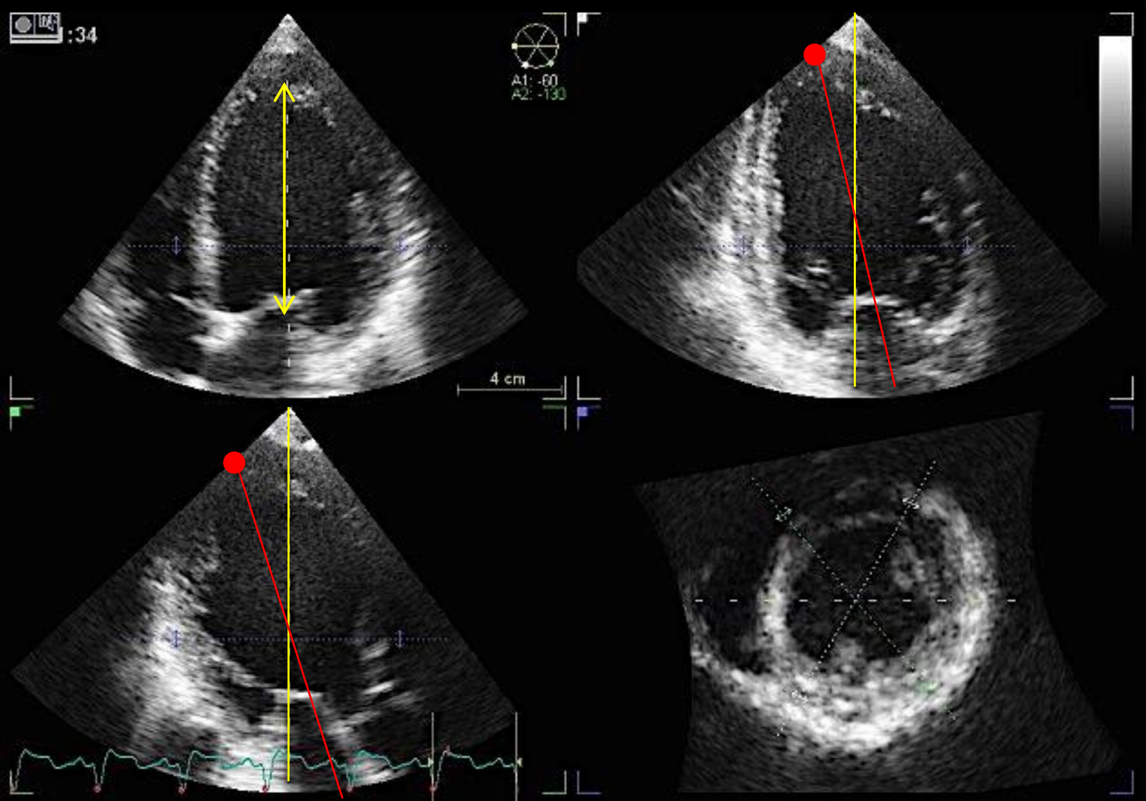
3D:

- EDV 126 ml
- ESV 70 ml
- EF 44%

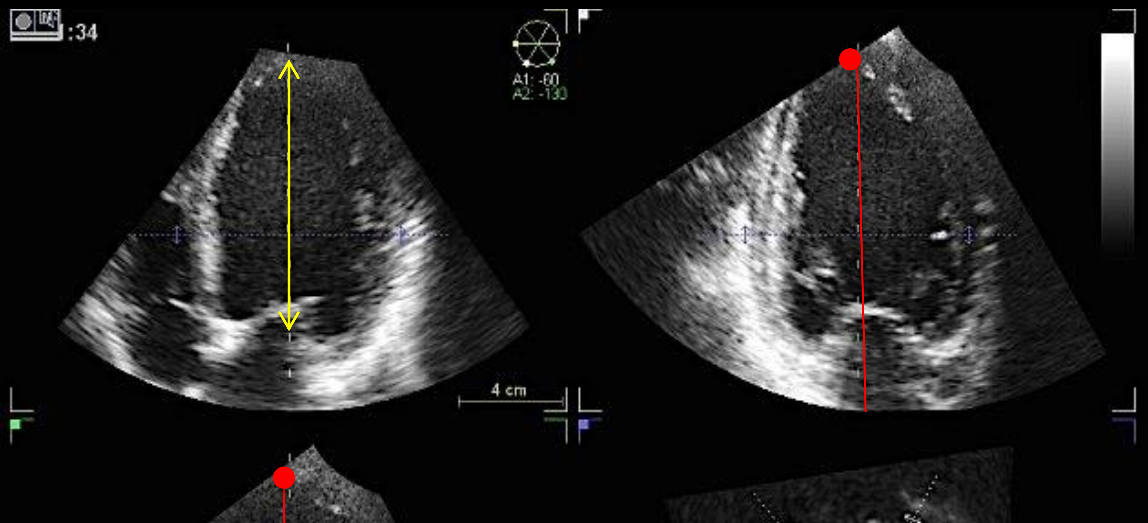


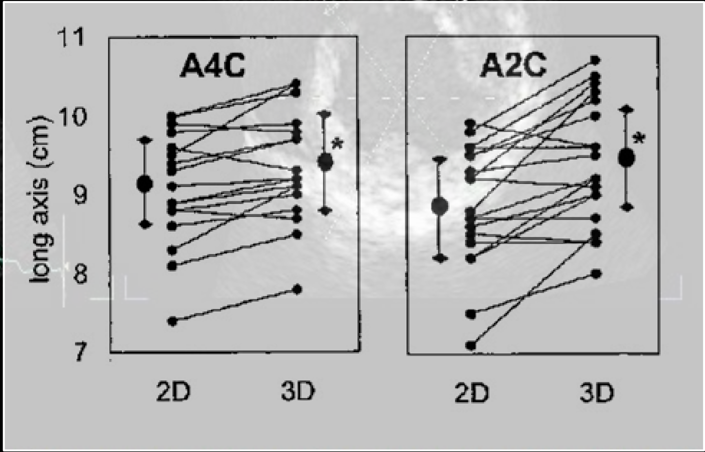
Eliminating LV foreshortening

LV length 4Ch 94 mm



LV length 4Ch 107 mm





Mor-Avi V., et al. Circulation 2004

Use method-specific reference values

Abnormality threshold	2DE	3DE
LV EDVi (ml/m^2)		
men	>74	>79
women	>61	>71
LV ESVi (ml/m^2)		
men	>31	>32
women	>24	>28
LV EF (%)		
men	<52	<52
women	<54	<54

Lang RM, et al. ***Recommendations for cardiac chamber quantification***. EHJ Cardiovasc Imaging, 2015

WASE study
1,589 subjects from around the world (feasibility 70%)

- LV EDVi in men and women: 70±15 and 65±12 mL/m^2
- LV ESVi in men and women: 28±7 and 25±6 mL/m^2
- EF in men and women: 60±5% and 62±5%.

Men had larger LV volumes / lower LVEFs than women.

In both sexes, LV volumes were lower and LVEF tended to be higher with increasing age.

Addetia K, et al.; WASE Investigators. ***Normal Values of Left Ventricular Size and Function on Three-Dimensional Echocardiography: Results of the World Alliance Societies of Echocardiography Study***. J Am Soc Echocardiogr. 2022 May;35(5):449-459.

Added value of 3DE in LV quantification

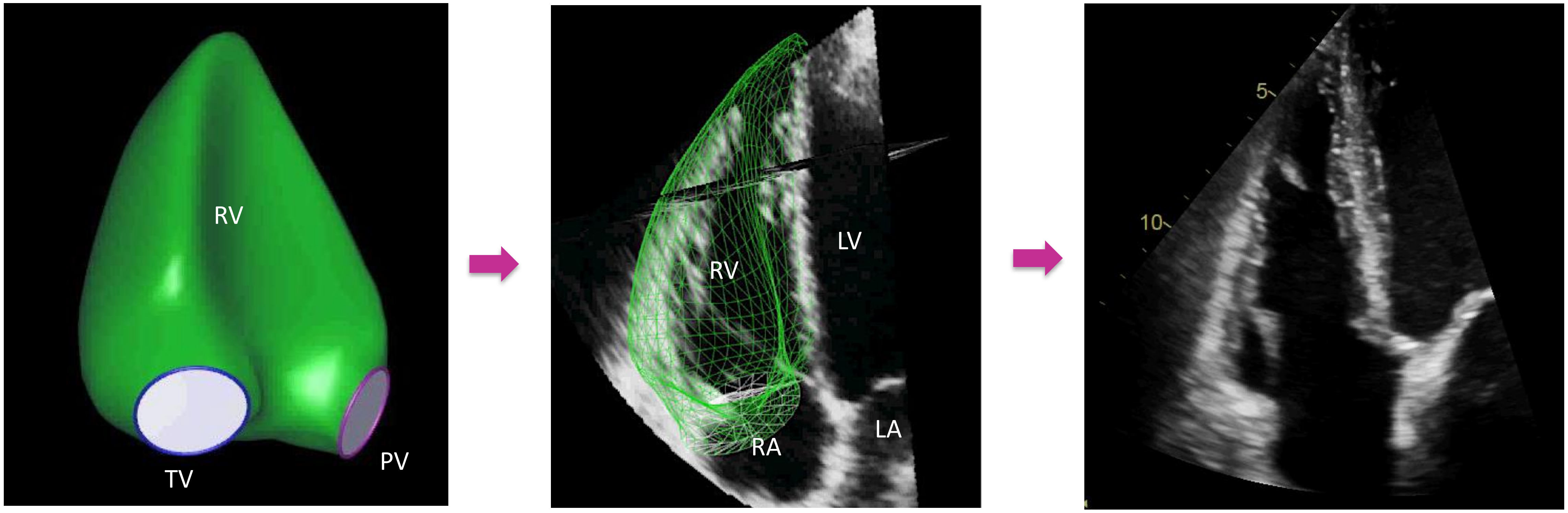
Advantages	• Comprehensive quantitation of LV volumes, EF and sphericity index from a single full-volume dataset • No geometric assumptions about LV shape • Re-aligning planes on 3D data sets eliminates foreshortening
Established clinical indications	• Measurement of LV volumes • Calculation of LV EF
Who benefits most	• Patients with extensive wall motion abnormalities • Patients with abnormal LV shape

> ***Recommendation.*** LV size should be routinely assessed on 2DE by calculating volumes using the biplane method of disks summation technique. In laboratories with experience in 3DE, 3D measurement and reporting of LV volumes is recommended when feasible depending on image quality. When reporting LV

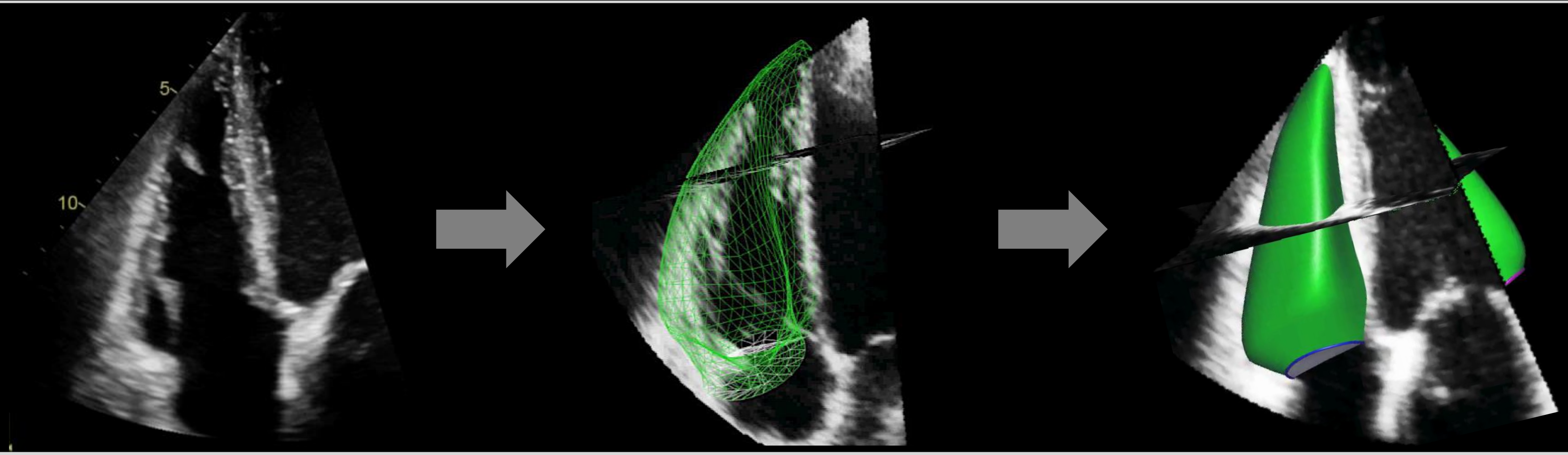
Lang RM, et al. ***Recommendations for cardiac chamber quantification***. EHJ Cardiovasc Imaging, 2015

RIGHT VENTRICLE

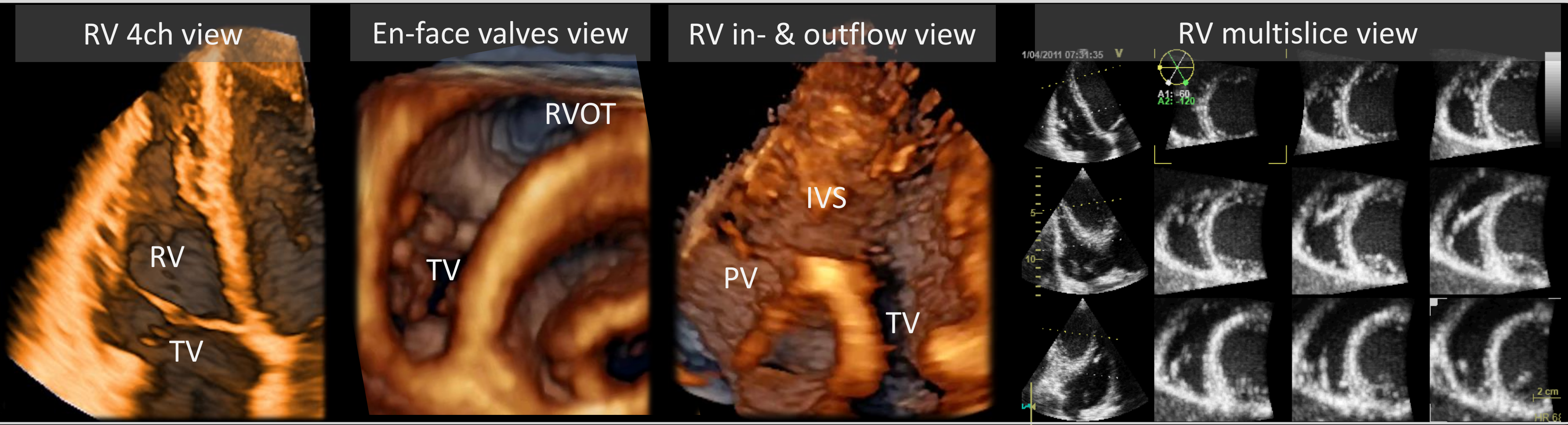
HOW TO ASSESS 3D STRUCTURE BY 2D TECHNIQUES?



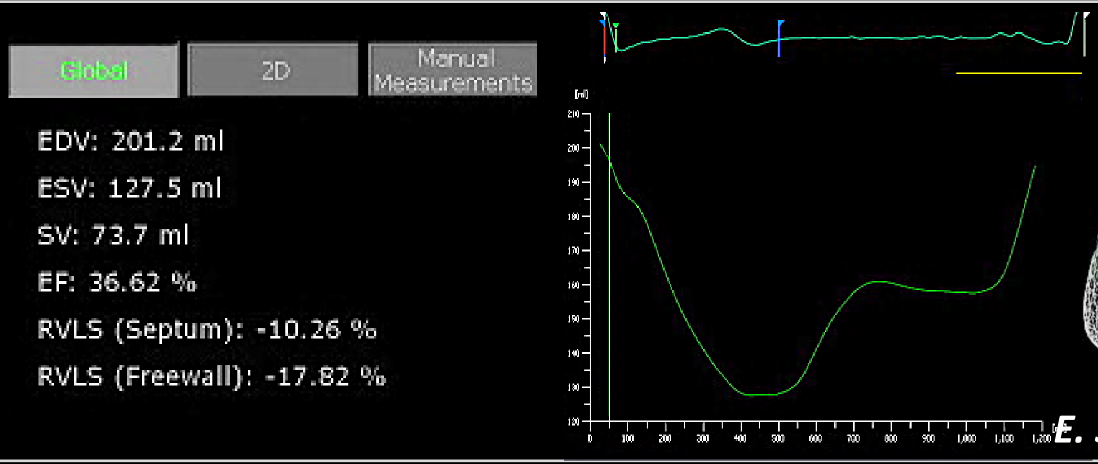
RIGHT VENTRICLE
3D ECHO CONCEPT

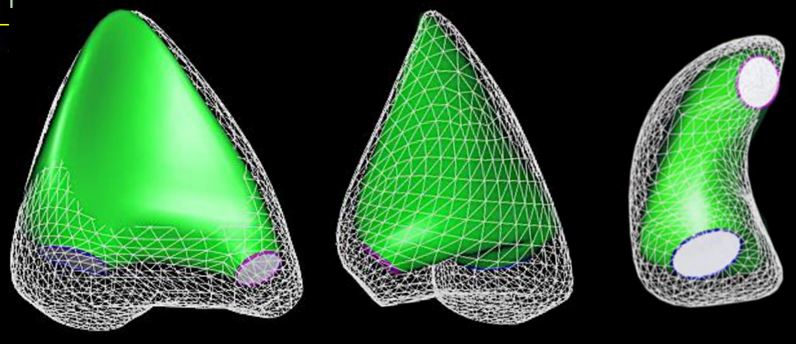


RIGHT VENTRICLE
3D DATA SET DISPLAY



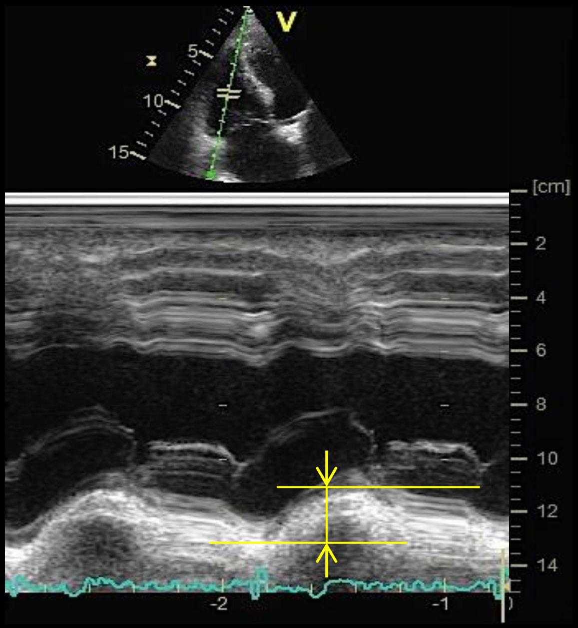
RIGHT VENTRICLE
3D DATA ANALYSIS



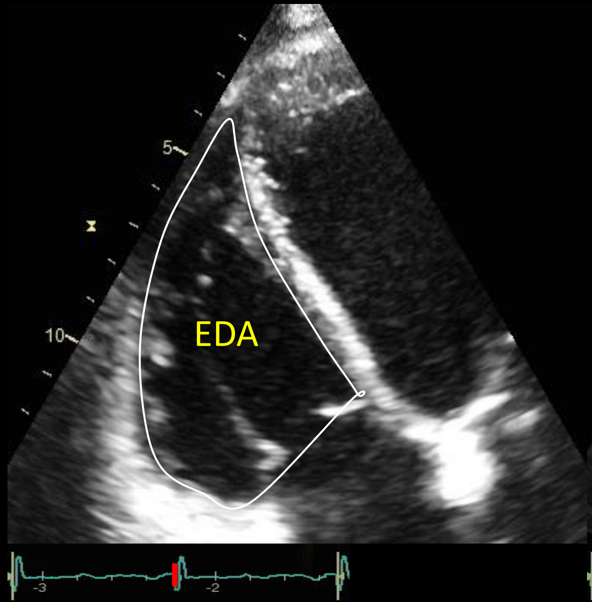


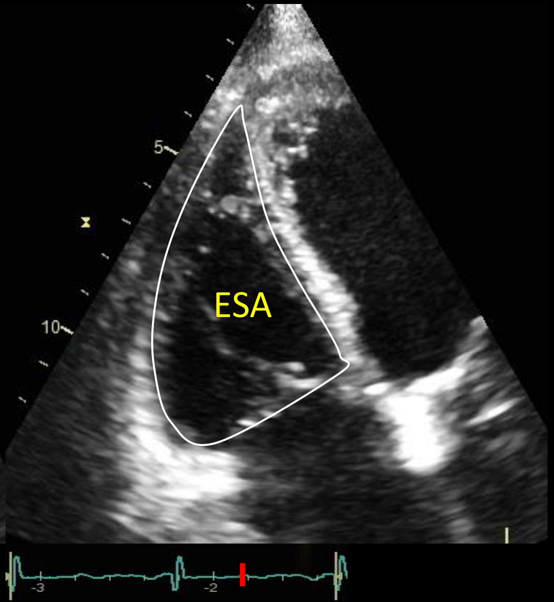
E. Surkova, et al. EHJ Cardiovasc Imaging, 2022

CASE #2 RV systolic function?

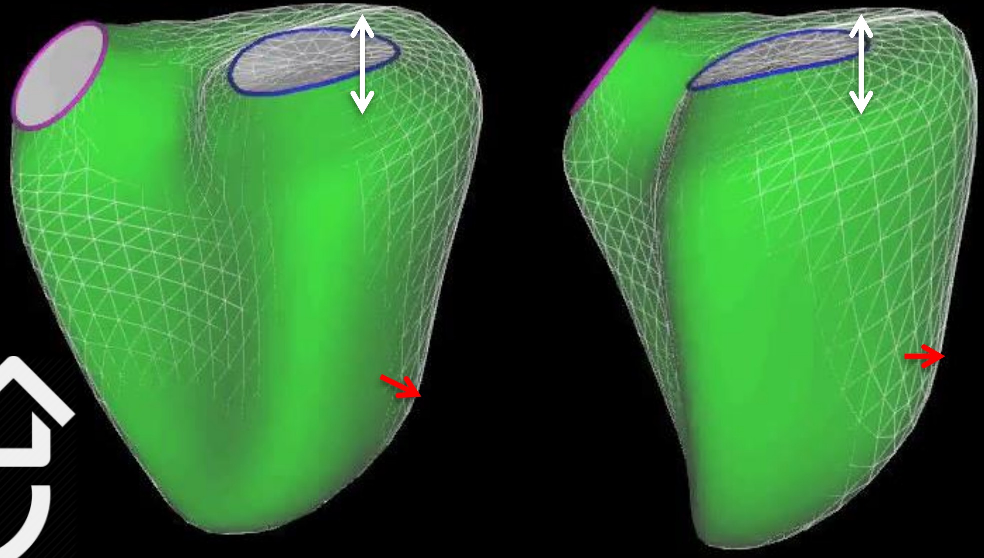


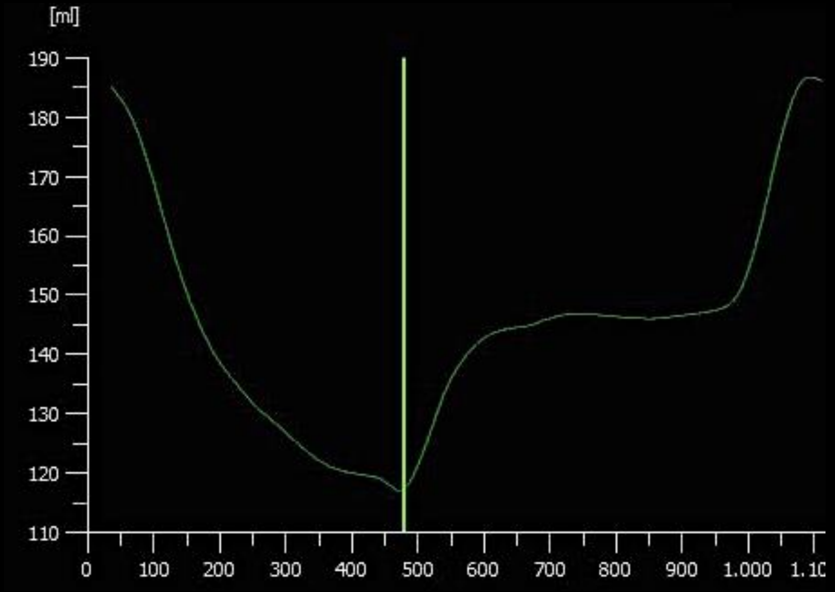
TAPSE 19 mm





FAC 28%





EDV: 186,8 ml

EDVi: 100,5 ml/m²

ESV: 117,1 ml

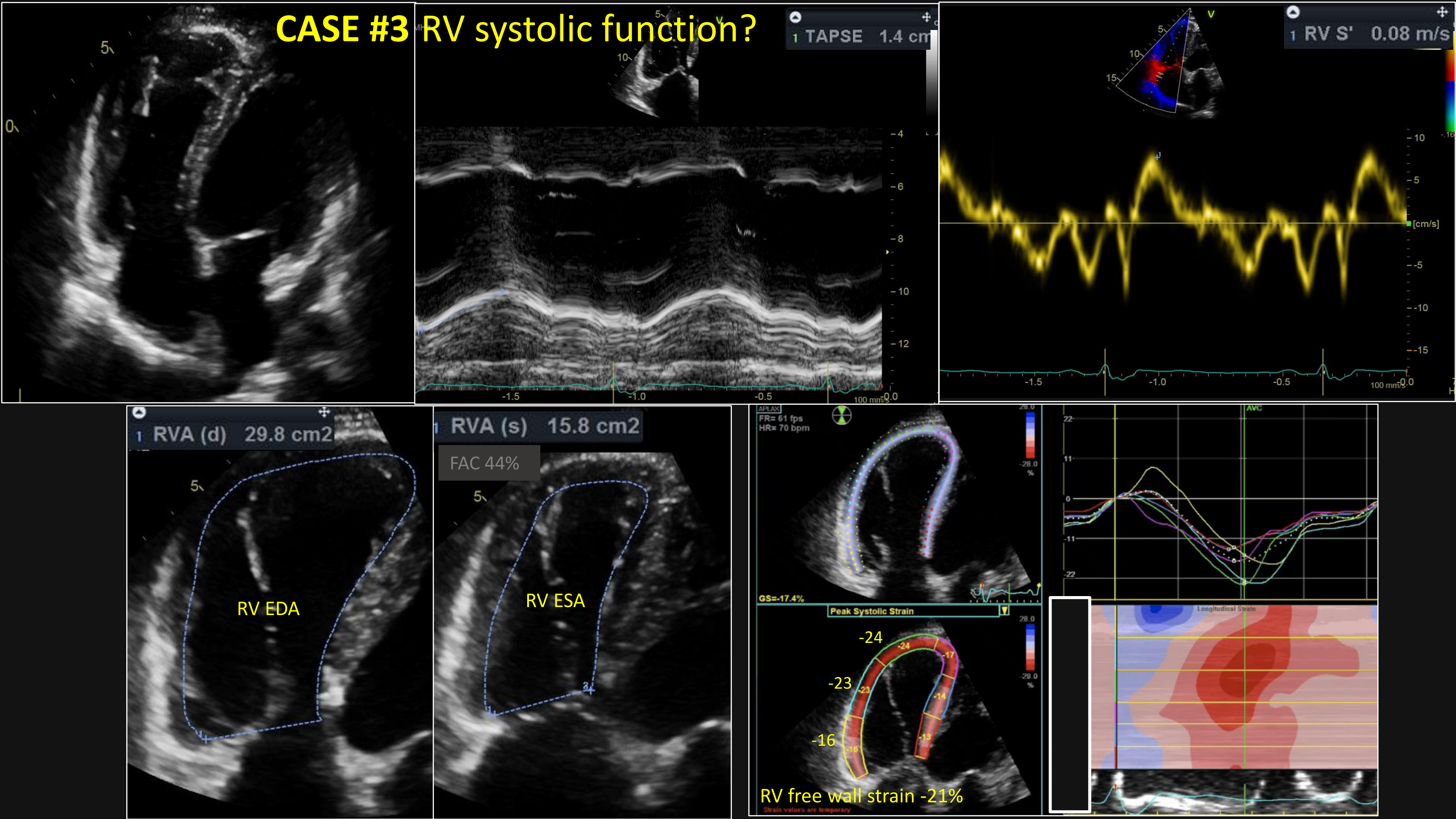
ESVi: 63,0 ml/m²

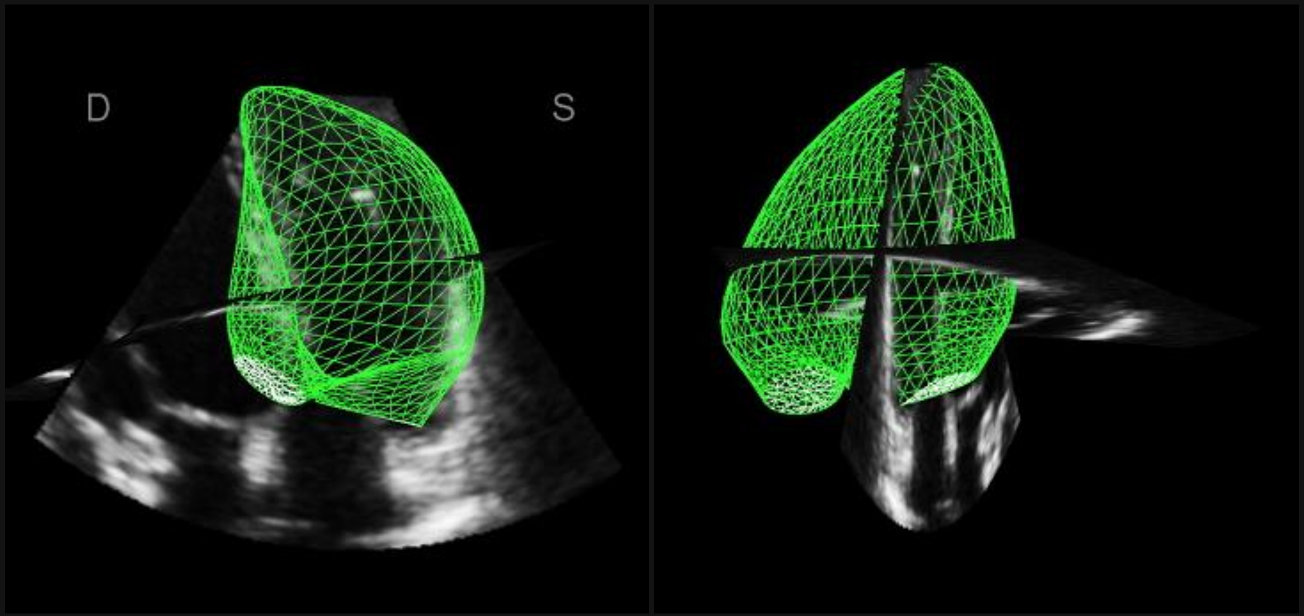
SV: 69,7 ml

EF: 37,3 %

3DE RV assessment should be used in case of discrepancy between conventional echo parameters

CASE #3 RV systolic function?





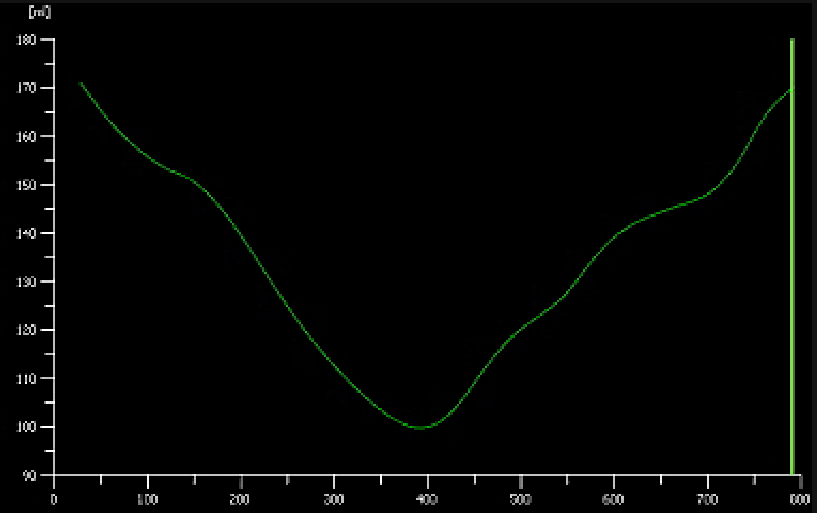
Global
2D
Manual Measurements

EDV: 171.0 ml
(93.4 ml/m²)

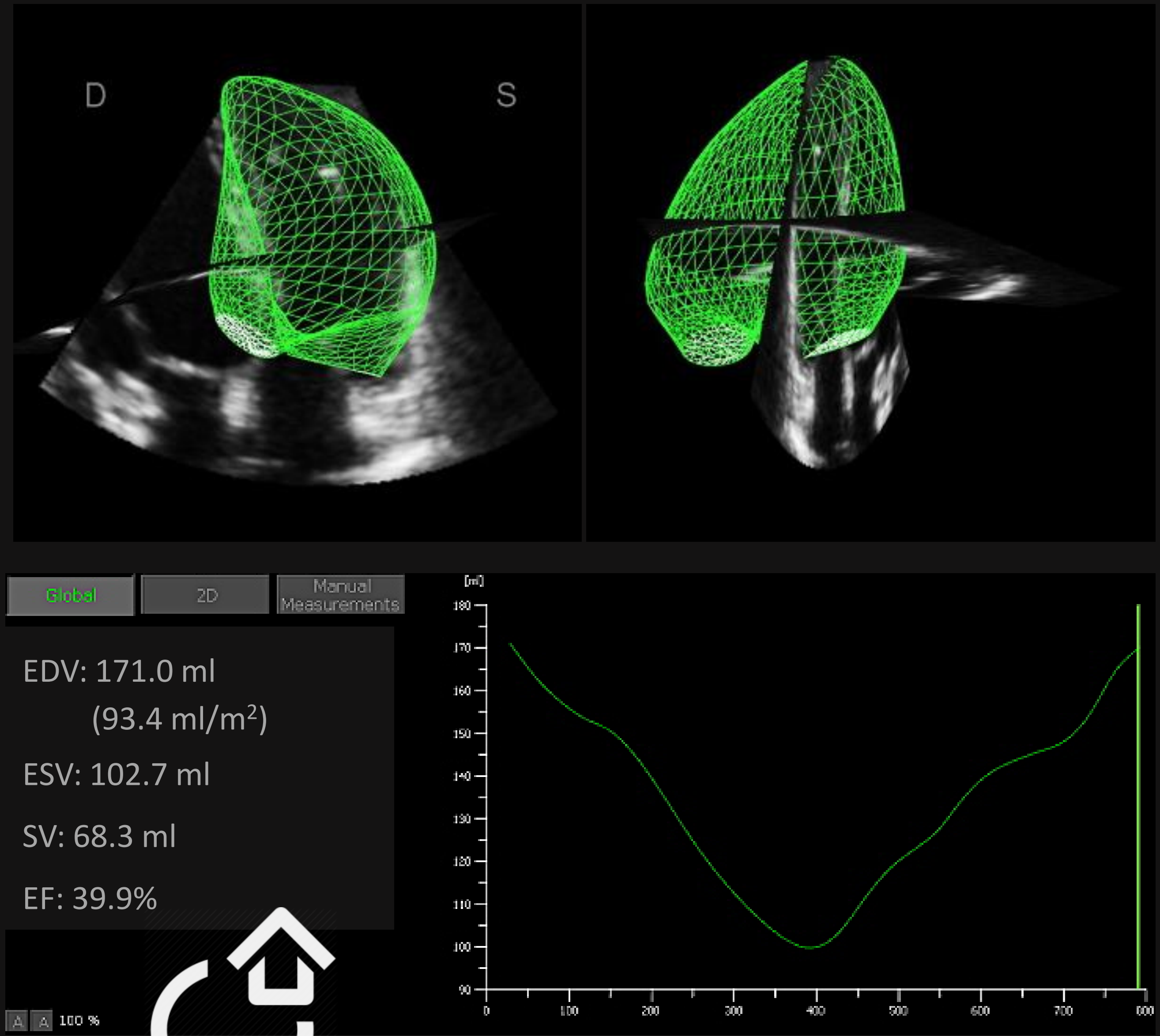
ESV: 102.7 ml

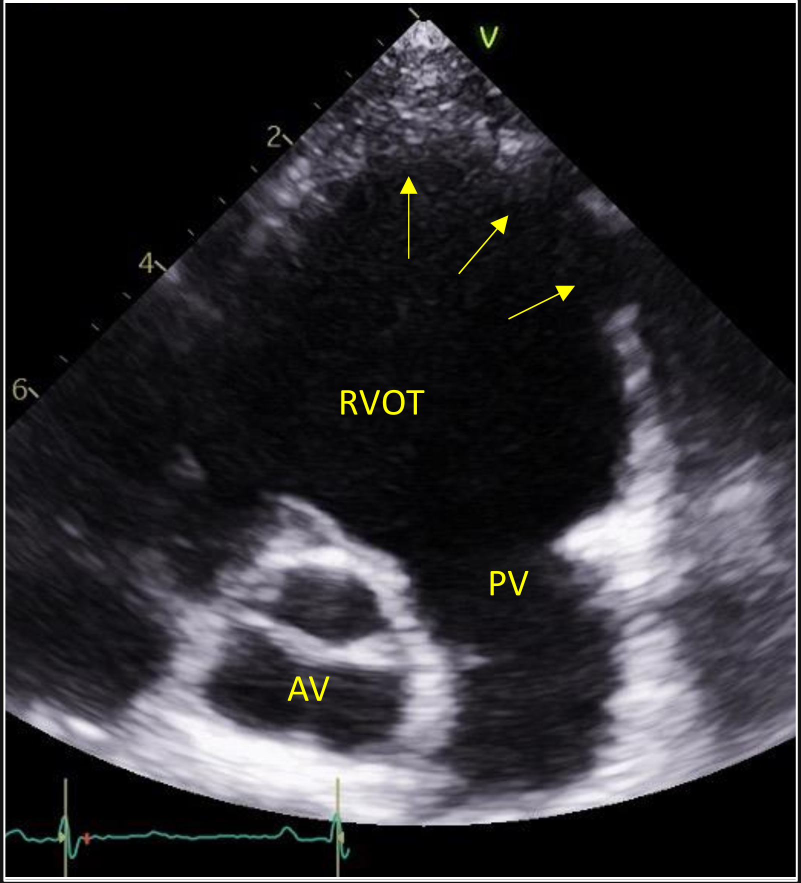
SV: 68.3 ml

EF: 39.9%



100 %





E.Surkova, et al. Rus J Cardiol. 2020;25(S3):4067.

Conventional echo parameters do not take into account RVOT contribution

RV function can be overestimated by conventional echo if RVOT dysfunction/WMAs present

3D RV EF: -significant predictor of mortality;
-more accurate than conventional echo parameters for prediction of all-cause mortality

ELSEVIER

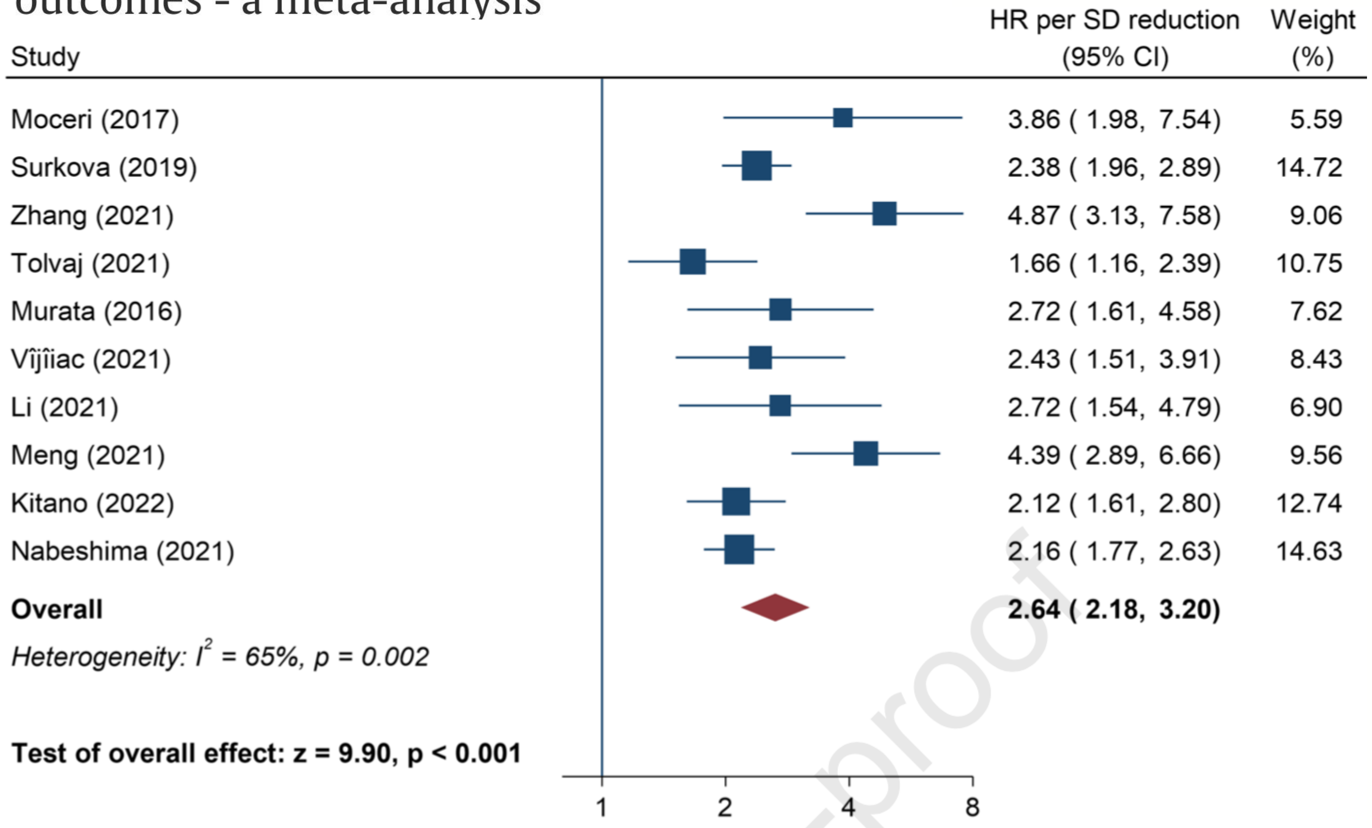
Journal of the American Society of Echocardiography

Available online 10 February 2023

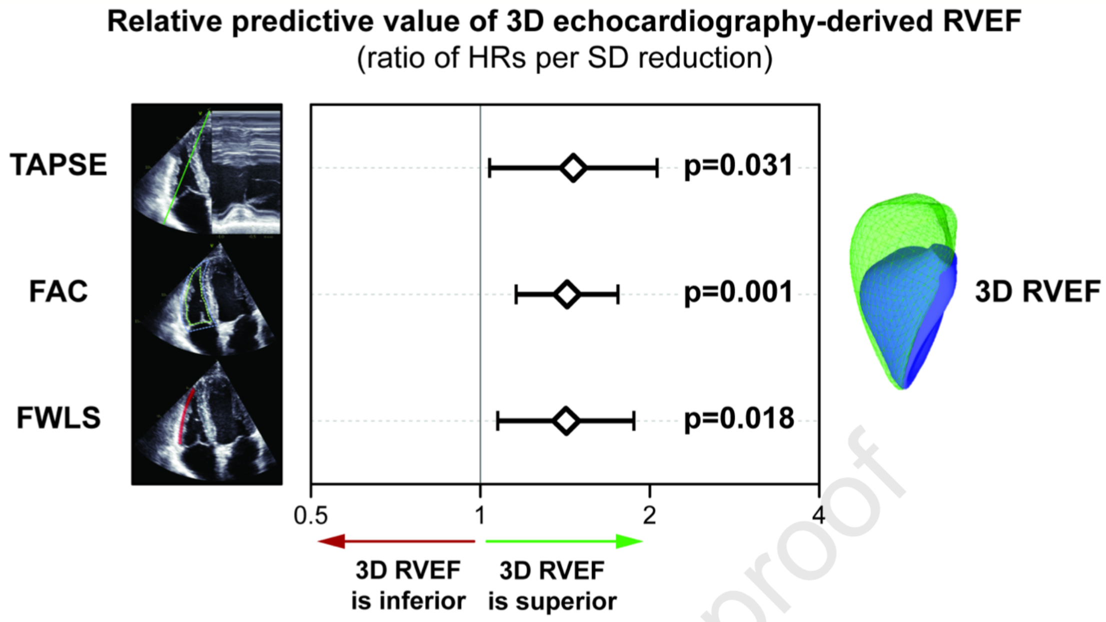
In Press, Journal Pre-proof ⓘ What's this?

Clinical Investigations

Association of right ventricular functional parameters with adverse cardiopulmonary outcomes - a meta-analysis

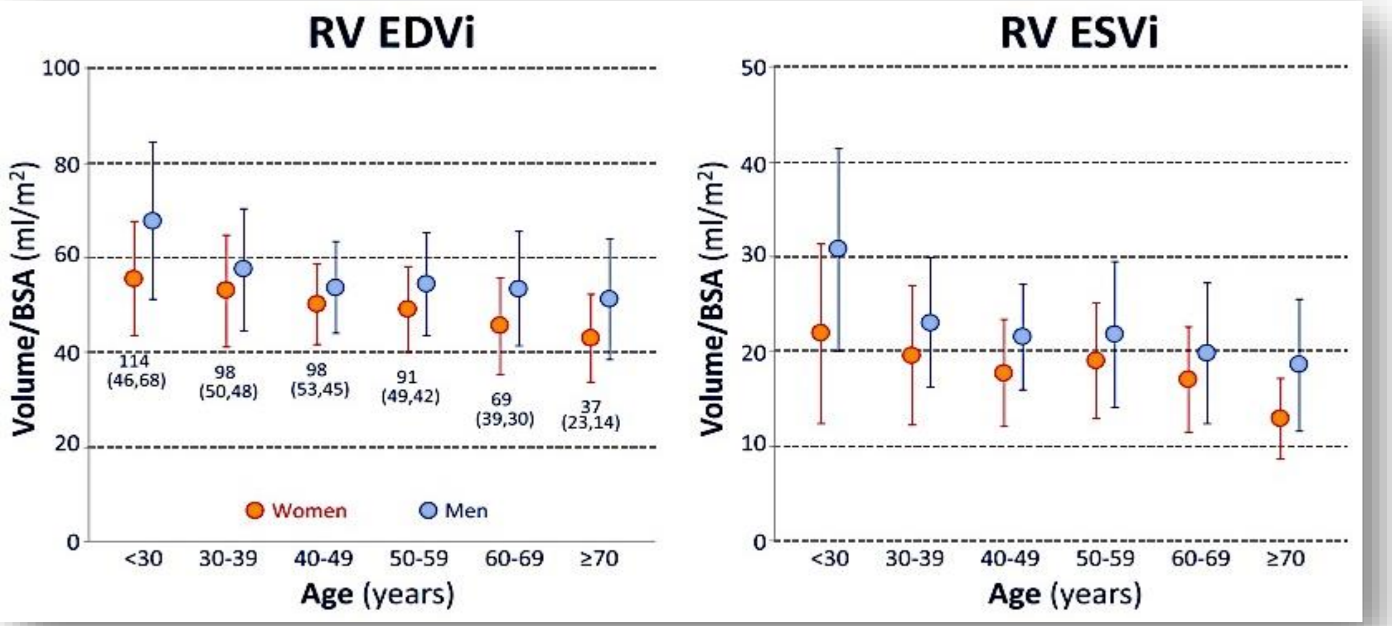


- 10 independent studies
- data on 1,928 patients with various cardiopulmonary conditions



A.Sayour, et al. *JASE, 2023.*

3DE RV Reference values



Maffessanti F, et al. Circ Cardiovasc Imaging, 2013

Parameter	Gender	3DE Threshold
RV EDVi (ml/m^2)	men	>87
	women	>74
RV ESVi (ml/m^2)	men	>44
	women	>36
RV EF (%)		<45

Lang RM, et al. Recommendations for cardiac chamber quantification. EHJ Cardiovasc Imaging, 2015

WASE Study

1,051 / 2,007 had adequate image quality for confident measurements.

- EDVi upper limits for men and women: 95 and 81 mL/m^2
- ESVi upper limits for men and women: and 43 mL/m^2 and 36 mL/m^2
- EF lower limits for men and women: 44% and 46%

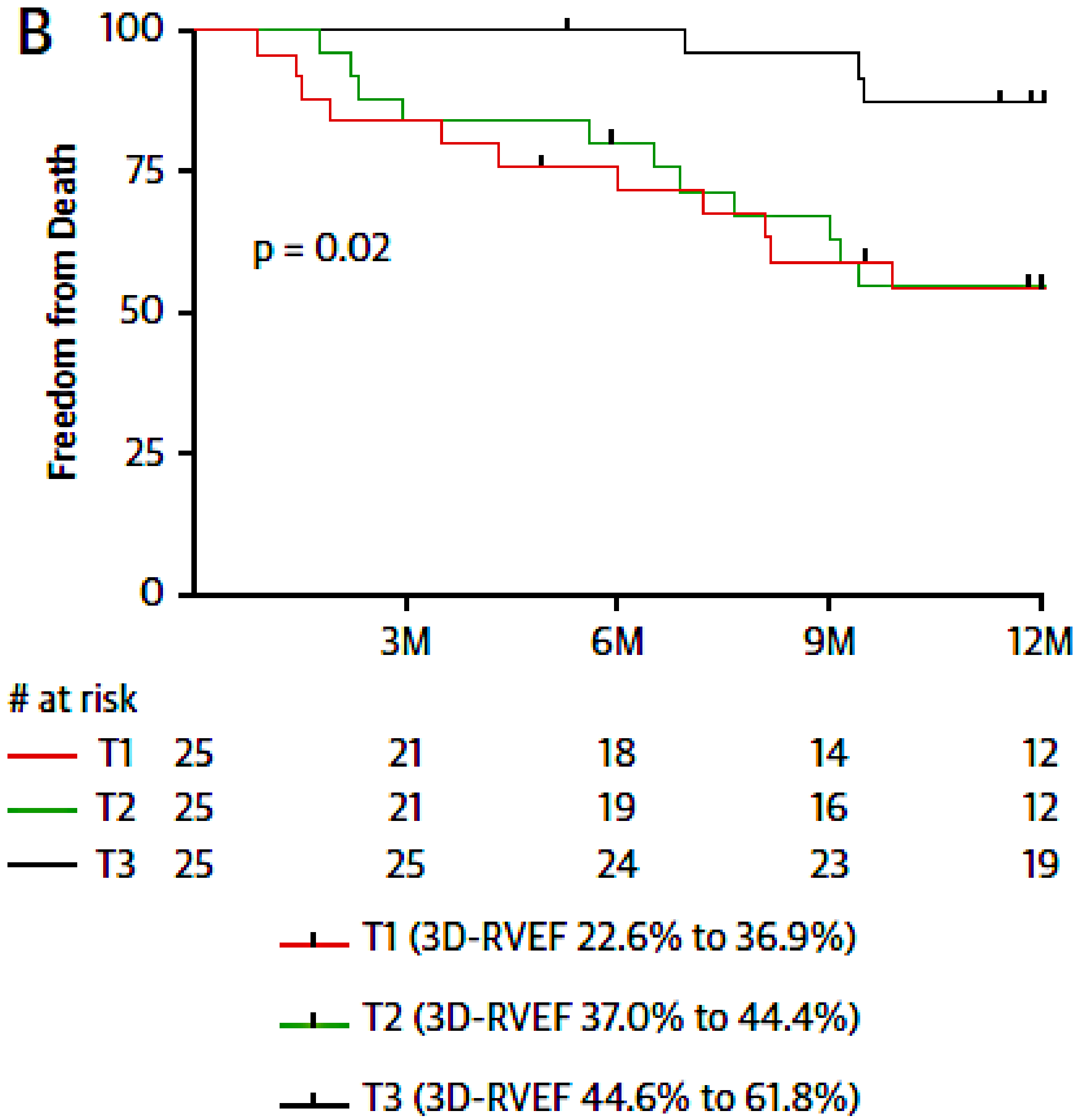
Addetia K, et al. ***Normal Values of Three-Dimensional Right Ventricular Size and Function Measurements: Results of the World Alliance Societies of Echocardiography Study***. J Am Soc Echocardiogr. 2023 Aug;36(8):858-866.e1.

Prognostic value of 3DE RV EF in the context of severe TR and T-TEER

FIGURE 1 3-Dimensional Echocardiography Is a Valuable Tool in Transcatheter Edge-to-Edge Tricuspid Repair

In patients with severe TR before edge-to-edge repair, a cut-off value of **45% of RVEF by 3DE** discriminated those having a better survival at 1-year than those in the lowest and intermediate tertiles (RVEF 22.6-36.9% and 37-44.4%, respectively, p=0.02)

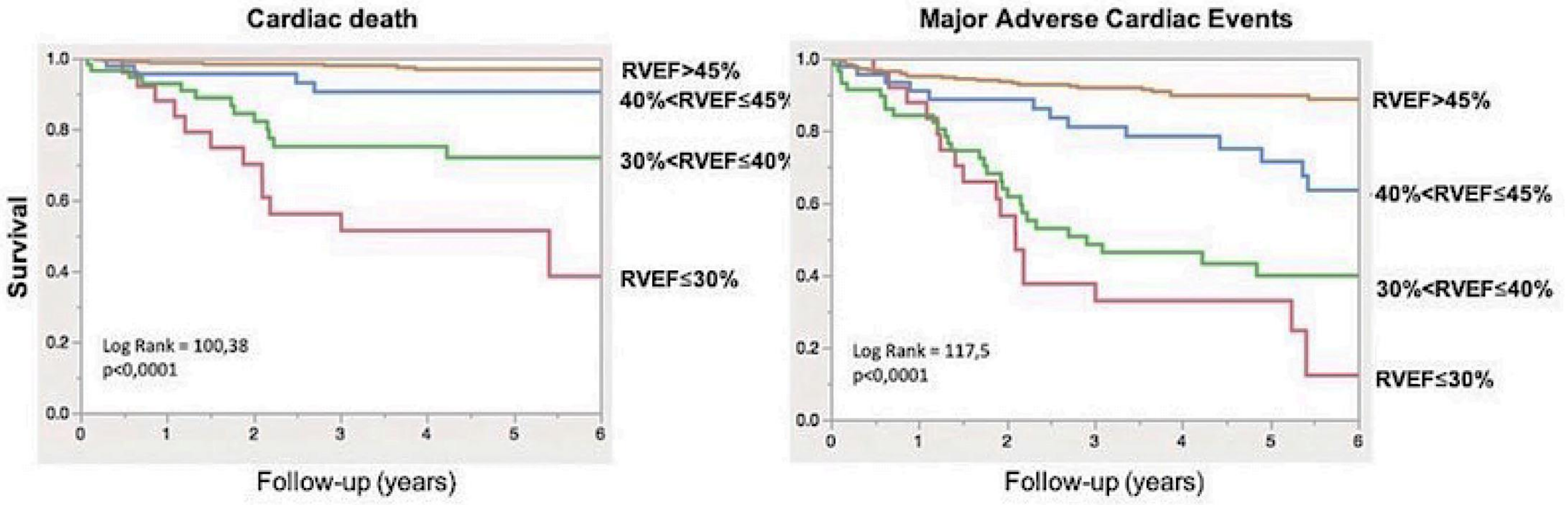
Neither TAPSE nor FAC predicted all-cause mortality



***Orban M, et al.** JACC Cardiovascular imaging 2021;14(12):2477-9.*

Partition values of RV EF

- ≥45% - normal
- 40-45% - mildly reduced
- 30-40% - moderately reduced
- <30% - severely reduced



Muraru D, et al. Eur Heart J Cardiovasc Imaging. 2020;21(1):10-21.

Added value of 3DE in RV quantification

Advantages	• The ONLY echocardiographic technique permitting quantitation of RV volumes and EF • Incorporates all three components of the RV in a single data set • No geometrical assumptions about RV shape
Established clinical indications	• Measurement of RV volumes • Calculation of RV EF
Who benefits most	• All patients' categories where RV information is clinically/prognostically important (PH, CHD, MI, RV pathology/failure)

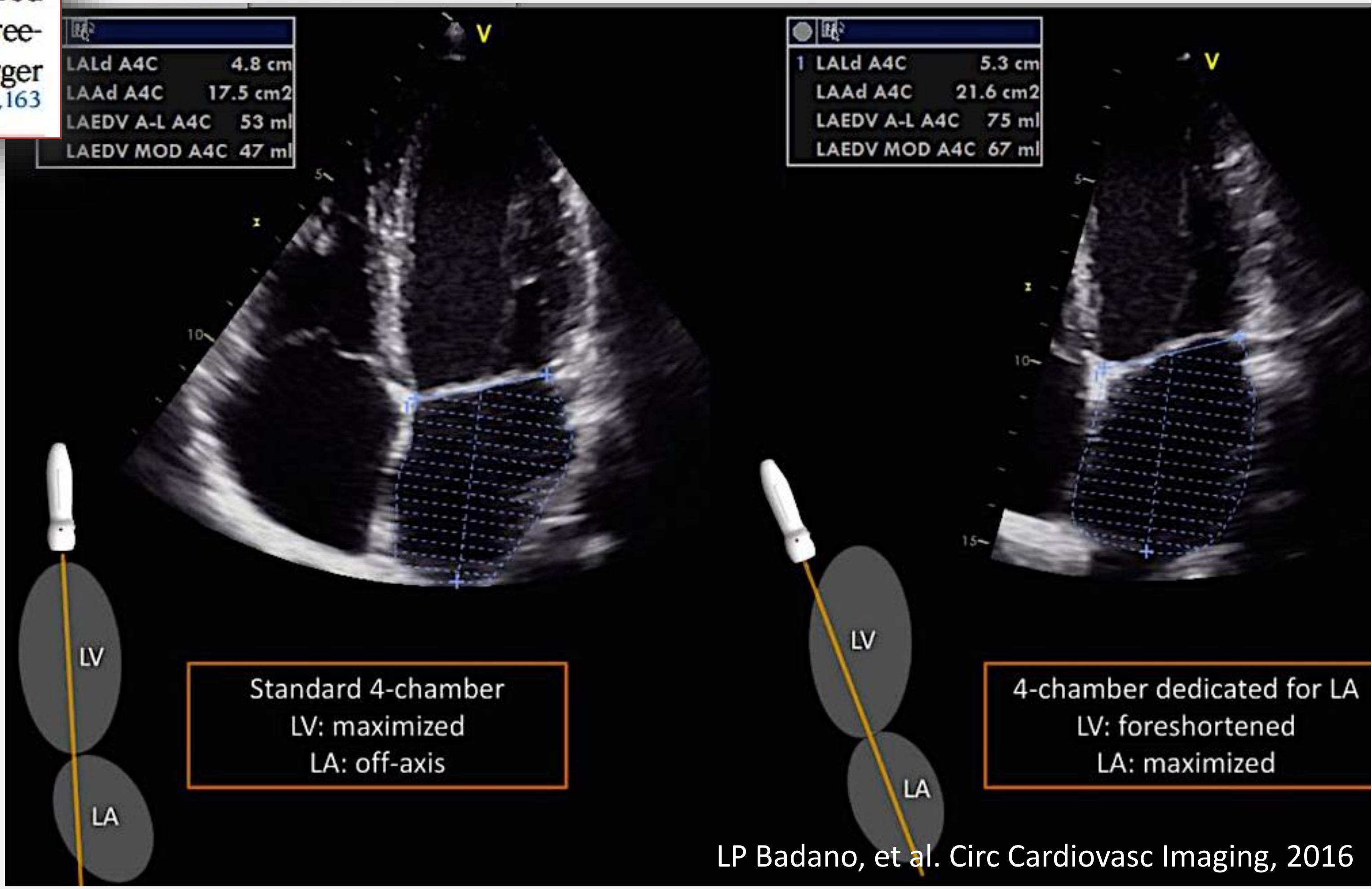
Recommendations. RV size should be routinely assessed by conventional 2DE using multiple acoustic windows, and the report should include both qualitative and quantitative parameters. In laboratories with experience in 3DE, when knowledge of RV volumes may be clinically important, 3D measurement of RV volumes is recommended. Although normal 3D echocardiographic values of RV

Lang RM, et al. ***Recommendations for cardiac chamber quantification***. EHJ Cardiovasc Imaging, 2015

LEFT and RIGHT ATRIA

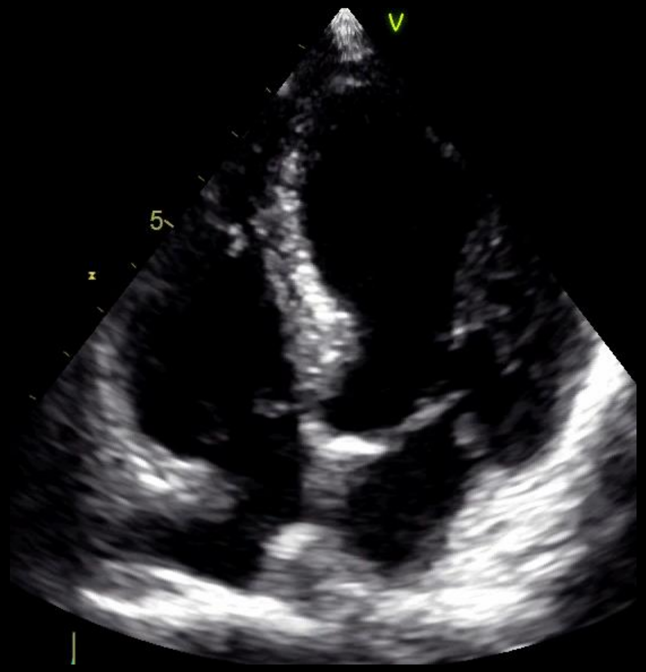
Three-dimensional echocardiography holds promise for assessing LA volume and correlates with cardiac computed tomography[157,158] and magnetic resonance imaging.[159,160] Compared with 2D assessment of LA volume, 3DE is more accurate compared with CMR[159,160] and has superior prognostic ability.[161,162] Three-dimensional echocardiographic LA volumes are typically larger than 2D echocardiographic volumes in most studies.[160,163]

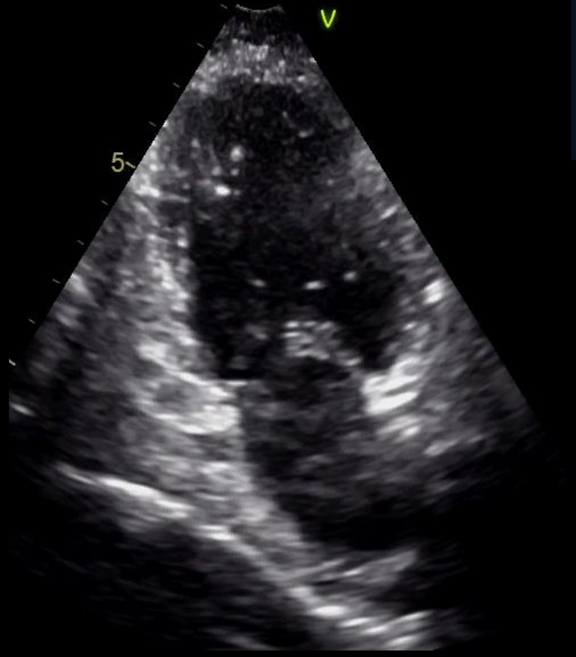
- Biplane method of discs
- Biplane area-length method



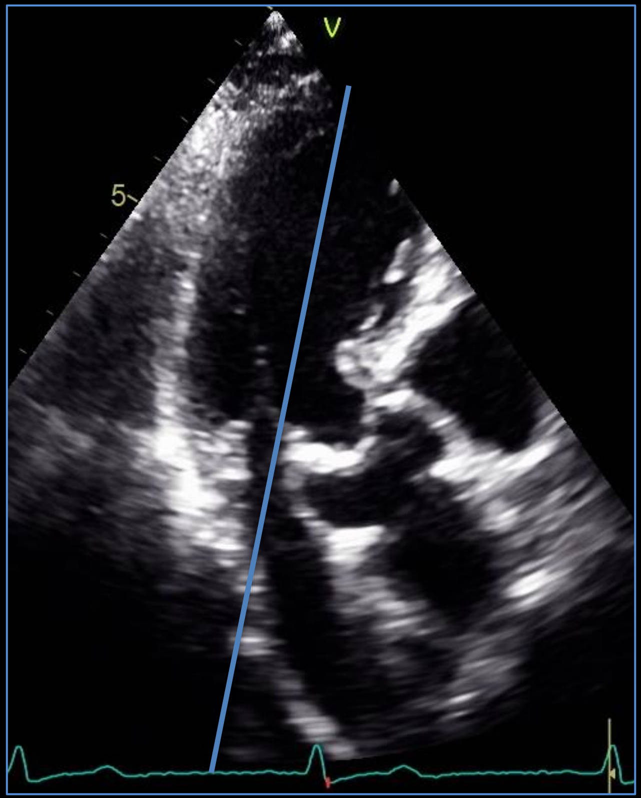
LP Badano, et al. Circ Cardiovasc Imaging, 2016

CASE #3 LA size?

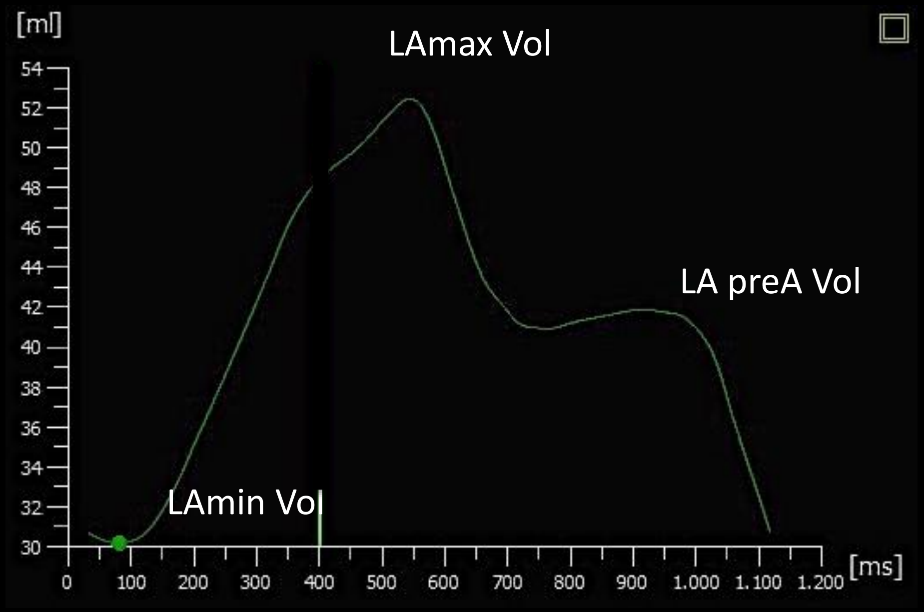




LAV	35 ml
LAVi	23.1 ml/m^2



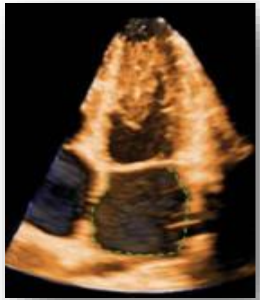
CASE #3 LA size?



LA Max Volume	**53.2 ml**
LA Max Volume index	**35.1 ml/m²**
LA Min Volume	**30.2 ml**
LA Min Volume index	**19.9 ml/m²**
LA Total EF	**43.2%**

Use method-specific reference values

276 healthy volunteers



200 healthy volunteers

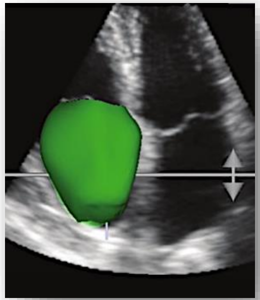


Table 3. Comparison of Left Atrial Volumes and Function Indices Obtained Using 3DE and 2DE

	3DE		2DE			
	median (p25; p75)	LN	median (p25; p75)	LN	*P* Value*	Δ% (95% CI)
Vmax, mL/m²	32 (28; 36)	43	24 (21; 28)	35	<0.001	26.7 (23.6 to 29.8)
VpreA, mL/m²	18 (14; 21)	31	14 (12; 18)	25	<0.001	21.7 (17.3 to 26.2)
Vmin, mL/m²	10 (8; 12)	18	8 (6; 10)	14	<0.001	29.9 (24.5 to 35.4)
Total EV, mL/m²	21 (18; 24)	13	16 (14; 18)	10	<0.001	26.4 (23.3 to 29.6)
Passive EV, mL/m²	14 (11; 16)	7	10 (7; 12)	4	<0.001	35.9 (31.2 to 40.7)
Active EV, mL/m²	7 (5; 9)	3	7 (5; 8)	3	0.64	9.4 (3.6 to 15.3)
Total EF, %	67 (63; 71)	53	67 (62; 74)	48	0.03	−0.3 (−2.3 to 1.6)
Passive EF, %	44 (38; 49)	24	41 (32; 48)	19	<0.001	9.9 (5.5 to 14.3)
Active EF, %	41 (35; 48)	21	46 (39; 53)	24	0.09	−12.2 (−16.2 to 8.3)

Badano LP, et al. *Circ Cardiovasc Imaging, 2016*

Table 4 Comparison between 3DE and 2DE parameters of RA size and function

	3DE	2DE	P-value	Limit 3D	Limit 2D
V_{max} (mL)	52 ± 15	41 ± 14	<0.0001	78[a]	69[a]
V_{min} (mL)	19 ± 8	17 ± 7	<0.0001	36[a]	33[a]
V_{preA} (mL)	28 ± 10	27 ± 11	<0.0001	49[a]	49[a]
Total SV (mL)	33 ± 10	24 ± 9	<0.0001	17[b]	11[b]
Passive SV (mL)	24 ± 9	14 ± 7	<0.0001	10[b]	4[b]
True SV (mL)	9 ± 4	10 ± 5	0.017	4[b]	3[b]
TotEF (%)	63 ± 9	58 ± 9	<0.0001	49[b]	42[b]
PassEF (%)	46 ± 11	34 ± 12	<0.0001	24[b]	14[b]
True EF (%)	31 ± 8	35 ± 11	<0.0001	18[b]	17[b]

Peluso D, et al. *EHJ Cardiovasc Imaging, 2013*

Use method-specific reference values

1765 healthy volunteers

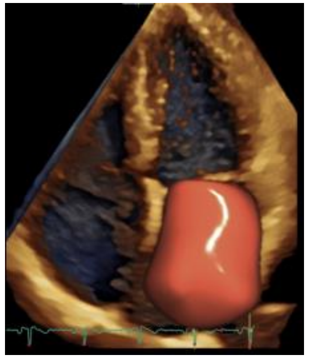


Table 3 Limits of normality for LA parameters

	Men			Women		
	18–40 y	41–65 y	>65 y	18–40 y	41–65 y	>65 y
	LLN–ULN	LLN–ULN	LLN–ULN	LLN–ULN	LLN–ULN	LLN–ULN
Size parameters						
2D maximum LAV, mL	22–82	22–91	22–84	21–71	21–78	20–80
2D maximum LAVi, mL/m^2	13–39	13–42	13–41	13–40	14–47	14–48
3D maximum LAV, mL	30–85	28–89	31–88	25–67	29–75	29–81
3D maximum LAVi, mL/m^2	16–41	16–46	18–48	17–39	18–43	18–47
3D minimum LAV, mL	9–37	10–38	11–42	8–27	9–36	10–36
3D minimum LAVi, mL/m^2	5–18	5–20	5–22	5–17	6–21	6–22
3D LA pre-A volume, mL	16–54	17–63	20–64	13–41	16–53	19–57
3D LA pre-A volume index, mL/m^2	9–26	10–31	11–34	9–23	10–30	13–35
3D LA reservoir volume, mL	16–55	16–56	17–53	15–45	16–45	16–46
3D LA reservoir volume index, mL/m^2	9–26	9–28	10–28	10–27	10–26	11–26
3D LA conduit volume, mL	9–35	8–32	7–31	9–32	7–27	5–25
3D LA conduit volume index, mL/m^2	5–18	4–16	4–16	5–19	4–16	3–16
Functional parameters						
2D LA EF, %	50–80	50–80	48–78	54–81	48–78	43–76
2D LA reservoir strain, %	25–63	23–61	24–57	29–62	22–56	21–56
2D LA conduit strain, %	18–50	12–43	10–36	19–52	12–42	9–36
2D LA booster strain, %	2–23	5–28	9–32	2–21	6–28	7–30
3D LA total EF, %	42–75	47–74	43–74	48–76	43–74	46–72
3D LA passive EF, %	21–55	16–48	14–47	26–63	20–52	14–48
3D LA active EF, %	17–54	26–59	24–60	18–54	21–56	27–59

***Singh A, et al.** WASE study. JASE, 2021*

Added value of 3DE in quantification of atria

Advantages	• Comprehensive quantitation of maximum, minimum and preA volumes • No geometric assumptions about atria shape • Re-aligning planes on 3D data sets eliminates foreshortening
Potential clinical indications	• Measurement of maximum, minimum and preA volumes • Calculation of phasic emptying volumes / EF
Who benefits most	• Patients with non-standard shape of the atria • Patients with difference in 4Ch/2Ch atria length >5 mm

Current recommendations[6] encourage the reporting of the LAV_{max} because there is a large body of evidence supporting LAV_{max} to stratify cardiovascular risk.[79] However, there is recent evidence suggesting that LAV_{min} may be a more important prognostic indicator using either 2DE or 3DE.[2,116] The correlation with LV filling pressures has also been reported to be stronger for LAV_{min} than for LAV_{max}.[117,118]

Although not yet recommended in guidelines, the assessment of LA function could significantly improve the prognostic value of LA metrics in many clinical conditions. It is important to un-

Thomas L, et al. *JASE, 2020*

Strengths and limitations of 3DE in cardiac chamber quantification

Major advantages	• Enables actual 3D acquisition and anatomically guided direct measurements of volumes and assessment of ejection fraction • Avoids calculations that imply geometrical assumptions • Extensively validated against CMR, reproducibility is higher than for 2DE • Reference values are now available for all cardiac chambers • Has unlimited repeatability • Cost-effective and safe
Major limitations	• Need for 3D probe and analysis software • Requires training and expertise • Regular rhythm and patient’s cooperation • Dependent on image quality

THANK YOU FOR YOUR ATTENTION

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